CONTROL SYSTEMS ENGINEERING EXAM REVIEW

Course Schedule

Tuesday, August 24, 1999

8:00 am	Welcome and Introductions Mr . Larry Sellers, College of Engineering, Auburn University Mr. Ken Holmes, President, ISA - Birmingham Section	
8:15 am	**Sensor and Data Transmission; Documentation (Tab 1)** Fundamentals of measurement; sensor principles, selection and installation practices; conductor pairs; coaxial cable; fiber optics, shielding and grounding; protocols. Standard symbols for process and instrument drawings; logic diagrams; displays.	**Mr. David Haynes**
12:15 pm	Lunch (provided)	
1:00 pm	**Discrete Logic, Interlocks, Alarms and Sequencing Tab 2)** Logic elements; timers/counters; design tools; recommended practices.	**Mr. Earl Snider**
4:30 pm	**Codes and Standards (Tab 3)** Wiring; bumer/boiler safety	**Mr. Stuart Nixon**
6:00 pm	Adjourn	

Wednesday, August 25, 1999

8:00 am	Control System Analysis and Design (Tab 4) Block diagrams; stability, accuracy and response-time considerations.	**Mr. Cyrus Taft**
Noon	Lunch (on your own)	
1:00 pm	**Digital Control Systems (Tab 5)** Hardware and software fundamentals. Reliability analysis; precision of process variables.	**Dr. Jack Mendel**
5:00 pm	**Low Pressure Tank Venting (Tab 6)** Safety considerations for low pressure vessels.	**Mr. Howard Richards**
6:00 pm	Adjourn	

Thursday, August 26, 1999

8:00 am	**Process- Characteristics; Controllers/Modes/Tuning (Tab 7)** Mass and energy balances, fluid flow and heat transfer for typical processes; transfer functions; responses to standard inputs; process identification by plant tests. Controller and mode selection; tuning procedures.	**Mr. Steve Morgan**
Noon	Lunch (on your own)	
1:00 pm	**Valves and Final Control Elements (Tab 8)** Fluid mechanics; valve characteristics, selection, sizing and installation practices; relief valves.	**Mr. Ed Andrews**
4:30 pm	Awarding of Certificates	**Mr. Larry Sellers**

Morning and afternoon breaks will be provided

DISCRETE LOGIC, INTERLOCKS, ALARMS AND SEQUENCING

Instructor

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Discrete Logic, Interlocks, Alarms, and Sequencing (Batch Applications)

Auburn Extension / ISA -- CSE PE Review Course
Earl D. Snider, P.E.
August 26, 1999

I. General Theory

- A. Binary number system
- B. Octal number system
- C. Hexadecimal number system
- D. Binary codes
  1. ASCII
  2. BCD (Binary Coded Decimal)
  3. Gray
- E. One's and Two's Complements
- F. Two types of Discrete Logic: Combinational Logic and Sequential Logic

II. Combinational Logic

- A. Logic Elements (Boolean Gates)
  1. Various symbol standards (ISA, IEEE, SAMA, Ladder, Switch equivalents)
  2. Timers and Counters
     a. Block types (Symbol standards -- Delay on, Delay off, Pulse)
     b. Timing diagrams
     c. Relay race solutions (ex. Pressure, Current)
- B. Logic Design Tools and Methods
  1. Boolean Algebra and reduction
  2. Truth tables (minterms, maxterms)
  3. Product of Sums and Sum of Products Forms
  4. Karnaugh Map reduction
  5. De Morgan's Theorem conversion
- C. Problems and Solutions
  1. Basic motor control logic (relay race)
     a. Logic Diagrams (DCS)
     b. Ladder diagram (PLC)
  2. Combinational logic problems
     a. Level control with pump
     b. Study Guide 2nd Ed., Pg. 90 , Prob. P401

III. Sequential Logic

- A. Logic Elements with memory (Flip-flops: D, J-K, S-R, Timers, Counters)
- B. Design Tools
  1. State Graphs (a.k.a. State Diagrams)
  2. State Tables
  3. Steps of sequential design
- C. Problems and Solutions
  1. Alternating Lead-lag sump pump service (DCS or PLC)
  2. First-out logic
  3. Study Guide 2nd Ed., Pg. 93, Prob. P402 - #6
  4. Study Guide 3rd Ed., Pg. 58, Problems A26-A35

IV. Alarming and Annunciation

- A. ANSI/ISA S18.1 Annunciator Sequences and Specifications
- B. Benefit vs. Nuisance
- C. Problems and Solutions
  1. Study Guide 3rd Ed., Pg. 81, Problems P26-P29
  2. Study Guide 2nd Ed., Pg. 92, Prob. P402 - #5

V. Batch Applications

- A. ISA dSP88.01 Batch programming standard
  1. Process Industries Reference Model
  2. Recipe Model
  3. Recipe Types
     a. Basic
     b. Master
     c. Control
     d. Working
  4. Unit Model
  5. Control Activity Model
  6. Abnormal Event Handling
- B. PLC Batch Applications -- Drum timer
- C. DCS Batch Applications -- Sequential program language
- D. Study Guide 2nd Ed., Pg. 116, Prob. P702

References:

Programmable Controllers by C.T. Jones and L.A. Bryan
An IPC/ASTEC Publication, Atlanta, GA 1983

Fundamentals of Logic Design by Charles H. Roth, Jr.
West Publishing Company, New York, NY 1985

Control Systems Engineering Study Guide, 2nd and 3rd Ed
ISA, Research Triangle Park, NC 1994

Attachments:

Electrical Engineering Quick Reference Cards -- DIGITAL LOGIC SECTION by Kenneth Nelson, P.E.
Professional Publications, Inc. Belmont, CA 1991

ISA Standard -- Binary Logic Diagrams for Process Operations
ISA, Research Triangle Park, NC 1976

SAMA Standard -- Functional Diagramming of Instrument and Control Systems
SAMA, Washington, D.C. 1981

I. GENERAL THEORY

A. Binary Number System

Because the outputs of most switching devices assume only two different values, it is natural to use binary numbers internally in digital systems.

THE BINARY CONCEPT

The binary concept is not a new idea; in fact, it is a very old one. It simply refers to the idea that many things can be thought of as existing in one of two states (bistable). For instance, a light can be ON or OFF, a switch OPEN or CLOSED, or a motor RUNNING or STOPPED. In digital systems, these two-state conditions can be thought of as a signal that is PRESENT or NOT PRESENT, ACTIVATED or NOT ACTIVATED, HIGH or LOW, ON or OFF, etc. This two-state concept can be the basis for making decisions, and since it is very adaptable to the binary number system, it is a fundamental building block for programmable controllers and digital computers.

Here as well as throughout this book, binary "1" represents the presence of a signal, or the occurrence of some event, while binary "0" represents the absence of the signal, or non-occurrence of the event. In digital systems, these two states are actually represented by two distinct voltage levels, as shown in Table 3-1. One voltage is more positive (or at a higher reference) than the other. Often, binary 1 (or logic 1) will be interchangeably referred to as TRUE, ON, or HIGH. Binary 0 (or logic 0) will be referred to as FALSE, OFF, or LOW.

Table 3-1. Binary Concept Using Positive Logic

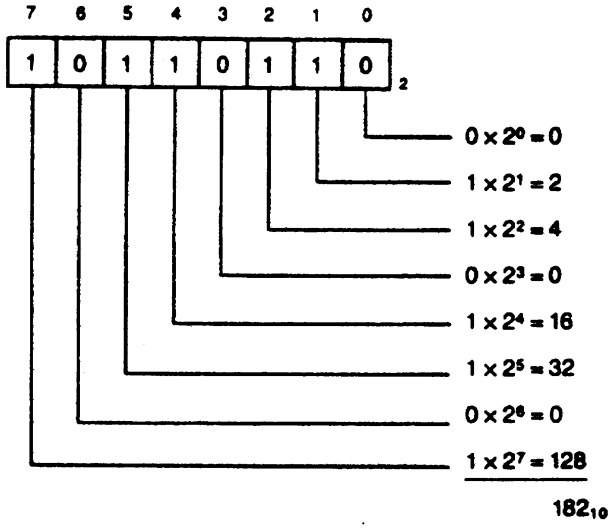
1 (+5V)	0 (0V)	EXAMPLE
OPERATED	NOT OPERATED	LIMIT SWITCH
RINGING	NOT RINGING	BELL
ON	OFF	LIGHT BULB
BLOWING	SILENT	HORN
RUNNING	STOPPED	MOTOR
ENGAGED	DISENGAGED	CLUTCH
CLOSED	OPEN	VALVE

It should be noted in Table 3-1, that the more positive (HIGH) voltage, represented as logic 1, and the less positive (LOW) voltage, represented as logic 0, were arbitrarily chosen. The use of binary logic so that "1" represents the more positive voltage level or the occurrence of some event is referred to as *positive logic*.

Negative logic, as illustrated in Table 3-2, is the use of binary logic so that the more positive voltage level of the occurrence of the event is represented by "0"; "1" represented non-occurrence of the event or the less positive voltage level. Although positive logic is the more conventional of the two, negative logic sometimes may be more convenient.

Binary Number System

The binary numbering system uses the number 2 as the base. The only allowable digits are 0 and 1. There are no 2s, 3s, etc. The binary system is most accommodating for devices such as programmable controllers and digital computers. It was adopted for convenience, since it would be easier to design machines that distinguish between only two entities or numbers rather than ten as in decimal. Most physical elements have two states only: a light bulb is on or off, a valve is open or closed, a switch is on or off, a door is open or closed, and so on. With digital circuits, it is possible to distinguish between two voltage levels (e.g. +5V, 0V), which makes binary very applicable.



EXAMPLE:

$$1011.11_2 = 1\times2^3 + 0\times2^2 + 1\times2^1 + 1\times2^0 + 1\times2^{-1} + 1\times2^{-2}$$

$$= 8 + 0 + 2 + 1 + \tfrac{1}{2} + \tfrac{1}{4} = 11\tfrac{3}{4} = 11.75_{10}$$

Each digit of a binary number is known as a "bit," therefore this particular binary number 10110110 (128 decimal) has 8 bits (or positions).

A group of 4 bits is known as a *nibble*, usually a group of 8 bits is a *byte*, and a group of one or more bytes is a *word*. Figure 2-1 shows a binary number composed of 16 bits, with the least and most significant bits.

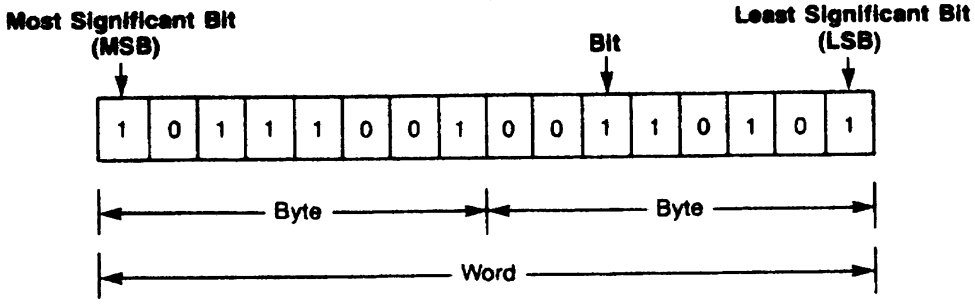
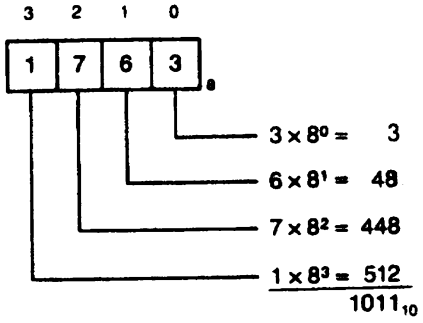


Figure 2-1. One word, two bytes, sixteen bits.

B.

Octal Number System

To express a number in binary requires substantially more digits than in the decimal system. For example, $91_{10} = 1011011_2$. Too many binary digits can become cumbersome to read or write when using large numbers, especially for human readers or writers. For convenience, the octal numbering system is brought into use. This system uses the number 8 as its base. The eight digits are 0,1,2,3,4,5,6, and 7. Like all other number systems, each digit in an octal number has a weighted decimal value according to its position. For example:

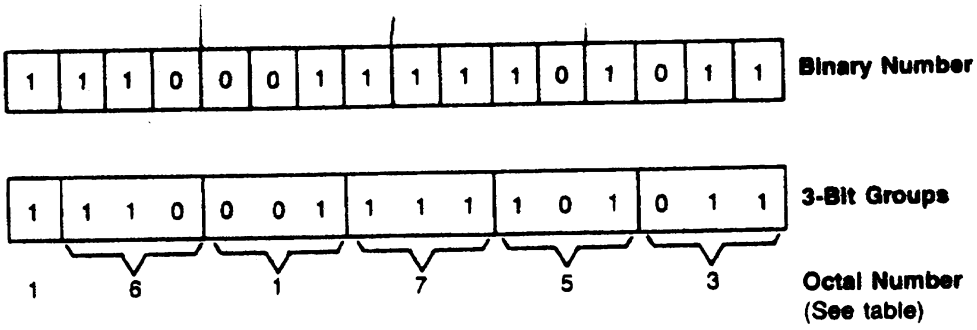


As noted, octal is used as a convenient means of writing or handling a binary number. If a binary number is very large (many 1s and 0s), it can be represented by an equivalent octal number. As shown in the Table 2-2, one octal digit can be used to express three binary digits.

Table 2-2. Binary and related Octal Code

Binary	Octal
000	0
001	1
010	2
011	3
100	4
101	5
110	6
111	7

Since the base of the system is 8, or 2 to the 3rd power, any binary number can be represented as octal by grouping binary bits in groups of three. In this manner, a very large binary number can be easily represented by an octal number with significantly fewer digits. For example:



So, the 16 bit binary number can be represented directly by 6 octal digits.

As we will see later, most programmable controllers use the octal number system for referencing input/output and memory addresses.

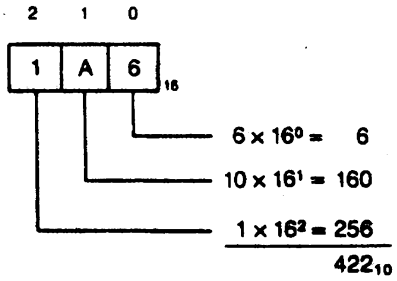
c.

Hexadecimal Number System

The hexadecimal (hex) numbering system uses 16 as the base. It consists of 16 digits, numbers 0 thru 9, and the letters A thru F, which are substituted for the numbers 10 to 15 respectively. These 16 hexadecimal numbers are shown in Table 2-3, along with their decimal and binary equivalents.

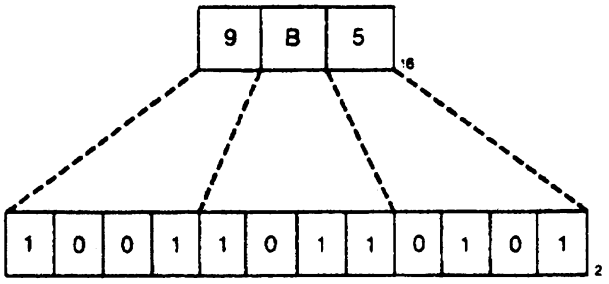
Table 2-3. Hexadecimal code related to binary and decimal

Hexadecimal	Binary	Decimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
A	1010	10
B	1011	11
C	1100	12
D	1101	13
E	1110	14
F	1111	15



As with the other number systems, hexadecimal numbers can be represented by their decimal equivalents by using the sum of the weights method. For example:

The value of A must be taken as 10 since A times 16 has to be expressed numerically, and A is equal to 10 decimal. The same rule applies thru F (10 thru 15). Like octal numbers, hexadecimal numbers can be easily converted to binary numbers without any mathematical conversion. Conversion is accomplished by writing the 4 bit binary equivalent of the hex digit of each position. For example:



D. BINARY CODES

An important requirement of programmable controllers is to communicate with various external devices that supply information to the controller or receive information from the controller. This input/output function involves the transmission, manipulation, and storage of binary data that at some point must be interpreted by humans. Although the machine can easily handle this binary data, we require that the data be converted to a more interpretable form.

One way of satisfying this requirement is to assign a unique combination of 1s and 0s to each number, letter, or symbol that must be represented. This technique is called *binary coding*. In general, there are 2 categories of codes — those used to represent numbers only, and those that represent letters, symbols, and decimal numbers. Several codes for representing numbers, symbols, and letters have been instituted and are standard throughout the industry. Among the most common are the following:

- ASCII
- BCD
- GRAY

1. ASCII

Alphanumeric (letters, symbols, decimal numbers) codes are used when information processing equipment, such as printers or CRTs, must handle the alphabet as well as numbers and special symbols. These characters — 26 letters (uppercase), 10 numerals (0-9), plus mathematical and punctuation symbols — can be represented using a 6 bit code (i.e. $2^6 = 64$). The most common code for alphanumeric representation is the *American Standard Code for Information Interchange* (ASCII). The acronym is pronounced "askey."

The ASCII code can be 6,7, or 8 bits. Even though the basic alphabet, numbers, and special symbols can be accommodated in a 6-bit code (64 possible characters), standard ASCII character sets use a 7-bit code ($2^7 = 128$ possible characters), which allows lower case and control characters for communication links, in addition to the characters already mentioned. This 7-bit code provides all possible combinations of characters used when communicating with peripherals or interfaces. The 8-bit ASCII code is used when parity check (see Chapter 4) is added to the standard 7-bit code for error checking. Note that all 8 bits can still be placed in one byte. Appendix E shows a standard ASCII table.

2. BCD

Binary Coded Decimal was introduced as a convenient means for humans to handle numbers that need to be input to digital machines and to interpret numbers output from the machine. To handle numbers that otherwise would have been in binary would be extremely tedious, since we are more familiar with the decimal number system. The best solution to this problem is a means of converting a code readily handled by man (decimal) to a code readily handled by the equipment (binary). The result is BCD.

In decimal, we have the numbers 0 thru 9, whereas in BCD, each of these numbers is represented by a 4-bit binary number. Table 2-4 illustrates the relationship between the BCD code and the binary and decimal number systems.

Table 2-4. BCD code with binary and decimal equivalents

Decimal	Binary	BCD
0	0	0000
1	1	0001
2	10	0010
3	11	0011
4	100	0100
5	101	0101
6	110	0110
7	111	0111
8	1000	1000
9	1001	1001

The BCD representation of a decimal number is obtained simply by replacing each decimal digit by its BCD equivalent. The BCD representation of decimal 7493 is shown here as an example.

0111 0100 1001 0011
7 4 9 3

Typical PC applications of BCD codes include data entry (time, volume, weights, etc.) via thumbwheel switches (TWS), data display via 7-segment displays, and input from absolute encoders. Because of the low cost of some integrated circuits, we find the necessary conversion of decimal to BCD and BCD to 7-segment already built into TWS and LED devices as illustrated in Fig. 2-2. This BCD data is then taken by the PC and converted internally into the binary equivalent of the input data through some instruction. To input or output BCD data, requires 4 lines to an input/output interface for each decimal digit.

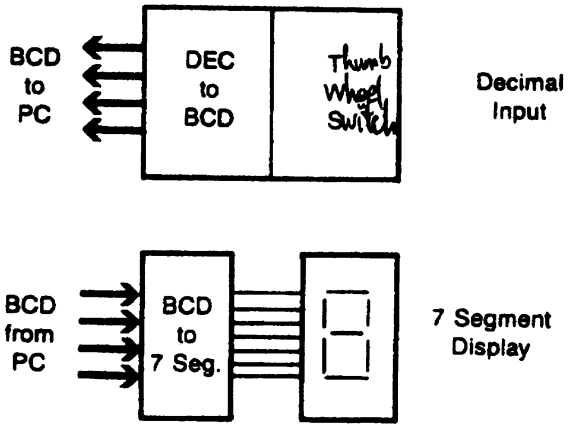


Figure 2-2. Illustration of thumbwheel switches (TWS), top; and seven segment LED display with converters.

3. GRAY

The *Gray* code is one of a series of cyclic codes known as reflected codes and suited primarily for position transducers. It is basically a binary code that has been modified in such a way that only 1 bit changes as the counting number increases. In binary, as many as 4 digits could change when counting. This drastic change is seen in the transition from binary 7 to 8. Such a change allows a greater chance for error, which would be unsuitable for positioning applications. Most encoders use this code to determine angular position. Table 2-5 shows the Gray code and binary equivalent for comparison.

Used with Optical Encode for Position Measurement

more robust fewer bits change than with binary

Table 2-5. Gray Code

Gray code	Binary
0000	0000
0001	0001
0011	0010
0010	0011
0110	0100
0111	0101
0101	0110
0100	0111
1100	1000
1101	1001
1111	1010
1110	1011
1010	1100
1011	1101
1001	1110
1000	1111

In an optical absolute encoder, the rotor disk consists of an opaque and transparent segment, arranged in a Gray code pattern and illuminated by a light source that shines through the transparent sections of the rotating disk. The transmitted light is then received at the other end in Gray code form and is available for PC input in Gray code or BCD code if converted. Figure 2-3 illustrates a typical absolute encoder and its output.

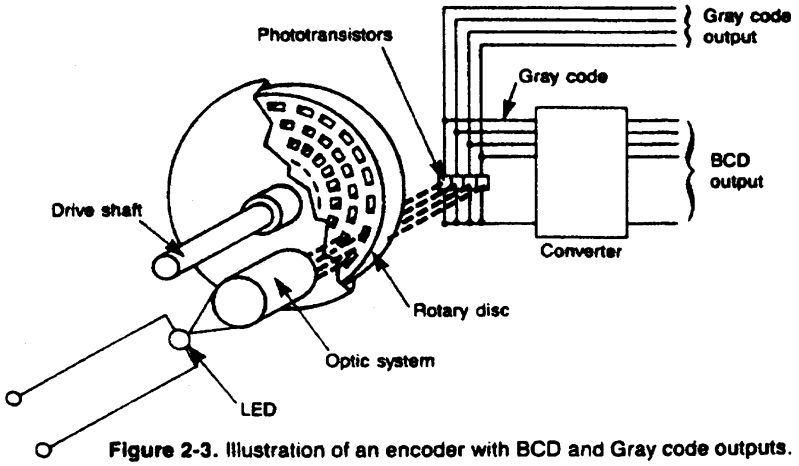


Figure 2-3. Illustration of an encoder with BCD and Gray code outputs.

E.

ONE'S AND TWO'S COMPLEMENT

One's and two's complement of a binary number is an operation used by programmable controllers, as well as computers, to perform internal mathematical calculations. To complement a binary number is to change it to a negative number. This allows the basic arithmetic operations of subtraction, multiplication, and division to be performed through successive addition. For example, to subtract the number 20 from 40 is done by first complementing 20 to obtain -20, and then performing an addition.

The intention here is to introduce the basic concepts of complementing rather than to provide a thorough analysis of arithmetic operations. However, several of the references listed in the back of this book cover this material.

computers cannot subtract multiply or divide

One's Complement

Let us assume that we have a 5 bit binary number that we wish to represent as a negative number. The number is decimal 23.

$$(10111)_2$$

There are two ways of representing this number as a negative number. The first method is simply to place the minus sign in front of the number, as with decimal numbers.

$$-(10111)_2$$

This method is suitable for us, but impossible for programmable controllers or computers, since the only symbols they use are binary 1s and 0s. To represent negative numbers then, digital computing devices use what is known as the complement method. First, the complement method places an extra bit (sign bit) in the most significant position (left-most), and lets this bit determine whether the number is positive or negative. The number is positive if the sign bit is 0 and negative if the sign bit is 1. Using the complement method, +23 would be represented as shown here:

$$0\ 10111_2$$

The negative representation of binary 23 using the 1s complement method, is simply obtained by inverting each bit, or changing 1s to 0s, and 0s to 1s. The one's complement of binary 23 then is shown here.

$$1\ 01000_2$$

If a negative number was given in binary, its complement would be obtained in the same fashion. Let's take the number -15:

$$1\ 0000 \longrightarrow -15$$
$$0\ 1111 \longrightarrow +15$$

Two's Complement

Two's complement is similar to 1s complement in the sense that 1 extra digit is used to represent the sign. The two's complement computation, however, differs slightly. In 1s complement, all bits are inverted; but in two's complement, each bit from right to left is inverted, but only after the first "1" is detected. Let's use the number +22 as an example:

$$0\ 10110 \longrightarrow +22$$

Its two's complement would be:

$$1\ 01010 \longrightarrow -22$$

Note that in the positive representation of the number 22, starting from the right, the first digit is a 0 so it is not inverted; the second digit is a 1; all digits after this one are inverted.

If a negative number is given in two's complement, its complement (a positive number) is found in the same fashion.

$$1\ 10010 \longrightarrow -14$$
$$0\ 01110 \longrightarrow +14$$

F. COMBINATIONAL LOGIC

Definition: Networks whose output values depend only on present values of inputs.
(i.e. No memory!)

SEQUENTIAL LOGIC

Definition: Combinational logic with added memory elements. The basic memory element is the flip-flop

II. Combinational Logic

A. Outputs depend only on current Inputs!

- Logic is comprised of Gates, Contacts, Switches Timers, Counters, etc.

Examples:

AND, OR, NOT	XAND, XOR	Pulses
NAND, NOR	Time Delays	Counters

1. Various Symbol Standards

The AND Function

The symbol shown in Fig. 3-1 is called an AND gate and is used to represent graphically the AND function.

ANSI/ IEEE

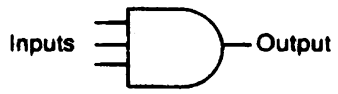
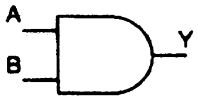


Figure 3-1. Symbol for AND function.

The AND output is True (1) only if all inputs are True (1).
The number of inputs to the AND gate is unlimited, but there is only one output. The truth table in Fig. 3-2 shows the resulting output (Y), based on all possible input combinations.



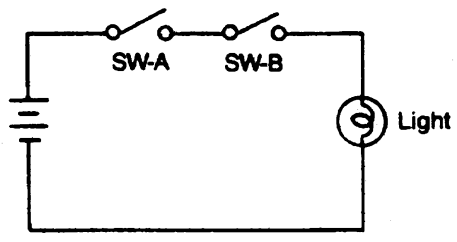
Two Input
AND Gate

Inputs		Output
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

AND Truth Table

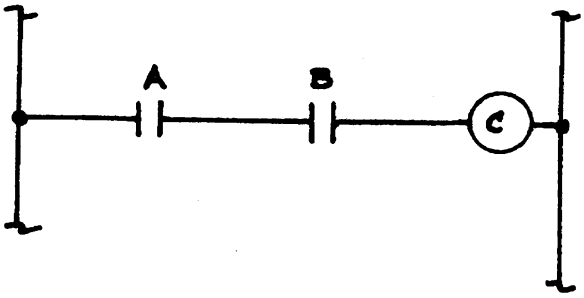
Figure 3-2.

Switched AND:



AND:

LADDER REPRESENTATION:



AND: ISA + SAMA STANDARDS...

The OR Function

The symbol shown in Fig. 3-3 is called an OR gate and is used to represent graphically the OR function.

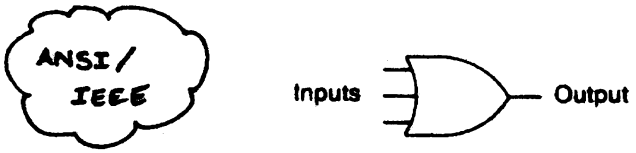


Figure 3-3. Symbol for OR function.

The OR output is True (1) if one or more inputs are True (1).

The number of inputs to an OR gate is unlimited, but there is only one output. The truth table in Fig. 3-4 shows the resulting output (Y), based on all possible input combinations.



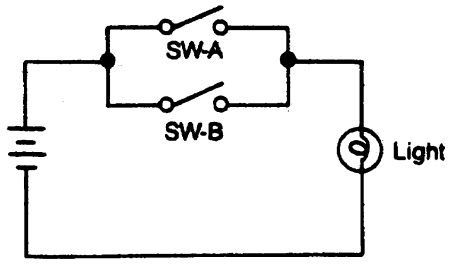
Two Input
OR Gate

Inputs		Outputs
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

OR Truth Table

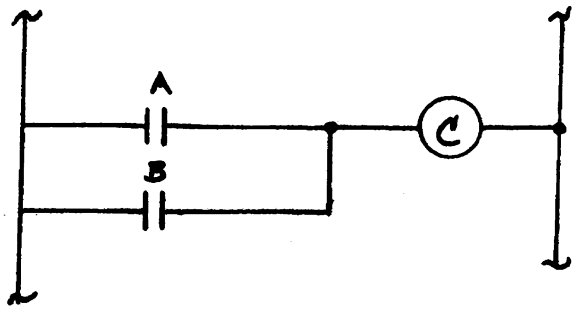
Figure 3-4.

SWITCHED OR:



OR:

LADDER REPRESENTATION:



OR: ISA + SAMA STANDARDS....

The NOT Function

The symbol shown in Fig. 3-5 is the NOT symbol and is used to represent graphically the NOT function.

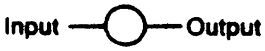
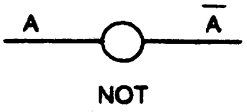


Figure 3-5. Symbol for NOT function.

The NOT output is True (1) if the input is False (0). The output is False (0) if the input is True (1). The result of the NOT operation is always the inverse of the input and is, therefore, sometimes called an *inverter*.

The NOT function, unlike the AND and OR, can have only one input and is never used alone, but in conjunction with the AND or the OR gate. The NOT operation and truth table are shown in Fig. 3-6.

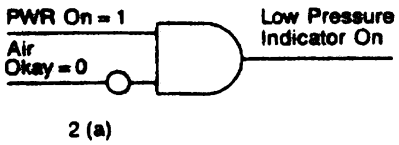


Input	Output
A	$\overline{A}$
0	1
1	0

NOT Truth Table

Figure 3-6.

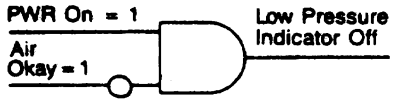
Example 3-6. Warning indicator. If power is ON AND pressure NOT okay (switch opened), the warning indicator will be ON.



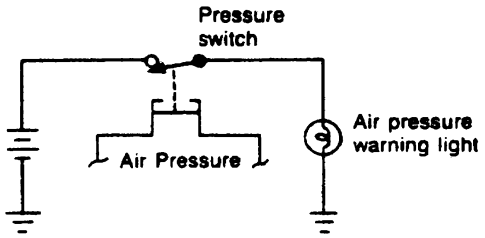
2 (a)

Air Okay	PWR	Pressure Indicator
0	1	1
1	1	0

Truth Table for 2a and 2b.



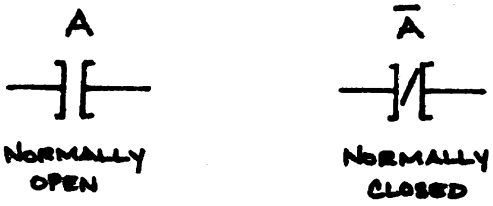
2(b)



Air pressure warning system

NOT:

LADDER REPRESENTATION:



NOTE! DESIGN WITH FAIL-SAFE LOGIC. ϕ = ALARM 1 = OK ϕ = STOP 1 = RUN

WHY?

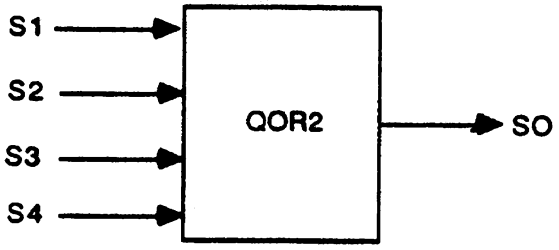
IF...

WIRE IS CUT...
POWER IS LOST....
CONTACT IS CORRODED...
SAFETY DEVICE (SWITCH) IS MISSING....

A JUMPER WOULD HAVE TO BE INTENTIONALLY INSTALLED TO DEFEAT FAIL-SAFE LOGIC.

Qualified OR Gate with 2 Inputs ON (QOR2)

This algorithm provides a 4-input qualified-OR function that requires at least two inputs to be ON before output SO is set to ON. The output is determined as follows:



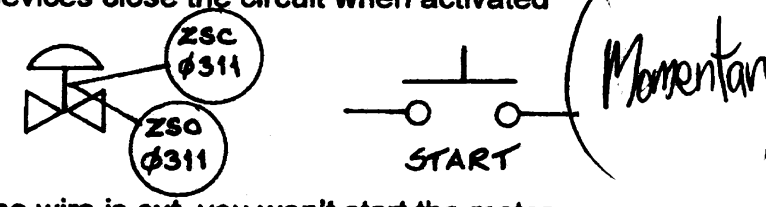
IF (at least 2 inputs out of S1, S2, S3, and S4 are ON) THEN
    SO = ON
ELSE
    SO = OFF

TO NOT .... OR NOT TO NOT: WHAT IS THE QUESTION?

Normally Open vs. Normally Closed

1. Normally Open:
Equipment that does not complete the circuit during normal process conditions or when the switch is not actuated. These devices close the circuit when activated

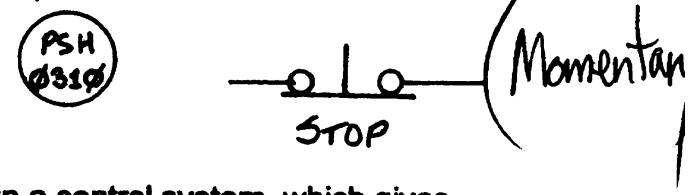
<u>examples</u>
Limit Switches on equipment
Start pushbuttons in the field



If a normally open contact corrodes or if the wire is cut, you won't start the motor or you won't get valve position feedback. That's OK though, because you'll realize the problem, it will be SAFE, and you'll contact maintenance to fix it.

2. Normally Closed:
Equipment that does complete the circuit during normal process conditions or when the switch is not actuated. These devices open the circuit when activated.

<u>examples</u>
Alarm indications (PSH, LSH, LSL, etc.)
Stop pushbuttons in the field



A closed contact generally gives a logic "ONE" in a control system, which gives **positive** indication of a functioning circuit.

The Fail-Safe Rule to Remember: **"ONE TO RUN"**

If a normally closed contact corrodes or if the wire is cut, the alarm will alarm or the motor will stop. That's OK too, because you'll realize the problem and get it fixed.

QUESTION	DESCRIPTION	AREA
P32-33	**Codes and Standards**	**I**

The following information refer to Questions P32 and P33.

Your assignment is to implement a burner management system using a solid-state microprocessor-based programmable logic controller (PLC). You will analyze boiler operation, develop system logic, and select control equipment.

The system design shall upgrade the burner management functions on a 50,000,000 btu/hr, two-burner, gas-fired boiler to current NFPA standards. Igniters will be interrupted (turned off) when the timed trial for ignition of the main burner has expired. PLC inputs and outputs will de-energize to shut off (trip) fuel to the boiler.

P32. The primary reason a non-redundant programmable logic controller is used for a burner management system instead of relay logic is to:

(A) Make functional changes by field personnel easier.

(B) Make functional changes while operating possible.

(C) Decrease space requirements and cost to implement more complex logic.

(D) Allow PID control in the burner management system.

P33. The burner system manual emergency shutdown shall be accomplished by:

(A) A normally-open contact to a PLC input.

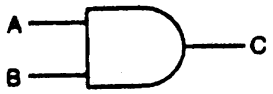
(B) A normally-closed contact to a PLC input.

(C) A normally-open contact to a PLC input and a normally-closed contact to another PLC input.

(D) A hard-wired normally-closed contact to de-energize a fuel trip relay.

Equivalent Logic/Ladder Diagrams

Logic Diagrams



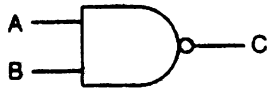
AND Gate



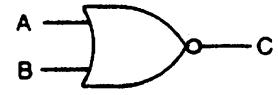
OR Gate



Exclusive-OR Gate

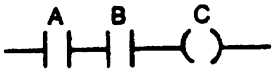


NAND Gate

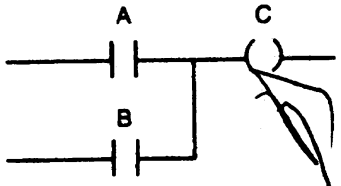


NOR Gate

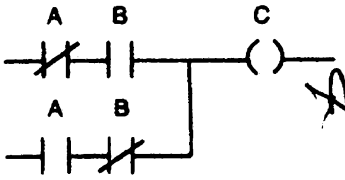
Ladder Diagrams



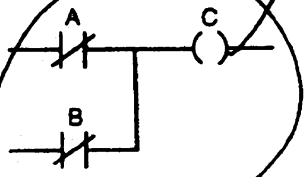
Equivalent Circuit



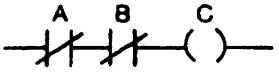
Equivalent Circuit



Equivalent Circuit



Equivalent Circuit



Equivalent Circuit

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

AND Truth Table

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

OR Truth Table

A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive-OR Truth Table

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

NAND Truth Table

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

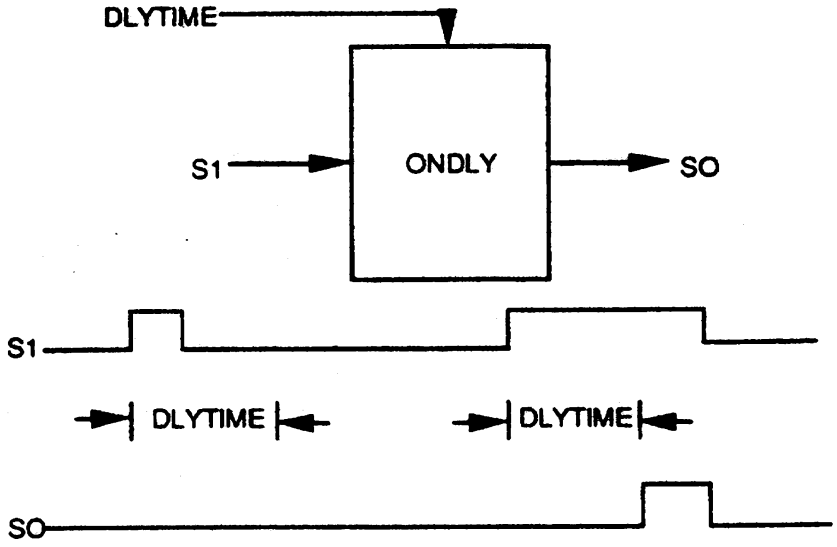
NOR Truth Table

2. Timers and Counters

a. Block Types - Delay on, Delay off, Pulse, Maxpulse, Minpulse

On Delay (ONDLY)

This logic algorithm delays the input signal supplied at the S1 input when the input signal is going from the OFF to the ON state. (There is no delay provided when the input changes from the ON to the OFF state.) When the input state changes from OFF to ON, an internal timer starts counting down the delay time specified by the DLYTIME parameter (in seconds). When it times out, the S1 input is monitored again, and if it is still ON, the SO output is set to ON. When the input state transitions to OFF, the SO output is set to OFF immediately, and the timer is shut off (if it is running). If the specified delay time is less than or equal to one sample time (of the logic point), it is assumed to be equal to one sample time.



SAMA Block #32 (Page 18)

ISA Block #4.8 b. (Page 10)

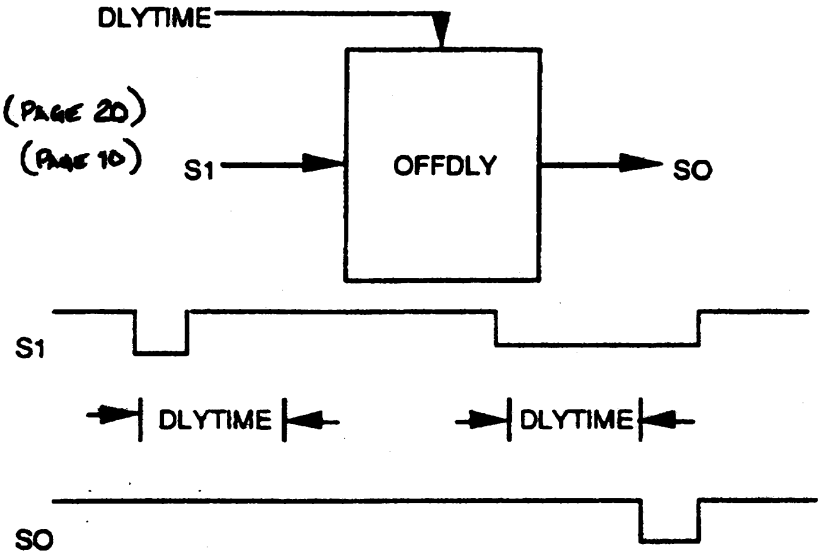
OR f1. (Page 11)

TIMERS & COUNTERS :

Off Delay (OFFDLY)

This logic algorithm delays the input signal supplied at the S1 input when the input signal is going from the ON to the OFF state. (There is no delay provided when the input changes from the OFF to the ON state.) When the input state changes from ON to OFF, an internal timer starts counting down the delay time specified by the DLYTIME parameter (in seconds). When it times out, the S1 input is monitored again, and if it is still OFF, the SO output is set to OFF. When the input state transitions to ON, the SO output is set to ON immediately, and the timer is shut off (if it is running). If the specified delay is less than or equal to one sample time (of the logic point), it is assumed to be equal to one sample time.

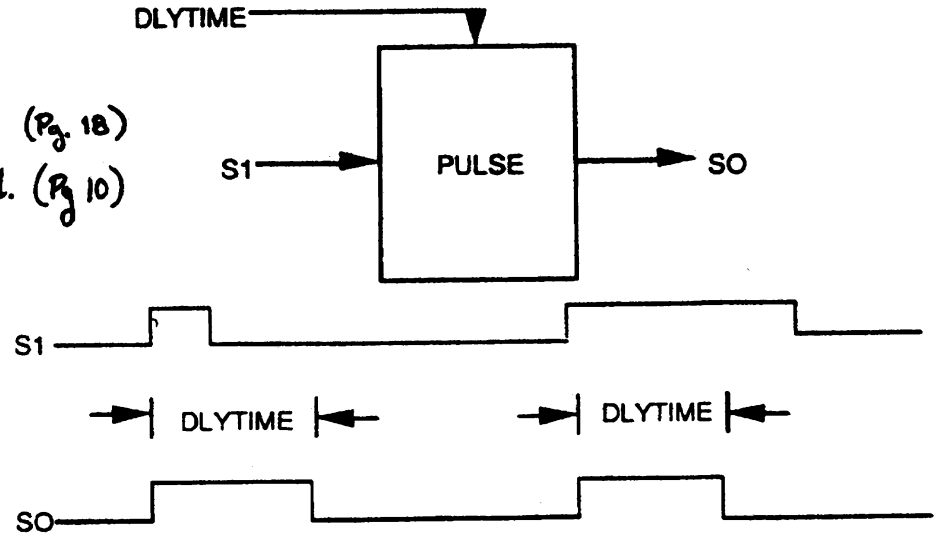
SAMA #34 (PAGE 20)
ISA #4.8c. (PAGE 10)



Fixed-Size Pulse (PULSE)

This logic algorithm provides a fixed-size output pulse at the SO output each time the S1 input transitions from the OFF state to the ON state. The output pulse width (in seconds) is specified by the DLYTIME parameter. If the delay time is less than or equal to one sample time (of the logic point), it is assumed to be equal to one sample time. Another output pulse cannot be generated until the generation of the preceding pulse has been completed.

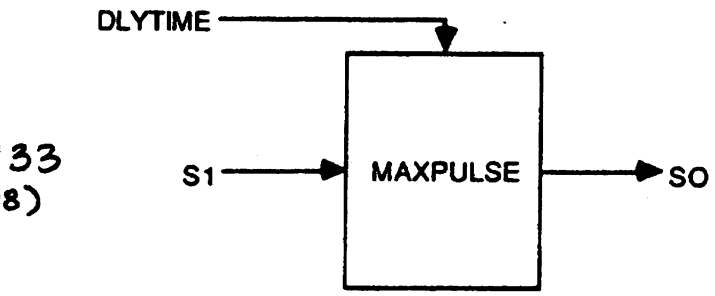
SAMA #31 (Pg. 18)
ISA # 4.8d. (Pg 10)

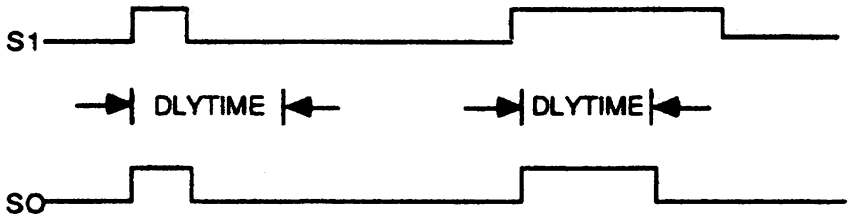


Pulse with Maximum Time Limit (MAXPULSE)

This logic algorithm provides a pulse at the SO output each time the S1 input transitions from the OFF to the ON state. If the input stays ON longer than a predefined time, the output pulse is terminated. The maximum output pulse width (in seconds) is specified by the DLYTIME parameter. If the specified output pulse width is less than or equal to one sample time (of the logic point), it is assumed to be equal to one sample time.

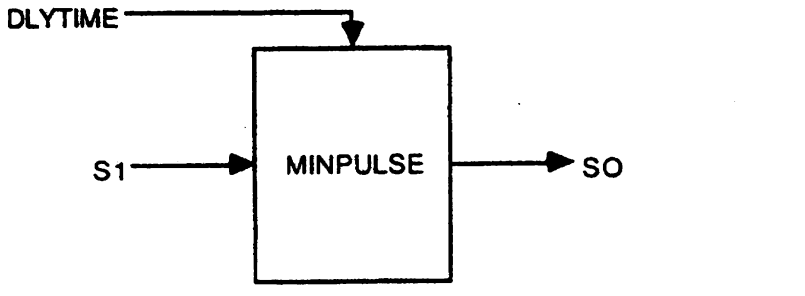
SAMA #33
(PAGE 18)

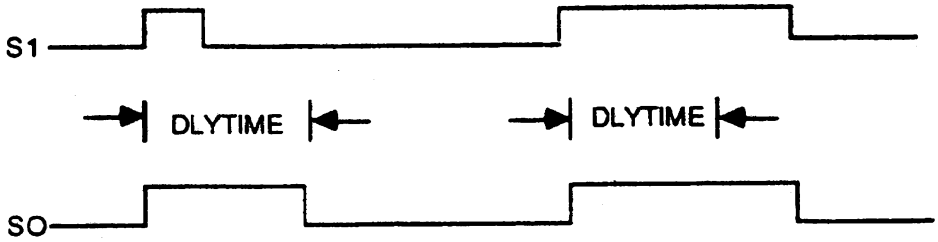




Pulse with Minimum Time Limit (MINPULSE)

This algorithm generates a pulse at the SO output each time the S1 input transitions from the OFF to the ON state. If the S1 input stays ON for an interval that is less than the specified time, the output pulse is extended until the timed interval is over. The minimum output pulse width (in seconds) is specified by the DLYTIME parameter. If the specified output pulse width is less than, or equal to, one sample time (of the logic point), it is assumed to be equal to one sample time.



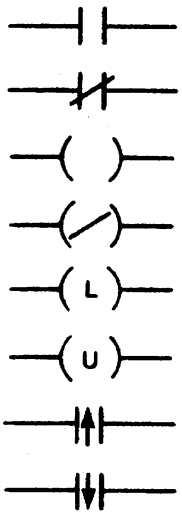
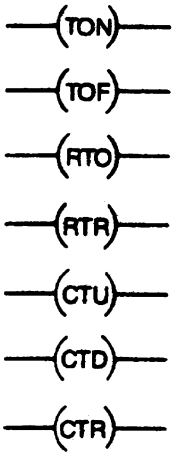


PLC COUNTER & TIMER INSTRUCTIONS

Timer And Counter Instructions

Timers and counters are output instructions that provide the same functions as would hardware timers and counters. They are used to activate or de-activate a device after an expired interval or count. The timer and counter instructions are generally considered internal outputs. Like the relay-type instructions, timer and counter instructions are fundamental to the ladder diagram instruction set.

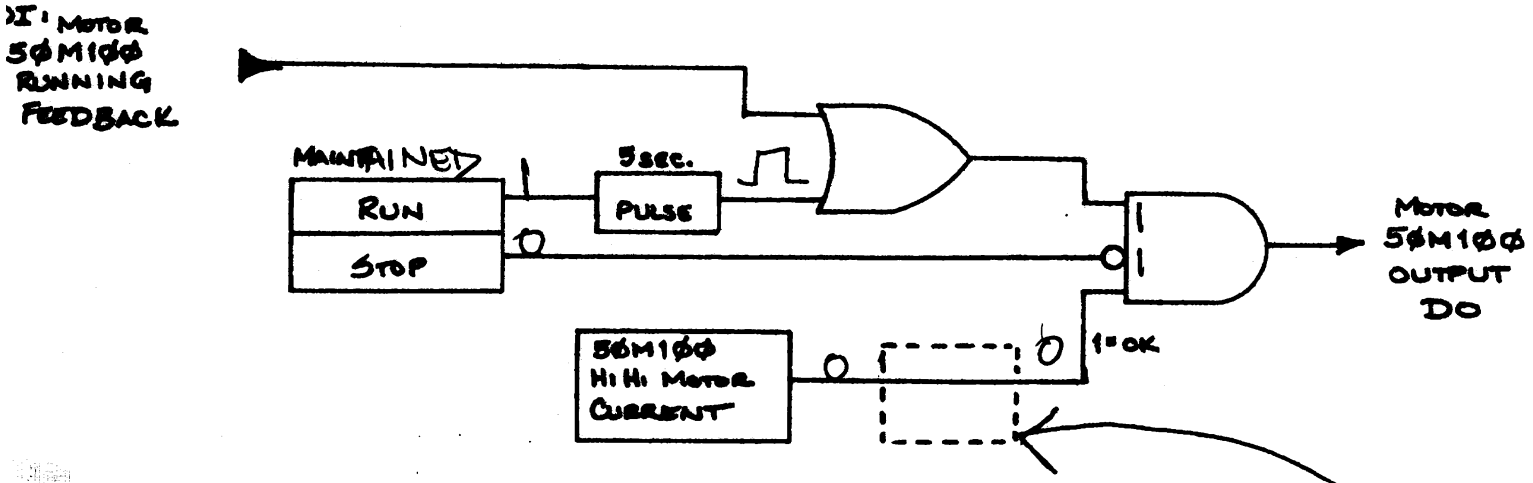
The operations of the software timer and counter are quite similar, in that they are both counters. A timer counts the number of times that a fixed interval of time (e.g. 0.1 sec, 1.0 sec) elapses. To time an interval of 3 seconds, a timer counts three 1 second intervals (time base). A counter simply counts the occurrence of an event. Both the timer and counter instructions require an accumulator register (word location) to store the elapsed count and a preset register to store a preset value. The preset value will determine the number of event occurrences or time base intervals that are to be counted.

Operation Type	Basic Level Language	High Level Language
Relay Logic		LATCH / UNLATCH TRANSITIONALS
Timer and Counter		TMR On TMR Off Count Up Count Down Count Up/Down RETENTIVE ON-DELAY } FOR LOSS OF POWER RETENTIVE TIMER RESET } FOR LOSS OF POWER UP COUNTER DOWN-COUNTER COUNTER RESET RESETS CTU + CTD

A.2.C. Relay Race Solutions

In Real Time Execution of Logic, oscillation can occur unintentionally due to Real World Limitations of Control Systems. These Relay Races can be due to Scan Times, Mechanical Links (e.g. Pressure, Current) or Both.

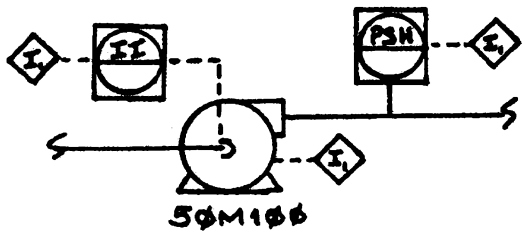
Example:



- Hi Hi Current Kills Output (HH = Ø)
- Motor Contacts Open and Hi Hi Current Clears Instantly
- Loss of Motor Feedback has not made it thru OR gate before HH Motor Current Clears and Tries to Re-Start Motor. Oscillation Begins due to Propagation Delay.

Solution: Add a "Delay On" Block for a 1-2 second delay for Current "OK" signal to Return.

! Note also that a delay may be necessary to Ignore In-Rush Current Alarm During Start of Motor.



d. Other Miscellaneous Gate Types You May See...

- Null (NULL)
- AND Gate (AND)
- OR Gate (OR)
- NOT Gate (NOT)
- NAND Gate (NAND)
- NOR Gate (NOR)
- XOR Gate (XOR)
- Qualified OR Gate With 2 Inputs ON (QOR2)
- Qualified OR Gate With 3 Inputs ON (QOR3)
- Switch (SWITCH)

- Compare Equal With Deadband (EQ)
- Compare Not Equal With Deadband (NE)
- Compare Greater Than With Deadband (GT)
- Compare Greater Than or Equal With Deadband (GE)
- Compare Less Than With Deadband (LT)
- Compare Less Than or Equal With Deadband (LE)

- Check for Bad (CHECKBAD)

- Fixed Size Pulse (PULSE)
- Pulse With Maximum Time Limit (MAXPULSE)
- Pulse With Minimum Time Limit (MINPULSE)
- Delay (DELAY)
- On Delay (ONDLY)
- Off Delay (OFFDLY)

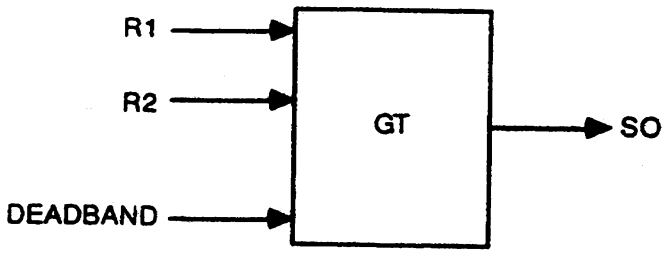
- Watchdog Timer (WATCHDOG)

- Flipflop (FLIPFLOP)

- Change Detect (CHDETECT)

Ex. Compare Greater Than with Deadband (GT)

This algorithm compares a real input (R1) for being greater than another real input (R2) with a predefined deadband. Output SO is determined as follows:




```
IF (R1 > R2) THEN
    SO = ON
ELSE IF (R1 <= (R2 - DEADBAND)) THEN
    SO = OFF
ELSE
    SO is not changed.
```

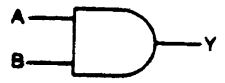
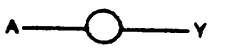
II. B. Logic Design Tools and Methods

1. Boolean Algebra and reduction

Boolean algebra was developed in 1849 by an Englishman named George Boole. The intent of this algebra was to aid in the logic of reasoning, an ancient form of philosophy, rather than to implement the purposes of digital logic, a technique not developed at the time. It was meant to provide a simple way of writing complicated combinations of *logical statements*, defined earlier as statements that can be either TRUE or FALSE.

When digital logic finally came to be, Boolean algebra already existed as a simple way to analyze and express logic statements. All digital systems are based on this TRUE/FALSE or two-valued logic concept, where 1 represents TRUE and 0 represents FALSE. Because of this relationship between digital logic and Boolean logic, we will occasionally hear logic gates referred to as Boolean gates, or several interconnected gates called a Boolean network.

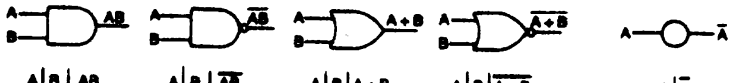
Boolean Operators

Logic Symbol	Logical Statement	Boolean Equation
	Y is "1" if A and B are "1"	$Y = A \cdot B$ or $Y = AB$
	Y is "1" if A or B is "1"	$Y = C + D$
	Y is "1" if A is "0" Y is "0" if A is "1"	$Y = \overline{A}$

Summary of Boolean algebra as related to the AND, OR, and NOT functions.

Boolean Expressions

1. Basic Gates. Basic logic gates implement simple logic functions. Each logic function is expressed in terms of a truth table and its Boolean expression.



A	B	AB
0	0	0
0	1	0
1	0	0
1	1	1

AND

A	B	$\overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

NAND

A	B	A + B
0	0	0
0	1	1
1	0	1
1	1	1

OR

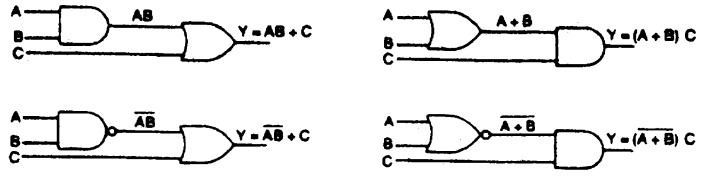
A	B	$\overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

NOR

A	$\overline{A}$
0	1
1	0

NOT

2. Combined Gates. Any combination of control functions can be expressed in Boolean terms using three simple operators: (•), (+), (—).



LAWS AND THEOREMS OF BOOLEAN ALGEBRA

Operations with 0 and 1:

1. $X + 0 = X$ — 1D. $X \cdot 1 = X$
2. $X + 1 = 1$ — 2D. $X \cdot 0 = 0$

Idempotent laws:

3. $X + X = X$ — 3D. $X \cdot X = X$

Involution law:

4. $(X')' = X$

$X' \equiv \bar{X}$

Laws of complementarity:

5. $X + X' = 1$ — 5D. $X \cdot X' = 0$

Commutative laws:

6. $X + Y = Y + X$ — 6D. $XY = YX$

Associative laws:

7. $(X + Y) + Z = X + (Y + Z) = X + Y + Z$ — 7D. $(XY)Z = X(YZ) = XYZ$

Distributive laws:

8. $X(Y + Z) = XY + XZ$ — 8D. $X + YZ = (X + Y)(X + Z)$

Simplification theorems:

9. $XY + XY' = X$ — 9D. $(X + Y)(X + Y') = X$
10. $X + XY = X$ — 10D. $X(X + Y) = X$
11. $(X + Y')Y = XY$ — 11D. $XY' + Y = X + Y$

DeMorgan's laws:

12. $(X + Y + Z + \ldots)' = X'Y'Z' \ldots$ — 12D. $(XYZ \ldots)' = X' + Y' + Z' + \ldots$
13. $[f(X_1, X_2, \ldots, X_n, 0, 1, +, \cdot)]' = f(X_1', X_2', \ldots, X_n', 1, 0, \cdot, +)$

Duality:

14. $(X + Y + Z + \ldots)^D = XYZ \ldots$ — 14D. $(XYZ \ldots)^D = X + Y + Z + \ldots$
15. $[f(X_1, X_2, \ldots, X_n, 0, 1, +, \cdot)]^D = f(X_1, X_2, \ldots, X_n, 1, 0, \cdot, +)$

Theorem for multiplying out and factoring:

16. $(X + Y)(X' + Z) = XZ + X'Y$ — 16D. $XY + X'Z = (X + Z)(X' + Y)$

Consensus theorem:

17. $XY + YZ + X'Z = XY + X'Z$ — 17D. $(X + Y)(Y + Z)(X' + Z) = (X + Y)(X' + Z)$

ALGEBRAIC SIMPLIFICATION

The Consensus Theorem

The consensus theorem is very useful in simplifying Boolean expressions. Given an expression of the form $XY + X'Z + YZ$ the term YZ is redundant and can be eliminated to form the equivalent expression $XY + X'Z$.

The term which was eliminated is referred to as the "consensus term." Given a pair of terms for which a variable appears in one term and the complement of that variable in another, the consensus term is formed by multiplying the two original terms together, leaving out the selected variable and its complement. For example, the consensus of ab and $a'c$ is bc; the consensus of abd and $b'de'$ is $(ad)(de') = ade'$. The consensus of terms $ab'd$ and $a'bd'$ is 0.

The consensus theorem can be stated as follows:

$$XY + X'Z + YZ = XY + X'Z$$

Proof: 1 AND'ed

$$XY + X'Z + YZ = XY + X'Z + (X + X')YZ = (XY + XYZ) + (X'Z + X'YZ)$$
$$= XY(1 + Z) + X'Z(1 + Y) = XY + X'Z$$

The consensus theorem can be used to eliminate redundant terms from Boolean expressions. For example, in the following expression, $b'c$ is the consensus of $a'b'$ and ac, and ab is the consensus of ac and bc', so both consensus terms can be eliminated:

$$a'b' + ac + bc' + b'c + ab = a'b' + ac + bc'$$

The dual form of the consensus theorem is

$$(X + Y)(X' + Z)(Y + Z) = (X + Y)(X' + Z) \qquad (4\text{-}2)$$

The brackets indicate how the consensus terms are formed.

Note again that the key to recognizing the consensus term is to first find a pair of terms, one of which contains a variable and the other its complement. In this case, the consensus is formed by adding this pair of terms together leaving out the selected variable and its complement. In the following expression, $(a + b + d')$ is a consensus term and can be eliminated by using the dual consensus theorem:

$$(a + b + c')(a + b + d')(b + c + d') = (a + b + c')(b + c + d')$$

CONSENSUS BY GROUPING

The final result obtained by application of the consensus theorem may depend on the order in which terms are eliminated.

Example: $A'C'D + A'BD + BCD + ABC + ACD' \qquad (4\text{-}3)$

First we eliminate BCD as shown. (Why can it be eliminated?)

Now that BCD has been eliminated, it is no longer there, and it *cannot* be used to eliminate another term. Checking all pairs of terms shows that no additional terms can be eliminated by the consensus theorem.

Now we start over again:

$$A'C'D + A'BD + BCD + ABC + ACD' \qquad (4\text{-}4)$$

This time, we do not eliminate BCD; instead we eliminate *two* other terms by the consensus theorem. After doing this, observe that BCD can no longer be eliminated. Note that the expression reduces to four terms if BCD is eliminated first, but that it can be reduced to three terms if BCD is not eliminated.

a+b = Z c' = X'
b+d' = Y c = X
(a+b+b+d')
b+b = b
(a+b+d')

A'(BD)+A(BC)
(BDBC) B·B = B
BCD

Algebraic Simplification of Switching Expressions

In this section we will apply the theorems of Boolean algebra to simplifying switching expressions. This is important because simplifying an expression reduces the cost of realizing the expression using gates. Later we will learn graphical methods for simplifying switching functions, but we will learn algebraic methods first. In addition to multiplying out and factoring, three basic ways of simplifying switching functions are combining terms, eliminating terms and eliminating literals.

a. *Combining terms.* Use the theorem $XY + XY' = X$ to combine two terms.

Example: $abc'd' + abcd' = abd' \quad [X = abd', Y = c]$ (4-5)

When combining terms by this theorem as above, the two terms to be combined should contain exactly the same variables, and exactly one of the variables should appear complemented in one term and not in the other. Since $X + X = X$, a given term may be duplicated and combined with two or more other terms.

Example: $ab'c + abc + a'bc = ab'c + abc + abc + a'bc = ac + bc$

The theorem still can be used, of course, when X and Y are replaced with more complicated expressions.

Example: $(a + bc)(d + e') + a'(b' + c')(d + e') = d + e'$

$[X = d + e', Y = a + bc, Y' = a'(b' + c')]$ ← DE MORGAN USED $\bar{Y} = \overline{a+bc} = \bar{a}\left(\overline{bc}\right) = \bar{a}(\bar{b}+$

b. *Eliminating terms.* Use the theorem $X + XY = X$ to eliminate redundant terms if possible; then try to apply the consensus theorem ($XY + X'Z + YZ = XY + X'Z$) to eliminate any consensus terms.

Examples: $a'b + a'bc = a'b \quad [X = a'b]$

$a'bc'd + bcd + a'bd = a'bc'd + bcd \; [X = c, Y = bd, Z = a'b]$ (4-6)

c. *Eliminating literals.* Use the theorem $X + X'Y = X + Y$ to eliminate redundant literals. Simple factoring may be necessary before the theorem is applied.

Example: $A'B + A'B'C'D' + ABCD'$

$= A'(B + B'C'D') + ABCD' = A'(B + C'D') + ABCD'$

$= B(A' + ACD') + A'C'D' = B(A' + CD') + A'C'D'$

$= A'B + BCD' + A'C'D'$ (4-7)

The expression obtained after applying a, b and c above will not necessarily have a minimum number of terms or a minimum number of literals. If it does not, and no further simplification can be made using a, b and c, deliberate introduction of redundant terms may be necessary before further simplification can be made.

d. *Adding redundant terms.* Redundant terms can be introduced in several ways such as adding xx', multiplying by $(x + x')$, adding yz to $xy + x'z$, or adding xy to x. When possible, the terms added should be chosen so that they will combine with or eliminate other terms.

Example: $WX + XY + X'Z' + WY'Z'$ (add WZ' by consensus theorem)

$= WX + XY + X'Z' + WY'Z' + WZ'$ (eliminate $WY'Z'$)

$= WX + XY + X'Z' + WZ'$ (eliminate WZ') BY CONSENSUS

$= WX + XY + X'Z'$ (4-8)

II. B. Logic Design Tools and Methods

2. Truth Tables (minterms and maxterms)

Conversion of English Sentences to Boolean Equations

Logic design problems are often stated in terms of one or more English sentences. The first step in designing a logic network is to translate these sentences into Boolean equations. In order to do this, we must break down each sentence into phrases and associate a Boolean variable with each phrase. If a phrase can have a value of "true" or "false", then we can represent that phrase by a Boolean variable. Phrases like "she goes to the store" or "today is Monday" can be either true or false, but a command like "go to the store" has no truth value. If a sentence has several phrases, we will mark each phrase with a brace. The following sentence has three phrases:

Mary watches TV if it is Monday night and she has finished her homework.

The "if" and "and" are not included in any phrase; they show the relationships among the phrases.

We will define a two-valued variable to indicate the truth or falsity of each phrase:

$F = 1$ if "Mary watches TV" is true; otherwise, $F = 0$

$A = 1$ if "it is Monday night" is true; otherwise, $A = 0$

$B = 1$ if "she has finished her homework" is true; otherwise $B = 0$

Since F is "true" if A and B are both "true", we can represent the sentence by

$$F = A \cdot B$$

The three main steps in designing a single-output combinational switching network are:

a. Find a switching function which specifies the desired behavior of the network.

b. Find a simplified algebraic expression for the function.

c. Realize the simplified function using available logic elements.

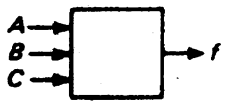
For simple problems, it may be possible to go directly from a word description of the desired behavior of the network to an algebraic expression for the output function. In other cases, it is better to first specify the function by means of a truth table and then derive an algebraic expression from the truth table.

Combinational Network Design Using a Truth Table

The next example illustrates network design using a truth table. A switching network has three inputs and one output as shown. The inputs A, B, and C represent the first, second, and third bits, respectively, of a binary number N. The output of the network is to be $f = 1$ if $N \geq 011_2$ and $f = 0$ if $N < 011_2$. The truth table for f is as follows:

Table 5-1

A	B	C	f	f'
0	0	0	0	1
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	1	0
1	0	1	1	0
1	1	0	1	0
1	1	1	1	0



3 Maxterms

5 minterms

Next we will derive an algebraic expression for f from the truth table by using the combinations of values of A, B, and C for which $f = 1$. The term $A'BC$ is 1 only if $A = 0$, $B = 1$, and $C = 1$. Similarly, the term $AB'C'$ is 1 only for the combination 100, $AB'C$ is 1 only for 101, ABC' is 1 only for 110, and ABC is 1 only for 111. ORing these terms together yields THM #9 THM #9

MINTERMS: $$f = A'BC + AB'C' + AB'C + ABC' + ABC \qquad (5\text{-}1)$$

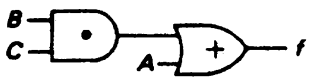
where $f=1$

The above expression equals 1 if A, B, and C take on any of the five combinations of values 011, 100, 101, 110, or 111. If any other combination of values occurs, f is 0 because all five terms are 0.

Equation (5-1) can be simplified by first combining terms and then eliminating A': THM #9 THM. 11B

$$f = A'BC + AB' + AB = A'BC + A = A + BC \qquad (5\text{-}2)$$

Equation (5-2) leads directly to the following network:



Instead of writing f in terms of the 1's of the function, we may also write f in terms of the 0's of the function. The function defined by Table 5-1 is 0 for three combinations of input values. Observe that the term $A + B + C$ is 0 only if $A = B = C = 0$. Similarly, $A + B + C'$ is 0 only for the input combination 001, and $A + B' + C$ is 0 only for the combination 010. ANDing these terms together yields

MAXTERMS: $$f = (A + B + C)(A + B + C')(A + B' + C) \qquad (5\text{-}3)$$

where $f=0$

The above expression equals 0 if A, B, and C take on any of the combinations of values 000, 001, or 010. For any other combination of values, f is 1 because all three terms are 1. Since Equation (5-3) represents the same function as Equation (5-1) they must both reduce to the same expression. Combining terms and using the second distributive law, Equation (5-3) simplifies to

$$f = (A + B)(A + B' + C) = A + B(B' + C) = A + BC \qquad (5\text{-}4)$$

which is the same as Equation (5-2).

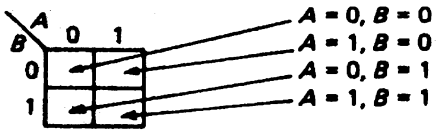
3. MINTERM EQUATION (5-1) IS IN THE SUM-OF-PRODUCTS FORM. MAXTERM EQUATION (5-3) IS IN THE PRODUCT-OF-SUMS FORM.

II. B. Logic Design Tools and Methods

4. Karnaugh Map reduction

Two- and Three-Variable Karnaugh Maps

Just like a truth table, the Karnaugh map of a function specifies the value of the function for every combination of values of the independent variables. A two-variable Karnaugh map is shown below. The values of one variable are listed across the top of the map, and the values of the other variable are listed on the left side. Each square of the map corresponds to a pair of values for A and B as indicated.



TWO VARIABLE

Figure 6-1 shows the truth table for a function F and the corresponding Karnaugh map. Note that the value of F for $A = B = 0$ is plotted in the upper left square and the other map entries are plotted in a similar way in Fig. 6-1(b).

Ex.

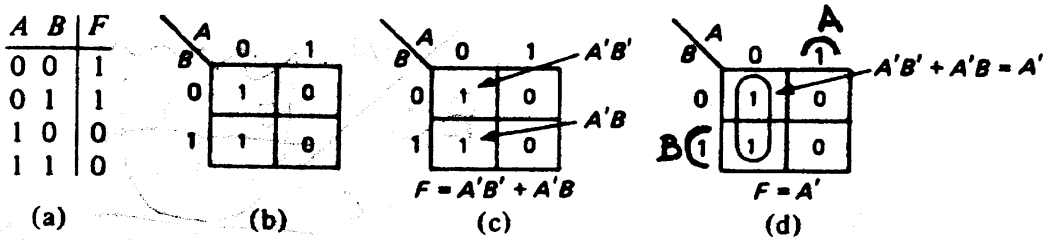
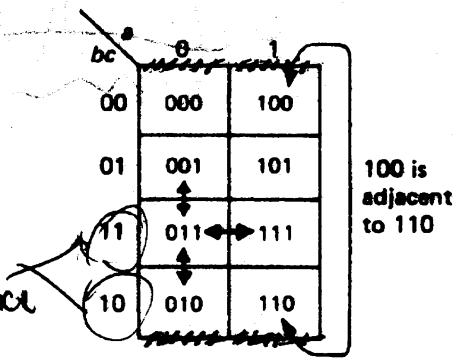


Fig. 6-1

COMBINE and circle IN POWERS OF 2: 2, 4, 8, etc.



(a) binary notation (b) decimal notation

THREE VARIABLE

like grey code so each successive state has only one bit change } not in sequence

Fig. 6-3. Location of minterms on a 3-variable Karnaugh map

TERMS CAN COMBINE BECAUSE THEY DIFFER BY ONLY ONE VARIABLE: $XY' + XY = X$

THREE VARIABLE EXAMPLE:

REVISIT PROBLEM 5-1.

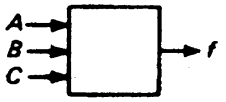


Table 5-1

A	B	C	f	f'
0	0	0	0	1
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	1	0
1	0	1	1	0
1	1	0	1	0
1	1	1	1	0

Next we will derive an algebraic expression for f from the truth table by using the combinations of values of A, B, and C for which $f = 1$. The term $A'BC$ is 1 only if $A = 0$, $B = 1$, and $C = 1$. Similarly, the term $AB'C'$ is 1 only for the combination 100, $AB'C$ is 1 only for 101, ABC' is 1 only for 110, and ABC is 1 only for 111. ORing these terms together yields

$$f = A'BC + AB'C' + AB'C + ABC' + ABC \qquad (5\text{-}1)$$

THM #9 THM #9

The above expression equals 1 if A, B, and C take on any of the five combinations of values 011, 100, 101, 110, or 111. If any other combination of values occurs, f is 0 because all five terms are 0.

Equation (5-1) can be simplified by first combining terms and then eliminating A':

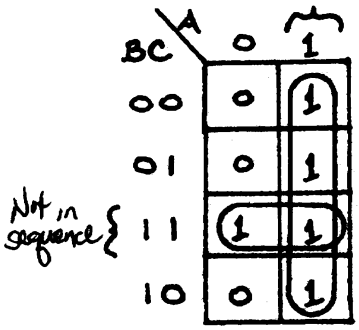
$$f = A'BC + AB' + AB = A'BC + A = A + BC \qquad (5\text{-}2)$$

THM #11D

THM #9

PLOT TABLE 5-1 ON A KARNAUGH MAP:

Find & Circle powers of 2



$f = A + BC$

REMEMBER: IN A 3 VAR. MAP TOP AND BOTTOM ARE ADJACENT!

FOUR VARIABLE MAP:

out of sequence

AB / CD	00	01	11	10
00	0	4	12	8
01	1	5	13	9
11	3	7	15	11
10	2	6	14	10

HERE... TOP + BOTTOM ARE ADJACENT

AND

LEFT AND RIGHT ARE ADJACENT

Location of minterms on 4-variable Karnaugh map

FOUR VARIABLE EXAMPLE:

TRUTH TABLE:

A	B	C	D	f
0	0	0	0	1
0	0	0	1	0
0	0	1	0	1
0	0	1	1	0
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	0
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	0
1	1	1	0	1
1	1	1	1	1

minterm expansion

$f = \Sigma m(0,2,4,5,6,7,8,10,11,12,14,15)$

$= A'B'C'D' + A'B'CD' + \text{etc.}$

REDUCE USING ALGEBRAIC LAWS.....

OR KARNAUGH MAP:

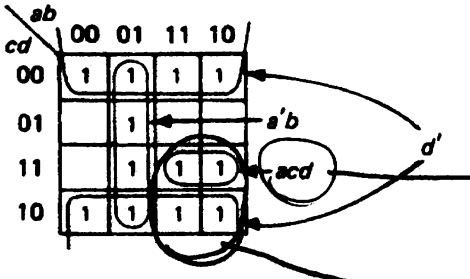


Fig. 6-11. Plot of $acd + a'b + d'$

incorrect should circle to maximize (both equivalent but without maximizing solution is complex)

$f = \underline{ac}\,\underline{d} + \underline{d'} + a'b$

BUT BY LAW 11D. $f = \underline{\underline{ac}} + d' + a'b$

WE COULD HAVE ENCIRCLED BOTTOM RIGHT 4 TO REDUCE EVEN MORE. THIS TERM IS $\underline{\underline{ac}}$.

II. B. 5. DeMorgan's Theorem

$\overline{(XYZ)} = \bar{X} + \bar{Y} + \bar{Z}$ NAND = OR w/ Notted Inputs

$\overline{(X+Y+Z)} = \bar{X}\bar{Y}\bar{Z}$ NOR = AND w/ Notted Inputs

EXAMPLE:

A	B	AB	$\overline{AB}$	$\bar{A}+\bar{B}$
0	0	0	1	1
0	1	0	1	1
1	0	0	1	1
1	1	1	0	0

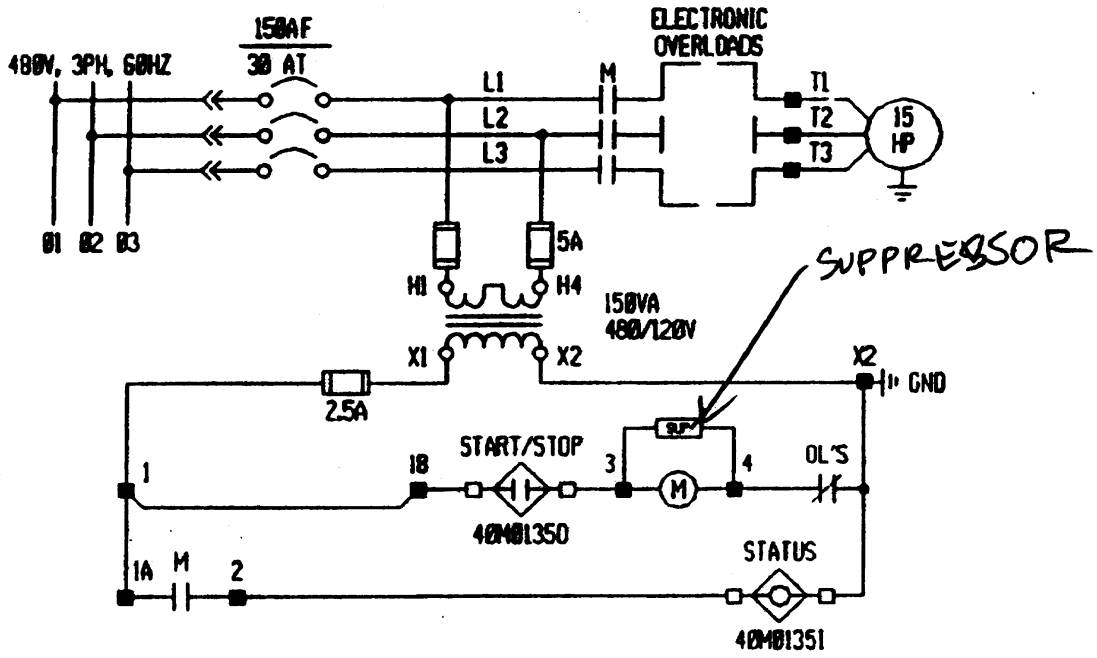


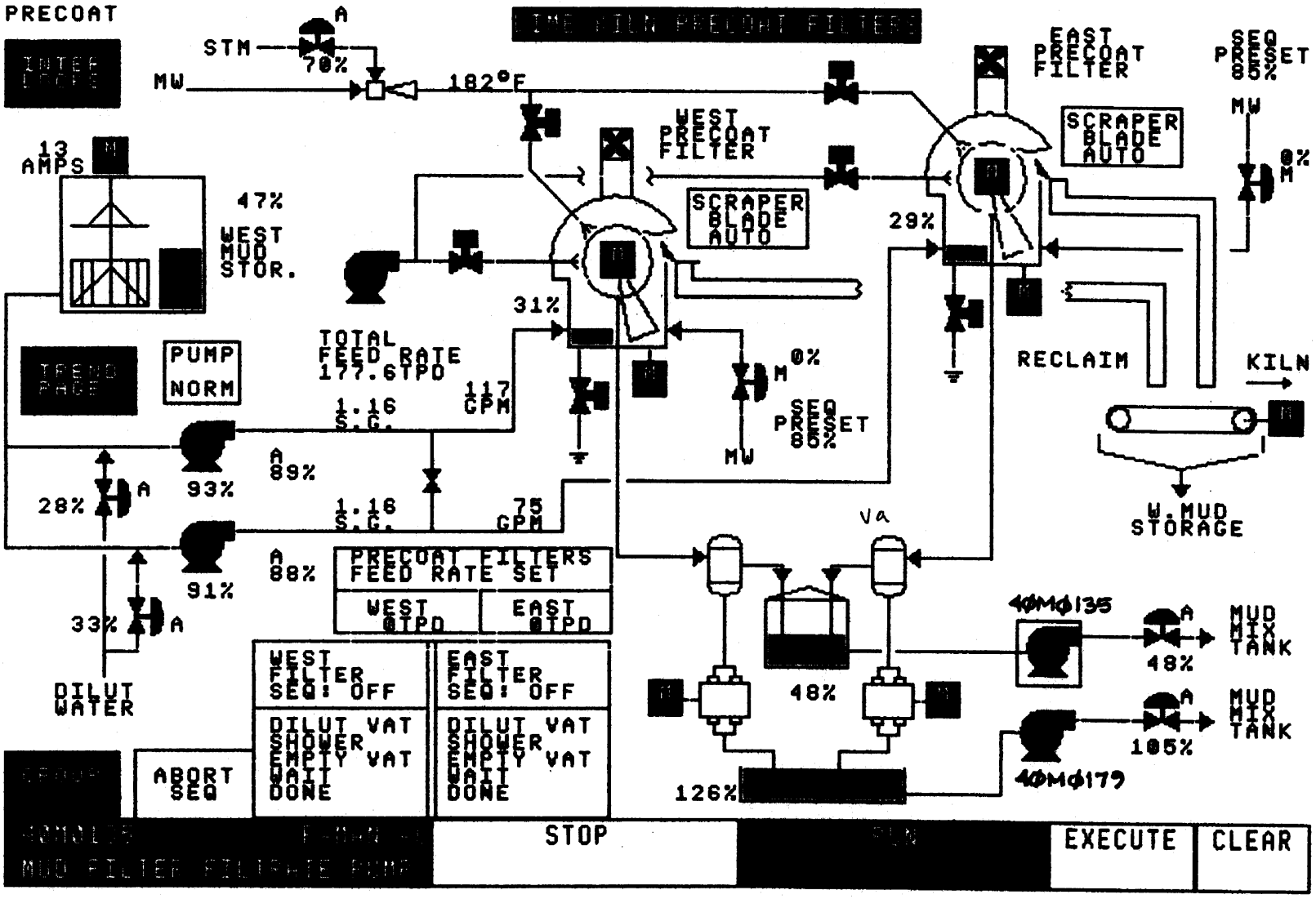


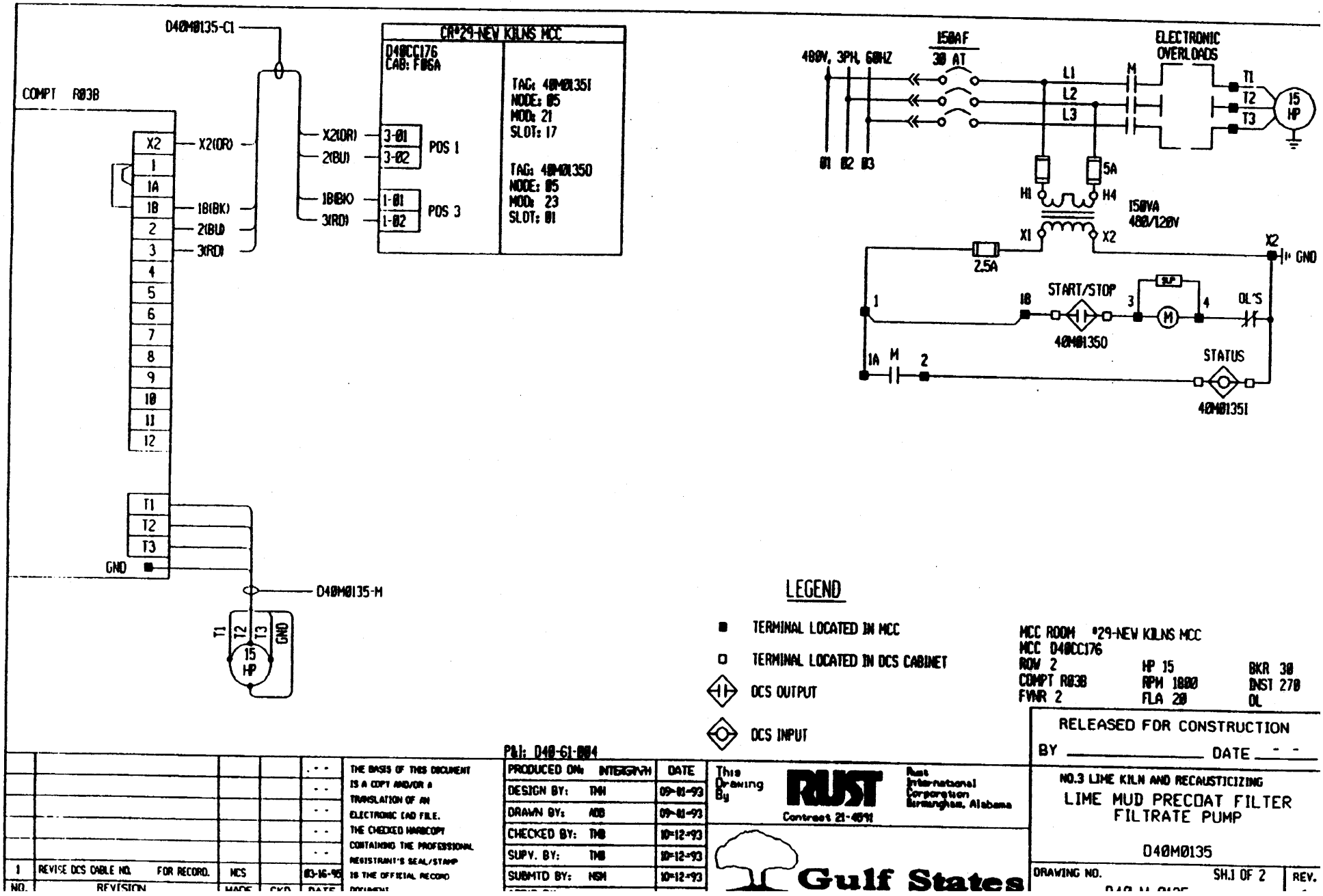
II. C. DISCRETE PROBLEMS AND SOLUTIONS

1. BASIC MOTOR CONTROL LOGIC

Much of the discrete logic encountered in industrial processes involves motor control and interlocking.




PRECOAT
INTER FACE
STM
A
70%
MW
182°F
13 AMPS
47%
WEST MUD STOR.
WEST PRECOAT FILTER
SCRAPER BLADE AUTO
EAST PRECOAT FILTER
SCRAPER BLADE AUTO
SEQ PRESET 85%
MW
0%
M
29%
31%
FEED PAGE
PUMP NORM
TOTAL FEED RATE 177.6TPD
1.16 S.G.
117 GPM
M 0%
MW
SEQ PRESET 85%
RECLAIM
KILN
W. MUD STORAGE
A 89%
28%
A
93%
1.16 S.G.
75 GPM
VA
A 88%
PRECOAT FILTERS FEED RATE SET
WEST 0TPD
EAST 0TPD
91%
33%
A
DILUT WATER
4ΦMΦ135
A
MUD MIX TANK
48%
48%
WEST FILTER SEQ: OFF
EAST FILTER SEQ: OFF
DILUT VAT SHOWER EMPTY VAT WAIT DONE
DILUT VAT SHOWER EMPTY VAT WAIT DONE
ABORT SEQ
A
MUD MIX TANK
105%
126%
4ΦMΦ179
STOP
EXECUTE
CLEAR



LEGEND

- ■ TERMINAL LOCATED IN MCC
- □ TERMINAL LOCATED IN DCS CABINET
- DCS OUTPUT
- DCS INPUT

MCC ROOM #29-NEW KILNS MCC
MCC D40CC176
ROW 2 | HP 15 | BKR 30
COMPT R03B | RPM 1800 | ENST 270
FVNR 2 | FLA 20 | OL

RELEASED FOR CONSTRUCTION
BY _____ DATE _ _

P&I: D40-G1-004

NO.	REVISION	MADE	CKD	DATE
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1	REVISE DCS CABLE NO. FOR RECORD.	MCS		03-16-95

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SUBMTD BY: MSM	10-12-93

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Gulf States

NO.3 LIME KILN AND RECAUSTICIZING
LIME MUD PRECOAT FILTER FILTRATE PUMP

D40M0135

DRAWING NO. | SH.1 OF 2 | REV.

LIME MUD PRECOAT FILTER
FILTRATE PUMP

MOTOR D40M0135

START AND STOP ARE MAINTAINED CONTACTS

COMMAND DISAGREE WILL ALARM IN DCS

DCS

A "1" BIT = RUN

MOTOR D40M0135
RUN CONFIRM

TAG: 40M01351
NODE: 05
MODULE: 21
SLOT: 17
POINT TYPE: DI

40M0135 START
STOP

ONE SHOT
5SEC

Low Level = 1 - NOT FAILSAFE SINCE ITS INTERNAL TO DCS & IT DOESN'T MATTER

40LL0177
REF. DWG. B40LL0177

START
LIME MUD PRECOAT FILTER
FILTRATE PUMP
MOTOR
D40M0135

TAG: 40M01350
NODE: 05
MODULE: 23
SLOT: 01
POINT TYPE: DO

INTERLOCK

DO NOT RUN!

PERMISSIVE

WON'T LET START
BUT WON'T TRIP

1	ADD 40LL0177	FOR RECORD.	HCS		03-16-95

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P&I: D40-61-004

PRODUCED ON:	INTERGRAPH	DATE
DESIGN BY:	TMH	09-01-93
DRAWN BY:	ADB	09-01-93
CHECKED BY:	DMB	09-03-93
SUPV. BY:	TMH	09-03-93
SUBMTD BY:	MSM	09-03-93

This Drawing By RUST Rust International Corporation Birmingham, Alabama
Contract 21-4591

Gulf States

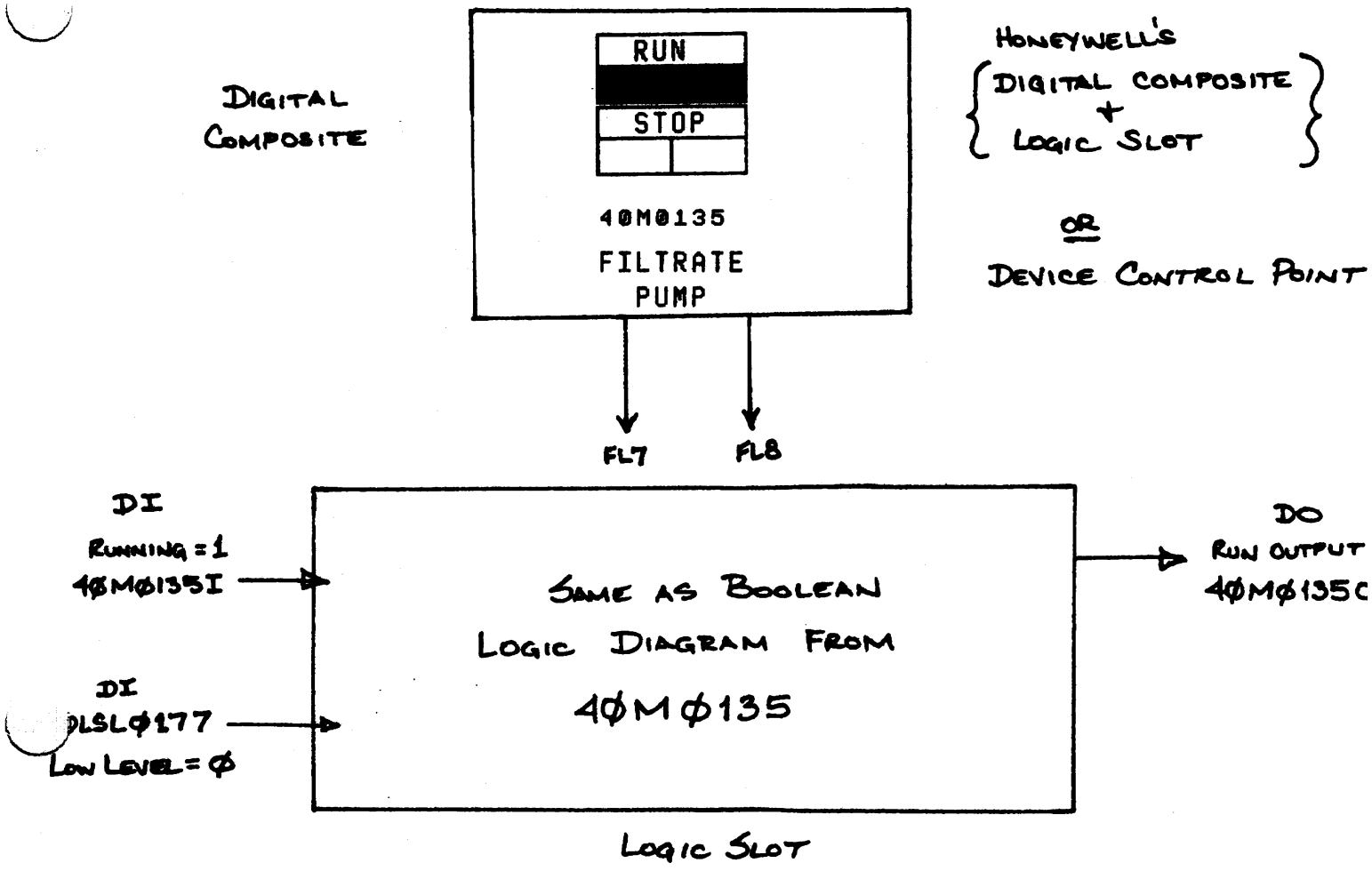
RELEASED FOR CONSTRUCTION
BY _____ DATE _____

NO.3 LIME KILN AND RECAUSTICIZING
LIME MUD PRECOAT FILTER
FILTRATE PUMP

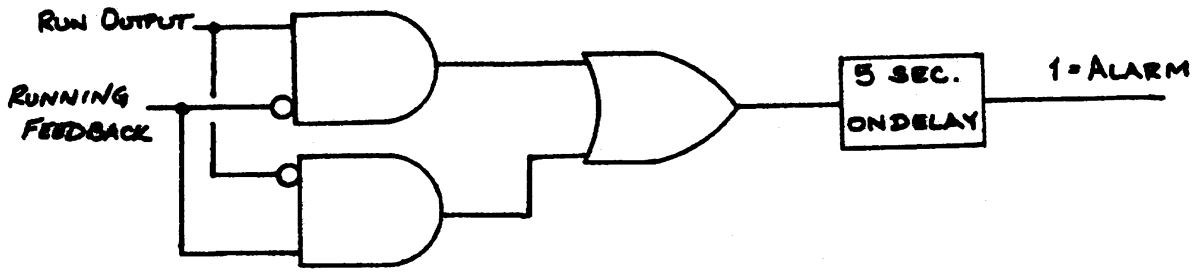
D40M0135

DRAWING NO. SH.2 OF 2 REV.

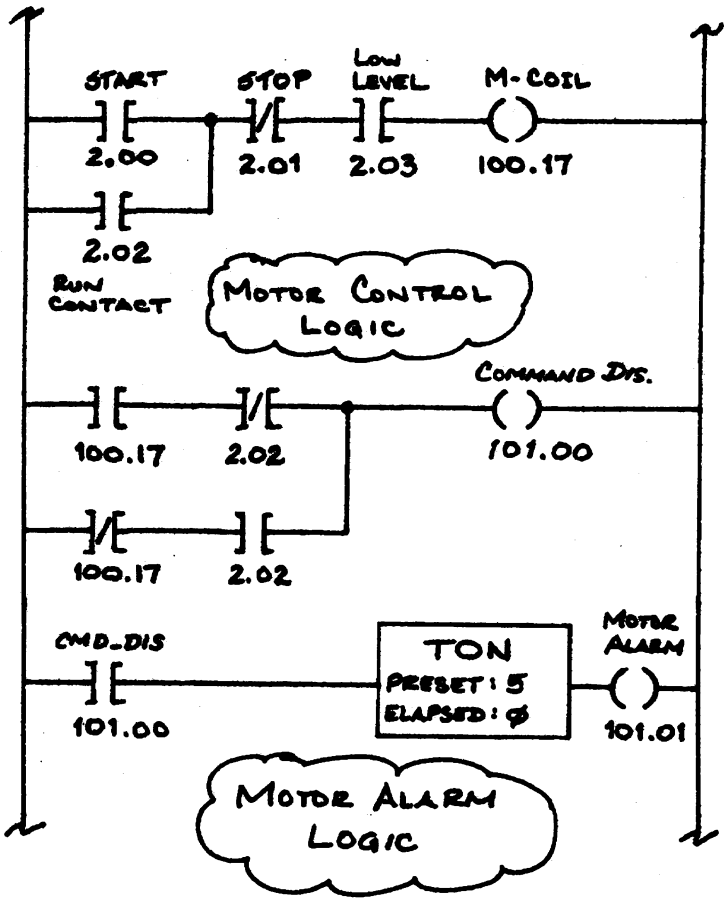
DCS Logic:



Motor Alarm Logic - Command Disagree or Uncommanded Change Alarm



PLC Motor Logic:



RUST. BIRMINGHAM. ALABAMA

PROPOSAL OR JOB NO. 21-473½

FOR Gulf States No. 3 Lime Kiln

AT

DESCRIPTION Motor Logic: Seal-in and Interlocks

DATE 7-11-94

BY EDS CKD.

DWG.

Logic Slot

TAGNAME : 4ØLØ179
APM NUMBER: Ø5
SLOT NUMBER: 8

REFER TO PRECOAT GRAPHIC
VACUUM PUMP SEAL WATER
SUMP PUMP

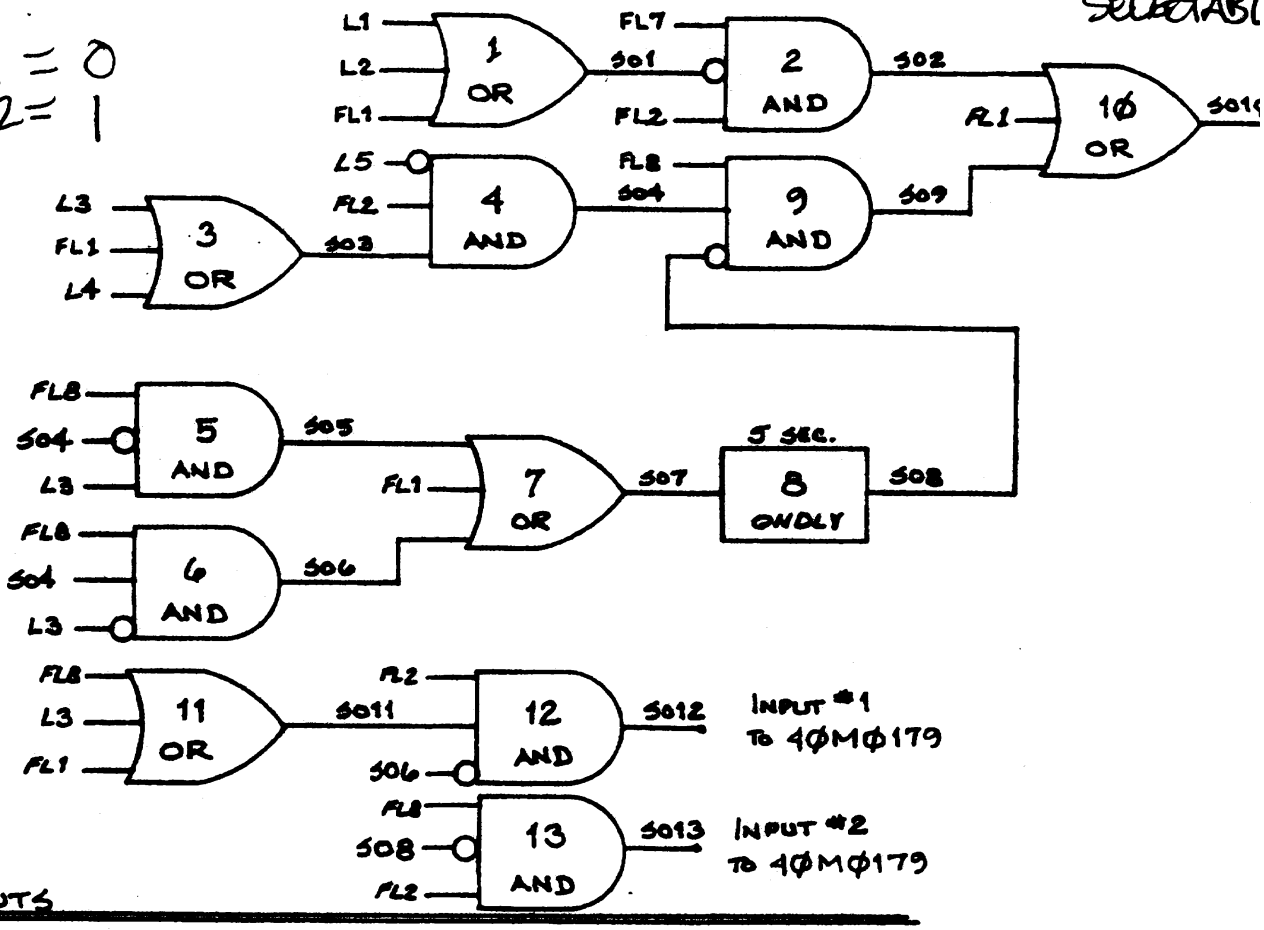
INPUTS

L1 = 4ØMØ179.CMDDISFL
L2 = 4ØMØ179.UNCMDFL
L3 = 4ØMØ179I.PVFL
L4 = 4ØLCØ18Ø.PVHIFL } SUMP LVL
L5 = 4ØLCØ18Ø.PVLOFL }

FL(7) = 4ØMØ179 (Run Command)
FL(8) = 4ØMØ179 (Auto Command)

OPERATOR SELECTABL

FL1 = 0
FL2 = 1



OUTPUTS

S01Ø = 4ØMØ1790.SO

AREA	DESCRIPTION	PROBLEM
D	**Safety Systems**	**P401**

Which statement best describes the relay logic diagram in the figure below?

(A) Trip F.D. fan if furnace pressure goes high and trip I.D. fan if it goes low. Trip fuel if drum level goes low for more than 10 seconds with override switch in the auto position.

(B) Trip F.D. fan and I.D. fan if furnace pressure goes high or low, and trip fuel if drum level goes low for more than 10 seconds with override switch in the auto position.

(C) Trip fuel, F.D. fan and I.D. fan if furnace pressure goes high or low for more than 10 seconds, or if drum level goes low with override switch in the auto position.

(D) Trip fuel, F.D. fan and I.D. fan if furnace pressure goes high or low, or if drum level goes low for more than 10 seconds with override switch in the auto position.

(E) Sound alarm if furnace pressure goes high or low, or if drum level goes low for more than 10 seconds. Trip if override switch is in the auto position.

SHOULD HAVE FAIL-SAFE (NEGATIVE) INPUTS
1 = OK
Ø = ALARM

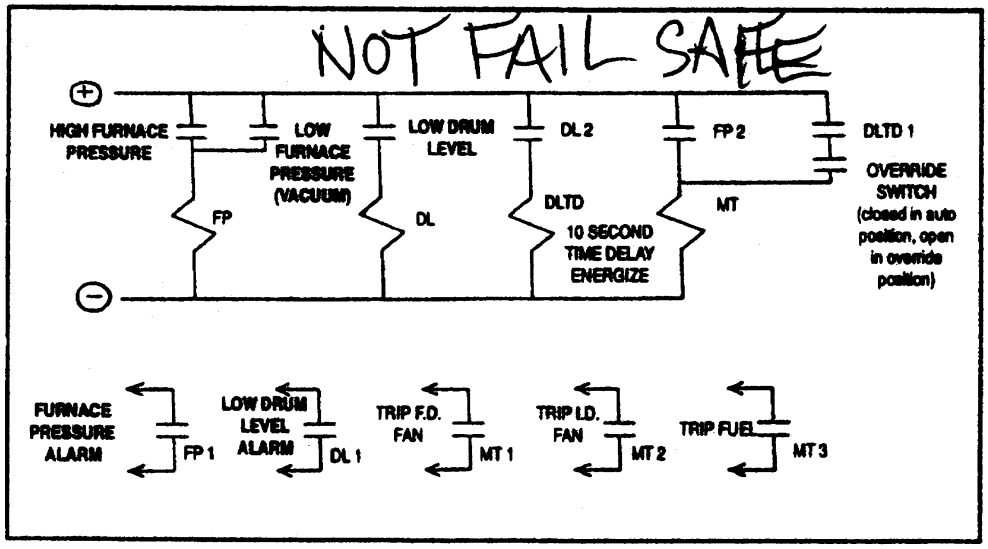


Figure P401

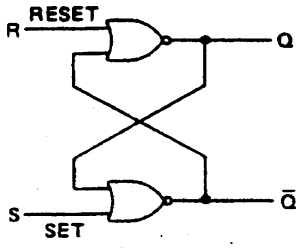
III. SEQUENTIAL LOGIC

Definition: **Combinational logic with added memory elements. The basic memory element is the flip-flop**

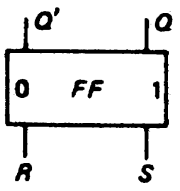
A. FLIP-FLOPS

Sequential switching networks have the property that the output depends not only on the present input but also on the past sequence of inputs. In effect, these networks must be able to "remember" something about the past history of the inputs in order to produce the present output. Flip-flops are the most commonly used memory devices in sequential networks. Basically, a flip-flop is a memory device which can assume one of two stable output states; which has a pair of complementary outputs, and which has one or more inputs that can cause the output state to change. Several common types of flip-flops are described in this unit.

1. S-R (SET/RESET FLIP-FLOP)



NOR S-R flip-flop



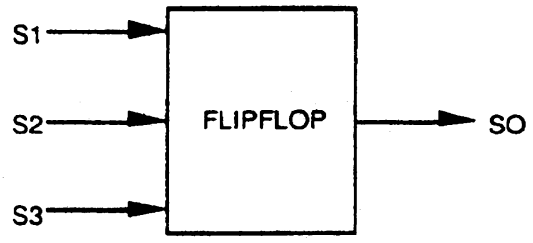
***S-R* flip-flop**

Next-State Table for S-R Flip-Flop

present			next
S	*R*	*Q*	*Q+*
0	0	0	0
0	1	0	0
1	0	0	1
1	1	0	*N*
0	0	1	1
0	1	1	0
1	0	1	1
1	1	1	*N*

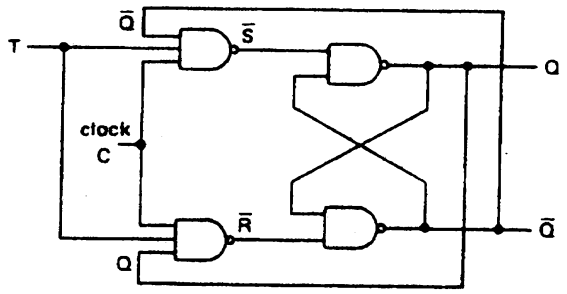
***N* = input not permitted**

HONEYWELL TDC-3000 FLIP-FLOP

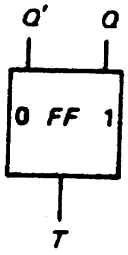


RESET	SET	
S1	S2	SO
OFF	OFF	Not changed
ON	OFF	OFF
OFF	ON	ON
ON	ON	S3 input

2. T Flip-Flop (Trigger or Toggle)

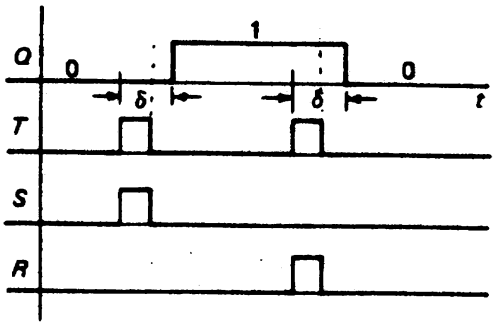


NAND *T* flip-flop



The Trigger Flip-Flop

The trigger or *T* flip-flop in Fig. 12-7(a) has a single input. Applying a pulse to this input causes it to change state. For example, if $Q = 1$ and the *T* input is pulsed, Q changes to 0. If *T* is pulsed again, Q changes back to 1.



T	Q	Q^+
0	0	0
0	1	1
1	0	1
1	1	0

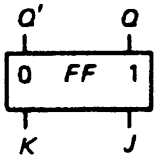
T NEXT-STATE TABLE

3. The *J-K* Flip-Flop

The *J-K* flip-flop combines the features of the *S-R* and *T* flip-flops. A 1 input applied to *J* or *K* alone acts exactly like an *S* or *R* input, respectively. That is, if $J = 1$ the flip-flop output is set to $Q = 1$; and if $K = 1$, the flip-flop output is reset to $Q = 0$. Unlike the *S-R* flip-flop, it is permissible to apply a 1 input simultaneously to *J* and *K*, in which case the flip-flop changes state just like a *T* flip-flop. For example, if $Q = 0$ and we momentarily apply a 1 input to both *J* and *K*, the flip-flop state will change to $Q = 1$. The next state table and characteristic equation for the *J-K* flip-flop are given in Fig. 12-8.

J	K	Q	Q^+	
0	0	0	0	LIKE SET-RESET
0	0	1	1	
0	1	0	0	
0	1	1	0	
1	0	0	1	
1	0	1	1	
1	1	0	1	LIKE TRIGGER
1	1	1	0	

Fig. 12-8(a)



$Q^+ = QK' + Q'J$

Fig. 12-8(b)

4. The *D* Flip-Flop

Delay

Another flip-flop available in integrated circuit form is the clocked *D* (delay) flip-flop, seen in Fig. 12-10(a). The state of this flip-flop after the clock pulse (Q^+) is equal to the input (D) before the clock pulse. For example, if $D = 1$ before the clock pulse, $Q = 1$ after the clock pulse regardless of the previous value of Q. Therefore, the characteristic equation is $Q^+ = D$. Like the clocked *J-K* flip-flop, the arrowhead on the *D* flip-flop symbol designates the clock input and the small inversion circle indicates that the state changes occur on a high to low transition – i.e., after the falling edge of the clock pulse.

D	Q	Q^+
0	0	0
0	1	0
1	0	1
1	1	1

PRESENT STATE MAKES NO DIFFERENCE

$Q^+ = D$

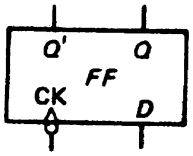


Fig. 12-10(a). Clocked *D* flip-flop

If *D* changes at most once following each clock pulse, the output of the flip-flop is the same as the *D* input, except that changes in the output are delayed until after the falling edge of the clock pulse as illustrated in Fig. 12-10(b).

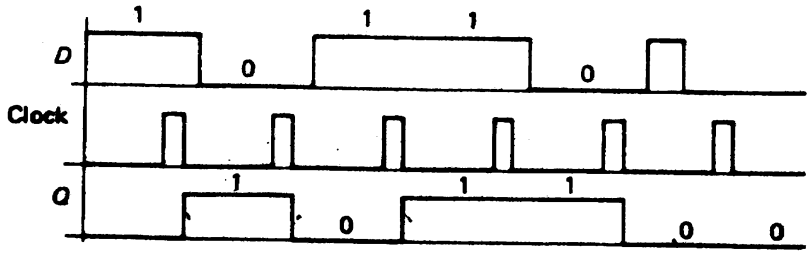
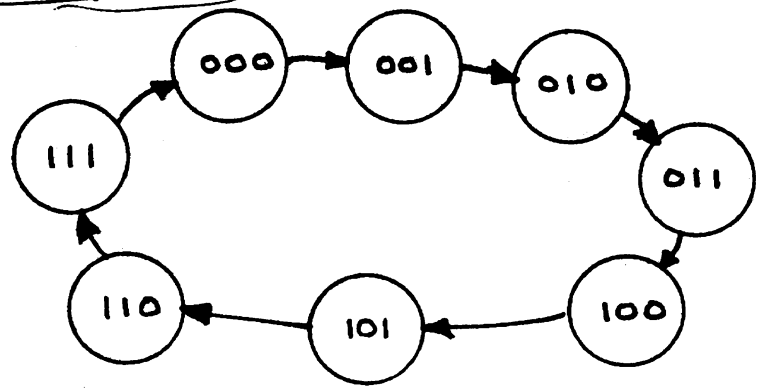


Fig. 12-10(b). Timing for clocked *D* flip-flop

B. DESIGN TOOLS

1. STATE GRAPH OR STATE DIAGRAM

(EX. FOR A BINARY COUNTER)



ARROWS INDICATE STATE SEQUENCE

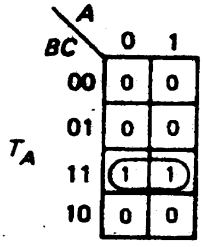
III.B.

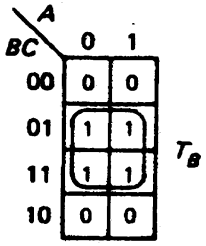
2. STATE TABLE (FOR TRIGGER FLIP-FLOPS)

State Table for Binary Counter

present state $A\ B\ C$				next state $A^+B^+C^+$				flip-flop inputs $T_A\ T_B\ T_C$		
0	0	0	1	0	0	1	2	0	0	1
0	0	1	2	0	1	0	3	0	1	1
0	1	0	3	0	1	1	4	0	0	1
0	1	1	4	1	0	0	5	1	1	1
1	0	0	5	1	0	1	6	0	0	1
1	0	1	6	1	1	0	7	0	1	1
1	1	0	7	1	1	1	8	0	0	1
1	1	1	8	0	0	0	1	1	1	1

T_A, T_B and T_C are now derived from the table as functions of A, B and C. By inspection, $T_C = 1$. Karnaugh maps are plotted for T_A and T_B:

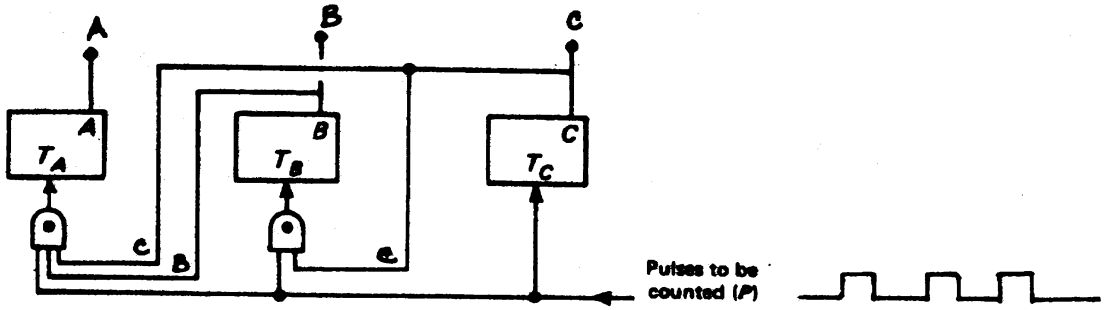




$T_C = 1$

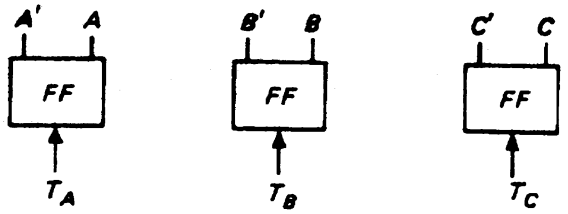
from which $T_A = BC$ and $T_B = C$. Since a pulse (P) is required to initiate each change of state, we multiply each input by P so that

$$T_A = BCP \qquad T_B = CP \qquad T_C = P$$



Synchronous binary counter

The sequence of flip-flop states is ABC = 000, 001, 010, 011, 100, 101, 110, 111, 000, . . .



NOTICE THAT A', B', C' WOULD CREATE A COUNT DOWN SEQUENCE!

III. B. SEQUENTIAL LOGIC DESIGN TOOLS

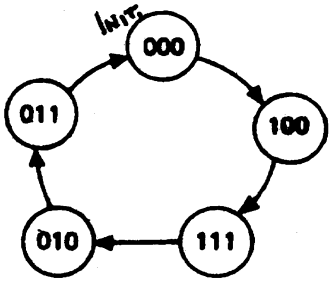
3. STEPS OF SEQUENTIAL DESIGN

A. Take problem statement and convert it to a state graph (diagram)
B. Convert the diagram into a state table
C. Write and reduce each flip-flop input equation (Karnaugh is preferable)
D. Draw out the resulting logic in gate form

ONE LAST EXAMPLE:

DESIGN A COUNTER TO CREATE THIS SEQUENCE USING S-R FLIP-FLOPS:

A.



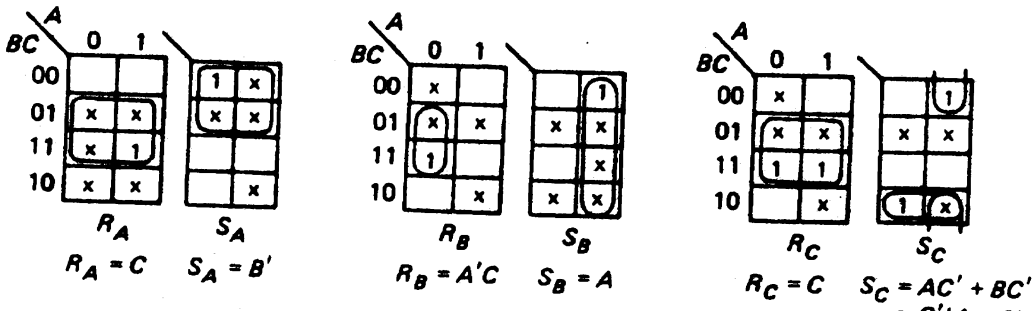
State graph for counter

B.

A	B	C	A^+	B^+	C^+	S_A	R_A	S_B	R_B	S_C	R_C
0	0	0	1	0	0	1	0	0	x	0	x
0	0	1	–	–	–	x	x	x	x	x	x ← don't care, don't mat
0	1	0	0	1	1	0	x	x	0	1	0
0	1	1	0	0	0	0	x	0	1	0	1
1	0	0	1	1	1	x	0	1	0	1	0
1	0	1	–	–	–	x	x	x	x	x	x } don't care, don't matte
1	1	0	–	–	–	x	x	x	x	x	x
1	1	1	0	1	0	0	1	x	0	0	1

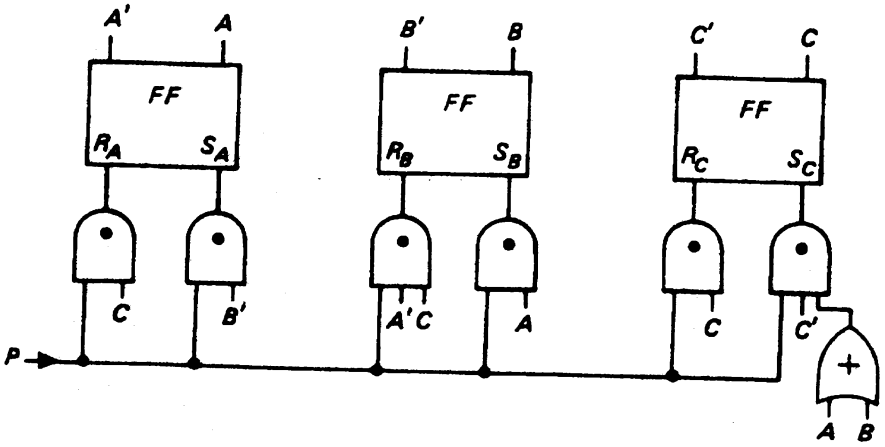
STATE TABLE

C.



(a) *S-R* flip-flop equations

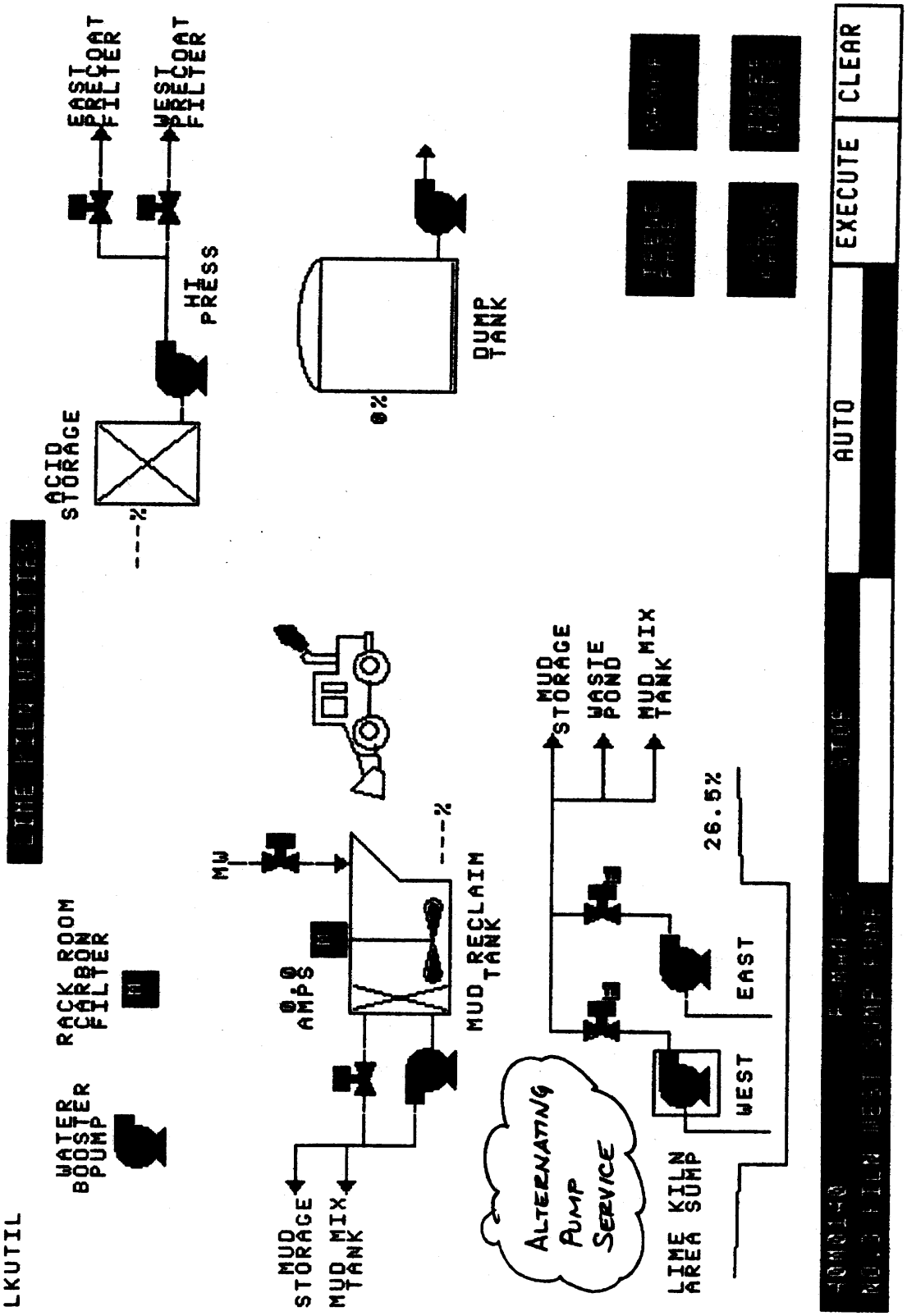
D.



COUNTER DESIGN USING S-R FLIP-FLOPS

II. C. SEQUENTIAL PROBLEMS AND SOLUTIONS

1. ALTERNATING LEAD-LAG PUMP SERVICE LOGIC



Form E-11

RUST. BIRMINGHAM. ALABAMA

PROPOSAL OR JOB NO. _____

FOR Gulf States Paper - No. 3 Lime Kiln

IT

DESCRIPTION Motor Logic: Seal-in and Interlocks

DATE 2-1-95

BY EDS CKD.

DWG.

Logic Slot

TAGNAME : 4ØLØ14Ø

APM NUMBER: Ø7

SLOT NUMBER: Ø3

Inputs

L1= 4ØMØ14ØI.PVFL

L2= 4ØLSØ242F.PVFL Ø=FAULT

L3= 4ØLHØ242.PVFL Ø=LVL HI

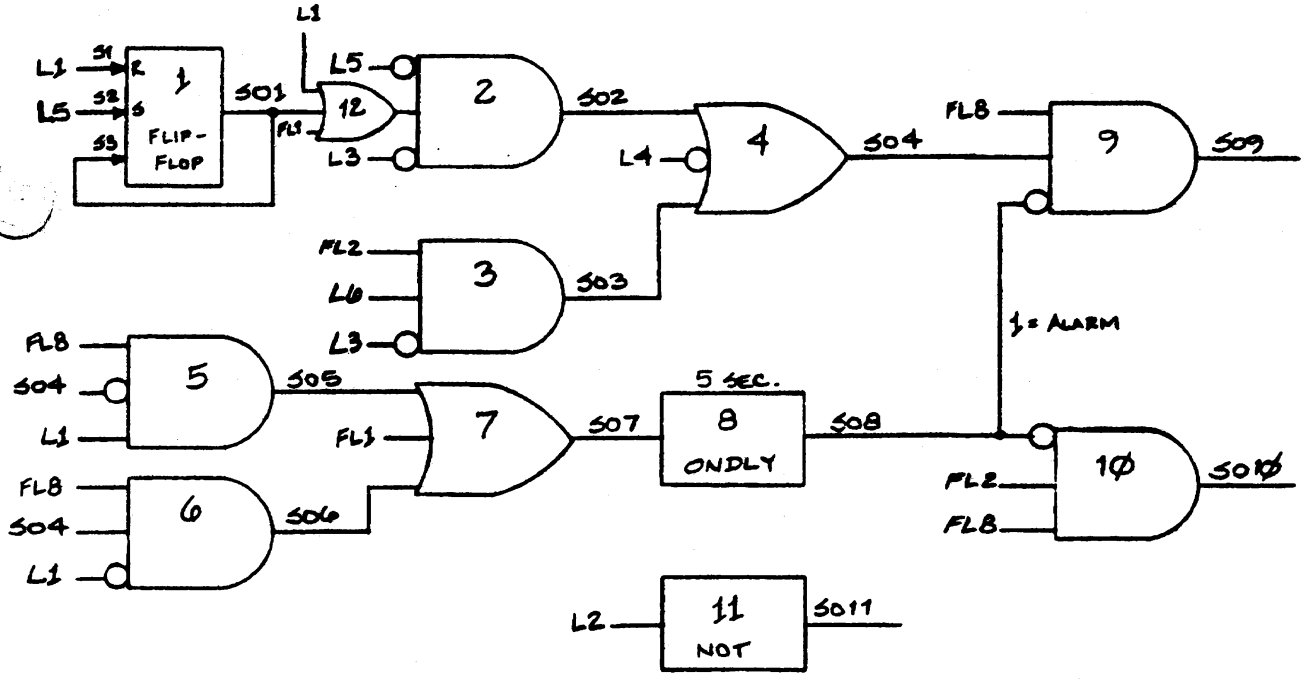
L4= 4ØLHHØ242.PVFL Ø=LVL HH

L5= 4ØMØ141I.PVFL

L6= 4ØMØ141.SO(Ø) 1=STOP

FL(7)= NOT USED (RUN COMMAND)

FL(8)= 4ØMØ14Ø (AUTO COMMAN



Outputs

SO9= 4ØMØ14ØO.SO

SO9= 4ØEVØ243.SO

SO11= 4ØMØ14Ø.IØ

Form E-11

RUST. BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR Gulf States Paper - No. 3 Lime Kiln

DATE 2-1-95

AT

BY EDS CKD.

DESCRIPTION Motor Logic: Seal-in and Interlocks

DWG.

Logic Slot

TAGNAME : 4ØLØ141

APM NUMBER: Ø7

SLOT NUMBER: Ø4

Inputs

L1= 4ØMØ141I.PVFL

L2= 4ØLSØ242F.PVFL Ø=FAULT

L3= 4ØLHØ242.PVFL Ø=LVL HI

L4= 4ØLHHØ242.PVFL Ø=LVL HH

L5= 4ØMØ140I.PVFL

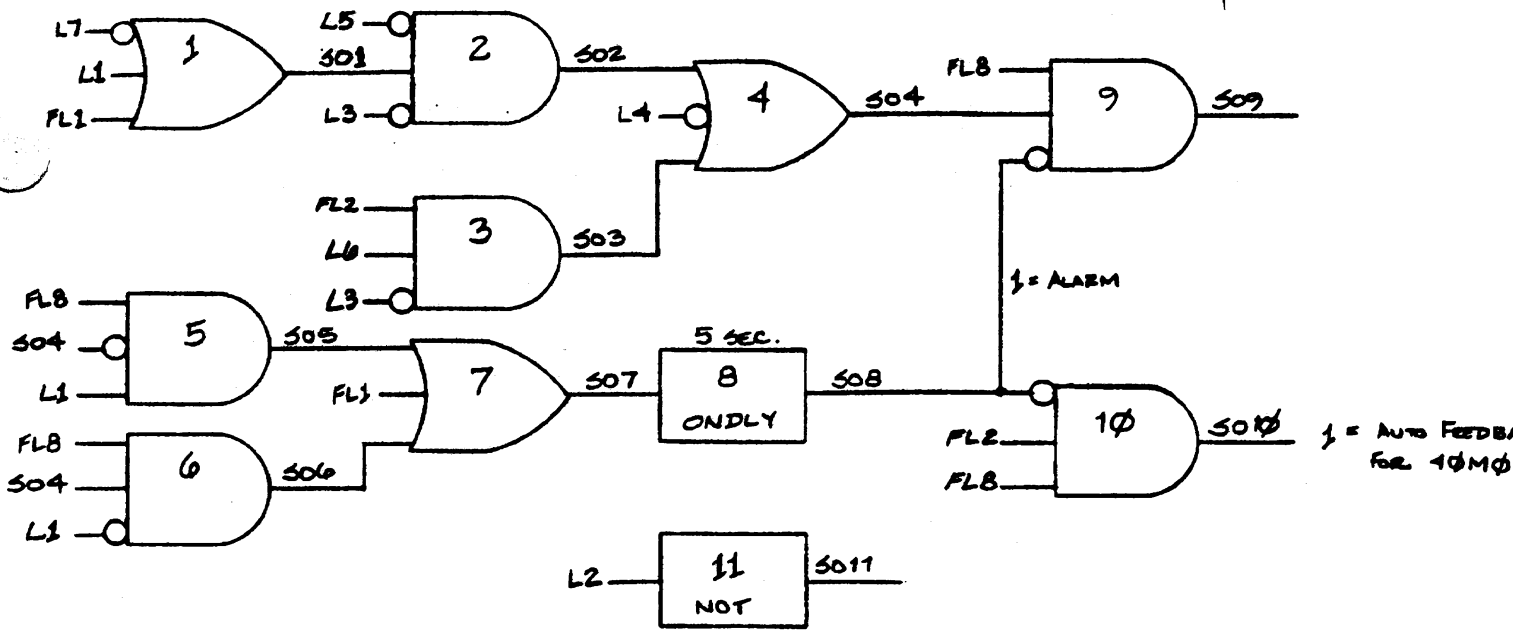
L6= 4ØMØ140.SO(Ø) 1=STP

L7= 4ØLØ140.SO(1)

FL(7)= NOT USED (RUN COMMAND

FL(8)= 4ØMØ141 (AUTO COMMAN

FROM LAST PAGE — ONE FLIP-FLOP/BOTH MOTORS



Outputs

S09 = 4ØMØ141Ø.SO

~~S10~~, S09 = 4ØEVØ244.SO

S011 = 4ØMØ141.IØ

ST

29 Aug 95 11:52:16 1

DRYERS

P1AIRCAP

INTLK OPEN TRIPS LOOPS	OVERFIRE AIR LINES						
	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 7
LOCAL/DCS	DCS	DCS	DCS	DCS	DCS	DCS	DCS
START/STOP BURNER	START	STOP	START	START	START	START	START
BURNER FAULT RESET	NORM	NORM	NORM	NORM	NORM	NORM	NORM
BURNER TEMP (DEF F)	206	109	500	476	475	381	475
SUPPLY AIR PRS ("H2O)	0.0	0.0	0.1	0.2	0.0	0.0	0.0
INTERLOCKS SATISFIED	■	■					
BURNER SYSTEM ON/OFF	OFF	ON	ON	ON	ON	ON	ON
SYSTEM PURGING							
FLAME ESTABLISHED			■	■	■	■	■
BURNER FAILED							
CAP OPEN/CLOSE	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
HIGH FIRE BYPASS	OFF	ON	OFF	OFF	OFF	OFF	OFF
HIGH FIRE			■	■	■	■	■
INTERLOCKS							
EXHAUST AIR FLOW	■	■					
SUPPLY AIR FLOW	■	■					
COMBUSTION AIR FLOW	■	■					
LOW GAS PRESS	■	■					
HIGH GAS PRESS	■	■					
HIGH TEMP	■	■					
✳ FIRST OUT	SUP FLW	EXH FLW		EXH FLW			EXH FLW

Form E-11

RUST, BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR Gulf States - Paper Machine #1

AT

DESCRIPTION Logic for AIRCAP #1

DATE

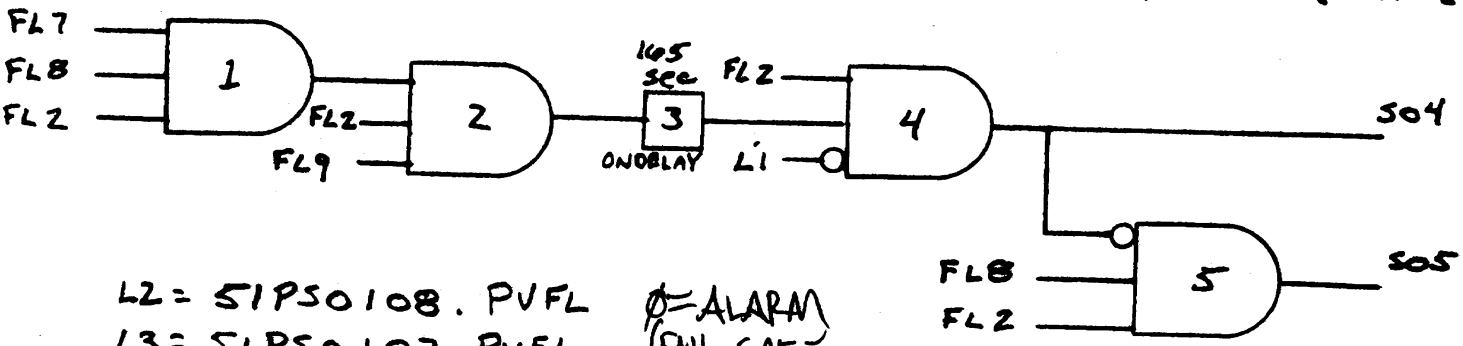
BY CKD.

DWG.

APM : 13
TAG : DILOG1301
Slot = 1

L1 = 51BC0101.PVFL

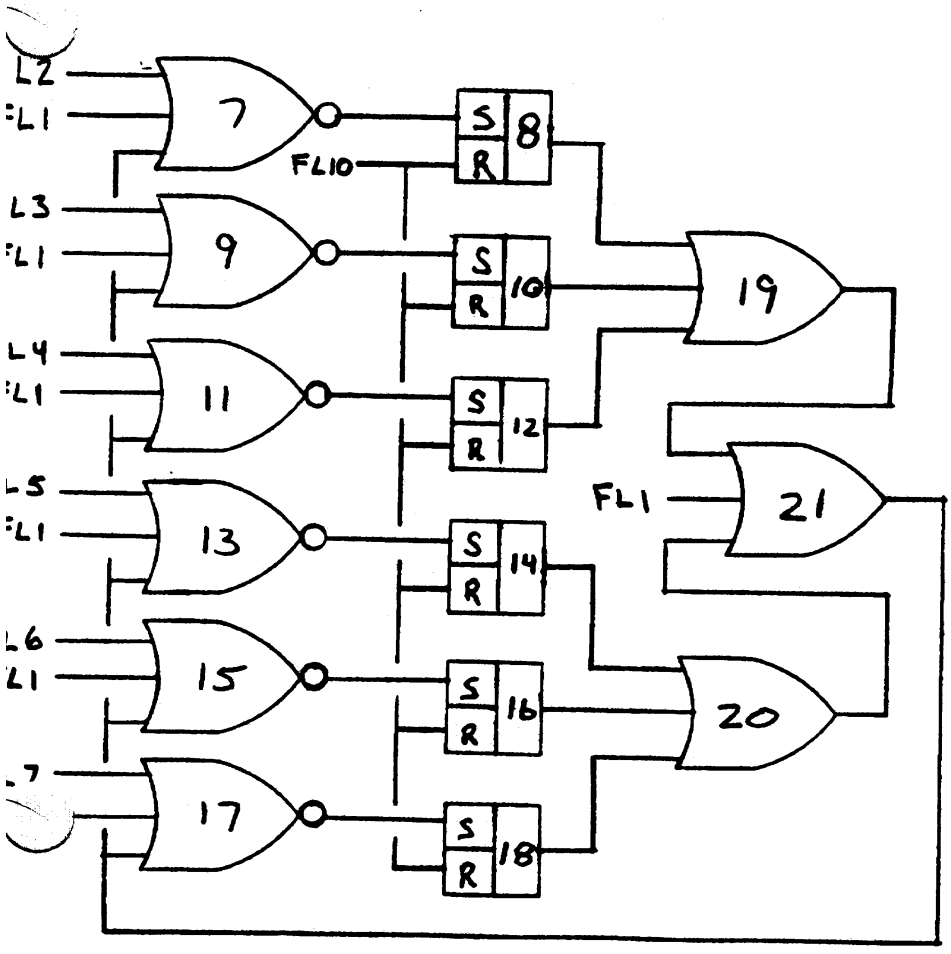
FL7 = 51HS0101 (1= START CMD)
FL8 = 51HS0101A
FL9 = 51HS0101C (MOM ∅)
FL10 = 51HS0101C (MOM 1)



L2 = 51PS0108.PVFL
L3 = 51PS0107.PVFL
L4 = 51PS0109.PVFL
L5 = 51PL0101.PVFL
L6 = 51PH0101.PVFL
L7 = 51QS0101.PVFL

∅=ALARM (FAIL-SAFE)

S04 = 51BA0101.PVI
S05 = 51BS0101A.S



MACHINE IR DRYER FIRST-OUT LOGIC

6. A "first out" alarm function is intended to determine which one of a group of near-simultaneous alarm conditions occurred first. Which of the following statements about this function are true and significant?

   I One alarm light can serve for a group of variables. NO

   II It assists in diagnosing off-normal conditions.

   III A fast system for input scanning is required.

   IV The function is valuable even if near-simultaneous alarms are reported as simultaneous.

   V Less printer paper is needed for an alarm log. NO

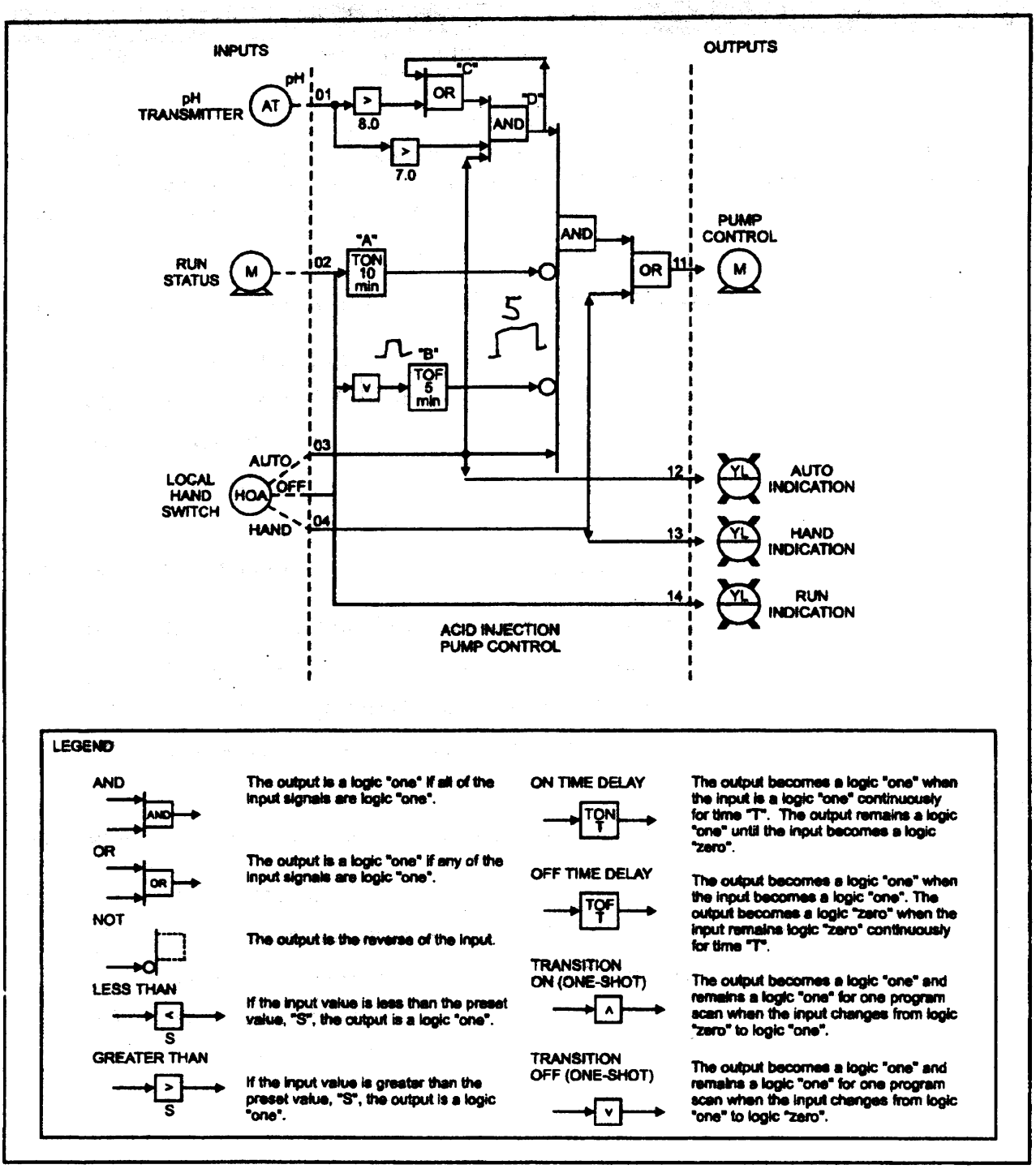
   (A) I and V
   (B) II and III
   (C) II, III and IV
   (D) III and IV
   (E) I, II and V

7. Field-mounted or outdoor instrumentation equipment in the pulping area of a pulp and paper mill would probably need a:

   (A) NEMA 1 enclosure.
   (B) NEMA 2 enclosure.
   (C) NEMA 3 enclosure.
   (D) NEMA 4 enclosure.
   (E) NEMA 5 enclosure.

8. Coal grinding areas in a coal-fired steam power plant would be classified under hazardous area provisions of the National Electric Code (NEC) as:

   (A) Class I, Group B
   (B) Class I, Group D
   (C) Class II, Group E
   (D) Class II, Group F
   (E) Class III, Group G



LEGEND

AND — The output is a logic "one" if all of the input signals are logic "one".

OR — The output is a logic "one" if any of the input signals are logic "one".

NOT — The output is the reverse of the input.

LESS THAN — If the input value is less than the preset value, "S", the output is a logic "one".

GREATER THAN — If the input value is greater than the preset value, "S", the output is a logic "one".

ON TIME DELAY — The output becomes a logic "one" when the input is a logic "one" continuously for time "T". The output remains a logic "one" until the input becomes a logic "zero".

OFF TIME DELAY — The output becomes a logic "one" when the input becomes a logic "one". The output becomes a logic "zero" when the input remains logic "zero" continuously for time "T".

TRANSITION ON (ONE-SHOT) — The output becomes a logic "one" and remains a logic "one" for one program scan when the input changes from logic "zero" to logic "one".

TRANSITION OFF (ONE-SHOT) — The output becomes a logic "one" and remains a logic "one" for one program scan when the input changes from logic "one" to logic "zero".

Figure A26-35

QUESTION	DESCRIPTION	AREA
A29-32	Discrete Logic/Sequencing	H

A29. Disregarding the timers, which statement best describes the pump action?

(A) The pump will not run if the level of the pH is between 7.0 and 8.0.

(B) The pump will continue running only if the pH is above 8.0.

(C) The pump starts when the pH drops below 7.0 and continues to run until the pH rises above 8.0.

(D) The pump starts when the pH rises above 8.0 and continues to run until the pH drops below 7.0.

A30. In a 24-hour period, with the hand switch in the "AUTO" position, what is the maximum running time of the pump?

(A) 8 hours

(B) 12 hours

(C) 16 hours

(D) 24 hours

A31. If the wire for input #01 is cut and pH measurement drops to zero, what happens?

(A) The pump stops immediately.

(B) The pump stops after 5 minutes.

(C) The pump starts after 10 minutes.

(D) The pump starts and runs for 5 minutes.

A32. What happens when the pump stops running?

(A) The output of time "B" turns on for 5 minutes.

(B) Timer "A" starts timing.

(C) Timer "B" stops timing.

(D) An alarm is generated after 5 minutes.

QUESTION	DESCRIPTION	AREA
A26-35	**Discrete Logic/Sequencing**	H

The logic diagram, Figure A26-35 (see page 59), depicts the control scheme for an acid injection pump used to control the pH in a plant water system. The control of the pump in performed exclusively by a Programmable Logic Controller (PLC). The "HOA" local hand switch is spring return to "OFF" from the "HAND" position.

A26. The combination of OR-gate "C" with AND-gate "D" is commonly referred to as:

(A) A flip-flop circuit
(B) An exclusive-OR circuit
(C) A seal circuit
(D) An inverter

A27. What effect does timer "A" have on the pump control?

(A) It starts the pump 10 minutes after the pH reaches 7.0.
(B) It stops the pump after it has run for 10 minutes.
(C) It automatically starts the pump every 10 minutes
(D) It delays the pump start for 10 minutes.

A28. What effect does timer "B" have on the pump control?

(A) It restricts pump running to 5 minutes.
(B) It provides a minimum rest time of 5 minutes.
(C) It automatically starts the pump every 5 minutes.
(D) None of the above.

QUESTION	DESCRIPTION	AREA
A33-35	**Discrete Logic/Sequencing**	H

A33. Which of the following statements is true?

(A) High pH means high acidity.

(B) Inputs #02 and #04 cannot be on simultaneously.

(C) The pump may be jogged at any time.

(D) The pump will start only if the local handswitch is in the "AUTO" position.

DISAGREE WITH ANSWER BOOK

A34. Why is the pump cycled on and off?

(A) The pump heats up the acid to dangerous levels.

(B) The motor is not designed for continuous service.

(C) It allows time for the pH to stabilize.

(D) Frequent pump cycling improves lubrication.

A35. What is the most likely purpose of the local handswitch?

(A) To allow testing the PLC logic manually.

(B) To prime the pump before starting.

(C) To satisfy the National Pump Code.

(D) To jog the pump for testing.

ANSI/ISA-S18.1-1979 (R1992)

Reaffirmed July 13, 1992

American National Standard

Annunciator Sequences and Specifications



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ANSI/ISA-S18.1 — Annunciator Sequences and Specifications

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1 Purpose

The purpose of this Standard is to establish uniform annunciator terminology, sequence designations, and sequence presentation and to assist in the preparation of annunciator specifications and documentation.

This Standard is intended to improve communications among those that specify, distribute, manufacture, or use annunciators.

2 Scope

This Standard is primarily for use with electrical annunciators that call attention to abnormal process conditions by the use of individual illuminated visual displays and audible devices. Annunciators can range from a single annunciator cabinet, to complex annunciator systems with many lamp cabinets and remote logic cabinets.

The sequence designations provided can be used to describe basic annunciator sequences and also many sequence variations. This Standard lists types of information that should be included in annunciator specifications and types of documents that should be provided by manufacturers; however, detailed design requirements and documentation formats are beyond the scope of this Standard.

3 Definition of terms

The following are terms and their definitions that have special meaning in relation to annunciators. Commonly used alternate terms are shown in parentheses. Defined terms used in other definitions are in italics to provide a cross-reference.

acknowledge: the *sequence action* that indicates recognition of a new *alarm*.

active alarm point: see *alarm point*.

alarm: 1. an abnormal *process condition*. 2. the *sequence state* when an abnormal *process condition* occurs. 3. a device that calls attention to the existence of an abnormal *process condition*. See *annunciator*. Types of *alarm* include:

momentary: an *alarm* that returns to normal before being acknowledged.

maintained: an *alarm* that returns to normal after being acknowledged.

alarm module (point or sequence module): a plug-in assembly containing the sequence logic circuit. Some *alarm* modules also contain *visual display* lamps or lamps and *windows*.

alarm point: the sequence logic circuit, *visual display*, auxiliary devices, and internal wiring related to one *visual display*. Types of *alarm point* include:

active: an *alarm point* that is wired internally and completely equipped. The *window* is labeled to identify a specific monitored variable.

spare: an *alarm point* that is wired internally and completely equipped. The *window* is not labeled to identify a monitored variable.

future (blank): an *alarm point* that is wired internally and equipped except for the plug-in *alarm module.* The *window* is not labeled to identify a monitored variable.

alert: see *process condition* and *sequence state.*

analog input point: an *alarm point* for use with an analog monitored variable signal, usually current or voltage. The logic circuit initiates an *alarm* when the analog signal is above or below a set point.

annunciator: a device or group of devices that call attention to changes in *process conditions* that have occurred. An annunciator usually calls attention to abnormal *process conditions*, but may be used also to show normal process status. Usually included are sequence logic circuits, labeled *visual displays, audible devices,* and manually operated *pushbuttons.*

audible device: a device that calls attention by sound to the occurrence of abnormal *process conditions.* An audible device may also call attention to return to normal conditions.

audible device follower: see *auxiliary output.*

automatic reset: see *reset.*

auxiliary contact: see *auxiliary output.*

auxiliary output (auxiliary contact): An output signal operated by a single *alarm point* or group of points for use with a remote device. Types of auxiliary output include:

field contact follower: an auxiliary output that operates while the *field contact* indicates an abnormal *process condition.*

lamp follower: an auxiliary output that operates while the *visual display* lamps indicate an *alarm*, silenced, or acknowledged state.

audible device follower (horn relay contact): an auxiliary output that operates while the common *alarm audible device* operates.

reflash: an auxiliary output that operates when any one of a group of *alarm points* indicates an abnormal *process condition.* The output usually returns to normal briefly when each *alarm point* changes to an abnormal *process condition* and returns to normal when all *alarm points* in the group indicate normal *process conditions.*

blank alarm point: see *alarm point.*

field contact (trouble or signal contact): the electrical contact of the device sensing the *process condition.* The contact is either open or closed. Annunciator field contacts are identified in relation to *process conditions* and annunciator operation, not the disconnected position of the devices. Types of field contact include:

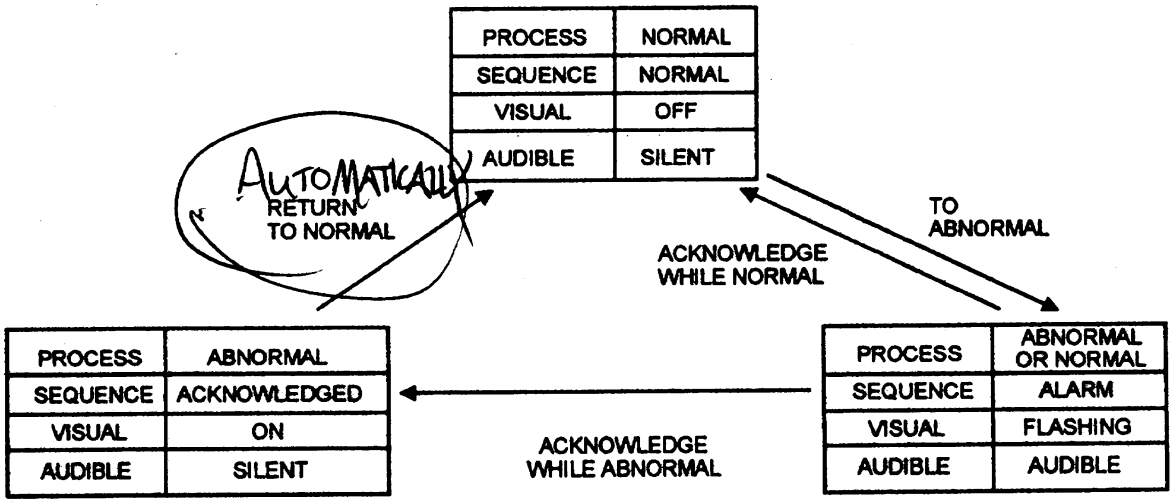
normally open (NO): a field contact that is open for a normal *process condition* and closed when the *process condition* is abnormal.

normally closed (NC): A field contact that is closed for a normal *process condition* and open when the *process condition* is abnormal.

field contact follower: see *auxiliary output.*

field contact voltage (trouble or signal contact voltage): the voltage applied to *field contacts.*

SEQUENCE DIAGRAM



SEQUENCE TABLE

LINE	PROCESS CONDITION	PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	REMARKS
1	NORMAL	-	NORMAL	OFF	SILENT	
2	ABNORMAL	-	ALARM	FLASHING	AUDIBLE	LOCK-IN
3A	ABNORMAL	ACKNOWLEDGE	ACKNOWLEDGED	ON	SILENT	MAINTAINED ALARM
3B	NORMAL	ACKNOWLEDGE	TO LINE 4			MOMENTARY ALARM
4	NORMAL	-	NORMAL	OFF	SILENT	AUTOMATIC RESET

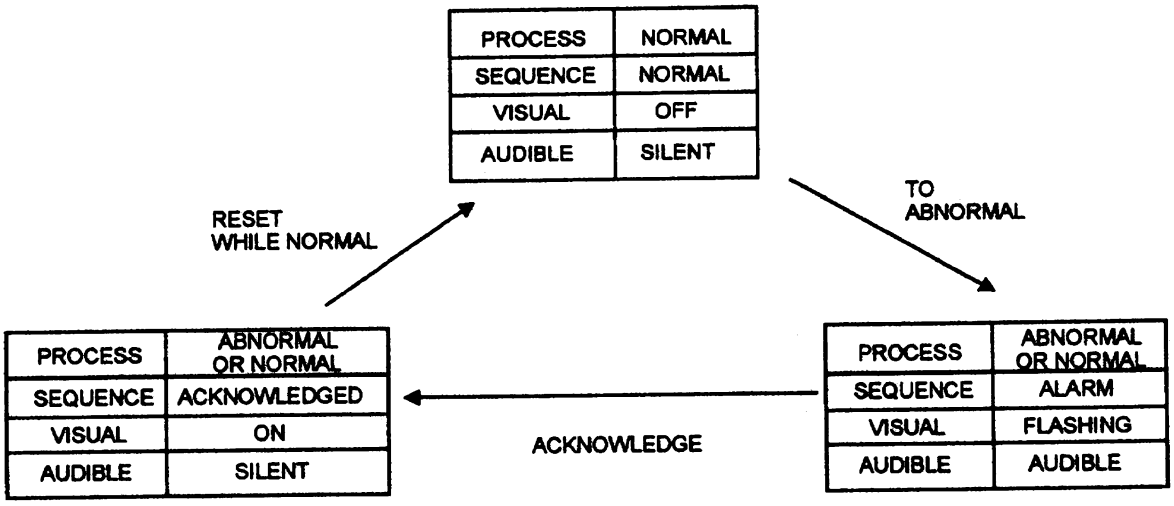
SEQUENCE FEATURES

1 - ACKNOWLEDGE AND TEST PUSHBUTTONS.
2 - ALARM AUDIBLE DEVICE.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - THE AUDIBLE DEVICE IS SILENCED AND FLASHING STOPS WHEN ACKNOWLEDGED.
5 - AUTOMATIC RESET OF ACKNOWLEDGED ALARM INDICATIONS WHEN PROCESS CONDITIONS RETURN TO NORMAL.
6 - OPERATIONAL TEST.

Figure 2 — Sequence A, automatic reset

Operator Must Acknowledge

SEQUENCE DIAGRAM



SEQUENCE TABLE

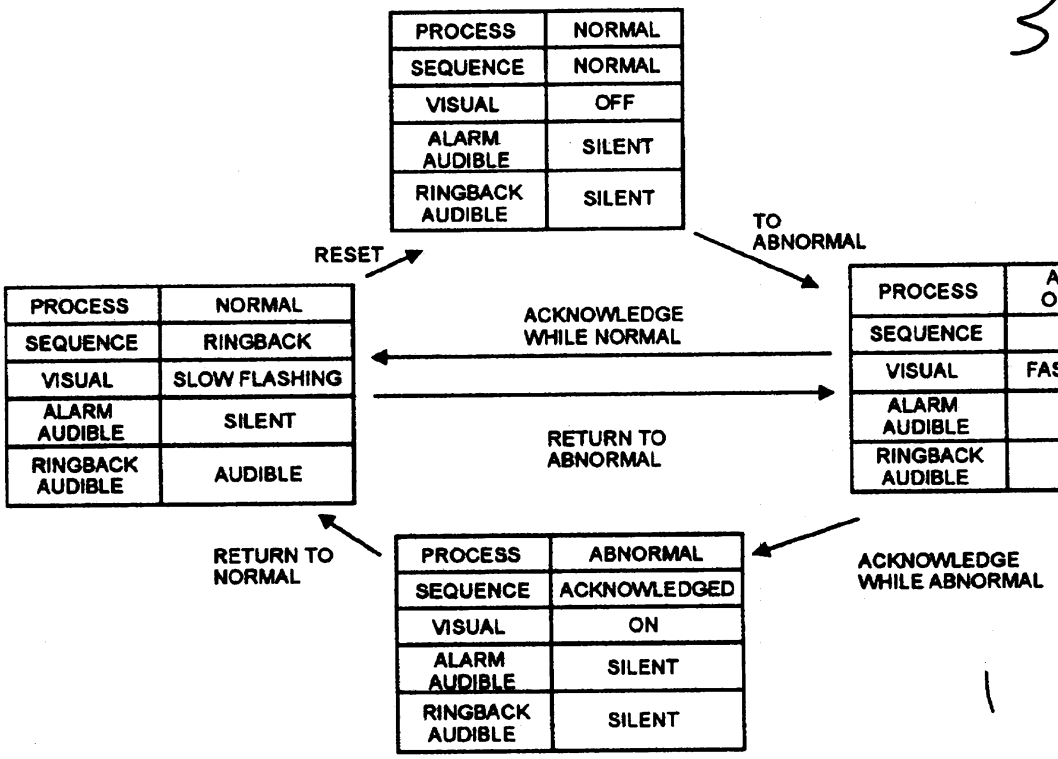
LINE	PROCESS CONDITION	PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	REMARKS
1	NORMAL	—	NORMAL	OFF	SILENT	
2	ABNORMAL	—	ALARM	FLASHING	AUDIBLE	LOCK-IN
3	ABNORMAL OR NORMAL	ACKNOWLEDGE	ACKNOWLEDGED	ON	SILENT	MANUAL RESET REQUIRED
4A	ABNORMAL	RESET	TO LINE 3			
4B	NORMAL	RESET	NORMAL	OFF	SILENT	MANUAL RESET

SEQUENCE FEATURES

1 - ACKNOWLEDGE, RESET, AND TEST PUSHBUTTONS.
2 - ALARM AUDIBLE DEVICE.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - THE AUDIBLE DEVICE IS SILENCED AND FLASHING STOPS WHEN ACKNOWLEDGED.
5 - MANUAL RESET OF ACKNOWLEDGED ALARM INDICATIONS AFTER PROCESS CONDITIONS RETURN TO NORMAL.
6 - OPERATIONAL TEST.

Figure 3 — Sequence M, manual reset

SEQUENCE DIAGRAM



SEQUENCE TABLE

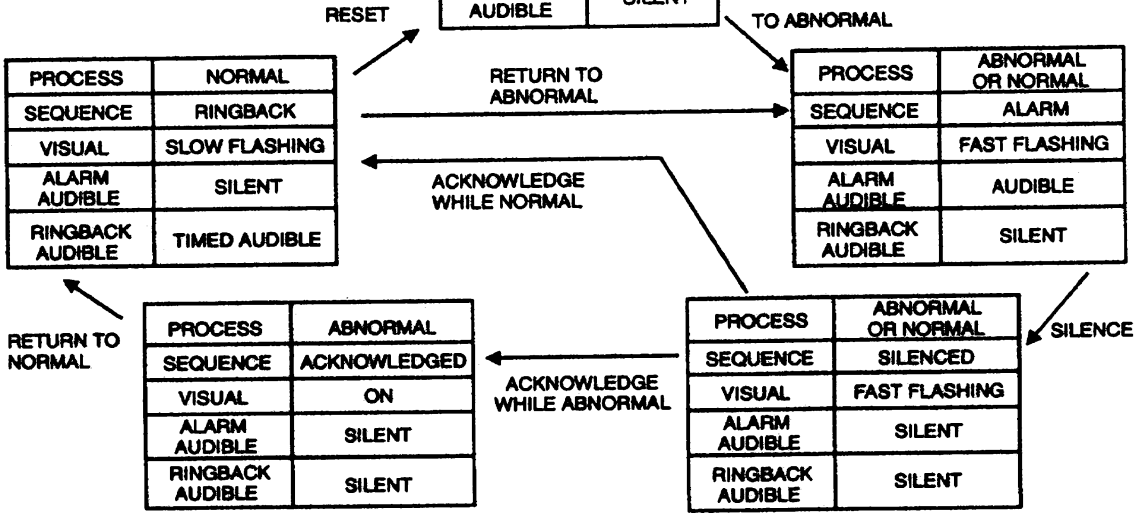
LINE	PROCESS CONDITION	PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	RINGBACK AUDIBLE DEVICE	REMARKS
1	NORMAL	—	NORMAL	OFF	SILENT	SILENT	
2	ABNORMAL	—	ALARM	FAST FLASHING	AUDIBLE	SILENT	LOCK-IN
3A	ABNORMAL	ACKNOWLEDGE	ACKNOWLEDGED	ON	SILENT	SILENT	MAINTAINED ALARM
3B	NORMAL	ACKNOWLEDGE	TO LINE 4				MOMENTARY ALARM
4	NORMAL	—	RINGBACK	SLOW FLASHING	SILENT	AUDIBLE	MANUAL RESET REQUIRED
5	ABNORMAL	—	TO LINE 2				RETURN TO ABNORMAL
6	NORMAL	RESET	NORMAL	OFF	SILENT	SILENT	MANUAL RESET

SEQUENCE FEATURES

1 - ACKNOWLEDGE, RESET, AND TEST PUSHBUTTONS.
2 - ALARM AND RINGBACK AUDIBLE DEVICES.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - THE AUDIBLE DEVICE IS SILENCED AND FAST FLASHING STOPS WHEN ACKNOWLEDGED.
5 - RINGBACK VISUAL AND AUDIBLE INDICATIONS WHEN PROCESS CONDITIONS RETURN TO NORMAL.
6 - MANUAL RESET OF RINGBACK INDICATIONS.
7 - OPERATIONAL TEST.

Figure 4 — Sequence R, ringback

SEQUENCE DIAGRAM



SEQUENCE TABLE

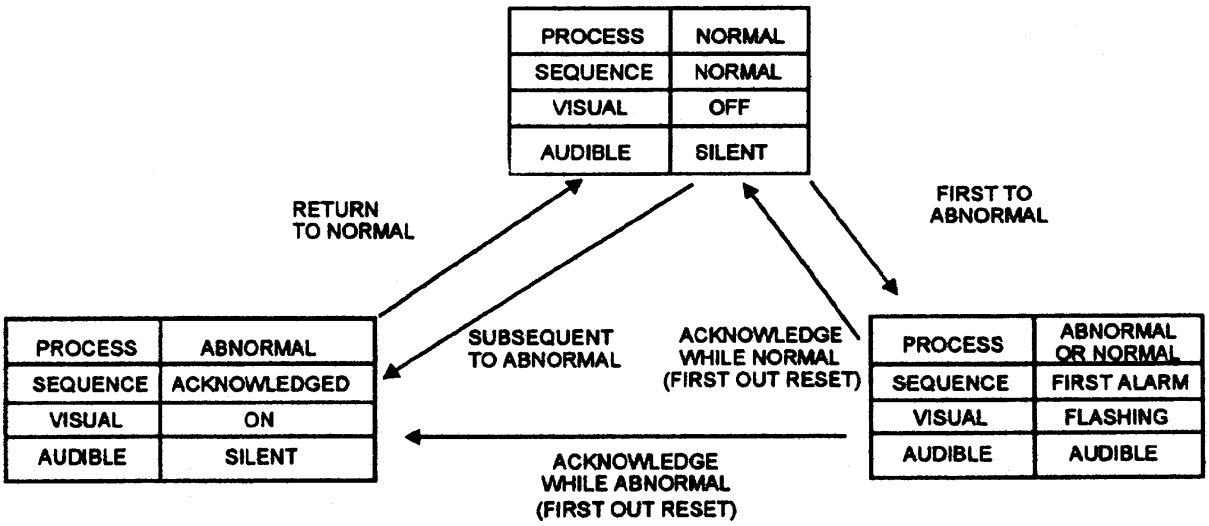
LINE	PROCESS CONDITION	PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	RINGBACK AUDIBLE DEVICE	REMARKS
1	NORMAL	—	NORMAL	OFF	SILENT	SILENT	
2	ABNORMAL	—	ALARM	FAST FLASHING	AUDIBLE	SILENT	LOCK-IN
3	ABNORMAL OR NORMAL	SILENCE	SILENCED	FAST FLASHING	SILENT	SILENT	LOCK-IN
4A	ABNORMAL	ACKNOWLEDGE	ACKNOWLEDGED	ON	SILENT	SILENT	MAINTAINED ALARM
4B	NORMAL	ACKNOWLEDGE	TO LINE 5				MOMENTARY ALARM
5	NORMAL	—	RINGBACK	SLOW FLASHING	SILENT	TIMED AUDIBLE	MANUAL RESET REQUIRED
6	ABNORMAL	—	TO LINE 2				RETURN TO ABNORMAL
7	NORMAL	RESET	NORMAL	OFF	SILENT	SILENT	MANUAL RESET

SEQUENCE FEATURES

1 - SILENCE, ACKNOWLEDGE, RESET, AND TEST PUSHBUTTONS.
2 - ALARM AND RINGBACK AUDIBLE DEVICES.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - OPTION 1 - SILENCE PUSHBUTTON TO SILENCE THE ALARM AUDIBLE DEVICE WHILE RETAINING FAST FLASHING INDICATIONS.
5 - OPTION 2 - SILENCE INTERLOCK TO REQUIRE OPERATION OF THE SILENCE PUSHBUTTON BEFORE THE ACKNOWLEDGE PUSHBUTTON.
6 - RINGBACK VISUAL AND AUDIBLE INDICATIONS WHEN PROCESS CONDITIONS RETURN TO NORMAL.
7 - OPTION 9 - AUTOMATIC RINGBACK SILENCE TO SILENCE THE RINGBACK AUDIBLE DEVICE AFTER A SET TIME.
8 - MANUAL RESET OF RINGBACK INDICATIONS.
9 - OPERATIONAL TEST.

Figure 5 — Sequence R-1-2-9, ringback with options

SEQUENCE DIAGRAM



SEQUENCE TABLE

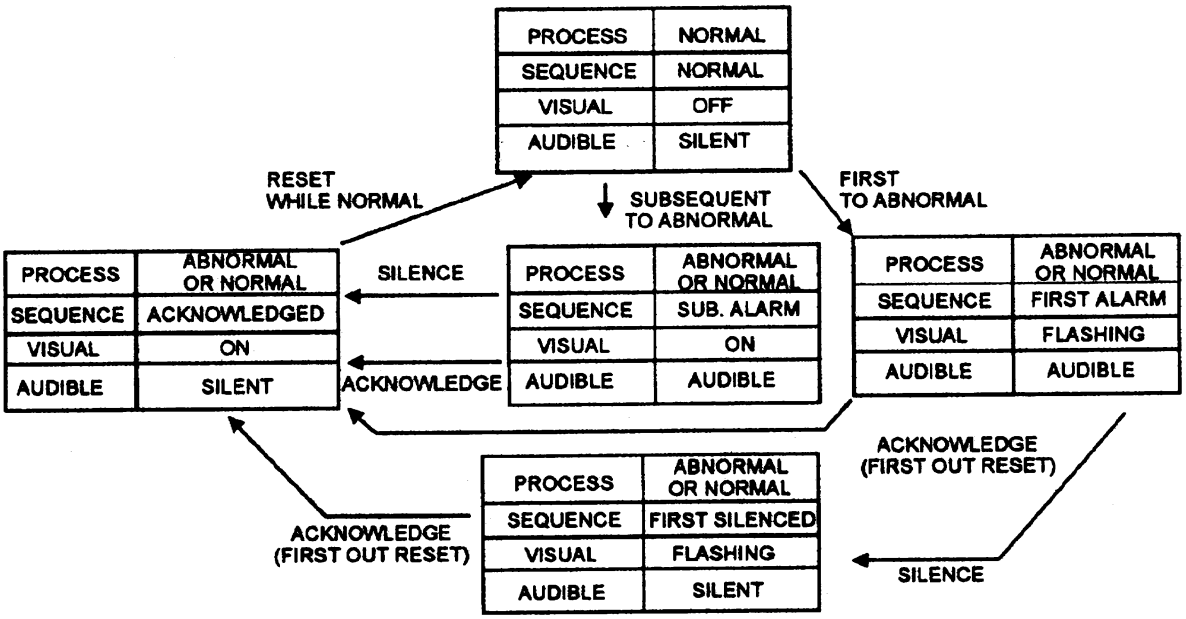
LINE	PROCESS CONDITION		PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	REMARKS
1	NORMAL		—	NORMAL	OFF	SILENT	
2	FIRST	ABNORMAL	—	FIRST ALARM	FLASHING	AUDIBLE	LOCK-IN
3	SUB.	ABNORMAL	—	ACKNOWLEDGED	ON	SILENT	NO LOCK-IN
4A	FIRST	ABNORMAL	ACKNOWLEDGE	TO LINE 3			MAINTAINED ALARM FIRST OUT RESET
4B	FIRST	NORMAL	ACKNOWLEDGE	TO LINE 5			MOMENTARY ALARM FIRST OUT RESET
5	NORMAL		—	NORMAL	OFF	SILENT	AUTOMATIC RESET

SEQUENCE FEATURES

1 - ACKNOWLEDGE AND TEST PUSHBUTTONS.
2 - ALARM AUDIBLE DEVICE.
3 - LOCK-IN OF MOMENTARY FIRST ALARM UNTIL ACKNOWLEDGED. NO LOCK-IN OF MOMENTARY SUBSEQUENT ALARMS.
4 - FLASHING AND AUDIBLE INDICATIONS FOR FIRST ALARM ONLY. NEW SUBSEQUENT ALARMS GO TO THE ACKNOWLEDGE STATE.
5 - FIRST OUT INDICATION IS RESET AND THE AUDIBLE IS SILENCED WHEN ACKNOWLEDGED.
6 - AUTOMATIC RESET OF ACKNOWLEDGED ALARM INDICATIONS WHEN PROCESS CONDITIONS RETURN TO NORMAL.
7 - OPERATIONAL TEST.

Figure 6 — Sequence F1A, automatic reset first out with no subsequent alarm state

SEQUENCE DIAGRAM



SEQUENCE TABLE

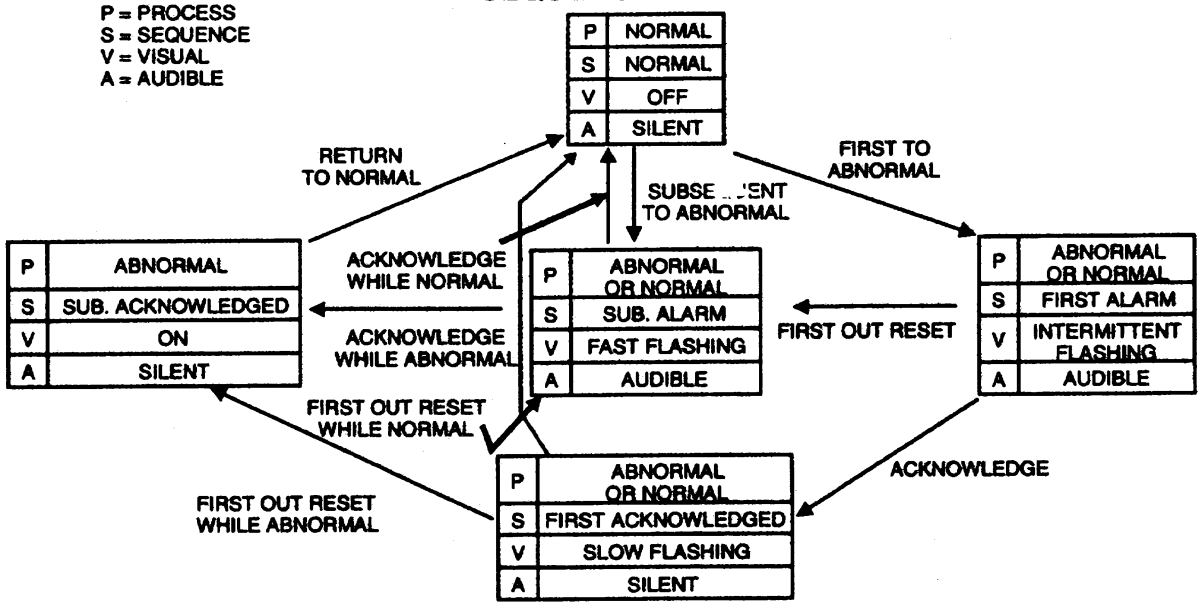
LINE	PROCESS CONDITION		PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	REMARKS
1	NORMAL		—	NORMAL	OFF	SILENT	
2	FIRST	ABNORMAL	—	FIRST ALARM	FLASHING	AUDIBLE	LOCK-IN
3	SUB.	ABNORMAL	—	SUB. ALARM	ON	AUDIBLE	LOCK-IN
4	FIRST	ABNORMAL OR NORMAL	ACKNOWLEDGE BEFORE SILENCE	TO LINE 7			FIRST OUT RESET
5	SUB.	ABNORMAL OR NORMAL					
6	FIRST	ABNORMAL OR NORMAL	SILENCE	FIRST SILENCED	FLASHING	SILENT	
7	SUB.	ABNORMAL OR NORMAL	SILENCE	ACKNOWLEDGE	ON	SILENT	MANUAL RESET REQUIRED
8	FIRST	ABNORMAL OR NORMAL	ACKNOWLEDGE AFTER SILENCE	TO LINE 7			FIRST OUT RESET
9	NORMAL		RESET	NORMAL	OFF	SILENT	MANUAL RESET

SEQUENCE FEATURES

1 - SILENCE, ACKNOWLEDGE, RESET, AND TEST PUSHBUTTONS.
2 - ALARM AUDIBLE DEVICE.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - OPTION 1 - SILENCE PUSHBUTTON TO SILENCE THE ALARM AUDIBLE DEVICE WHILE RETAINING FIRST OUT FLASHING INDICATION.
5 - FLASHING INDICATION FOR FIRST ALARM ONLY. NEW SUBSEQUENT ALARMS HAVE SAME VISUAL INDICATION AS ACKNOWLEDGED ALARMS.
6 - FIRST OUT INDICATION IS RESET WHEN ACKNOWLEDGED.
7 - MANUAL RESET OF ACKNOWLEDGED ALARM INDICATIONS AFTER PROCESS CONDITIONS RETURN TO NORMAL.
8 - OPERATIONAL TEST.

Figure 7 — Sequence F2M-1, manual reset first out with no subsequent alarm flashing and silence pushbutton

SEQUENCE DIAGRAM



SEQUENCE TABLE

LINE	PROCESS CONDITIONS		PUSHBUTTON OPERATION	SEQUENCE STATE	VISUAL DISPLAY	ALARM AUDIBLE DEVICE	REMARKS
1	NORMAL		—	NORMAL	OFF	SILENT	
2	FIRST	ABNORMAL	—	FIRST ALARM	INTERMITTENT FLASHING	AUDIBLE	LOCK-IN
3	SUB.	ABNORMAL	—	SUB. ALARM	FAST FLASHING	AUDIBLE	LOCK-IN
4	FIRST	ABNORMAL OR NORMAL	FIRST OUT RESET BEFORE ACKNOWLEDGE	TO LINE 3			FIRST OUT RESET
5	FIRST	ABNORMAL OR NORMAL	ACKNOWLEDGE	FIRST ACKNOWLEDGED	SLOW FLASHING	SILENT	FIRST OUT RESET REQUIRED
6A	SUB.	ABNORMAL		SUB. ACKNOWLEDGED	ON	SILENT	MAINTAINED ALARM
6B	SUB.	NORMAL		TO LINE 8			MOMENTARY ALARM
7A	FIRST	ABNORMAL	FIRST OUT RESET AFTER ACKNOWLEDGE	TO LINE 6A			FIRST OUT RESET
7B	FIRST	NORMAL		TO LINE 8			FIRST OUT RESET
8	NORMAL		—	NORMAL	OFF	SILENT	AUTOMATIC RESET

SEQUENCE FEATURES

1 - ACKNOWLEDGE, FIRST OUT RESET, AND TEST PUSHBUTTONS.
2 - ALARM AUDIBLE DEVICE.
3 - LOCK-IN OF MOMENTARY ALARMS UNTIL ACKNOWLEDGED.
4 - FIRST OUT FLASHING DIFFERENT FROM SUBSEQUENT FLASHING.
5 - FIRST OUT RESET PUSHBUTTON TO CHANGE THE FIRST OUT VISUAL INDICATION TO BE THE SAME AS SUBSEQUENT VISUAL INDICATIONS.
6 - AUTOMATIC RESET OF ACKNOWLEDGED ALARM INDICATIONS WHEN PROCESS CONDITIONS RETURN TO NORMAL.
7 - OPERATIONAL TEST.

Figure 8 — Sequence F3A, automatic reset first out with first out flashing and reset pushbutton

4.4 Basic sequence letter designations

Three basic types of annunciator sequence are in common use. The operation of each is different after process conditions return to normal. This Standard makes use of the following basic sequence letters to designate the three basic sequence types:

Basic Sequence Letter	Key Words	Description
A	Automatic Reset	The sequence returns to the normal state automatically after acknowledge when the process condition returns to normal.
M	Manual Reset	The sequence returns to the normal state after acknowledge when the process condition has returned to normal and the reset pushbutton is operated.
R	Ringback	The sequence provides distinct visual and audible indications when the process condition returns to normal. The sequence returns to normal after acknowledge when the process condition has returned to normal and the reset pushbutton is operated.

Sequence diagrams and sequence tables for these basic sequences are shown in Figures 2, 3, and 4.

The types of flashing shown in this Standard such as fast flashing and slow flashing are examples based on frequent use. Alternate types of flashing may be used without requiring a change in the sequence designation.

Since annunciator sequences usually include lock-in of momentary alarms, sequences in this Standard include lock-in as a standard feature. A sequence option number is provided to permit deleting the lock-in feature. Some alarm modules have provisions for deleting the lock-in feature on individual alarm points.

Variations in the basic sequences can be defined using basic sequence letter designations combined with option numbers—see 4.5, Option Number Designations.

First out sequences require a first out designation in addition to the basic sequence letter designation—see 4.6, First Out Designations.

4.5 Option number designations

Option numbers can be used with the basic sequence letter designations to define many different sequence variations. This Standard makes use of the following option numbers to designate many of the common sequence variations. Other sequence variations are considered to be special and should be defined by sequence diagrams, sequence tables, or notes.

An example of a sequence designation with option numbers is shown in Figure 1. Figures 5 and 7 illustrate the use of option numbers.

Option Number	Key Words	Description
1	Silence Pushbutton	A separate pushbutton is added to allow silencing the alarm audible device without affecting the visual displays.
2	Silence Interlock	An interlock is added to require operation of the silence pushbutton before alarms can be acknowledged.
3	First Out Reset Interlock	An interlock is added to require operation of the acknowledge pushbutton before first out alarms can be reset by the first out reset pushbutton.
4	No Lock-In	The lock-in feature is deleted. Momentary alarms return to the normal sequence state without operation of the acknowledge pushbutton.
5	No Flashing	The visual display flashing feature is deleted. New alarms have the same visual display indication as acknowledged alarms.
6	No Audible	The audible device is deleted.
7	Automatic Alarm Silence	A time delay device is added to silence the alarm audible device after a set time without affecting the visual displays.
8	Common Ringback Audible	A common audible device is used to call attention to both the alarm and ringback sequence states.
9	Automatic Ringback Silence	A time delay device is added to silence the ringback audible device after a set time without affecting the visual displays.
10	No Ringback Audible	The ringback audible device is deleted.
11	Common Ringback Visual	A common type of flashing is used to indicate both the alarm and ringback sequence states.
12	Automatic Momentary Ringback	Ringback sequence momentary alarms go to the ringback sequence state without operation of the acknowledge pushbutton.
13	Dim Lamp Monitor	The visual display indication is dim in the normal sequence state to reveal lamp failure.
14	Lamp Test	Operation of the test pushbutton tests the visual displays only.

4.6 First out designations

First out annunciators are used to indicate which one of a group of alarm points operated first. To accomplish this, the visual display indication for the alarm point that operates first must be different from the visual display indication for subsequent alarm points in that group. Only one first out alarm indication can exist in any one first out group.

Three methods for differentiating between first and subsequent alarms are in common use. Two make use of the usual sequence features for the first alarm and delete features for subsequent alarms. The third provides additional features to indicate first alarms. This Standard makes use of the following first out designations to designate the three methods.

First Out Designation	Key Words	Description
F1	No Subsequent Alarm State	Subsequent alarms appear in the acknowledged state. Subsequent visual displays do not flash. The audible device does not operate when subsequent alarms occur, unless still operating from the first alarm. The first out indication is reset by the acknowledge pushbutton.
F2	No Subsequent Alarm Flashing	Subsequent visual quent displays do not flash. The audible device does not operate when subsequent alarms occur. The first out indication is reset by the acknowledge pushbutton.
F3	First Out Flashing and Reset Pushbutton	Additional types of flashing are added to identify new and acknowledged first alarms. A first out reset pushbutton is added to reset the first out indication, whether the process condition has returned to normal or not.

First out sequences can be automatic reset or manual reset or can provide ringback indication when alarms return to normal. First out sequences are designated by a combination of the first out designation, the basic sequence letter designation, and option numbers. An example of a first out sequence designation is in Figure 1.

First out sequence diagrams consist of an outer loop of actions and states associated with the first alarm and an inner loop associated with subsequent alarms. The two loops have a common normal state.

Not all of the possible first out sequences are readily available. In some cases, a particular first out sequence may be a standard design for only one manufacturer. Sequence designations for a range of first out sequences are listed below. Some of these use a silence pushbutton, option number 1, to silence the audible device while retaining the visual display indications in the alarm state—see 4.5, Option Number Designations. The sequences commonly available at the time of publication are indicated. Sequence diagrams and sequence tables for three of the common first out sequences are shown in Figures 6, 7, and 8.

Key Words	Automatic Reset	Manual Reset	Ringback
No Subsequent Alarm State	F1A (Common) (Figure 6)	F1M (Common)	F1R
No Subsequent Alarm State and Silence Pushbutton	F1A-1 (Common)	F1M-1 (Common)	F1R-1
No Subsequent Alarm Flashing	F2A (Common)	F2M (Common)	F2R
No Subsequent Alarm Flashing and Silence Pushbutton	F2A-1 (Common)	F2M-1 (Common) (Figure 7)	F2R-1
First Out Flashing and Reset Pushbutton	F3A (Common) (Figure 8)	F3M	F3R

5 Specifications

Annunciator specifications provide manufacturers with the information necessary to prepare proposals and to design and produce the required annunciator equipment. Many details of annunciator design are relatively standard and may not need to be specified. Some annunciators require only standard specification forms* or brief specifications. Complex annunciator systems generally require more elaborate specifications to define the system requirements.

When preparing annunciator specifications, careful thought must be given when specifying features that are not readily available. The advantages of such features should be weighed against the disadvantages of special design.

The following types of information should be included in annunciator specifications, but other features should also be specified as required.

5.1 All annunciators

1) Logic circuit location: integral logic, remote logic cabinet
2) Sequence: ISA designation, other identification, sequence diagram, sequence table, notes, arrangement when more than one sequence is used
3) Number of alarm points: total, active, spare, future
4) Power source: nominal voltage, frequency
5) Nominal window size: dimension high, dimension wide

*Refer to ISA Standard ISA-S20, "Specification Forms for Process Measurement and Control Instruments, Primary Elements, and Control Valves."

6) Visual display arrangement: rows high, columns wide

7) Cabinet mounting: flush, surface, rack

8) Cabinet type: NEMA enclosure type or electrical classification

9) Window engraving: legend list, lettering size, maximum number of lines, maximum characters per line (May also be provided later.)

10) Logic circuit type: solid state, electromechanical relay

11) Field contact operation: normally open (close to alarm), normally closed (open to alarm), mixed

12) Field contact voltage: nominal voltage, frequency

13) Information required with proposal: descriptions, drawings, price, delivery

14) Documentation required: after award, before delivery, with delivery

5.2 Remote logic annunciators

1) Logic cabinet mounting: surface, chassis, rack, freestanding

2) Logic cabinet type: NEMA enclosure type or electrical classification

3) Logic cabinet requirements: arrangement, cable entrance, color

4) Prefabricated cables: supplier, length, conductor size, insulation type, jacket type

5) Lamp cabinet connections: plug connectors, screw terminals

6) Logic cabinet connections to lamp cabinet: plug connectors, screw terminals

5.3 Complex annunciator systems

1) System arrangement drawing: cabinets, prefabricated cables, pushbuttons, audible devices, power sources

2) System operation description

5.4 Annunciator accessories and special features

1) Pushbuttons: location, supplier, number, type

2) Audible devices: location, supplier, power, type

3) Special cabinet finish: annunciator or lamp cabinet color, logic cabinet color, materials to be used, application methods

4) Special visual display: individual windows, graphic displays

5) Special window or window bezel colors: colors, windows

6) Reflash points: number of field contacts, alarm points

7) Special field contact time delay: time delay, alarm points

8) Analog input points: analog signals, alarm points

9) Auxiliary outputs: function, operation on test, grouping, type, electrical rating

10) Solid state field contacts or solid state auxiliary outputs: type, electrical rating, common potential

11) Special power source requirements: voltage variation range, frequency variation range

12) Backup power system: power sources, requirements

13) Isolation from power sources: field contacts, window lamps, logic circuits

14) Special power source for receptacles and lights: nominal voltage, frequency

15) Power failure detector: alarm, indication

16) Ground detector: alarm, indication, isolation switches

17) Window legibility: lettering size, ambient light

18) Special service conditions: temperature, humidity, ambient light, noise, hazardous atmosphere, intrinsically safe design, nonincendive design, purged cabinet, high field contact wiring impedance

19) Special wire insulation: voltage rating, insulation type, test requirements

20) Special field contact wiring terminations: terminal type, terminal size, wiring space

21) Special grounding connections: terminal size, ground bus

22) Special cabinet locks: type, keys

23) Special factory tests: dielectric strength, functional, surge with stand capability, radio frequency interference, seismic, nuclear Class 1E

24) Special documentation: test procedures, test reports

25) Spare components: type, number

26) Logic circuit tester: portable, built-in

6 Documentation

Documentation is provided by manufacturers to describe the equipment produced to meet annunciator specifications. Before delivery of annunciators, this documentation is used to confirm that specification requirements are met and to allow design of the annunciator mounting, external wiring, and power sources. After delivery, this documentation is used by those installing, operating, and maintaining annunciators.

The following types of information should be included in the documentation provided by the manufacturer, but other documentation should be provided as required by specifications.

6.1 All annunciators

1) Annunciator description: appearance, standard features, special features

2) Dimensioned drawings: outline, arrangement, enclosure type, panel cutout, mounting method, wiring entrance

3) Sequence description: ISA designation, sequence diagram, sequence table, notes

4) Schematic diagram drawings: logic circuit, circuit wiring, jumper and switch settings, modules, pushbuttons, audible devices, field contact voltage, lamp voltage, power supply circuit, electrical ratings

5) Wiring diagram drawings: external wiring, power source voltage and frequency

6) Power requirements: normal, maximum, allowable voltage and frequency variation ranges

7) Instruction manual: installation, operation, operating limitations, logic circuit operation, maintenance procedures, special test device operation

8) Parts list: replacement parts, recommended spare parts, prices

6.2 Remote logic annunciators

1) Logic cabinet arrangement drawings: internal devices, terminal blocks, wiring space, ground connections, receptacles, lights, fans

2) Interconnection drawings: external wiring connections between cabinets

3) Power supply drawings: power supply and distribution system

6.3 Complex annunciator systems

1) System arrangement drawings: components, interconnections

2) System operation description

6.4 Annunciator accessories and special features

Necessary information concerning accessories and special features should be provided with the annunciator documents.

Appendix A — Annunciator application guide

This Appendix is included for informational purposes and is not a part of this Standard.

A.1 Purpose

The purpose of this Appendix is to provide information to assist in specifying annunciators that will best serve the requirements of the users while making use of standard and special features that are readily available. Catalogs and other information from annunciator manufacturers should also be used because of the wide variety of features that are available.

A.2 Introduction

Annunciators are normally used to call attention to abnormal process conditions. Annunciators may also be used to show normal process status. Annunciators usually include individual illuminated visual displays that are labeled to identify the particular monitored variable that is abnormal and audible devices. Annunciators may also call attention to the return to normal of the process conditions.

Visual displays usually flash to indicate abnormal process conditions. Manual operation of pushbuttons is usually required to silence audible devices and acknowledge new alarms. Visual displays usually change from flashing to on when alarms are acknowledged. Figure A.1 illustrates a typical annunciator sequence.

Additional types of flashing can indicate that process conditions have returned to normal or which of a group of alarm points operated first. Additional pushbuttons can be used to acknowledge alarms that return to normal, to reset first out indications, and to test annunciator lamps and circuits.

Annunciators are available in an almost infinite variety of physical arrangements, operating sequences, and special features. In some cases, the annunciation function is performed by computer systems using CRT (cathode ray tube) visual displays or recording annunciators—see A.5, Special Annunciators.

This Standard is primarily for use with electrical annunciators that use illuminated visual displays and audible devices. Enclosures with lamps behind labeled translucent windows are commonly used as visual displays. Annunciators usually operate from electrical contacts that are part of the devices that sense the process conditions.

In this Standard, sequences making use of more than one indication device as a part of each visual display to indicate the sequence state are considered to be special because of their many variations and relatively infrequent use. When additional wiring and sockets are provided, colored lights such as red and green may be used along with flashing to indicate sequence states or which is the first of a group of alarms. Colored lights may also be used to uniquely identify some of the alarms in an annunciator—see A.8.2, Windows.

A.3.1 Designation method

The sequence designation method provided in this Standard uses letters for basic sequences in common use, numbers for common options, and first out designations. Combinations of letters and numbers can define many different sequence variations. Refer to Figure 1, of this Standard for sequence designation examples and a summary of the basic sequence letters, option numbers, and first out designations.

This Standard does not designate any particular sequences as being standard. Refer to Appendix B, Sequence Designation Conversion, for the ISA sequences from ISA Recommended Practice ISA-RP18.1-1965 that are superseded and the corresponding new sequence designations.

Sequence diagrams, sequence tables, or notes should be used when sequence letter and option number designations do not adequately define required sequences.

When selecting sequence designations, careful thought must be given when including features or combinations of features that are not readily available. The advantages of such features should be weighed against the disadvantages of special design.

A.3.2 Lock-in

Lock-in is a sequence feature that retains the alarm state until acknowledged when momentary alarms occur. With lock-in, momentary alarms can be observed before the acknowledge pushbutton is operated. Without lock-in, momentary alarms may not be observed at all, even though the audible device operates briefly.

Since annunciator sequences usually include lock-in, the sequences in this Standard include lock-in as a standard feature. Option Number 4 is provided to permit deleting the lock-in feature—see 4.5, Option Number Designations. Some alarm modules include movable jumpers or switches to allow deleting the lock-in feature on individual alarm points.

When momentary alarms occur frequently enough to be a nuisance, the lock-in feature is often deleted to avoid having to acknowledge the alarms repeatedly. In such cases, a better solution may be to correct the cause of the momentary alarms or to use time delays in field contact circuits in order to alarm only abnormal process conditions that exist longer than a given time.

A.3.3 Sequence A, automatic reset

Sequence A is a basic annunciator sequence with automatic reset that automatically returns acknowledged alarms to normal when process conditions return to normal. A sequence diagram and sequence table for sequence A are shown in Figure 2, of this Standard.

In some applications, sequence A may have a disadvantage since new momentary alarms return to off and new maintained alarms change to on when and during the time the audible device is silenced by operation of the acknowledged pushbutton. New alarms may be lost or may be confused with existing acknowledged alarms. New alarms may have to be reviewed or logged while flashing, with the continual distraction of the audible device signal. If these features are not desirable, sequence A-1 with a silence pushbutton or sequence A-1-2 with a silence pushbutton and interlock should be used—see 4.5, Option Number Designations.

If an audible signal is required when process conditions return to normal, sequence R that includes ringback should be used—see A.3.5, Sequence R, Ringback.

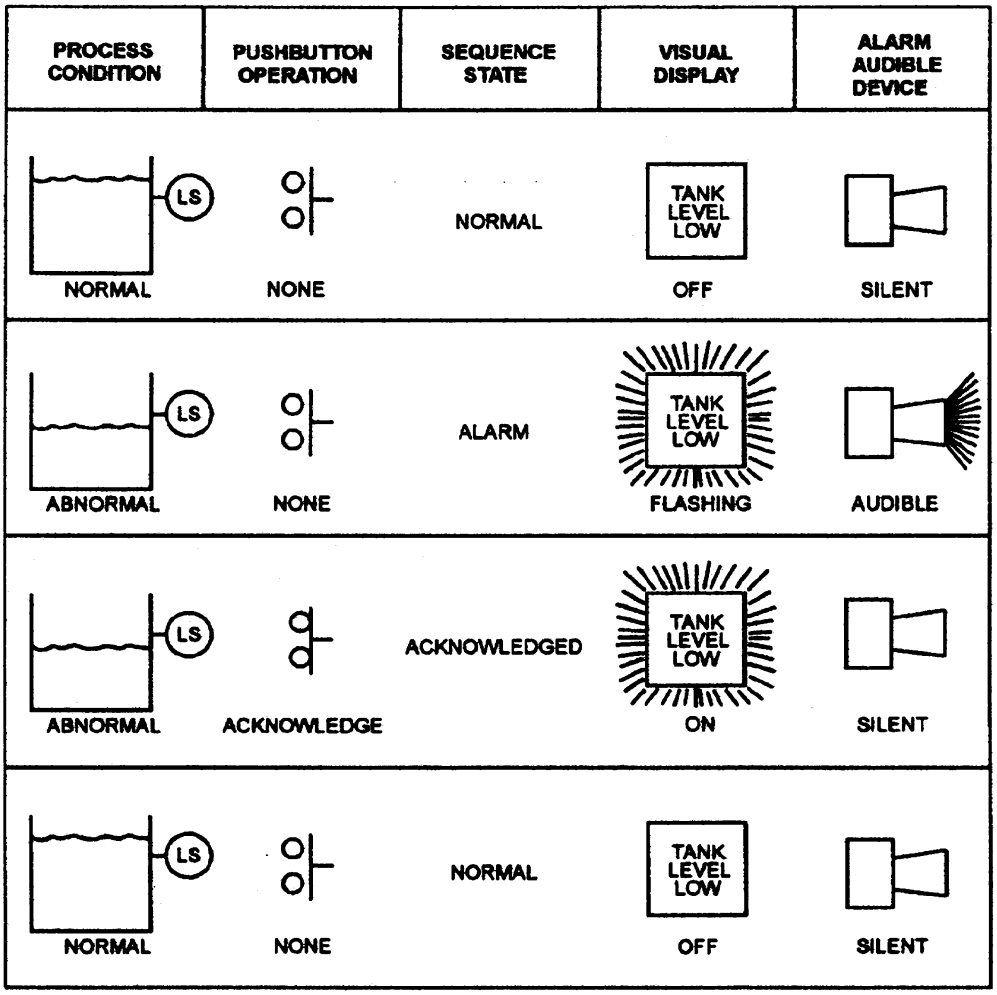


Figure A.1 — Typical annunciator sequence, sequence A, automatic reset

A.3.4 Sequence M, manual reset

Sequence M is a basic annunciator sequence with manual reset that retains acknowledged alarms until the process conditions return to normal and the manual reset pushbutton is operated. A sequence diagram and sequence table for sequence M are shown in Figure 3 of this Standard.

In some applications, sequence M may have a disadvantage since new alarms change to on when and during the time the audible device is silenced by operation of the acknowledge pushbutton. New alarms may be confused with existing acknowledged alarms. New alarms may have to be reviewed or logged while flashing, with the continual distraction of the audible device signal. If these features are not desirable, sequence M-1 with a silence pushbutton or sequence M-1-2 with silence pushbutton and interlock should be used—see 4.5, Option Number Designations.

In order to reset alarms, sequence M requires that the reset pushbutton be operated repeatedly to determine if process conditions have returned to normal. When the reset pushbutton is operated, it may be difficult to observe which of a number of acknowledged alarms have returned to normal. With sequence M, it is not evident when process conditions return to normal or return again to abnormal. If these features are not desirable, sequence R that includes ringback should be used—see A.3.5, Sequence R, Ringback.

Sequence M usually cannot be used with reflash circuits or to operate from remote reflash auxiliary outputs since the sequence does not return to the alarm state when the field contact circuit returns to normal briefly. Refer to A.9.3, Shared Alarm Points, and A.9.5, Auxiliary Outputs. If this feature is required, sequence A or R should be used—see A.3.3, Sequence A, Automatic Reset and A.3.5, Sequence R, Ringback.

A.3.5 Sequence R, ringback

Sequence R is a basic annunciator sequence with ringback that provides distinct visual and audible indications when process conditions return to normal. The ringback indications are retained until the process conditions return to normal and the manual reset pushbutton is operated. A sequence diagram and sequence table for sequence R are shown in Figure 4 of this Standard.

In some applications, sequence R may have a disadvantage since new momentary alarms change to slow flashing and new maintained alarms change to on when and during the time the audible device is silenced by operation of the acknowledge pushbutton. New alarms may be confused with existing alarms. New alarms may have to be reviewed or logged while fast flashing, with the continual distraction of the alarm audible device signal. If these features are not desirable, sequence R-1 with a silence pushbutton or sequence R-1-2 with silence pushbutton and interlock should be used—see 4.5, Option Number Designations.

Sequence R includes different visual display indications and different audible device signals for alarm and ringback. Several variations of this arrangement can be used. Sequence R-8 uses a common audible device for both alarm and ringback and relies on the different visual display indications for differentiation. Sequence R-9 uses a time delay device to silence the ringback audible device after a set time. Sequence R-10 deletes the ringback audible device and uses only the ringback visual displays. Sequences R-9 and R-10 avoid the need for pushbutton operation to silence an audible device when process conditions return to normal. Sequence R-11 uses a common type of flashing for both alarm and ringback and relies on the different audible devices for differentiation. See 4.5, Option Number Designations.

Sequence R retains both momentary and maintained alarms in the alarm state until acknowledged. Sequence R-12 causes momentary alarms to go to the ringback sequence state as soon as process conditions return to normal. New momentary alarms are evident sooner, but may be confused with existing alarms in the ringback state.

Sequence R-1-2-9, shown as an example of the use of option number designations in Figure 5, of this Standard, includes a silence pushbutton and interlock to allow new alarms to be reviewed or logged while flashing after the audible signal has been silenced and to require operation of the silence pushbutton first. In addition, the ringback audible device is silenced after a set time to retain a ringback signal while avoiding the need for pushbutton operation to silence the ringback audible device when process conditions return to normal.

A.3.6 First out

First out annunciators are used to indicate which one of a group of alarm points operated first. To accomplish this, the visual display indication for the alarm point that operates first must be different from the visual display indication for subsequent alarm points in that group. Only one first out alarm indication can exist in any one first out group.

When first out annunciators are used primarily to identify the first alarm, a flashing visual display can be used to indicate the first alarm, and visual displays without flashing can be used to indicate subsequent alarms. With this approach, the visual display indication for subsequent alarms does not differentiate between new and acknowledged alarms. Two methods using this approach are in common use. (1) First out designation F1 designates a first out sequence with no subsequent alarm state. Subsequent alarms appear in the acknowledged state. Subsequent visual displays do not flash. The audible device does not operate when subsequent alarms occur, unless still operating from the first alarm. The first out indication is reset by the acknowledge pushbutton. It should be noted that subsequent alarms do not lock in when sequence F1A is used. (2) First out designation F2 designates a first out sequence with no flashing for subsequent alarms. The audible device operates when subsequent alarms occur. The first out indication is reset by the acknowledge pushbutton.

To allow the first out visual display indication to be reviewed or logged after silencing the audible device when using first out designations F1 and F2, a separate silence pushbutton should be used in addition to the other annunciator pushbuttons. The silence pushbutton feature is designated by option number 1. — see 4.5, Option Number Designations.

When use of the annunciator requires differentiation between new and acknowledged subsequent alarms, the first out sequence should include different types of visual display flashing to identify the first alarm while new subsequent alarms are indicated by the usual flashing visual display. One method using this approach is in common use. First out designation F3 designates a first out sequence with first out flashing to identify new and acknowledged first alarms and a first out reset pushbutton to reset the first out indication, whether the process condition was returned to normal or not. If desired, an interlock can be provided to require operation of the acknowledge pushbutton before the first out indication can be reset by the first out reset pushbutton by use of option number 3—see 4.5, Option Number Designations.

After the first out indication is reset, that alarm point indicates the process condition in the same manner as subsequent alarms. The next alarm point to operate will display a first out indication.

First out sequences can be automatic reset or manual reset or can provide ringback indication when alarms return to normal. First out sequences are designated by a combination of the first out designation, the basic sequence letter designation, and any required option numbers. Refer to Figure 1, in this Standard for a first out sequence designation example.

Sequence designations for a range of first out sequences are listed in 4.6, First Out Designations. Sequence diagrams and sequence tables for three of the common first out sequences are shown in Figures 6, 7, and 8 of this Standard. Because of the complex nature of first out annunciator sequences, use of those sequences that are readily available should be considered when making a selection.

When annunciators include both first out alarm points and alarm points without the first out feature, the first out windows and alarm modules are usually located together for easy recognition and to facilitate first out logic bus interconnections. Colored window bezels, windows, or lamps may be used to identify first out alarm points. Several separate first out groups can be created by using several first out logic buses.

Annunciator first out windows may not be needed if a recording annunciator or computer printer is provided for sequence of events analysis.

A.3.7 Test

2 TESTS
① LAMP
② FUNCTION

Annunciator test pushbuttons initiate an annunciator sequence to reveal lamp or circuit failures. Most annunciators include a test pushbutton and operational test of the sequence, visual display lamps, audible devices, and pushbuttons. The sequences in this Standard include operational test as a standard feature.

Operation of the test pushbutton simulates simultaneous abnormal process conditions on all related alarm points. Release of the test pushbutton simulates return to normal. Operation of the other annunciator pushbuttons to complete the sequence and observation of the operation of the visual displays and audible devices can reveal lamp or circuit failures. Alarm points in the acknowledged state as a result of actual abnormal process conditions usually remain in the acknowledged state during test and will be in the acknowledged state after the test sequence.

Since the test signal usually operates the sequence logic circuit in the alarm module, annunciator input auxiliary circuits such as reflash or time delay circuits and some auxiliary output circuits may not operate during the test sequence. In some cases, operation of auxiliary outputs during the test sequence may not be desirable since false alarm signals would be transmitted to the connected alarm, recording, or control circuits.

Some annunciator sequences make use of visual display indications that are dim in place of off to reveal lamp failures in addition to an operational test sequence. The dim lamp monitor feature is designated by option number 13—see 4.5, Option Number Designations.

Test pushbuttons used with some electromechanical relay logic annunciators test only the visual display lamps. Operation of the test pushbutton turns all related visual display lamps on simultaneously. The lamp test feature is designated by option number 14—see 4.5, Option Number Designations.

A.4 Arrangement

A.4.1 Integral logic annunciators

Integral logic annunciators include visual displays and sequence logic circuits in one assembly as illustrated in Figure A.2. Plug-in alarm modules contain the sequence logic circuits. The visual display lamps and windows may or may not be a part of the plug-in alarm modules. Terminal blocks are provided for the field contact, pushbutton, audible device, and power source wiring.

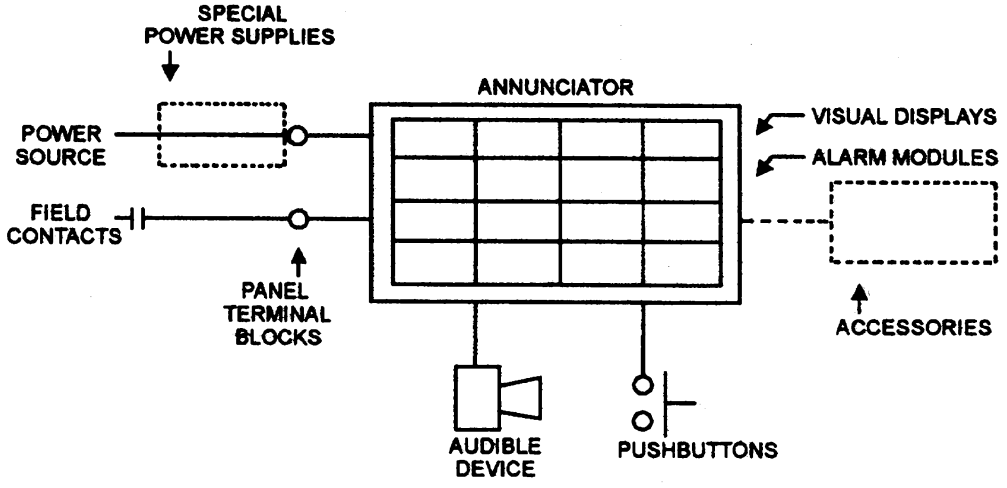


Figure A.2 — Integral logic annunciator arrangement

When large annunciator windows are subdivided to form two, three, or four smaller windows, a single plug-in alarm module may serve each group of alarm points.

Common flashers, audible device drivers, and required power supplies are usually located within integral logic annunciators. Small pushbuttons and audible devices can be mounted in window positions when preferred and when annunciators are easily accessible.

Since the space in integral logic annunciator cabinets is limited, it may be necessary to locate special power supplies and accessories such as auxiliary output, reflash, ground detector, and power failure detector components in separate cabinets. The separate cabinets are usually designed for surface mounting.

Integral logic annunciators should be located so that alarm module replacement and other required maintenance can be done without excessive interference with nearby activities.

Panel wiring is often used to connect from the annunciator terminal blocks to larger panel terminal blocks where the field wiring is terminated.

A.4.2 Remote logic annunciators

Remote logic annunciators locate visual displays and sequence logic circuits in separate assemblies as illustrated in Figure A.3. Lamp cabinets contain the visual displays and the necessary terminal blocks or plug connectors. The plug-in alarm modules, accessory components, and special power supplies can be supplied in separate assemblies for rack or cabinet mounting by the user, or else complete logic cabinets can be supplied by the manufacturer. Pushbuttons and audible devices are usually located near the lamp cabinets.

Logic cabinets are usually arranged to suit the requirements of a particular annunciator specification. The arrangement can include space for power supplies and accessories such as auxiliary output, reflash, ground detector, and power failure detector components. A ground bus may be required and electrical receptacles or lights may be desirable for use during maintenance. Large terminal blocks and adequate space for field wiring and terminations can be provided.

When required, terminal blocks can be specified to be separated from the logic circuits to minimize circuit damage during installation or to allow installation of terminal blocks and field wiring before the logic circuits are installed.

To reduce congestion, logic cabinets are often located such that field contact wiring avoids control panel wiring areas. Special cables with large numbers of small conductors are usually used to connect between the logic cabinets and the lamp cabinets. These cables often connect directly to the lamp cabinets so that panel wiring and terminal blocks are not required. Installation time may be reduced if prefabricated lamp cabinet cables with plug connectors are provided by the manufacturer. Care must be taken when specifying the length of prefabricated cables with plug connectors on both ends. In some cases, plug connectors on one end of each cable are installed in the field after the cables are cut to the correct length.

The higher cost of remote logic annunciators is often justified for large or complex annunciator systems. Installation and maintenance costs are reduced since the logic cabinets can contain special power supplies and accessory components, field contact wiring terminates away from control panels, special requirements for field wiring space and terminal blocks can be met, and lamp replacement is the only annunciator maintenance required in the control panel area.

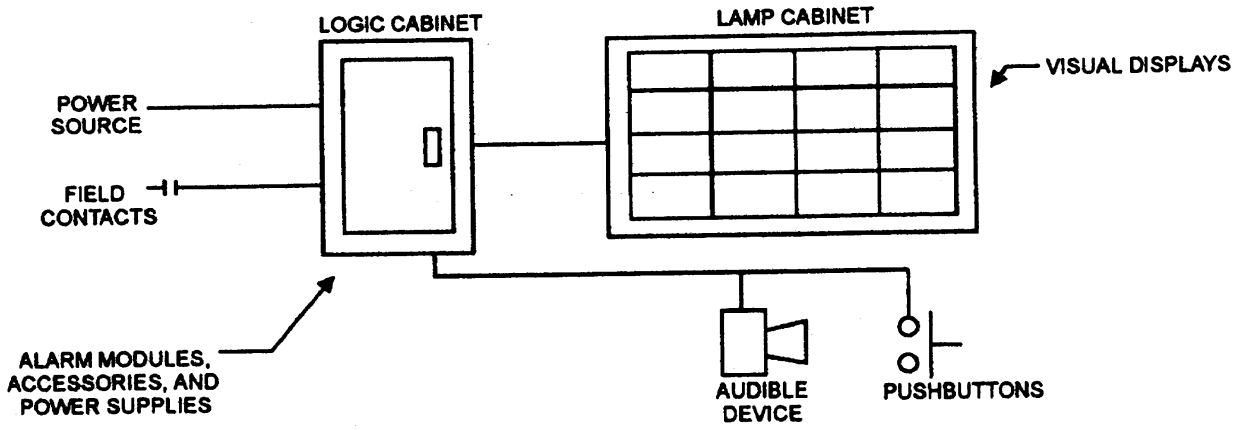


Figure A.3 — Remote logic annunciator arrangement

A.5 Special annunciators

A.5.1 General

The more commonly used annunciators include groups of illuminated visual displays and sequence logic circuits that are dedicated for use with individual alarm points. The following special types of annunciators and visual displays should also be considered when their use can improve the annunciation function. The terminology, sequence designations, and sequence presentation in this Standard should be used wherever practicable when specifying these special annunciators.

A.5.2 Drop type annunciators

Drop type annunciators make use of inexpensive electromechanical devices that release labeled cards to fall to a position where the labels can be seen. A separate device operates the audible device. The audible device and drops can be reset independently by mechanical levers or electrical pushbuttons. Auxiliary output contacts are available.

Drop type annunciators are sometimes used at unattended locations to transmit general trouble alarms to central control room annunciators and to indicate the specific abnormal condition to maintenance personnel.

A.5.3 Individual visual displays

Control panel arrangements sometimes require that annunciator visual displays be located adjacent to related control and indication devices. Individual light boxes or pilot lights suitable for location on panels can be used as visual displays with remote logic annunciators. Some individual light boxes contain the sequence logic and can operate as individual annunciators.

A.5.4 Graphic displays

Graphic displays with colored shapes to represent process equipment and interconnections are often used to enable a more clear understanding of the process operation. Individual visual displays can be included as a part of the graphic display to show the location of alarms in the process. The individual visual displays can be a part of remote logic annunciators or they can operate in parallel with the visual displays of integral logic annunciators.

A.5.5 Recording annunciators

Recording annunciators, often called sequence of events recorders, provide a printed record of the alarm point identification and the date and time that alarms occur and return to normal. The printed identification to identify the alarms can be coded alarm point numbers or short worded alarm messages.

Recording annunciator circuits usually scan field contacts rapidly, store information when alarms occur in rapid succession, and print the information in chronological sequence. The time can be recorded to as close as the nearest millisecond to allow accurate analysis of the sequence of events. The printers are usually separate from the circuit cabinets.

Recording annunciators are sometimes used in parallel with illuminated visual display annunciators to record the operation of important alarm points. Since they cannot be read from a distance, recording annunciators can be used to both indicate and record alarms only when there is no need to react to alarms quickly or from different control locations. An alarm summary can be printed when required to indicate all points in alarm at that time.

Printers and circuit cabinets can be provided just for recording alarms, or they can be part of larger computer systems that also perform other functions.

A.5.6 CRT visual displays

CRTs (cathode ray tubes) can be used as alarm visual displays. Alarms can be presented by worded alarm messages or by words or symbols that appear near the related equipment on CRT process graphic displays. The alarm indications can flash or be colored or both until acknowledged.

The CRTs are usually separate from the sequence logic and CRT display control circuit cabinets.

Commonly used annunciators with conventional illuminated visual displays require additional panel space for each additional alarm point. Since CRTs usually indicate only the points that are in alarm, additional alarm points require only additional capacity in the circuit cabinets. On the other hand, alarms must be displayed on the CRT in sections when a large number of alarms exist at one time since space on a CRT is limited. When a large number of alarms is anticipated, several CRTs should be used. Each display can indicate a selected portion of the alarms.

When CRTs are used, conventional annunciator illuminated visual displays are often installed also to indicate the more important alarms. Since they are dedicated displays and can be located near the related process controls, they direct attention to the trouble area more rapidly than CRT alarm messages.

CRTs and circuit cabinets can be provided for indication of alarms only, or they can be part of larger computer systems that also perform other functions.

A.5.7 Voice annunciators

Voice annunciators use speakers to broadcast verbal alarm messages. The words may be created by electronic synthesis or by playing messages recorded on magnetic tape.

Voice annunciators tend to command immediate response and can be projected over large control and process areas. They can also be used along with visual display annunciators to call attention to the more important alarms.

A.5.8 Combined annunciation systems

Annunciation systems can combine annunciators of different types in order to best serve each of the required functions. As an example, a large number of alarms could be presented in a compact control room by the combined annunciation system described below.

Important Alarms	Indicated by conventional annunciator visual displays located on the related control panels. Reflash circuits are used to conserve panel space by indicating several related alarms on one visual display.
All Alarms	Indicated on CRTs located in several major control areas. Each alarm indicates only on the related CRT. The CRTs indicate the reflash circuit alarms individually for better alarm definition.
All Alarms and Important Process Status Inputs	Recorded by a printer for later analysis of alarms and process status and the sequence of events.The printer is located away from the control room to minimize noise in the operating area.
Audible Device and Pushbuttons	Designed to allow silencing audible devices and acknowledging alarms as a coordinated annunciation system.

A.5.9 Multiplexing

Multiplexing is the use of a single communication channel to transmit many individual signals. Multiplexing systems may include redundant circuits and communication channels for increased reliability. While multiplexing is not inherently related to alarms, it is being used with increasing frequency along with annunciators or as a part of annunciation systems to reduce the amount and the cost of field contact wiring. Multiplexing should be considered when the length of field contact wiring is greater than about 1000 feet (300 m).

A.6 Audible devices

Annunciator audible devices call attention by sound to the occurrence of alarm and return to normal conditions. They are often located inside control panels near the annunciators or lamp cabinets. The sound can usually be heard adequately in the adjacent area. In noisy areas, openings in the panels can be provided to increase the sound or the audible devices can be mounted on top of the panels. Small audible devices can be provided on the front of annunciator cabinets. Audible devices are usually supplied with annunciators to ensure coordination with the audible device driver circuits.

Audible devices can be horns, bells, chimes, buzzers, or speakers operating from adjustable solid state tone generators. The sound can be continuous or intermittent until silenced by manual pushbutton operation or the sound can be silenced automatically after a set time. The sound can be steady or it can fluctuate or warble.

Audible devices in relatively quiet control rooms are often speakers or intermittent chimes that call attention to alarms without undue noise. Audible devices with different sounds or tones may be selected to distinguish between different functions, systems, or levels of alarm importance.

Annunciators in locations that are frequently unattended should silence audible devices automatically after a set time to avoid unnecessary noise and wear of the audible devices. Sequence option numbers 7 and 9 are provided to allow adding the automatic silence feature—see 4.5, Option Number Designations.

When annunciators are in unattended or noisy areas, attention can be drawn to alarms by large flashing lights mounted on top of the panels. These lights can be connected to the audible device driver circuits.

Audible devices should meet the environmental requirements that apply to other panel mounted devices.

A.7 Pushbuttons

Annunciator pushbuttons are momentary manual switches that cause a change from one annunciator sequence state to another. They are usually located on the panels below the annunciators or lamp cabinets. Pushbuttons can also be provided on the front of annunciator cabinets. Usually one normally open or normally closed pushbutton contact is wired to the annunciator. Pushbuttons can be supplied with annunciators or provided by others.

Miniature or heavy duty pushbuttons can be used, depending on the application and the need to coordinate with other panel devices. Since annunciator pushbuttons may be operated frequently and in a hurry when responding to alarms, they should be selected and located for convenient operation and to minimize the possibility of accidental operation of other nearby pushbuttons.

Pushbuttons should meet the environmental requirements that apply to other panel mounted devices.

An interlock is usually provided to require operation of acknowledge pushbuttons before alarms can be reset. It may also be desirable to require operation of silence and acknowledge pushbuttons or acknowledge and first out reset pushbuttons in sequence to avoid accidental loss of alarm indications. Sequence option numbers 2 and 3 are provided to add these interlocks—see 4.5, Option Number Designations.

When several annunciators or lamp cabinets in a large control room operate together as a system, the pushbuttons should be arranged and connected to allow operation from appropriate locations. As an example, the following arrangement could be used in a control room with separate supervision and control panels.

Silence Pushbuttons	Located on all supervision and control panels and connected to silence the alarm audible device for any alarm in the control room. This avoids continued noise while retaining the flashing visual displays.
Acknowledge Pushbuttons	Located only on control panels where corrective control action can be taken and connected to acknowledge new alarms related to the controls on that panel only. This encourages observation of related indicators and controls.
Reset Pushbuttons	Located on all supervision and control panels and connected to reset any ringback alarm in the control room. Return-to-normal conditions usually do not require control action.
Test Pushbuttons	Located only near annunciators or lamp cabinets and connected to test the related annunciator or lamp cabinet only. This avoids disrupting the entire annunciator system by test at one time.

A.8 Visual displays

A.8.1 General

Annunciator visual displays indicate the sequence state. They are usually enclosures containing lamps behind translucent windows. The windows are labeled to identify the monitored variables. Bullseye pilot lights with round glass lenses and adjacent labeled nameplates can also be used as annunciator visual displays. Pilot lights are sometimes better suited for use in adverse environments than are displays with translucent windows.

A.8.2 Windows

The size of annunciator windows has not been standardized among manufacturers. Windows commonly used are in the order of 2 inches (50 mm) high and 3 inches (75 mm) wide. These windows often can be subdivided to form two, three, or four smaller windows to reduce the required panel space when the viewing distance is short or a small amount of lettering is necessary. These alarm points may make use of a common window or alarm module.

Annunciator windows are usually translucent white with black letters. Clear or white lamps are normally used. When it is necessary to uniquely identify some of the alarms in an annunciator, such as more important alarms or alarms related to one process area, it is usually possible to obtain colored window bezels, windows, or lamps. Methods used and colors available vary widely. Lamps are often colored by the addition of colored boots that are slipped over the lamps. The brightness and legibility of displays are reduced when colored windows or lamps are used.

To avoid interfering with more alarms than necessary during relamping, windows or alarm modules usually can be removed individually from the front.

For best visibility, the windows should be approximately perpendicular to the line of sight of viewers. Since annunciators and lamp cabinets are often located above other devices on control panels, some windows are wedge-shaped for better visibility from below. Some control panels are designed with an inclined section at the top for improved visibility. These factors should be considered during the design of control panels.

The size of lettering used on annunciator windows should be selected to be legible from any point in the related operating area. A compromise is required, however, since larger lettering reduces the number of characters available to identify alarms. For uniform appearance, the same lettering size should be used for all windows of a given size in any one control room. Recommended reading distances for different letter sizes are included in ISA Recommended Practice ISA-RP60.6, "Nameplates, Tags, and Labels for Control Centers" (being prepared at the time of publication).

In order to identify the monitored variable completely in the space available, abbreviations are usually required. Abbreviations should be consistent, and periods are usually omitted. For standard abbreviations, refer to American National Standards Institute Standard ANSI Y1.1, "Abbreviations for Use on Drawings and in Text." The lettering on each line is usually centered. To facilitate maintenance, windows can be marked with instrument numbers or small identification numbers to correlate with similar numbers adjacent to alarm modules. Annunciator legend lists should be prepared with care, since the legends will appear exactly as indicated.

The arrangement of information on annunciator windows should be consistent. From top to bottom, the words usually become increasingly specific. For example:

COOLING WATER	PRIMARY PMP A102
HEADER PRESS	BEARING TEMP
LOW	HIGH TRIP

A.8.3 Lamps

Annunciator visual displays usually are incandescent lamps. Two lamps are usually connected in parallel to light the windows more evenly and also to allow visual displays to function even if one lamp has failed. Lamps with bayonet bases are usually used to avoid loss of electrical contact because of vibration.

To minimize maintenance, annunciator lamps are usually operated below the rated voltage. The particular type of lamp, the rated voltage, and the applied voltage are usually selected by

annunciator manufacturers. Lamps with a higher watt rating usually cannot be substituted without damage to annunciator circuits or windows.

Care should be taken so the illumination level in areas where annunciator windows are located is not so high that legibility is reduced below an acceptable level.

A.9 Logic circuits

A.9.1 General

Annunciator logic circuits operate the visual displays and audible devices through a chronological series of states to indicate and call attention to alarm and return to normal conditions. Changes from one sequence state to another are caused by changes in process conditions and also by manual operation of pushbuttons. Annunciators usually operate from field contacts that are located in the devices that sense the process conditions.

Annunciator logic normally uses solid state circuits on plug-in printed circuit boards, although electromechanical relay circuits are also available. The widest variety of annunciator features and accessories is available when solid state circuits are used. Solid state logic circuits usually operate on a low dc voltage, from 5 to 15 volts dc. Electromechanical relay logic circuits usually operate on the annunciator power source voltage.

Even when solid state logic circuits are used, some electromechanical relays may be provided to drive large audible devices and to provide isolation in pushbutton, auxiliary output, and reflash circuits. Miniature relays mounted on printed circuit boards are often used to provide isolation because of small size.

Alarm modules usually include movable jumpers or switches to allow operation with either normally open or normally closed field contacts. Other jumpers or switches may be provided to allow selection of the annunciator sequence.

All of the alarm points of an annunciator usually have the same operating sequence; however, different sequences can be provided for individual alarm points or groups of points in one annunciator.

All of the visual displays of an annunciator or lamp cabinet usually flash in unison to minimize confusion, particularly during test. It is usually not necessary to have all visual displays of a large system flash in unison.

A.9.2 Field contacts

Annunciator field contacts are the electrical output contacts of the devices sensing the process conditions. In relation to annunciators, field contacts are either normally open and close to alarm or they are normally closed and open to alarm. This contact operation description is usually not adequate when specifying the devices that sense the process conditions. It is usually necessary to specify that the contacts of these devices close or open when the process conditions increase or decrease. Field contacts may be either electromechanical or solid state.

Movable jumpers or switches are usually provided as a part of alarm modules to allow sequence logic circuits to operate from either normally open or normally closed field contacts. To avoid confusion during maintenance, however, all annunciator field contacts used with one annunciator or in one installation are usually selected to be of the same type.

Many annunciators are used with normally open field contacts and many are used with normally closed contacts. Some applications and industries are fairly consistent in this selection, while others are not consistent. The selection is most often based on past practice, but differences in annunciator operation when failures occur and during maintenance can be factors. Failures in the mechanical or electrical devices sensing the process conditions affect both normally open

and normally closed field contacts. Open circuits in the field contact wiring prevent alarms from normally open contacts, but cause false alarms from normally closed contacts. Short circuits in the field wiring cause just the opposite results. Disconnecting field contact wiring briefly to locate grounded wires temporarily prevents alarms from normally open contacts, but causes false alarms from normally closed contacts. Spare alarm points with normally closed field contacts require shorting jumpers on the field contact terminal blocks or some other action to avoid the continuous display of alarms.

The field contact voltage is the voltage applied to the field contacts by the annunciator circuits. It is usually from 12 to 125 volts and can be either ac or dc. Annunciators with normally open field contacts often use from 48 to 125 volts for more reliable operation when electromechanical field contacts are contaminated. Lower voltages may be used with normally closed field contacts where contamination cannot prevent an alarm and also to be compatible with other low voltage instrument and control circuits. A single voltage is used when both field contact types are used with one annunciator.

The annunciator response time is the time period between the operation of the field contacts and initiation of the alarm state. Momentary field contact operations with a duration of less than the response time do not initiate alarms. Annunciator response times are in the order of 5 to 50 milliseconds, depending on the manufacturer. Electrical transients induced in the field contact wiring may cause false annunciator operation if the response time is not long enough. Because of the filtering provided by the response time, annunciators usually do not require shielded field contact wiring.

Longer response times or special time delay circuits can usually be provided when required to prevent false operation caused by extraneous circuit pulses or to avoid nuisance alarms caused by momentary operation of field contacts.

The steady state current that passes through field contacts from annunciators is usually in the order of 1 to 10 milliamperes, depending on the manufacturer. This current is necessary to minimize false operation caused by electrical transients and to provide enough arcing to assist in cleaning electromechanical field contacts. This current is usually sufficient for proper operation of solid state field contacts.

The maximum length of field contact wiring that can be used with annunciators depends on the conductor dc resistance or ac impedance, leakage resistance, the field contact voltage, and the annunciator input circuit design. Special design may be required when field contact wiring involves unusually small conductors or long lengths.

A.9.3 Shared alarm points

In many cases, annunciator alarm points are connected to only one field contact. Sometimes alarm points operate from two or more contacts that are wired in a series or parallel arrangement to develop the required alarm logic or to avoid nuisance alarms during certain operating or maintenance conditions. These series or parallel contact arrangements operate together as a single field contact in relation to the annunciator alarm point.

In order to conserve space on control panels, it may be desirable to use one annunciator visual display for more than one related monitored variable. This can be done by operating alarm points from two or more normally open field contacts in parallel or normally closed field contacts in series so any field contact operation causes an alarm. When this is done, that alarm point alarms when the first abnormal process condition occurs, and can return to normal only after all process conditions have returned to normal. That alarm point cannot alarm subsequent abnormal process conditions that occur while the first abnormal process condition still exists. This method is convenient and economical because it does not require special annunciator circuits, but it should be used only when knowledge of the occurrence of subsequent abnormal process conditions is not required.

The loss of information that occurs when two or more field contacts are connected in parallel or series does not occur if reflash circuits are added to the annunciator. Reflash circuits allow two or more abnormal process conditions to initiate or reinitiate the alarm state of one annunciator alarm point at any time. Reflash alarm points cannot return to normal until all related process conditions return to normal.

Two or more field contacts are wired independently to reflash circuits. The reflash circuit outputs are connected to sequence logic circuits. The annunciator sequence operates in the usual manner when the first abnormal process condition occurs. When subsequent abnormal process conditions occur while previous abnormal process conditions still exist, the reflash circuit causes the sequence to go to the alarm state again. The sequence cannot return to the normal state until all related process conditions return to normal. Reflash circuits allow annunciators to alarm the first and all subsequent abnormal process conditions, but the identity of the individual monitored variables must be determined from nearby instruments, field instruments, or observation of process conditions.

The number of individual reflash circuits on one reflash module is determined by the manufacturer. Reflash circuit outputs are interconnected to accommodate the required number of field contacts and then wired to alarm modules. Unused individual reflash circuits on some reflash modules may not be available for use with another group, depending on the module internal connections. In some cases, annunciator circuit design limits the number of reflash circuits that can be in any one reflash group.

Reflash modules are usually located together and not intermixed with alarm modules. This allows flexibility as the annunciator requirements develop and change.

A.9.4 Analog input alarm points

While annunciators usually operate from field contacts, they can operate from analog input signals also. Analog input points are for use with analog monitored variable signals. Additional logic circuits initiate alarms when the analog signals are above or below set points.

Analog input points can operate from a variety of dc currents and voltages. In some cases thermocouples, resistance temperature detectors, and ac currents and voltages can be used also. When required, terminal block points should be specified for grounding the shields of analog input point field wiring.

Solid state circuits compare the analog input signals against set points established on the printed circuit boards by adjustable potentiometer. Movable jumpers or switches can be set to determine whether alarms occur when the signals are above or below the set points. The analog signal dead band is usually adjustable.

Separate analog input modules have output contacts for connection to alarm modules. In some cases, the analog input circuits and sequence logic circuits are included in one module.

A.9.5 Auxiliary outputs

Annunciator auxiliary outputs are operated by single alarm points or groups of points for use with remote devices. Auxiliary outputs may be contact or voltage signals that are connected to remote alarm, recording, or control devices. Auxiliary output contacts may be electromechanical or solid state. These contacts are usually isolated electrically from the annunciator and powered from the remote device. Auxiliary output contacts are usually available that are normally open and closed to alarm or are normally closed and open to alarm.

The four common types of auxiliary output and the operation of a graphic display in parallel with annunciator visual displays are shown functionally in Figure A.4. The type selected for a particular application depends on the required operation. The operation of auxiliary outputs should be added to sequence diagrams and sequence tables or the operation should be defined by notes.

Field contact follower auxiliary outputs operate while individual field contacts indicate abnormal process conditions. The outputs usually do not operate during annunciator test. When field contact follower operation is required, it may be possible to avoid auxiliary outputs by operating annunciators in parallel with other devices using the same field contacts. The possibility and any technical problems should be discussed with the manufacturers of the annunciator and other device.

Lamp follower auxiliary outputs operate while individual visual display lamps indicate alarm, silenced, or acknowledged states. The outputs do not change when visual display lamps flash. The outputs usually operate during operational test, but not during lamp test.

Audible device follower auxiliary outputs operate while the common alarm audible devices operate. The outputs usually operate during operational test, but not during lamp test.

Reflash auxiliary outputs operate when any one of a group of alarm points indicates an abnormal process condition. The outputs usually return to normal briefly when each alarm point changes to an abnormal process condition the outputs return to normal when all alarm points in the group indicate normal process conditions. The outputs usually operate during annunciator test.

Consideration should be given to the operation of auxiliary outputs during annunciator test. In some cases operation of auxiliary outputs can test the remote devices also; however, in other cases operation during annunciator test would be undesirable or unacceptable.

When auxiliary outputs are connected to recording devices for analysis of sequence of events, the response time of the annunciator input and auxiliary output circuits should be considered. This delay may change the recorded sequence when compared to signals that do not pass through the annunciator.

Some installations use annunciator auxiliary outputs for control and protection interlocks and others use separate field contacts. The use of auxiliary outputs is often convenient, but separate field contacts may provide improved operating reliability and avoid unexpected control actions during annunciator maintenance.

Auxiliary outputs are often used to retransmit alarms from local annunciators to annunciators in central control rooms. Local annunciator auxiliary outputs can retransmit the operation of an entire local annunciator, groups of alarm points, or individual alarm points. Outputs from local annunciator power failure detectors are often transmitted also. When a group of local annunciator alarm points is retransmitted to one alarm point in the central control room, the central annunciator indicates that a local alarm has occurred but not which alarm. The following methods are commonly used to retransmit the operation of local annunciators.

Audible Device Follower Auxiliary Outputs	The central control room annunciator operates when local alarms occur and can return to normal after they are acknowledged at local annunciators. The central control room annunciator does not indicate when local alarms return to normal or that local alarms continue to exist. Operators acknowledging alarms at local annunciators are responsible for correcting all local alarm conditions. This method is convenient, economical, and can be added easily to existing local annunciators.
Reflash Auxiliary Outputs	The central control room annunciator operates when each local alarm occurs and can return to normal after all local alarms return to normal. The central control room annunciator does not indicate when individual local alarms return to normal. This method requires reflash auxiliary outputs in local annunciators and field wires to the control room annunciator from each local annunciator.
Field Contact or Lamp	Reflash alarm points in the central control room annunciator are Follower Auxiliary Outputs used to indicate when each local alarm occurs and when all local alarms return to normal. The central control room annunciator does not indicate when individual local alarms return to normal. This method requires field contact or lamp follower auxiliary outputs in local annunciators, reflash alarm points in the central room annunciator, and field wires to the control room annunciator for each local annunciator alarm point.

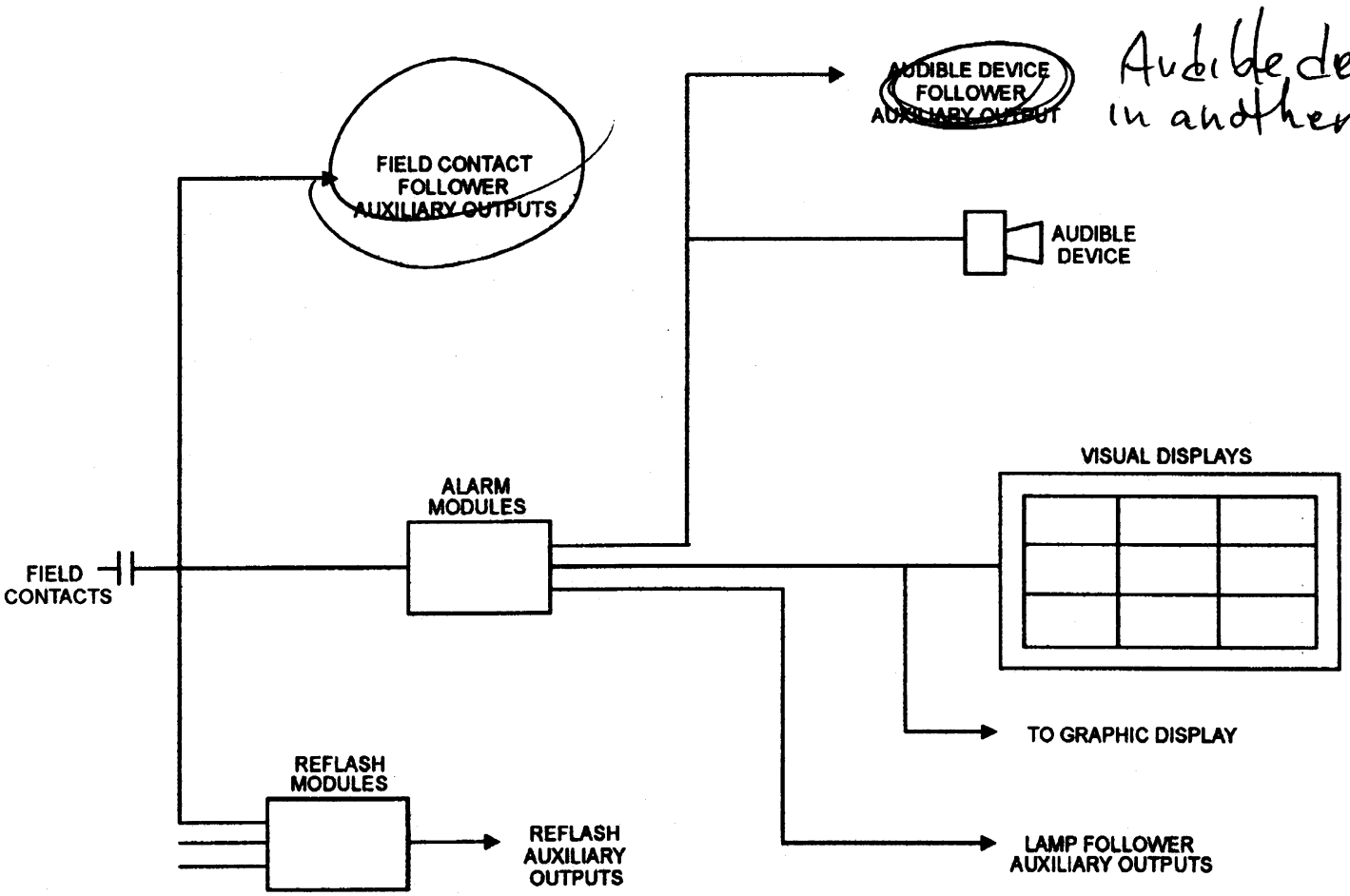


Figure A.4 — Auxiliary output functional diagram

A.10 Hazardous atmosphere location annunciators

A.10.1 General

Special precautions are required when electrical equipment and circuits are installed in locations where fires or explosion hazards exist or may exist. Hazardous atmosphere locations are classified by class, division, and group. Class I locations are those in which flammable gases or vapors are or may be present in quantities sufficient to produce ignitable or explosive mixtures. Class II locations are those that are hazardous because of the presence of combustible dust. Class III locations are those that are hazardous because of the presence of easily ignitable fibers. Class I, Division 1, includes locations in which the gas or vapor hazard exists continuously or intermittently. Class I, Division 2, includes locations in which hazardous materials are normally confined but can escape when failures or abnormal conditions occur. Specific hazardous atmospheres are identified by group letters.

Special circuit or enclosure design may be avoided in Class I, Division 2, locations when current interrupting contacts are hermetically sealed against the entrance of gases and vapors.

For detailed application and installation information, refer to (1) ISA Recommended Practice ISA-RP12.1, "Electrical Instruments in Hazardous Atmospheres," and (2) National Fire Protection Association Standard NFPA 70, "National Electrical Code," Articles 500-503.

Annunciators for use in hazardous atmosphere locations may require certification to meet the requirements of specific codes or agencies.

A.10.2 Intrinsically safe annunciator systems

Intrinsically safe annunciator systems are designed and installed so that field contacts and field contact wiring are incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of specific hazardous gas or vapor atmospheric mixtures in the most easily ignited concentrations. Field contacts and field contact wiring connected to intrinsically safe annunciators can be installed in many Class I, Division 1 and Division 2, hazardous locations without the use of explosion proof enclosures.

Intrinsically safe annunciator systems limit the release of energy from field contacts and field contact wiring under both normal and abnormal conditions by special power supply design, low field contact voltage, current limiting resistors, wiring barriers or separation from nonintrinsically safe circuits, and limited field contact wiring capacitance and inductance. Abnormal conditions include any two independent device or circuit failures in combination.

The annunciator cabinets, power supplies, pushbuttons, and audible devices of intrinsically safe annunciator systems are not intrinsically safe themselves. They must be installed in nonhazardous areas or must be designed for the specific hazardous atmosphere involved. Refer to A.10.3, Nonincendive Annunciators; A.10.4, Purged Cabinets; and A.10.5, Explosion Proof Cabinets.

In some applications, increased flexibility is obtained by the use of special relays and power supplies in the nonhazardous annunciator area to provide intrinsically safe barriers between the annunciator and intrinsically safe field contacts and field contact wiring. These barriers can be supplied with annunciators.

For detailed application and installation information, refer to (1) information from annunciator manufacturers, (2) ISA Recommended Practice ISA-RP12.6, "Installation of Intrinsically Safe Instrument Systems in Class I Hazardous Locations," and (3) National Fire Protection Association Standard NFPA 493, "Intrinsically Safe Apparatus in Class I, II, and III, Division 1, Hazardous Locations."

A.10.3 Nonincendive annunciators

Nonincendive annunciators are designed so that annunciator cabinets, power supplies, pushbuttons, and audible devices are incapable of releasing sufficient electrical or thermal energy under normal operating conditions to cause ignition of specific hazardous gas or vapor atmospheric mixtures in the most easily ignited concentrations. Nonincendive annunciators can be installed in many Class I, Division 2, hazardous locations without the use of explosion proof cabinets.

The design is not required to consider abnormal conditions such as device or circuit failure. The probability of simultaneous annunciator failure and abnormal conditions causing the escape of hazardous materials is considered negligible. No energy limit is placed on circuits or on contacts, switches, or plugs that are used only during maintenance.

Nonincendive annunciators make use of hermetically sealed contacts where current is interrupted under normal operating conditions. Annunciator cabinet covers that require the use of a tool for removal and approved warning nameplates remind the user to determine that the atmosphere is not hazardous before performing maintenance.

The annunciator field contacts and field contact wiring of nonincendive annunciators are not protected in any way by the nonincendive design. They must be designed and installed for the specific hazardous atmosphere involved. Refer to A.10.2, Intrinsically Safe Annunciator Systems.

For detailed application information, refer to (1) information from annunciator manufacturers, and (2) National Fire Protection Association Standard NFPA 70, "National Electrical Code," Article 501.

A.10.4 Purged cabinets

Annunciators with purged cabinets are designed so that a supply of clean air or inert gas around the electrical devices at sufficient flow reduces hazardous gas or vapors initially present to a safe level and maintains a safe level by positive pressure. Annunciators with purged cabinets can be installed in many Class 1, Division 1 and Division 2, hazardous locations without the use of explosion proof cabinets. Pushbuttons and audible devices that are not in the annunciator cabinet must be designed for the specific hazardous atmosphere involved.

Purging requirements are divided into three classifications. Type X purging reduces the classification of the area within cabinets from Division 1 to nonhazardous, Type Y from Division 1 to Division 2, and Type Z from Division 2 to nonhazardous. Depending on the classification, purged cabinets require special construction, low pressure alarms, nonincendive design, power interlocks, warning nameplates, and special operating procedures.

For detailed application and installation information, refer to (1) information from annunciator manufacturers, (2) ISA Standard ISA-SI2.4, "Instrument Purging for Reduction of Hazardous Area Classification," and (3) National Fire Protection Association Standard NFPA 496, "Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Locations."

A.10.5 Explosion proof cabinets

Annunciators with explosion proof cabinets are designed so that the cabinets are capable of withstanding explosions of a specified gas or vapor that may occur within them while preventing the ignition of specific hazardous gas or vapor atmospheric mixtures surrounding the cabinets. Annunciators with explosion proof cabinets can be installed in many hazardous locations. Pushbuttons and audible devices that are not in the annunciator cabinet must be designed for the specific hazardous atmosphere involved.

For NEMA enclosure requirements, refer to National Electrical Manufacturers Association Standard NEMA ICS 6, "Enclosures for Industrial Controls and Systems."

A.11 Cabinets

Annunciator cabinets and lamp cabinets are usually flush mounted on steel panels. The cabinet bezels and windows extend about 1 inch (25 mm) in front of the panels. Annunciator cabinets extend further behind the panels than lamp cabinets. Cabinets usually fit into rectangular cutouts in the panels and are held in place by clamps. Access for lamps and alarm modules is usually from the front. Access for wiring is usually from the rear. Openings for ventilation may be provided. Forced ventilation and high temperature alarm contacts are usually not required. Special surface mounted annunciator and lamp cabinets with access from the front are also available.

Logic circuits for use with remote logic annunciators usually can be supplied as open chassis assemblies, enclosed chassis assemblies, or 19 inch (475 mm) rack mount assemblies for mounting in logic cabinets by others. Logic circuits can also be provided in free-standing or surface mounted logic cabinets.

Annunciator cabinets are usually for general purpose indoor installation and are classified as NEMA 1. Special cabinets to meet NEMA 12 indoor driptight and dusttight requirements, and NEMA 4 indoor and outdoor watertight and dusttight requirements may also be available. For NEMA enclosure requirements, refer to National Electrical Manufacturers Association Standard NEMA ICS 6, "Enclosures for Industrial Controls and Systems." For annunciators located in hazardous atmospheres, see A.10, Hazardous Atmosphere Location Annunciators.

A.12 Power supply systems

A.12.1 Power sources

Annunciators are available for use on a wide range of power source voltages, on ac at 50 or 60 hertz, and on dc. The most common power source voltage is 120 volts, 60 hertz, but other ac voltages such as 24, 48 and 230 volts are used also. Annunciators can usually operate over a range of at least 90 to 110 percent of the rated ac voltage.

Many annunciators operate on dc power sources to allow continued operation from batteries in the event ac power is lost. Larger installations usually provide 125 volt dc power for this purpose. Other dc voltages such as 24, 48, and 250 volts are used also. Annunciators can usually operate at the high equalizing charge voltage applied to some batteries during periodic maintenance and the low voltage that may exist during emergency operation. This voltage range is usually from 105 to 140 volts for annunciators designed to operate on 125 volts dc.

Annunciator electrochemical relay logic circuits usually use the power source voltage directly for the logic relays, lamps, and field contacts. Solid state logic circuits usually require power supplies to develop the dc voltages used for logic circuits, lamps, and field contacts.

A.12.2 Power supplies

Annunciator power supplies convert ac or dc power source voltages to one or more dc voltages for use with solid state logic circuits, lamps, and field contacts. Power supplies are usually supplied with annunciators to ensure coordination with the annunciator circuits.

When dc power sources are used, special power supplies may be provided to convert dc power source voltages directly to the required dc annunciator circuit voltages, or separate inverters may be used to invert the dc to ac for connection to conventional ac to dc power supplies.

Power supplies provide electrical isolation between power sources and annunciator circuits. This isolation allows annunciator circuits to operate ungrounded. When accidental circuit grounds

occur on ungrounded annunciator circuits, ground detectors operate annunciator alarms and the grounds can be located and removed without affecting the annunciator operation or the power source.

Inverters and power supplies used with annunciators should be provided with overload protection and should not require manual actions when voltage is applied or after brief overloads occur.

A.12.3 Backup power

Annunciators are no more reliable than the power on which they operate. The power sources, power supplies, and power distribution systems for annunciators should provide the reliability required by the annunciation function.

A single power supply may provide power for only a few alarm points or for an entire annunciator. An annunciator power source may come from a 120 volt ac lighting panel or from a large battery and charger system. The failure of a single power supply or power source can disable an entire annunciator, or backup power supplies and power sources can be used so that any single failure affects no more than one alarm point. Power supply system designs should suit the power sources available and provide the required annunciator reliability.

While an annunciator powered from a dc power source provides reliable operation, a single failure in the dc distribution panel or annunciator feeder can leave the annunciator without power. In addition, dc power source buses are often ungrounded. When a ground occurs, the load circuits are switched off and on again in turn until the grounded circuit is located. When the annunciator feeder is switched off and on again, the alarm points usually assume a random sequence state and auxiliary outputs may operate incorrectly. It is then necessary for the annunciator pushbuttons to be operated before the correct alarms are displayed again.

When two independent power sources are used to power an important annunciator, the reliability becomes very high. Backup power supplies can also be used so that failure of a single power supply does not affect annunciator operation. When backup power sources or power supplies are used, power failure detectors should be provided to alarm the failure of each power source and power supply.

A.12.4 Power failure detectors

Power failure detectors provide outputs to alarm the loss of voltage on annunciator logic circuit, lamp, and field contact power buses. Power failure detectors cannot alarm on the failed annunciator, so another alarm device must be used.

Local annunciator power failure can be alarmed on central control room annunciators. Separate CRT visual display or recording annunciators can be used to alarm control room annunciator failure. In some cases, separate annunciator audible and visual devices powered by an independent power source are provided to alarm annunciator power failure. In these cases the independent power source must, in turn, be monitored by the annunciator.

A.12.5 Ground detectors

Annunciator buses are often ungrounded so that accidental circuit grounds can be detected and ground alarms initiated without affecting the operation of annunciators. Grounds on the field contact wiring are the most common since this wiring is often run in areas that have an adverse environment.

Ground detectors are usually connected to alarm the presence of a ground on either conductor of an ungrounded system. The ground should be located and removed before a second ground occurs, since two or more simultaneous grounds can affect annunciator operation.

Grounds are usually located by disconnecting individual circuits in turn until the ground detector indicates that no ground exists. The ground is on the disconnected circuit.

Annunciator circuits are usually disconnected to check for grounds by briefly disconnecting field contact wires or by briefly removing individual alarm modules. Large annunciators often include power supply system disconnect switches to subdivide the system for more convenient ground isolation and maintenance. Some remote logic annunciators include field contact wiring terminal blocks that include switches or other devices to allow ground isolation without affecting the field wiring terminations.

The location of grounds is made easier if an indication of grounds is within sight of the disconnecting devices. Lights operating from ground detectors can be located in alarm module and terminal block areas for this purpose.

A.13 Factory tests

A.13.1 General

Annunciator factory tests can include prototype, component, module, and final assembly tests. The routine tests performed by the manufacturer are often the only tests performed. In some cases, users specify specific tests to confirm that annunciators will operate as required in special applications.

Annunciators are usually tested using test procedures that apply to industrial electrical and electronic instrumentation and control equipment.

A.13.2 Dielectric strength

Dielectric strength tests, sometimes referred to as high potential or high pot tests, are usually performed on annunciator final assemblies to confirm that insulation and clearances are adequate between circuits and cabinets and also between separate circuits. To avoid damage, solid state circuit modules are usually removed, grounded, or shorted during these tests.

Test voltages range from 1000 to 1500 volts ac and are usually applied for one minute. Dielectric strength standards are included in (1) National Electrical Manufacturers Association Standard NEMA ICS 1, Part ICS 1-109, "Industrial Controls and Systems, Tests and Test Procedures," (2) American National Standards Institute Standard ANSI C39.5, "American National Standard Safety Requirements for Electrical and Electronic Measuring and Controlling Instrumentation," and (3) Underwriters Laboratories Standard UL 508, "Industrial Control Equipment."

A.13.3 Functional

Functional tests are usually performed on annunciator modules and final assemblies to confirm that the operation is as specified. Tests on final assemblies are sometimes referred to as simulation tests.

Functional tests usually include operation in all of the normal operating modes and also in abnormal modes such as high and low power source voltage, grounds, short circuits, and unusual service conditions. Cabinet internal temperatures are often measured to confirm ventilation designs.

Annunciator modules are often subjected to a burn-in period. This reveals modules with weak components that would fail early in the annunciator life. The burn-in period varies widely, depending on the manufacturer or the specification requirements.

Logic circuit test assemblies can usually be provided to facilitate testing individual modules in the field.

A.13.4 Surge withstand capability

Annunciator solid state logic circuits operate at low power levels. Annunciator circuits are designed to suppress electrical surges and transients that may be induced in field wiring. Tests are usually performed on prototype modules to confirm that expected surges and transients do not cause false operation or damage.

A specific surge withstand capability test is included in Institute of Electrical and Electronics Engineers Standard IEEE 472, "IEEE Guide for Surge Withstand Capability (SWC) Tests."

A.13.5 Radio frequency interference

There is some possibility that false operation of annunciator solid state logic circuits can be caused by operation of nearby portable radio transmitters, especially when cabinet doors are open.

A radio frequency interference test method and a classification of signal field strengths and frequency bands are included in Scientific Apparatus Makers Association Standard SAMA PMC 33.1, "Electromagnetic Susceptibility of Process Control Instrumentation."

A.13.6 Seismic

In some applications, annunciators may be required to operate during and after specified earthquakes, or annunciator cabinets may be required only to remain intact externally so as not to endanger nearby personnel or equipment. When required, seismic tests are usually performed on prototype assemblies.

Seismic test procedures are included in Institute of Electrical and Electronics Engineers Standard IEEE 344, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

A.13.7 Class 1E equipment for nuclear generating stations

Annunciators that perform Class 1E safety-related functions in nuclear power generating stations must be qualified to confirm the adequacy of the equipment design under all expected normal and abnormal operation conditions.

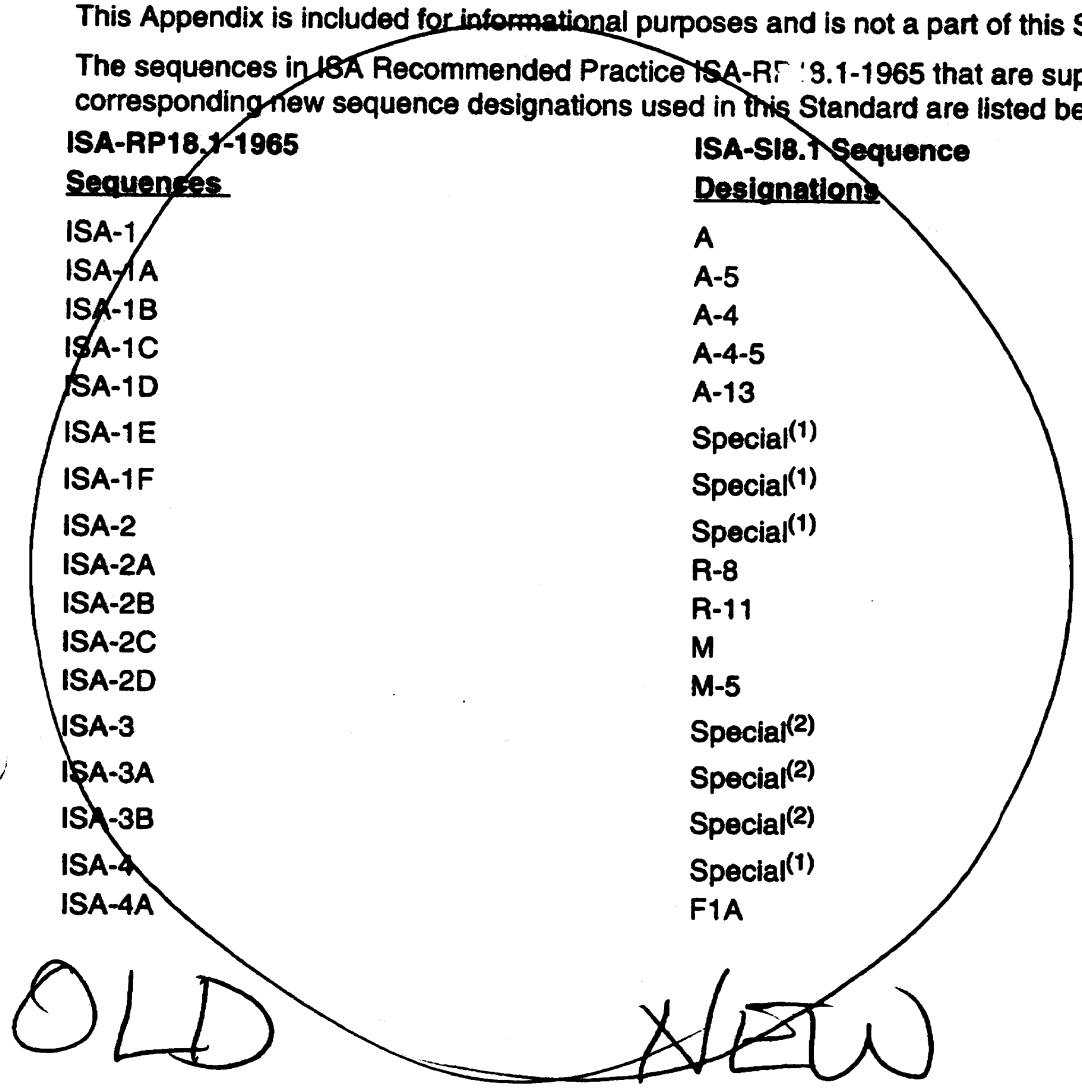
Qualification procedures making use of type testing, operating experience, and analysis are included in Institute of Electrical and Electronics Engineers Standard IEEE 323, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations."

Appendix B — Sequence designation conversion

This Appendix is included for informational purposes and is not a part of this Standard.

The sequences in ISA Recommended Practice ISA-RP18.1-1965 that are superseded and the corresponding new sequence designations used in this Standard are listed below.

ISA-RP18.1-1965 Sequences	ISA-S18.1 Sequence Designations
ISA-1	A
ISA-1A	A-5
ISA-1B	A-4
ISA-1C	A-4-5
ISA-1D	A-13
ISA-1E	Special(1)
ISA-1F	Special(1)
ISA-2	Special(1)
ISA-2A	R-8
ISA-2B	R-11
ISA-2C	M
ISA-2D	M-5
ISA-3	Special(2)
ISA-3A	Special(2)
ISA-3B	Special(2)
ISA-4	Special(1)
ISA-4A	F1A



(1) Requires two visual display indication devices.

(2) Requires three visual display indication devices.

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HARDWOOD BLEACH PLANT | DESC | UNIT HB ALARM SUMMARY > | AREA:000/007/205 PAGE: 1
FREEZE DISPLAY | SORT: CHRON | ON DISP: ■▲▼ | AUDIBLE: ■▲▼ | UNIT:000/003/040 OF: 3

07:33:52	▼ 50LT0314	PVHI	80.0	HW OFF-GRADE HD CHEST LV	HB		81.2
12:25:02	▼ 47AT0807	PVLO	2.0	STOCK TO D TOWER PH	HB		0.4
20:42:43	▼ 47M389	UNCEVT		EOP TOWER CIRCULATOR #1	HB	STOP	
20:42:42	▼ 47PH1118	OFFNORM		EOP TWR AGIT 1 S.W. PRES	HB	PRESS_HI	
20:41:06	▼ 47M389	CMDDIS		EOP TOWER CIRCULATOR #1	HB	STOP	
11:01:52	▼ 47LC0411	PVLO	50.0	BLEACH NO.2 HOT WTR TANK	HB		85.3
07:37:55	▲ 47AT1015F	PVHI	0.30	CLO2 SEN GRN FLR SL TUBE	HB		-0.01
06:32:45	▲ 47AT1015A	BADPV		CL2 SEN 3RD FL 1ST STAGE	HB		-0.00
23:28:40	▼ 47SL372	OFFNORM		D/C CLO2 MIXER SHAFT SPD	HB	SPEED_LO	
23:16:36	▼ 47M371	CMDDIS		SCREENED STK TO HW BLCH	HB	STOP	
22:37:17	▼ 47IT0307	PVHI	154.8	D/C HI SHEAR CLO2 MIXER	HB		89.6
20:56:49	▼ 47FC0804	BADPV		CLO2 FLOW TO D MIXER	HB		78.0
20:53:52	▲ 47AT1015C	PVHI	1.00	CL2 SEN GRN FLR HI S MIX	HB		-0.02
19:12:18	▼ 47LC0503	BADPV		D/C WASHER VAT LEVEL	HB		82.3
19:04:07	▼ 47IT0708	PVHI	129.6	EOP STEAM MIXER CURRENT	HB		77.3

Already Returned to Normal

CO SB HB H1 H2

13 Aug 99 14:55:34 1

PULP MILL UWS | DESC | ENGINEERALARM SUMMARY > | *LIST OVRFLW* | PAGE: 1

FREEZE DISPLAY | SORT: CHRON | ON DISP: ■▲▼ | AUDIBLE: ■▲▼ | OF: 5

14:55:13 ▼	43IT0904	PVHI	17.0	TOP SEPARATOR DRIVE - C	K1	15.3
14:51:14 ▼	47FT1201	BADPV		HW BLEACH 160# STEAM FLW	HB	739
14:25:21 ▼	47IT0814	PVHI	50.0	D TWR AGITATOR #3 CURR	HB	44.2
14:15:31 ▼	47IT0812	PVHI	50.0	D TWR AGITATOR #1 CURR	HB	45.0
13:20:24 ▼	43LI0400	PVLO	10.0	DIGESTER CHIP LEVEL	K2	6.6
12:57:48 ▼	47TT2174	BADPV		2ND CLO2 TOWER UPPER TMP	SB	--------
12:48:44 ▼	43FC0420	BADPV		LOWER COOKING CIRC FLOW	K2	634
12:45:26 ▼	47TT2174	PVHI	200.0	2ND CLO2 TOWER UPPER TMP	SB	--------
12:21:44 ▼	48LC102	PVHH	80.0	SALTCAKE DISOLVE TNK LVL	CD	81.4
11:59:38 ▼	33HH0715	OFFNORM		AIR DRYER HUMIDITY ALARM	CD	HI_HUMID
11:56:11 ▼	48PC090	PVLO	10.0	FILTER FEED PRESSURE	CD	28.1
11:53:35 ▼	48PT092	BADPV		FILTER VACUUM PRESSURE	CD	136.9
11:42:47 ▼	48PT092	PVLL	25.0	FILTER VACUUM PRESSURE	CD	136.9
11:42:44 ▼	48PT092	PVLO	30.0	FILTER VACUUM PRESSURE	CD	136.9
11:42:25 ▼	48M319	UNCEVT		FILTER FEED PUMP	CD	STOP
11:41:54 ▼	48PC090	BADPV		FILTER FEED PRESSURE	CD	28.1

CD SB HB K1 K2

QUESTION	DESCRIPTION	AREA
P26-29	**Alarms**	**H**

Questions P26-29 concern the application of a hydrogen sulfide (H_2S) analyzer that a plant is installing for a personnel protection.

The maximum permissible level of H_2S for an 8-hour (weighted average) exposure is 20 ppm (parts per million). A dose of 150 ppm or more for a short time can cause permanent injury or possibly death. The human nose can detect 1 ppm levels but is desensitized quickly with continuing exposure.

P26. Assuming no mechanical problems or other limitations at the site, where should a field sensor be placed to provide the earliest possible warning of an excessive concentration of H_2S?

Is the gas lighter than air or heavier than air?

(A) 1 foot above ground

(B) 3 feet above ground

(C) Eye level

(D) 15 feet above ground

P27. The range of the H_2S analyzer is 0-20 ppm. The most appropriate setting for the alarm point (in ppm) would be:

(A) 0 - 4.9

(B) 5.0 - 9.9

(C) 10.0 - 14.9

(D) 15.0 or higher

Set low as possible with no nuisance alarms

QUESTION	DESCRIPTION	AREA
P28-29	**Alarms**	**H**

Questions P28-29 both concern the location of audible and/or visual alarms of excessive H_2S concentrations. Please consider them together. Cost is not to be treated as a factor in your answers.

P28. The most important location for audible and/or visual alarms is:

(A) At the field sensor (analyzer inlet) location

(B) At the process operator's console

(C) In the process engineer's office

(D) In the safety department office

operator safety is paramount

P29. The second-most important location for audible and/or visual alarm is:

(A) At the field sensor (analyzer inlet) location

(B) At the process operator's console

(C) In the process engineer's office

(D) In the safety department office

Questions 3 - 4 both concern the location of audible and/or visual alarms of excessive H_2S concentrations. Please consider them together. Cost is not to be treated as a factor in your answers.

3. The most important location for audible and/or visual alarms is:

(A) At the field sensor (analyzer inlet) location
(B) At the process operator's console
(C) In the process engineer's office
(D) In the safety department office
(E) In the plant manager's office

4. The second-most important location for audible and/or visual alarms is:

(A) At the field sensor (analyzer inlet) location
(B) At the process operator's console
(C) In the process engineer's office
(D) In the safety department office
(E) In the plant manager's office

Questions 5 - 10 are concerned with other safety aspects of control systems.

5. In a typical annunciator or equivalent process computer system, a light and a horn are used to notify the operator of off-normal conditions (e.g., a process variable exceeding a high safety limit). When an off-normal condition occurs, the light starts flashing and the horn is turned on.

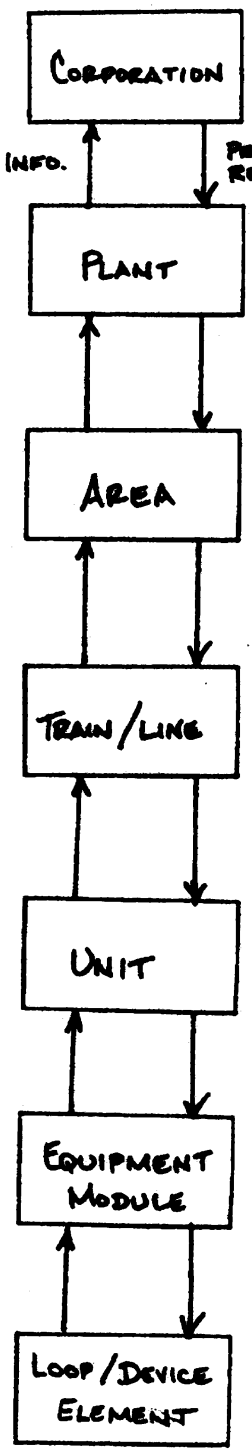
When the operator indicates his recognition of the alarm condition by pushing an "ACKNOWLEDGE" button, the following actions should occur:

(A) The horn continues to sound and the light continues to flash.
(B) The horn continues to sound and the light goes from flashing to steady.
(C) The horn stops and the light continues to flash.
(D) The horn stops and the light goes from flashing to steady.
(E) The horn stops and the light goes off.

Draft Stage

IV. A. ISA dSP88.01 BATCH CONTROL SYSTEMS STANDARD

1.



CORPORATE MANAGEMENT INFORMATION SYSTEMS
BILLING, ACCOUNTING, ORDER HANDLING

PLANT MANAGEMENT
PRODUCTION SCHEDULING, INVENTORY CONTROL
COST ACCOUNTING
TIMEBASE TRANSACTION B

PLANNING AND MANAGEMENT OF MULTIPLE LINES
BATCH SCHEDULING, PRODUCTION REPORTING, DATA STORAGE
RECIPE HANDLING *REAL-TIME RESPONSE REQUIRED FROM THIS LEVEL DOWN.

PROCESS SUPERVISORY CONTROL
COORDINATION OF MULTIPRODUCT SERIES/PARALLEL PROCESSES
WORKING BATCH RECIPES

ELEMENTS, LOOPS, DEVICES AND EQUIPMENT MODULES ARE COMBINED AND COORDINATED AT THIS LEVEL.

COMBINES LOOPS/DEVICES/EQUIPMENT

REAL-TIME PROCESS CONTROL ELEMENTS
DISCRETE AND REGULATORY

PROCESS INDUSTRIES REFERENCE MODEL

IV. 2. RECIPE MODEL

The term recipe is used in virtually every batch production facility. The recipe is the complete set of data and procedure that define the control requirements of a particular product. Specifically, it is the combination of procedure, formula, header, and equipment requirements (see Figure 2).

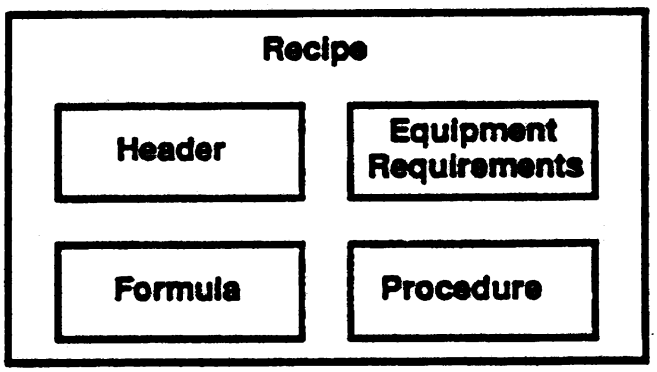


Figure 2. Recipe Model

Procedures define and order the actions to be performed and the associated control requirements necessary for making a general class of products in the batch process.

Formulas are sets of parameters that distinguish the products defined by procedures. Formulas may include types and quantities of ingredients, along with information such as the duration and the magnitude of process variables. They may affect procedures. The recipe concept simplifies generating different products or grades using an established procedure.

Headers provide information about the purpose, source, and version of the recipes, such as recipe and product identification, originator, issue date, etc. *Equipment requirements* specify the type and size of equipment needed, materials of construction, etc.

In some plants, a recipe may have a further level of generality to accommodate processing in any of several batch units. The specifications that particularize the recipe for the assigned batch unit are the unit descriptors. Examples might be Reactor T-101, Filter F-305, etc.

DRAFT

IV. 3. RECIPE TYPES

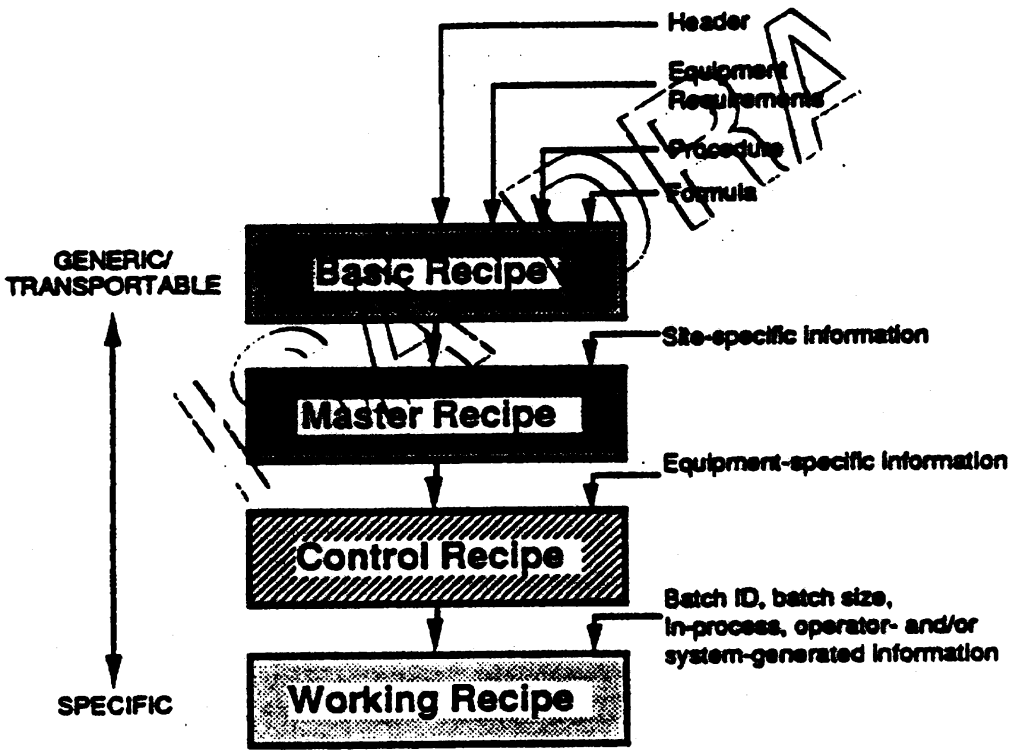


Figure 3. Recipe Types

HONEYWELL TDC-3000

EQUIPMENT LIST : GENERIC CONTROL LANGUAGE (CL)
GENERIC GRAPHIC
ASSIGNMENT LIST

GENERIC - "MASTER RECIPE"
CONTROL - ATTACHED EQUIPMENT ASSIGNMENTS

IV. 4. UNIT MODEL

PERMANENT OR TEMPORARY OBJECT ASSIGNMENTS

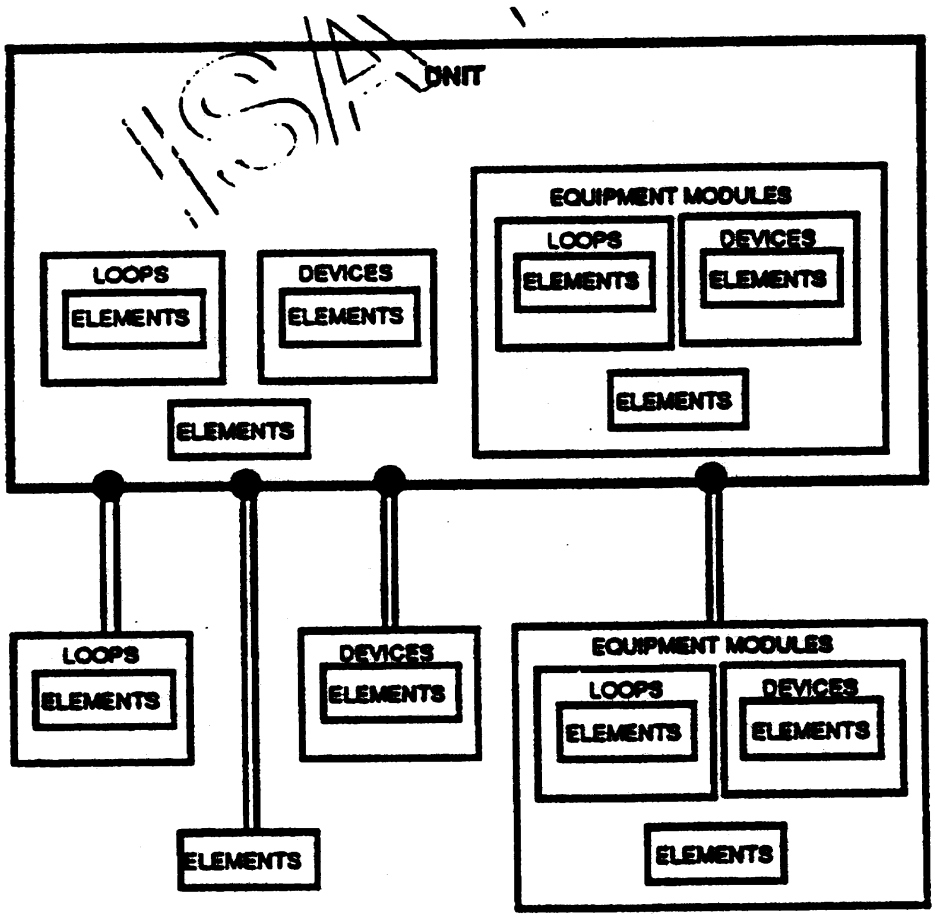


Figure 6. Unit Model

IV. 5. CONTROL ACTIVITY MODEL

EDITOR'S NOTE #11

Figure D14 below is the Detailed Control Activity Model referred to in Section 10, Batch Process Control.

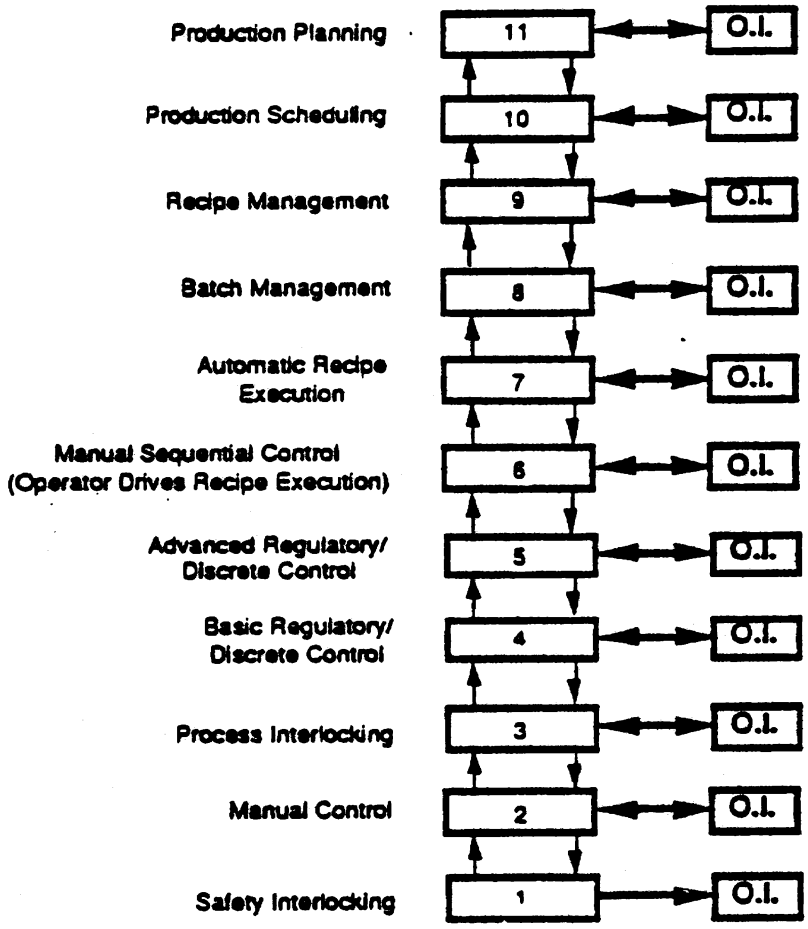


Figure D14. Detailed Control Activity Model

IV. 6. ABNORMAL EVENT HANDLING

A means of handling abnormal events during the execution of a batch must be provided. That is, some alternative phase logic, parallel phase logic, or other phase logic that takes over from the main phase logic.

A means is required to cancel the batch and set equipment to a safe status or to continue or restart the batch at any of the following places:

1. From the control step in the phase where it left off,
2. From the start of the current phase,
3. From the start of any other phase,
4. From any control step within any phase.

Phase Time-outs and/or phase entry condition time-outs are other abnormal conditions that must be addressed by exception handling. Phase time-outs are time limitations given to execution of a phase before it is automatically aborted. Phase entry time-outs are time limits on conditions that must be met before a phase is allowed to start.

ISA DRAFT

Phase Mode/States and Transitions:

There remains a need to define the mode/states of operation within Unit Management. As an input to the working group, I submit the following three operation or phase mode/states plus 5 transition states:

Mode/States	Transitions
Idle (Ready to Run)	Start
Running	Hold
Held	Restart
	Aborted
	Kill

NAMUR has a fourth state called "Frozen" and two additional transitions of "Freeze" and "Thaw" which are attached to the "Held" state, but I don't know what "Frozen" means.

In addition, user operation conditions can be defined. These are the modes of a running batch.

1. Automatic (Continuous execution of the operation phase logic and phases.)
2. Semi-Automatic (Manual intervention required to go from one phase to another.)
3. Manual (Each step requires an operator intervention)

The sequencing nature of batch process operations results in many potential equipment operational states. These operational states must be identified and functionally defined, e.g., so that the system can handle abnormal conditions during the production of a batch of product. The following operational states are typical of many batch processes (Refs. 3 and 4):

1. Start-up – A batch is ready to start. Any necessary auxiliary equipment is brought to operational condition.

2. Normal (run) – The process is operating according to the prescribed procedure.

3. Hold – This is a partial shutdown because of one or more abnormal conditions. Operating conditions are maintained at a safe level.

4. Normal shutdown – This is a planned shutdown, e.g., at the end of a batch or the end of a campaign. All equipment is emptied out to save as much of the raw materials and product as possible and to minimize safety problems while the equipment is idle.

5. Emergency shutdown – This is an unplanned shutdown that occurs because of a hazardous condition in the process. All equipment is stopped immediately. Usually, no effort is made to empty out the contents unless required for safety considerations.

6. Restart – This is exception logic that enables a safe transfer from a hold condition back to the normal state (i.e., the state the process was in prior to going to the hold state).

7. Maintenance (idle) -- The equipment has been emptied and cleaned, if necessary, and is ready for the next normal processing.

An additional operational state that might be defined is Service, which is the execution of non-batch related service logic. e.g. CLEAN-IN-PLACE SEQ.

DRAFT

IV. B. PLC BATCH – DRUM TIMER (SEQUENCER)

Sequencers. The sequencer block is a powerful instruction that is used to simulate a drum timer. A sequencer is analogous to a music box mechanism in which each peg produces a tone as the cylinder rotates and strikes the resonators. In a sequencer, each peg (bit) can be interpreted as a logic 1, and no-peg as a logic 0. Sequencers are generally specified, using a table which is similar to the music box cylinder spread-out. Depending on the controller, the number of bits can vary

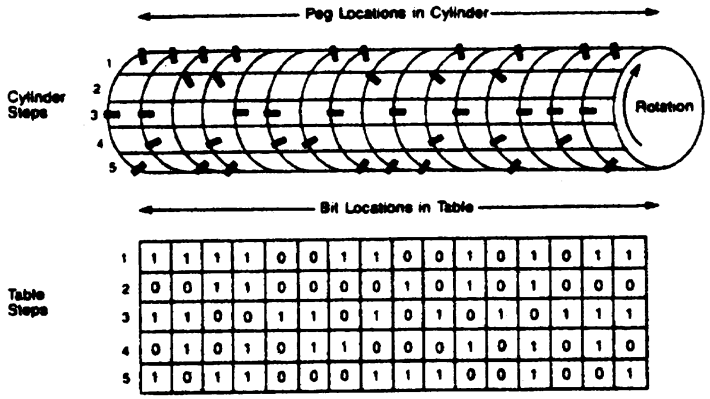


Figure 7-34. Music box cylinder and sequencer data table comparison.

from 8 to 64 or more. Figure 7-34 illustrates a cylinder and sequencer table comparison.

The width of the table may vary, as does the size of the music cylinder. Each of the steps in the sequencer can be an output (through I/O registers) representing each of the pegs. Figure 7-35 shows a typical functional sequencer block.

The block is initiated by the OFF-to-ON transition of the control input, and the contents of the sequencer table will be output in a sequential manner. Each step being output is pointed to by the contents of the pointer register. Every time the control input is energized, the pointer register is automatically incremented and points to the next table location. The reset pointer input is provided in case the pointer register needs to be reset to zero (point to step 1). The sequence length and width specify respectively how many steps and bits are used in the table. The output of the block is energized whenever the sequencer instruction is enabled.

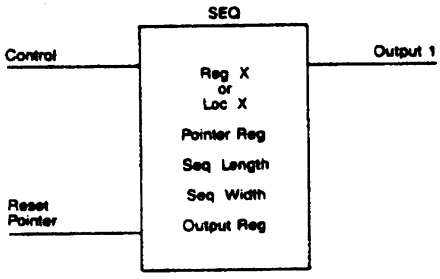


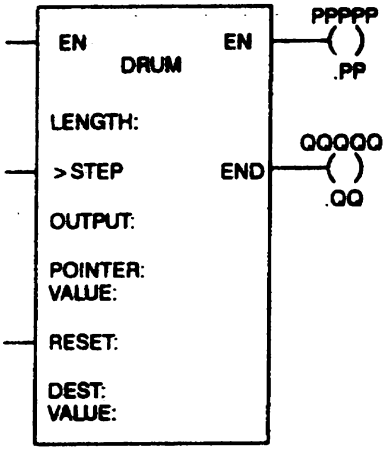
Figure 7-35.

Instruction: DRUM SEQUENCER

Mnemonic: DRUM

Purpose: This instruction is used to simulate an electromechanical drum sequencer.

Processor: AutoMate 15E, 20, 20E, 30, 30E, 40X, 40, 40E



Parameters:

PPPPP.PP is the coil address of the DRUM instruction. PPPPP.PP can be any valid coil address.

LENGTH is the number of registers to be used in the drum sequence. This number can range from 1 to 256.

STEP is an input signal that causes the software drum to increment to the next register in the sequence.

QQQQQ.QQ is the END coil of the instruction. You must program QQQQQ.QQ. It can be any valid coil address.

OUTPUT is the first register where data for the drum is to be stored. You can designate any register as the OUTPUT.

POINTER is the register used to track which output register is currently controlling the output of the instruction. You can designate any register as the POINTER.

RESET is an input signal that, when energized, causes the POINTER to return to the first output register of the sequence.

OPERATING SEQUENCE FOR HYDRAPULPER SYSTEM

Stage 1 - Loading

Step 1.1: Operator load broken bales onto slat conveyor until 9,000 lbs. (± 100 lbs.) have been loaded. (A jog switch will be used to move the load up so that more scrap can be added).

Stage 2 - Pulping

Step 2.1: Start pulping sequence.
Step 2.2: Operator initiates sequence start.
Step 2.3: P.C. calculates water amount required for pulping and additional water needed for later dump cycle. (A ratio of .680 gal./lb. for 15% consistency is used to calculate required pulping water).
Step 2.4: P.C. begins adding requried pulping water to pulper.
Step 2.5: After 500 gallons of water have been added, begin dumping caustic from head tank and start dispersant pump and add programmed amount of dispersant. (When caustic is dumped, tank must immediately begin refilling).
Step 2.6: Complete addition of white water then start pulper and loaded conveyor.
Step 2.7: Start pulper temperature loop and raise temperature to 160°F.
Step 2.8: Pulp until batch is visually ready to dump (approx. 20 min.) (While batch is pulping, operator should be reloading conveyor.
Step 2.9: Stop temp. loop (Sparger).

Stage 3 - Dumping

Step 3.1: Operator initiate pump sequence.
Step 3.2: Start hydrapurge unit.
Step 3.3: Start white water pump.
Step 3.4: Start stock transfer pump.
Step 3.5: Open stock transfer valve.
Step 3.6: Open pulper discharge valve.
Step 3.7: Open white water fill valve and consistency control valve, both to 100%, begin totalizer white water added.
Step 3.8: After 5 seconds, set consistency valve output to 70%, and fill valve output to 30% and make bumpless transfer to automatic consistency control. Control will be configured so that fill valve throttles to maintain trim valve at 70% output, ± 10%.
Step 3.9: Operator stops pump out or P.C. stops pump out when white water used is equal to or greater than 105% of total requried for 4% consistency.
3.9.1: Stop pulper.
3.9.2: Stop white water pump and close valves.
3.9.3: Close pulper discharge valve.
3.9.4: Close stock transfer valve.
3.9.5: Stop stock transfer pump.
3.9.6: Stop hydrapurge unit.

Step 3.10: Operator signals batch complete or restarts dump out.
Step 3.11: (If required) Restart dump out.
- 3.11.1: Start hydrapurge unit
- 3.11.2: Start stock transfer pump.
- 3.11.3: Open stock transfer valve.
- 3.11.4: Open pulper discharge valve.
- 3.11.5: Start white water pump and set valves to last position on consistency control.
- 3.11.6: Start pulper.

Step 3.12: Operator initiates dumpout Stop
- 3.12.1: Go to 3.9.1

JOB NO. _____ DATE 12/12/89

GULF STATES PAPER CORPORATION
Demopolis Engineering Department

HYDRAPULPER AUTOMATIC SEQUENCE (DRUM CONTROLLE

DRUM REGISTERS
OUTPUT REGISTER: 10000
POINTER (STEP # STORED HERE): 2000
FIRST REGISTER OF DRUM SEQUENCER (STEP Ø): 2001

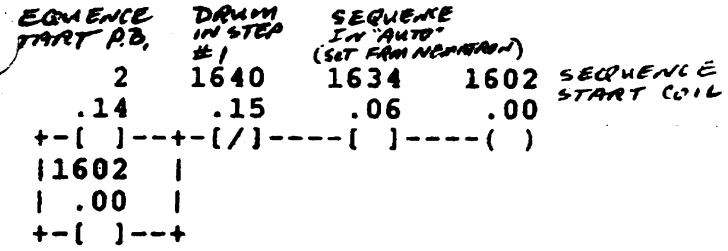
B:T ASSIGNMENT FOR REGISTER 10000 #

STEP	DRUM REG	17 SPARE	16 PULPER DRAIN VALVE STOCK XFER	15 CONSISTENCY VALVE DISCHARGE	14 PRIMARY DILUTION VALVE CONSIST. TANK	13 FILL VALVE	12 SPARE	11 SPARE	10 PRIMARY DILUTION VALVE INTAKE	07 DILUTION PUMP	06 SPARE	05 STOCK XFER PUMP	04 PULPER DRAIN VALVE	03 PRIMARY DILUTION VALVE	02 SECONDARY DILUTION VALVE	01 SECONDARY DILUTION VALVE	00 (SPARE)
Ø	2001	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1
1	2002	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
2	2003	0	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0
3	2004	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0
4	2005	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0
5	2006	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0
6	2007	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7	2010	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1
8	2011	0	1	1	0	0	0	0	0	1	0	1	1	1	1	0	0
9	2012	0	1	1	0	0	0	0	1	1	0	1	1	1	0	0	0
10	2013	0	1	1	0	0	0	0	1	1	0	1	1	0	0	0	0
11	2014	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
12	2015	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0
13	2016	0	1	1	0	0	0	0	1	1	0	1	1	0	1	0	0

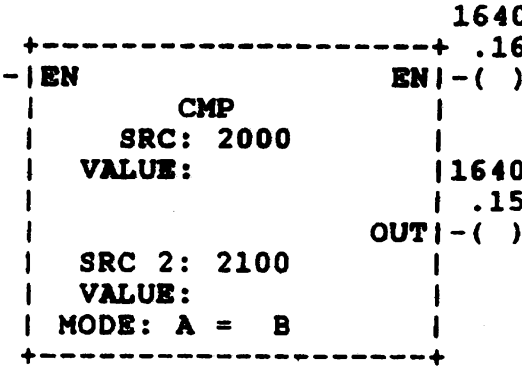
NOTE: BITS LOCATED IN CONSISTENCY VALVE AND PRIMARY DILUTION VALVE COLUMNS ARE FOR OPENING OR CLOSING THESE VALVES, DEPENDING ON STEP #.

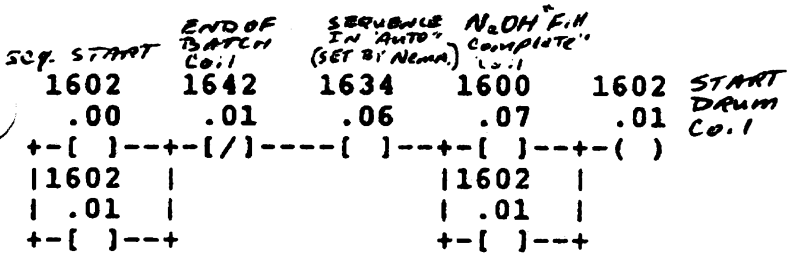
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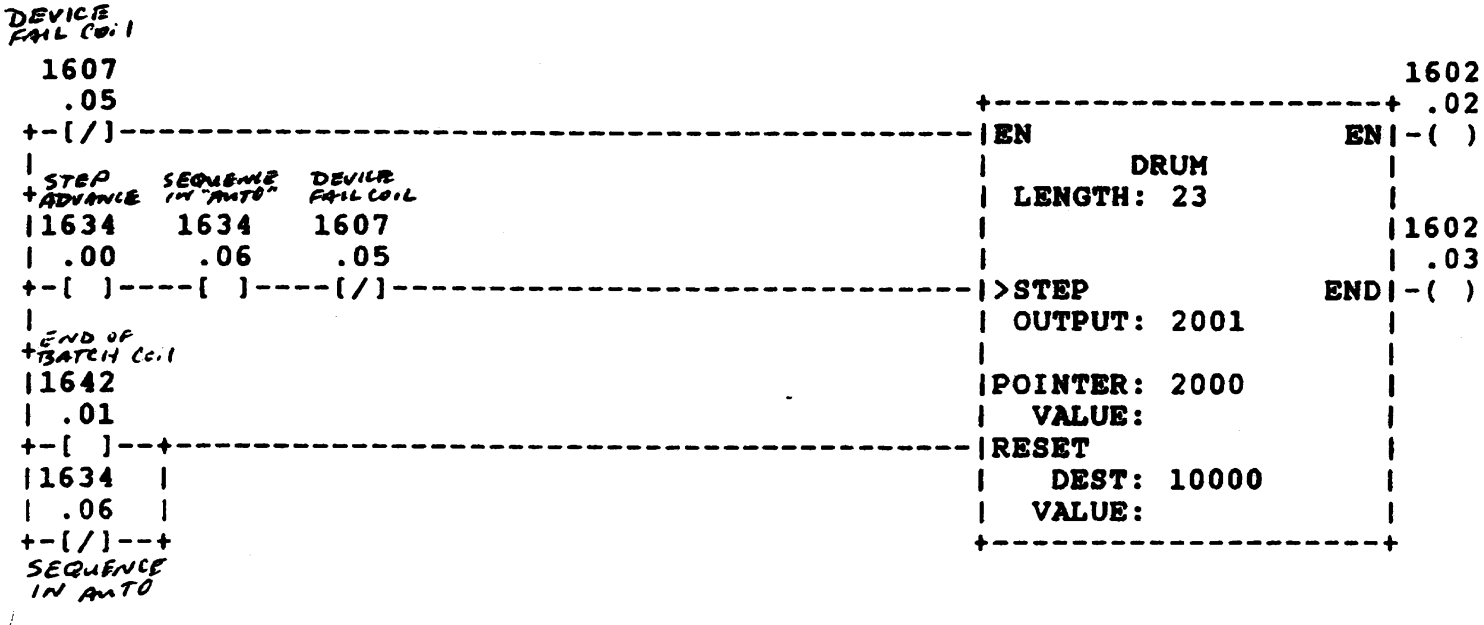
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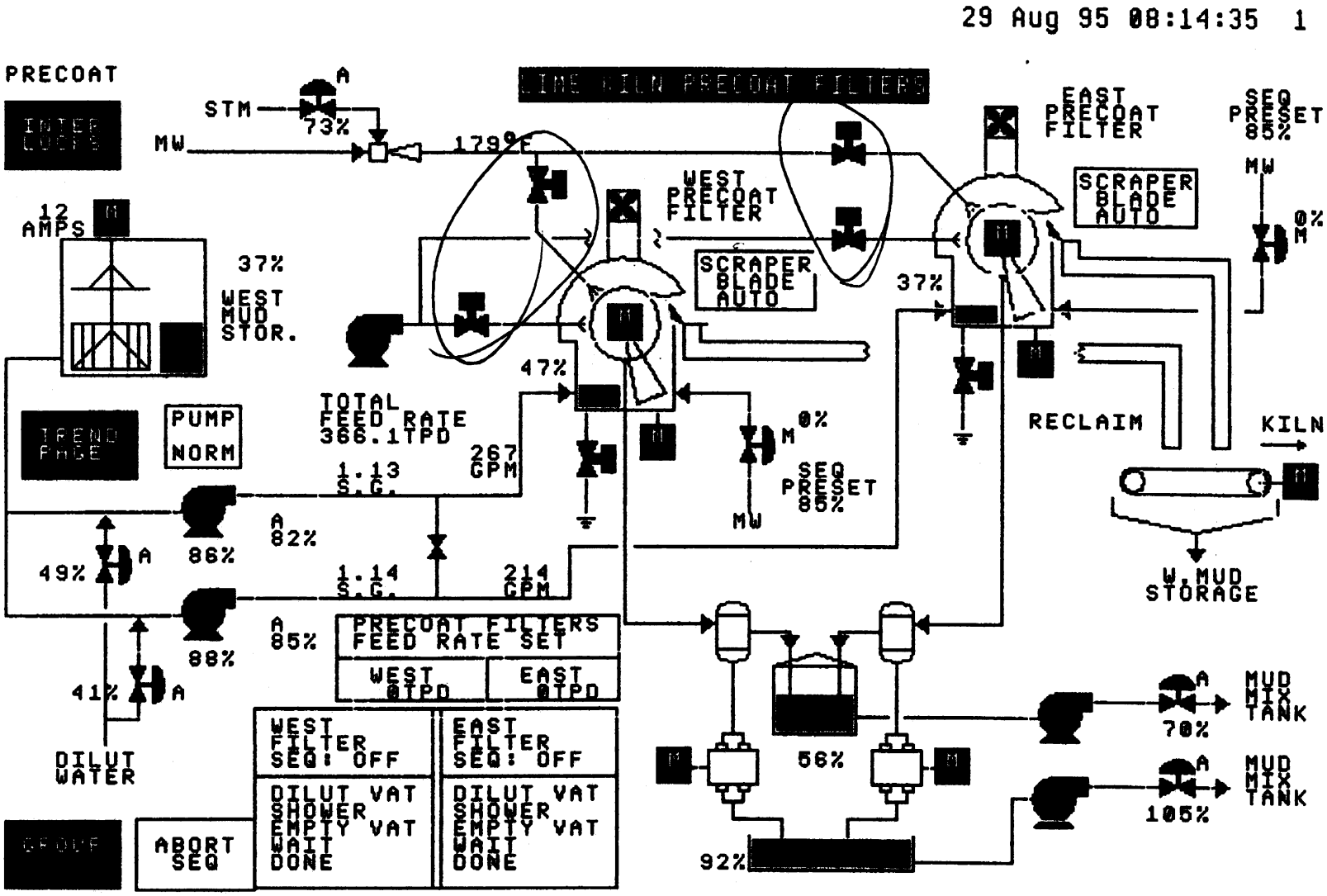


OUTPUT Coil of This BLOCK is "ON" if Drum Sequencer is in STEP NO. 1. This coil is used TO RESET "SEQUENCE START COIL" AND AS A permissive in the STEP CONTROL Logic for the drum sequencer.









Batch Program To Recover from blinding over drum

CL Back

```
LKCL501.CL
08/29/95 14:13:28

--------------------------------------------------------------------------------
--                          APM/CL SOURCE CODE FOR APM 5                      --
                           PRECOAT FILTERS AUTO SEQUENCES                     --
                                  LIME KILN AREA                              --
                             GULP STATE PAPER COMPANY     (9-14-94)           --
--------------------------------------------------------------------------------

SEQUENCE LKCL501(APM;POINT LKCL501)

EXTERNAL 40M0120, 40M0121, 40M0132, 40M0126, 40M0136, 40M0122I, 40M0128I
EXTERNAL 40LT0129, 40LT0148, LKFLAG501, LKFLAG502, LKFLAG503, LKFLAG504
EXTERNAL 40HS0112, 40HS0126, 40HS0136, 40HS0143, 40HS0153, 40HC0127, 40HC0147
EXTERNAL LKNUM0501, LKNUM0502, LKNUM0503, LKNUM0504, ABORTFLG

PHASE PRECOAT

STEP WFILT

     IF NOT 40M0128I.PVFL THEN GOTO STEP EFILT            -- CHECK W. FILTER RUN

     IF (LKFLAG502.PVFL AND 40LT0129.PVHIFL) OR (LKFLAG501.PVFL)
&       THEN SET LKNUM0503.PV=1                           --AUTO&HI LVL OR START
     ELSE GOTO STEP EFILT

     IF 40HS0112.OP = NORMAL THEN SET 40M0121.FL(7)=ON    -- STOP MUD PUMP FOR
     ELSE IF 40HS0112.OP = SWAP THEN SET 40M0120.FL(7)=ON -- W. FILTER & HOLD

     SET 40M0132.MODATTR = PROGRAM
     SET 40HC0127.MODATTR = PROGRAM
     SET 40HS0126.MODATTR = PROGRAM
     SET 40M0136.MODATTR = PROGRAM
     SET 40HS0136.MODATTR = PROGRAM

     SET 40M0132.OPCMD = ON                              -- RUN VACUUM PUMP
     SET 40HC0127.OP = LKNUM0501.PV                      -- SET DILUT VLV TO PRESET
     SET 40HS0126.OPCMD = OFF                            -- CLOSE SHOWER VALVE
     SET 40M0136.OPCMD = OFF                             -- STOP SHOWER PUMP
     SET 40HS0136.OPCMD = OFF                            -- CLOSE VAT DRAIN VLV
     WAIT ABORTFLG.PVFL = ON (WHEN 15 SECS: GOTO A1)
     IF ABORTFLG.PVFL = ON THEN GOTO STEP WRESET

A1:  SET LKNUM0503.PV = 2
     SET 40M0132.OPCMD = OFF                              -- STOP VACUUM PUMP
     SET 40HC0127.OP = 0                                  -- CLOSE VAT DILUT VLV
     SET 40HS0126.OPCMD = ON                              -- OPEN SHOWER VLV
     SET 40M0136.OPCMD = ON                               -- RUN SHOWER PUMP
     WAIT ABORTFLG.PVFL = ON (WHEN 150 SECS: GOTO A2)
     IF ABORTFLG.PVFL = ON THEN GOTO STEP WRESET

A2:  SET LKNUM0503.PV=3
     SET 40HC0127.OP=LKNUM0501.PV                         -- OPEN VAT DILUT VLV
     SET 40HS0136.OPCMD=ON                                -- OPEN VAT DRAIN VLV
     WAIT (40LT0129.PVLOFL=ON OR ABORTFLG.PVFL=ON)        -- WAIT UNTIL VAT LOW
     IF ABORTFLG.PVFL=ON THEN GOTO STEP WRESET

     SET LKNUM0503.PV=4
     WAIT ABORTFLG.PVFL=ON (WHEN 30 SECS: GOTO A3)
     IF ABORTFLG.PVFL=ON THEN GOTO STEP WRESET

A3:  SET LKNUM0503.PV=5
     SET 40HS0126.OPCMD=OFF                               -- CLOSE SHOWER VLV
     SET 40M0136.OPCMD=OFF                                -- STOP SHOWER PUMP
     SET 40HC0127.OP=0                                    -- CLOSE VAT DILUT VLV
     SET 40HS0136.OPCMD=OFF                               -- CLOSE VAT DRAIN VLV
     SET 40M0132.OPCMD=ON                                 -- RUN VACUUM PUMP

     SET 40M0132.MODATTR = OPERATOR
     SET 40HC0127.MODATTR = OPERATOR
     SET 40HS0126.MODATTR = OPERATOR
     SET 40M0136.MODATTR = OPERATOR
     SET 40HS0136.MODATTR = OPERATOR

     IF 40HS0112.OP=NORMAL THEN
;    (SET 40M0121.FL(7)=OFF; WAIT 10 SECS; SET 40M0121.FL(8)=ON;
;     WAIT 5 SECS; SET 40M0121.FL(8)=OFF)
     ELSE IF 40HS0112.OP=SWAP THEN
```

```
&     (SET 40M0120.FL(7)=OFF; WAIT 10 SECS; SET 40M0120.FL(8)=ON;
&      WAIT 5 SECS; SET 40M0120.FL(8)=OFF)
                                                    -- RUN W. FILT MUD PUMP
      SET LKNUM0503.PV=0

STEP EFILT

      IF NOT 40M0122I.PVFL THEN GOTO STEP WFILT          -- CHECK FILTER RUN

      IF (LKFLAG504.PVFL AND 40LT0148.PVHIFL) OR (LKFLAG503.PVFL)
&        THEN SET LKNUM0504.PV=1                         --AUTO+LVL HI OR START
      ELSE GOTO STEP WFILT

      IF 40HS0112.OP=NORMAL THEN SET 40M0120.FL(7)=ON    -- STOP MUD PUMP FOR
      ELSE IF 40HS0112.OP=SWAP THEN SET 40M0121.FL(7)=ON --      E.FILTER & HOLD

      SET 40M0126.MODATTR = PROGRAM
      SET 40HC0147.MODATTR = PROGRAM
      SET 40HS0143.MODATTR = PROGRAM
      SET 40M0136.MODATTR = PROGRAM
      SET 40HS0153.MODATTR = PROGRAM

      SET 40M0126.OPCMD=ON                              -- RUN VACUUM PUMP
      SET 40HC0147.OP=LKNUM0502.PV                      --SET DILUT VLV TO PRESET
      SET 40HS0143.OPCMD=OFF                            -- CLOSE SHOWER VALVE
      SET 40M0136.OPCMD=OFF                             -- STOP SHOWER PUMP
      SET 40HS0153.OPCMD=OFF                            -- CLOSE VAT DRAIN VLV
      WAIT ABORTFLG.PVFL=ON (WHEN 15 SECS: GOTO A4)
      IF ABORTFLG.PVFL=ON THEN GOTO STEP ERRESET

A4:   SET LKNUM0504.PV=2
      SET 40M0126.OPCMD=OFF                             -- STOP VACUUM PUMP
      SET 40HC0147.OP=0                                 -- CLOSE VAT DILUT VLV
      SET 40HS0143.OPCMD=ON                             -- OPEN SHOWER VLV
      SET 40M0136.OPCMD=ON                              -- RUN SHOWER PUMP
      WAIT ABORTFLG.PVFL=ON (WHEN 150 SECS: GOTO A5)
      IF ABORTFLG.PVFL=ON THEN GOTO STEP ERESET

A5:   SET LKNUM0504.PV=3
      SET 40HC0147.OP=LKNUM0502.PV                       -- OPEN VAT DILUT VLV
      SET 40HS0153.OPCMD=ON                             -- OPEN VAT DRAIN VLV
      WAIT (40LT0148.PVLOFL=ON OR ABORTFLG.PVFL=ON)     -- WAIT UNTIL VAT LOW
      IF ABORTFLG.PVFL=ON THEN GOTO STEP ERESET

      SET LKNUM0504.PV=4
      WAIT ABORTFLG.PVFL=ON (WHEN 30 SECS: GOTO A6)
      IF ABORTFLG.PVFL=ON THEN GOTO STEP ERRSET

A6:   SET LKNUM0504.PV=5
      SET 40HS0143.OPCMD=OFF                            -- CLOSE SHOWER VLV
      SET 40M0136.OPCMD=OFF                             -- STOP SHOWER PUMP
      SET 40HC0147.OP=0                                 -- CLOSE VAT DILUT VLV
      SET 40HS0153.OPCMD=OFF                            -- CLOSE VAT DRAIN VLV
      SET 40M0126.OPCMD=ON                              -- RUN VACUUM PUMP

      SET 40M0126.MODATTR = OPERATOR
      SET 40HC0147.MODATTR = OPERATOR
      SET 40HS0143.MODATTR = OPERATOR
      SET 40M0136.MODATTR = OPERATOR
      SET 40HS0153.MODATTR = OPERATOR

      IF 40HS0112.OP=NORMAL THEN
&     (SET 40M0120.FL(7)=OFF; WAIT 10 SECS; SET 40M0120.FL(8)=ON;
&      WAIT 5 SECS; SET 40M0120.FL(8)=OFF)
      ELSE IF 40HS0112.OP=SWAP THEN
&     (SET 40M0121.FL(7)=OFF; WAIT 10 SECS; SET 40M0121.FL(8)=ON;
&      WAIT 5 SECS; SET 40M0121.FL(8)=OFF)
                                                    -- RUN E. FILT MUD PUMP

      SET LKNUM0504.PV=0

GOTO PHASE PRECOAT

--  ------------------------------------------------------------------------

ERESET

      IF 40HS0112.OP=NORMAL THEN SET 40M0121.FL(7)=OFF   -- RELEASE W. FILTER
      ELSE IF 40HS0112.OP=SWAP THEN SET 40M0120.FL(7)=OFF --       MUD PUMP
```

```
      SET 40M0132.OPCMD=OFF                                  -- STOP VACUUM PUMP
      SET 40M0136.OPCMD=OFF                                  -- STOP SHOWER PUMP
      SET 40HS0126.OPCMD=OFF                                 -- CLOSE SHOWER VLV
      SET 40HC0127.OP=0                                      -- CLOSE VAT DILUT VLV
      SET 40HS0136.OPCMD=OFF                                 -- CLOSE VAT DRAIN VLV

         SET 40M0132.MODATTR = OPERATOR
         SET 40HC0127.MODATTR = OPERATOR
         SET 40HS0126.MODATTR = OPERATOR
         SET 40M0136.MODATTR = OPERATOR
         SET 40HS0136.MODATTR = OPERATOR

      SET ABORTFLG.PV=OFF
      SET LKNUM0503.PV=0
      GOTO PHASE PRECOAT

STEP ERESET

      IF 40HS0112.OP=NORMAL THEN SET 40M0120.FL(7)=OFF       -- RELEASE E. FILTER
      ELSE IF 40HS0112.OP=SWAP THEN SET 40M0121.FL(7)=OFF  --       MUD PUMP
      SET 40M0126.OPCMD=OFF                                  -- STOP VACUUM PUMP
      SET 40M0136.OPCMD=OFF                                  -- STOP SHOWER PUMP
      SET 40HS0143.OPCMD=OFF                                 -- CLOSE SHOWER VLV
      SET 40HC0147.OP=0                                      -- CLOSE VAT DILUT VLV
      SET 40HS0153.OPCMD=OFF                                 -- CLOSE VAT DRAIN VLV

         SET 40M0126.MODATTR = OPERATOR
         SET 40HC0147.MODATTR = OPERATOR
         SET 40HS0143.MODATTR = OPERATOR
         SET 40M0136.MODATTR = OPERATOR
         SET 40HS0153.MODATTR = OPERATOR

      SET ABORTFLG.PV=OFF
      SET LKNUM0504.PV=0
      GOTO PHASE PRECOAT

END LKCL501
```

AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702**

You have been asked to design and implement a process control strategy for the production of a chemical intermediate product. The process consists of a distillation column and two batch reactors as shown in Figure P702. An acidic feed is fed to the column which is operated at 500 mm Hg. Ninety (90) percent of the column feed is taken as overhead product. The column overheads are fed into one of the two reactors until the control system switches the flow to the other reactor based on level. Once flow to a batch reactor is complete, an additive is fed to that reactor in a ratio of 0.15 pounds of additive per pound of column overheads. The following data and design requirements are given.

Data:

Column overheads specific gravity	0.9 liquid
Additive specific gravity	0.8
Batch reactor volume	20,000 gal
On-stream factor	95%
Maximum allowable batch reactor level	90%
Reactor pressure input scale	0 to 60 psig
Final product requirement	100,000,000 lb/yr

SCALE

Permissives to open feed valve to Reactor 1:

No emergency shutdown
Not feeding Reactor 2
Reactor pressure <50 psig
Level in Reactor 1 <72.5%
Column feed not cut off

$\frac{50}{60} = 83.3\%$

Permissives to empty product batch from Reactor 1:

No emergency shutdown
Not feeding Reactor 1
Level in Reactor 1 = ≥90%

PERMISSIVES VS. INTERLOCK

Permissives to open additive valve to Reactor 1:

No emergency shutdown
Not feeding Reactor 1
Level in Reactor 1 = ≥72.5%
Reactor pressure < 50 psig
Reactor 1 not emptying

Permissives to open vent on Reactor 1:

Emergency shutdown
"OR"
Reactor pressure ≥ 50 psig

AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702, cont.**

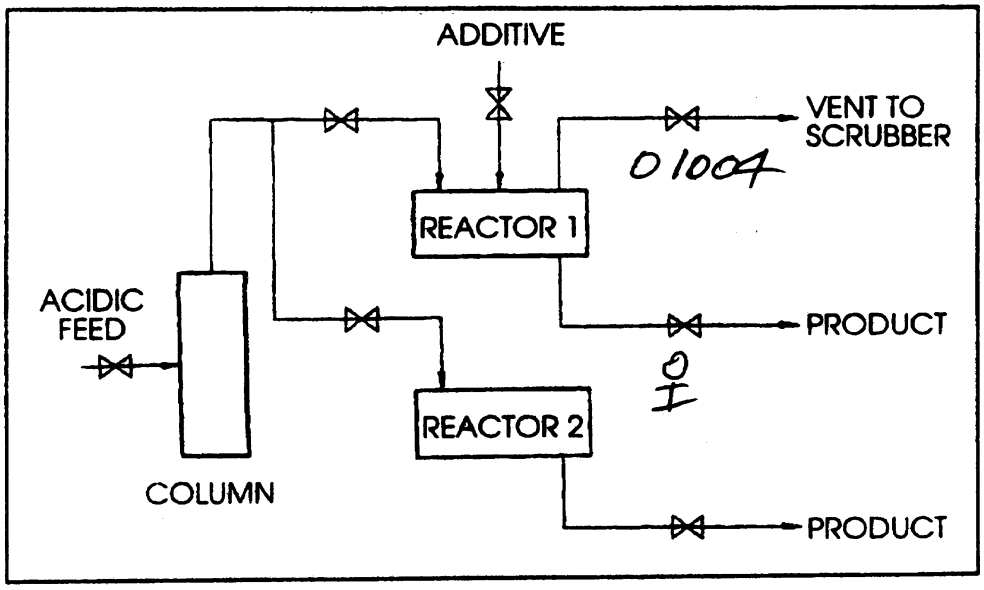
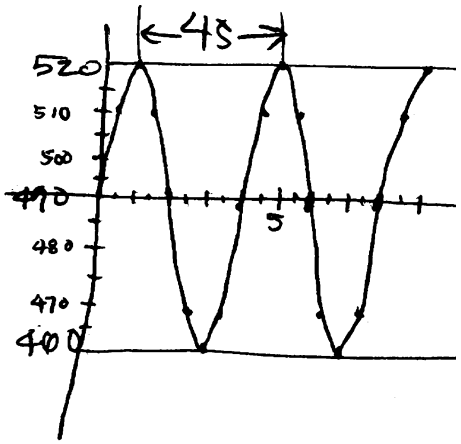


Figure P702

Time (min)	Top Pressure (mmHg)
0.5	511
1.0	520
1.5	510
2.0	491
2.5	469
3.0	460
3.5	468
4.0	489
4.5	510
5.0	520
5.5	512
6.0	489
6.5	469
7.0	460
7.5	470
8.0	490
8.5	511
9.0	520

Data taken at
Controller Gain = 2



$P_u = 4s$

$K_p = 0.5K_u = 1.2$

$T_I = 0.5P_u = 2.0$

$T_D = 0.125P_u = 0.5m$

ZIEGLER-NICHOLS CONTROLLER TUNING EQUATIONS (FROM CLOSED LOOP TEST)

PROPORTIONAL

GAIN	$K_p = 0.5\ G_u$

PROP + INTEGRAL (PI)

GAIN	$K_p = 0.45\ G_u$
RESET (Minutes/Repeat)	$T_I = 0.83\ P_u$

PROP + INTEGRAL + DERIV (PID)

GAIN	$K_p = 0.6\ G_u$
RESET (Minutes/Repeat)	$T_I = 0.5\ P_u$
DERIVATIVE (Minutes)	$T_D = 0.125\ P_u$

AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702, cont.**

Programmable Logic Controller Channels (Note: Open valve = 1 or "energized" contact; Emergency Shutdown pushbutton pushed = 0 or "de-energized" contact)		
Channel	Description	Contact Type
Discrete Inputs		
0000	Emergency Shutdown Pushbutton	Normally open
0001	Reactor 1 feed valve position	Normally open
0002	Reactor 2 feed valve position	Normally open
0003	Column fresh feed	Normally open
0004	Reactor 1 product VALVE POSITION	Normally open
Discrete Outputs		
1001	Feed valve to Reactor 1	
1002	Additive valve to Reactor 1	
1003	Reactor 1 product valve	
1004	Reactor 1 vent valve	
Analog Inputs		
5001	Level in Reactor 1 (percent)	
5002	Pressure in Reactor 1 (percent of scale)	
Memory Registers	Value	
M01	90.0% MAX LEVEL	
M02	83.3% MAX PRESSURE	
M03	72.5% PERM LEV	

1=RUN
FAIL-SAF

AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702, cont.**

1. The plant operating time in hours per year is most nearly:

   (A) 8784
   (B) 8760
   (C) 8640
   (D) ~~8332~~
   (E) 7008

Given: 95% onstream factor

$\frac{24\text{hr}}{\text{day}} \left| \frac{365\text{day}}{\text{yr}} \right| 0.95 = 8322 \frac{\text{hr}}{\text{yr}}$

2. To achieve the annual production target of 100 million pounds, the required feed rate to the column per hour is nearly:

   (A) 10,449
   (B) 11,030
   (C) 11,610
   (D) 12,976
   (E) 13,352

$\frac{100,000,000\text{ lb}}{8322\text{ hr}} = 12,016.3$

1.00 column overhead = 86%
0.15 additive = 13%
1.15 product = 100.0%

$(12,016)(86.96\%)(0.9) = 11610$

3. If the column overhead rate is set at 11,000 pounds per hour, how many hours must a batch reactor remain on-line in order to produce a maximum quantity of product per batch?

   (A) 10.5
   (B) 11.0
   (C) 11.5
   (D) 12.2
   (E) 12.9

$\frac{11000\text{ lb}}{\text{hr}} \left| \frac{\text{gal}}{8.32\text{ lb}} \right| 0.95 = 1392 \frac{\text{gal}}{\text{hr}}$ overhead feed

$\frac{11,000\text{ lb}}{\text{hr}} \left| \frac{0.15\text{ lb}}{\text{lb}} \right| \frac{\text{gal}}{8.32\text{ lb}} \left| 98 \right. = 247.9 \frac{\text{gal}}{\text{hr}}$ additive

$\frac{1800\text{ gal batch}}{1640\text{ gal}} \left| \frac{\text{hr}}{10.99} \right. = 1640 \frac{\text{gal}}{\text{hr}}$ Total feed

4. When tuning the feed flow controller, which of the following statements best describes the situation?

   ~~(A) A relative gain analysis will be needed.~~ (relative to the weed out)
   ~~(B) Only integral action is needed.~~
   ~~(C) Internal reflux control should be used.~~ (what is the weed out)
   ~~(D) The column temperature profile should first be examined.~~

Correct → (E) No derivative action should be used.
flow is too fast for flow

5. To obtain data for tuning the overhead pressure control loop, it is placed in closed-loop control (with no integral or derivative action) and the controller gain is increased until the loop cycles. Oscillation occurs when K = 2. At this time, the data given in the table is collected. Using a PID controller and a quarter-amplitude-decay tuning criterion, what initial controller parameters would you select for this loop?

   (A) Gain = 2.0; Integral = 4.0 mins; Derivative = 0

   (B) Gain = 0.9; Integral = 3.3 mins; Derivative = 3.3 mins

   (C) Gain = 0.4; Integral = 1.3 mins; Derivative = 2.0 mins

   (D) Gain = 1.2; Integral = 1.0 mins; Derivative = 0.2 mins

   (E) Gain = 1.2; Integral = 2.0 mins; Derivative = 0.5 mins

6. If the controller gain is set at 2.34, what would be the corresponding proportional band?

   (A) 0.40

   (B) 1.20

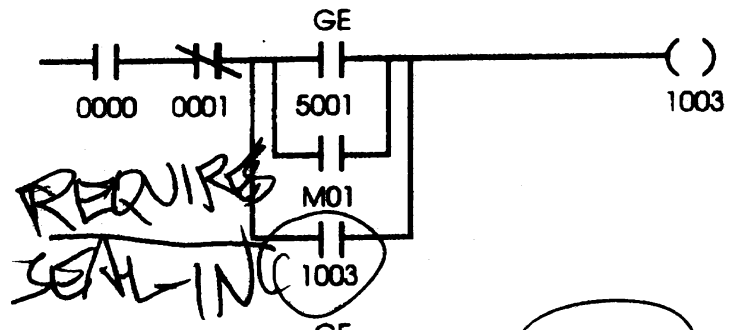
   (C) 2.34

   (D) 42.70

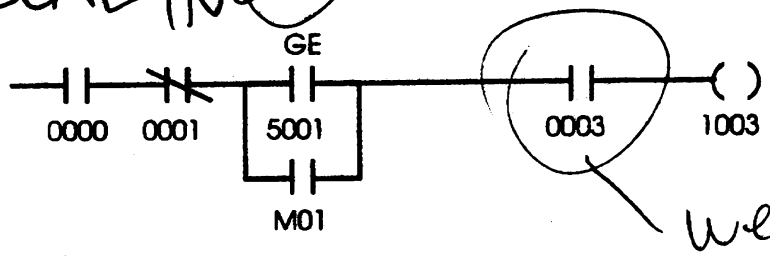
   (E) 100.00

9. The programmable controller ladder logic to empty Reactor 1 is:

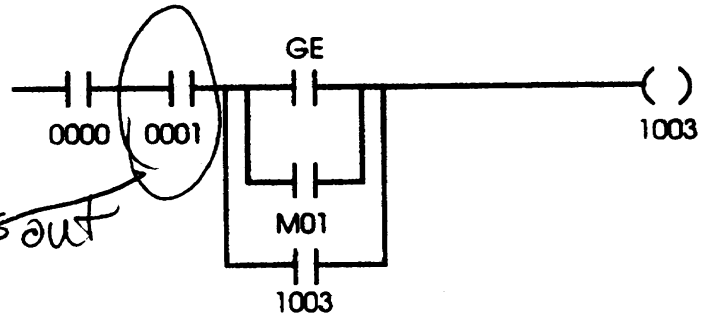
CORR (A)



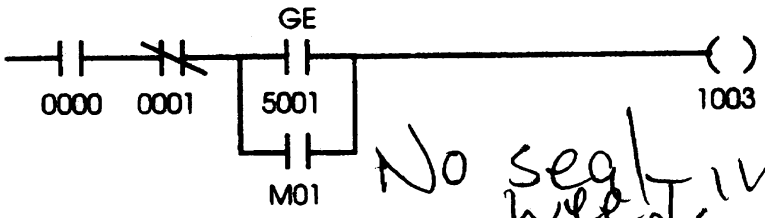
(B)



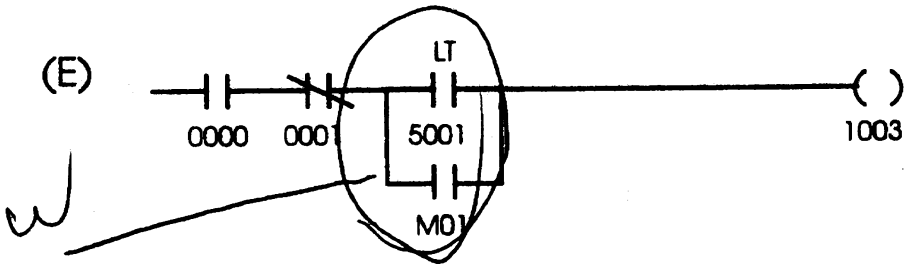
(C)



(D)



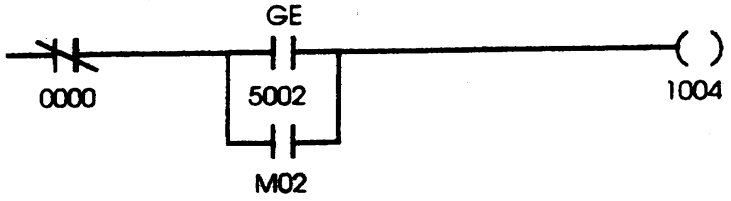
(E)



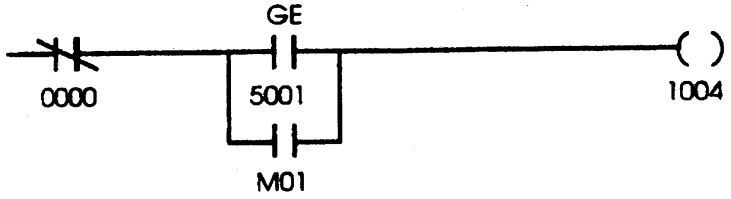
AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702, cont.**

10. The programmable controller ladder logic to open the Reactor 1 emergency vent is:

(A)

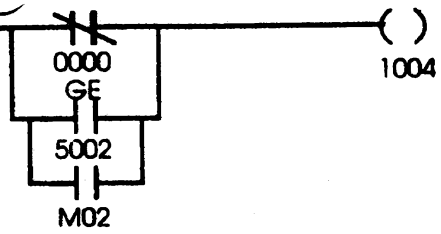


(B)

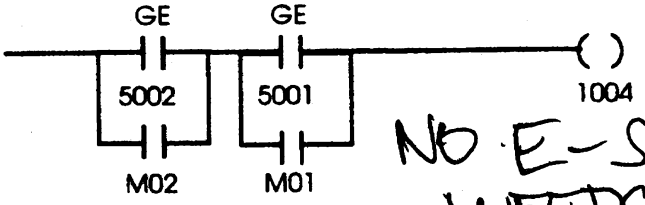


CORRECT ANSWER

(C)

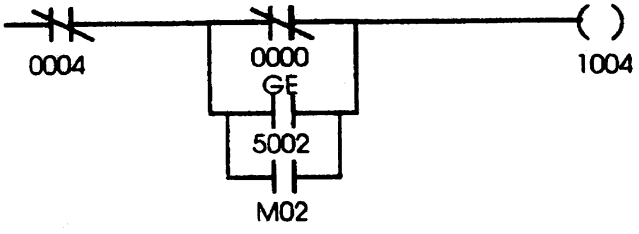


(D)



NO E-STOP WEEDS OUT

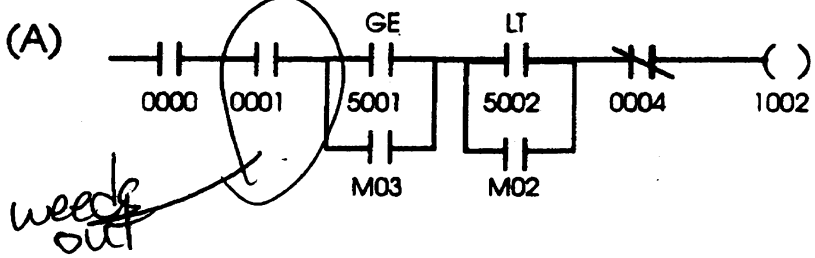
(E)



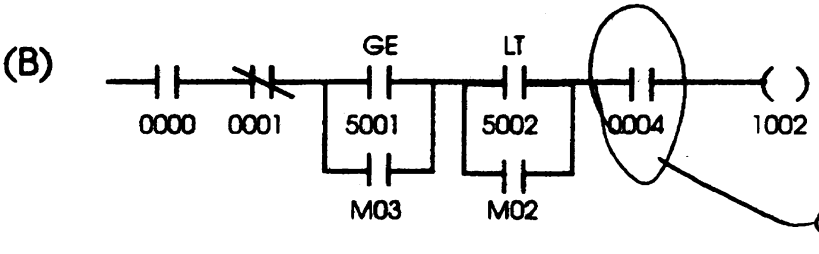
AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702, cont.**

8. The programmable controller ladder logic to open the additive feed valve to Reactor 1 is:

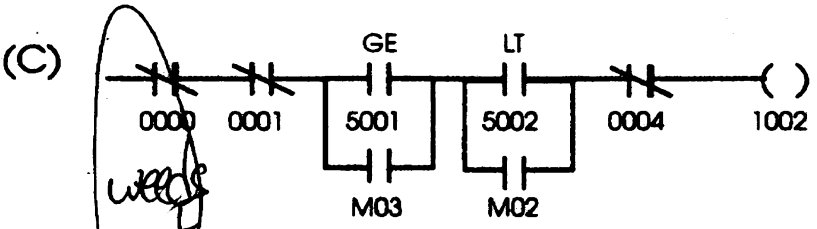
(A)



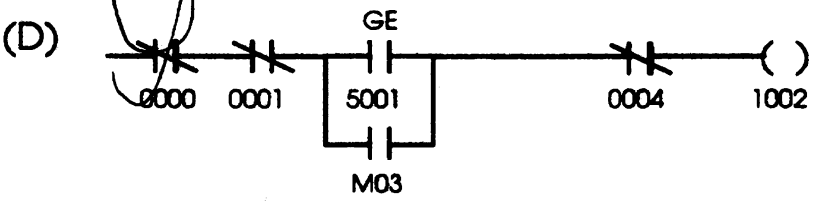
(B)



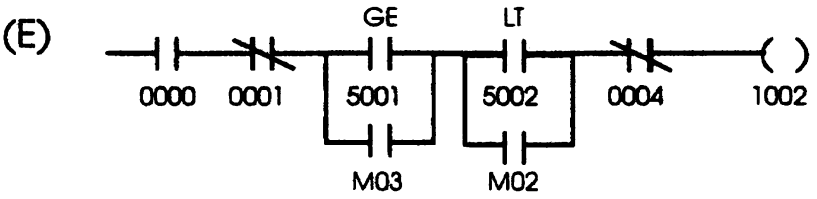
(C)



(D)



(E)





DIGITAL LOGIC

BOOLEAN ALGEBRA

A logical variable can have one of two possible states known as true (1) or false (0). A logical constant can have the value of 1 or 0.

Function	*XY* Variable Combination				Logic	Logic
Binary	00	01	10	11	Gate	Operation
Decimal	0	1	2	3		
F_0	0	0	0	0		
F_1	0	0	0	1	AND	$X \cdot Y$
F_2	0	0	1	0		
F_3	0	0	1	1		
F_4	0	1	0	0		
F_5	0	1	0	1		
F_6	0	1	1	0	XOR	$X \oplus Y$
F_7	0	1	1	1	OR	$X + Y$
F_8	1	0	0	0	NOR	$\overline{X+Y}$
F_9	1	0	0	1	XNOR	$\overline{X \oplus Y}$
F_{10}	1	0	1	0	NOT Y	$\overline{Y}$
F_{11}	1	0	1	1		
F_{12}	1	1	0	0	NOT X	$\overline{X}$
F_{13}	1	1	0	1		
F_{14}	1	1	1	0	NAND	$\overline{X \cdot Y}$
F_{15}	1	1	1	1		

FUNCTIONS OF TWO VARIABLES

In general, there are 2^n possible combinations of n variables and 2^{2^n} functions.

LOGICAL IDENTITIES

Relationships Between Constants

$$0 \cdot 0 = 0$$
$$0 \cdot 1 = 0$$
$$1 \cdot 1 = 1$$
$$0 + 0 = 0$$
$$0 + 1 = 1$$
$$1 + 1 = 1$$
$$\overline{0} = 1$$
$$\overline{1} = 0$$
$$0 \oplus 0 = 0$$
$$0 \oplus 1 = 1$$
$$1 \oplus 0 = 1$$
$$1 \oplus 1 = 0$$

Relationships Between Variables

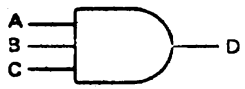
$$A + B = B + A$$
$$A \cdot B = B \cdot A$$
$$A + \overline{A} = 1$$
$$A \cdot \overline{A} = 0$$
$$A + A = A$$
$$A \cdot A = A$$
$$\overline{\overline{A}} = A$$
$$A + (B + C) = A + B + C$$
$$A \cdot (B + C) = (A \cdot B) + (A \cdot C)$$
$$A + (B \cdot C) = A + B \cdot C$$
$$A \oplus B = \overline{A} \cdot B + A \cdot \overline{B}$$
$$A \odot B = \overline{A} \cdot \overline{B} + A \cdot B$$
$$A \oplus B \oplus C = A \oplus (B \oplus C)$$
$$= (A \oplus B) \oplus C$$

LOGICAL THEOREMS

$$A + A \cdot B = A$$
$$A + \overline{A} \cdot B = A + B$$
$$A \cdot C + \overline{A} \cdot B \cdot C = A \cdot C + B \cdot C$$
$$A \cdot B + A \cdot C + \overline{B} \cdot C = A \cdot B + \overline{B} \cdot C$$
$$A \cdot B + A \cdot \overline{B} = A \text{ (logical adjacency)}$$
$$\overline{A \cdot B \cdot C \cdot D \cdot E} = \overline{A} + \overline{B} + \overline{C} + \overline{D} + \overline{E} \text{ (de Morgan)}$$
$$\overline{A + B + C + D + E} = \overline{A} \cdot \overline{B} \cdot \overline{C} \cdot \overline{D} \cdot \overline{E} \text{ (de Morgan)}$$

LOGIC GATES AND TRUTH TABLES

AND Gate



$$D = A \cdot B \cdot C$$

Truth Tables for AND Gate

A	*B*	*C*	*D*
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

NAND Gate

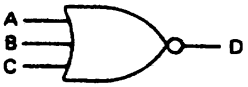


$$D = \overline{A \cdot B \cdot C}$$

Truth Table for NAND Gate

A	B	C	D
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

NOR Gate

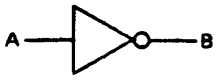


$$D = \overline{A + B + C}$$

Truth Table for NOR Gate

A	B	C	D
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

NOT Gate

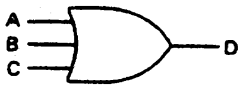


$$B = \overline{A}$$

Truth Table for NOT Gate

A	B
0	1
1	0

OR Gate

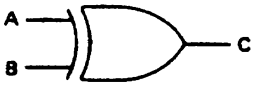


$$D = A + B + C$$

Truth Table for OR Gate

A	B	C	D
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

XOR Gate

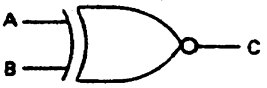


$$C = A \oplus B$$

Truth Table for XOR Gate

A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

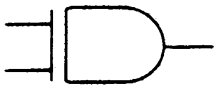
XNOR Gate



$$C = \overline{A \oplus B} = A \odot B$$

Truth Table for XNOR Gate

A	B	C
0	0	1
0	1	0
1	0	0
1	1	1



Alternate XNOR (coincidence gate symbol)

MINTERMS AND MAXTERMS

Variable Combinations $A\ B$	Product Terms (Minterms)	Sum Term (Maxterms)
0 0	$\overline{A} \cdot \overline{B} = m_{00}$	$A + B = M_{00}$
0 1	$\overline{A} \cdot B = m_{01}$	$A + \overline{B} = M_{01}$
1 0	$A \cdot \overline{B} = m_{10}$	$\overline{A} + B = M_{10}$
1 1	$A \cdot B = m_{11}$	$\overline{A} + \overline{B} = M_{11}$

Minterms are variables "ANDed." Where $C = AB$ is true (1), the minterms are "ORed" to obtain the sum of products (SOP) form.

$$C = m_{00} + m_{01} + m_{10} + m_{11}$$

$$C = (\overline{A} \cdot \overline{B}) + (\overline{A} \cdot B) + (A \cdot \overline{B}) + (A \cdot B)$$

Maxterms are "NOTed" variables "ORed." Where C is false (0), the maxterms are "ANDed" to obtain the product of sum (POS) form.

$$C = M_{00} + M_{01} + M_{10} + M_{11}$$

$$C = (A + B)(A + \overline{B})(\overline{A} + B)(\overline{A} + \overline{B})$$

CANONICAL REALIZATION

When all variables or their complements appear only once in each term of a logical expression, that expression is said to be in canonical form. A realisation is the design of a logical gate circuit from the canonical form. The following steps illustrate the process.

step 1: For a given truth table, complete the maxterms and minterms. Minterms are where $F = 1$ (true). Maxterms are where $F = 0$ (false).

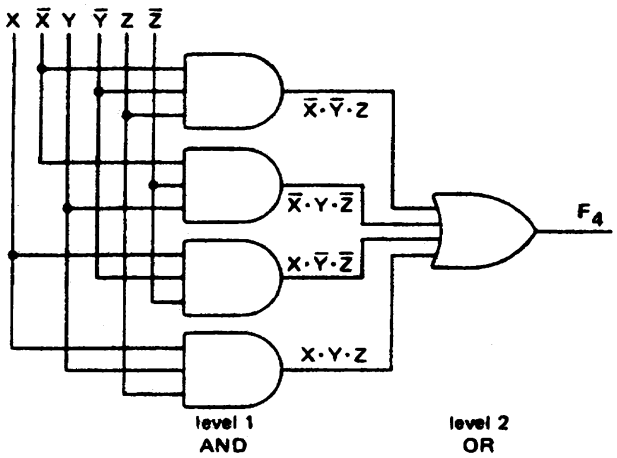
XYZ	F_4	m	M
0 0 0	0	–	$X + Y + Z$
0 0 1	1	$\overline{X} \cdot \overline{Y} \cdot Z$	–
0 1 0	1	$\overline{X} \cdot Y \cdot \overline{Z}$	–
0 1 1	0	–	$X + \overline{Y} + \overline{Z}$
1 0 0	1	$X \cdot \overline{Y} \cdot \overline{Z}$	–
1 0 1	0	–	$\overline{X} + Y + \overline{Z}$
1 1 0	0	–	$\overline{X} + \overline{Y} + Z$
1 1 1	1	$X \cdot Y \cdot Z$	–

step 2: Combine the minterms and maxterms to get the SOP and POS expressions.

$$\text{SOP } F_4 = \overline{X}\,\overline{Y}Z + \overline{X}Y\overline{Z} + X\overline{Y}\,\overline{Z} + XYZ$$

$$\text{POS } F_4 = (X + Y + Z)(X + \overline{Y} + \overline{Z})$$
$$(\overline{X} + Y + \overline{Z})(\overline{X} + \overline{Y} + Z)$$

step 3: Design the circuit using AND and OR gates working from the inside of the SOP or POS expressions. The use of other gates is also possible.



SOP AND/OR realisation

MINIMIZATION USING KARNAUGH MAPS

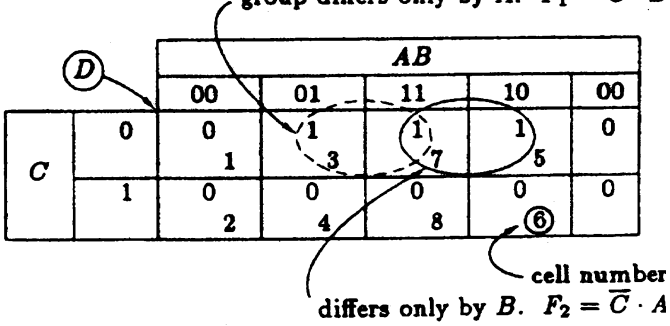
To minimise a function, follow these steps:

step 1: Construct a Karnaugh map from the truth table.

Truth Table

cell number	A	B	C	D
1	0	0	0	0
2	0	0	1	0
3	0	1	0	1
4	0	1	1	0
5	1	0	0	1
6	1	0	1	0
7	1	1	0	1
8	1	1	1	0

Karnaugh Map



step 2: Combine adjacent terms into the largest possible groupings. SOP are 1's and are easiest to work with.

step 3: Include a sufficient number of groupings to include each of the terms in at least one group.

step 4: "OR" the SOP terms together to obtain the logical expression.

$$D = \overline{C}B + \overline{C}A$$

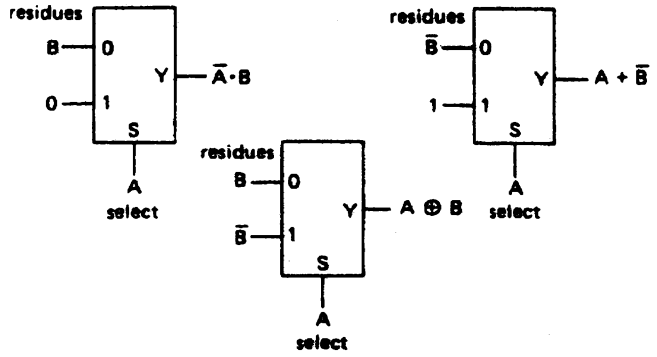
step 5: Check the expression against the truth table.

DATA SELECTORS

Data selectors are also called multiplexers or MUXs.

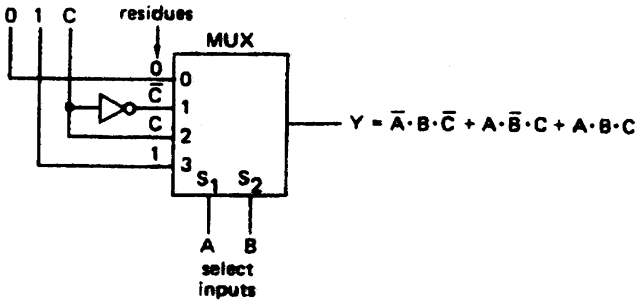
input		functions		
A	B	$\overline{A} \cdot B$	$A + \overline{B}$	$A \oplus B$
0	0	0	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	1	0

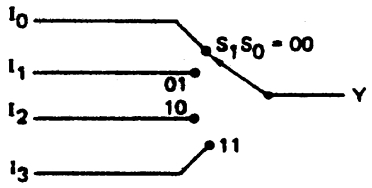
select input	residues		
	$\overline{A} \cdot B$	$A + \overline{B}$	$A \oplus B$
$\overline{A}$	B	$\overline{B}$	B
A	0	1	$\overline{B}$



2-input MUX logic

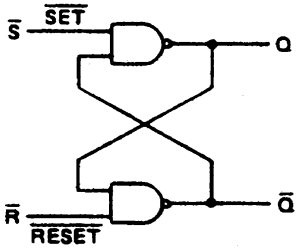
AB	C	Y	residues
0 0	0	0	
0 0	1	0	0
0 1	0	1	
0 1	1	0	$\overline{C}$
1 0	0	0	
1 0	1	1	C
1 1	0	1	
1 1	1	1	1



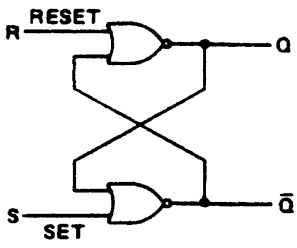


4-input data selector realization

FLIP-FLOPS



NAND S-R flip-flop

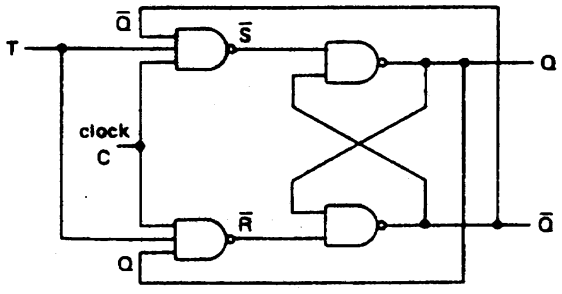


NOR S-R flip-flop

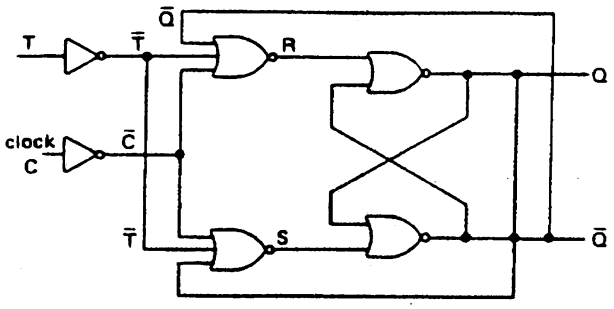
Next-State Table for S-R Flip-Flop

present S	R	Q	next Q
0	0	0	0
0	1	0	0
1	0	0	1
1	1	0	N
0	0	1	1
0	1	1	0
1	0	1	1
1	1	1	N

N = input not permitted



NAND T flip-flop



NOR T flip-flop

Transition Table for T Flip-Flop

present Q	next Q	T	$\overline{S}$	$\overline{R}$
0	0	0	1	X
0	1	1	0	1
1	0	1	1	0
1	1	0	X	1

X = don't care

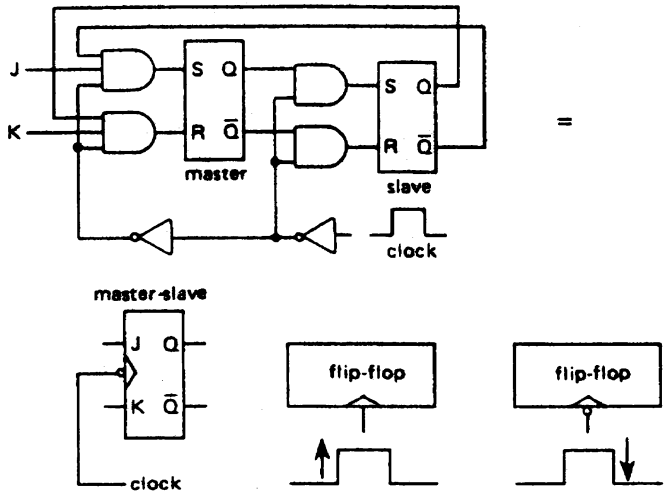
$S = \overline{Q} \cdot T$

$S = \overline{\overline{Q} \cdot T}$

Transition Table for D Flip-Flop

E	D	present Q	next Q	S	R
1	0	0	0	0	X
1	0	1	0	0	1
1	1	0	1	1	0
1	1	1	1	X	0
0	X	X	present	0	0

E = enable input



master-slave J-K flip-flop

Truth Table for J-K Flip-Flop

J	K	present Q	next Q	S	R
0	0	0	0	0	X
0	0	1	1	X	0
0	1	0	0	0	X
0	1	1	0	0	1
1	0	0	1	1	0
1	0	1	1	X	0
1	1	0	1	1	0
1	1	1	0	0	1

$S = J \cdot \overline{Q}$

$R = K \cdot Q$

Transition Table for Flip-Flop

present Q		next Q^+	S	R	J	K	T	D
0	$\longrightarrow$	0	0	X	0	X	0	0
0	$\longrightarrow$	1	1	0	1	X	1	1
1	$\longrightarrow$	0	0	1	X	1	1	0
1	$\longrightarrow$	1	X	0	X	0	0	1

$Q^+ = S + \overline{R} \cdot Q$

$= J \cdot \overline{Q} + \overline{K}$

$= T \oplus Q$

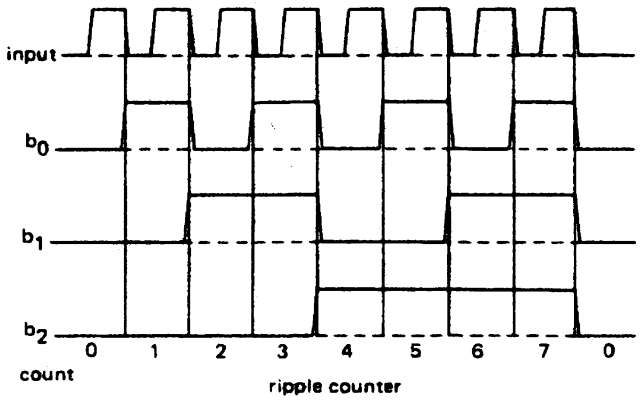
$= D$

COUNTERS

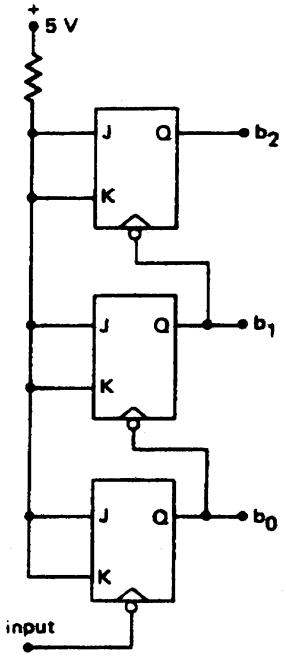
Counters are sets of flip-flops. The count is 2^n where n = number of flip-flops in the circuit.

A synchronous counter has each flip-flop state changed a the same time by a clock.

Asynchronous counters do not have simultaneous clocke inputs. An example is the ripple counter.



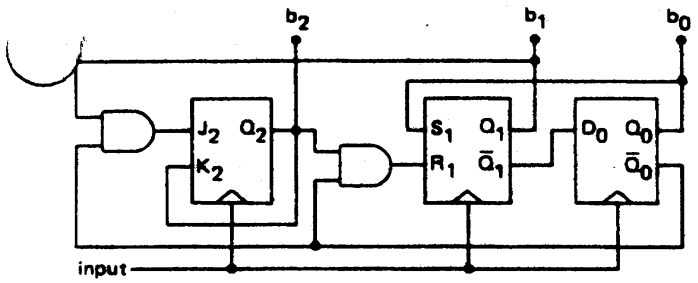
timing diagram



ripple counter circuit

COUNTER ANALYSIS

step 1: Write the logical expressions from the circuit.



$J_2 = Q_1 \cdot \overline{Q}_0$ $\quad S_1 = Q_0$ $\quad D_0 = \overline{Q}_1$

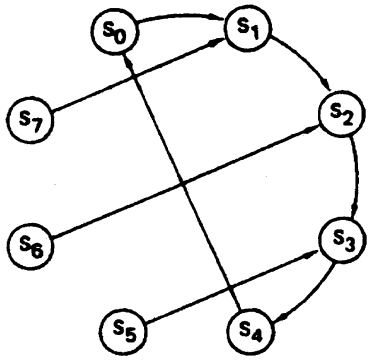
$K_2 = Q_2$ $\quad R_1 = Q_2 \cdot \overline{Q}_0$

step 2: Write the next-state variables from the flip-flop transition table.

$$Q_2^+ = J_2 \cdot \overline{Q_2} + \overline{K_2} \cdot Q_2 = \overline{Q_2} \cdot Q_1 \cdot \overline{Q_0} + \overline{Q_2} \cdot Q_2$$
$$= \overline{Q_2} \cdot Q_1 \cdot \overline{Q_0}$$
$$Q_1^+ = S_1 + \overline{R_1} \cdot Q_1 = Q_0 + (\overline{Q_2} + Q_0) \cdot Q_1$$
$$= Q_0 + \overline{Q_2} \cdot Q_1$$
$$Q_0^+ = D_0 = \overline{Q_1}$$

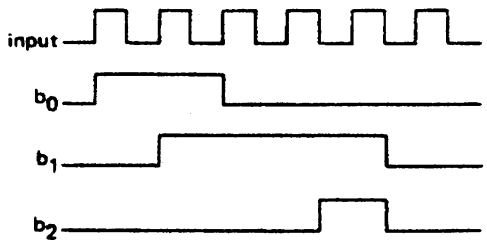
step 3: Complete the state table for the present state and next state determined in step 2.

	present state $Q_2Q_1Q_0$	next state $Q_2^+Q_1^+Q_0^+$
S_0	0 0 0	0 0 1
S_1	0 0 1	0 1 1
S_2	0 1 1	0 1 0
S_3	0 1 0	1 1 0
S_4	1 1 0	0 0 0
S_5	1 1 1	0 1 0
S_6	1 0 1	0 1 1
S_7	1 0 0	0 0 1



step 4: Draw the state diagram. Hang-up states are two or more unused states that have no next state in the desired sequence. Unless there is an automatic clearing of all flip-flops when the system is energized, it could come up into one of the unused states, never getting into the desired sequence.

step 5: Draw the timing diagram.



The analysis can be reversed when a circuit is not given.

ISA-S5.2

1976

STANDARD

BINARY LOGIC DIAGRAMS FOR PROCESS OPERATIONS



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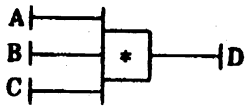
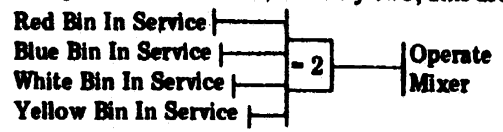
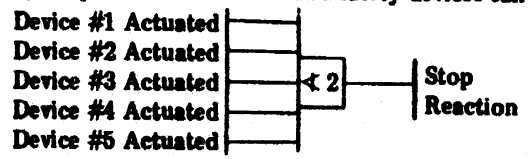
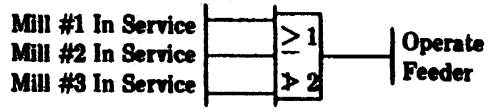
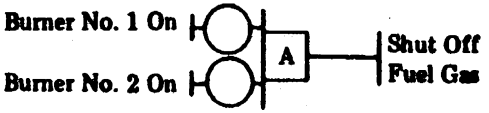
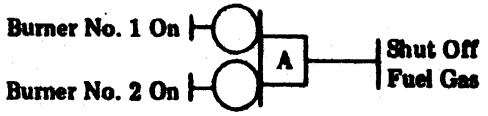
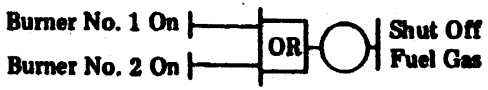
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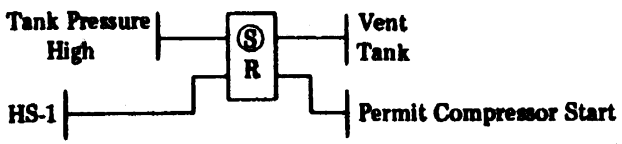
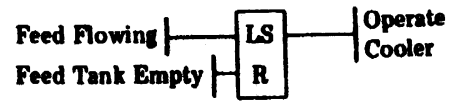
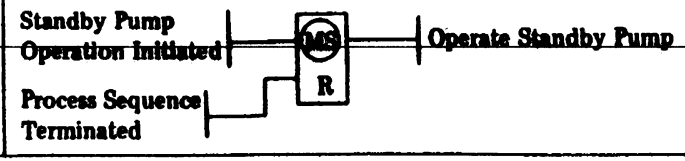
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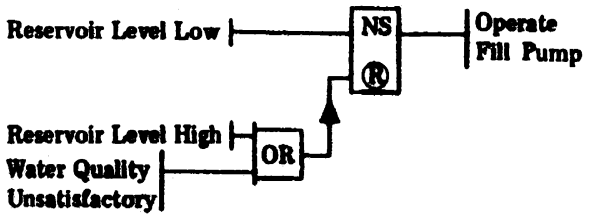
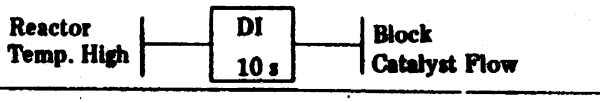
Symbols

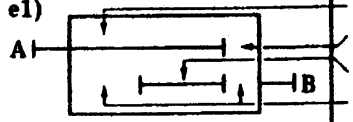
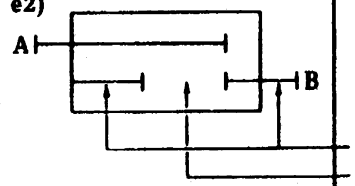
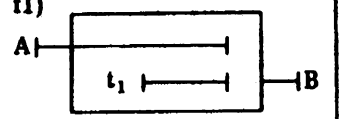
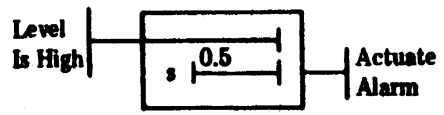
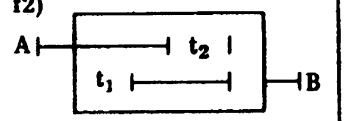
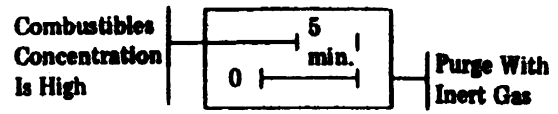
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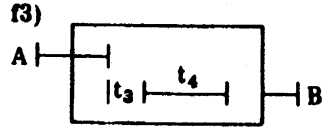
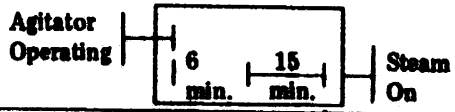
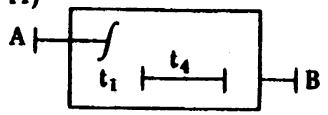
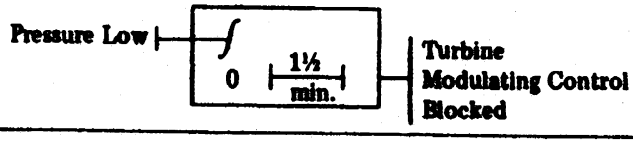
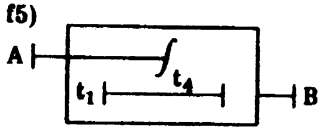
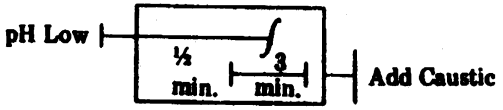
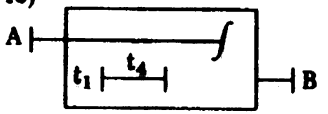
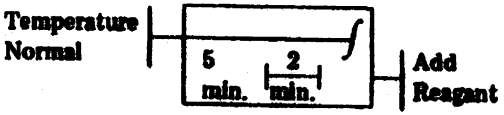
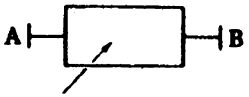
FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.1 INPUT	Statement of Input Alternatively: Statement of Input Initiating instrument or device number, if known	An input to the logic sequence	The start position of a hand switch *HS-1*, is actuated to provide an input to start a conveyor. Alternative diagrams: a) HS-1 Start Conveyor Manually b) HS 1 Start Conveyor Manually
4.2 OUTPUT	Statement of Output Alternatively: Statement of Output Operated instrument or device number, if known	An output from the logic sequence.	An output from the logic sequence commands valve *HV-2* to open. Alternative diagrams: a) Open Valve HV-2 b) Open Valve HV 2
4.3 AND BASIC	A, B, C → A → D	Logic output *D* exists if and only if all logic inputs *A*, *B*, and *C* exist.	Operate pump if suction tank level is high and discharge valve is open. Tank Level High, Valve Open → A → Operate Pump
4.4 OR BASIC	A, B, C → OR → D	Logic output *D* exists if and only if one or more of logic inputs *A*, *B*, and *C* exist.	Stop compressor if cooling water pressure is low or bearing temperature is high. Water Pressure Low, Bearing Temperature High → OR → Stop Compressor

FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.5 QUALIFIED OR	 *Internal details represent numerical quantities (see "Definition").	Logic output *D* exists if and only if a specified number of logic inputs *A*, *B*, and *C* exist. Mathematical symbols, including the following, shall be used, as appropriate, in specifying the number: a. = equal to b. ≠ not equal to c. < less than d. > greater than e. ≮ not less than f. ≯ not greater than g. ≤ less than or equal to [equivalent to *f*] h. ≥ greater than or equal to [equivalent to *e*]	a) Operate mixer if two, and only two, bins are in service.  b) Stop reaction if at least two safety devices call for stop.  c) Operate materials feeder if at least one and no more than two mills are in service. 
4.6 NOT BASIC	 The *NOT* symbol may be drawn tangent to an adjacent logic symbol.	Logic output *B* exists if and only if logic input *A* does not exist.	Shut off fuel gas if burners no. 1 and no. 2 are not on.  Some Alternatives:  

FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.7 MEMORY (Flip-Flop) BASIC	a) A, B → S, R → C, D* *Output *D* shall not be shown if it is not used.	S represents *set memory* and R represents *reset memory*. Logic output *C* exists as soon as logic input *A* exists. *C* continues to exist, regardless of the subsequent state of *A*, until the memory is reset, i.e., terminated by logic input *B* existing. *C* remains terminated regardless of the subsequent state of *B*, until *A* causes the memory to be set. Logic output *D*, if used, exists when *C* does not exist, and *D* does not exist when *C* exists.	If tank pressure becomes high, vent tank and continue venting, regardless of pressure, until venting is stopped by manual actuation of hand switch, HS-1, provided that the pressure is not high. If the venting is stopped, a compressor may be started. 
		Input-Override Option If inputs *A* and *B* exist simultaneously, and if it is desired to have *A* override *B*, then *S* should be encircled, i.e., Ⓢ ; if *B* is to override *A*, then *R* should be encircled, i.e., Ⓡ . *Loss-Of-Power-Supply Option* The unmodified letter *S* denotes that *no consideration* has been given to the action of the memory on loss of the logic power supply. See paragraphs 4.7 b, c, and d, below, and 3.8.	
	b) A, B → LS, R → C, D (See Appendix C)	Similar to definition of symbol (a) except that the memory shall be *lost* in the event of loss of the logic power supply.	If feed begins to flow, the cooler shall operate until the feed tank is empty. In the event of loss of the logic power supply, the cooler shall not operate 
	c) A, B → MS, R → C, D	Similar to definition of symbol (a) except that the memory shall be *maintained* in the event of loss of the logic power supply.	If standby pump operation is initiated, the pump shall operate, even on loss of the logic power supply, until the process sequence is terminated. The pump shall operate if start and stop commands exist simultaneously. 
(cont'd)			

FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.7 (cont'd)	d) A, B → NS, R → C, D	Similar to definition of symbol (a) except that *after consideration* it is deemed *not significant*, so far as the process is concerned, whether the memory is maintained or lost in the event of loss of power supply.	If reservoir level is low, operate fill pump until either level is high or water quality is unsatisfactory. It is not significant to the process what happens to the pump on loss of the logic supply. If start and stop commands are simultaneous, the pump shall stop. 
4.8 TIME ELEMENT	a) A → * → B *For functional details, see the following (also see Section 3.9):	Logic output *B* exists with a time relationship to logic input *A* as specified.	
BASIC (cont'd)	b) A → DI, t → B (Delay Initiation of output)	The continuous existence of logic input *A* for time *t* causes logic output *B* to exist when *t* expires. *B* terminates when *A* terminates.	If reactor temperature exceeds a high limit continuously for 10 seconds, block catalyst flow. Resume flow when temperature does not exceed the limit. 
BASIC (cont'd)	c) A → DT, t → B (Delay Termination of output)	The existence of logic input *A* causes logic output *B* to exist immediately. *B* terminates when *A* has terminated and has not again existed for time *t*.	If system pressure falls below a low limit, operate compressor at once. Stop the compressor when pressure is not low continuously for one minute. 
BASIC (cont'd)	d) A → PO, t → B (Pulse Output)	The existence of logic input *A*, regardless of its subsequent state, causes logic output *B* to exist immediately. *B* exists for time *t* and then terminates.	If vessel purge fails for any period of time, operate evacuation pump for 3 minutes and then stop the pump. 

FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.8 (cont'd)	A generalized method for diagramming all time functions is outlined as follows. The symbols that are defined are intended to be illustrative but are not all-inclusive.		
	e1) 	Input logic state exists. Input logic state does not exist. Output logic state exists. Output logic state does not exist. The time at which the logic input *A* is initiated is represented by the left-hand edge of the box. Passage of time is from left to right and is usually shown unscaled. The logic output *B* always begins and ends in the same state within the time-element box. More than one output may be shown, if required.	
	e2) 	The timing of logic may be applied to either the existence state or the non-existence state, as applicable. Output logic state exists. Output logic state does not exist.	
	f1) 	The continuous existence of logic input *A* for time t_1 causes logic output *B* to exist when t_1 expires. *B* terminates when *A* terminates. ON DELAY	Avoid nuisance alarms on high level by actuating alarm only if level remains high continuously for 0.5 second. The alarm signal terminates when there is no high level. 
	f2) 	The continuous existence of logic input *A* for time t_1 causes logic output *B* to exist when t_1 expires. *B* terminates when *A* has been terminated continuously for time t_2.	Purge immediately with inert gas when combustibles concentration is high. Stop the purge when concentration is not high continuously for 5 minutes. 
(cont'd)			

FUNCTION	SYMBOL	DEFINITION	EXAMPLE
4.8 (cont'd)	f3) 	The termination of logic input *A* and its continuous non-existence for time t_3 cause logic output *B* to exist when t_3 expires. *B* terminates when either (1) *B* has existed for time t_4, or (2) *A* again exists, whichever occurs first.	Steam is turned on for 15 minutes beginning 6 minutes after agitator has stopped except that the steam shall be turned off if the agitator restarts. 
	f4) 	The existence of logic input *A*, regardless of its subsequent state, causes logic output *B* to exist when time t_1 expires. *B* exists for time t_4 and then terminates.*	If pressure dips to low value momentarily, block modulating control of turbine immediately, maintain for 1½ minutes, then release turbine to modulating control. 
	f5)  FIXPU SE IN HONEYWELL	The continuous existence of logic input *A* for time t_1 causes logic output *B* to exist when t_1 expires. *B* exists for time t_4, regardless of the state of *A*, and then terminates.*	If pH is low continuously for ½ minute, add caustic for 3 minutes. 
	f6) 	The continuous existence of logic input *A* for time t_1 causes logic output *B* to exist when t_1 expires. *B* terminates when either (1) *B* has existed for time t_4, or (2) *A* terminates, whichever occurs first.*	If temperature is normal continuously for 5 minutes, add reagent for 2 minutes except that reagent shall not be added if temperature is abnormal. 
	*For symbols f4, f5, and f6, the action of logic output *B* depends on how long logic input *A* is in continuous existence, up to the line break for *A*. Beyond the break in *A*, the state of *A* is not significant to the completion of the *B* sequence. If it is desired to have a *B* time segment, e.g., t_1, go to completion only if *A* exists continuously, then *A* must be drawn beyond that segment. If *A* is drawn past the beginning but not beyond the end of a time segment, then the segment will be initiated and go to completion regardless of whether *A* exists only momentarily or longer.		
4.9 SPECIAL	 Statement of Special Requirements	Logic output *B* exists with a relationship to logic input *A* as specified in the statement of special requirements. The statement may cover a logic function not otherwise specified in this standard or a logic system that is further defined elsewhere.	

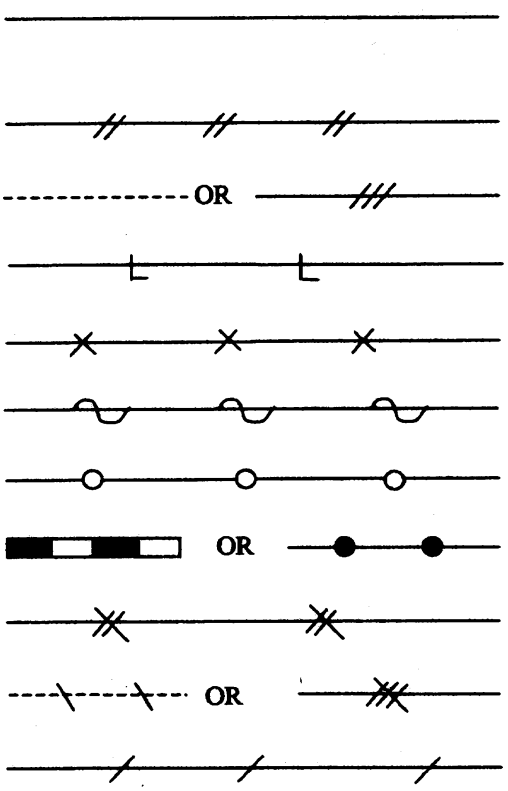
SENSORS AND DATA TRANSMISSION *AND* DOCUMENTATION

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INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL
STANDARD S5.1

TYPICAL INSTRUMENT LINE IDENTIFICATION



INSTRUMENT SUPPLY (1)
Direct connection to the process

PNEUMATIC SIGNAL (2)

ELECTRIC or ELECTRONIC SIGNAL

HYDRAULIC SIGNAL

CAPILLARY TUBE

ELECTROMAGNETIC or SONIC (3)

SOFTWARE LINK

MECHANICAL LINK

PNEUMATIC BINARY

ELECTRIC BINARY

UNDEFINED SIGNAL

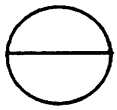
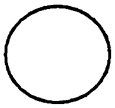
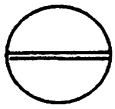
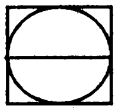
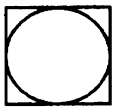
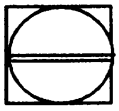
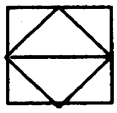
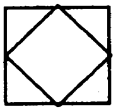
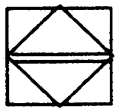
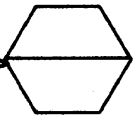
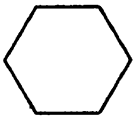
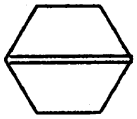
(1) The following abbreviations are suggested to denote the types of power supply
AS...Air supply
IA...Instrument air
PA...Plant air
ES...Electric supply
GS...Gas supply
HS...Hydraulic supply
NS...Nitrogen supply
SS...Steam supply
WS...Water supply

(2) Applies to a signal using any gas as a medium.

(3) Includes heat, radio waves, nuclear radiation, and light.

INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL
STANDARD S5.1

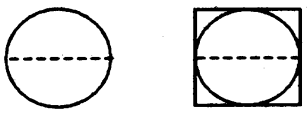
GENERAL INSTRUMENT OR FUNCTION SYMBOLS

	PRIMARY LOCATION	FIELD MOUNTED	AUXILIARY LOCATION
DISCRETE INSTRUMENT			
SHARED INSTRUMENT (1)			
PROGRAMMABLE LOGIC CONTROLLER			
COMPUTER FUNCTION Recipes			

(1) **Shared Controller** – A controller pre-programmed algorithms that are usually accessible, configurable, and assignable.
Shared Display – The operator interface device (usually a video screen) used to display process control information from a number of sources at the command of the operator.

(2) **Accessible** – A term applied to a device or function that can be used or seen by an operator for the purpose of performing control.

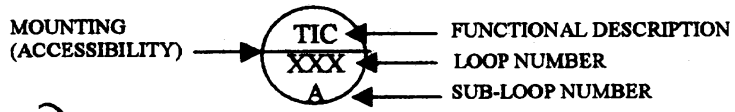
Normally inaccessible or behind-the-panel devices or functions are depicted by using the same symbols but with dashed horizontal bars.



Instruments sharing a common housing



Typical Instrument Identification

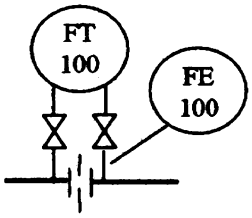


INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL
STANDARD S5.1

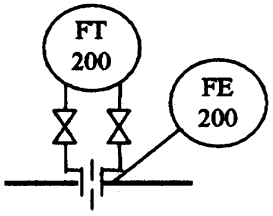
LETTER	FIRST LETTER	SUCCEEDING LETTERS			
	MEASURED OR INITIATING VALUE	MODIFIER TO FIRST LETTER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER TO OUTPUT FUNCTION
A	ANALYSIS		ALARM		
B	BURNER		USER'S CHOICE	USER'S CHOICE	USER'S CHOICE
C	USER'S CHOICE			CONTROL	
D	USER'S CHOICE	DIFFERENTIAL			
E	VOLTAGE		SENSOR (PRI. ELEM.)		
F	FLOW	RATIO			
G	USER'S CHOICE		GLASS, VIEWING DEVICE		
H	HAND				HIGH
I	CURRENT		INDICATE		
J	POWER (WATTS)	SCAN			
K	TIME	TIME RATE OF CHANGE		CONTROL STATION	
L	LEVEL		LIGHT		LOW
M	USER'S CHOICE	MOMENTARY			MIDDLE
N	USER'S CHOICE		USER'S CHOICE	USER'S CHOICE	USER'S CHOICE
O	USER'S CHOICE		ORIFICE, RESTRICTION		
P	PRESSURE, VACUUM		POINT (TEST)		
Q	QUANTITY, EVENT	INTEGRATE, TOTALIZE			
R	RADIATION, RESTRICTION		RECORD		
S	SPEED, FREQUENCY	SAFETY		SWITCH	
T	TEMPERATURE			TRANSMIT	
U	MULTI-VARIABLE				
V	VIBRATION			VALVE, DAMPER, LOUVER	
W	WEIGHT, FORCE		WELL		
X	UNCLASSIFIED	X-AXIS	UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED
Y		Y-AXIS			
Z	POSITION ,D DIMENSION	Z-AXIS		DRIVER, ACTUATOR, UNCLASSIFIED FINAL CONTROL ELEMENT	

INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL
STANDARD S5.1

FLOW SYMBOLS

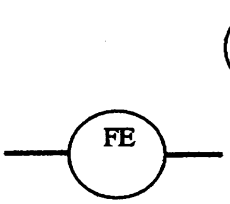


ORIFICE WITH TRANSMITTER (RADIUS OR PIPE TAPS)

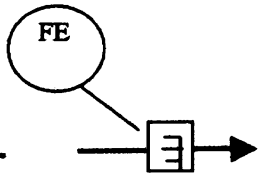


ORIFICE WITH TRANSMITTER (FLANGE TAPS)

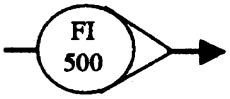
REQUIRES 303# FLANGE TAPS



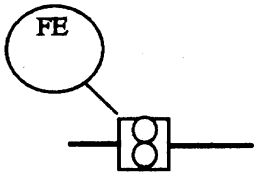
GENERAL SYMBOL



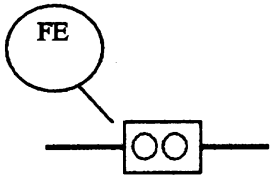
AVERAGING PITOT TUBE



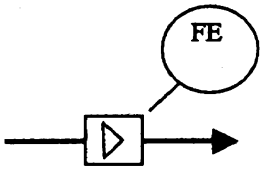
VARIABLE AREA FLOW INDICATOR



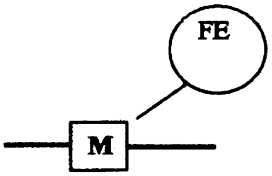
TURBINE



POSITIVE DISPLACEMENT

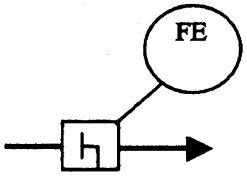


VORTEX SENSOR

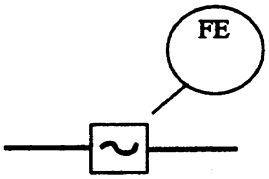


MAGNETIC FLOWMETER

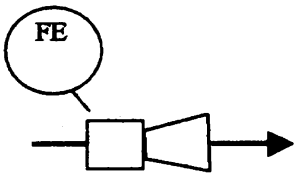
FA



TARGET FLOWMETER



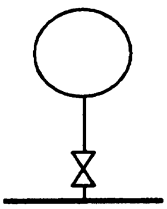
SONIC FLOWMETER



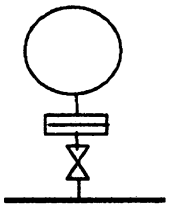
VENTURI TUBE

dP tube

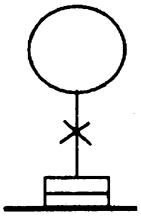
PRESSURE SYMBOLS



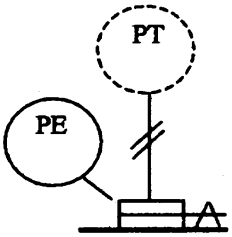
DIRECT CONNECTED



WITH SEAL



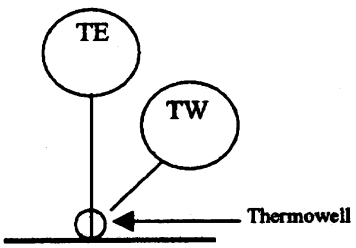
WITH CAPILLARY SEAL



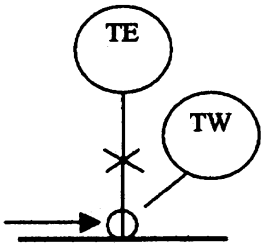
1:1 REPEATER

INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL STANDARD S5.1

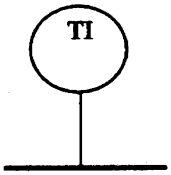
TEMPERATURE SYMBOLS



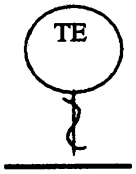
RESISTANCE BULB OR THERMOCOUPLE



TRANSMITTER WITH FILLED CAPILLARY



TEMPERATURE GAUGE WITHOUT THERMOWELL

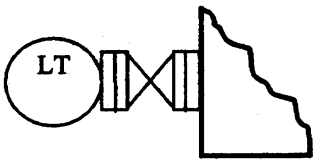


INFARED

LEVEL SYMBOLS

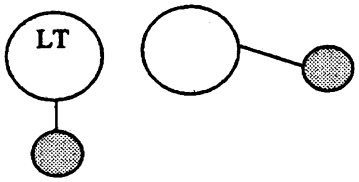


FLANGE MOUNTED LEVEL TRANSMITTER

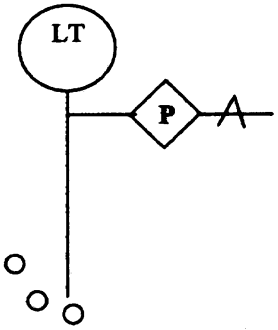


FLANGE MOUNTED LEVEL TRANSMITTER WITH ISOLATION VALVE

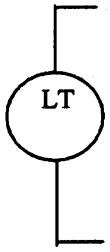
W/Purge



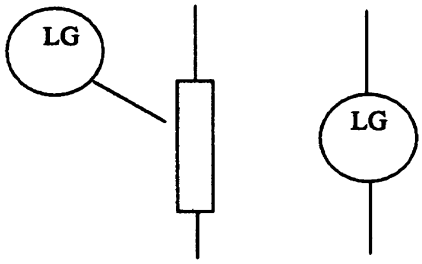
FLOAT TYPE



TRANSMITTER WITH BUBBLE PIPE



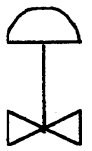
DIRECT CONNECTED DP CELL



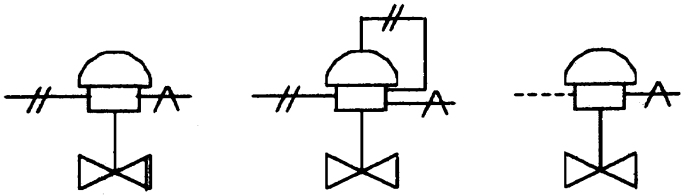
GAUGE GLASS

INTERNATIONAL SOCIETY FOR MEASUREMENT AND CONTROL
STANDARD S5.1

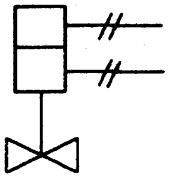
ACTUATORS



DIAPHRAGM ACTUATOR

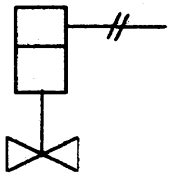


DIAPHRAGM ACTUATOR WITH POSITIONER

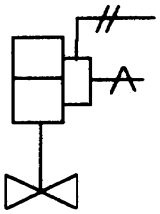


PISTON ACTUATOR (DOUBLE ACTING)

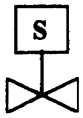
Air on both sides



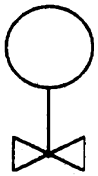
PISTON ACTUATOR (SINGLE ACTING)



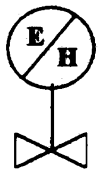
PISTON ACTUATOR WITH POSITIONER



SOLENOID

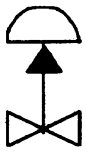


ROTARY MOTOR



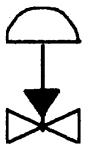
ELECTRO-MECHANICAL

ACTUATOR ACTIONS



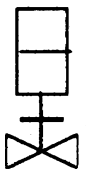
FAIL OPEN

FO

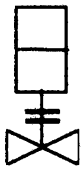


FAIL CLOSED

FC



FAIL INDETERMINATE

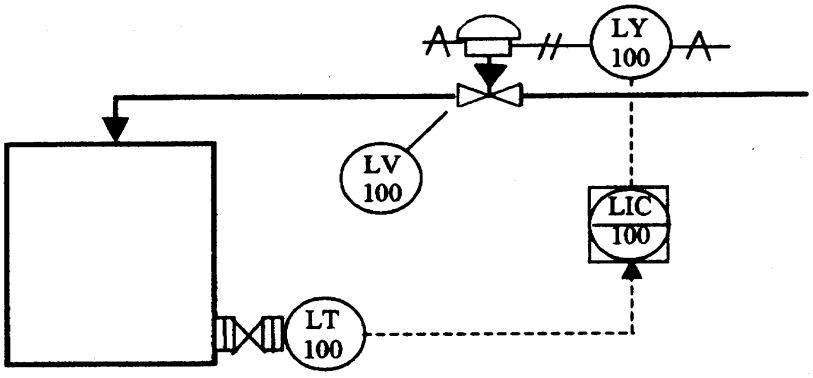


FAIL LAST

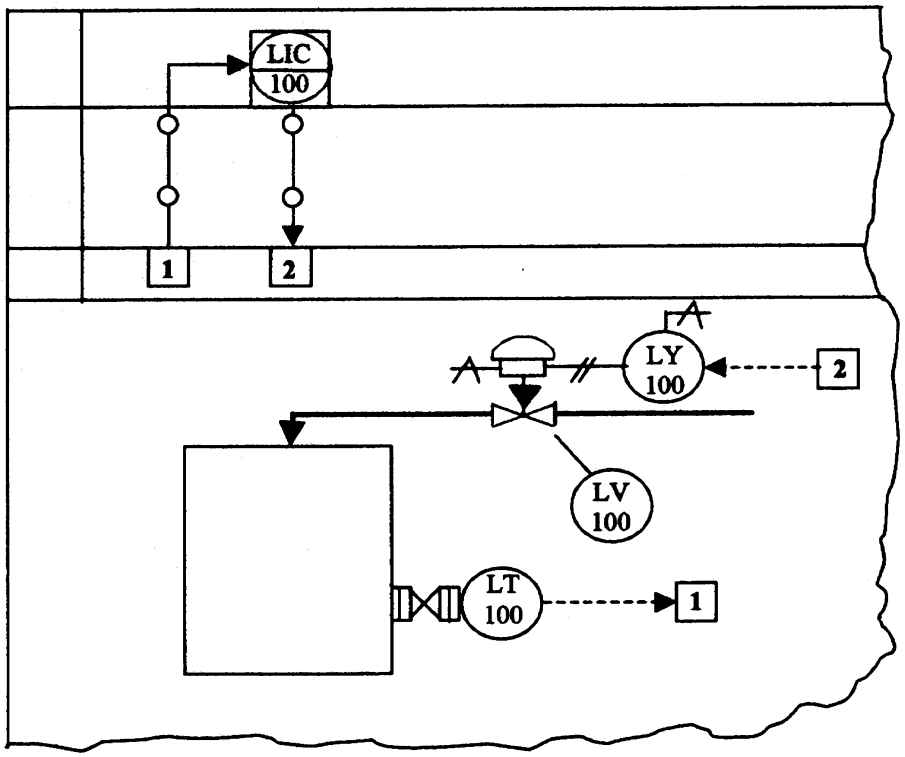
FO – FAIL OPEN
FC – FAIL CLOSED
FI – FAIL INDETERMINATE
FL – FAIL LAST

FAIL ON LOSS OF ACTUATING MEDIA AND

VARIATIONS OF PROCESS AND INSTRUMENTATION DIAGRAMS

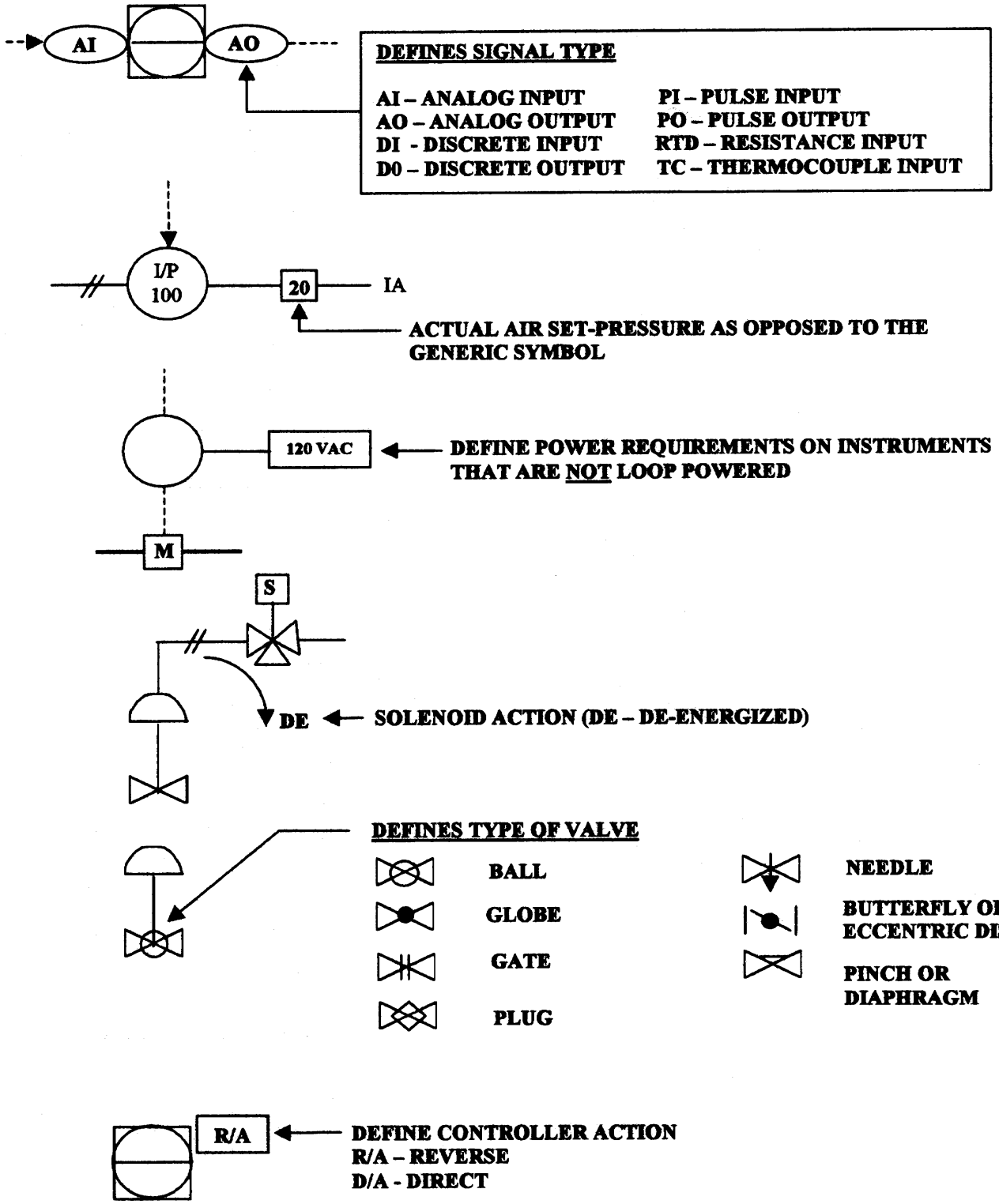


METHOD 1 – ALL INSTRUMENT AND CONTROL SYMBOLS ARE SHOWN IN THE BODY OF THE PROCESS AND INSTRUMENTATION DIAGRAM

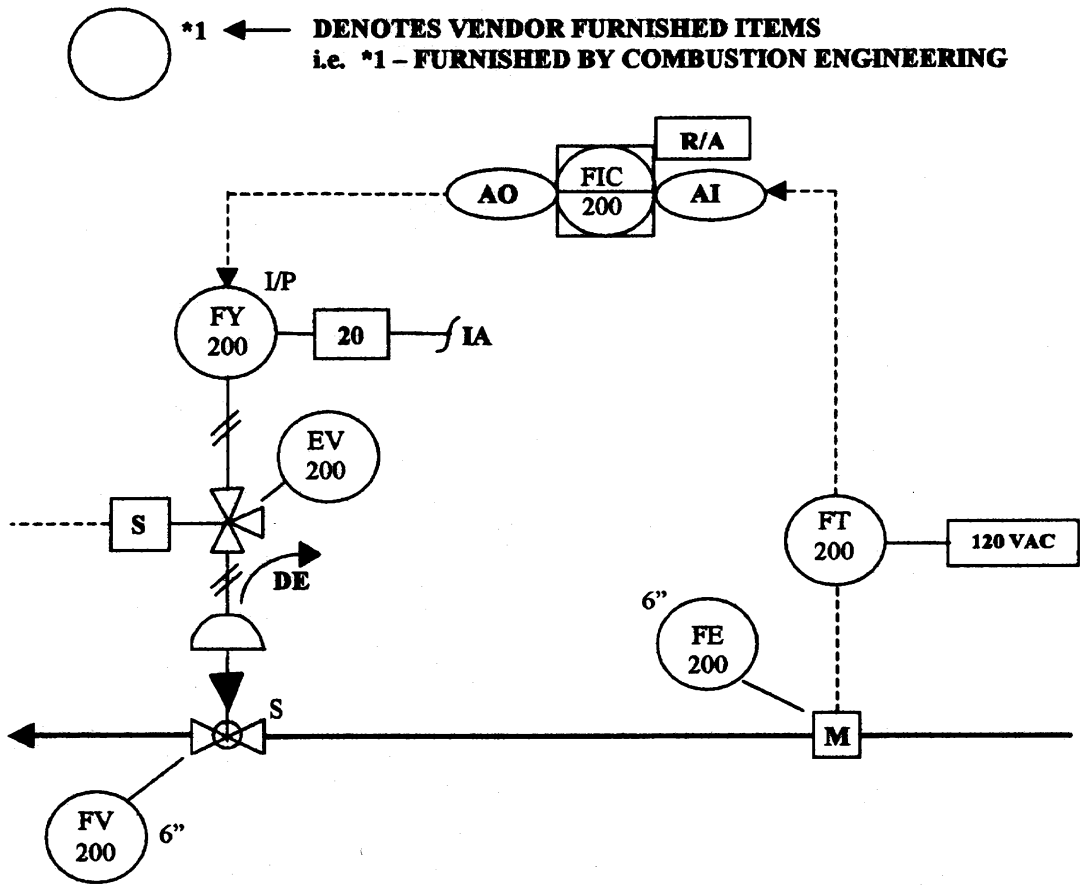


METHOD 2 – FIELD DEVICE SYMBOLS ARE SHOWN IN THE BODY OF THE PROCESS AND INSTRUMENTATION DIAGRAM. CONTROLLER AND PANEL FUNCTIONS ARE SHOWN AT THE TOP OF THE DRAWING.

SYMBOL ENHANCEMENTS



SYMBOL ENHANCEMENTS



DEGREE OF DETAIL

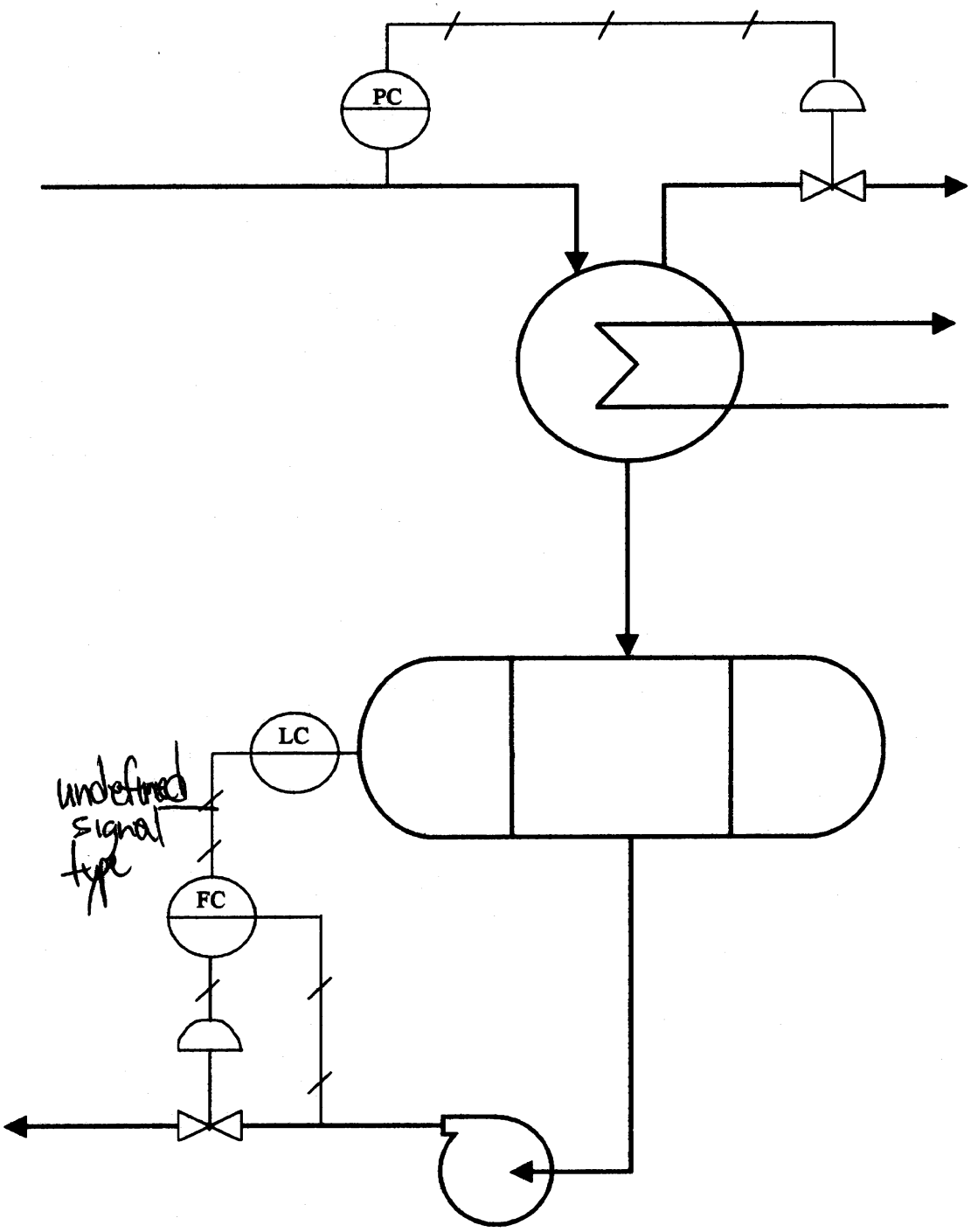
- **SIMPLIFIED DIAGRAMS**
- **CONCEPTUAL DIAGRAMS**
- **DETAILED DIAGRAMS**

Simplified Diagrams
Simplified symbolism and abbreviated identification used to define the principle points of measurement and control interest.

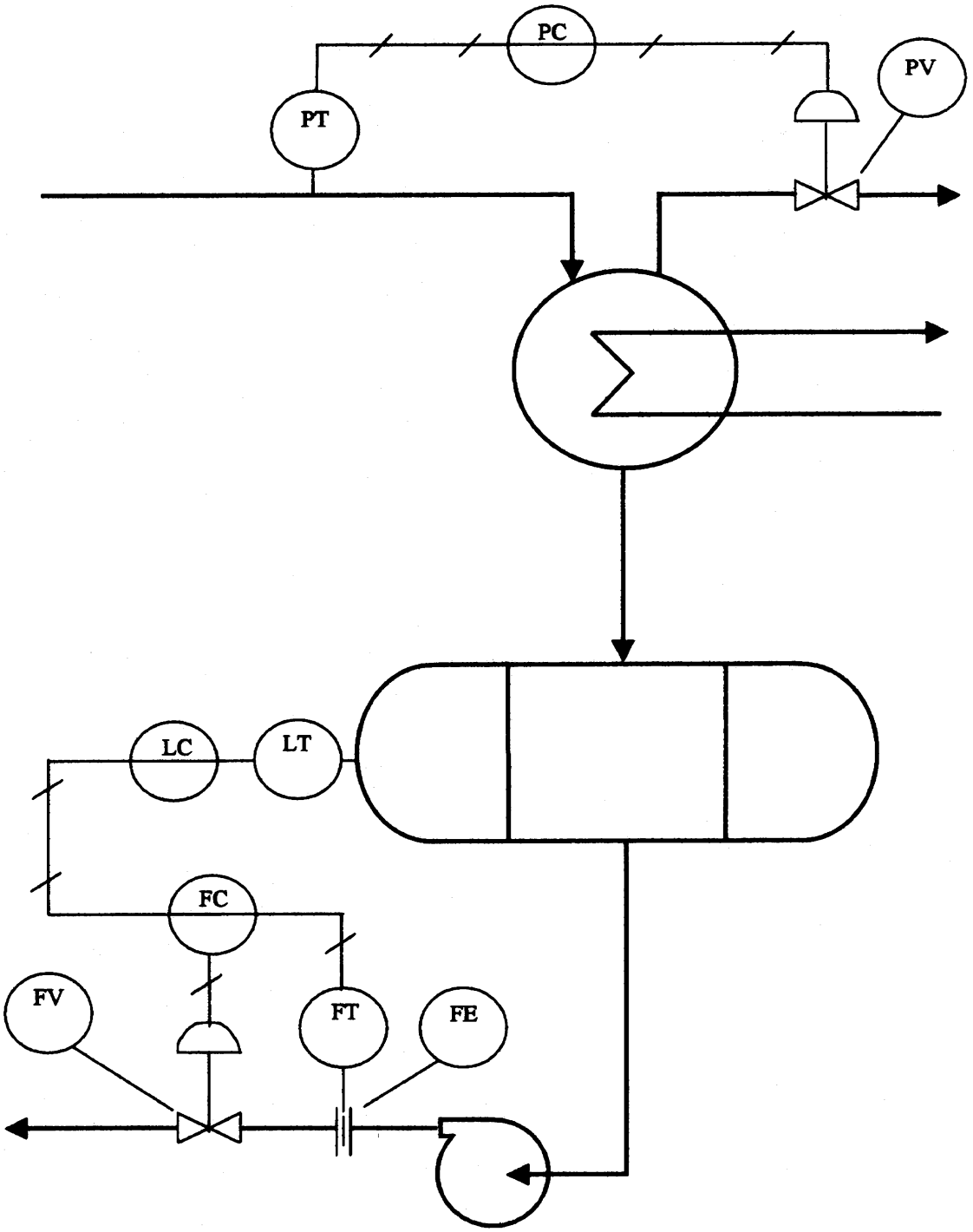
Conceptual Diagrams
Functionally oriented symbolism and abbreviated identification used to develop control concepts without concern for specific hardware.

Detailed Diagrams
Detailed symbolism and more complete identification used to describe the control system when the type of hardware and kinds of signals have been chosen.

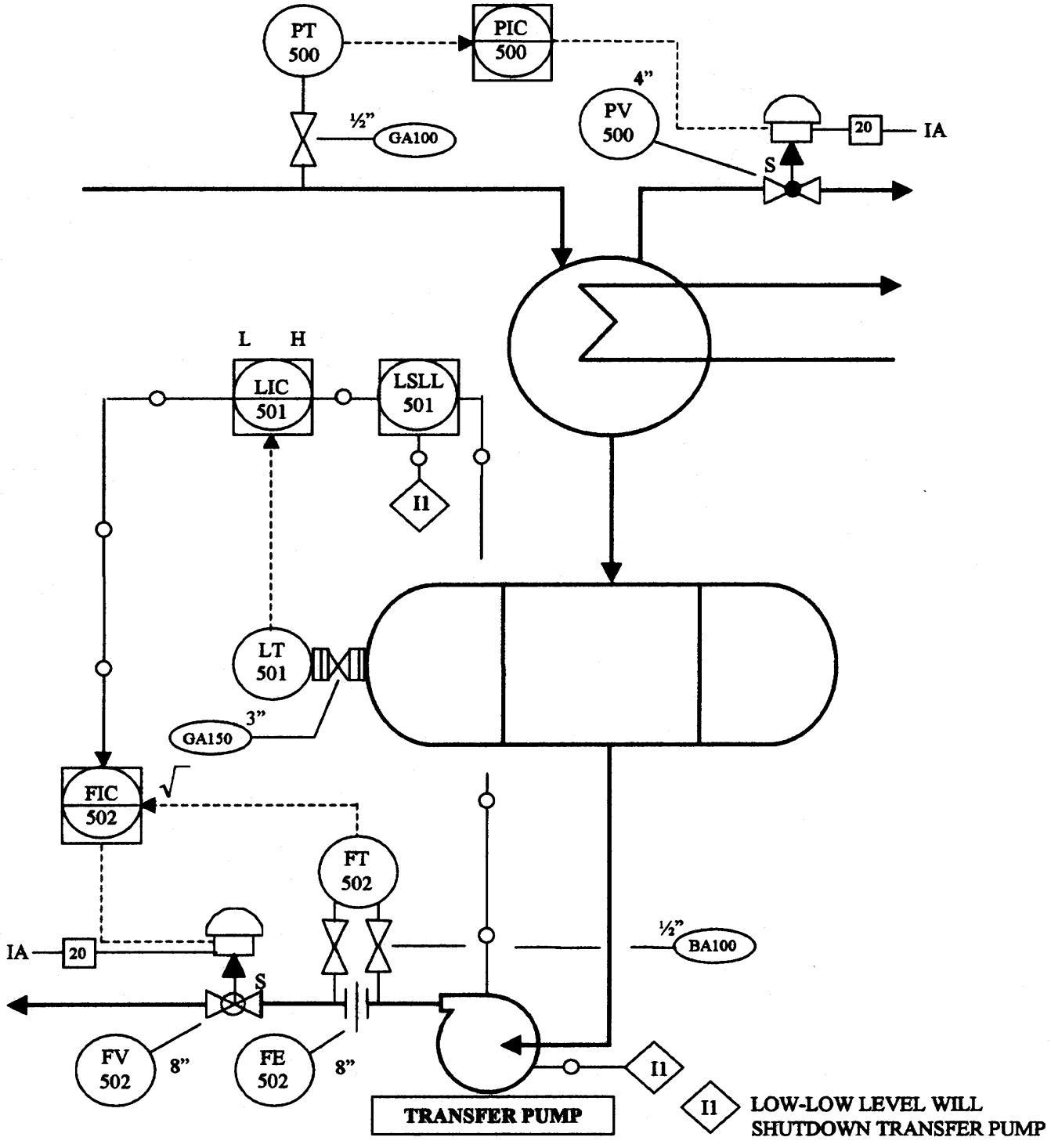
SIMPLIFIED DIAGRAM



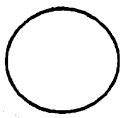
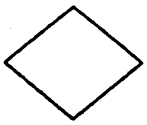
CONCEPTUAL DIAGRAM

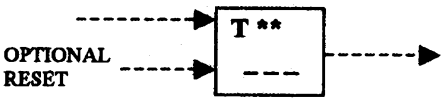
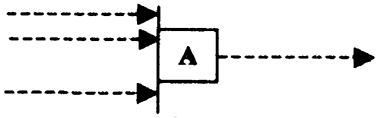
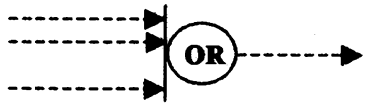
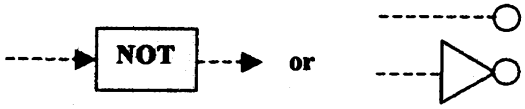


DETAILED DIAGRAM



FUNCTIONAL DIAGRAM SYMBOLS
SAMA PMC 20.1 – 1973

MEASURING OR READOUT	
MANUAL SIGNAL PROCESSING	
AUTOMATIC SIGNAL PROCESSING	
FINAL CONTROLLING ELEMENT	
FINAL CONTROLLING ELEMENT WITH POSITIONER	

TIME DELAY OR PULSE FUNCTION	
LOGICAL AND	
LOGICAL OR	
LOGICAL NOT	

** TON TIME DELAY ON
TOF TIME DELAY OFF
PD PULSE DURATION

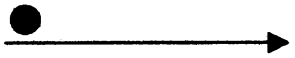
FUNCTIONAL DIAGRAM SYMBOLS
SAMA PMC 20.1 – 1973

FUNCTION	SYMBOL	FUNCTION	SYMBOL
SUMMING	Σ	HIGH SELECT	$>$
AVERAGING	Σ/n	LOW SELECT	$<$
DIFFERENCE	$\triangle$	HIGH LIMIT	$\not>$
PROPORTIONAL	K or P	LOW LIMIT	$\not<$
INTEGRAL	$\int$ or I	REVERSE PROPORTIONAL	-K or -P
DERIVATIVE	d/dt or D	VELOCITY LIMITING	$\vee\not>$
MULTIPLYING	$\times$	BIAS	$\pm$
DIVIDING	$\div$	TIME FUNCTION	$f(t)$
ROOT EXTRACTION	$\sqrt[n]{\ }$	VARIABLE SIGNAL GENERATOR	A
EXPONENTIAL	X^n	TRANSFER	T
NON-LINEAR FUNCTION	$f(x)$	SIGNAL MONITOR	H/ , H/L , /L
TRI-STATE SIGNAL	↕		
INTEGRATE	Q		

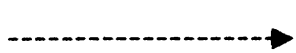
Split range in DCS



CONTINUOUSLY VARIABLE SIGNAL

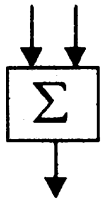
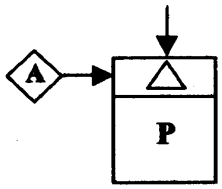
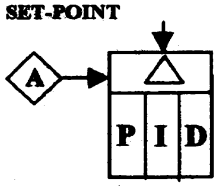
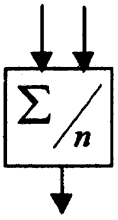
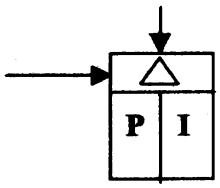
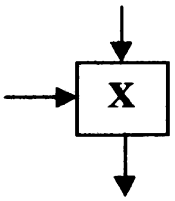
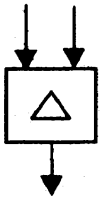
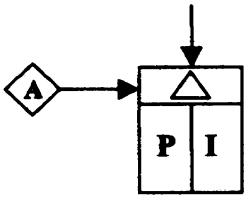
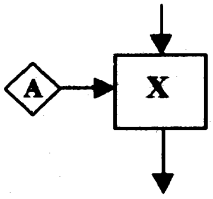
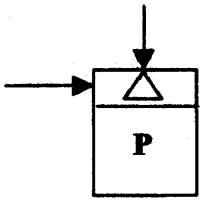
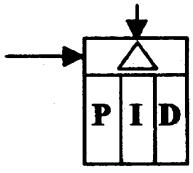
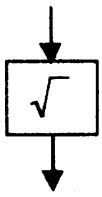


INCREMENTAL CHANGE SIGNAL

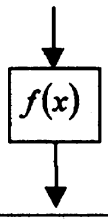
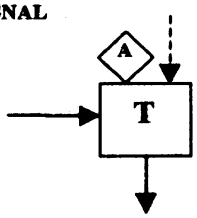
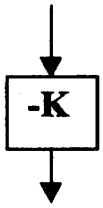
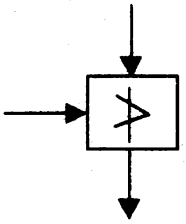
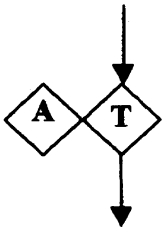
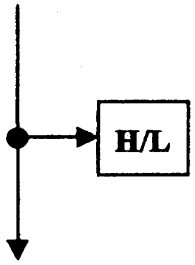
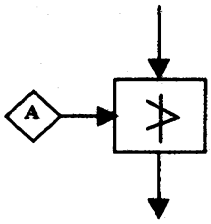
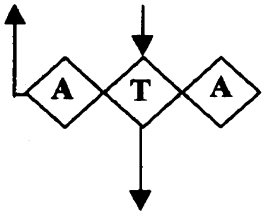
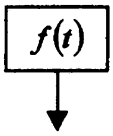
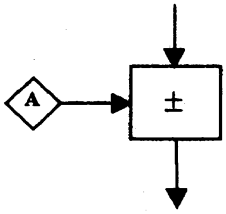
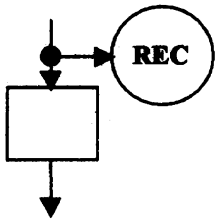
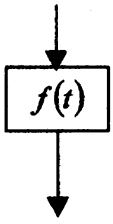


ON-OFF SIGNAL

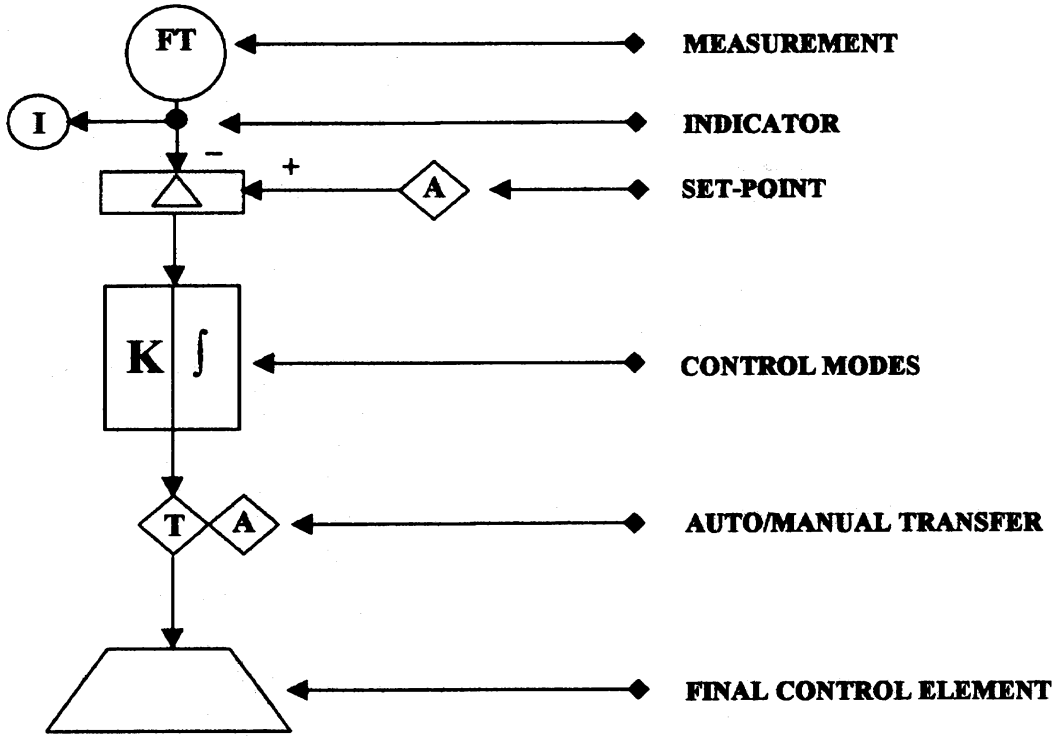
FUNCTIONAL DIAGRAM SYMBOLS
SAMA PMC 20.1 – 1973

1 **SUMMING OF TWO SIGNALS** 	**5** **PROPORTIONAL CONTROL WITH INTERNAL SET-POINT** 	**9** **PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL WITH INTERNAL SET-POINT** 
2 **AVERAGING TWO SIGNALS** 	**6** **PROPORTIONAL PLUS INTEGRAL CONTROL WITH SET-POINT FROM EXTERNAL SOURCE** 	**10** **MULTIPLY ONE SIGNAL BY ANOTHER** 
3 **DIFFERENCE OF TWO SIGNALS** 	**7** **PROPORTIONAL PLUS INTEGRAL CONTROL WITH INTERNAL SET-POINT** 	**11** **MULTIPLYING ONE SIGNAL BY A MANUALLY ADJUSTED MULTIPLIER** 
4 **PROPORTIONAL CONTROL WITH SET-POINT FROM EXTERNAL SOURCE** 	**8** **PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL WITH SET-POINT FROM EXTERNAL SOURCE** 	**12** **ROOT EXTRACTING** 

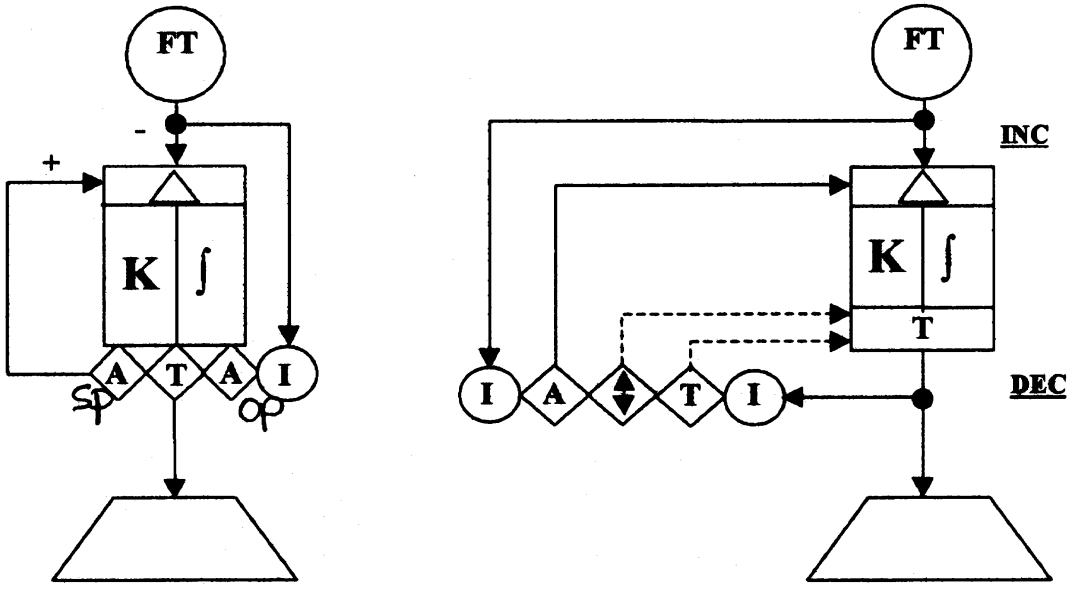
FUNCTIONAL DIAGRAM SYMBOLS
SAMA PMC 20.1 –1973

13 **NON-LINEAR FUNCTION PERFORMED ON A SIGNAL** 	**17** **AUTOMATIC TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL** 	**21** **SIGNAL REVERSAL** 
14 **HIGH LIMITING OF ONE SIGNAL BY ANOTHER** 	**18** **MANUAL TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL** 	**22** **SIGNAL MONIYOR** 
15 **HIGH LIMITING OF A SIGNAL BY A MANUAL ADJUSTMENT** 	**19** **MANUAL TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL INCLUDING SET-POINT** 	**23** **TIME FUNCTION (FUNCTION OF TIME ONLY)** 
16 **BIAS OF A SIGNAL BY A MANUAL ADJUSTMENT** 	**20** **READOUT FUNCTION (RECORDER , INDICATOR)** 	**24** **TIME FUNCTION (SIGNAL MODIFIED BY A FUNCTION OF TIME)** 

FUNCTION ORIENTED FORMAT



EQUIPMENT ORIENTED FORMAT



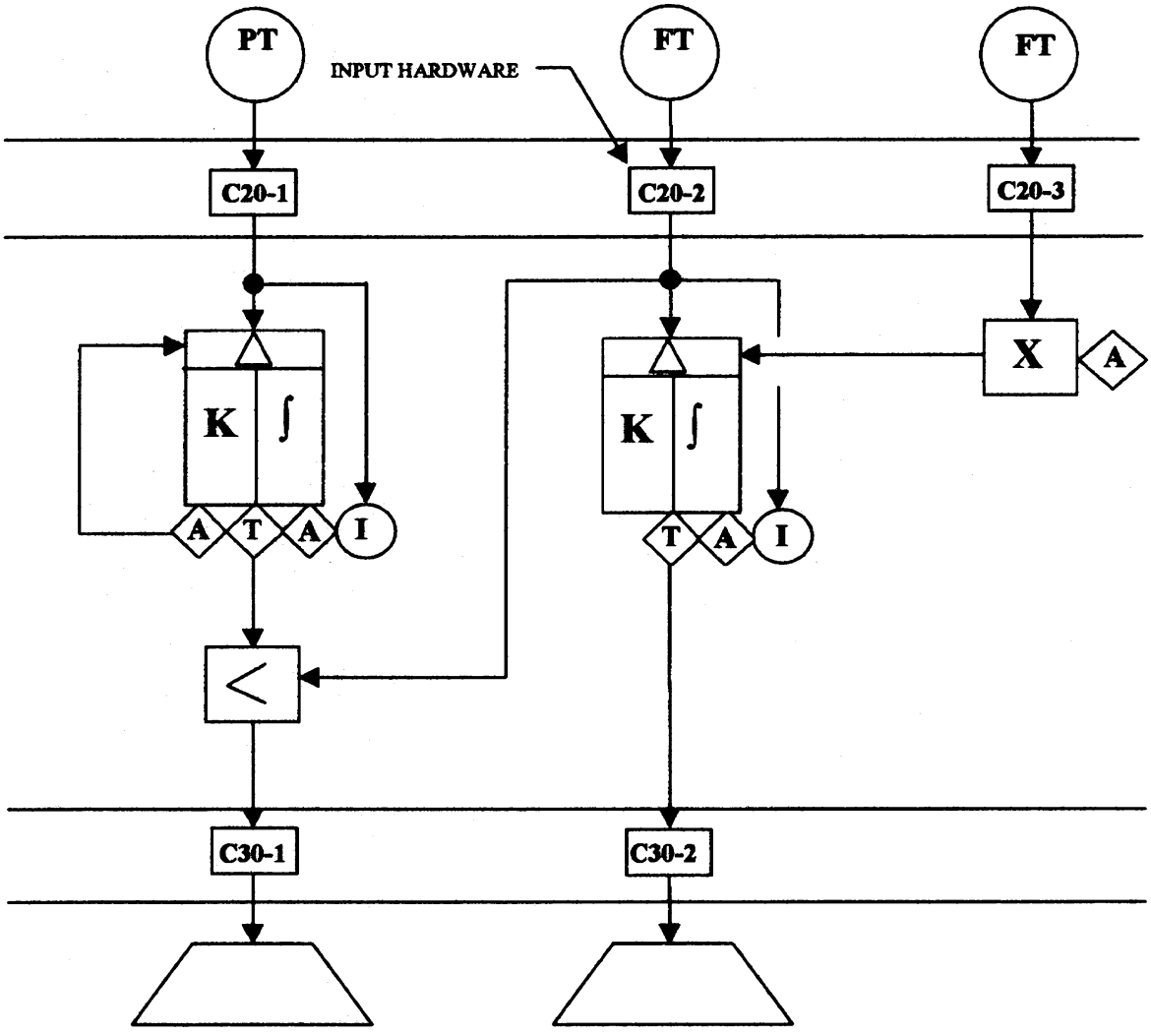
VERTICAL FORMAT

In the vertical format, the measuring functions are located at the top with the flow of the diagram downward. The processing and manual functions are in the center area and the final control functions are at the bottom.

In general, the main signals enter at the top of the signal enclosures (input) and leave at the bottom (output). On systems that have input and output hardware (cards), an area can be designated at the top for inputs and the bottom for outputs.

Auxiliary functions such as manual operations, set-point, biasing, etc.; enter the symbol enclosure at either side. Arrowheads are to be used for clarity.

If desired, input signals for readout functions can be taken off horizontally from the point of the desired measurement.



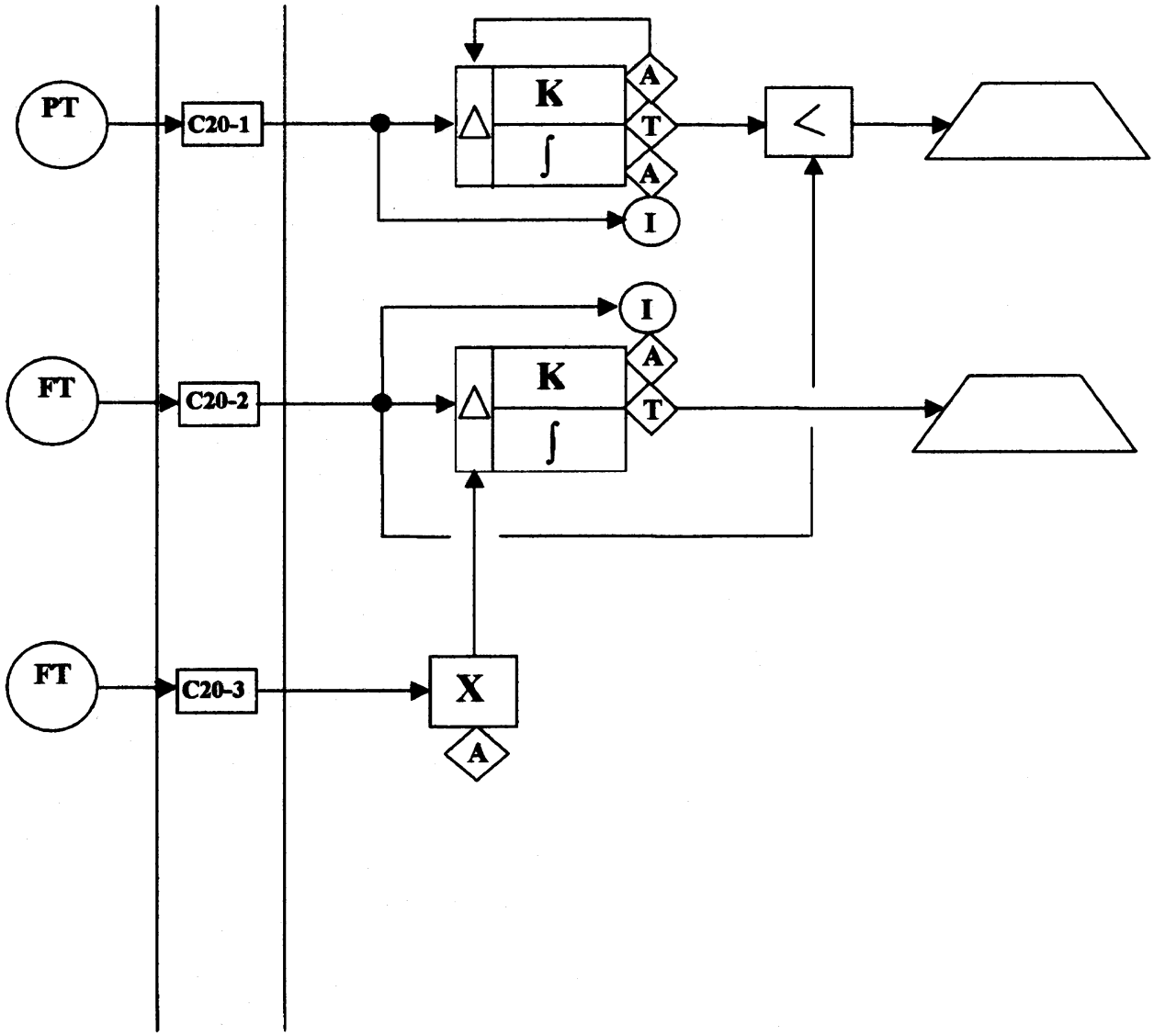
HORIZONTAL FORMAT

In the horizontal format, the measuring functions are located at the left with flow of the diagram to the right. The signal processing and manual functions are in the center area and the final control functions are at the right.

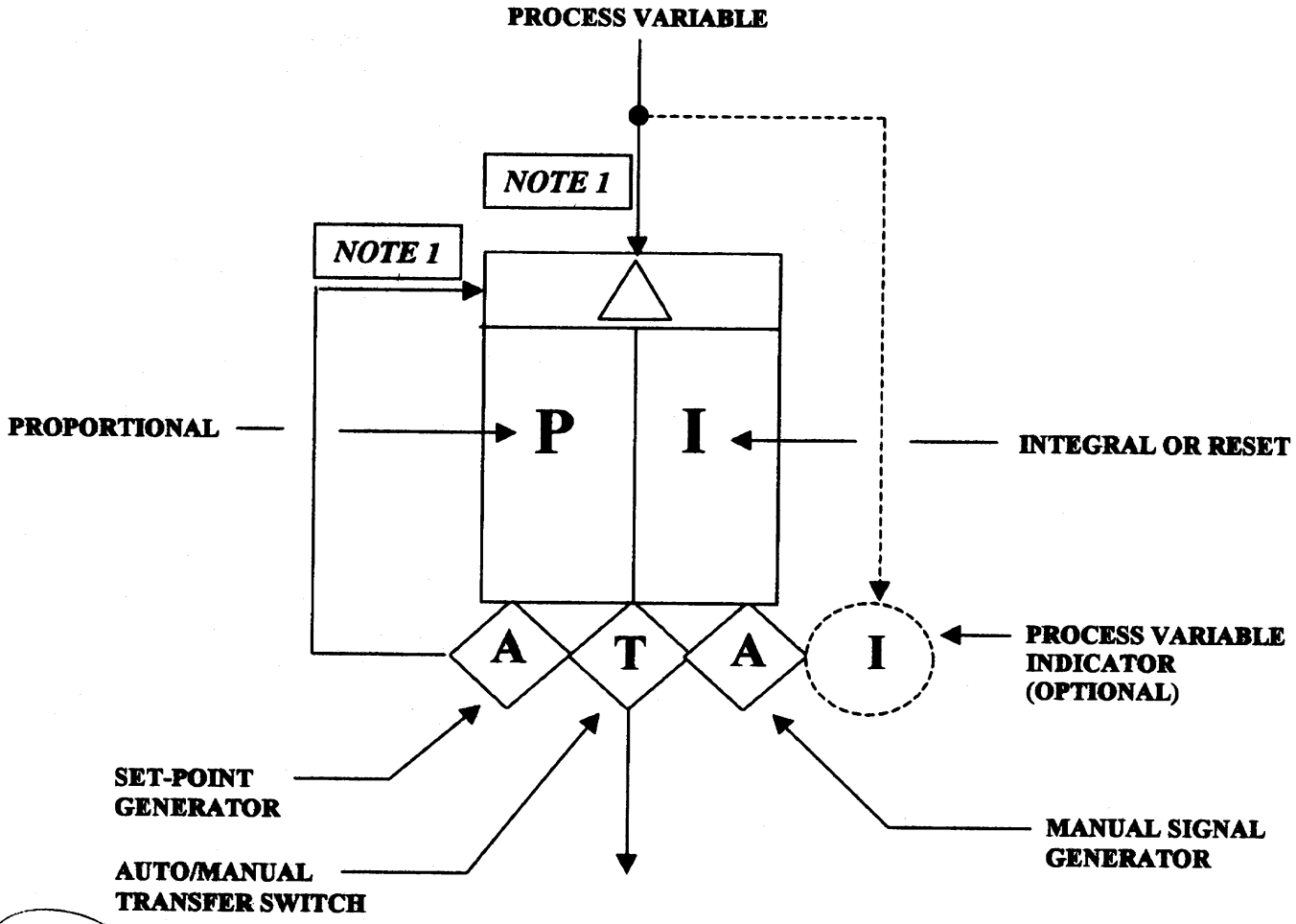
In general, the main signals enter at the left of the symbol enclosures (input) and leave at the right (output). On systems that have input and output hardware (cards), an area can be designated at the left for inputs and the right for outputs.

Auxiliary functions such as manual operations, set-point, biasing, etc.; enter the symbol enclosure at either the top or bottom. Arrowheads are used for clarity.

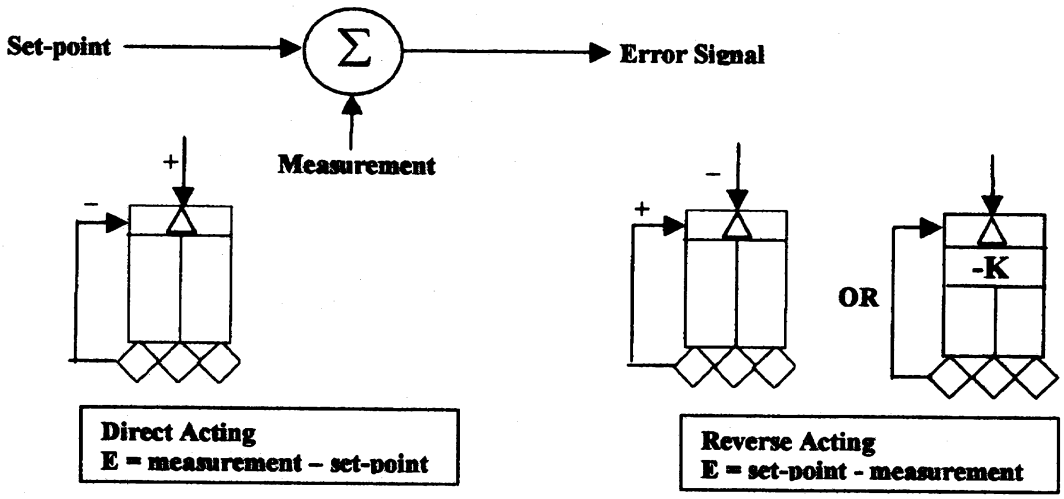
If desired, input signals for readout functions can be taken off vertically from the point of desired measurement.



BASIC CONTROLLER



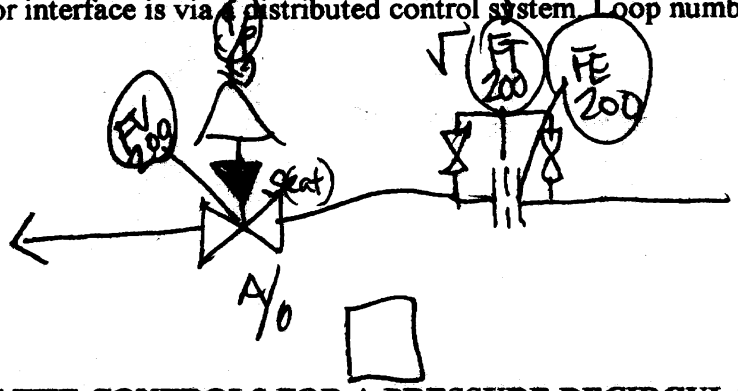
CONTROLLER ACTION – Reverse or Direct



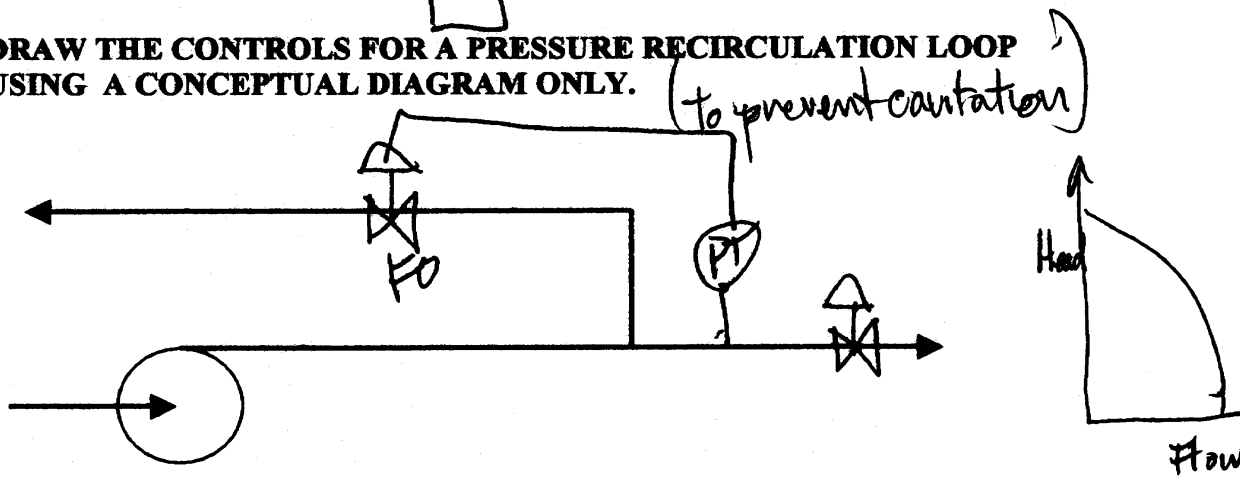
INSTRUMENTATION SYMBOLS AND IDENTIFICATION PROBLEMS

1. DRAW A DETAILED P&I DIAGRAM FOR THE FOLLOWING:

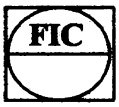
Flow control loop utilizing an orifice plate with pipe taps. Control valve to be diaphragm operated, air-to open, with a field mounted current-to-pneumatic transducer. The control valve is to be equipped with a pneumatic positioner. Operator interface is via a distributed control system. Loop number is 200.



2. DRAW THE CONTROLS FOR A PRESSURE RECIRCULATION LOOP USING A CONCEPTUAL DIAGRAM ONLY.



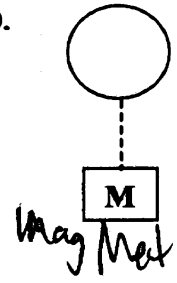
3. DESCRIBE THE FOLLOWING SYMBOLS:

A. 

B. 

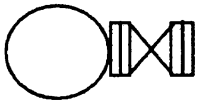
C. 

DCS inaccessible

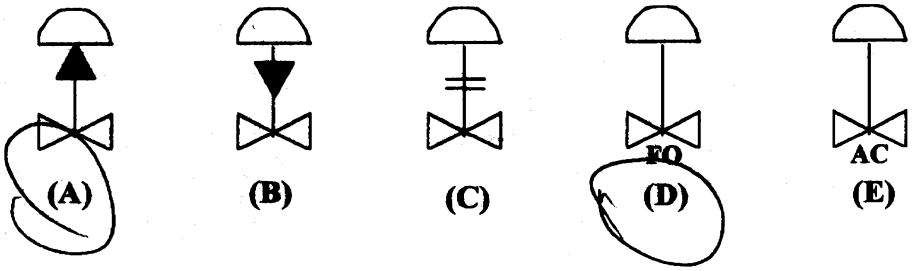
D. 

E. 

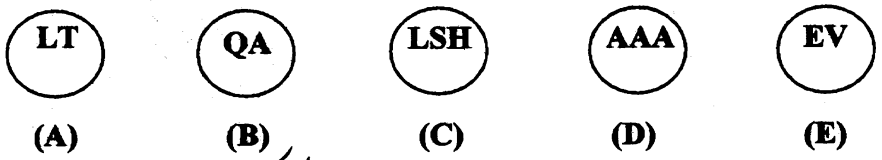
F. 

G. 

4. **ACCORDING TO ISA STANDARD S5.1 WHICH OF THE FOLLOWING IS A SYMBOL FOR A FAIL-OPEN VALVE ?**

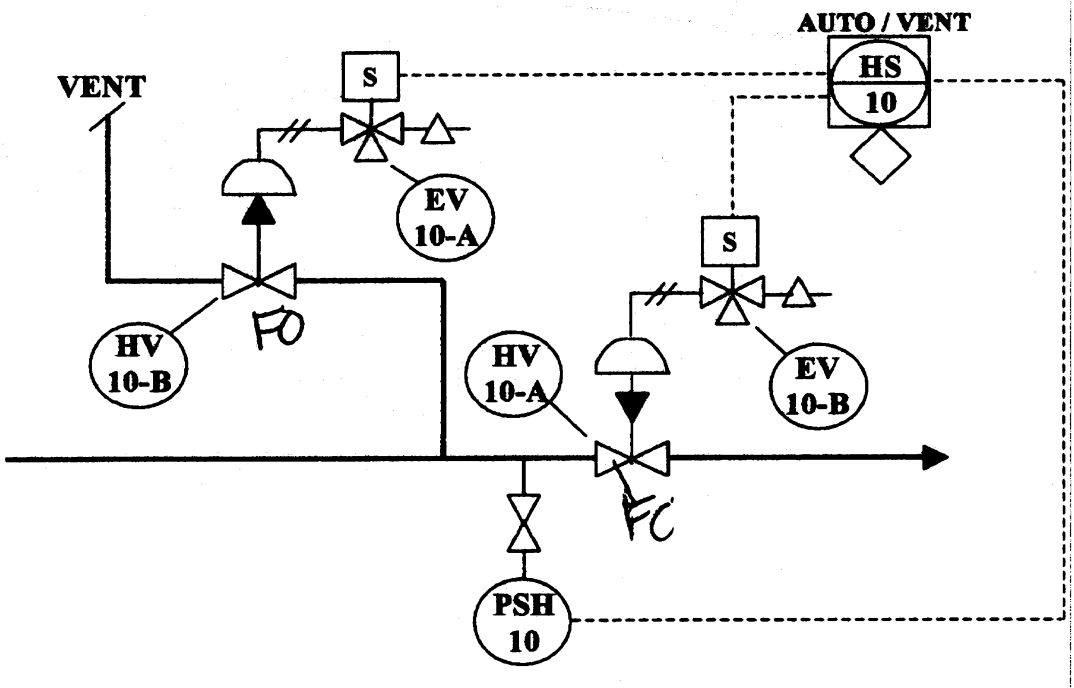


5. **DEFINE THE FOLLOWING INSTRUMENTS:**

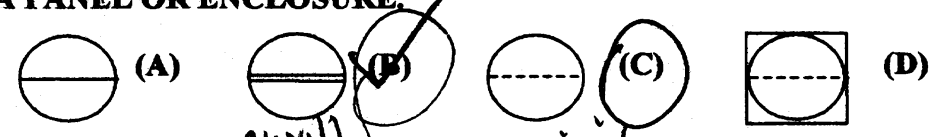


EVENT ALARM

6. **DESCRIBE THE INTERLOCK FOR THE FOLLOWING.**



7. **ACCORDING TO ISA STANDARD S5.1, WHICH OF THE FOLLOWING IS THE SYMBOL FOR A DISCRETE INSTRUMENT MOUNTED INSIDE A PANEL OR ENCLOSURE.**



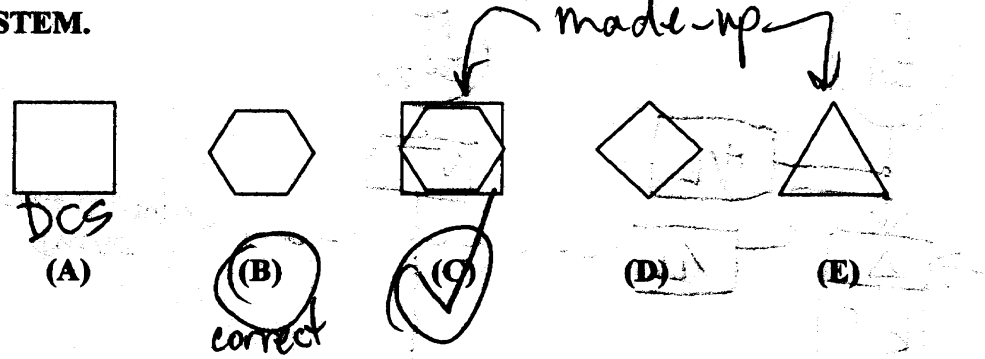
auxil location

inside unaccessible

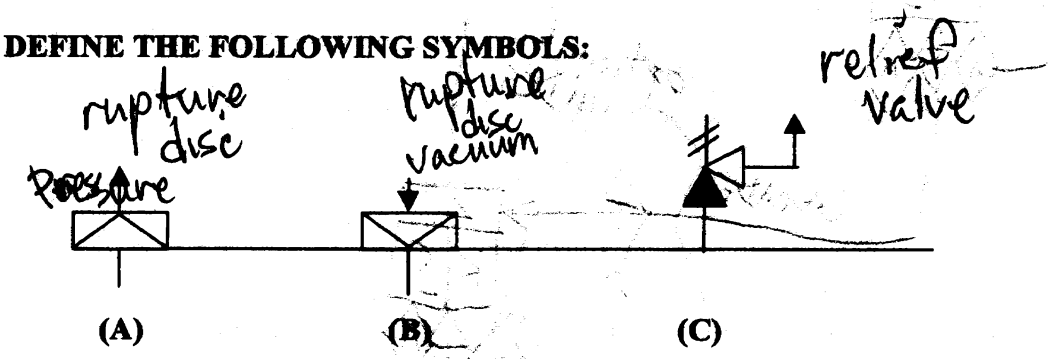
to the operator

8. **DEFINE THE TERM <u>ACCESSIBLE</u> AS USED IN ISA STANDARD S5.1.**

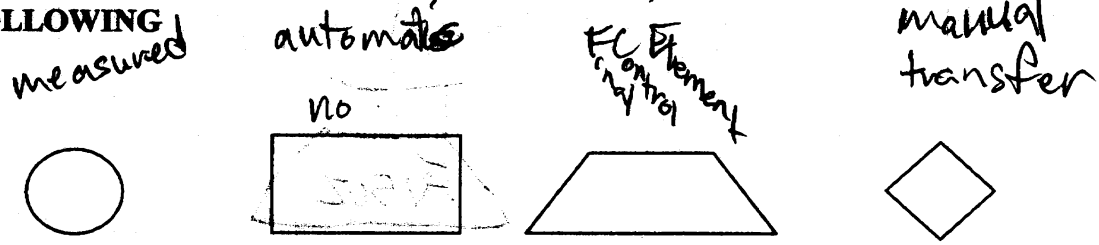
9. **ACCORDING TO ISA STANDARD S5.1, WHICH OF THE FOLLOWING SYMBOLS REPRESENT A MILLS ENVIROMENTAL COMPUTER SYSTEM.**



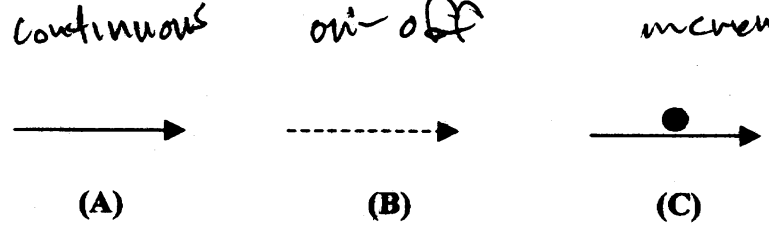
10. **DEFINE THE FOLLOWING SYMBOLS:**



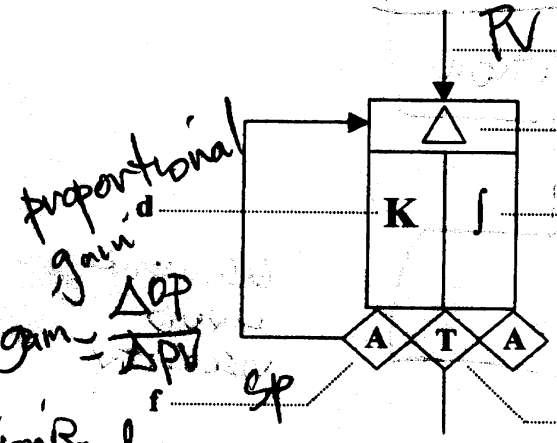
11. **ACCORDING TO SAMA STANDARD PMC 20.1, DEFINE THE FOLLOWING**



12. **ACCORDING TO SAMA STANDARD STANDARD 20.1, DEFINE THE FOLLOWING**



13. DEFINE THE FOLLOWING FUNCTIONS:

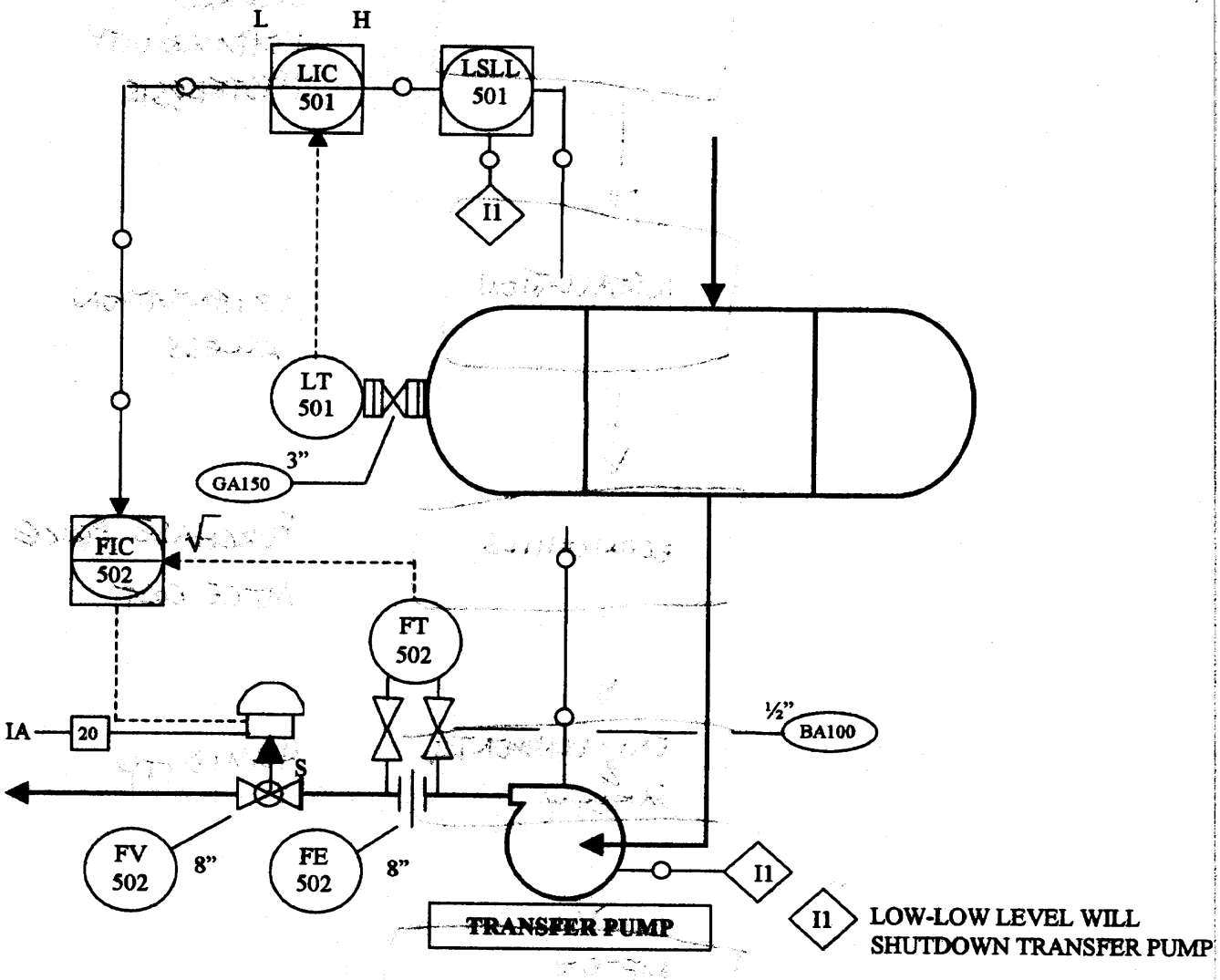


proportional gain

$\frac{100}{P.B.} = gain = \frac{\Delta OP}{\Delta PV}$

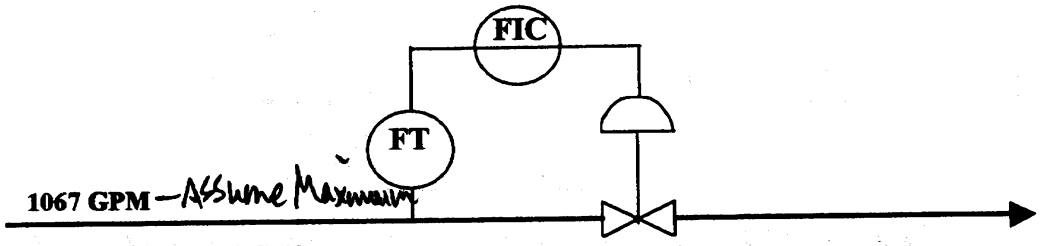
P.B. = Proportion Band

14. DRAW A SAMA DIAGRAM FOR THE FOLLOWING:



MEASUREMENT / SENSORS
FLOW

1. GIVEN THE FOLLOWING PROCESS CONDITIONS:



WATER @ 125 DEG. F
8 INCH C.S. SCH. 40 PIPE
I.D. = 7.981 inches

A. SELECT THE DESIRED RANGE FOR SIZING THE FLOW ELEMENT

- ☐ **0 – 1067 GPM**
- ☐ **0 – 1100 GPM** too close
- ☑ **0 – 1400 GPM** Best answer
- ☐ **0 – 3000 GPM** too high

$\frac{1067}{75\%} = 1422 \approx 1400$

B. WHAT FLOW RATE SHOULD BE USED TO SIZE THE CONTROL VALVE?

- ☐ **SAME AS THE FLOW ELEMENT**
- ☐ **10 PERCENT MORE THAN THE FLOW ELEMENT**
- ☐ **20 PERCENT MORE THAN THE FLOW ELEMENT**
- ☑ **1067 GPM** — Size valve for exact flow conditions
- ☐ **1100 GPM**
- ☐ **1450 GPM**

since only one flow – Best answer

min / max / norm

C. SIZE A MAGNETIC TYPE FLOW ELEMENT FOR THE STATED CONDITIONS.

fluid must be conductive
velocity – type not head type

normal velocity 2-25 fps
abrasive 3-10 fps
non-abrasive 5-15 fps

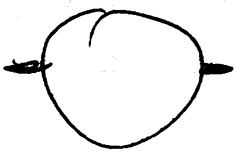
$V = \frac{0.4085\ GPM}{D^2}$ fps

V = feet per sec
GPM = gal/min
D = inches

6" meter	8"
12.1	6.

best answer

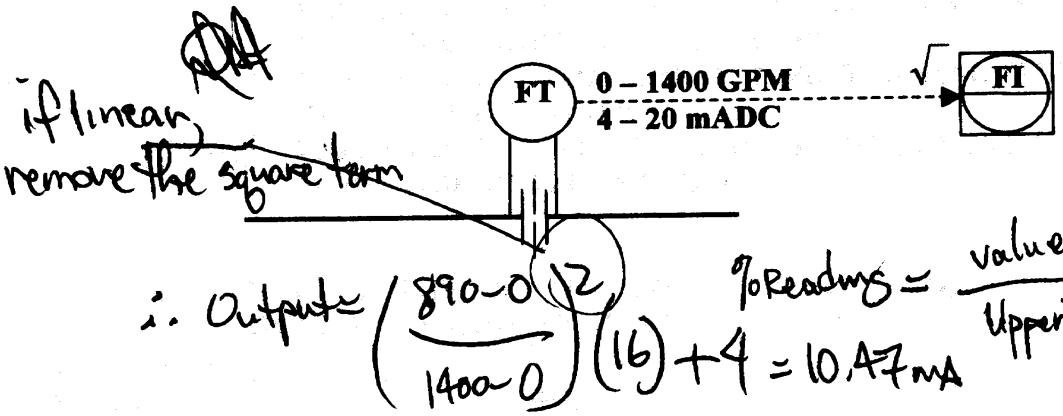
D. STATE THE PHYSICAL INSTALLATION REQUIREMENTS FOR THE MAGNETIC FLOW ELEMENT AS RELATED TO PHYSICAL PIPING REQUIREMENTS, GROUNDING AND ELECTRODE ORIENTATION.



liquid with solids type

10D-5D upstream
5D-3D downstream
} straight run

3. **GIVEN THE FOLLOWING DIAGRAM, DETERMINE THE TRANSMITTER OUTPUT (mADC) AT A FLOWRATE OF 890 GPM.**



if linear, remove the square term

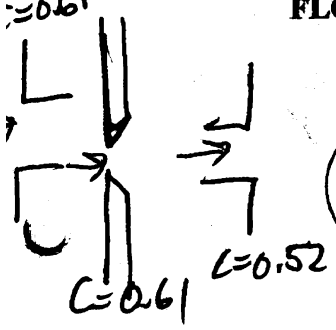
$$\therefore \text{Output} = \left(\frac{890-0}{1400-0}\right)(16)+4 = 10.47\text{ mA}$$

$$\%\text{Reading} = \frac{\text{value} - \text{LowerRange}}{\text{UpperRange} - \text{LowerRange}}$$

4. **GIVEN THE FOLLOWING INFORMATION, CALCULATE THE FLOWRATE AT A DIFFERENTIAL OF 40 INCHES OF WATER.**

Use (1) $Q = (19.636)(.61)(5.81)^2\sqrt{333}\sqrt{0.78}$ from Cameron Hydraulics or Crane

$Q = 870.04$ GPM



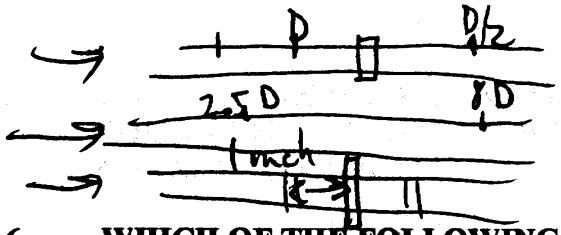
D = 7.981 inches
d = 5.81

$$\text{Beta Ratio } \beta = \frac{d}{D} = 0.728$$

(1) for $\beta > 0.3$: $Q = 19636\, C d^2 \sqrt{h}\sqrt{\frac{1}{1-\left(\frac{d}{D}\right)^2}}$ GPM

(2) for $\beta \leq 0.3$: $Q = 19636\, C d^2 \sqrt{h}$ ← ft of H_2O

5. **DEFINE THE TWO MOST COMMON TAP ARRANGEMENTS USED ON HEAD TYPE FLOW ELEMENTS.**



Radius Taps – most common

Pipe Taps – seldom used

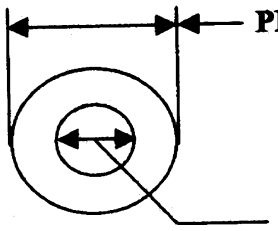
Flange Taps – Must be 300# Flange up 8"

6. **WHICH OF THE FOLLOWING FLUIDS CANNOT BE MEASURED USING MAGNETIC FLOW TECHNOLOGY?**

- ☐ **WATER** YES (NO – IF DEMIN WATER)
- ☐ **KEROSENE** NO
- ☐ **MILK** YES
- ☐ **STEAM** NO
- ☐ **PAPER STOCK (PULP)** YES
- ☐ **SULFURIC ACID** YES

E. DEFINE AND CALCULATE THE BETA RATIO FOR THE FOLLOWING.

$\beta = \frac{\text{bore}}{ID}$



$\beta = \frac{5.81}{7.981} = 0.72798$

F. WHAT IS THE ACCEPTABLE OPERATING BETA RATIO RANGE FOR AN ORIFICE PLATE METER?

0.6 or 0.2 – 0.75

G. AS THE BETA RATIO IS DECREASED, WHAT IS THE EFFECT ON PERMANENT PRESSURE LOSS AND PIPING CONFIGURATION?

permanent pressure loss increases

piping configuration decreases
10 upstream
5 downst

2. DEFINE THE MEASUREMENT PRINCIPLE BEHIND THE FOLLOWING FLOW DEVICES:

A. VORTEX FLOW ELEMENT

velocity
Pr



alternating frequency proportional to flow

B. MAGNETIC FLOW METER

veloc

C. VENTURI TUBE

differential or head type

D. ROTAMETER

head-type differential (like variable orifice)

E. WEIR

For V-Notch (60°) $Q = 1.46 H^{5/2}$

F. TURBINE FLOW METER

velocity

high accuracy

clean fluid
non-viscous

custodial transfer

factory calibrated to fluid

Facsimile Cover Sheet

Ref: General Policies and Procedures No. 39 5006 110

Raytheon Engineers & Constructors

Raytheon Engineers & Constructors, Inc.
100 Corporate Parkway
Birmingham, AL 35242-2928
205-995-7878 RNX: 549
FAX: 205-995-6842
Confirmation: 205-995-6228

Date	Message No.	
To	Telephone No.	Location/Department
Organization	Fax No. 334-621-5139	
From D. Haynes	Telephone No.	Mail Stop

Message:

Contents: Total Pages Transmitted 3 including Cover Page

This should help.

David

Notes:
1. *If message is not received completely or not received by intended party, please contact sender.*
2. *No classified information shall be sent via facsimile.*
3. *No technical data related to defense or services shall be Transmitted out of the United States.*
4. *No "Company Private" material shall be sent to an unattended machine and transmission to an attended machine requires telephone confirmation to intended recipient upon receipt.*

RUST, BIRMINGHAM, ALABAMA

JOB NO.

FOR

AT

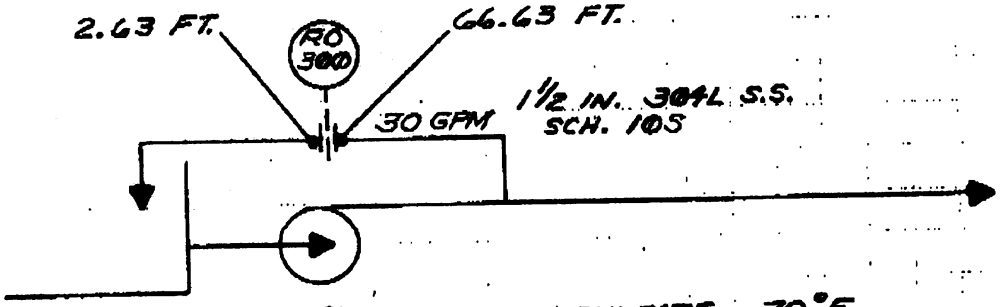
DESCRIPTION PROBLEM F-2, RESTRICTION ORIFICE

DATE

BY D. Haynes CKD.

DWG.

CRITERIA: 1. Calculate orifice bore diameter for pump recirculation.



10% MAGNESIUM SULFATE, 70°F
Specific gravity = 1.1
Viscosity = 2 cp

REFERENCE: FISHER & PORTER
FLOWMETER ORIFICE SIZING HANDBOOK 10B9000
RESTRICTION ORIFICE SIZING METHOD 10B-5

(1) $$KB^2 = \frac{(gpm)}{5.667\,Fa\,(D^2)}\sqrt{\frac{G}{hw}}$$

$Fa = 1.0$
$hw = 775.56''$ (66.63' - 2.63' = 64.63')
$D = 1.682''$
$G = 1.1$

$$KB^2 = \frac{30}{5.667 * 1.0 * 1.682^2}\sqrt{\frac{1.1}{775.56}} = .071$$

(2) SOLVE FOR REYNOLDS NUMBER

$$R_D = \frac{3160\,(gpm)\,(G)}{D\,(centipoise)} = \frac{3160 * 30 * 1.1}{1.682 * 2} = 30,998.8$$

(3) DETERMINE β
$KB^2 = 0.071$, $R_D = 30,998$ ∴ USE FIG. 2c (10B-5 F&P)
$\beta = .331$

$$d = \beta D = .331 * 1.682 = .557$$

27

RUST, BIRMINGHAM, ALABAMA

JOB NO. OR

FOR

AT

DESCRIPTION F-2.1 , RESTRICTION ORIFICE

DATE

BY D. Haynes CKD.

DWG.

ALTERNATE - RESTRICTION ORIFICE SIZING

REFERENCE : CAMERON HYDRAULIC DATA, 16 TH ED., FIRST PRINTING
PP 2-8

EQUATION FOR APPROXIMATE DISCHARGE THROUGH ORIFICE

$$Q = 19.636\ Cd_1^2\sqrt{h}\ \sqrt{\frac{1}{1-\left(\frac{d_1}{d_2}\right)^4}}$$

replace d_1 with d and d_2 with D

$$Q = 19.636\ Cd^2\sqrt{h}\ \sqrt{\frac{1}{1-\left(\frac{d}{D}\right)^4}}$$

1. Solve for d
2. Add Fa
3. Rearrange into 2 equations, substituting K for the combination of constants.

$$K = \frac{Q^2}{(19.636\ Fa\ C)^2 h} \qquad d = \sqrt[4]{\frac{K}{1+\frac{K}{D^4}}}$$

Q = flow rate, gpm
Fa = area factor for thermal expansion of orifice
C = discharge coefficient
h = differential head, feet of liquid
d = bore diameter, inches
D = internal pipe diameter, inches

Values from problem F-2

Q = 30, Fa = 1.0, C = .61, D = 1.682, h = 64.63'

$$K = \frac{30^2}{[(19.636)(1.0)(.61)]^2(64.63)} = 0.097061 \qquad d = \sqrt[4]{\frac{.097061}{1+\frac{.097061}{1.682^4}}}$$

$d = 0.556484$ USE 0.556

Pg. 3-122 $Q = 19.65\, d^2 \sqrt{\frac{h_L}{K}}$

$$K = \frac{Q^2}{[19.636\, F_A\, C]^2 h} \qquad h_f = K \frac{Q^2}{3861\, d^4}$$

$$d = \sqrt[4]{\frac{K}{1 + \frac{K}{D^4}}}$$

$$d^4 = \frac{K}{1 + \frac{K}{D^4}} \Rightarrow K = d^4\left[1 + \frac{K}{D^4}\right]$$

$$K = d^4 + K\left(\frac{d}{D}\right)^4$$

$$K - K\left(\frac{d}{D}\right)^4 = d^4$$

$$K\left[1 - \left(\frac{d}{D}\right)^4\right] = d^4$$

$$K = \frac{d^4}{\left[1 + \left(\frac{d}{D}\right)^4\right]}$$

$$\frac{Q^2}{19.636\, F_A\, C\, h} = \frac{d^4}{1 + \left(\frac{d}{D}\right)^4}$$

$$\frac{30.00^2}{[(19.636)(1.0)(0.61)]^2(64.62)} = \frac{d^4}{1 + \left(\frac{d}{1.682}\right)^4}$$

$$0.09706 = \frac{d^4}{1 + \left(\frac{d}{D}\right)^4}$$

$$0.09706\left[1 + \left(\frac{d}{1.682}\right)^4\right] = d^4$$

$$0.09706 + 0.01213\, d^4 = d^4$$

$$0.09706 = d^4[1 - 0.01213]$$

$$= d^4\, 0.9879$$

$$d^4 = 0.09825 \qquad d = \sqrt[4]{0.09825} = 0.55$$

gpm

ft

inches

inches

$$\frac{Q}{19.63\, C\sqrt{h}} = \frac{d^2}{\sqrt{1-\left(\frac{d}{D}\right)^4}}$$

$$\frac{(30\text{ gpm})}{(19.63)(0.61)\sqrt{6463}} = (0.3115) = \left(\frac{d^2}{\sqrt{1-\left(\frac{d}{D}\right)^4}}\right)^2$$

$$0.09706 = d^4\left(\frac{1}{1-\left(\frac{d}{D}\right)^4}\right)$$

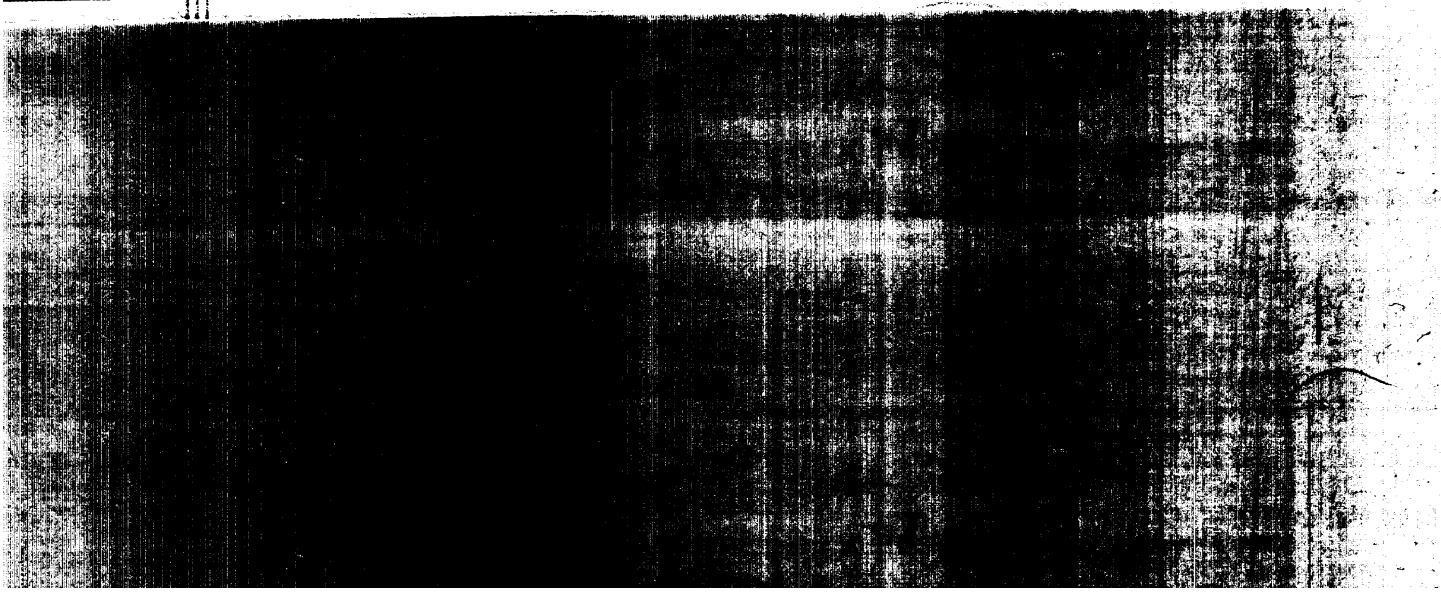
$$0.09706 = \frac{d^4}{1-\left(\frac{d}{D}\right)^4}$$

$$0.09706\left[1-\left(\frac{d}{D}\right)^4\right] = d^4$$

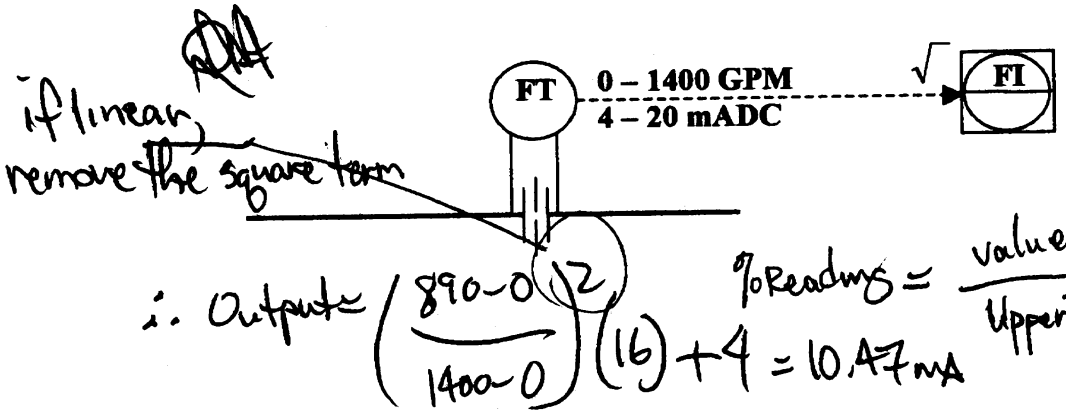
$$0.09706 - 0.09706\,\frac{d^4}{D^4} = d^4$$

$$0.09706 = 1.01213\, d^4$$

$$0.09590 \approx d^4 \Rightarrow d = \sqrt[4]{0.09590} \approx 0.5$$



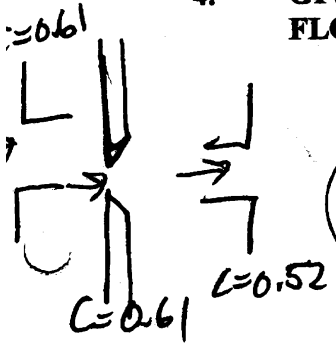
3. **GIVEN THE FOLLOWING DIAGRAM, DETERMINE THE TRANSMITTER OUTPUT (mADC) AT A FLOWRATE OF 890 GPM.**



$\therefore$ Output $= \left(\frac{890-0}{1400-0}\right)^{2}(16)+4 = 10.47\text{ mA}$

$\%\text{Reading} = \frac{\text{value} - \text{LowerRange}}{\text{UpperRange} - \text{LowerRange}}$

4. **GIVEN THE FOLLOWING INFORMATION, CALCULATE THE FLOWRATE AT A DIFFERENTIAL OF 40 INCHES OF WATER.**





D = 7.981 inches
d = 5.81

Use (1) $Q = (19.636)(.061)(5.81)^2\sqrt{333}\sqrt{1-(0.728)^4}$ from Cameron Hydraulics or Crane

$Q = 870.04$ GPM

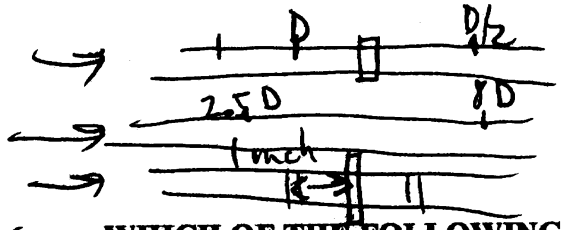
$\text{Beta Ratio} = \beta = \frac{d}{D} = 0.728$

(1) for $\beta \le 0.3$ $\quad Q = 19636\, C d^2 \sqrt{h}\sqrt{\frac{1}{1-\left(\frac{d}{D}\right)^4}}$

(2) for $\beta \ge 0.3$ $\quad Q = 19636\, C d^2 \sqrt{h}$ ← ft of H_2O

GPM

5. **DEFINE THE TWO MOST COMMON TAP ARRANGEMENTS USED ON HEAD TYPE FLOW ELEMENTS.**



Radius Taps – most common

Pipe Taps – seldom used

Flange Taps – Must be 300# Flange up

6. **WHICH OF THE FOLLOWING FLUIDS CANNOT BE MEASURED USING MAGNETIC FLOW TECHNOLOGY?**

- ☐ **WATER** YES (NO – DEMIN WATER)
- ☐ **KEROSENE** NO
- ☐ **MILK** YES
- ☐ **STEAM** No
- ☐ **PAPER STOCK (PULP)** YES
- ☐ **SULFURIC ACID** YES

12. **GIVEN AN EXISTING ORIFICE PLATE AND TRANSMITTER THAT IS TO BE REUSED FOR A DIFFERENT APPLICATION, WHAT ARE SOME OF THE PRIMARY ITEMS THAT MUST BE EVALUATED TO DETERMINE ITS ACCEPTABILITY TO THE NEW PROCESS?**

Flow rate
Differential
Plate thickness
Plate material

13. **AS A GENERAL RULE OF THUMB, WHAT IS THE MAXIMUM DIFFERENTIAL WHICH CAN BE USED FOR SIZING A HEAD TYPE METER IN A GAS OR VAPOR APPLICATION AND WHY?**

$\frac{\text{in H}_2\text{O}}{\text{psia}} \rightarrow \frac{h_w}{P_{f_1}} \leq 1.0$

14. **THE FLOW OF WATER IN A 4-INCH STEEL PIPE IS MEASURED WITH AN ORIFICE PLATE AND DIFFERENTIAL PRESSURE TRANSMITTER. AT A FLOW RATE OF 120 GPM, THE DIFFERENTIAL PRESSURE IS 27 INCHES OF WATER. AT A FLOW RATE OF 176 GPM, THE DIFFERENTIAL PRESSURE WILL BE APPROXIMATELY EQUAL TO :**

- ☐ 12 IN. W.C.
- ☐ 18 IN. W.C.
- ☐ 39 IN. W.C.
- ☐ 58 IN. W.C.
- ☐ 68 IN. W.C.

$\frac{\Delta P_2}{\Delta P_1} = \left(\frac{F_2}{F_1}\right)^2 \quad \therefore \Delta P_2 = \Delta P_1 \left(\frac{F_2}{F_1}\right)^2$

$= 27 \left(\frac{176}{120}\right)^2$

$\Delta P_2 = 58.1$

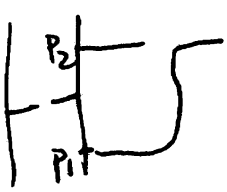
15. **ON A GIVEN MAGNETIC FLOW METER INSTALLATION, THE READING IS NEGATIVE. WHAT IS THE PRIMARY REASON?**

coils are wired backwards

16. **WHAT IS THE EFFECT OF A CHANGE IN SPECIFIC GRAVITY ON A LIQUID FLOW APPLICATION UTILIZING A HEAD TYPE FLOW METER?**

increase S.G. → increase flow

For vertical pipe

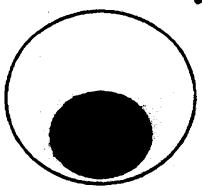




used for gas & vapor

Used for liquid

9. DEFINE THE FOLLOWING TYPE OF ORIFICE BORE AN WHAT TYPE OF APPLICATION WOULD REQUIRE SUCH A BORE.



Use for Entrained Solids mixed phase

ECCENTRIC

10. ON A GAS FLOW MEASUREMENT UTILIZING AN ORIFICE PLATE, WHAT IS THE EFFECT OF PRESSURE AND TEMPERATURE CHANGES ON THE MEASUREMENT?

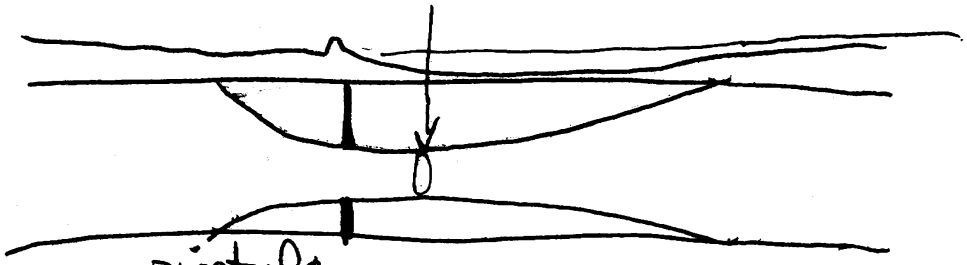
FM≈

FM

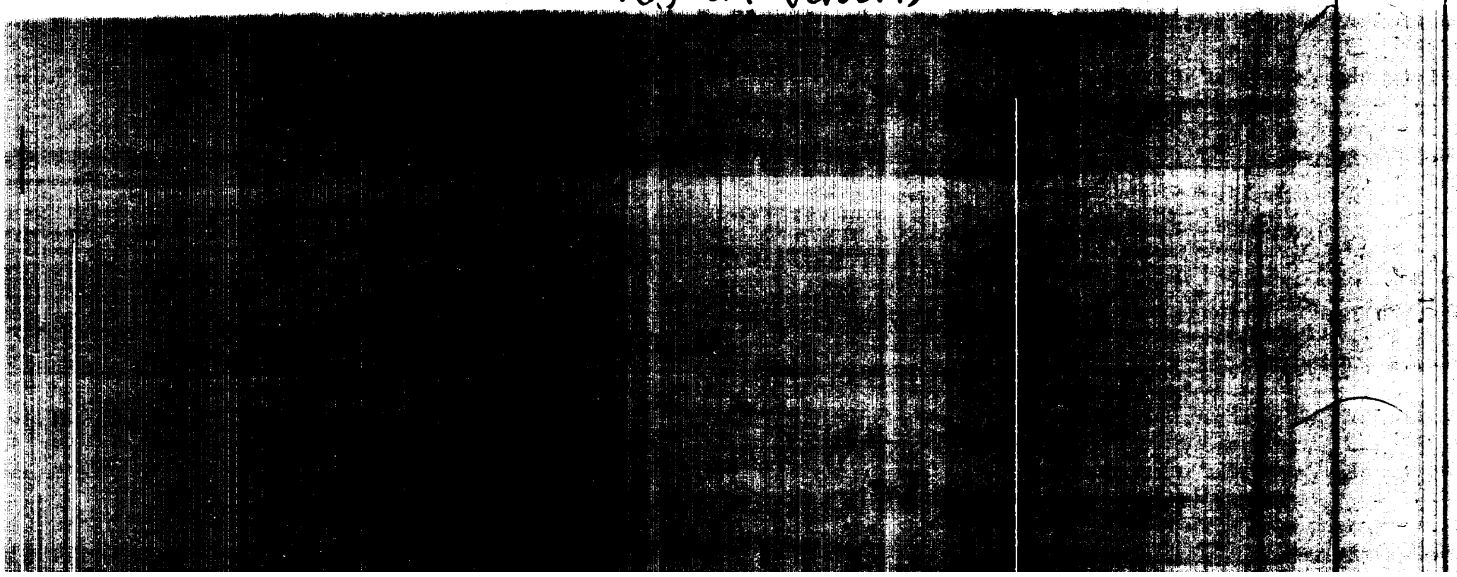
(↑P) pressure → direct-acting (increase measure

(↑T) temperature → reverse-acting (decrease measurem

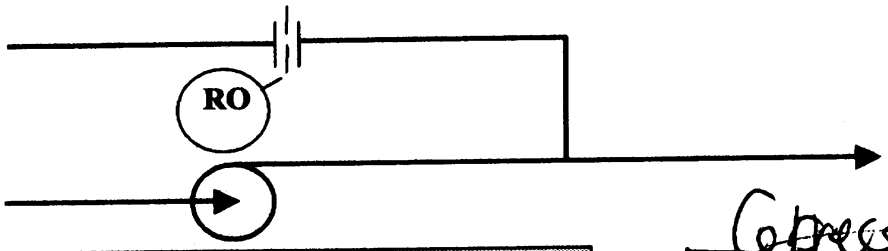
11. DEFINE THE TERM VENA CONTRACTA.



point of: smallest Area
largest ΔP, lowest pressure
highest velocity



17. GIVEN THE FOLLOWING, CALCULATE THE ORIFICE BORE FOR A PUMP RECIRCULATION LINE.



P1 = 66.63 FEET
P2 = 2.63 FEET ≅ 2 ft
FLOWRATE = 30 GPM
1-1/2 304L SS SCH. 10 PIPE
10 % MAGNESIUM SULFATE
70 DEG.F SPECIFIC GRAVITY = 1.1
VISCOSITY = 2 CP

Correct Answer

$d = 0.0556484$

From Crane Pg 8-16
$D = 1.682$
Internal Diameter

$h = P_1 - P_2$
$h = 64.63$ F
differential

$F_a = 1.0$
Thermal Expansion Factor

$C = 0.61$
Discharge Coeff

(1) $K = \frac{d^4 Q^2}{[19.636 F_A C]^2 h^2}$

(2) $d = \sqrt[4]{\frac{K}{[1 + K]^2}}$

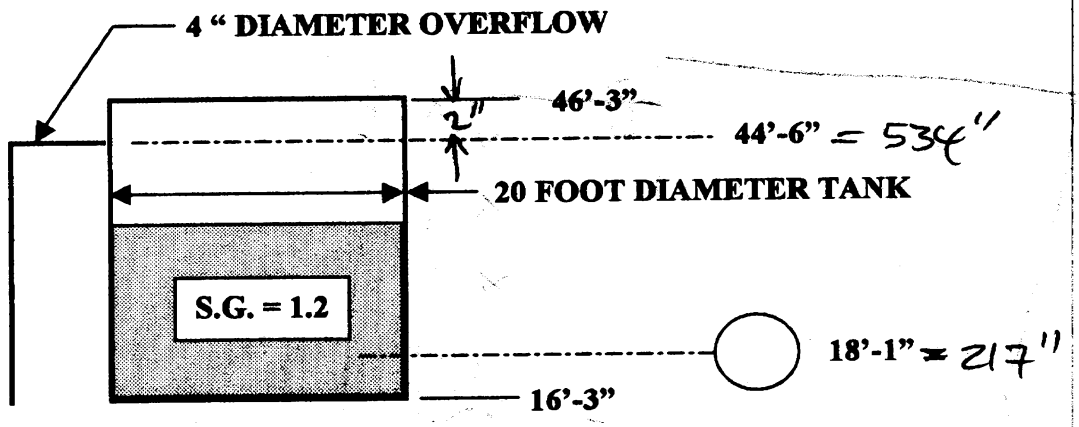
Cameron
(Orange book Pg 2-8)

for $\beta > 0.3$ $\quad Q = 19.636 C d^2 \sqrt{h} \sqrt{\frac{1}{1 - \left(\frac{d}{D}\right)^4}}$

for $\beta < 0.3$ $\quad Q = 19.636 C d^2 \sqrt{h}$

LEVEL

1. **GIVEN THE FOLLOWING INFORMATION:**



A. **DETERMINE PHYSICAL DIMENSION TO BE MEASURED.**

44'6" = 534" 18'1" = 217"

534" − 217" = 317" − 2" = 315"

B. **DETERMINE CALIBRATION OF TRANSMITTER.**

$h = X(S.G.) = (315)(1.2) = 378$ IN.W.C.

C. **THE TANK IS REFILLED WITH A FLUID HAVING A SPECIFIC GRAVITY OF 0.94, WHAT WILL THE MEASUREMENT READING BE WITH THE TANK 50 PERCENT FULL?**

0 - 378 IN.W.C

S.G. = 0.94

$(315)(0.94) = 269.1 = 148.05 = 391$

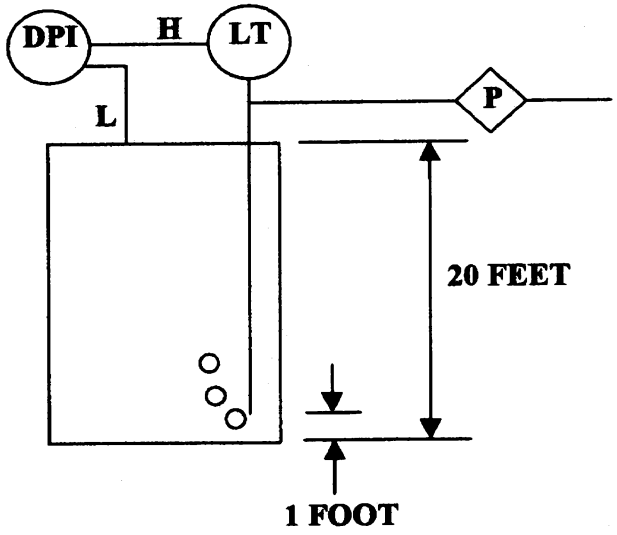
$\frac{}{2}$ $\frac{}{378}$

D. **THE TANK IS INCREASED TO 30 FOOT DIAMETER, SHOULD THE CALIBRATION OF THE TRANSMITTER BE INCREASED OR DECREASED?**

DO NOTHING

2. **GIVEN THE FOLLOWING INFORMATION, WHAT WILL THE READING BE ON THE GAUGE WITH A 14-FOOT LEVEL IN THE TANK?**

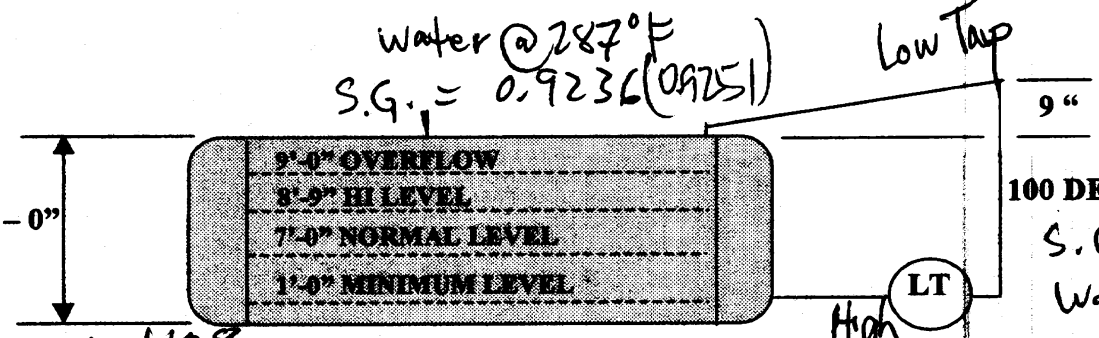
0-10 LB GAGE



$(14-1)\left(\frac{62.4}{144}\right) = 5$ P

3. **GIVEN THE FOLLOWING, DETERMINE THE PROPER CALIBRATION FOR THE LEVEL TRANSMITTER.**

wet-leg condition



h = (120)(0.9236) = 110.8"

e = (12")(0.989) = 11.9" 0"

s = (129")(0.989) = 127.6"

(120)(0.9236)

– 127.58 to –16.7 IN W.C.

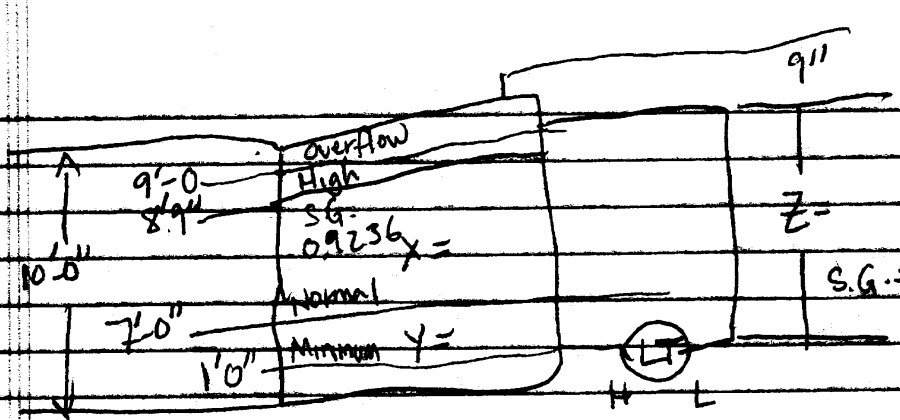
e – s = 11.9 – 127.6 = –115.7 to h to – s = 110.8 + 11.9 – 127.6 = –16.75"

4. **WHAT TYPE OF LEVEL SENSOR(S) SHOULD BE GIVEN CONSIDERATION FOR MEASUREMENT OF A PRODUCT IN A HIGHLY PRESSURED VESSEL IN WHICH NO PROCESS CONNECTION MAY BE MADE ON OR INTO THE VESSEL?**

Capillary tube

Nuclear
Load cell
Strain Sonic





$x = 9'0" = 108"$

$y = 6'-0 = 72"$

$Z = 129"$

$h = (108)(.9236) = 99.75$

~~$e = (72)(.9236) = 66.5$~~

$s = (129)(0.989) = 127.6$

$e - s = 66.5 - 127.6 = -116.5$

$h + e - s = 99.75 + 66.5 - 127.6 = -16.75"$

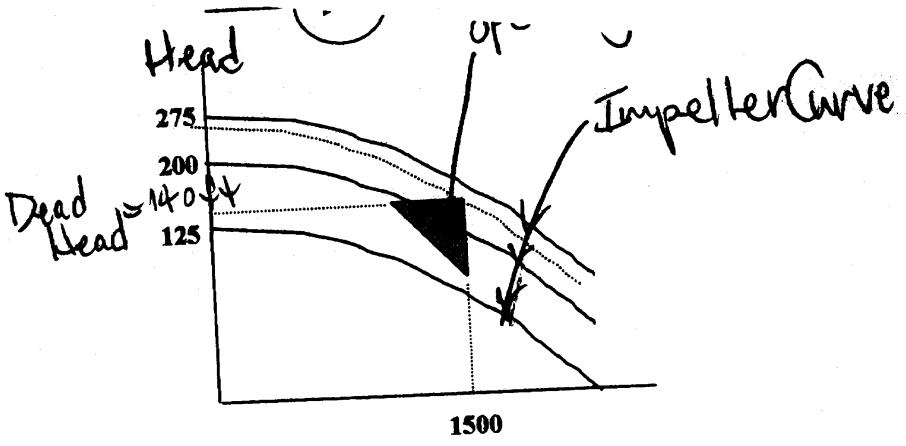
-127.6 to -16.7

Span 110.9

$e = (12)(0.9236) = 11.1$

20 +100	Suppressed Zero Range	20 to 100	20		100	80
−25 0 +100	Elevated Zero Range	−25 to 100	−25		100	125
−100 0	Elevated Zero Range	−100 to 0	−100		0	100
−100 −20	Elevated Zero Range	−100 to −20	−100		−20	80

Illustrations of the Use of Range and Span Terminology

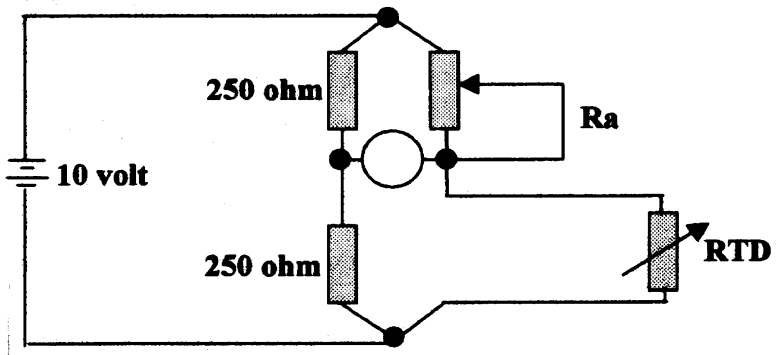


From Cameron Pg 1-10

$$P = \frac{(h)(sg)}{2.31}$$

TEMPERATURE

1.



COPPER RTD
100 ohms @ 32 deg. F
TEMPERATURE COEFFICIENT = 0.245 ohm/ deg F

A. **IF Ra IS ADJUSTED TO BALANCE THE BRIDGE (V=0) @ 200 DEGREES F, WHAT IS THE RESISTANCE OF Ra IN OHMS?**

$R_{RTD} = 100\left(\frac{0.245}{200-32}\right) = 141.6\Omega$

$\frac{250}{250} = \frac{R_A}{R_{RTD}}$ $\quad R_A = R_{RTD} = 141.$

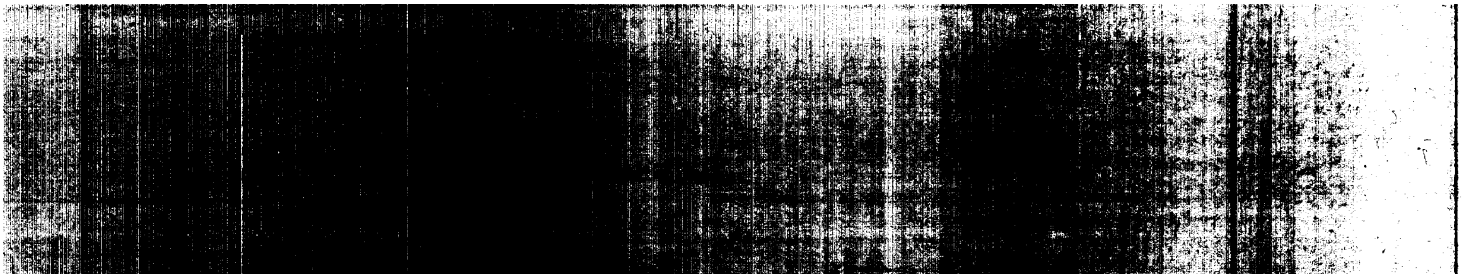
B. **A READING OF 162.5 OHMS IS EQUIVALENT TO WHAT TEMPERATURE?**

$162.5 = 100 + \left(.245\frac{\Omega}{DegF}\right)(T-32)$

$62.5 = 0.245T - (0.245)(32)$

$62.5 = 0.245T - 7.84$

$\frac{70.340}{.245} = T = 287.1\,^{\circ}F$



PSIG = (INWC)(S.G.)(.036)

IN.W.C. = 27.7 PSIG / S.G.

PSIG = (FT WATER)(S.G.)(.43

FT H2O = (PSIG) / (S.G.)(0.43278)

PRESSURE

1. **CONVERT THE FOLLOWING TO INCHES OF WATER:**

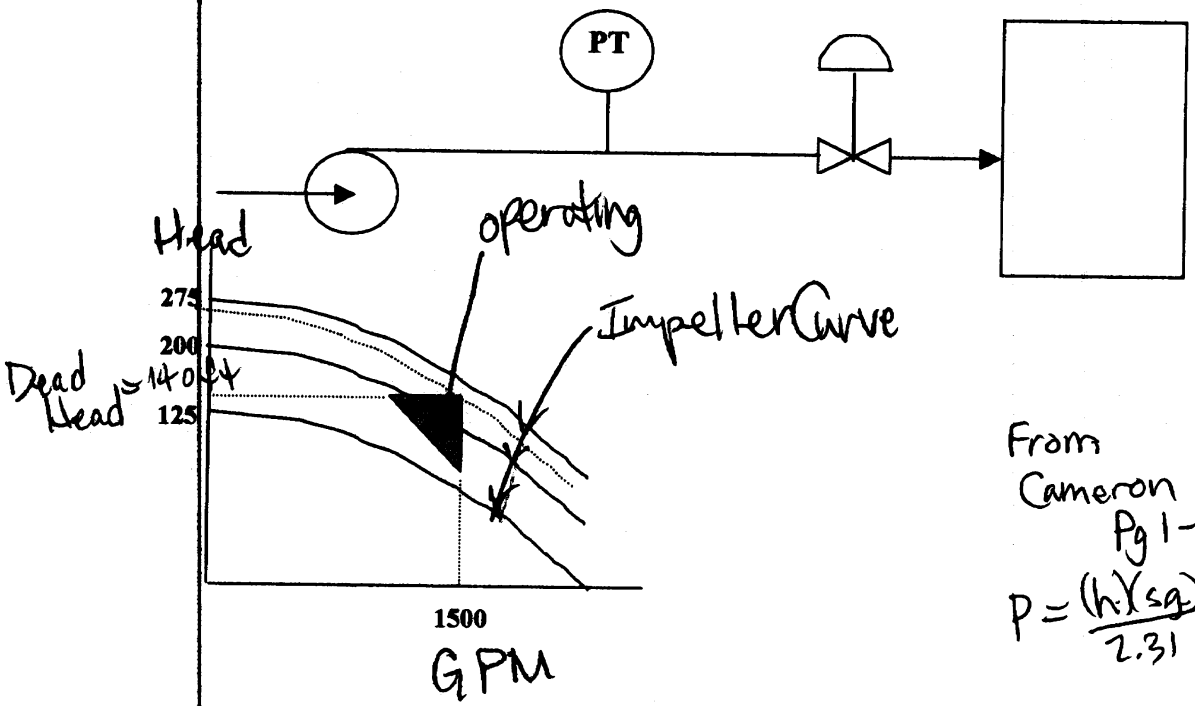
   A. **86.5 FEET , S.G. = 1.2** = 44.92 PSIG = 1037 In.W.C.

   B. **60 PSIG , S.G. = 1.0** = 1664 In W.C.

2. **DEFINE SPECIFIC GRAVITY**

   S.G. = (Fluid Density / ~~Fluid~~ Water Density) @ 60°

3. **GIVEN THE FOLLOWING INFORMATION, WHAT SCALE RANGE SHOULD BE SELECTED FOR THE PRESSURE TRANSMITTER?**



From Cameron Pg 1-10

$P = \frac{(h)(sg)}{2.31}$

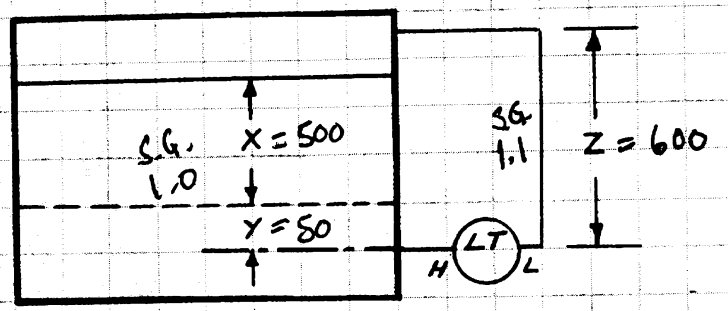
(275 ft)(0.43278) = 119 psig

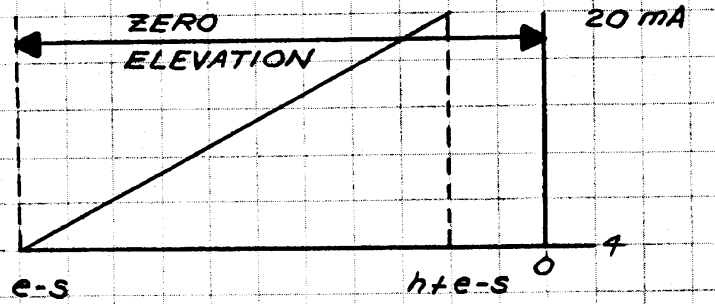
200 ft = 86

175 ft = 54

140 ft = 60 ← Answer?

WET LEG CONDITION





X = Vertical distance between the minimun and maximum measurable levels

Y = Vertical distance between the transmitter datum line and the minimum measurable level.

Z = Vertical distance between the top of the liquid in the wet leg and the transmitter datum line.

SG_1 = Specific gravity of the fluid.

SG_2 = Specific gravity of the fluid in the wet leg.

h = maximum head pressure to be measured in inches of water.

e = head produced by Y expressed in inches of water.

S = head pressure produced by Z expressed in inches of water.

▶ RANGE = e-s to h+e-s

Example: X = 500 inches, Y = 50 inches, Z = 600 inches, $SG_1 = 1.0$, $SG_2 =$

$h = (X)(SG_1) = 500(1.0) = 500$ inH2O

$e = (Y)(SG_2) = 50(1.0) = 50$ inH2O

$S = (Z)(SG_2) = 600(1.1) = 660$ inH2O

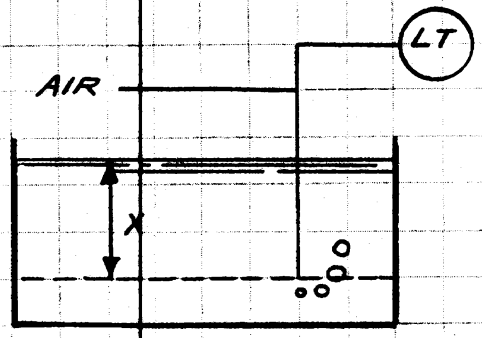
Range = e-s to h+e-s = 50-660 to 500+50-660

= -610 to -110 inH2O

BUBBLER SYSTEM

A bubbler system that has a top mounted pressure transmitter can be used in open vessels. This system consists of an air supply, pressure supply, pressure transmitter, and a tube that extends down into the vessel.

Bubble air through the tube at a constant flow rate. The pressure required to maintain flow equals the liquids specific gravity multiplied by the vertical height of the liquid above the tube opening.

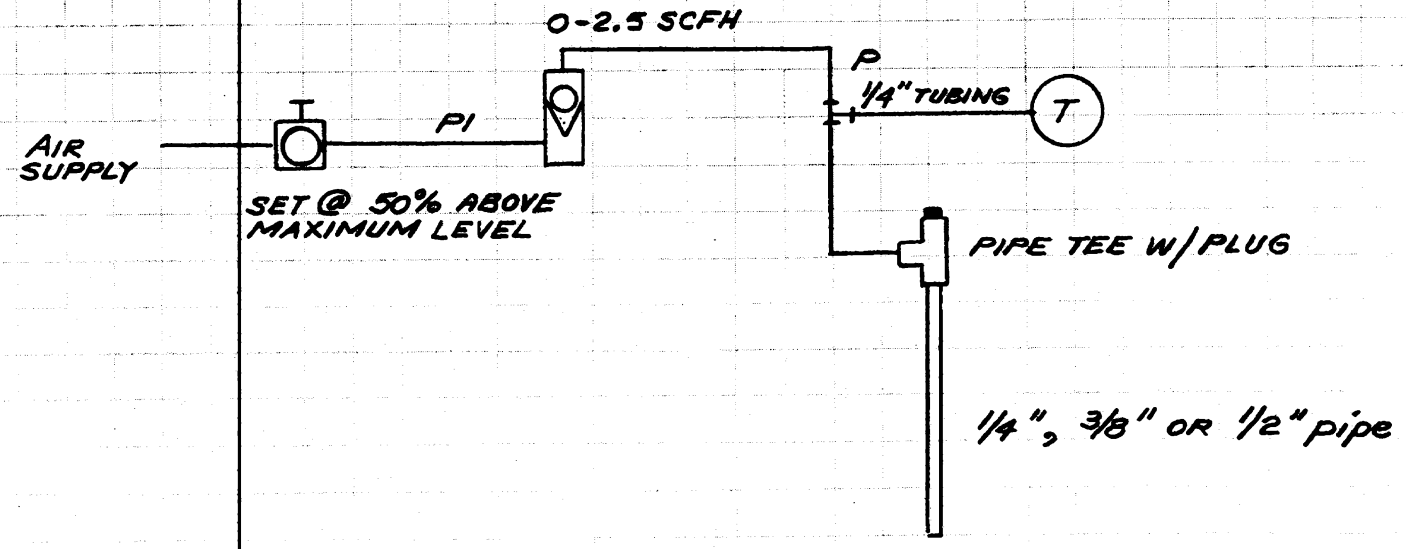


X = Vertical distance between the minimum and maximum measurable levels.

SG = specific gravity of fluid.

h = maximum head pressure to be measured in inches of water.

▶ RANGE = 0 to h = 0 to h(SG)



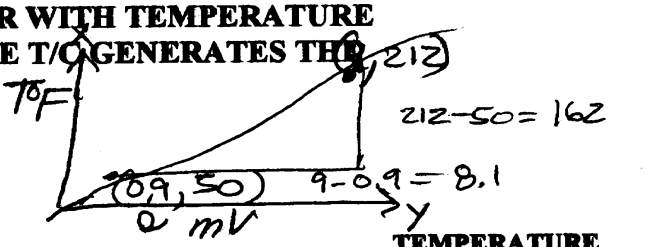
$y = f(x)$

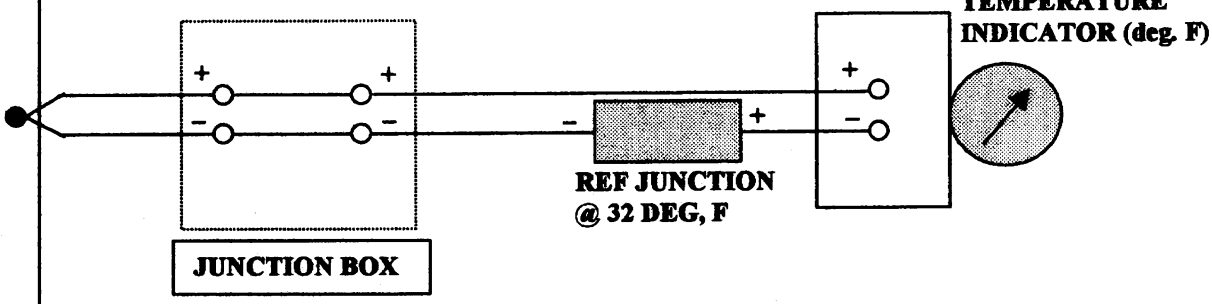
$e = f(T)$

2. THERMOCOUPLE CIRCUIT

ASSUME THE T/C VOLTAGE IS LINEAR WITH TEMPERATURE FROM 0 DEG. F TO 300 DEG. F AND THE T/C GENERATES THE FOLLOWING VOLTAGE:

212 deg. F = 9.0 mV 50 deg. F = 0.9 mV





A. DETERMINE THE VOLTAGE THE T/C PRODUCES AT 70 DEGREES F.

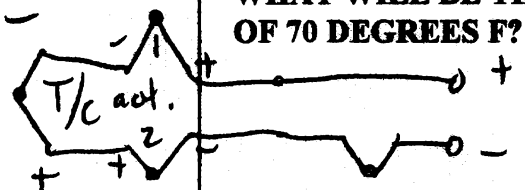
$212 - 50 = 162°F$ $9.0 - 0.9 = 8.1\ mV$

$\therefore$ voltage @ 70°F

$e = (0.05)(T - 50) + 0.9$ $\frac{8.1}{162} = 0.05$

1.9 mV @ 70°F

B. IF THE LEADS ARE REVERSED AT THE JUNCTION BOX, WHAT WILL BE THE READING AT A TRUE TEMPERATURE OF 70 DEGREES F?



Reversing the leads creates 2 new Junctions

3. AT 433 DEG. F A TYPE "J" THERMOCOUPLE WITH A 32 DEG.F REFERENCE JUNCTION WILL PRODUCE AN OUTPUT IN MILLIVOLTS THAT IS CLOSER TO:

Use Thermocouple Table & interpolate

- ☐ 9.04
- ☐ 10.51
- ☐ 12.05
- ☐ 17.79
- ☐ 23.67

11.96 mV @ 430°F

12.26 mV @ 440°F

$\frac{12.26 - 11.96}{3} = \frac{10}{3}$

$12.05\ mV = 11.96 + \left(\frac{3}{10}\right)(12.26 - 11.96)$

12.05 mV @ 433°F

4. **A CHROMEL / ALUMEL METAL COMBINATION IS REFERRED TO AS WHAT TYPE OF THERMOCOUPLE?**

- ☐ TYPE J
- ☐ TYPE N
- ☐ TYPE S
- ☐ TYPE K

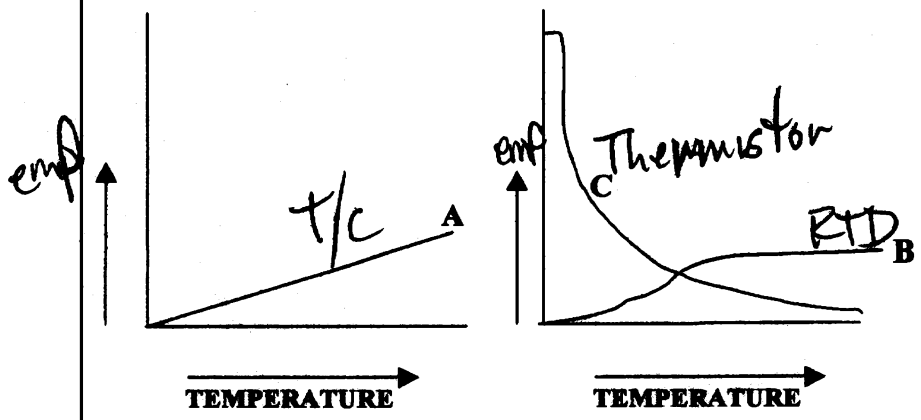
5. **A TYPE "K" THERMOCOUPLE HAS A YELLOW AND RED LEAD WIRE, WHICH IS THE POSITIVE LEAD?**

always minus lead

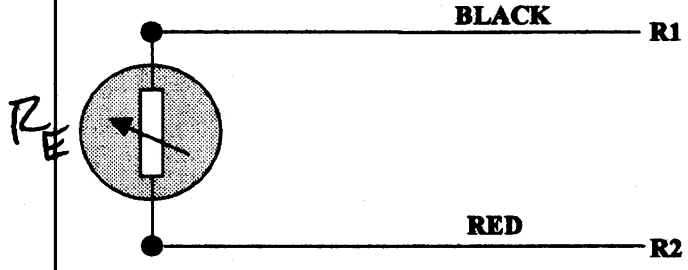
6. **WHICH OF THE FOLLOWING MEASURING TECHNIQUES EXHIBITS THE MOST STABLE RESPONSE.**

- ☑ RTD
- ☐ THERMOCOUPLE
- ☐ THERMISTOR

7. **DEFINE THE FOLLOWING CHARACTERISTIC ELEMENT CURVES.**

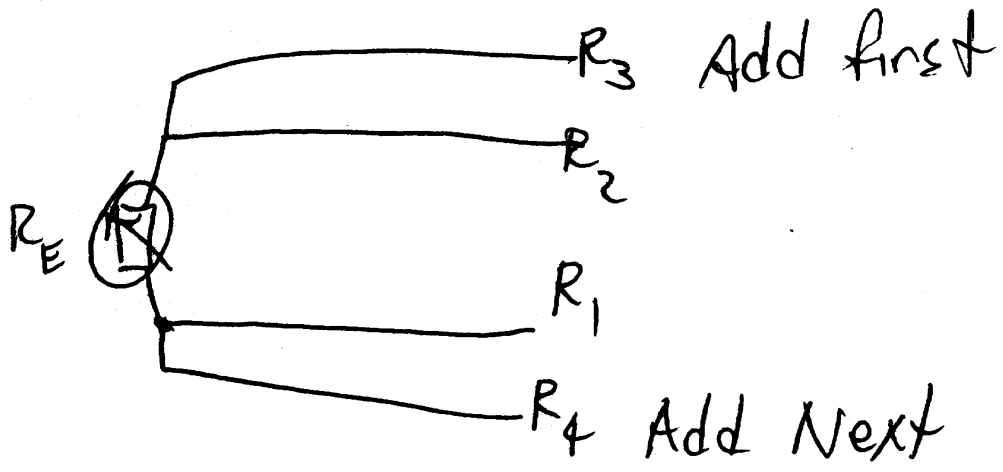


8. **EXPLAIN THE PROBLEMS ASSOCIATED WITH A TWO WIRE RTD MEASUREMENT.**

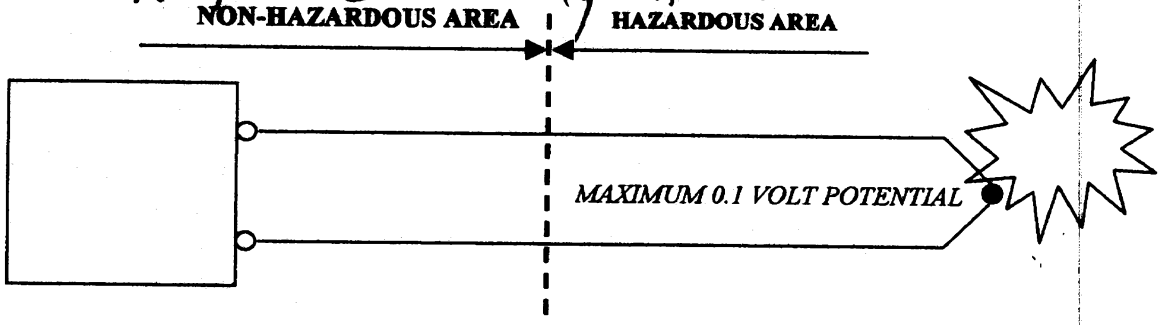


$R_{TOTAL} = R_1 + R_2 + R_{TE}$

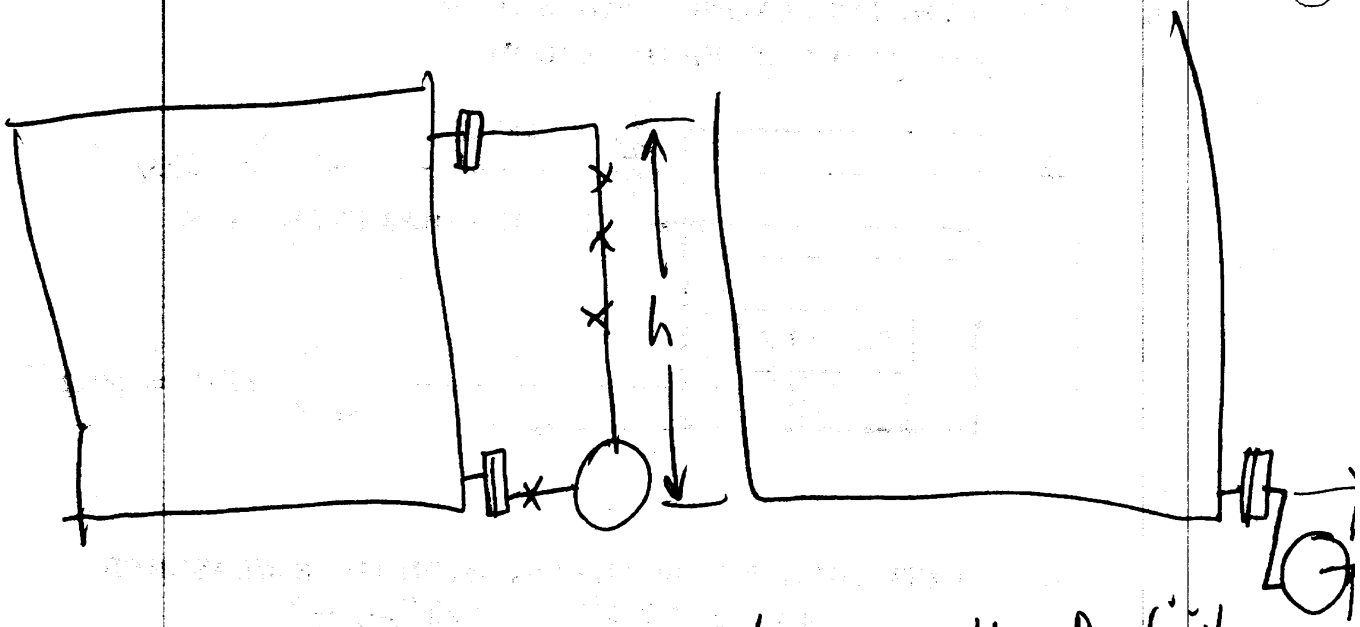
9. **DIAGRAM AND SHOW RESISTANCE EQUATIONS OF TWO(2) METHODS EMPLOYED TO ELIMINATE THE PROBLEMS ASSOCIATED WITH THE MEASURING DEVICE SHOWN IN PROBLEM NO.10.**



10. **IS THE T/C INSTALLATION BELOW ADEQUATE TO PREVENT AN EXPLOSION?** NO, add Intrinsically safe barrier

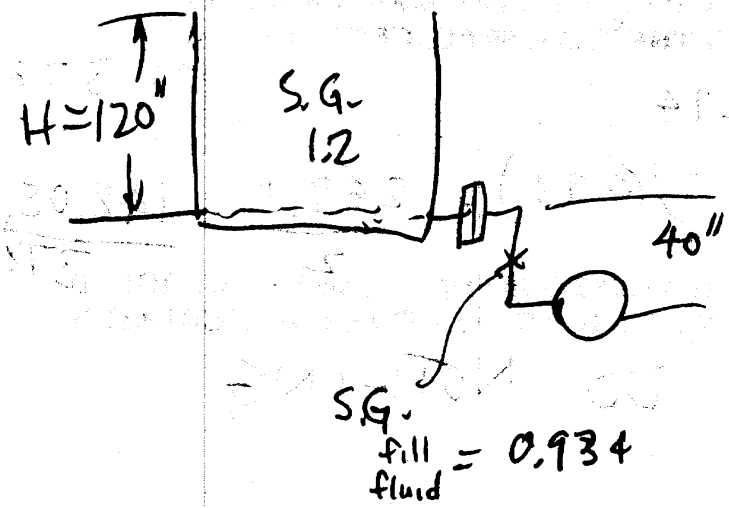


NEC Handbook



$$h \leq \frac{\text{Upper Range Limit}}{\text{fill fluid S.G.}}$$

Example



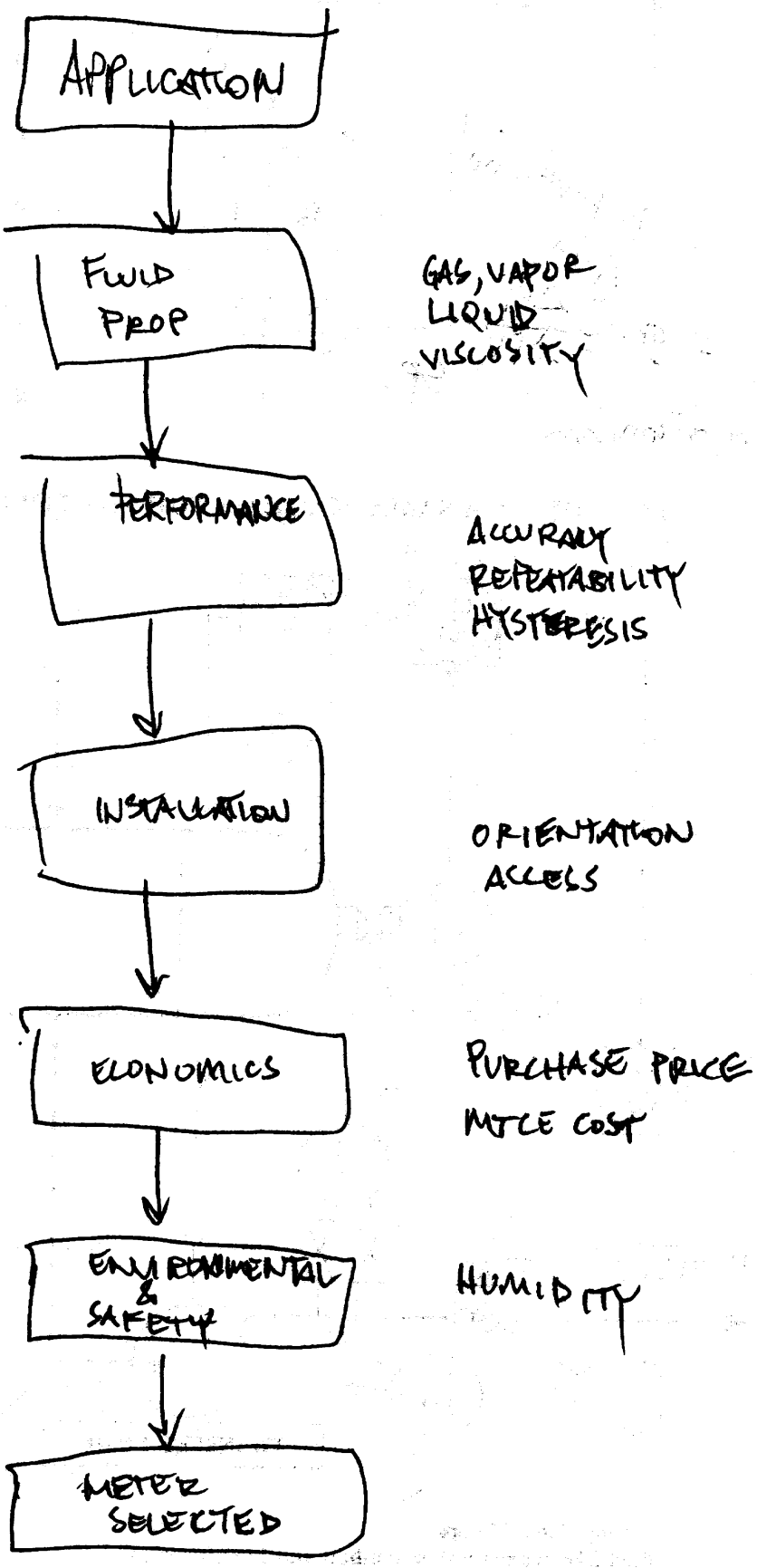
Suppression = (40)(.934) = 37.4

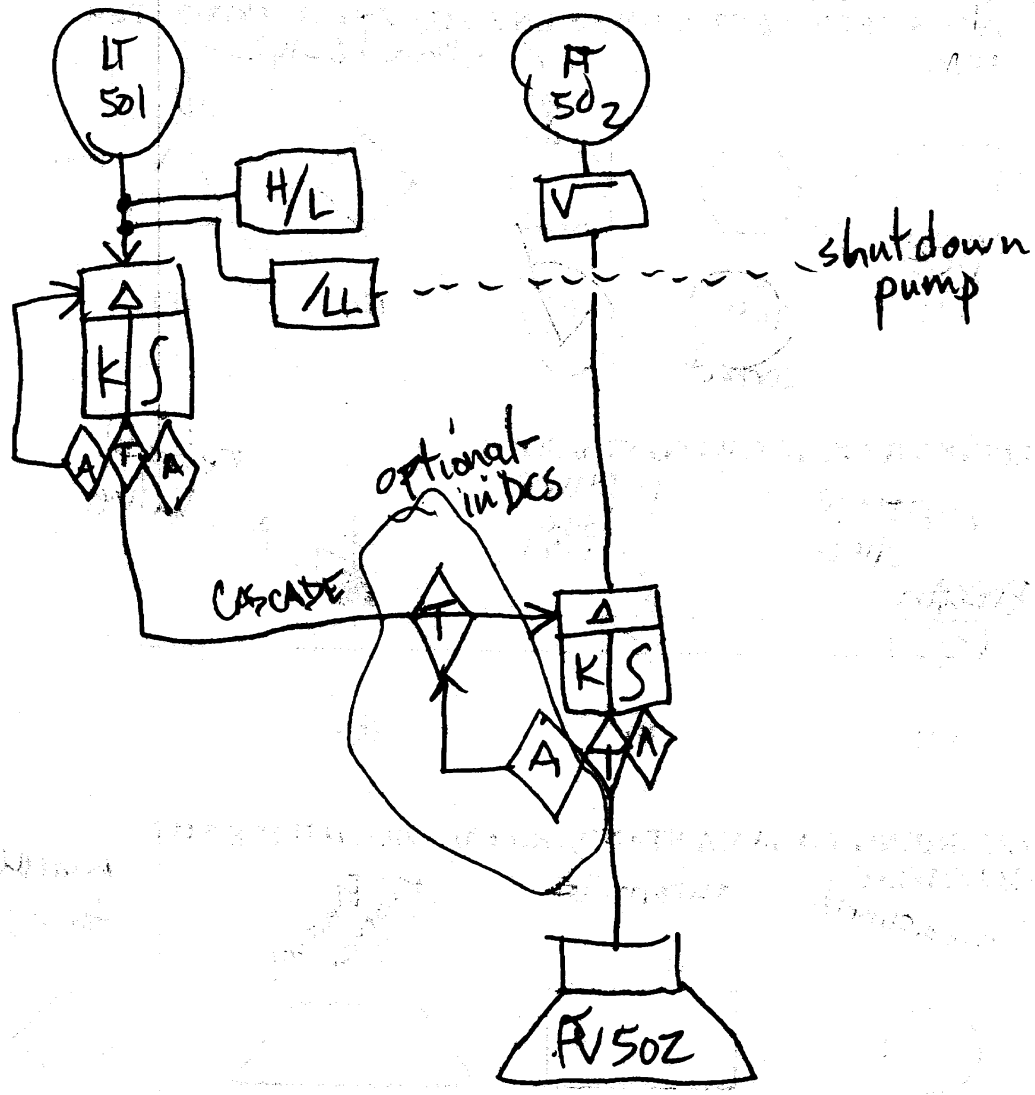
Span = (120)(1.20) = 144"

calib: 37.4 to (37.4+144)

181.4

Choosing A Flowmeter




LT
501
FT
502
H/L
V
shutdown
pump
L/L
K S
A T A
optional-
in DCS
CASCADE
T
K S
A T A
FV502

CONTROL SYSTEM ANALYSIS AND DESIGN

Instructor

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Control System Analysis and Design

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Control Systems Engineering
Examination Review

August 24-26, 1999
Birmingham, Alabama

Auburn University
and
Birmingham Section
of the
Instrument Society of America

Outline
System Design and Analysis Section
CSE Review Course

I. Control System Theory

- System Representation
- Basic Laplace Transforms
- Transfer Functions
- Block Diagrams
- Characteristic Equation
- S-plane
- Stability
  - Routh Criteria
- Frequency Response
  - Bode Diagrams
  - Gain and Phase Margin
- Root Locus
  - Calibrating the S-plane
  - Basic Trajectories

II. Process Dynamics

- First Order Systems
- Second Order Systems
- Integrators

III. Controllers/Control Modes

- PID Controllers
- Cascade Control
- Feedforward Control

IV. Loop Tuning Methods/Tools

- Performance Criteria
- Zeigler Nichols
- Process Reaction Curve

V. Example Problems in Book

Laplace Transforms

Transforms an expression from a function of time to a function of a new variable called 's'.

$$f(t) \longrightarrow F(s); \qquad \text{where } s = \sigma + j\omega \quad ; \; j = \sqrt{-1}$$

Laplace transforms functions are generally shown with a capital letter.

It also changes a differential equation into an algebraic equation which is much easier to solve.

In general:

$$\frac{d}{dt} = s$$

and

$$\int dt = \frac{1}{s}$$

The above equations are only true when the initial conditions are equal to zero, which is most of the time for us.

There are only about five Laplace transforms which need to be learned to model typical industrial processes. They are the first order lag, the integrator, the second order system, the derivative and the deadtime.

Laplace Transform

Definition:

$$f(s) = \int_0^{\infty} f(t)\, e^{-st}\, dt = \mathcal{L}\{f(t)\}$$

Properties:

1. Transforms the operation of differentiation with respect to time to that of multiplication by s

   Differential Eqns (Time Domain) $\longrightarrow$ Algebraic Eqns (Frequency Domain)

2. Linearity: $\mathcal{L}\{a\, f1(t) + b\, f2(t)\} = a\, \mathcal{L}\{f1(t)\} + b\, \mathcal{L}\{f2(t)\}$

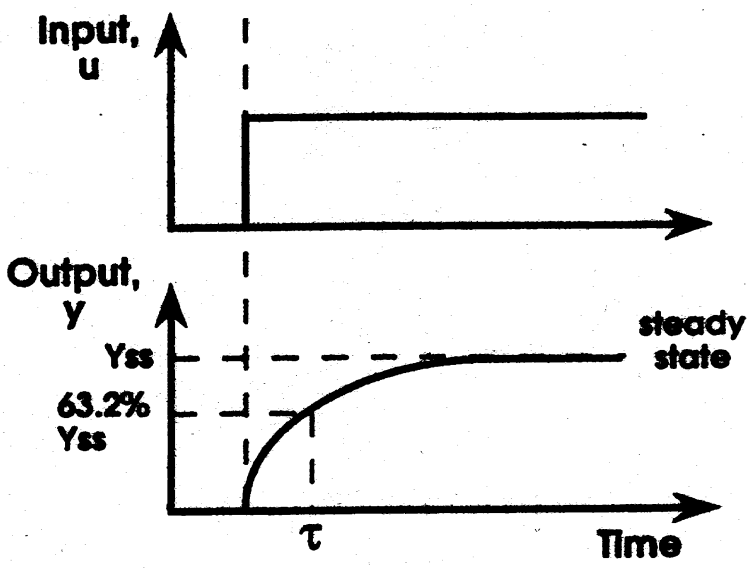
3. $\mathcal{L}\left\{\frac{dy}{dt}\right\} = sY(s) - y(0)$

   $\mathcal{L}\left\{\frac{d^2y}{dt^2}\right\} = s^2Y(s) - sy(0) - \frac{dy}{dt}(0)$

DETERMINING POWER PLANT DYNAMICS FROM TIME HISTORY DATA

First Order Lag

$$\frac{y}{u} = \frac{K}{\tau s + 1}$$



Examples:
Megawatt response to change in firing rate, Throttle pressure response to a change in turbine valve position

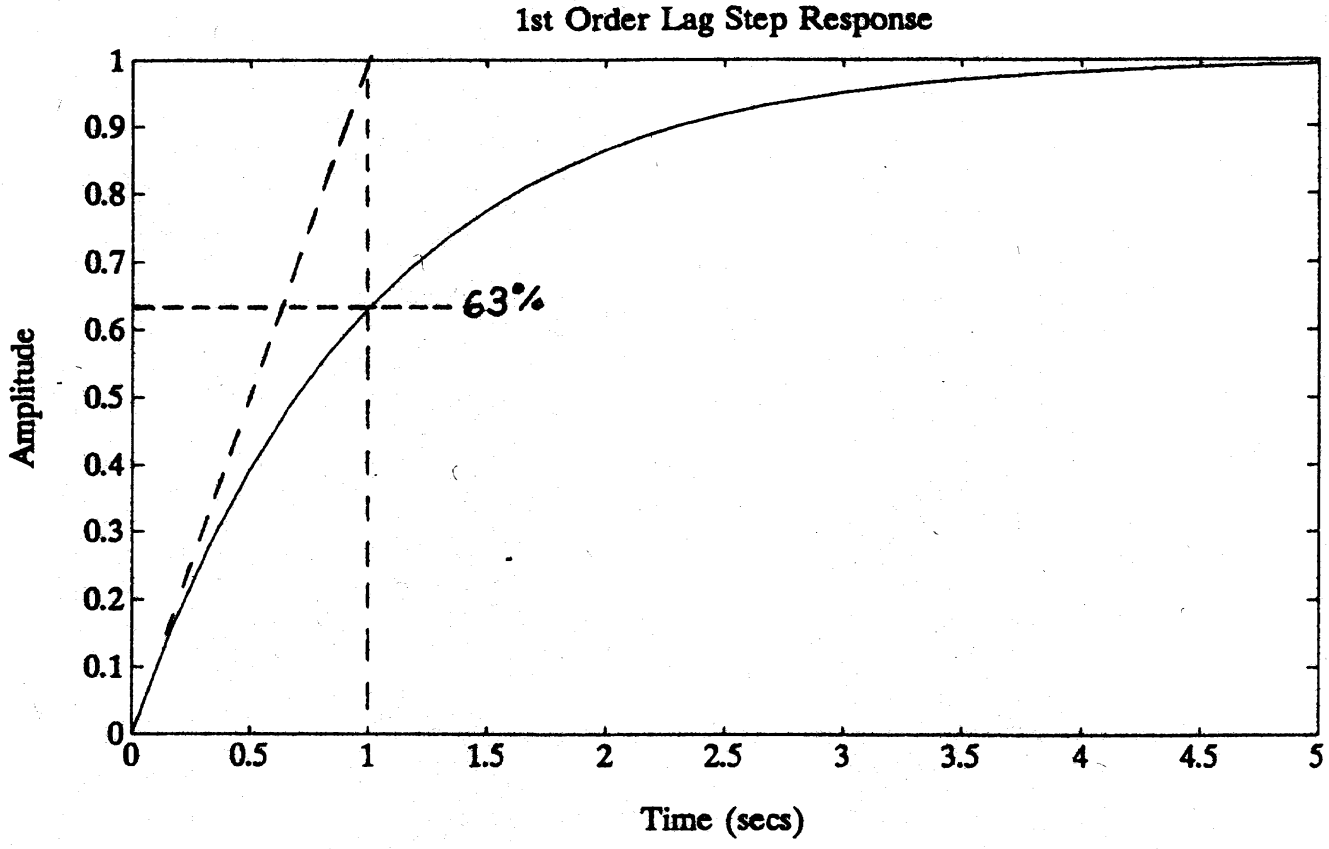
K: Steady State Gain, a measure of the "sensitivity" of the plant process

$$K = \frac{\text{Change in output}}{\text{Change in input}} = \frac{\Delta Yss}{\Delta u}$$

τ: Time Constant, determines the speed of response of the plant process.

For small τ, plant responds quickly.

For large τ, plant responds slowly.


1st Order Lag Step Response
Amplitude
Time (secs)
63%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

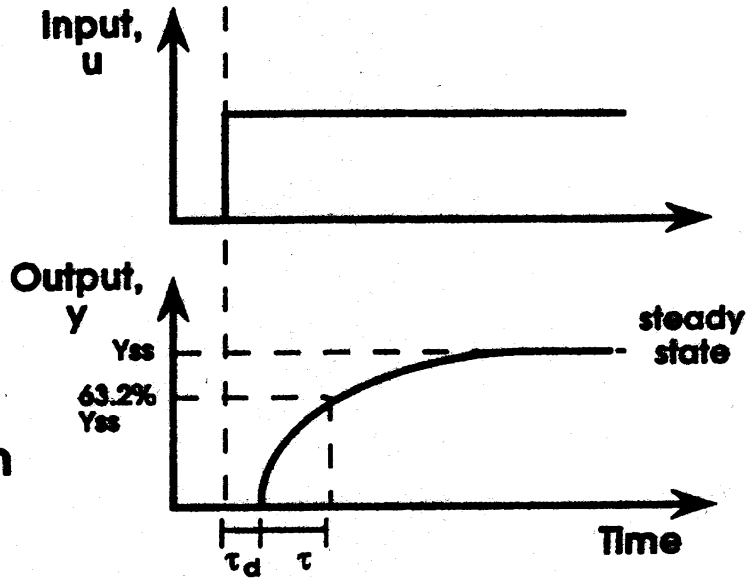
DETERMINING POWER PLANT DYNAMICS FROM TIME HISTORY DATA

First Order Lag with Dead Time

$$\frac{y}{u} = \frac{Ke^{-\tau_d s}}{\tau s + 1}$$

τ_d: Time Delay

Examples: Fan flow response to change in damper position, Steam temperature response to change in spray valve



Differences between a Lag and a Time Delay

Lag

- Immediate response to the input
- attenuates a signal (changes its magnitude)

Time Delay

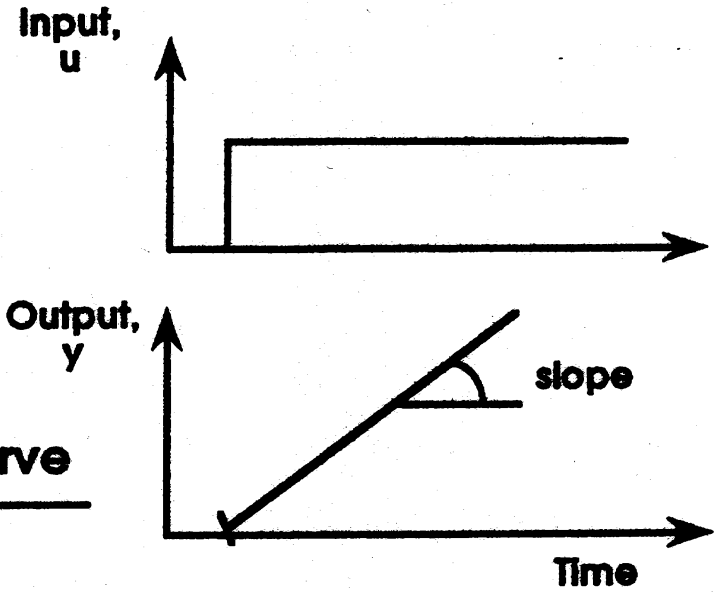
- no immediate response to an input
- reproduces the signal exactly as it was received

DETERMINING POWER PLANT DYNAMICS FROM TIME HISTORY DATA

Integrator

$$\frac{y}{u} = \frac{K}{s}$$

K: Integration Constant



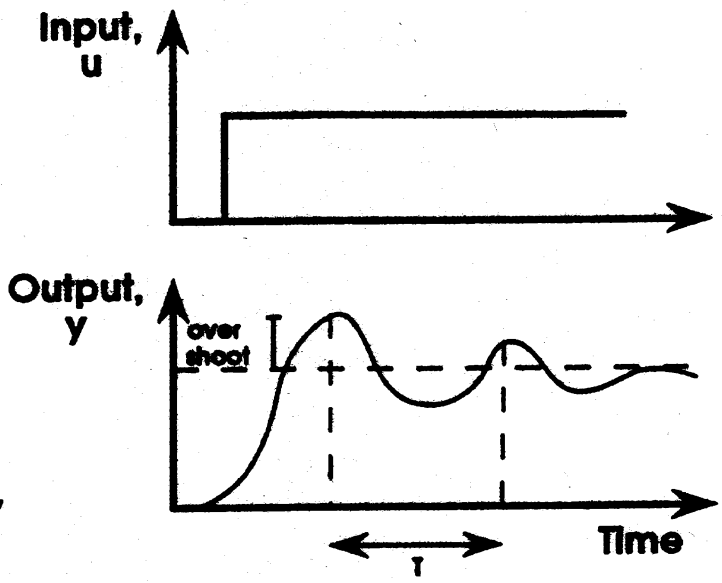
$$K = \frac{\text{slope of response curve}}{\Delta u}$$

Examples: Drum level response to change in feedwater valve position

DETERMINING POWER PLANT DYNAMICS FROM TIME HISTORY DATA

Second Order

$$\frac{y}{u} = \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$



K: Steady State Gain

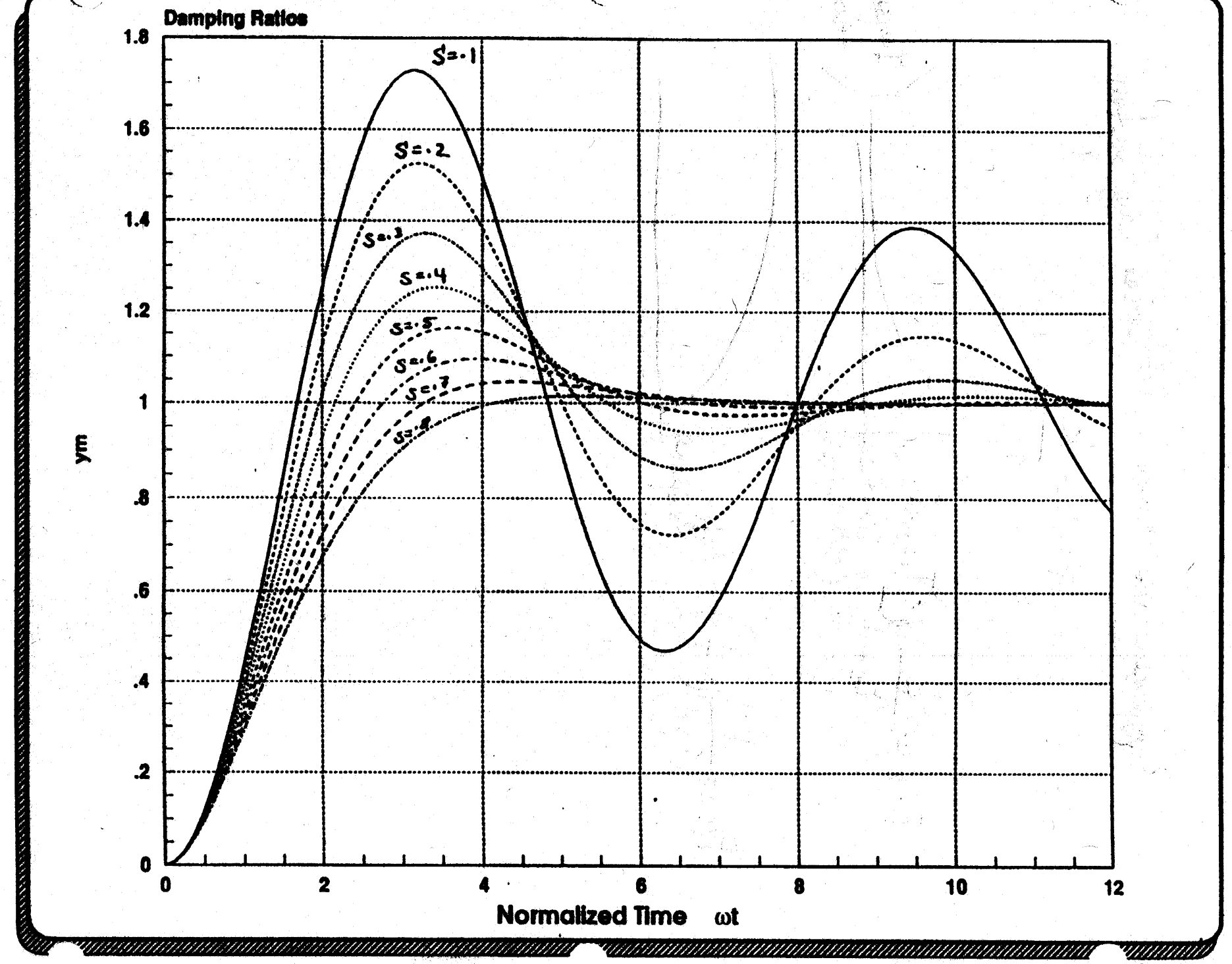
ζ: Damping Ratio

ω_n: Natural Frequency

Damping Ratio, ζ, can be approximated by estimating the amount of overshoot and using the table below. The period of oscillation, T, can be determined from the time history. Given T and ζ, the natural frequency can be determined from:

$$\omega_n = \frac{2\pi/T}{\sqrt{1-\zeta^2}} \text{ rad/sec}$$

Overshoot , %	Damping Ratio
0	1.0
0.15	0.9
1.5	0.8
4.6	0.7
9.5	0.6
16	0.5
25	0.4
37	0.3
53	0.2
73	0.1


Damping Ratios
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
0
ym
S=.1
S=.2
S=.3
S=.4
S=.5
S=.6
S=.7
S=.8
0
2
4
6
8
10
12
Normalized Time ωt

Transfer Functions

Transfer functions are ratios of polynomials in 's' and represent the dynamic characteristics of the system. In the 's' domain, the response of a system can be determined by multiplying the input function by the system transfer function.

Some common input functions are the impulse, the step and the ramp.

Impulse:

$$F(s) = 1$$

Step:

$$F(s) = \frac{1}{s}$$

Ramp:

$$F(s) = \frac{1}{s^2}$$

Notice that since the impulse function is equal to 1, that the system response to an impulse input is equal to the transfer function. Therefore the transfer function is also the impulse response.

Laplace Transforms

$f(t) \rightarrow F(s)$ where $s = \sigma \pm j\omega$; $j = \sqrt{-1}$

$\frac{d}{dt} = s$; $\frac{d^2}{dt^2} = s^2$, ...

$\int dt = 1/s$;

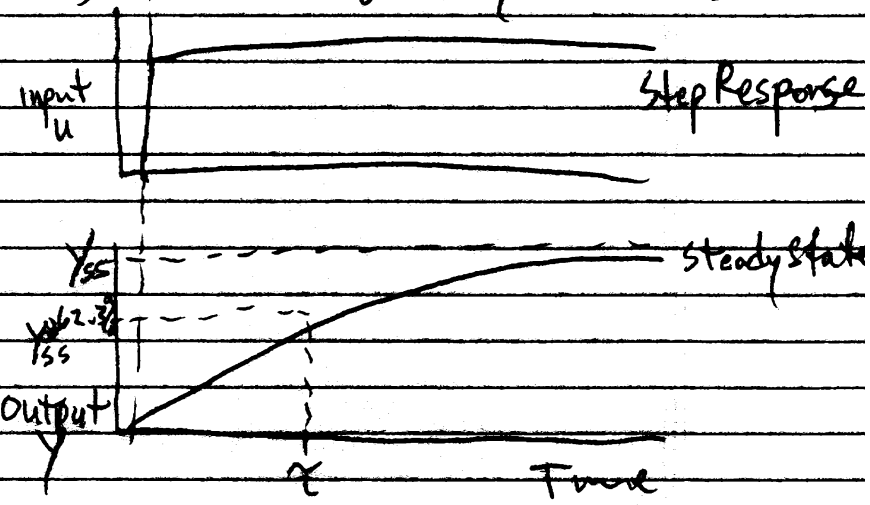
Five Most important Laplace Tra

1) 1st order lag
2) integral
3) 2nd order
4) Derivative
5) Deadtime

Purpose: Differential Eqn (time domain) → Algebraic Eqn (frequency domain)

1st order lag

$$\frac{y}{u} = \frac{K}{\tau s + 1}$$



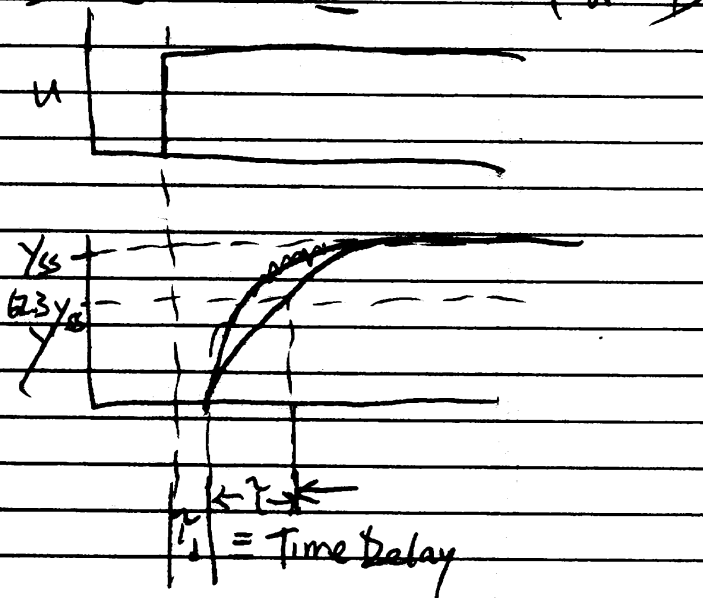
$K \equiv$ Steady State Gain

$$K = \frac{\Delta \text{output}}{\Delta \text{input}} = \frac{\Delta y_{ss}}{\Delta u}$$

For large τ, plant responds slowly
For small τ, plant responds quickly

First Order Lag with Dead Time (IS SELF-REGULATING)

$$\frac{Y}{U} = \frac{Ke^{-\tau_d s}}{\tau s + 1}$$



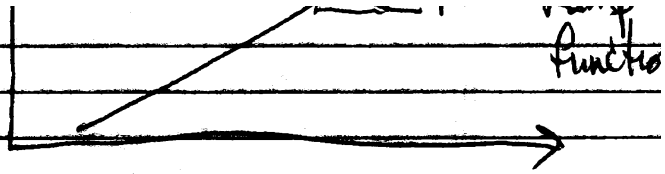
Differences Between Lag & Time Delay (Dead Time)

Lag

Time Delay

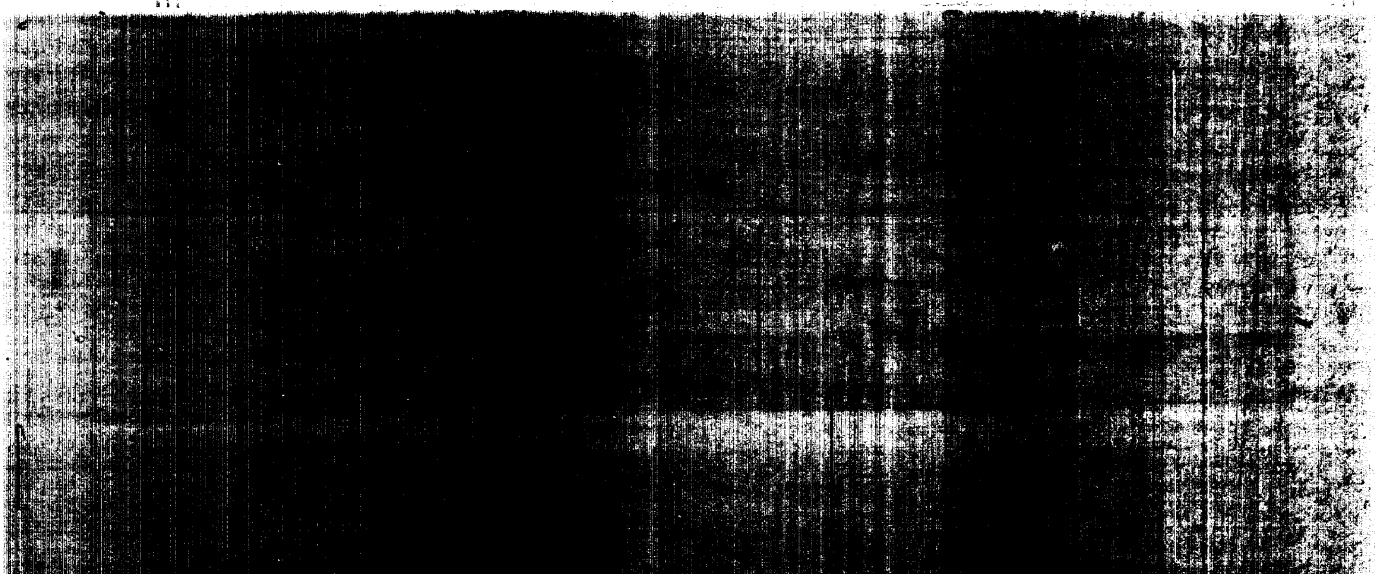
← No Immediate Response

K = integration constant



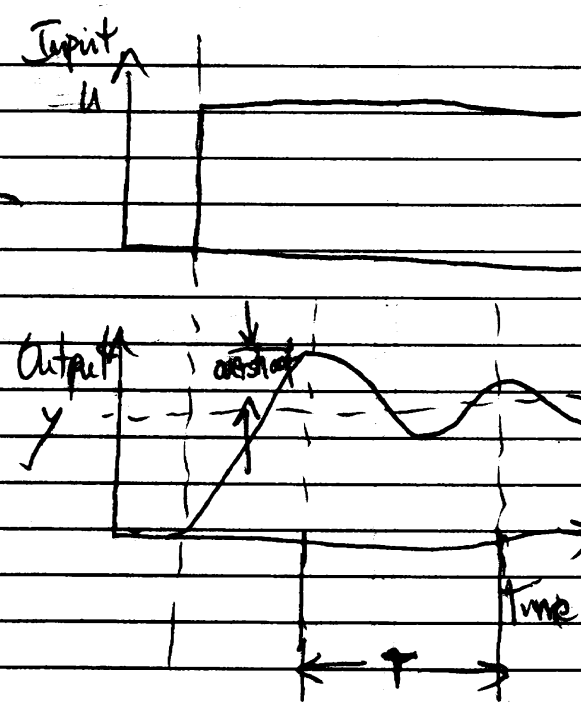
$$K = \frac{\text{Slope of response curve}}{\Delta u}$$

Level is an Integrating Response



SECOND ORDER

$$\frac{y}{u} \quad \frac{K\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$



$K \equiv$ Steady State gain

$\xi \equiv$ Damping Ratio

$\omega_n \equiv$ Natural Frequency

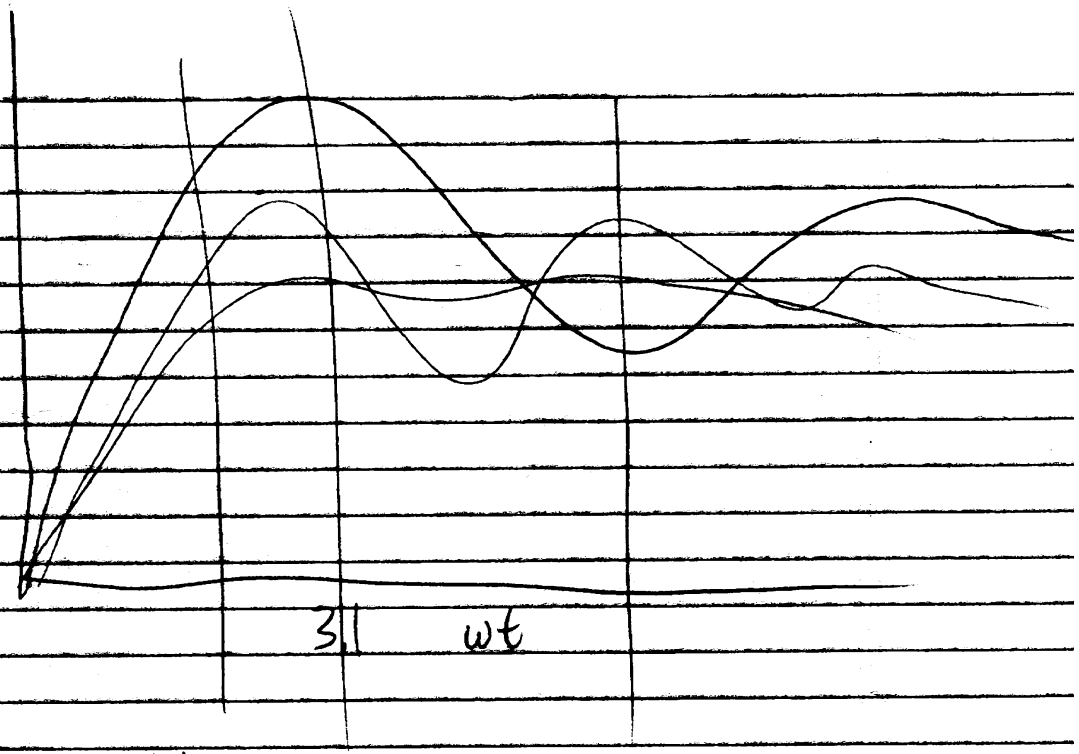
$$\omega_n = \frac{2\pi/T}{\sqrt{1-\xi^2}} \text{ rad/sec}$$

given

Underdamped most common

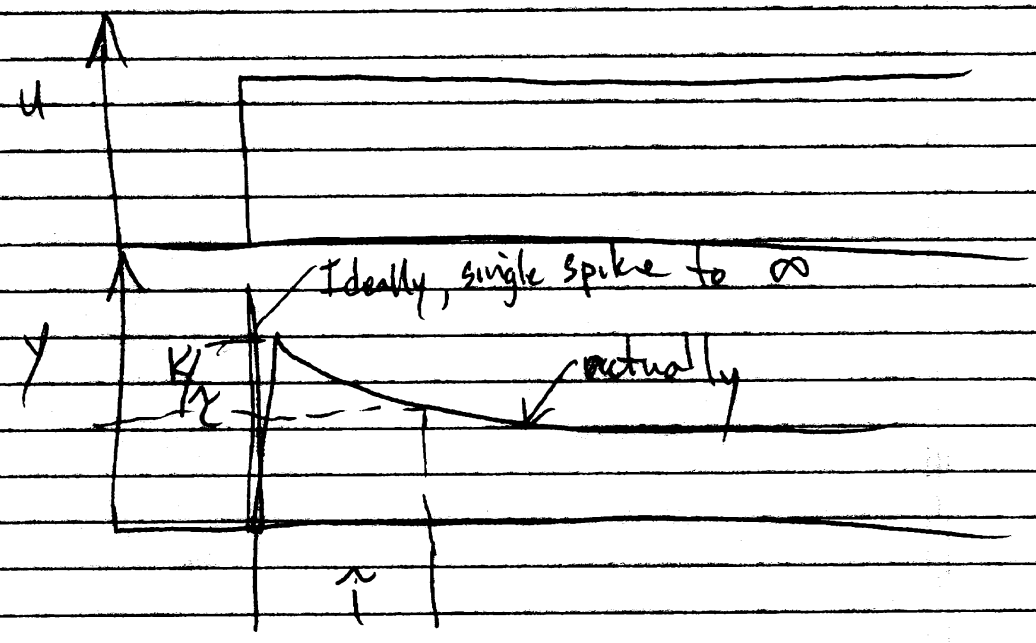
Overshoot, %	D
0	1.0 ← Critically Damped
95	0.7
73	0.4

In Quarter Wave Damping for each successive overshoot, they are 1/4 of previous overshoot



$$w = \frac{3.1}{60} \approx 0.05$$

KS



Impulse $F(s) = 1$

Step $F(s) = \frac{1}{s}$

} most often used

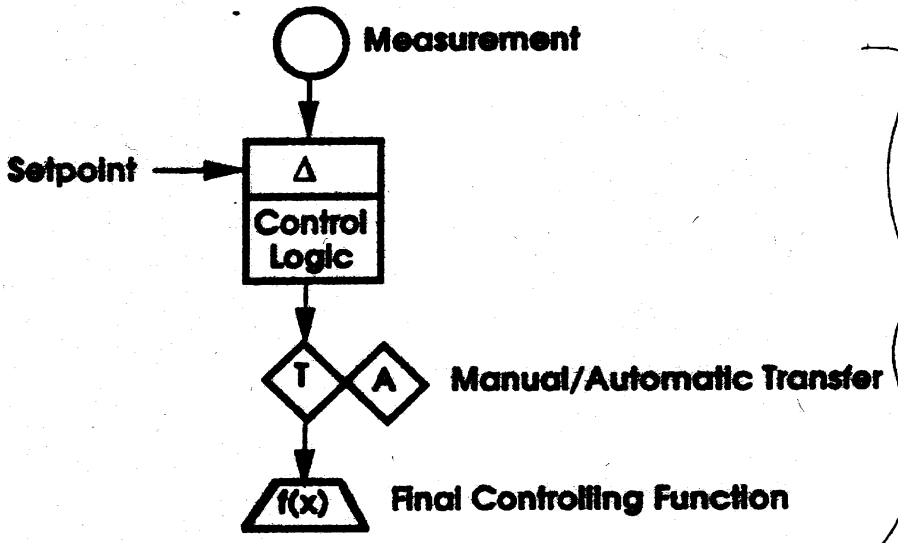
Ramp $F(s) = \frac{1}{s^2}$

Not often used maybe in target tracking

Control System Diagramming

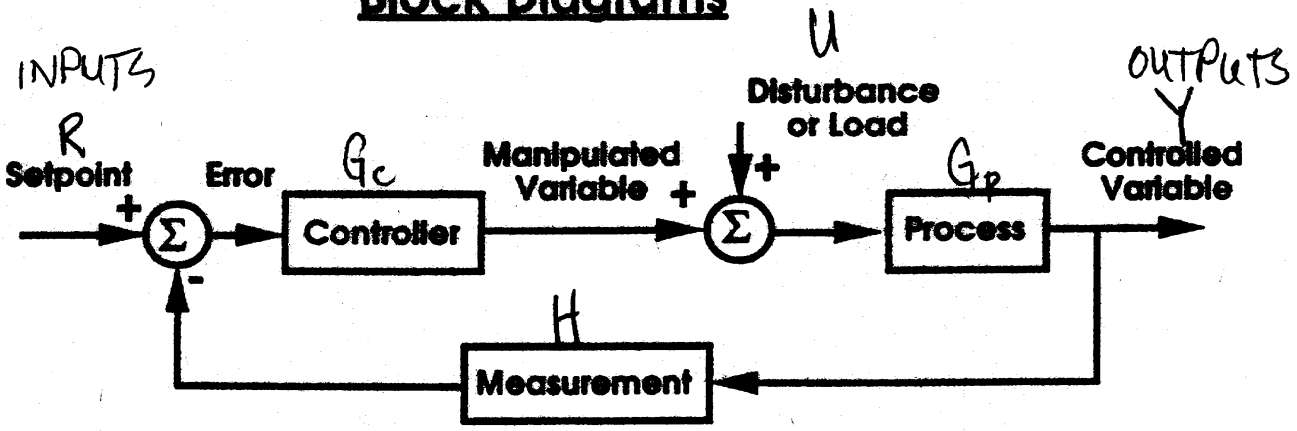
Graphical representation of a physical system illustrating the functional relationships among its components

SAMA Diagrams
(Scientific Apparatus Makers Association)



LIMITATION
DoNot Represent the Process!

Block Diagrams



Block Diagram Terminology

Reference Signal

The **setpoint R or SP,** is the desired value of the controlled variable.

The **controlled variable C or PV,** is that process variable we would like to maintain at or near the desired value (setpoint). Sometimes Y

The **error E** is the algebraic difference between the values of the setpoint and the measured controlled variable.

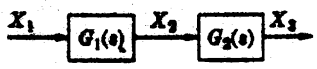
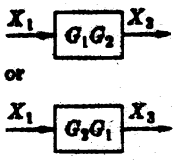
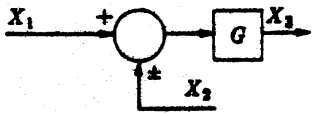
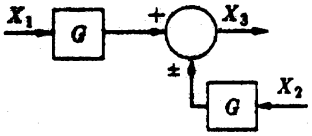
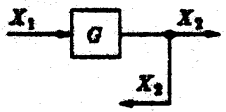
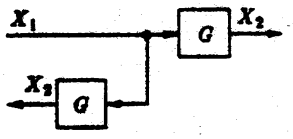
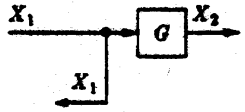
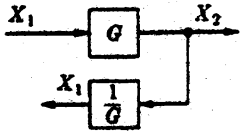
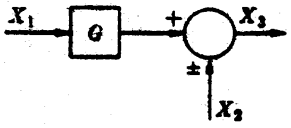
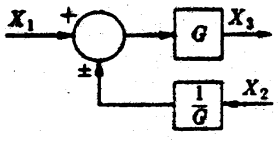
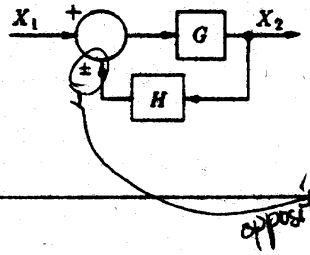
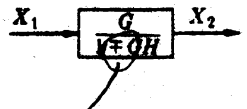
The **manipulated variable M** is that variable manipulated by the controller in its efforts to maintain the controlled variable at or near the setpoint.

A **disturbance U** is an undesired input signal which affects the value of the controlled variable.

The block **Gc** represents the controller. The block **Gp** represents the plant or system being controlled.

The **B**lock **H** represents the sensors or measuring equipment.

Block Diagram Transformations

Transformation	Original diagram	Equivalent diagram
1. Combining blocks in cascade		
2. Moving a summing point behind a block		
3. Moving a pickoff point ahead of a block		
4. Moving a pickoff point behind a block		
5. Moving a summing point ahead of a block		
6. Eliminating a feedback loop		

opposite sign

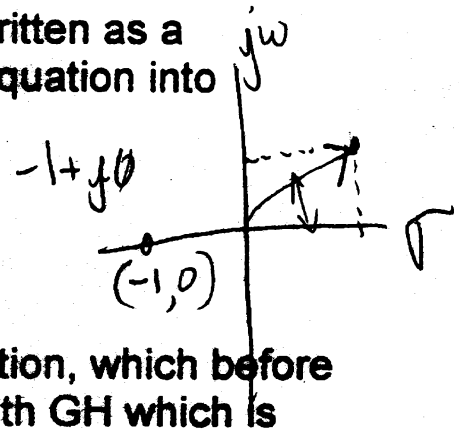
Characteristic Equation

The Characteristic Equation is formed by setting the denominator of the closed loop transfer function equal to zero. This is typically written:

$$1+GH = 0$$

If any roots of the equation have positive real parts (are in the right half of the s-plane), the system is unstable.

Since GH is a complex number it can be written as a magnitude and an angle. Converting the equation into complex notation we get:



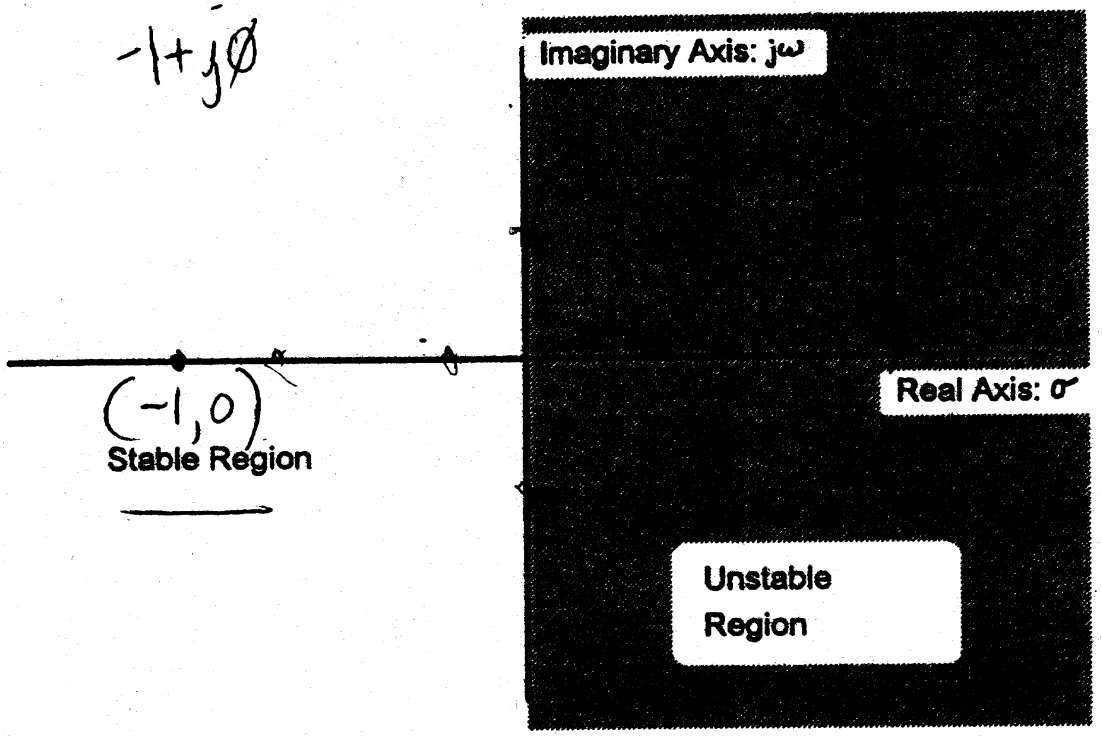
$$GH = -1$$
$$GH = 1\angle 180^\circ$$

Rather than solving the characteristic equation, which before computers was difficult, we instead work with GH which is typically factored already. This is the basis of root locus and frequency response analysis.

If $|GH| > 1$ when the phase angle is -180°, then the system is unstable.

S - plane

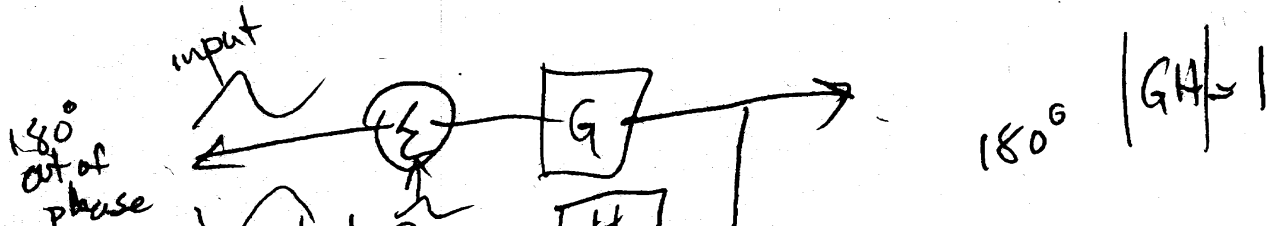
$s = \sigma + j\omega$



Stability limits

$G_{Gain} \doteq 1$, $\phi \angle 180^\circ$

$\phi = 180^\circ$, $G < 1$



Routh Stability Criterion

Characteristic Equation

$$Q(s) = b_n s^n + b_{n-1} s^{n-1} + ... + b_1 s^1 + b_0 = 0$$

Routh Array

s^n	b_n	b_{n-2}	b_{n-4}	b_{n-6}
s^{n-1}	b_{n-1}	b_{n-3}	b_{n-5}	
s^{n-2}	c_1	c_2	c_3	
s^{n-3}	d_1	d_2		
s^1	j_1			
s^0	k_1			

$$c_1 = \frac{b_{n-1}b_{n-2} - b_n b_{n-3}}{b_{n-1}}$$

$$c_2 = \frac{b_{n-1}b_{n-4} - b_n b_{n-5}}{b_{n-1}}$$

$$d_1 = \frac{c_1 b_{n-3} - b_{n-1} c_2}{c_1}$$

If there is one or more sign changes in the first column of the Routh Array then the system is unstable.

The Data Triplet

When analyzing a system with frequency response techniques there are three pieces of data to deal with. They are the magnitude, the phase angle, and the frequency. These three parameters can be plotted in a variety of ways. Each plotting method has its advantages, but they all contain the same information. These three parameters are sometimes referred to as the data triplet.

Data Triplet { magnitude, phase angle, frequency

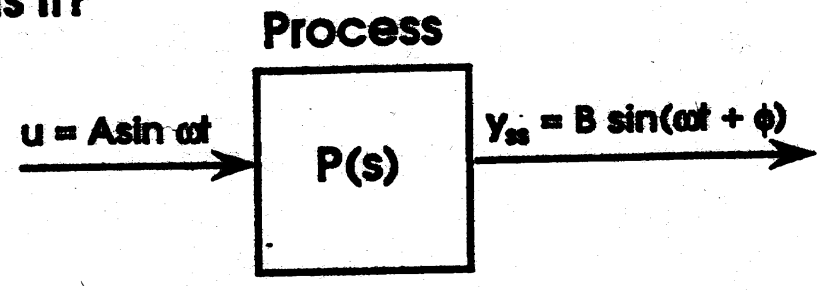
Bode Plot

Nyquist Plot

Nichols Diagram

FREQUENCY RESPONSE

What is it?



Steady State Response of process has same frequency as input sinusoid but

- **magnitude is changed (attenuated or amplified)**
- **phase angle is shifted**

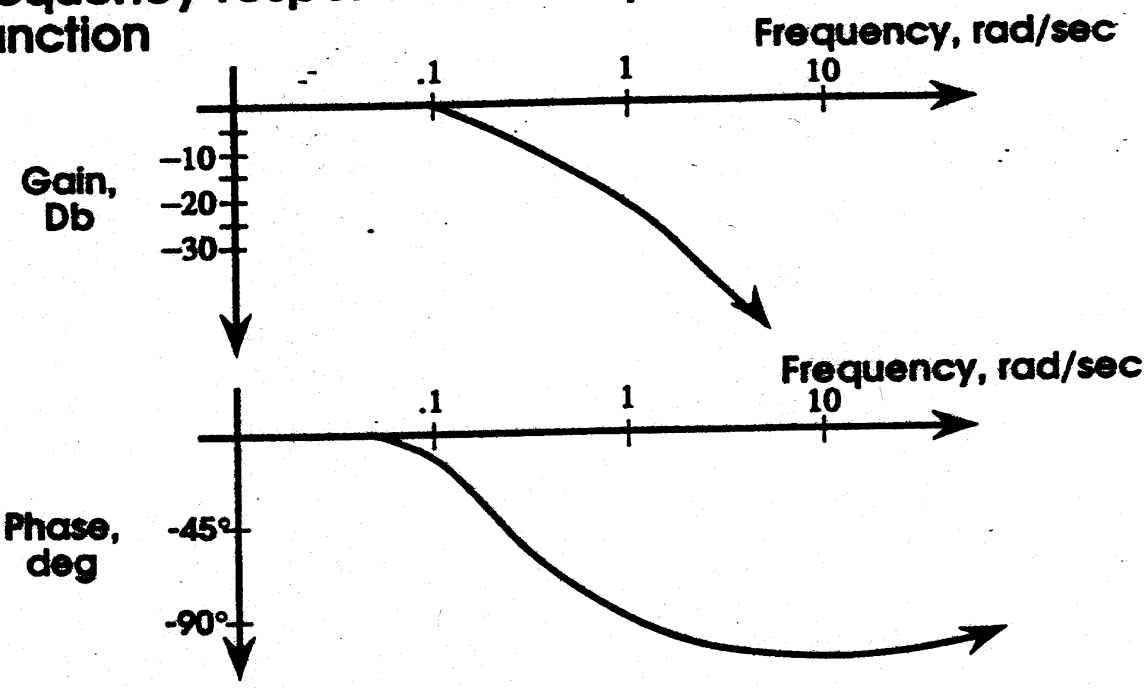
At high enough frequency, you get no response

Why do it?

- **Valuable tool in the analysis and design of control systems (processes with dead time)**
- **Provides information on the steady state response of a linear, stable power plant process**
- **Provides information on stability of open loop process (degree of stability and stability limits)**
- **Useful for empirical determination of the transfer functions of higher-order (order>2) linear systems** (when you don't know P(s))

Bode Plot

One method for graphically representing the frequency response of the open loop transfer function



Information obtained from Bode Plot:

Stability
- a. Gain margin
- b. Phase margin
- c. Critical Frequency/Critical Gain

Note: Amplitude or Magnitude Ratio = $\frac{B}{A}(\omega)$

Decibels (Db) = $20 \log_{10}(\text{Mag})$

Phase = Φ

Gain	Magnitude
20 dB	= 10
40	100
60	1000

TYPICAL TRANSFER FUNCTIONS AND THEIR FREQUENCY RESPONSES

3dB = Deviation @ Break Frequency

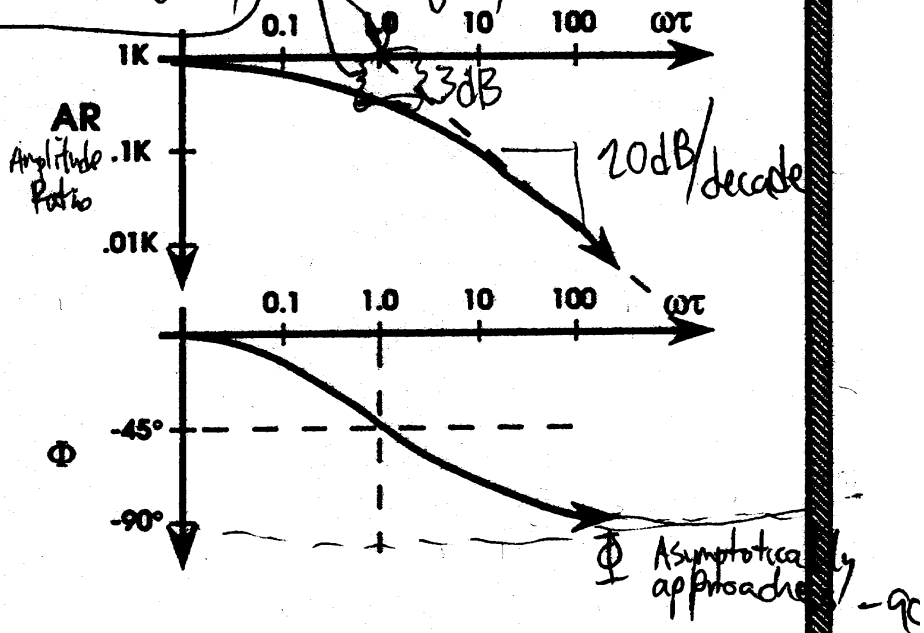
Break Frequency $\cong 1/\tau$

First Order Lag

$$\frac{y}{u} = \frac{K}{\tau s + 1}$$

$$AR = \frac{K}{\sqrt{\omega^2\tau^2 + 1}}$$

$$\text{Phase} = \tan^{-1}(-\omega\tau)$$

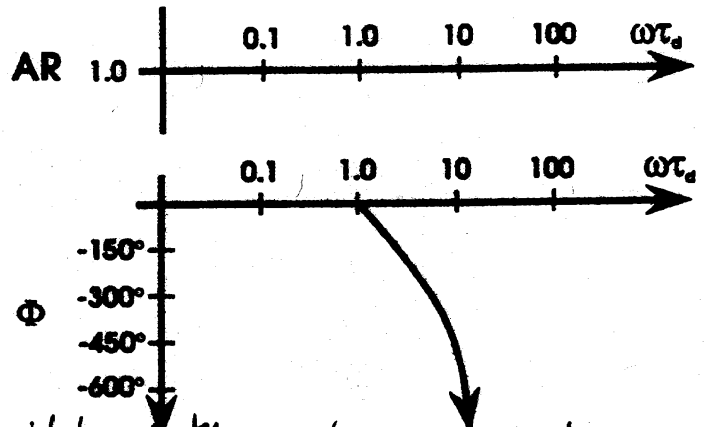


Dead Time

$$\frac{y}{u} = e^{-\tau_d s}$$

$$AR = 1$$

$$\text{Phase} = -\omega\tau_d$$

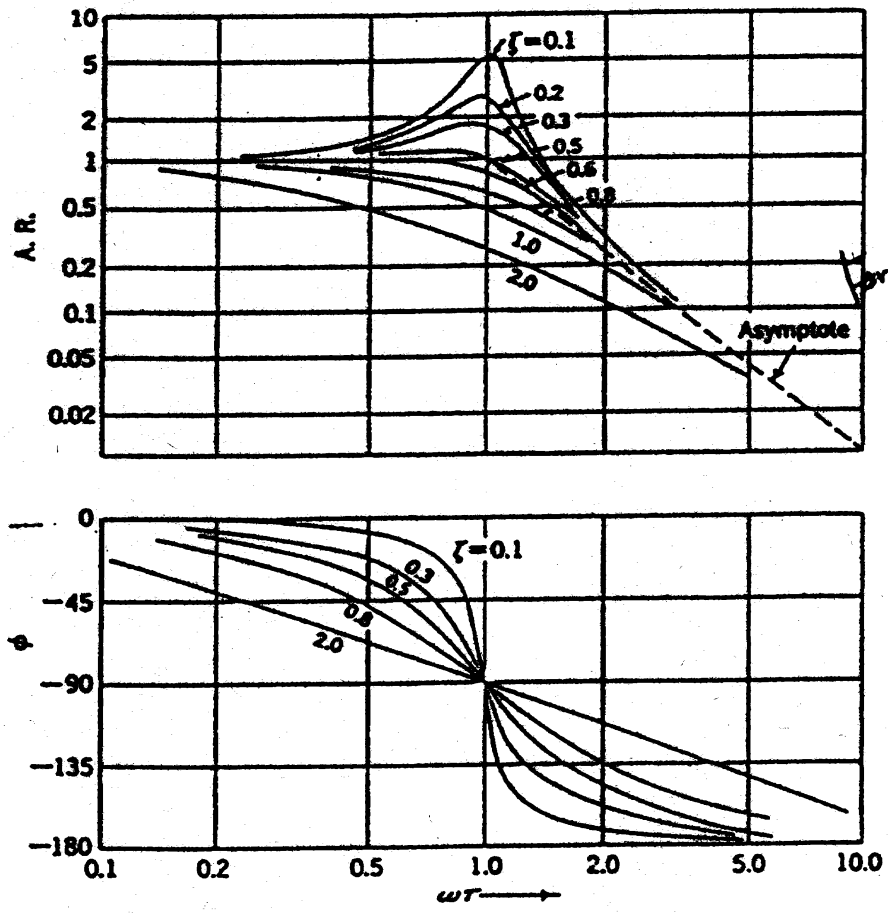


★ Deadtime add a lot of phase lag to system, which tends to make it unstable

TYPICAL TRANSFER FUNCTIONS AND THEIR FREQUENCY RESPONSES

Second Order

$$\frac{y}{u} = \frac{1}{\tau^2 s^2 + 2\zeta\tau s + 1}$$



Bode diagram for second-order system $1/(\tau^2 s^2 + 2\zeta\tau s + 1)$.

For highly damped looks like 1st order Syst

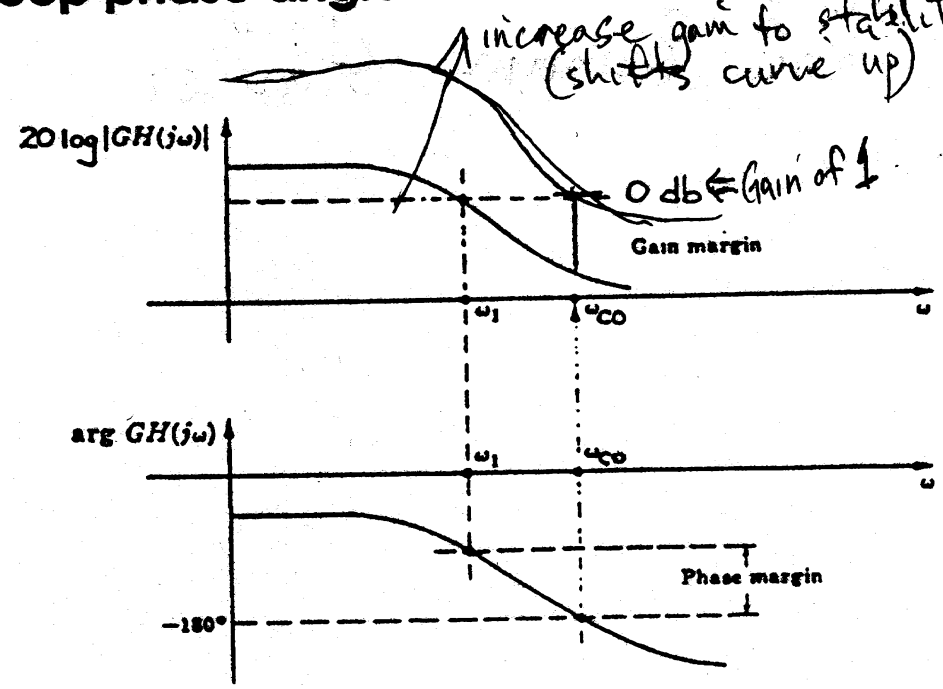
For no damping behaves like a step response

FREQUENCY DOMAIN PERFORMANCE SPECIFICATIONS

Gain Margin: The measure of additional gain a system can tolerate with no change in phase, while remaining stable.

Phase Margin: The measure of additional phase shift that can be tolerated with no gain change, while remaining stable.

Critical Frequency: The frequency at which the open loop phase angle first reaches -180°.



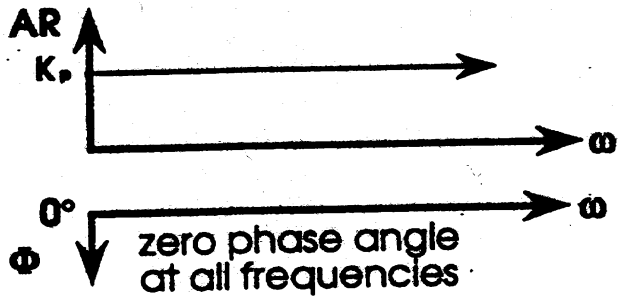
For larger Gain & Phase margins, the greater (more stable) the system

DEALS WITH OPEN LOOP TRANSFER FU
TO SIMPLIFY SO WE CAN DETERMINE THE CLOSED LOOP RESPONSE

FREQUENCY RESPONSE OF P, PI, AND PID CONTROLLERS

P Controller:

$$G_c = K_p$$

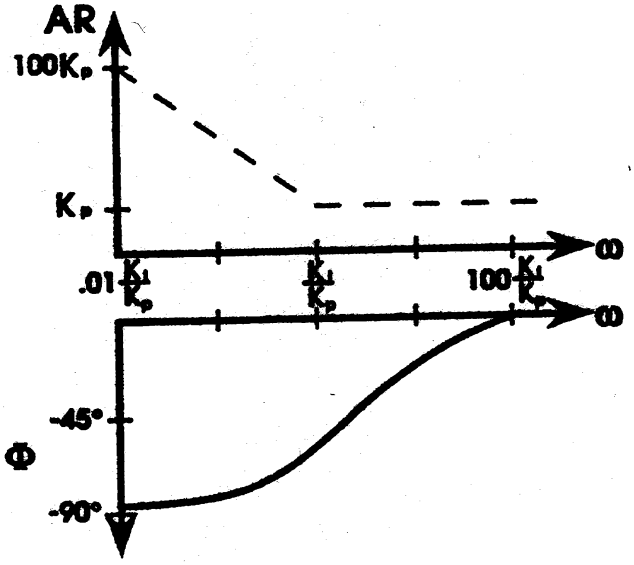


PI Controller:

$$G_c = K_p + \frac{K_I}{s}$$

$$= \frac{K_p s}{s} + \frac{K_I}{s}$$

$$= \frac{K_p s + K_I}{s}$$



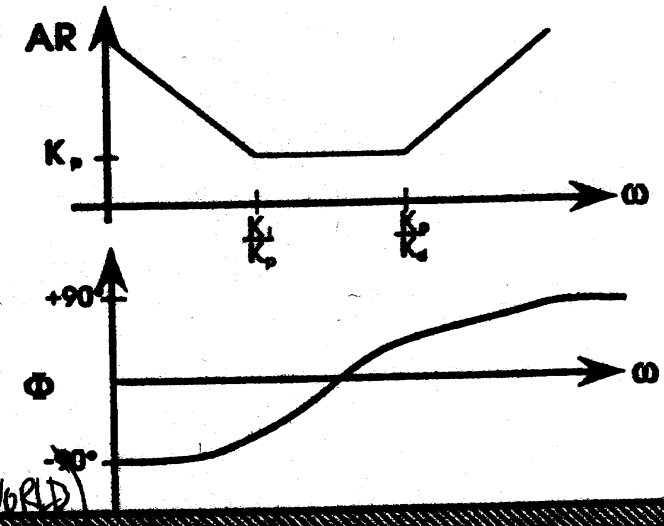
PID Controller:

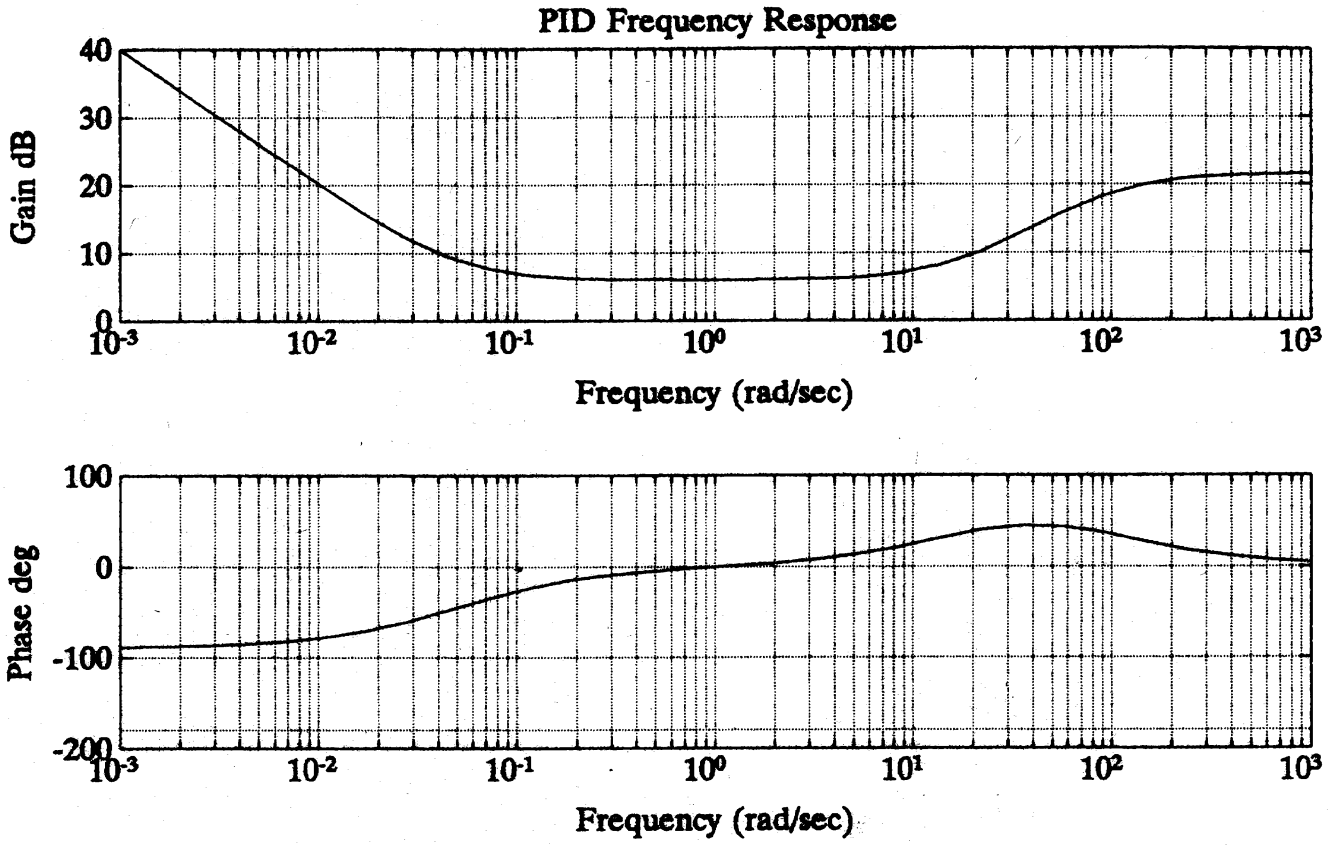
$$G_c = K_p + \frac{K_I}{s} + K_d s$$

$\alpha K_d s + 1$

LAG TERM (REAL WORLD)

(Default - set $\alpha = 0.1$)

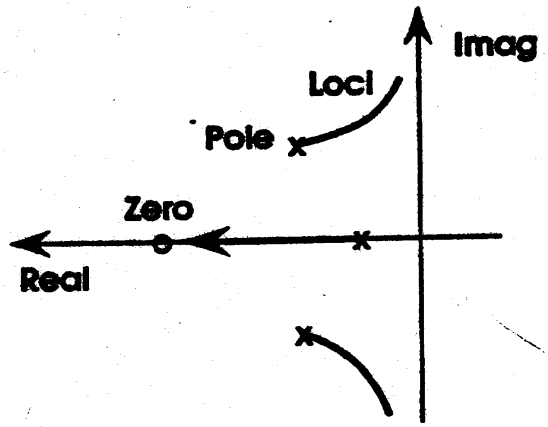




$K_p = 1.0$, $K_i = 0.1$, $K_d = 0.1$, $\alpha = 0.1$

Root Locus

A plot of the poles of the closed loop system as one of the design parameters varies continuously.



Information obtained from Root Locus:

1. Closed Loop Stability

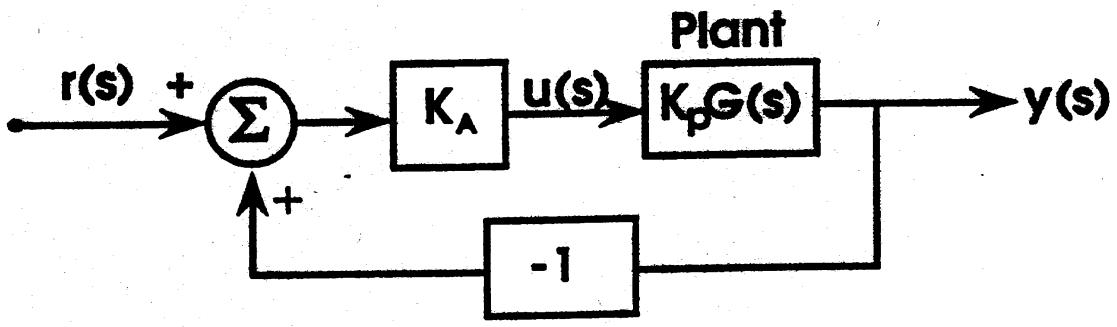
    a. Location of closed loop poles
    b. Critical Gain

2. Transient Response Characteristics

    a. Oscillatory/Non-oscillatory
    b. Damping
    c. Natural frequency
    d. Dominant modes

Root Locus Technique

- Based on studying the effects of a single parameter on closed-loop pole locations.



$$\frac{y(s)}{r(s)} = \frac{K_A K_p G(s)}{1 + K_A K_p G(s)}$$

- Characteristic Equation: $1 + K_A K_p G(s) = 0$
- Roots of characteristic equation are poles of the transfer function Y(s)/R(s).
- Closed loop poles depend on the amplifier gain K_A.

Root Locus Construction Rules

Root loci start at the open loop poles and end at the open loop zeros or at infinity.

There is one loci for each open loop pole.

The loci is symmetric about the real axis.

The loci is on the real axis to the left of an odd number of open loop poles and zeros.

The number of asymptotes is equal the the number of open loop poles minus the number of open loop zeros.

The center of the asymptotes is at:

$$x = \frac{\Sigma(\text{poles}) - \Sigma(\text{zeros})}{(n_p - n_z)}$$

The angles of the asymptotes are:

$$\text{Angle} = \frac{[(2q+1)180]}{n_p - n_z} \quad ; \quad q = 0, 1, 2, \ldots, (np - nz - 1)$$

Basic Example

Transfer function: $H(s) = \frac{num}{den}$

Example:

Num = $2s + 1$
Den = $s^2 + 3s + 2$

Poles: Values of s where H(s) is infinity. (s=-1, S =-2)

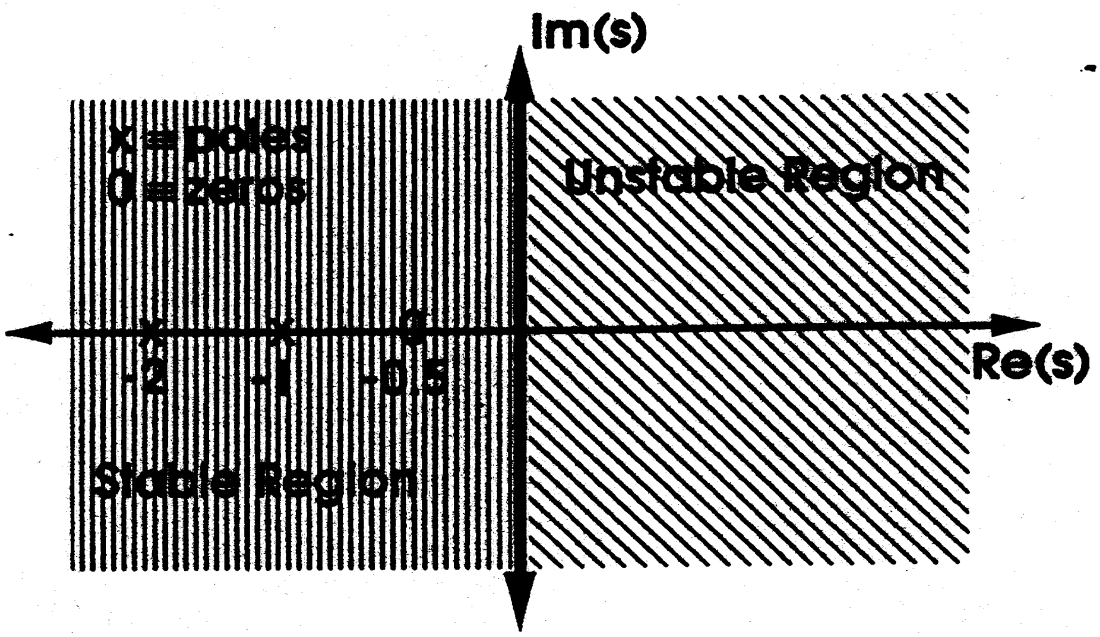
Zeros Values of s where H(s) is equal to zero. (s=-0. 5).

$$H(s) = \frac{2s+1}{s^2+3s+2} = \frac{2s+1}{(s+1)(s+2)}$$

$$H(s) = \frac{-1}{s+1} + \frac{3}{s+2}$$

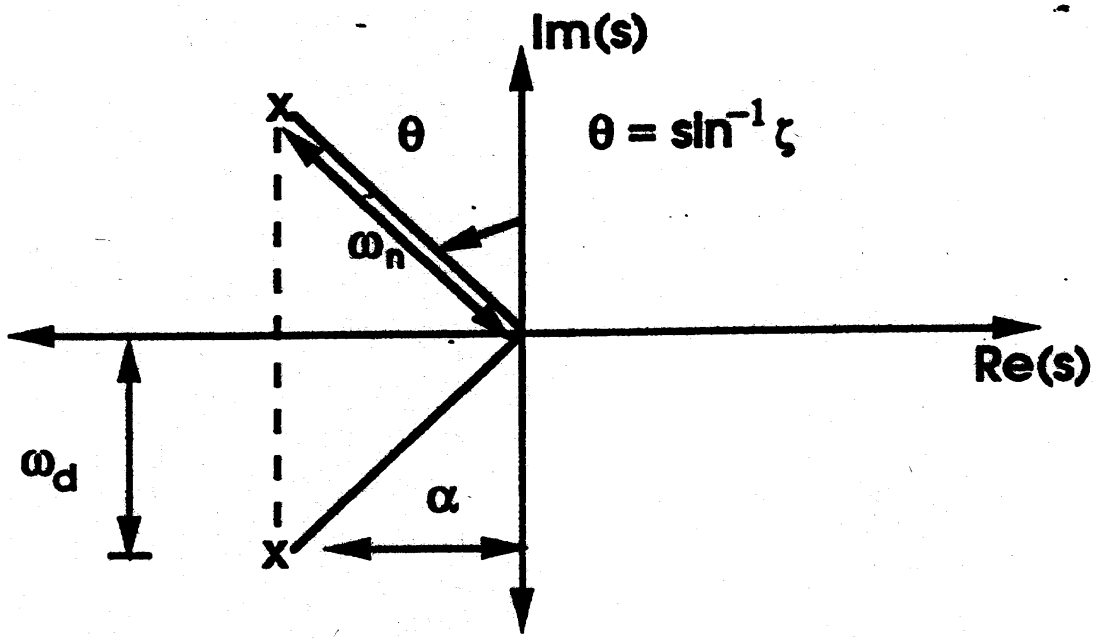
$$h(t) = -e^{-t} + 3e^{-2t}; t \geq 0$$
$$= 0 \quad ; t < 0$$

S Plane



- Poles farthest left associated with signals that decay faster.
- Poles located farther up/down Im(s) axis are associated with signals that are more oscillatory in nature.
- By changing pole locations you influence stability and dynamic response.

Complex S Plane



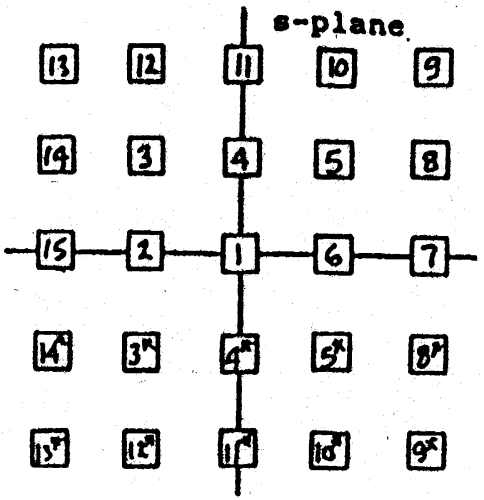
$S = -\alpha \pm j\omega_d$ Complex Pole Locations

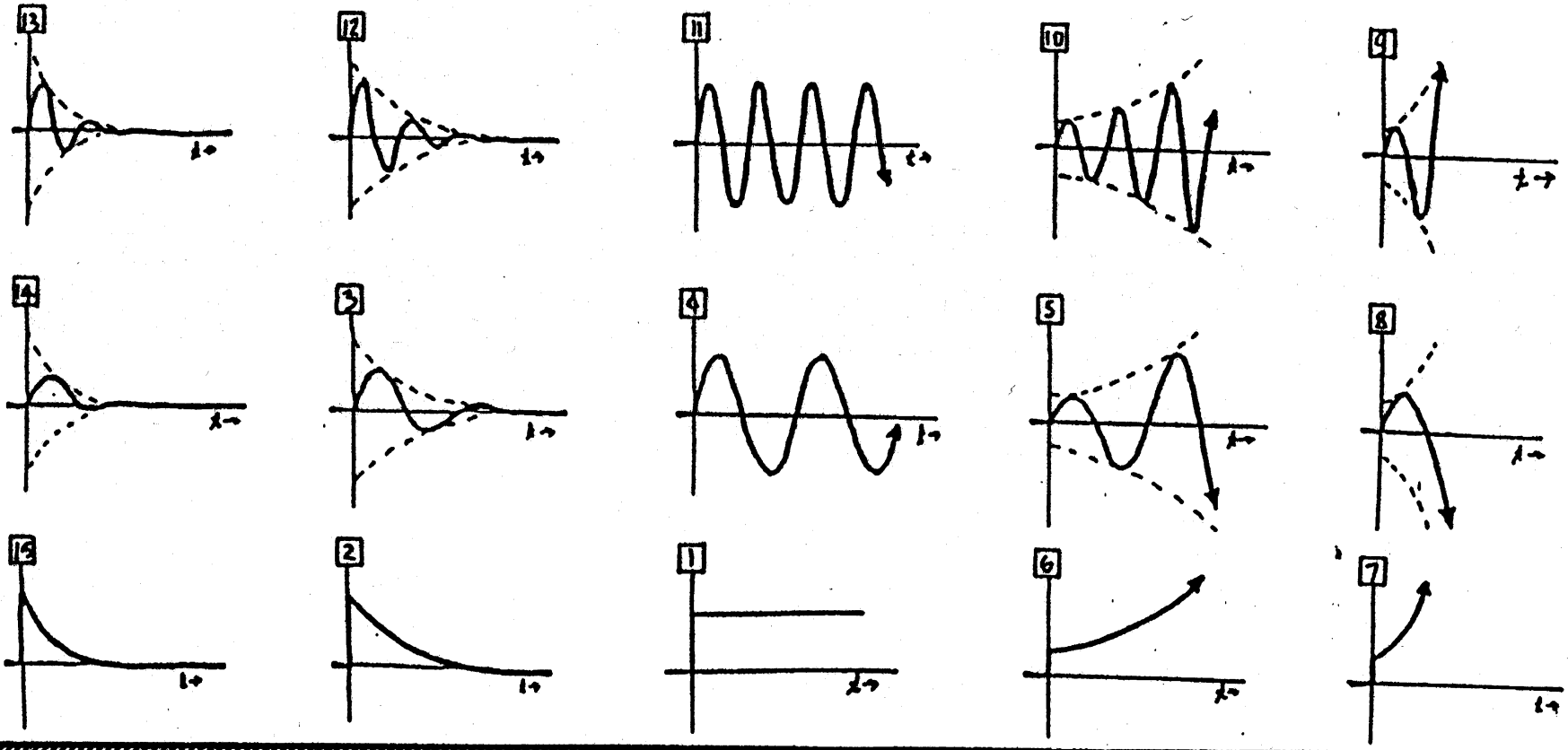
ζ = damping ratio

ω_n = undamped natural frequency

$\omega_d = \omega_n \sqrt{1-\zeta^2}$

Transient Response Characteristics From Root Locus Plots





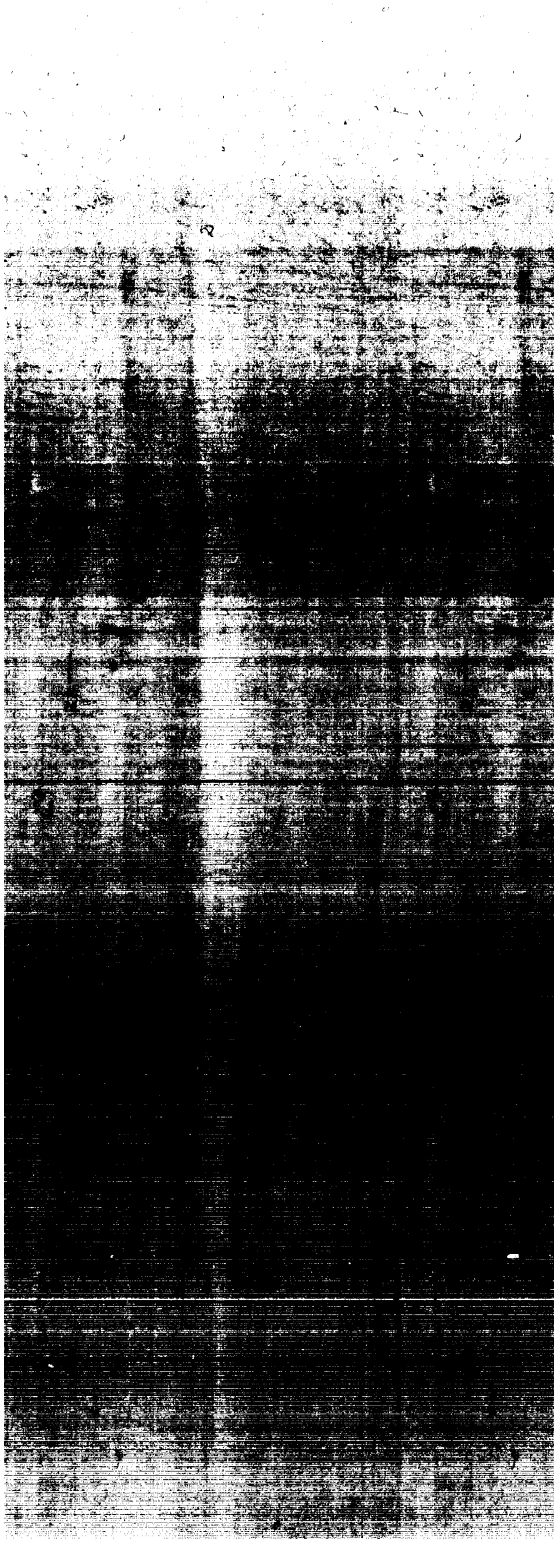
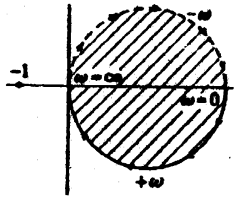
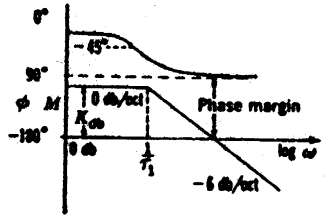
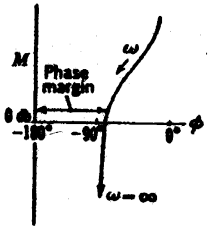
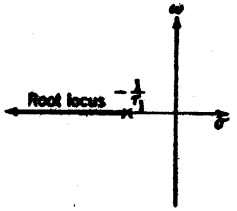
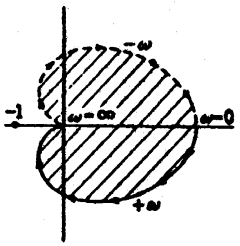
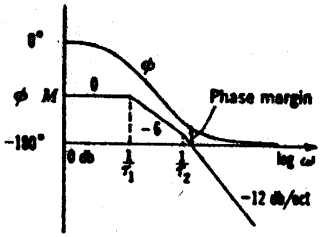
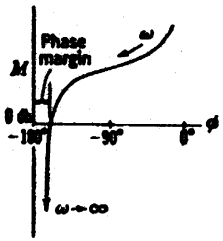
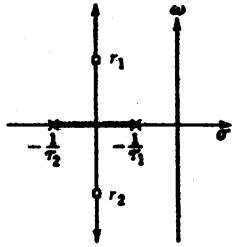
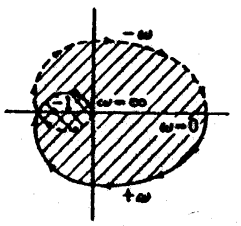
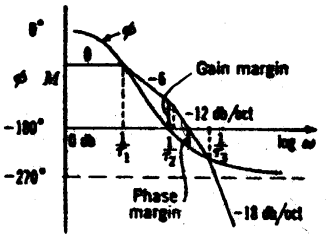
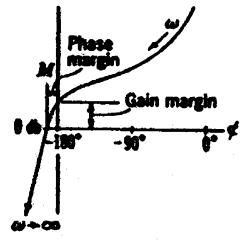
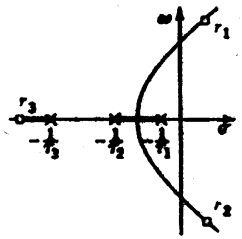
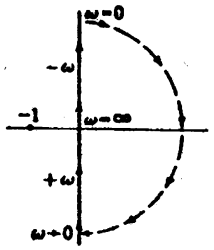
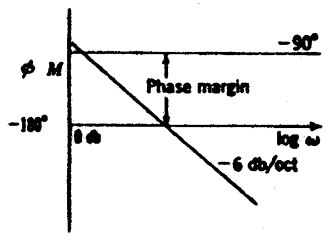
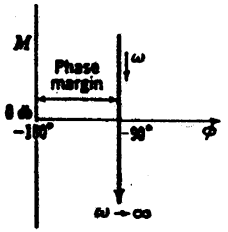
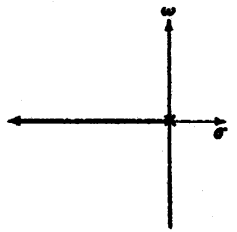
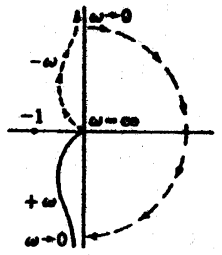
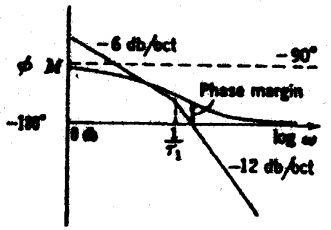
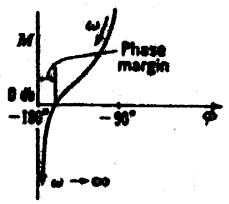
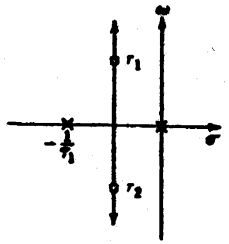
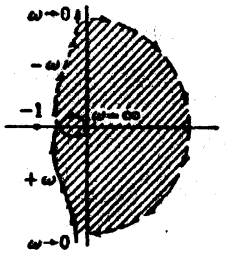
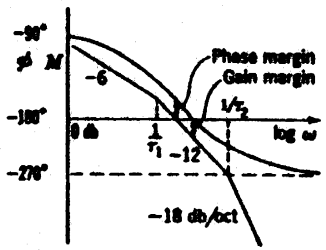
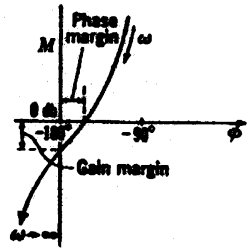
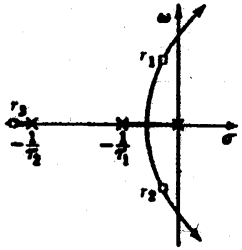
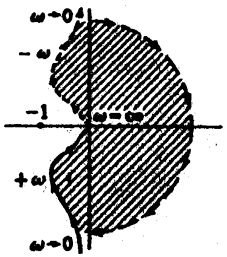
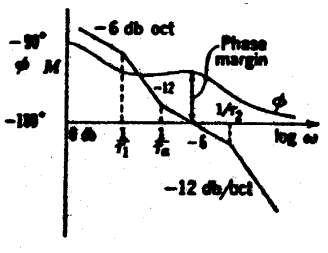
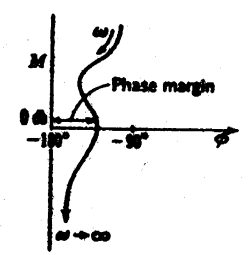
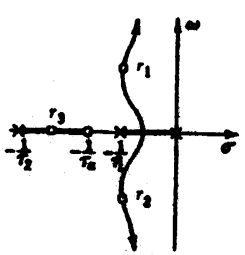
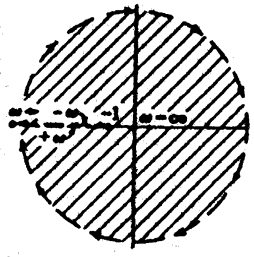
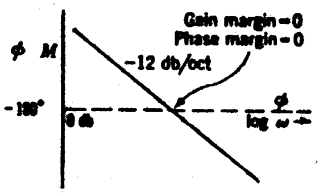
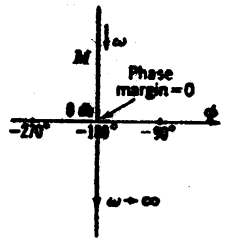
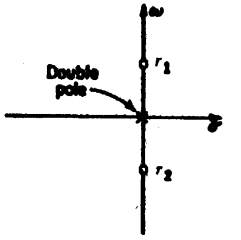


Table 8–3 TRANSFER-FUNCTION PLOTS FOR TYPICAL TRANSFER FUNCTION

	$G(s)$	Polar plot	Bode diagram	Nichols diagram	Root locus	Comments
1.	$\frac{K}{s\tau_1 + 1}$					Stable; gain margin = ∞
2.	$\frac{K}{(s\tau_1 + 1)(s\tau_2 + 1)}$					Elementary regulator; stable; gain margin = ∞
3.	$\frac{K}{(s\tau_1 + 1)(s\tau_2 + 1)(s\tau_3 + 1)}$					Regulator with additional energy-storage component; unstable, but can be made stable by reducing gain
4.	$\frac{K}{s}$					Ideal integrator; stable

(Continued)

Table 8–3 (*Continued*)

$G(s)$	Polar plot	Bode diagram	Nichols diagram	Root locus	Comments
5. $\frac{K}{s(\tau_1 s + 1)}$					Elementary instrument servo; inherently stable; gain margin = ∞
6. $\frac{K}{s(\tau_1 s + 1)(\tau_2 s + 1)}$					Instrument servo with field-control motor or power servo with elementary Ward-Leonard drive; stable as shown, but may become unstable with increased gain
7. $\frac{K(\tau_3 s + 1)}{s(\tau_1 s + 1)(\tau_2 s + 1)}$					Elementary instrument servo with phase-lead (derivative) compensator; stable
8. $\frac{K}{s^2}$					Inherently unstable; must be compensated

(*Continued*)

PROPORTIONAL CONTROL
(Single Mode Controller)

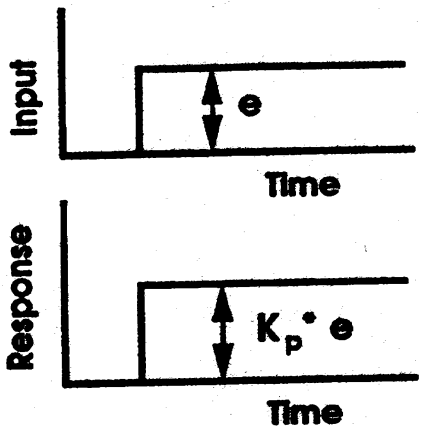
Only Drawback – won't always drive offset to 0
(must add integral)

Proportional control adusts the manipulated variable by an amount proportional to the error (deviation of the controlled variable from its desired value).

$G_c(s) = K_p$

Proportional Band:

$$P.B. = \frac{100}{K_p} \%$$



Characteristics:

1. **An error or offset is necessary to provide a steady state controller setting which will support the desired load.**
2. **Easy to tune.**
3. **Provides good stability and rapid response.**

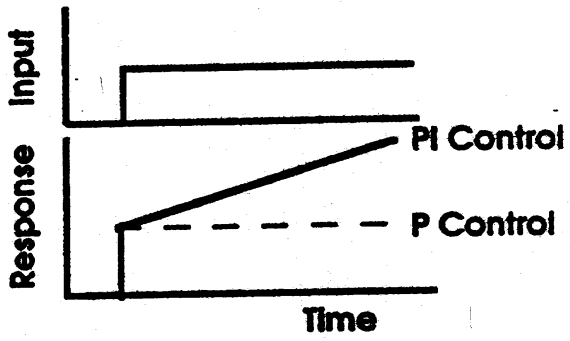
PROS: Simplicity
CONS: Steady State Offset

PROPORTIONAL PLUS INTEGRAL CONTROL (Two Mode Controller)

Integral Action adjusts the rate of change of the manipulated variable by an amount proportional to the error.

$$G_c(s) = K_p + \frac{K_I}{s}$$

K_I : Reset Rate



Repeats per min: # of times the integral action repeats the proportional action per minute :

$$\left[\frac{K_I \bullet 60}{K_P}\right]$$

Characteristics:

1. **The output of an integral controller will continue to change as long as there is a deviation from set point; hence it is capable of driving the deviation to zero.**

2. **If the error cannot be eliminated when the load exceeds the range of the manipulated variable the controller will saturate its integral mode; this condition is called windup.**

PROS: Steady State Error = 0
CONS: 1. Integral Windup.
2. Tends to destabilize response.

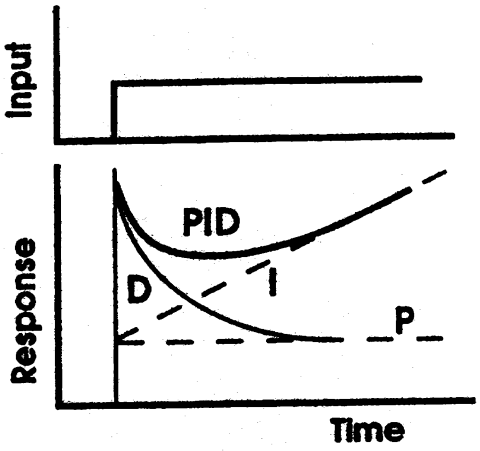
If you have an inherently fast control system, you can stand more integral w

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL
(Three Mode Controller)

Derivative action adusts the manipulated variable by an amount proportional to the rate of change of the error. Derivative feedback alone will not drive the error to zero.

$$G_c(s) = K_p + \frac{K_I}{s} + K_D s$$

$$\text{Rate time} = \frac{K_D}{60} \text{ mins}$$



<u>Characteristics:</u>

1. Derivative control serves to lower the maximum deviation and to eliminate some of the oscillation realized with PI control.

2. Derivative controllers are extremely sensitive to noise and other high-frequency disturbances. Therefore, derivative action must be limited in gain to avoid controller instability and noise propagation.

noisy signal amplifies output noise

PROS: Increased Controller Response Speed CONS: Sensitivity to Noise

Non-Interactive PID Controller

$$K_{p1} + \frac{K_{I1}}{s} + K_{D1}\,s$$

Interactive PID Controller

$$K_{p2}\left(1 + \frac{K_{I2}}{s} + K_{D2}\,s\right)$$

Converting from Non-Interactive to Interactive

$$K_{p2} = K_{p1}$$

$$K_{I2} = \frac{K_{I1}}{K_{p1}}$$

$$K_{D2} = \frac{K_{D1}}{K_{p1}}$$

Converting from seconds to minutes

$$K_I\,(1/\text{min}) = K_I\,(1/\text{sec}) * 60$$

$$K_D\,(\text{min}) = K_D\,(\text{sec}) / 60$$

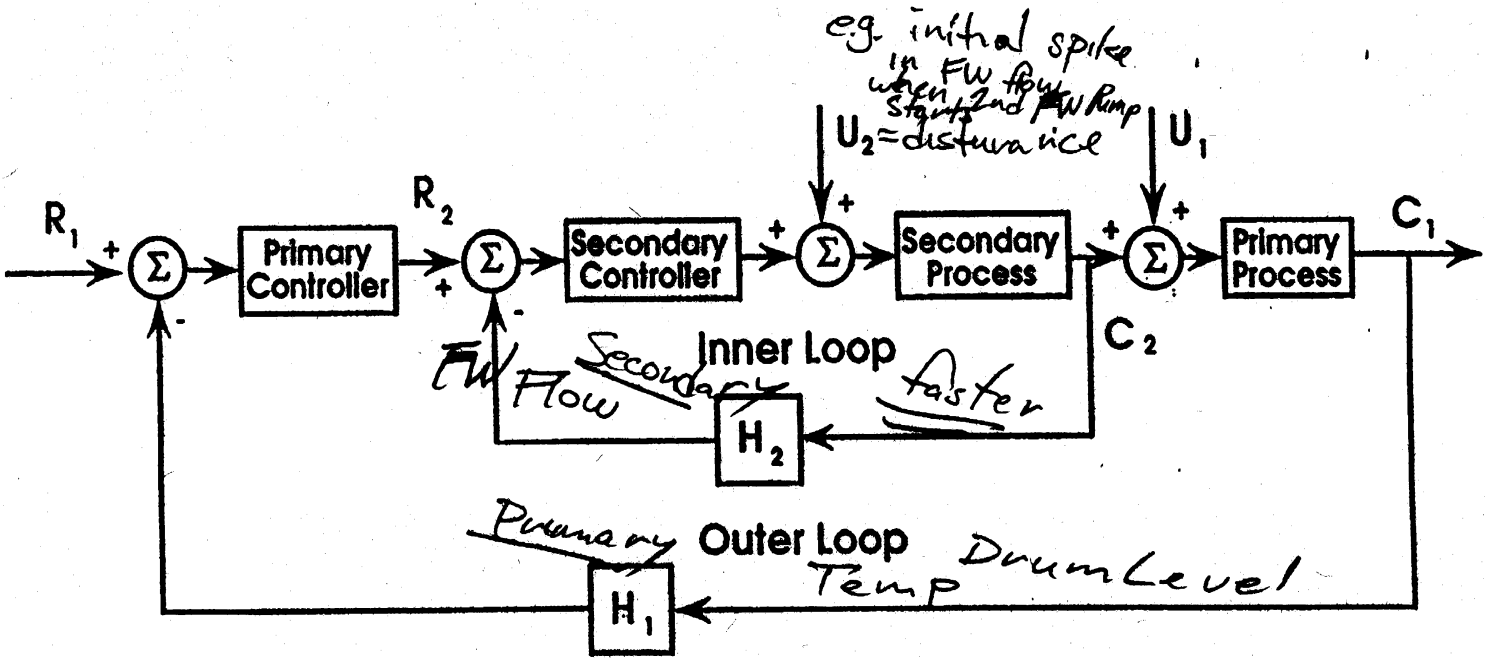
Typical Values for Interactive PID Gains

$$K_p: \; 0.1 \rightarrow 10$$

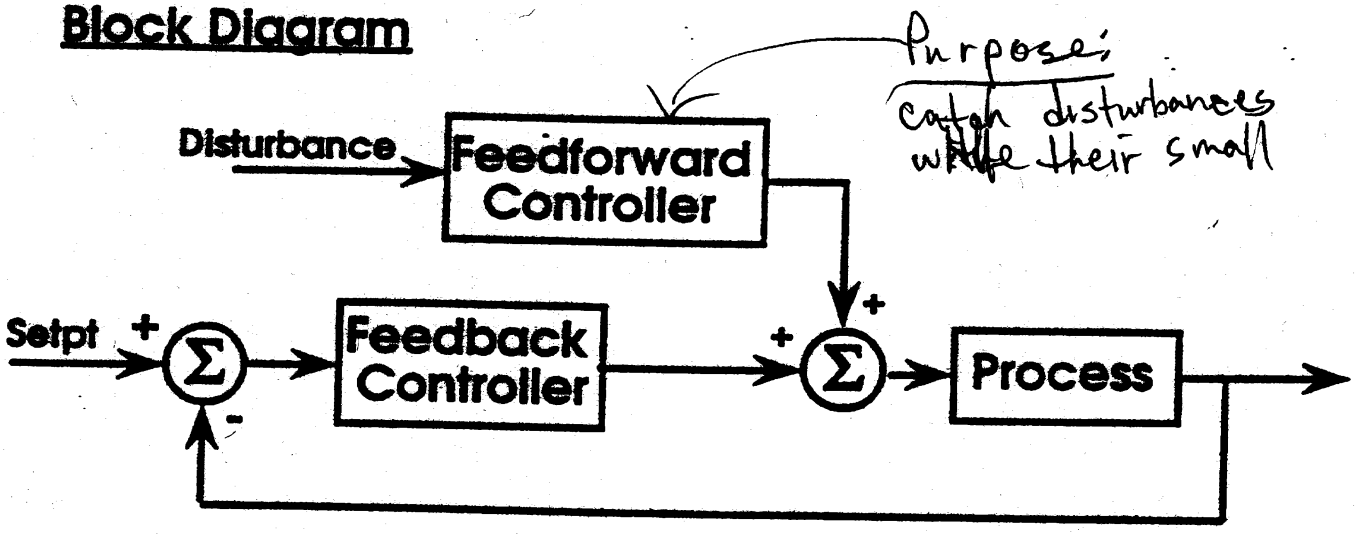
$$\frac{1}{K_I}\,(\text{min}): \; 0 \rightarrow 30$$

$$K_D\,(\text{min}): \; 0 \rightarrow 1$$

CASCADE CONTROL



Block Diagram



Performance Criteria

Control system performance is generally judged by its step response characteristics. Some of the measurements used to quantify the performance are:

Steady State Offset (Error)

Overshoot $\leq 20\%$.

Rise Time

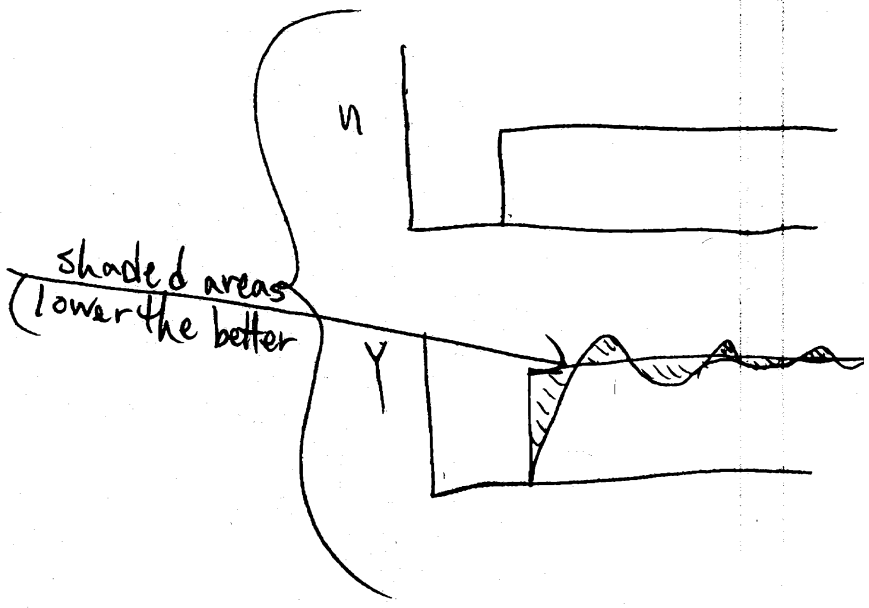
Settling Time

Time to first crossing

Integral of Absolute Error

Integral of Error Squared

similar



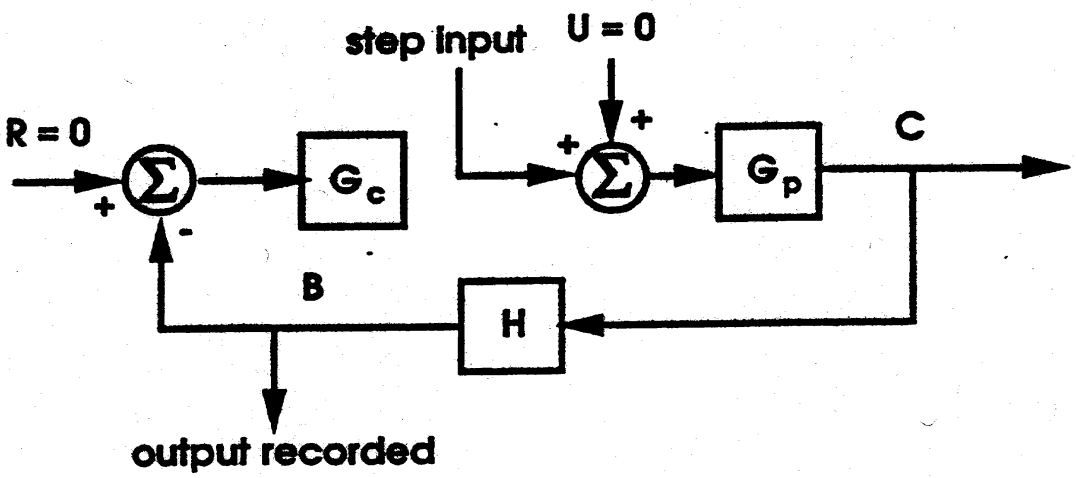
PID TUNING

PROCESS REACTION CURVE METHOD

- Quarter wave damping criteria yields underdamped closed loop systems which are generally not acceptable for power plant controls
- Method difficult to apply to processes not easily modeled by first order lag plus dead time

PID TUNING

Process Reaction Curve Method



From the recorded output curve determine

1. apparent dead time, T_d
2. apparent time constant, T
3. steady state magnitude of the output variable, B_{ss}

Define K = B_{ss}/(magnitude of step input)

4. Determine the Controller Gains from the following

Controller	K_c	T_R	T_D
P	$\frac{1}{K}\frac{T}{T_d}\left(1+\frac{T_d}{3T}\right)$		
PI	$\frac{1}{K}\frac{T}{T_d}\left(\frac{9}{10}+\frac{T_d}{12T}\right)$	$T_d\frac{30+3T_d/T}{9+20T_d/T}$	
PID	$\frac{1}{K}\frac{T}{T_d}\left(\frac{4}{3}+\frac{T_d}{4T}\right)$	$T_d\frac{32+6T_d/T}{13+8T_d/T}$	$T_d\frac{4}{11+2T_d/T}$

PID TUNING

PROCESS REACTION CURVE METHOD

Loop in MANUAL and do a STEP change

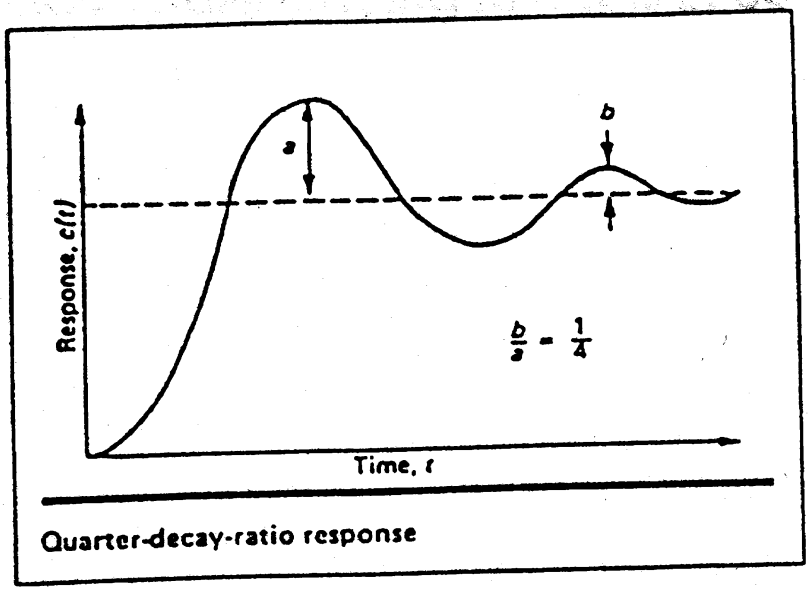
Assumptions:

1) **Open loop process described by:**

$$\frac{Ke^{-T_d s}}{Ts + 1}$$

ASSUMES: 1st order lag plus dead time

2) **Optimum response characterized by 1/4 decay ratio (also called quarter wave damping)**



Quarter-decay-ratio response

PID TUNING

Ziegler-Nichols Method

1. A proportional controller is operated in closed loop with process to be controlled ($K_I = K_D = 0$).
2. Increase proportional gain until self-sustained oscillations are obtained.
3. Record critical gain, K_{cmax}, and critical period, P_u.
4. Determine PID gains from the following chart $G_C(S) = K_P\left(1 + \frac{1}{T_R S} + T_D S\right)$, thus $K_I = \frac{K_P}{T_R}$.

T_R S — min/repeat

Controller	K_c	T_R	T_D
P	$0.5K_{cmax}$	-	-
PI	$0.45K_{cmax}$	$P_u/1.2$	-
PID	$0.6K_{cmax}$	$P_u/2$	$P_u/8$

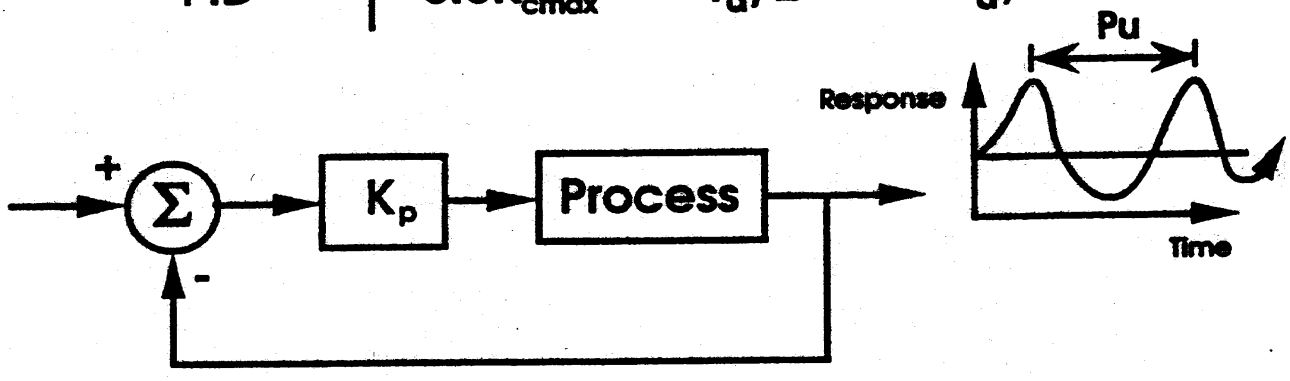


TABLE 1.1
Typical Controller Mode Settings

Loop Type	*PB Setting, %*	*T_i Setting, r/m*	*T_d Setting, m*
Flow*	100—500	10—50	none
Liquid pressure*	100—500	10—50	none
Gas pressure*	1—50	0.02—1	0.02—0.1
Level*	1—50	0.01—0.1	0.01—0.05
Temperature	10—100	0.02—0.05	0.5—2
Chromatogrpah	200—800	0.01—0.1	none

%—percent (proportional band)
r/m—repeats per minute (reset)
m—minutes (rate)

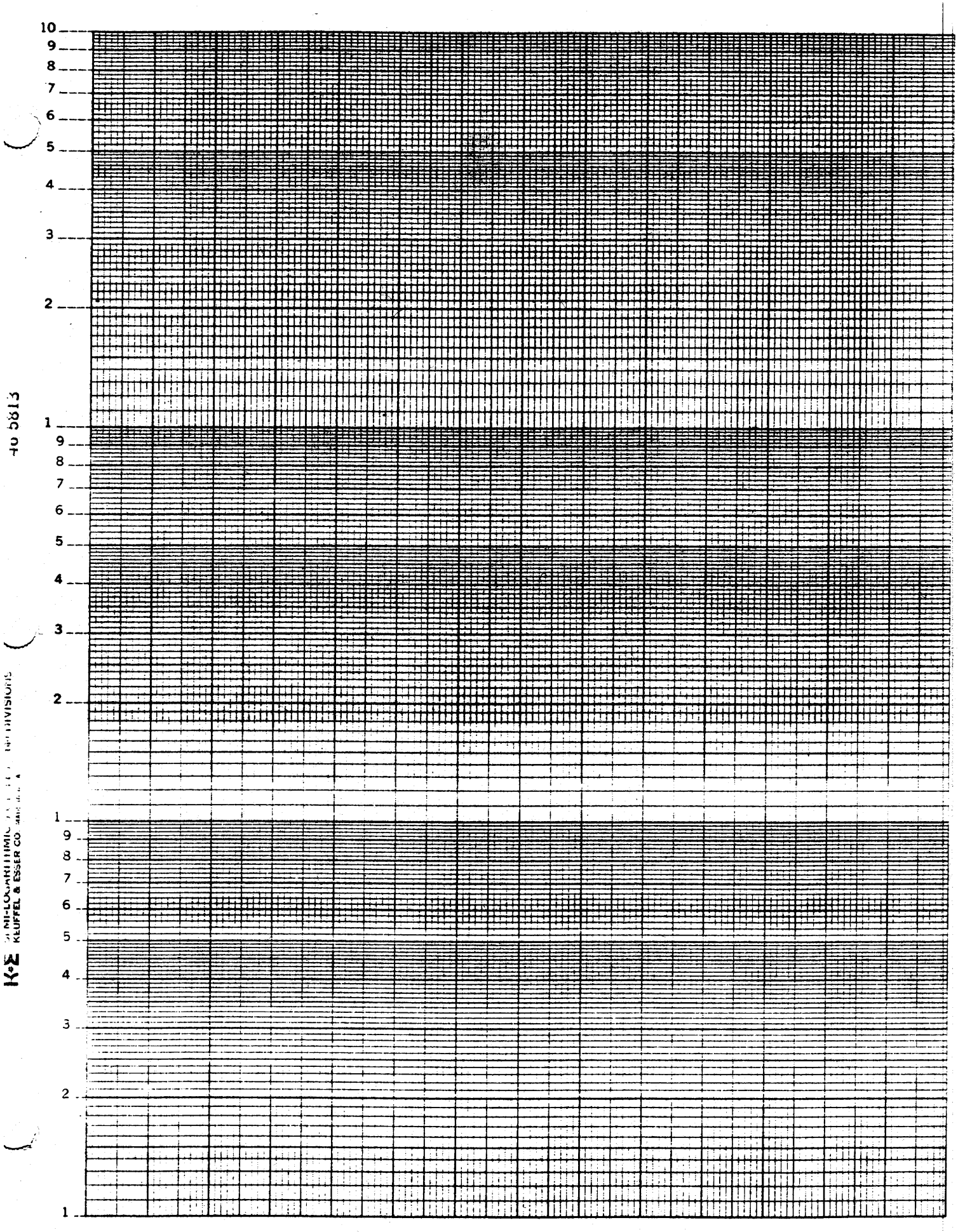
time dominant processes. Most of the literature to date describes the second class, which is an open-loop method. The last class will not be discussed because the better estimate of derivative mode setting is usually not worth the extra effort.

1.4.1 QUARTER AMPLITUDE OSCILLATION METHOD

The quarter amplitude oscillation method is the only method carried out with the controller in automatic (closed-loop). It is a modification of the ultimate oscillation method developed by J.G. Ziegler and N.B. Nichols (Ziegler and Nichols, 1942). This revised oscillation method uses damped oscillations to arrive at tuning settings that provide less gain and reset action but more rate action. A closed-loop method is generally easier because it requires no estimates of loop gain, dead time, or time constant but requires some courage to make the loop oscillate. The oscillations can be killed at any time within one dead time by increasing the proportional band or decreasing the gain. It is actually safer than the other methods because the controller remains in automatic with stable tuning settings, which is absolutely essential for difficult non-self-regulating loops or loops subjected to big upsets.

The quarter amplitude method has the following advantages over open-loop methods:

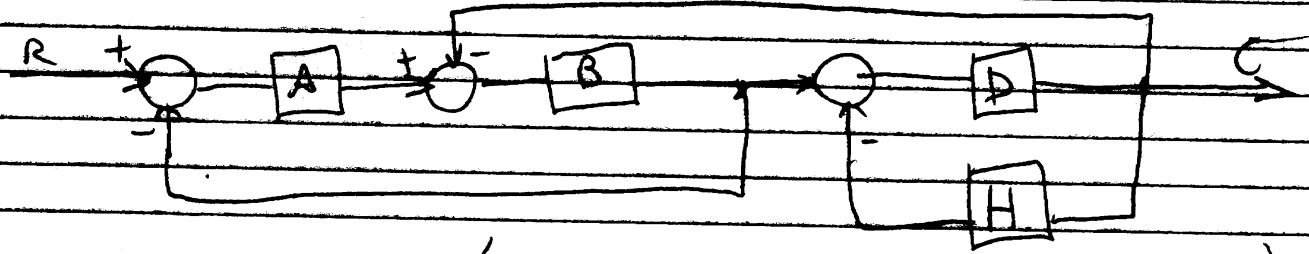
1. Forces one to find the maximum gain, which is important for minimizing the peak error, finding out whether reset or


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
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1
46 5613
K+E
KEUFFEL & ESSER CO

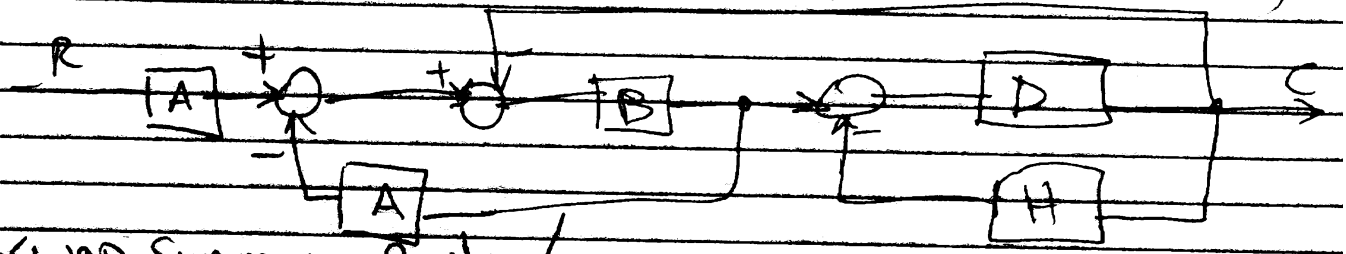
Work Alg

Control Systems Diagramming — A18 Problem

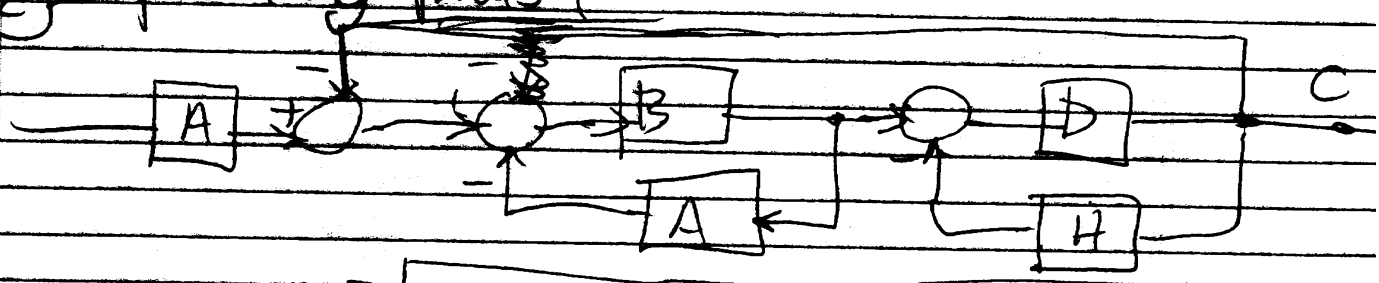
Block Diagram — Reduction

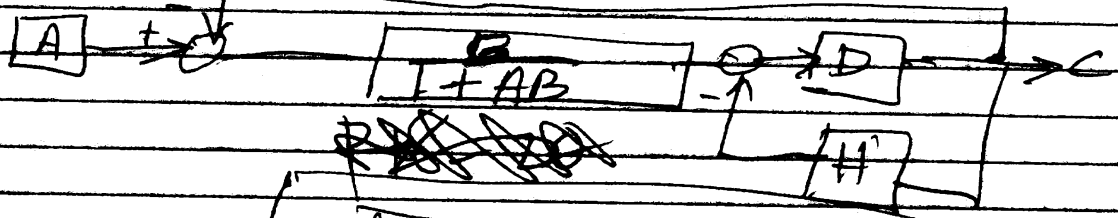


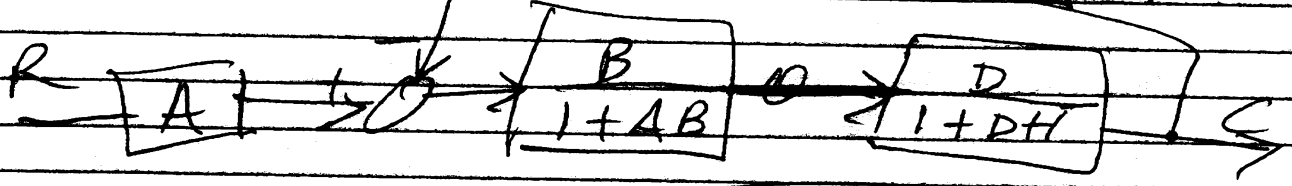
(1) Use Rule 2 — (Move a summing point behind a block)

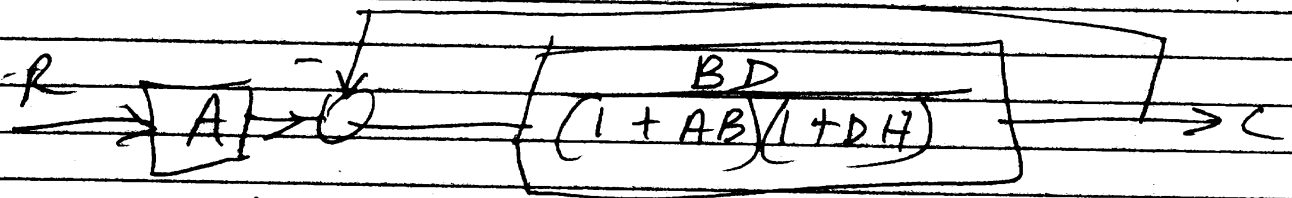


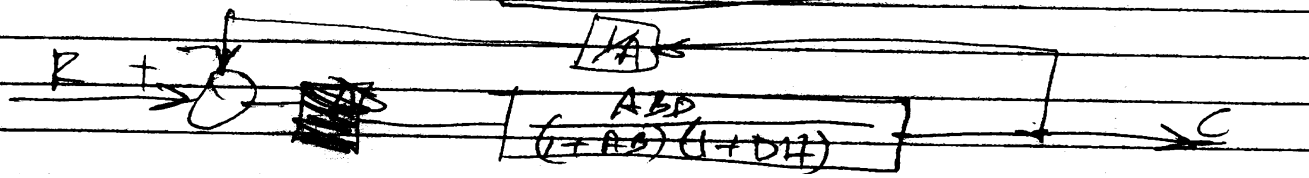
(2) Swap Summing Points.



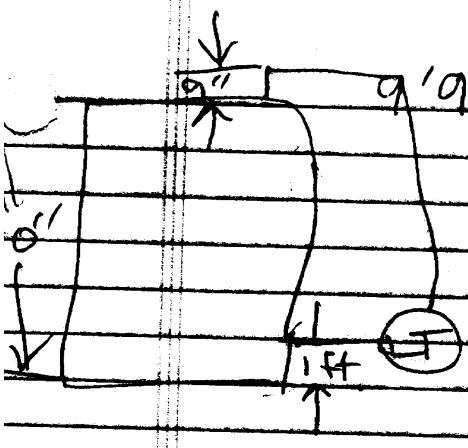








08 0.01391



$h = (12")(.9236) = 110.8$

$e = (12")(.9236) = 11.08$

$s = (117")(.989) = 115.7$

$e - s = 11.08 - 115.7 = -104.6$

$h + e - s = 110.8 + 11.08 - 115.7 = 6.180$

$S = (117")(.989) = 115.7"$

$e = (12")(.9236) = 11.1$

$1 \quad (12)(.989) = 11.6$

$\frac{ABD}{(1+AB)(1+DH)+BD}$

$\frac{14.696 \text{ PSIG}}{33 \text{ ft } H_2O}$

$\frac{ABD}{1+AB+DH+ABDH+BD}$

$\frac{ABD}{(1+AB)(1+DH)}$

$1+\left(\frac{1}{A}\right)\left(\frac{ABD}{(1+AB)(1+DH)}\right)$

$\frac{(1+AB)(1+DH)+BD}{1+AB+DH+BHD^2}$

$\frac{ABD}{1+}$

PID TUNING

ZIEGLER-NICHOLS METHOD

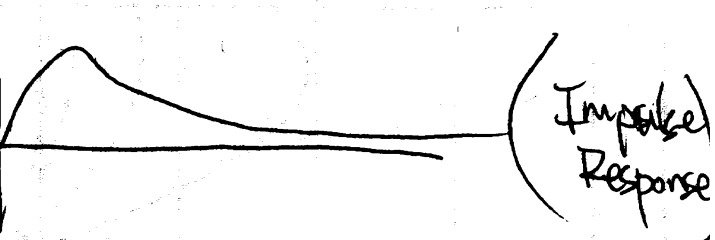
- Closed Loop operation in condition of borderline stability could cause physical damage to equipment
- No information about actual open loop plant dynamics (transfer function) is obtained
- Proportional gain calibrations may be inaccurate leading to errors in control settings

Theoretically If Phase angle never reaches -180° you can increase gain to ∞ and Remain Stable.

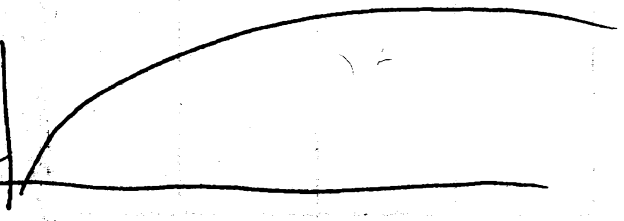
Suppose we have 1st Order Lag System

$$F(s) = \frac{k}{\tau s + 1}$$

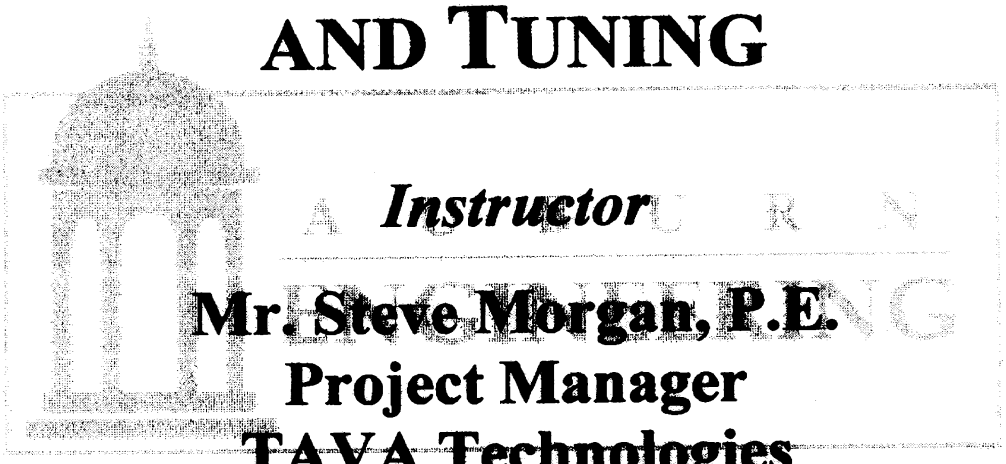
$F(s) = \left(\frac{k}{\tau s+1}\right)(1)$ (Transfer function system by itself)



$F(s) = \left(\frac{k}{\tau s+1}\right)\left(\frac{1}{s}\right)$ (step Response)



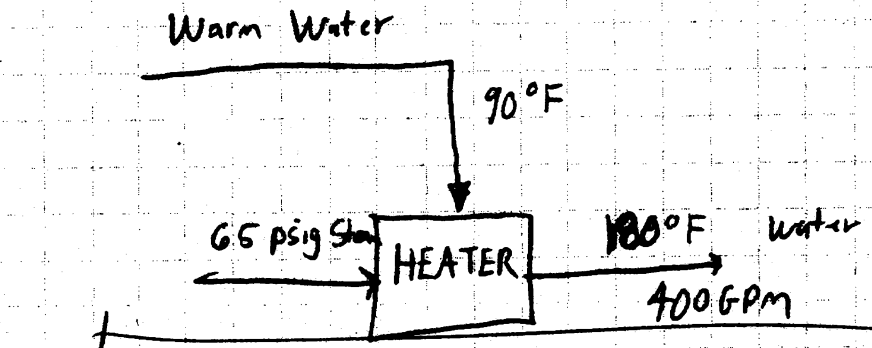
PROCESS CHARACTERISTICS *AND* CONTROLLERS, MODES, AND TUNING



Instructor

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(205) 328-4279 (f)

Direct Injection Heater



What is water in in GPM and steam in in lb/hr?

$MASS_{IN} = MASS_{OUT}$

$ENERGY_{IN} = ENERGY_{OUT}$

90°F water { S.V. = .016099 ft³/lb, Density = 62.11 lb/ft³ } h = 58.1 Btu/lb

180°F water S.V. = .01651 ft³/lb, Density = 60.569 lb/ft³ h = 147.93 Btu/lb

Convert outlet to lb/min

$$400 \frac{gal}{min} \times \frac{ft^3}{7.48052\ gal} \times 60.569 \frac{lb}{ft^3} = 3238.7 \frac{lb}{min}$$

65 psig steam h = 1183.1 Btu/lb

x = lb/min water

y = lb/min steam

$$(x)(58.1) + (y)(1183.1) = (3238.7)(147.93)(1)$$

$$58.1x + 1183.1y = 479100.891 \text{ Btu/min}$$

$$x + 20.363y = 8246.143$$

$Water_{IN}$ ↓ ↓ $Steam_{IN}$

$x + y = 3238.7$ (2) MASS EQUATION

$y = 3238.7 - x$

~~$x + (20.363)(3238.7)$~~

$x + (20.363)(3238.7 - x) = 8246.143$

$x + 65949.65 - 20.363x = 8246.143$

$-19.363x = 8246.143 - 65949.65$

WATER $x = 2980\ lb/min$

$y = 3238.7 - 2980$

$y = 258.7\ lb/min.$

STEAM $y = 258.7\ lb/min \times \frac{60\ min}{hr} =$ [redacted] $15522\ lb/hr$

$2980\ lb/min \times \frac{7.48052\ gal}{ft^3} \times \frac{ft^3}{62.11\ lb} = 358.9\ gal/min.$

Properties of Saturated Steam and Saturated Water*

Absolute Pressure Lbs. per Sq. In. P'	Absolute Pressure Inches of Hg	Vacuum Inches of Hg	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume V Water Cu. ft. per lb.	Specific Volume V Steam Cu. ft. p
0.08859	0.02	29.90	32.018	0.0003	1075.5	1075.5	0.016022	3302.4
0.10	0.20	29.72	35.023	3.026	1073.8	1076.8	0.016020	2945.5
0.15	0.31	29.61	45.453	13.498	1067.9	1081.4	0.016020	2004.7
0.20	0.41	29.51	53.160	21.217	1053.5	1084.7	0.016025	1526.3
0.25	0.51	29.41	59.323	27.382	1060.1	1087.4	0.016032	1235.5
0.30	0.61	29.31	64.484	32.541	1057.1	1089.7	0.016040	1039.7
0.35	0.71	29.21	68.939	36.992	1054.6	1091.6	0.016048	898.6
0.40	0.81	29.11	72.869	40.917	1052.4	1093.3	0.016056	792.1
0.45	0.92	29.00	76.387	44.430	1050.5	1094.9	0.016063	708.8
0.50	1.02	28.90	79.586	47.623	1048.6	1096.3	0.016071	641.5
0.60	1.22	28.70	85.218	53.245	1045.5	1098.7	0.016085	540.1
0.70	1.43	28.49	90.09	58.10	1042.7	1100.8	0.016099	466.9
0.80	1.63	28.29	94.38	62.39	1040.3	1102.6	0.016112	411.6
0.90	1.83	28.09	98.24	66.24	1038.1	1104.3	0.016124	368.4
1.0	2.04	27.88	101.74	69.73	1036.1	1105.8	0.016136	333.6
1.2	2.44	27.48	107.91	75.90	1032.6	1108.5	0.016158	280.9
1.4	2.85	27.07	113.26	81.23	1029.5	1110.7	0.016178	243.0
1.6	3.26	26.66	117.98	85.95	1026.8	1112.7	0.016196	214.3
1.8	3.66	26.26	122.22	90.18	1024.3	1114.5	0.016213	191.8
2.0	4.07	25.85	126.07	94.03	1022.1	1116.2	0.016230	173.7
2.2	4.48	25.44	129.61	97.57	1020.1	1117.6	0.016245	158.8
2.4	4.89	25.03	132.88	100.84	1018.2	1119.0	0.016260	146.4
2.6	5.29	24.63	135.93	103.88	1016.4	1120.3	0.016274	135.8
2.8	5.70	24.22	138.78	106.73	1014.7	1121.5	0.016287	126.6
3.0	6.11	23.81	141.47	109.42	1013.2	1122.6	0.016300	118.7
3.5	7.13	22.79	147.56	115.51	1009.6	1125.1	0.016331	102.7
4.0	8.14	21.78	152.96	120.92	1006.4	1127.3	0.016358	90.6
4.5	9.16	20.76	157.82	125.77	1003.5	1129.3	0.016384	83.03
5.0	10.18	19.74	162.24	130.20	1000.9	1131.1	0.016407	73.53
5.5	11.20	18.72	166.29	134.26	998.5	1132.7	0.016430	67.24
6.0	12.22	17.70	170.05	138.03	996.2	1134.2	0.016451	61.98
6.5	13.23	16.69	173.56	141.54	994.1	1135.6	0.016472	57.50
7.0	14.25	15.67	176.84	144.83	992.1	1136.9	0.016491	53.65
7.5	15.27	14.65	179.93	147.93	990.2	1138.2	0.016510	50.29
8.0	16.29	13.63	182.86	150.87	988.5	1139.3	0.016527	47.34
8.5	17.31	12.61	185.63	153.65	986.8	1140.4	0.016545	44.73
9.0	18.32	11.60	188.27	156.30	985.1	1141.4	0.016561	42.40
9.5	19.34	10.58	190.80	158.84	983.6	1142.4	0.016577	40.31
10.0	20.36	9.56	193.21	161.26	982.1	1143.3	0.016592	38.42
11.0	22.40	7.52	197.75	165.82	979.3	1145.1	0.016622	35.14
12.0	24.43	5.49	201.96	170.05	976.6	1146.7	0.016650	32.39
13.0	26.47	3.45	205.88	174.00	974.2	1148.2	0.016676	30.08
14.0	28.50	1.42	209.56	177.71	971.9	1149.6	0.016702	28.04

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume V Water Cu. ft. per lb.	Specific Volume V Steam Cu. ft. per lb
14.696	0.0	212.00	180.17	970.3	1150.5	0.016719	26.799
15.0	0.3	213.03	181.21	969.7	1150.9	0.016726	26.290
16.0	1.3	216.32	184.52	967.6	1152.1	0.016749	24.750
17.0	2.3	219.44	187.66	965.6	1153.2	0.016771	23.385
18.0	3.3	222.41	190.66	963.7	1154.3	0.016793	22.168
19.0	4.3	225.24	193.52	961.8	1155.3	0.016814	21.074
20.0	5.3	227.96	196.27	960.1	1156.3	0.016834	20.087
21.0	6.3	230.57	198.90	958.4	1157.3	0.016854	19.190
22.0	7.3	233.07	201.44	956.7	1158.1	0.016873	18.373
23.0	8.3	235.49	203.88	955.1	1159.0	0.016891	17.624
24.0	9.3	237.82	206.24	953.6	1159.8	0.016909	16.936
25.0	10.3	240.07	208.52	952.1	1160.6	0.016927	16.301
26.0	11.3	242.25	210.7	950.6	1161.4	0.016944	15.7138
27.0	12.3	244.36	212.9	949.2	1162.1	0.016961	15.1684
28.0	13.3	246.41	214.9	947.9	1162.8	0.016977	14.6607
29.0	14.3	248.40	217.0	946.5	1163.5	0.016993	14.1869
30.0	15.3	250.34	218.9	945.2	1164.1	0.017009	13.7436
31.0	16.3	252.22	220.8	943.9	1164.8	0.017024	13.3280
32.0	17.3	254.05	222.7	942.7	1165.4	0.017039	12.9376
33.0	18.3	255.84	224.5	941.5	1166.0	0.017054	12.5700
34.0	19.3	257.58	226.3	940.3	1166.6	0.017069	12.2234

*Abstracted from ASME Steam Tables (1967), with permission of the publisher, The American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

(continued on the next page)

AREA	DESCRIPTION	PROBLEM
G	Applications - Continuous	A701

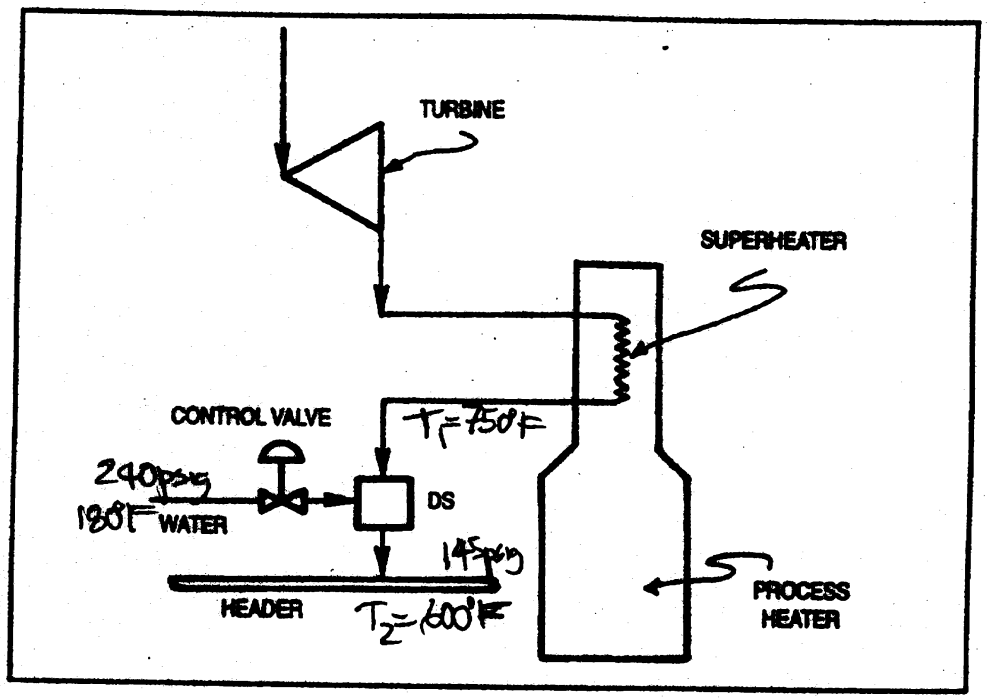


Figure A701

Situation:

A back-pressure steam turbine driving a process pump discharges saturated steam as shown in Figure A701. The saturated steam is at 150 psig and is delivered at a rate of 46,000 pounds/hour.

Before entering a steam header, the steam is superheated in a coil in the convection section of a process heater. The outlet temperature from the superheater is 750°F, and there is a 5-psi pressure drop through the piping and superheater.

It is desired to have the steam enter a plant header at 145 psig and 600°F, so a desuperheater (DS) is installed in the piping between the superheater and the header. Boiler feedwater, at 240 psig and 180°F is used in the desuperheater.

Requirements:

(a) Determine how much water is required for the desuperheater.

(b) Allowing for a 40-psi pressure drop in the water piping and desuperheater, calculate the C_v for the control valve in the water line.

(c) State the kind of valve trim characteristic that should be used.

Form E-11

RUST, BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR | DATE

AT | BY | CKD.

DESCRIPTION | DWG.

Problem A701

Given:

Pressure	145 psig	$F_1 = 46{,}000$ lbs hr
T_1	750 °F	
T_2	600 °F	
Water Pressure	240 psig	
Water Temp.	180 °F	

From Steam table: (Interpolate from Steam table: 1402)

$$h_{in} = \frac{1427.2 - 1376.4}{2} = 1402 \text{ Btu/lb}$$

$h_{out} = 1325.4$ Btu/lb

From Water table: $h_{water} = 147.93 \approx 140$ Btu/lb

Specific Volume = .01651

Density = $1/0.01651$ lbs/min water

Let x = lbs/min water

(energy) Balance

ENERGY EQUATION

(1) $1402 \text{ Btu/lb} + 148(x) = 1325.4(1+x)$

lb of steam

$1402 + 148x = 135.4 + 1325.4x$

$1402 - 1325.4 = 1325.4x - 148x$

$x = .065$ lb water / lb steam

Steam flow

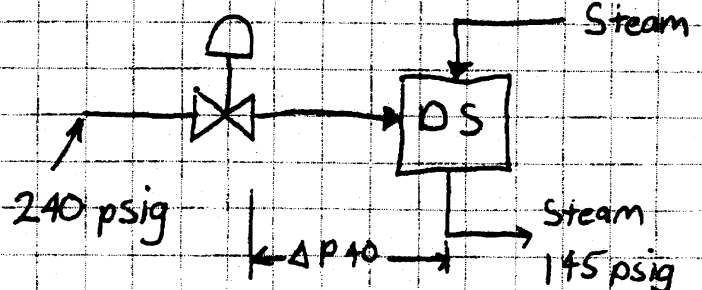
$46000 \times .065 = 2992$ lb/hr water

$2992 \text{ lb/hr} \times \frac{1 \text{ hr}}{60 \text{ min}} = 50 \text{ lbs/min} =$

$50 \frac{\text{lbs}}{\text{min}} \times .01651 \frac{\text{cuft}}{\text{lbs}} \times 7.48052 \frac{\text{gal}}{\text{cuft}} = 6.16 \text{ gal/min}$

(b.) Problem A701

water valve



Given ΔP of pipe + DS = 40 psi

$\therefore$ $240 - 40 - \Delta P_{valve} = 145$ psig

$\Delta P_{valve} = 240 - 40 - 145 = 55$ psi

$$C_v = \frac{gpm}{\sqrt{\frac{\Delta P}{S.G.}}}$$

gpm = 6.16
ΔP = 55 psi
S.G. = .971

Specific Volume from Crane
water at 180 °F = 0.01651 ft^3/lb

Density = $1/0.01651 = 60.57$ lbs/ft^3

S.G. = $\frac{60.57}{62.3663} = .970$

$$C_v = \frac{6.16}{\sqrt{\frac{55}{.971}}} = 0.818$$

(C.) use equal percentage trim

equal percentage used in 75 - 80 %

See table on next page

NELES-JAMESBURY BULLETIN 1501

CONSIDERATION OF PROCESS DYNAMICS

A very important consideration in choosing the proper valve characteristic for a given process is the dynamic response of the process and the transmitter/primary device combination. To exactly determine the dynamic response of a process requires a complete dynamic analysis for each control loop. This is difficult and usually impractical. It is possible, however, to establish general guidelines.

Among the normal control applications encountered in industrial instrumentation are: flow control, pressure control, temperature control, level control, and pH control. The suggested valve characteristics to be used for these applications follow.

For stability over the entire control range, most control loops require flow to be manipulated in uniform proportion to controller output. Because frictional losses through pipes and fittings increase and pump output pressures decrease with increasing flow, the available pressure differential at the control valve usually diminishes as flow increases. To maintain the desired uniform proportionality, an equal percentage characteristic is used in these varying pressure differential applications. In other cases where a nearly constant pressure differential will exist at the control valve, a linear characteristic is preferable on all but temperature control.

A misapplied equal percentage valve characteristic results in increasing valve sensitivity at high flow rates and can cause instability unless the controller proportional band is adjusted at the high flow rate. The control loop will then tend to be overdamped at the low flow rates, with corresponding sluggish response.

A misapplied linear valve exhibits the opposite effect. A controller properly adjusted at the high flow rate would have too narrow a proportional band setting for stability at low flows. The proportional band would have to be adjusted at the low flow rates, and the control loop would then be overdamped and sluggish at higher flow rates.

The recommendations given are only as good as the hydraulic analysis of the pressure conditions in the system. Maximum differential pressure is usually fairly exact since it is close to the shutoff pressure. Minimum valve pressure drop at full flow is more often a guess than the result of a hydraulic analysis. This guess is usually much too low. Using this guessed number as a guide to the selection of a valve characteristic will normally result in the choice of an equal percentage valve. The end result is the selection of an oversized valve that even at maximum flow will be operating in the low portions of valve opening. Consequently, rangeability and response at low flow conditions are lost.

CHARACTERISTIC SELECTION BY APPLICATION*

APPLICATIONS (FACTOR CONTROLLED)	% OF SYSTEM DROP ACROSS VALVE AT MAX. FLOW	CHARACTERISTICS
Flow — linear w/ dp	<20%	equal percentage
Flow — linear w/ flow	<40%	equal percentage
Flow — linear w/ dp	> 20%	linear
Flow — linear w/ flow	> 40%	linear
Pressure	~ 100%	linear
Pressure	< 50%	equal percentage
Liquid level	< 40%	equal percentage
Liquid level	> 40%	linear
pH	< 50%	equal percentage
pH	> 50%	linear
Temperature	> 50%	equal percentage

A701

FEEDFORWARD CONTROL SYSTEMS

Valve characteristics will be determined by system characteristics and resultant function used.

CASCADED CONTROL LOOPS

Take same characteristic required for a normal manual-set feedback loop.

* This table should be used as a guide only. Many other factors related to individual applications should also be considered.

With the above considerations in mind, it becomes obvious that where there is doubt about which characteristic to choose, equal percentage is the best choice. This is substantiated by the fact that between 75-80% of all control valves are equal percentage. Consider that errors made in hydraulic analysis usually result in oversized control valves which operate at relatively small openings where equal percentage is most stable.

Properties of Saturated Steam and Saturated Water*

Absolute Pressure Lbs. per Sq. In. P'	Absolute Pressure Inches of Hg	Vacuum Inches of Hg	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume V Water Cu. ft. per lb.	Specific Volume V Steam Cu. ft. per lb.
0.08859	0.02	29.90	32.018	0.0083	1075.5	1075.5	0.016022	3302.4
0.10	0.20	29.72	35.023	3.026	1073.8	1076.8	0.016020	2945.5
0.15	0.31	29.61	45.453	13.498	1067.9	1081.4	0.016020	2004.7
0.20	0.41	29.51	53.160	21.217	1053.5	1084.7	0.016025	1526.3
0.25	0.51	29.41	59.323	27.382	1060.1	1087.4	0.016032	1235.5
0.30	0.61	29.31	64.484	32.541	1057.1	1089.7	0.016040	1039.7
0.35	0.71	29.21	68.939	36.992	1054.6	1091.6	0.016048	898.6
0.40	0.81	29.11	72.869	40.917	1052.4	1093.3	0.016056	792.1
0.45	0.92	29.00	76.387	44.430	1050.5	1094.9	0.016063	708.8
0.50	1.02	28.90	79.586	47.623	1048.6	1096.3	0.016071	641.5
0.60	1.22	28.70	85.218	53.245	1045.5	1098.7	0.016085	540.1
0.70	1.43	28.49	90.09	58.10	1042.7	1100.8	0.016099	466.94
0.80	1.63	28.29	94.38	62.39	1040.3	1102.6	0.016112	411.69
0.90	1.83	28.09	98.24	66.24	1038.1	1104.3	0.016124	368.43
1.0	2.04	27.88	101.74	69.73	1036.1	1105.8	0.016136	333.60
1.2	2.44	27.48	107.91	75.90	1032.6	1108.5	0.016158	280.96
1.4	2.85	27.07	113.26	81.23	1029.5	1110.7	0.016178	243.02
1.6	3.26	26.66	117.98	85.95	1026.8	1112.7	0.016196	214.33
1.8	3.66	26.26	122.22	90.18	1024.3	1114.5	0.016213	191.85
2.0	4.07	25.85	126.07	94.03	1022.1	1116.2	0.016230	173.76
2.2	4.48	25.44	129.61	97.57	1020.1	1117.6	0.016245	158.87
2.4	4.89	25.03	132.88	100.84	1018.2	1119.0	0.016260	146.40
2.6	5.29	24.63	135.93	103.88	1016.4	1120.3	0.016274	135.80
2.8	5.70	24.22	138.78	106.73	1014.7	1121.5	0.016287	126.67
3.0	6.11	23.81	141.47	109.42	1013.2	1122.6	0.016300	118.73
3.5	7.13	22.79	147.56	115.51	1009.6	1125.1	0.016331	102.74
4.0	8.14	21.78	152.96	120.92	1006.4	1127.3	0.016358	90.64
4.5	9.16	20.76	157.82	125.77	1003.5	1129.3	0.016384	83.03
5.0	10.18	19.74	162.24	130.20	1000.9	1131.1	0.016407	73.532
5.5	11.20	18.72	166.29	134.26	998.5	1132.7	0.016430	67.249
6.0	12.22	17.70	170.05	138.03	996.2	1134.2	0.016451	61.984
6.5	13.23	16.69	173.56	141.54	994.1	1135.6	0.016472	57.506
7.0	14.25	15.67	176.84	144.83	992.1	1136.9	0.016491	53.650
→ 7.5	15.27	14.65	179.93	147.93	990.2	1138.2	0.016510	50.294
8.0	16.29	13.63	182.86	150.87	988.5	1139.3	0.016527	47.348
8.5	17.31	12.61	185.63	153.65	986.8	1140.4	0.016545	44.733
9.0	18.32	11.60	188.27	156.30	985.1	1141.4	0.016561	42.402
9.5	19.34	10.58	190.80	158.84	983.6	1142.4	0.016577	40.310
10.0	20.36	9.56	193.21	161.26	982.1	1143.3	0.016592	38.420
11.0	22.40	7.52	197.75	165.82	979.3	1145.1	0.016622	35.142
12.0	24.43	5.49	201.96	170.05	976.6	1146.7	0.016650	32.394
13.0	26.47	3.45	205.88	174.00	974.2	1148.2	0.016676	30.057
14.0	28.50	1.42	209.56	177.71	971.9	1149.6	0.016702	28.043

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume V Water Cu. ft. per lb.	Specific Volume V Steam Cu. ft. per lb.
14.696	0.0	212.00	180.17	970.3	1150.5	0.016719	26.799
15.0	0.3	213.03	181.21	969.7	1150.9	0.016726	26.290
16.0	1.3	216.32	184.52	967.6	1152.1	0.016749	24.750
17.0	2.3	219.44	187.66	965.6	1153.2	0.016771	23.385
18.0	3.3	222.41	190.66	963.7	1154.3	0.016793	22.168
19.0	4.3	225.24	193.52	961.8	1155.3	0.016814	21.074
20.0	5.3	227.96	196.27	960.1	1156.3	0.016834	20.087
21.0	6.3	230.57	198.90	958.4	1157.3	0.016854	19.190
22.0	7.3	233.07	201.44	956.7	1158.1	0.016873	18.373
23.0	8.3	235.49	203.88	955.1	1159.0	0.016891	17.624
24.0	9.3	237.82	206.24	953.6	1159.8	0.016909	16.936
25.0	10.3	240.07	208.52	952.1	1160.6	0.016927	16.301
26.0	11.3	242.25	210.7	950.6	1161.4	0.016944	15.7138
27.0	12.3	244.36	212.9	949.2	1162.1	0.016961	15.1684
28.0	13.3	246.41	214.9	947.9	1162.8	0.016977	14.6607
29.0	14.3	248.40	217.0	946.5	1163.5	0.016993	14.1869
30.0	15.3	250.34	218.9	945.2	1164.1	0.017009	13.7436
31.0	16.3	252.22	220.8	943.9	1164.8	0.017024	13.3280
32.0	17.3	254.05	222.7	942.7	1165.4	0.017039	12.9376
33.0	18.3	255.84	224.5	941.5	1166.0	0.017054	12.5700
34.0	19.3	257.58	226.3	940.3	1166.6	0.017069	12.2234

*Abstracted from ASME Steam Tables (1967), with permission of the publisher, The American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

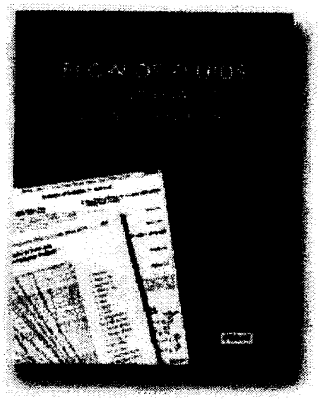
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Properties of Superheated Steam*

$\overline{V}$ = specific volume, cubic feet per pound
h_g = total heat of steam, Btu per pound

Pressure Lbs. per Sq. In.		Sat. Temp		Total Temperature—Degrees Fahrenheit (t)										
Abs. P'	Gage P	t		350°	400°	500°	600°	700°	800°	900°	1000°	1100°	1300°	1500°
15.0	0.3	213.03	$\overline{V}$	31.939	33.963	37.985	41.986	45.978	49.964	53.946	57.926	61.905	69.858	77.807
			h_g	1216.2	1239.9	1287.3	1335.2	1383.8	1433.2	1483.4	1534.5	1586.5	1693.2	1803.4
20.0	5.3	227.96	$\overline{V}$	23.900	25.428	28.457	31.466	34.465	37.458	40.447	43.435	46.420	52.388	58.352
			h_g	1215.4	1239.2	1286.9	1334.9	1383.5	1432.9	1483.2	1534.3	1586.3	1693.1	1803.3
30.0	15.3	250.34	$\overline{V}$	15.859	16.892	18.929	20.945	22.951	24.952	26.949	28.943	30.936	34.918	38 896
			h_g	1213.6	1237.8	1286.0	1334.2	1383.0	1432.5	1482.8	1534.0	1586.1	1692.9	1803.2
40.0	25.3	267.25	$\overline{V}$	11.838	12.624	14.165	15.685	17.195	18.699	20.199	21.697	23.194	26.183	29.168
			h_g	1211.7	1236.4	1285.0	1333.6	1382.5	1432.1	1482.5	1533.7	1585.8	1692.7	1803.0
50.0	35.3	281.02	$\overline{V}$	9.424	10.062	11.306	12.529	13.741	14.947	16.150	17.350	18.549	20.942	23.332
			h_g	1209.9	1234.9	1284.1	1332.9	1382.0	1431.7	1482.2	1533.4	1585.6	1692.5	1802.9
60.0	45.3	292.71	$\overline{V}$	7.815	8.354	9.400	10.425	11.438	12.446	13.450	14.452	15.452	17.448	19.441
			h_g	1208.0	1233.5	1283.2	1332.3	1381.5	1431.3	1481.8	1533.2	1585.3	1692.4	1802.8
70.0	55.3	302.93	$\overline{V}$	6.664	7.133	8.039	8.922	9.793	10.659	11.522	12.382	13.240	14.952	16.661
			h_g	1206.0	1232.0	1282.2	1331.6	1381.0	1430.9	1481.5	1532.9	1585.1	1692.2	1802.6
80.0	65.3	312.04	$\overline{V}$	5.801	6.218	7.018	7.794	8.560	9.319	10.075	10.829	11.581	13.081	14.577
			h_g	1204.0	1230.5	1281.3	1330.9	1380.5	1430.5	1481.1	1532.6	1584.9	1692.0	1802.5
90.0	75.3	320.28	$\overline{V}$	5.128	5.505	6.223	6.917	7.600	8.277	8.950	9.621	10.290	11.625	12.956
			h_g	1202.0	1228.9	1280.3	1330.2	1380.0	1430.1	1480.8	1532.3	1584.6	1691.8	1802.4
100.0	85.3	327.82	$\overline{V}$	4.590	4.935	5.588	6.216	6.833	7.443	8.050	8.655	9.258	10.460	11.659
			h_g	1199.9	1227.4	1279.3	1329.6	1379.5	1429.7	1480.4	1532.0	1584.4	1691.6	1802.2
120.0	105.3	341.27	$\overline{V}$	3.7815	4.0786	4.6341	5.1637	5.6813	6.1928	6.7006	7.2060	7.7096	8.7130	9.7130
			h_g	1195.6	1224.1	1277.4	1328.2	1378.4	1428.8	1479.8	1531.4	1583.9	1691.3	1802.0
140.0	125.3	353.04	$\overline{V}$	...	3.4661	3.9526	4.4119	4.8588	5.2995	5.7364	6.1709	6.6036	7.4652	8.3233
			h_g	...	1220.8	1275.3	1326.8	1377.4	1428.0	1479.1	1530.8	1583.4	1690.9	1801.7
160.0	145.3	363.55	$\overline{V}$	...	3.0060	3.4413	3.8480	4.2420	4.6295	5.0132	5.3945	5.7741	6.5293	7.2811
			h_g	...	1217.4	1273.3	1325.4	1376.4	1427.2	1478.4	1530.3	1582.9	1690.5	1801.4
180.0	165.3	373.08	$\overline{V}$	...	2.6474	3.0433	3.4093	3.7621	4.1084	4.4508	4.7907	5.1289	5.8014	6.4704
			h_g	...	1213.8	1271.2	1324.0	1375.3	1426.3	1477.7	1529.7	1582.4	1690.2	1801.2
200.0	185.3	381.80	$\overline{V}$	...	2.3598	2.7247	3.0583	3.3783	3.6915	4.0008	4.3077	4.6128	5.2191	5.8219
			h_g	...	1210.1	1269.0	1322.6	1374.3	1425.5	1477.0	1529.1	1581.9	1689.8	1800.9
220.0	205.3	389.88	$\overline{V}$	...	2.1240	2.4638	2.7710	3.0642	3.3504	3.6327	3.9125	4.1905	4.7426	5.2913
			h_g	...	1206.3	1266.9	1321.2	1373.2	1424.7	1476.3	1528.5	1581.4	1689.4	1800.6
240.0	225.3	397.39	$\overline{V}$	...	1.9268	2.2462	2.5316	2.8024	3.0661	3.3259	3.5831	3.8385	4.3456	4.8492
			h_g	...	1202.4	1264.6	1319.7	1372.1	1423.8	1475.6	1527.9	1580.9	1689.1	1800.4
260.0	245.3	404.44	$\overline{V}$	...	..	2.0619	2.3289	2.5808	2.8256	3.0663	3.3044	3.5408	4.0097	4.4750
			h_g	...	...	1262.4	1318.2	1371.1	1423.0	1474.9	1527.3	1580.4	1688.7	1800.1
280.0	265.3	411.07	$\overline{V}$	...	...	1.9037	2.1551	2.3909	2.6194	2.8437	3.0655	3.2855	3.7217	4.1543
			h_g	...	...	1260.0	1316.8	1370.0	1422.1	1474.2	1526.8	1579.9	1688.4	1799.8
300.0	285.3	417.35	$\overline{V}$	...	...	1.7665	2.0044	2.2263	2.4407	2.6509	2.8585	3.0643	3.4721	3.8764
			h_g	...	...	1257.7	1315.2	1368.9	1421.3	1473.6	1526.2	1579.4	1688.0	1799.6
320.0	305.3	423.31	$\overline{V}$	...	...	1.6462	1.8725	2.0823	2.2843	2.4821	2.6774	2.8708	3.2538	3.6332
			h_g	...	...	1255.2	1313.7	1367.8	1420.5	1472.9	1525.6	1578.9	1687.6	1799.3
340.0	325.3	428.99	$\overline{V}$	...	...	1.5399	1.7561	1.9552	2.1463	2.3333	2.5175	2.7000	3.0611	3.4186
			h_g	...	...	1252.8	1312.2	1366.7	1419.6	1472.2	1525.0	1578.4	1687.3	1799.0
360.0	345.3	434.41	$\overline{V}$	...	...	1.4454	1.6525	1.8421	2.0237	2.2009	2.3755	2.5482	2.8898	3.2279
			h_g	...	...	1250.3	1310.6	1365.6	1418.7	1471.5	1542.4	1577.9	1686.9	1798.8

*Abstracted from ASME Steam Tables (1967) with permission of the publisher, the American Society of Mechanical Engineers, 345 East 47th Street, New York, N.Y. 10017.

(continued on the next page)

AREA	DESCRIPTION	PROBLEM
G	Applications - Continuous	A702

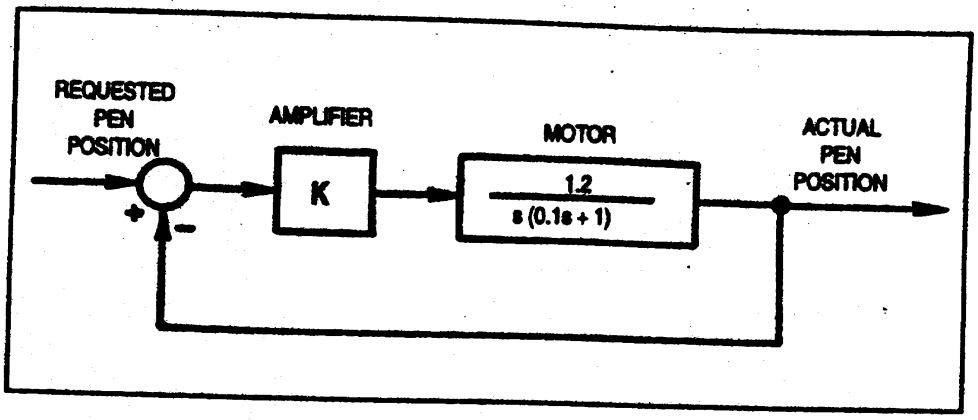


Figure A702

Situation:

You are told to build an X-Y plotter and decide to use two (2) identical servomechanisms, one for each axis, to move the pen around a flat table. Each of the servomechanisms can be represented by the diagram shown in Figure A702.

Requirements:

(a) Determine the amplifier gain (K) required for critical damping (NO OVERSHOOT)

(b) Is critical damping a reasonable specification? Explain your answer.

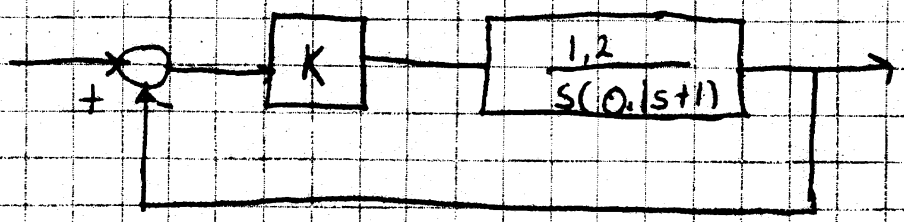
(c) The inputs to the servomechanism, supplied by a computer through D-to-A converters, call for drawing a circle with a 2-inch radius in 6 seconds. (The motor time constant, as shown in the diagram, is 0.1 seconds.) Neglecting errors in the computer and D-to-A converters, determine the radius of the circle that the plotter actually draws. Treat this question as a steady-state problem, ignoring any initial transients in starting to draw the circle.

(d) Determine the velocity at which the pen is moving in Requirement (c) above.

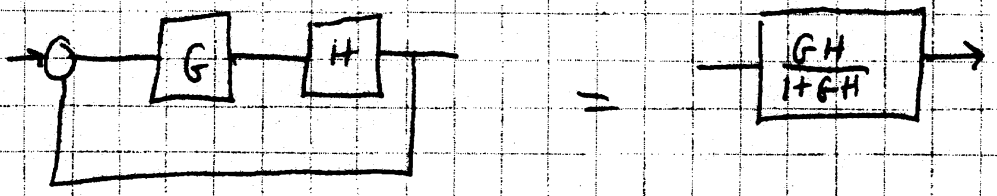
(e) If the maximum pen velocity was 20 inches/second, determine the limit(s) this would place on the size of circle that could be drawn and/or the time required to draw it.

(f) For Requirement (c) above, state what would happen if the servomechanisms did not have exactly identical characteristics (motor time constant and amplifier gain).

Problem A.702



(a) Determine K for critical damping



$$\frac{\frac{K(1.2)}{S(0.1s+1)}}{1+\frac{K(1.2)}{S(0.1s+1)}} = \frac{\frac{1.2K}{0.1s^2+s}}{1+\frac{1.2K}{0.1s^2+s}} \times \frac{0.1s^2+s}{0.1s^2+s}$$

$$= \frac{1.2K}{0.1s^2+s+1.2K}$$

C.E. $= 0.1s^2 + s + 1.2K$

2nd order eq $= s^2 + 2\zeta\omega_n s + \omega_n^2$

For critical damping $\zeta = 1$

multiply C.E by 10

$s^2 + 10s + 12K$ $\therefore$ $2\zeta\omega_n = 10$

$\omega_n = \sqrt{12K}$

$1 = \omega_n^2 = 12K$ $\quad K = \frac{25}{12} = 2.083$

Form E-11

RUST, BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR

AT

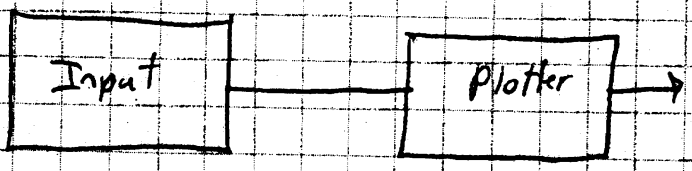
DESCRIPTION

DATE

BY CKD.

DWG.

(c)



2) $\sin 2\pi \frac{t}{T}$ ~~$T = 6$ sec~~ — Time to draw circle

$2 \sin \frac{\pi}{3} t$

From Laplace transform $\sin \omega t = \frac{\omega}{s^2 + \omega^2}$

2 is linear transform so multiply by it at the end

$\sin \frac{\pi}{3} t \Rightarrow \frac{\frac{\pi}{3}}{s^2 + (\frac{\pi}{3})^2}$

$$\frac{\left(\frac{\pi}{3}\right)(25)}{\left(s^2 + \left(\frac{\pi}{3}\right)^2\right)(s^2 + 10s + 25)}$$

to max fraction make denominator small ∴ set $s = 0$

$$\frac{\left(\frac{\pi}{3}\right)(25)}{\left(\frac{\pi}{3}\right)^2 (25)} \qquad \frac{3}{\pi} = .955$$

$2 \times .955 = 1.91$ in

d) Velocity ~~radius in~~ Circumference of circle

$= 2\pi r = 2\pi(1.91) =$ [redacted] 12.0008

Time = 6 sec

Velocity = $\frac{12.0008}{6} =$ 2.0001 in/sec

e) max vel = 20 in/sec

circle = $2\pi r$

Velocity = $\frac{2\pi r}{t}$

$\frac{2\pi r}{t} < 20$

$\frac{r}{t} < 3.183$

f) ellipse

AREA	DESCRIPTION	PROBLEM
G	**Applications - Continuous / Batch**	**P702**

You have been asked to design and implement a process control strategy for the production of a chemical intermediate product. The process consists of a distillation column and two batch reactors as shown in Figure P702. An acidic feed is fed to the column which is operated at 500 mm Hg. Ninety (90) percent of the column feed is taken as overhead product. The column overheads are fed into one of the two reactors until the control system switches the flow to the other reactor based on level. Once flow to a batch reactor is complete, an additive is fed to that reactor in a ratio of 0.15 pounds of additive per pound of column overheads. The following data and design requirements are given.

Data:

Column overheads specific gravity	0.9 liquid
Additive specific gravity	0.8
Batch reactor volume	20,000 gal
On-stream factor	95% ← Uptime
Maximum allowable batch reactor level	90%
Reactor pressure input scale	0 to 60 psig
Final product requirement	100,000,000 lb/yr

Permissives to open feed valve to Reactor 1:

No emergency shutdown
Not feeding Reactor 2
Reactor pressure <50 psig
Level in Reactor 1 <72.5%
Column feed not cut off

Permissives to empty product batch from Reactor 1:

No emergency shutdown
Not feeding Reactor 1
Level in Reactor 1 = ≥90%

Permissives to open additive valve to Reactor 1:

No emergency shutdown
Not feeding Reactor 1
Level in Reactor 1 = ≥72.5%
Reactor pressure < 50 psig
Reactor 1 not emptying

Permissives to open vent on Reactor 1:

Emergency shutdown
"OR"
Reactor pressure ≥ 50 psig

AREA	DESCRIPTION	PROBLEM
G	Applications - Continuous / Batch	P702, cont.

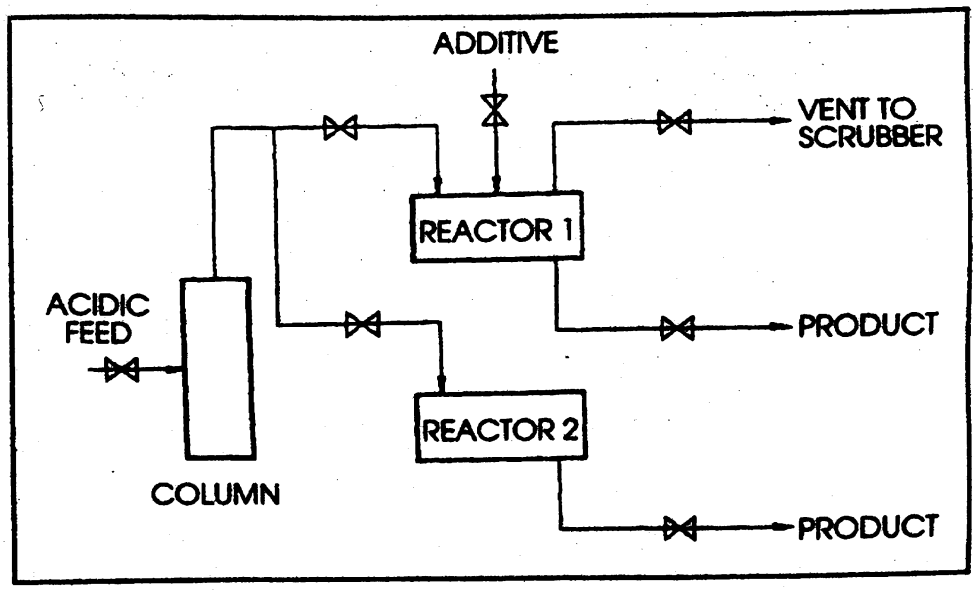


Figure P702

Time (min)	Top Pressure (mmHg)
0.5	511
1.0	520
1.5	510
2.0	491
2.5	469
3.0	460
3.5	468
4.0	489
4.5	510
5.0	520
5.5	512
6.0	489
6.5	469
7.0	460
7.5	470
8.0	490
8.5	511
9.0	520

Data taken at Controller Gain = 2

AREA	DESCRIPTION	PROBLEM
G	Applications - Continuous / Batch	P702, cont.

Programmable Logic Controller Channels (Note: Open valve = 1 or "energized" contact; Emergency Shutdown pushbutton pushed = 0 or "de-energized" contact)		
Channel	Description	Contact Type
Discrete Inputs		
0000	Emergency Shutdown Pushbutton	Normally open
0001	Reactor 1 feed valve position	Normally open
0002	Reactor 2 feed valve position	Normally open
0003	Column fresh feed	Normally open
0004	Reactor 1 product	Normally open
Discrete Outputs		
1001	Feed valve to Reactor 1	
1002	Additive valve to Reactor 1	
1003	Reactor 1 product valve	
1004	Reactor 1 vent valve	
Analog Inputs		
5001	Level in Reactor 1 (percent)	
5002	Pressure in Reactor 1 (percent of scale)	
Memory Registers	Value	
M01	90.0%	
M02	83.3%	
M03	72.5%	

AREA	DESCRIPTION	PROBLEM
G	Applications - Continuous / Batch	P702, cont.

1. The plant operating time in hours per year is most nearly:

   (A) 8784
   (B) 8760
   (C) 8640
   (D) 8332
   (E) 7008

onstream factor

$\frac{365\ \text{Days}}{\text{Day}} \left| \frac{24\ \text{Hr}}{\text{Day}} \right| 0.95 = 8332$

2. To achieve the annual production target of 100 million pounds, the required feed rate to the column per hour is nearly:

   (A) 10,449
   (B) 11,030
   (C) 11,610
   (D) 12,976
   (E) 13,352

$\frac{100{,}000{,}000\ \text{lb}}{\text{Yr}} \left| \frac{\text{Yr}}{8322\ \text{hr}} \right. = 13{,}01$

3. If the column overhead rate is set at 11,000 pounds per hour, how many hours must a batch reactor remain on-line in order to produce a maximum quantity of product per batch?

   (A) 10.5
   (B) 11.0
   (C) 11.5
   (D) 12.2
   (E) 12.9

4. When tuning the feed flow controller, which of the following statements best describes the situation?

   (A) A relative gain analysis will be needed.
   (B) Only integral action is needed.
   (C) Internal reflux control should be used.
   (D) The column temperature profile should first be examined.
   (E) No derivative action should be used.

5. To obtain data for tuning the overhead pressure control loop, it is placed in closed-loop control (with no integral or derivative action) and the controller gain is increased until the loop cycles. Oscillation occurs when K = 2. At this time, the data given in the table is collected. Using a PID controller and a quarter-amplitude-decay tuning criterion, what initial controller parameters would you select for this loop?

   (A) Gain = 2.0; Integral = 4.0 mins; Derivative = 0

   (B) Gain = 0.9; Integral = 3.3 mins; Derivative = 3.3 mins

   (C) Gain = 0.4; Integral = 1.3 mins; Derivative = 2.0 mins

   (D) Gain = 1.2; Integral = 1.0 mins; Derivative = 0.2 mins

   (E) Gain = 1.2; Integral = 2.0 mins; Derivative = 0.5 mins

$P_u = 4$

Ziegler-N
$P = 0.6K =$
$I = P_u/2 =$
$D = P_u/8 =$

6. If the controller gain is set at 2.34, what would be the corresponding proportional band?

   (A) 0.40

   (B) 1.20

   (C) 2.34

   (D) 42.70

   (E) 100.00

$P.B. = \frac{100}{GAIN}$

$P.B = \frac{100}{2.34} = 42.7$

Form 5007 (Rev. 9/95)

Raytheon Engineers & Constructors — GENERAL COMPUTATION SHEET

CALCULATION SET NO.			REV.	COMP. BY / DATE	CHK'D. BY / DATE
PRELIM.	FINAL	VOID			
SHEET		OF		DATE	DATE
J.O.					

PROJECT

SUBJECT

Problem P702

1) on-stream factor = 0.95

$$365 \text{ days} \times \frac{24 \text{ hour}}{\text{day}} \times .95 = 8322 \text{ hours for 1 year}$$

2) $$100{,}000{,}000 \frac{\text{lbs}}{\text{year}} \times \frac{\text{year}}{8{,}322 \text{ hour}} = 12016.3 \text{ lbs/hr.}$$

Let x = column output

COLUMN FEED IN ↘ ↙ ADDITIVE IN

$$x + 0.15x = 12016.3 \text{ lbs/hr}$$

$$1.15x = 12016.3 \text{ lbs/hr}$$

$$x = 10448.9 \text{ lbs/hr.}$$

$$\text{Column Feed} = \frac{\text{Column output}}{0.9} \leftarrow 90\% \text{ overhead Column Product}$$

$$= \frac{10448.9}{0.9}$$

$$= 11610 \text{ lbs/hr.}$$

Form 5087 (Rev. 9/95)

Raytheon Engineers & Constructors — GENERAL COMPUTATION SHEET	CALCULATION SET NO.	REV.	COMP. BY / DATE	CHK'D. BY / DATE
PROJECT	PRELIM. / FINAL / VOID		DATE	DATE
SUBJECT	SHEET OF		DATE	DATE
	J.O.			

3) overhead rate = $\frac{11{,}000 \text{ lbs}}{\text{hr}}$ = $11{,}000 \frac{\text{lbs}}{\text{hr}} \cdot \frac{\text{gal}}{(8.33 \text{ lbs}) \cdot (0.9)}$

= $1467 \frac{\text{gal}}{\text{hr}}$

additive = $\left(11{,}000 \frac{\text{lbs}}{\text{hr}} \times 0.015 \frac{\text{lbs}}{\text{lbs}}\right) \frac{\text{gal}}{(8.33 \text{ lbs}) \cdot (0.8)}$ ← S.G. of Additive

= $247.6 \frac{\text{gal}}{\text{hr}}$

Total feed rate = 1467 + 247.6 = 1714.6 $\frac{\text{gal}}{\text{hr}}$

Given Reactor Volume 90% Max

20,000 gal × 0.9 level = 18,000 gal capacity

book answer = $\frac{18{,}000 \text{ gal}}{1714.6 \frac{\text{gal}}{\text{hr.}}}$ = 10.5 hours

better answer

18,000 gal × $\frac{1467 \frac{\text{gal}}{\text{hr}}}{1714.6 \frac{\text{gal}}{\text{hr}}}$ = 15,383 gallons overhead

15,383 gal • $\frac{\text{hr}}{1467 \text{ gal}}$ = 10.5 hours

t additive time

(additive rate not given)

Form 5007 (Rev. 9/95)

Raytheon Engineers & Constructors — GENERAL COMPUTATION SHEET

CALCULATION SET NO.			REV.	COMP. BY / DATE	CHK'D. BY / DATE
PRELIM.	FINAL	VOID			
SHEET		OF		DATE	DATE
J.O.					

PROJECT

SUBJECT

4) B and D make no sense

C who knows what it means

A relitive to what

That leaves E

derivative is used when a quick response to a process change is needed. Derivative action tends to de-stabilize a system.

5) $K_u = 2$ (Period from table = 4 min measured from peak to peak)

$K = (0.6)\,K_u = (0.6)(2) = 1.2$

$T_i = (0.5)(P_u) = (0.5)(4) = 2 \text{ min}$

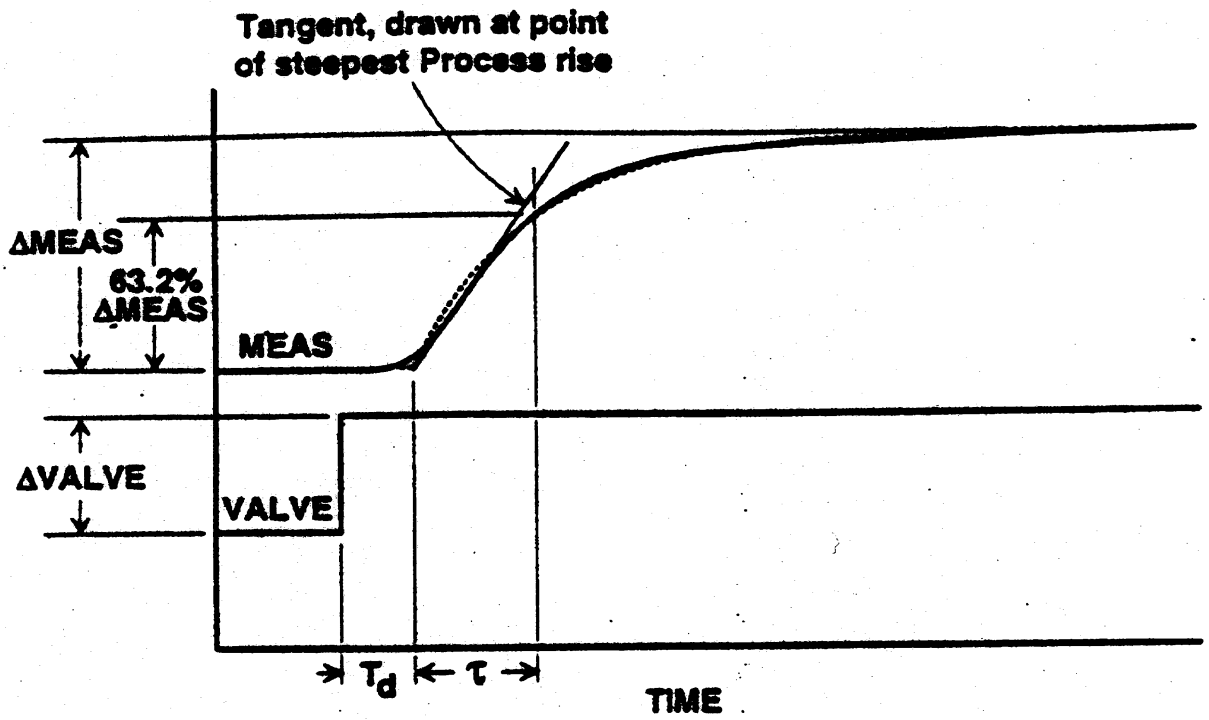
$T_1 = (0.125)(P_u) = (0.125)(4) = 0.5 \text{ min}$

6) proportional band $= \frac{100}{K} = \frac{100}{2.34} = 42.7$

DETERMINING PROCESS DYNAMIC CHARACTERISTICS BY OPEN LOOP TEST



UNKNOWN DYNAMICS
DETERMINE BY TEST



K_p = PROCESS GAIN = $\frac{\Delta MEAS}{\Delta VALVE}$

T_d = DEAD TIME = Time, from Valve Change to "Knee" of Process Reaction Curve

τ = TIME CONSTANT = Rise time of Process, from end of Dead Time to 63.2% of Total Change

WA-92030302-0

ZIEGLER-NICHOLS CONTROLLER TUNING EQUATIONS (FROM OPEN LOOP TEST)

Put in Manual & change outp

PROPORTIONAL

GAIN $K_p = \frac{\tau}{K_c T_d}$

PROP + INTEGRAL (PI)

GAIN $K_p = \frac{0.9\,\tau}{K_c T_d}$

RESET (Minutes/Repeat) $T_I = 3.33\,T_d$

PROP + INTEGRAL + DERIV (PID)

GAIN $K_p = \frac{1.1\,\tau}{K_c T_d}$

RESET (Minutes/Repeat) $T_I = 2.0\,T_d$

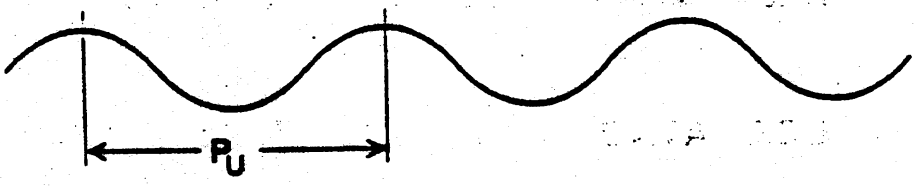
DERIVATIVE (Minutes) $T_D = 0.5\,T_d$

DETERMINING PROCESS CHARACTERISTICS BY CLOSED LOOP TEST

1. TAKE OUT ALL RESET AND DERIVATIVE CONTROL ACTION.
2. START WITH A LOW VALUE OF GAIN
3. PUT CONTROLLER IN AUTOMATIC
4. MAKE SMALL SET POINT CHANGE, OR LOAD CHANGE, TO START CONTROL LOOP OSCILLATION
5. IF OSCILLATION DECAYS, OR IF LOOP DOESN'T OSCILLATE AT ALL, THEN INCREASE GAIN AND TRY AGAIN.
6. CONTINUE INCREASING GAIN UNTIL ULTIMATELY A SUSTAINED OSCILLATION (NEITHER INCREASING NOR DECREASING) IS OBTAINED.
7. WHEN A SUSTAINED OSCILLATION IS OBTAINED, NOTE THE FOLLOWING DATA:

   ULTIMATE GAIN: G_U

   ULTIMATE PERIOD: P_U



CONTROLLER GAIN WHICH PRODUCED SUSTAINED OSCILLATION = G_U

WA-92030304-0

ZIEGLER-NICHOLS CONTROLLER TUNING EQUATIONS (FROM CLOSED LOOP TEST)

PROPORTIONAL

GAIN	$K_p = 0.5\ G_u$

PROP + INTEGRAL (PI)

GAIN	$K_p = 0.45\ G_u$
RESET (Minutes/Repeat)	$T_I = 0.83\ P_u$

PROP + INTEGRAL + DERIV (PID)

GAIN	$K_p = 0.6\ G_u$
RESET (Minutes/Repeat)	$T_I = 0.5\ P_u$
DERIVATIVE (Minutes)	$T_D = 0.125\ P_u$

Form E-11

RUST, BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR

AT

DESCRIPTION

DATE

BY CKD.

DWG.

Your BOSS tells you to add two Day tanks between the storage tank of chemical 'X' and the addition point of the process. The tanks will be alternated so that one tank is used per day while the other tank is aging. You determine that the process uses 10 gpm of chemical x at 5% Concentration. The chemical is at ~~95%~~ concentation in the storage tank. The chemical is to be aged at 5% concentration. Each day tank should hold 30 hrs. of 5% solution.

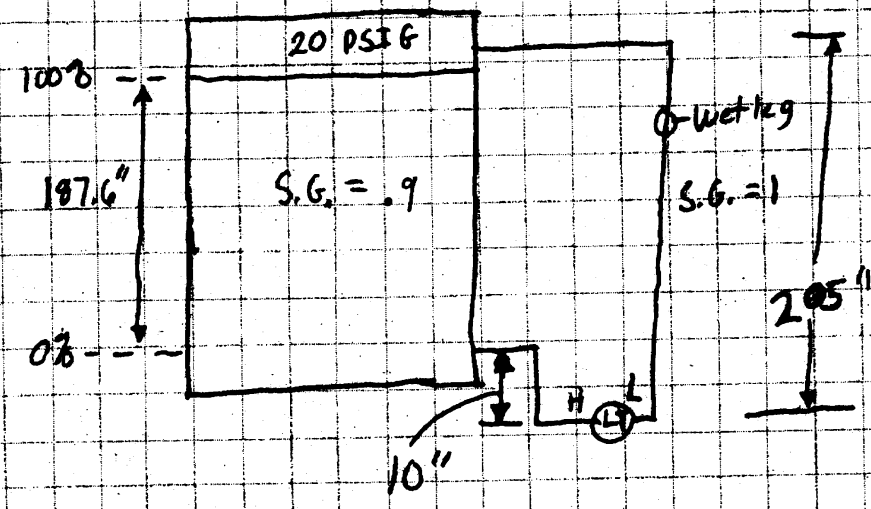
A) What is the required capacity of the tank between the 0% & 100% level (NOT VOLUME) 18000GAL

B) at what % level should the tank be when there is 6 hours of solution left in the tank

C) what are the flows of chemical 'x' from the storage tank and dilution water to fill the tank from 20% to 100% in 1 hour.

d) If the day tank is to be 14 ft in diameter, what will be the height in inches between the 0% & 100% level.

e) given the following physical



What is the range & span of the level transmitter?

Is the zero suppressed or elevated?

~~0 - (10)(.9) (205~~

Form E-11

RUST, BIRMINGHAM, ALABAMA

PROPOSAL OR JOB NO.

FOR

AT

DESCRIPTION

DATE

BY CKD.

DWG.

A) $10\ gpm \times \frac{60\ min}{hr} = 600\ gph$

$600\ \frac{gal}{hr} \times 30\ hr = \underline{18{,}000\ gallons}$

B) $\frac{30\ hrs}{60\ hrs} = \frac{100\ \%}{x\ \%}$

$\frac{600}{30} = \underline{20\ \%}$

C) $18{,}000\ gallons \times 80\ \% = 14{,}400\ gallons$

$14{,}400\ gal/hr \times \frac{1\ hr}{60\ min} = 240\ gal/min$ → total flow

let x = ~~gal chemical 'x'~~ / gal water

for every gallon of chemical 'x'

0.95 Chemical + 0.05 water added to tank

~~.95x = .05~~

let x = gal of water / gal ST] in the tank

.95 gal chemical 'x' must be diluted to .05 gal

$\therefore$ .95 gal chem + .05 gal water in conc + x gal water = $\frac{.95}{.05}$ ga

$x = 19 - 1 = 18\ \frac{gal\ water}{gal\ of\ ST}$

check $\frac{.95}{18+1} = .05$ (ok)

(C continued)

Q

$240\ gal/min \times \frac{18}{19} = 227.37\ gal/min$ water

$240\ gal/min \times \frac{1}{19} = 12.63\ gal/min$ from storage tan

d) $18{,}000\ gal \times \frac{1}{7.48052\ gal/ft^3} = 2406.25\ ft^3$

radius = $14/2 = 7\ ft$

Area of a circle = $\pi r^2 = (3.14159)(49)$
$= 153.938\ ft^2$

height = $\frac{2406.25\ ft^3}{153.938\ ft^2} = 15.63\ ft$

$15.63\ ft \times \frac{12\ in}{ft} = 187.6$ inches

transmitter inches below lower tap

Gwen

e) $P_0 = (10)(.9) - (205)(1) = -196$ " H_2O

$P_{100\%} = (10)(.9) + (187.6)(.9) - (205)(1)$

$= 9 + 168.84 - 205$

$= -27.16$

0% Full

100% Full

range = -196 to -27.16 in H_2O

span = $|-196 - (-27.16)| = 168.84$

Zero is elevated. See last case in Table I

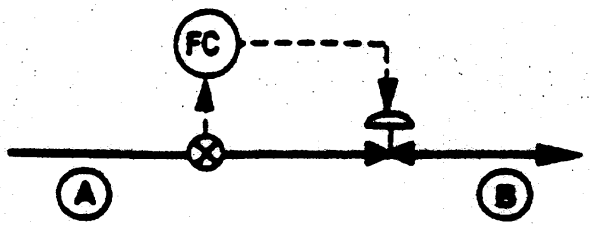
TABLE 1. Illustrations of the Use of Range and Span Terminology.

Typical Ranges	Name	Range	Lower Range Value	Upper Range Value	Span	Sup
	—	0 to 100	0	100	100	
	Suppressed Zero Range	20 to 100	20	100	80	Supp
	Elevated Zero Range	–25 to 100	–25	100	125	
	Elevated Zero Range	–100 to 0	–100	0	100	
	Elevated Zero Range	–100 to –20	–100	–20	80	

Illustrations of the Use of Range and Span Terminology

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For the following questions 1 - 6, consider the gas flow control loop with the initial process conditions as given below:



P_A = 65 PSIG P_B = 15 PSIG
T_A = 140 Deg. F
MW_A = 40 Mole Wt.

1. If all other conditions remained constant and only the open flow area (X) of the valve increased, which of the following best describes how the mass flow (F) would change?

A) $F_2 = F_1(X_1/X_2)^{0.5}$
B) $F_2 = F_1$
C) $F_2 = F_1(X_2/X_1)^{0.5}$
D) $F_2 = F_1(X_2/X_1)$
E) $F_2 = F_1(X_2/X_1)^2$

2. If all other conditions remained constant and only the molecular weight (MW_A) of the upstream gas decreased from 40 to 36, which of the following best describes how the mass flow (F) would change?

A) $F_2 = 0.90\ F_1$
B) $F_2 = 0.95\ F_1$
C) $F_2 = F_1$
D) $F_2 = 1.05\ F_1$
E) $F_2 = 1.11\ F_1$

3. If all other conditions remained constant and only the temperature (T_A) of the upstream gas decreased by 100 Deg F, which of the following best describes how the mass flow (F) would change?

A) $F_2 = 0.83\ F_1$
B) $F_2 = 0.91\ F_1$
C) $F_2 = F_1$
D) $F_2 = 1.10\ F_1$
E) $F_2 = 1.20\ F_1$

Terry Tolliver Monsanto

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1) $F_1 = 63.3 F_p C_{v1} Y \sqrt{\frac{\Delta P_1}{\gamma_1}}$ $\quad C_{v1} = X_1$

$F_2 = 63.3 F_p C_{v2} Y \sqrt{\frac{\Delta P_1}{\gamma_1}}$ $\quad C_{v2} = X_2$

Cancelled Items remain constant GIVE

$$\frac{F_1}{F_2} = \frac{C_{v1}}{C_{v2}} = \frac{X_1}{X_2}$$

$$F_2 = F_1\left(\frac{X_2}{X_1}\right)$$

2) $F_1 = 19.3 F_p C_v P_1 Y \sqrt{\frac{\rho_1 (40)}{P_1 Z}}$

$F_2 = 19.3 F_p C_v P_1 Y \sqrt{\frac{\rho (36)}{P_1 Z}}$

$$\frac{F_1}{F_2} = \frac{\sqrt{40}}{\sqrt{36}}$$

$$F_2 = F_1 \frac{\sqrt{36}}{\sqrt{40}} = .95 F_1$$

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3) $F_1 = 19.3\, F_p\, C_v\, P_1\, Y \sqrt{\frac{x M_w}{T_1 Z}}$

$F_2 = 19.3\, F_p\, C_v\, P_1\, Y \sqrt{\frac{x M_w}{(T_1 - 100) Z}}$

$\frac{F_1}{F_2} = \frac{\sqrt{\frac{1}{T_1}}}{\sqrt{\frac{1}{(T_1 - 100)}}}$

GIVEN

$T_1 = 140°F = 140 + 460 = 600°R$

$T_1 = 600°R$

$T_1 - 100 = 500°R$

$\frac{F_1}{F_2} = \frac{\sqrt{\frac{1}{600}}}{\sqrt{\frac{1}{500}}}$

$\frac{F_1}{F_2} = .912$

$F_2 = \frac{1}{.912} F_1 = 1.1\, F_1$

NELES JAMESBURY Bulletin 150-1

CALCULATING C_v FOR GASES

Introduction

Because of compressibility, gases and vapors expand as the pressure drops at the vena contracta, decreasing their specific weight. To account for the change in specific weight, an expansion factor, Y, is introduced into the valve sizing formula. The form of the Equation used is one of the following, depending on the process variables available:

$$w = 63.3\, F_p C_v Y \sqrt{x P_1 \gamma_1} \qquad (3.11)$$

$$Q = 1360\, F_p C_v P_1 Y \sqrt{\frac{x}{G_g T_1 Z}} \qquad (3.12)$$

$$w = 19.3\, F_p C_v P_1 Y \sqrt{\frac{x M_w}{T_1 Z}} \qquad (3.13)$$

$$Q = 7320\, F_p C_v P_1 Y \sqrt{\frac{x}{M_w T_1 Z}} \qquad (3.14)$$

Where:

- w = Gas flow rate, lb/hr
- F_p = Piping geometry factor
- C_v = Valve sizing coefficient
- Y = Expansion factor
- x = Pressure drop ratio $= \frac{\Delta P}{P_1}$
- γ_1 = Specific weight at inlet conditions, lb/ft³
- Q = Gas flow in standard ft³/hr (SCFH)
- G_g = Specific gravity of gas relative to air at standard conditions
- T_1 = Absolute upstream temperature °R = (°F + 460°)
- Z = Compressibility factor
- M_w = Molecular weight
- P_1 = Upstream absolute pressure, psia

***NOTE:** The numerical constants in Equations 3.11–3.14 are unit conversion factors.*

The following steps should be used to compute the correct C_v, body size and trim number:

Step 1: Select the Appropriate Equation

Based on the information available, select one of the four Equations: 3.11, 3.12, 3.13 or 3.14.

Step 2: Check for Choked Flow

Determine the terminal pressure drop ratio, x_T, for that particular valve by referring to Table 3-V.

Next, determine the ratio of specific heats factor, F_k, by using the Equation below:

$$F_k = \frac{k}{1.40} \qquad (3.15)$$

Where:

- F_k = Ratio of specific heats factor
- k = Ratio of specific heats (taken from Table 3-VI).

Calculate the ratio of actual pressure drop to absolute inlet pressure, x, by using Equation 3.16:

$$x = \frac{\Delta P}{P_1} \qquad (3.16)$$

Where:

- x = Ratio of pressure drop to absolute inlet pressure
- ΔP = Pressure drop ($P_1 - P_2$)
- P_1 = Inlet pressure, psia
- P_2 = Outlet pressure, psia

Choked flow occurs when x reaches the value of $F_k x_T$. Therefore, if x is less than $F_k x_T$, the flow is not choked. If x is greater, the flow is choked. If flow is choked, then $F_k x_T$ should be used in place of x (whenever it applies) in the gas sizing Equations.

Table 3-V: Pressure Drop Ratios, x_T

Valve Type	Flow Direction	Trim Size	x_T
Globe	Flow-to-close	Full Area	0.70
	Flow-to-close	Reduced Area	0.70
	Flow-to-open	Full Area	0.75
	Flow-to-open	Reduced Area	0.75
High Performance Butterfly Multi-stage	60° Open	Full	0.38
	90° Open	Full	0.28
	Under Seat	All	~1.00
Ball	90° Open	Full	0.30

Solving Compressible Flow Equations

Before solving any of the compressible flow equations, a number of variables must be known. They are flow rate, upstream pressure, pressure drop, temperature and either specific gravity or molecular weight. These variables are a function of system design and must be supplied by those familiar with the application. Once these parameters have been established, the C_v can be found by the method shown below.

$$C_v = \frac{Q}{1360 P_1 Y}\sqrt{\frac{GT}{X}} \qquad \text{where: } Y = 1 - \frac{X}{3F_K X_T}$$

$$X = \frac{\Delta p}{P_1}$$

NOTE:

Under choked flow conditions, the actual pressure drop ratio may exceed X_T in the sizing equations, however, $\Delta P/P_1$ or X must be numerically limited to $F_K X_T$. This means that at choked flow, the expansion factor, Y, reduces to 0.667.

Write the above equations down as shown. Now rewrite each again with the process conditions with appropriate units as shown above. It can be seen now that the expansion factor, Y, includes two terms for which there is no value as part of the conditions. These terms are derived as follows:

1. F_K is the ratio of specific heats factor which is described on page 12. The value of F_K for air is one and can be assumed as one for most other common gases without incurring any significant error.

2. X_T is the limiting pressure drop ratio and is a function of valve opening. When sizing a butterfly or ball control valve, use a value of 0.43 for X_T. This corresponds to a valve opening of 75%. When sizing an on-off valve, use 0.16 for ball valves and 0.37 for butterfly valves. These correspond to the fully open position.

The choice of 0.43 as the value of X_T for rotary control valve sizing is a conservative starting point for solving the equation and reduces the expansion factor equation to the form below (for $F_K = 1.0$):

$$Y = 1 - \frac{X}{1.29}$$

As an example, assume that solving for C_v as described yields a required value of 165. Referring to the ball valve sizing coefficient chart it can be seen that the required C_v corresponds to a 6" valve at 60% open, a 3" at about 80%, or an 8" at about 40% open. All are within the recommended throttling range. If the 3" or 8" valve in the example above was chosen, recalculate the required C_v with the value of X_T which corresponds to the actual valve opening from Figure 10.

Also check to be sure that the pressure drop ratio, X, used in the C_v calculation does not exceed $F_K X_T$.

CHOKED FLOW AND SONIC VELOCITY

When a compressible fluid at a constant upstream pressure is flowing through a restriction, the flow will increase when the downstream pressure is reduced. This change in downstream pressure is communicated by a pressure wave which travels at sonic velocity relative to the stream. The downstream pressure may be gradually reduced until the maximum fluid velocity reaches the speed of sound. After this point a greater reduction in downstream pressure cannot be sensed upstream because the velocity of the pressure wave relative to the stream becomes zero. This condition is known as choked flow and occurs when the pressure drop ratio $X = \Delta P/P_1$ equals $F_K X_T$. A further reduction in downstream pressure will not increase the flow rate. The geometry of the flow path varies with the percent of opening, and therefore X_T could be expected to vary in a similar manner. A substantial amount of flow testing with air was performed by an independent laboratory to determine the variation of X_T with percent opening in Neles-Jamesbury control valves. This characteristic is presented in Figure 10. Although X_T limits the flow capacity of a given valve it should be noted that physical damage to valve or piping does not result from exceeding these limits as it does in the case of cavitation.

The expansion factor, Y, accounts for the change in fluid density, as it passes from the valve inlet to the *Vena Contracta* which is the point of minimum jet cross sectional area just beyond the orifice. It also accounts for the change in area of the *Vena Contracta* as the pressure drop is varied. The factor, Y, is a function of F_K, X, and X_T and is expressed as:

$$Y = 1 - \frac{X}{3F_K X_T}$$

PRESSURE DROP RATIO FACTOR X_T AS A FUNCTION OF VALVE OPENING FOR NELES-JAMESBURY CONTROL VALVES LINE SIZE = VALVE SIZE

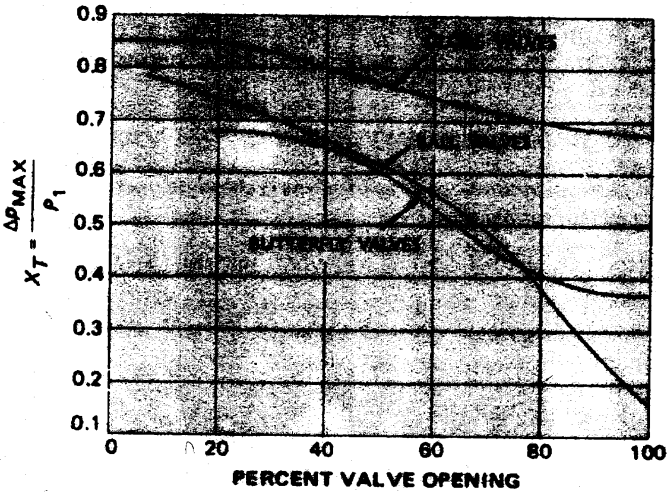


Figure 10

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To modify your process to produce a new product 96.1 lbs/min of $Stuff_1$ must be added to the process. $Stuff_1$ needs to be mixed with 5% (by weight) of $Stuff_2$. $Stuff_1$ must be added to the process in a 32 °F water Stream. However the concetration of $Stuff_2$ in the final stream can not exceed 0.25%. $Stuff_2$ is only available in a water steam at 3.5% concentration at 100 °F. $Stuff_2$ Can not be put through a heat exchanger. Clean water is available at 90 °F.

i) what is the mass rate for $stuff_2$

$$Stuff_2 = Stuff_1(0.05) = (96.1)(0.05) = 4.8 \text{ lbs/min}$$

2) what is the volume (rate) of water in the final stream

$$\text{Final Stream} = Stuff_1 + Stuff_2 + \text{water}$$

$$\frac{4.8 \text{ lbs/min}}{\text{Final Stream}} = 0.25\% = \frac{4.8}{.0025} = 1920 \text{ lbs/min}$$

$$1920 = 96.1 + 4.8 + \text{water} \qquad \text{water} = 1819.1 \text{ lbs/min}$$

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water density at 32°F = 62.418 $\frac{lbs}{ft^3}$

$$1819.1 \frac{lbs}{min} \cdot \frac{ft^3}{62.418\ lbs} \cdot \frac{7.48\ Gal}{ft^3} = 211.2 \frac{gallons}{min}$$

Water

3) what is the clean water volume rate?

Total water = clean water + water in $Stuff_2$ stream.

$$1819.1 \frac{lbs}{min} = \text{clean water} + \frac{4.8\ lbs/min}{.035 \frac{lbs}{lb}}$$

$$\text{Clean water} = 1819.1 \frac{lbs}{min} - 137.14 \frac{lbs}{min}$$

$$= 1681.96 \frac{lbs}{min}$$

$$1681.96 \frac{lbs}{min} \cdot \frac{ft^3}{62.113\ lbs} \cdot \frac{7.48\ gal}{ft^3} = 202.55 \frac{gal}{min}$$

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Bayflow Engineers & Constructors	GENERAL COMPUTATION SHEET	CALCULATION SET NO.	REV.	COMP. BY	CHK'D. BY
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4) If the water leaving the heat exchanger is 32 °F and the heat Capacity of the stuff2 steam and the water steam are both 1 $\frac{Btu}{lb/°F}$ what in the temperature in tank 1 ?

Assume solids don't Matter

water only

water = 1681.96 $\frac{lbs}{min}$

$Stuff_2$ stream = 137.14 $\frac{lbs}{min}$

$\frac{Btu/(LB)(°F)}{LB/}$ $\frac{}{min}$

ENERGY EQUATION

$$\text{Temp in tank}_1 = \frac{(1681.96)(32) + (137.14)(100)}{1681.96 + 137.14} = 37.13\ °F$$

5) How much ICE must be added to Tank 1 to get the temp to 32 °F

Heat of Formation of ICE = 144 $\frac{Btu}{lb}$ ASSUME ICE 32°F

x = lbs ICE

water from Melted ice

melt the

$$32\ °F = \frac{(137.14)(100) + (1681.96 - x)(32) + (x)(144)}{137.14 + (1681.96 - x) + x}$$

$stuff_2$

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Raytheon Engineers & Constructors

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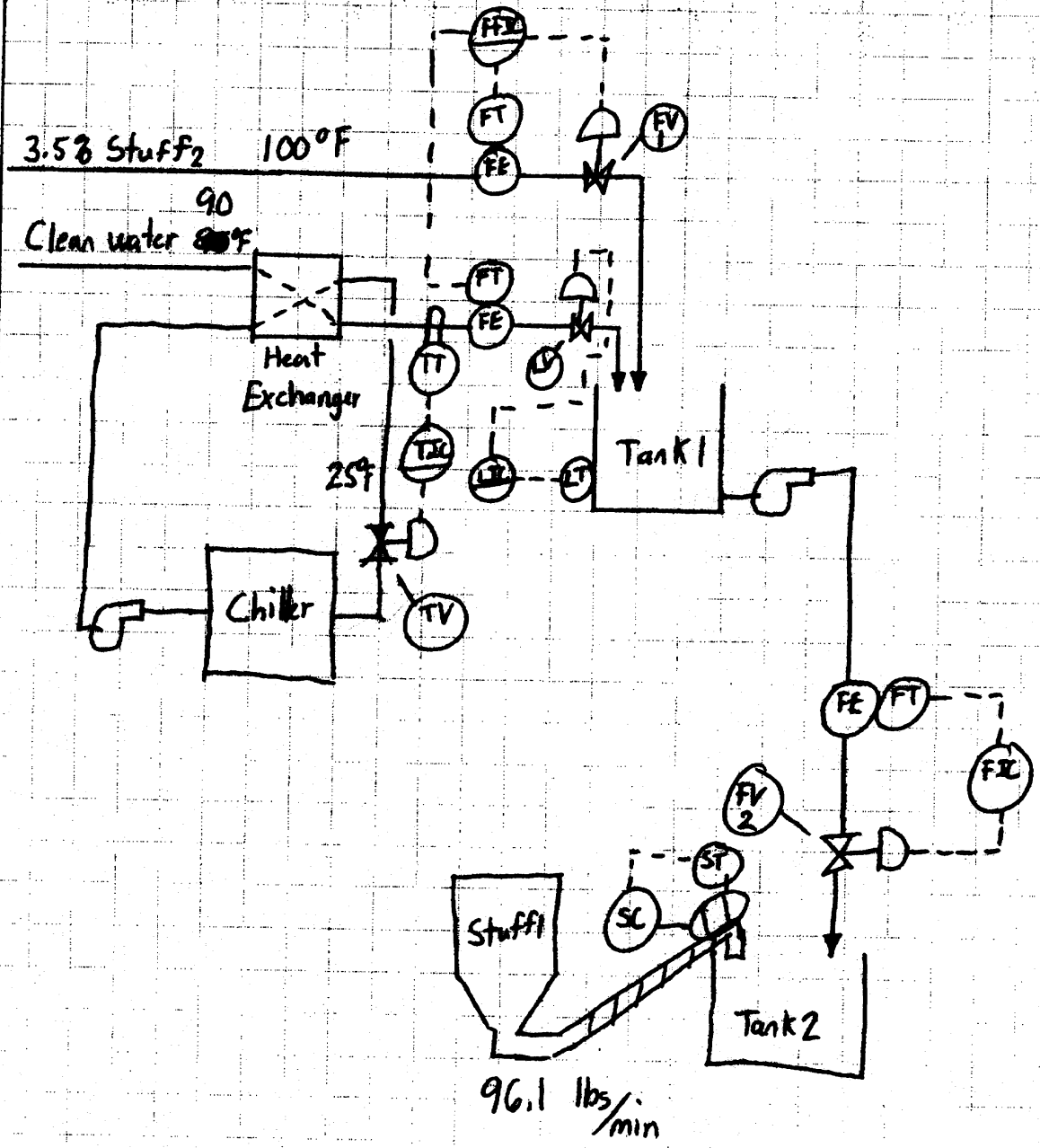
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$$32 = \frac{13714 + 53822.72 - 32x - 144x}{1819.1}$$

$$(32)(1819.1) - 13714 - 53822.72 = -176x$$

$$-9325.52 = -176x$$

$$x = 53 \text{ lbs/min}$$

5) What is the new clean water volume rate

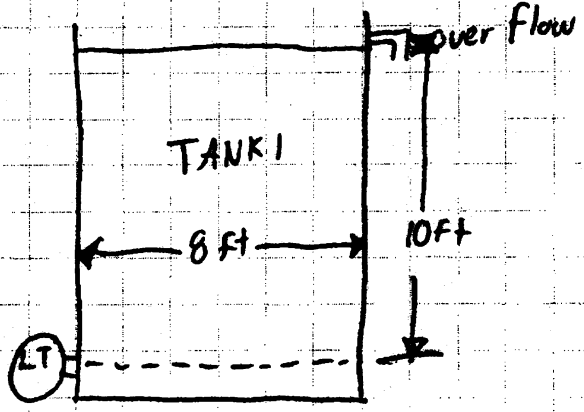
$$1681.96 - 53 = 1628.96 \text{ lbs/min}$$

$$\frac{1628.96}{\cancel{1681.96}} \text{ lbs/min} \cdot \frac{\text{Ft}^3}{62.113 \text{ lbs}} \cdot \frac{7.48 \text{ gal}}{\cancel{\text{Ft}^3}} = 196.17 \text{ gal/min}$$

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6)



What should the level transmitter calibration be.

$$SG = \frac{62.418 \leftarrow \text{water @ } 32^\circ F}{62.3663 \leftarrow \text{water @ } 60^\circ F}$$

$$= 1.001$$

$$\text{Span} = (10)' \cdot \frac{12 \text{ in}}{\text{Ft}} \cdot SF$$

$$= 120 \cdot 1.001 = \underline{120.12 \text{ in of water}}$$

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7) what is the requirer Chiller Capacity to cool the Clean water stream

$$\text{Chiller tons} = \frac{1628.96 \text{ lbs/min} \cdot (90-32)^{\circ}F}{200 \text{ lb/min TON}} \cdot \frac{12000 \text{ BTU/hr}}{60 \text{ min/hr}}$$

$$= 472.4 \text{ tons}$$

8) What should the pipe size be for the clean water Steam to keep the velocity to less than 6 ft/sec

$$\text{Velocity} = \frac{GPM}{2.448\, D^2}$$

$$6 = \frac{196.17}{2.448\, D^2}$$

$$D^2 = \frac{196.17}{(2.448)(6)}$$

$$D = \sqrt{13.356}$$

$D = 3.6$ inches use 4 inch pipe

Table B.4 Coefficient of Thermal Expansion†

Material		Coefficient of thermal expansion	
		α, in/(in·°F)	α', mm/(mm·°C)
Plain carbon steel (SAE 1020)			
	70–600°F (21–315°C)	0.0000067	0.000012
	−300–70°F (−185–21°C)	0.0000047	0.000009
Stainless steels			
301	70–600°F (21–314°C)	0.0000097	0.0000175
	−300–70°F (−185–21°C)	0.0000076	0.0000137
304	70–600°F (21–315°C)	0.0000095	0.0000171
	−300–70°F (−185–21°C)	0.0000074	0.0000133
310	70–600°F (21–315°C)	0.0000090	0.0000162
	−300–70°F (−185–21°C)	0.0000070	0.0000126
316	70–600°F (21–315°C)	0.0000096	0.0000173
	−300–70°F (−185–21°C)	0.0000071	0.0000128
330	70–600°F (21–315°C)	0.0000089	0.0000160
	−300–70°F (−185–21°C)	0.0000058	0.0000104
347	70–600°F (21–315°C)	0.0000097	0.0000175
	−300–70°F (−185–21°C)	0.0000075	0.0000135
Hastelloy B	32–212°F (0–100°)	0.0000056	0.0000101
Hastelloy C		0.0000063	0.0000113
Inconel X, annealed		0.0000067	0.0000120
Haynes Stellite 25 (L605)		0.0000076	0.0000137
Copper (ASTM B152, B124, B133)		0.0000093	0.0000167
Yellow brass (ASTM B36, B134, B135)		0.0000105	0.0000189
Aluminum bronze (ASTM B169 Alloy A)		0.0000092	0.0000166
Beryllium copper 25 (ASTM B194)		0.0000093	0.0000167
Cupronickel 30%		0.0000085	0.0000154
K-Monel		0.0000074	0.0000133
Nickel		0.0000083	0.0000149
Pyrex glass	32–580°F (0–300°C)	0.0000002	0.0000004
Titanium	70–212°F (20–100°C)	0.0000047	0.0000085
Tantalum	70–212°F (20–100°C)	0.0000036	0.0000065

Table 9.28 β_e Approximate Sizing Equations

Type	Equation	
Venturi		
Machined inlet	$\beta_e = \left[1 + \left(\frac{0.995}{S_M}\right)^2\right]^{-1/4}$	(a)
Rough-cast inlet	$\beta_e = \left[1 + \left(\frac{0.984}{S_M}\right)^2\right]^{-1/4}$	(b)
Rough-welded sheet iron	$\beta_e = \left[1 + \left(\frac{0.985}{S_M}\right)^2\right]^{-1/4}$	(c)
Universal Venturi Tube†	$\beta_e = \left[1 + \left(\frac{0.9797}{S_M}\right)^2\right]^{-1/4}$	(d)
Lo-Loss tube‡	$\beta_e = \left[1 + \left(\frac{0.92}{S_M} - 0.31\right)^2\right]^{-1/4}$	(e)
Nozzle		
ASME long radius	$\beta_e = \left[1 + \left(\frac{0.9975}{S_M}\right)^2\right]^{-1/4}$	(f)
ISA	$\beta_e = \left[1 + \left(\frac{0.9944}{S_M} - 0.118\right)^2\right]^{-1/4}$	(g)
Venturi nozzle (ISA inlet)	$\beta_e = \left[1 + \left(\frac{0.989}{S_M} - 0.09\right)^2\right]^{-1/4}$	(h)
Orifice		
Corner, flange, D-and-$D/2$ taps		
$R_D < 200{,}000$	$\beta_e = \left[1 + \left(\frac{0.6}{S_M} + 0.06\right)^2\right]^{-1/4}$	(i)
$R_D > 200{,}000$	$\beta_e = \left[1 + \left(\frac{0.6}{S_M}\right)^2\right]^{-1/4}$	(j)
$2\frac{1}{2}D$ and $8D$ taps	$\beta_e = \left[1 + \left(\frac{0.61}{S_M} + 0.55\right)^2\right]^{-1/4}$	(k)
Eccentric, all taps	$\beta_e = \left[1 + \left(\frac{0.607}{S_M} + 0.068\right)^2\right]^{-1/4}$	(l)

Table 9.28 β_0 Approximate Sizing Equations (*continued*)

Type	Equation	
Segmental, all taps	$\beta_0 = \left[1 + \left(\frac{0.634}{S_M} - 0.062\right)^2\right]^{-1/4}$	(m)
Quadrant ($\beta \leq 0.6$)	$\beta_0 = \left[1 + \left(\frac{0.76}{S_M} + 0.26\right)^2\right]^{-1/4}$	(n)
Conic, corner ($\beta \leq 0.3$)	$\beta_0 = \left[1 + \left(\frac{0.734}{S_M}\right)^2\right]^{-1/4}$	(o)

†From BIF CALC 440/441; the manufacturer should be consulted for exact coefficient information.

‡Derived from Badger Meter, Inc. Lo-Loss flow-tube coefficient curve.

Table 9.29 Procedure for β_0 Sizing: Liquids

Procedure	Symbol: U.S. units	Symbol: SI units	Reference
1. Select flow rate,† line size, differential pressure, and S_M-factor equation			
a. Select the flow-rate value to be at the upper-range chart value, and the minimum far enough out on the chart for the desired readability (the flow unit may be mass or volume).	$(q)_{URV}$	$(q^*)_{URV}$	Figs. 9.7, 9.8
b. Select the S_M-factor equation for liquid or gas based on the flow-rate unit and the method of density determination (ρ_f, G_f).	S_M	S_M	Tables 9.23–9.24
c. Obtain the N factor for the desired flow-rate unit ($q_{ft^3/s}$, $q_{gal/s}$, $q_{lbm/s}$, etc.).	N	N^*	Tables 9.14–9.17
d. Select the upper-range differential pressure for the upper-range flow rate. Use $h_w = 100$ in, $\Delta p^* = 25$ kPa if not otherwise specified.	$(h_w)_{URV}$	$(\Delta p^*)_{URV}$	
e. Obtain the nominal pipe diameter from Table B.1. For SI units, $D^* = 25.4D$.	D	D^*	Table B.1

Table 9.1 Equations and Values for C_∞, b, and n of Eq. (9.49)[a]

Primary device	Discharge coefficient C_∞ at infinite Reynolds number	Reynolds-number term	
		Coefficient b	Expo
Venturi			
Machined inlet	0.995	0	0
Rough cast inlet	0.984	0	0
Rough welded sheet-iron inlet	0.985	0	0
Universal Venturi Tube[b]	0.9797	0	0
Lo-Loss tube[c]	$1.005 - 0.471\beta + 0.564\beta^2 - 0.514\beta^3$	0	0
Nozzle:			
ASME long radius	0.9975	$-6.53\beta^{0.5}$	0.5
ISA	$0.9900 - 0.2262\beta^{4.1}$	$(-0.00175\beta^2 + 0.0033\beta^{4.15})10^{6.9}$	1.1
Venturi nozzle (ISA inlet)	$0.9858 - 0.196\beta^{4.5}$	0	0
Orifice:			
Corner taps	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8$	$91.71\beta^{2.5}$	0.7
Flange taps (D in inches)			
$D \geq 2.3$	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + 0.09\frac{\beta^4}{D(1-\beta^4)} - 0.0337\frac{\beta^3}{D}$	$91.71\beta^{2.5}$	0.7
$2 \leq D \leq 2.3$[d]	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + 0.039\frac{\beta^4}{1-\beta^4} - 0.0337\frac{\beta^3}{D}$	$91.71\beta^{2.5}$	0.7
Flange taps (D^a in millimeters)			
$D^a \geq 58.4$	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + 2.336\frac{\beta^4}{D^a(1-\beta^4)} - 0.866\frac{\beta^3}{D^a}$	$91.71\beta^{2.5}$	0.
$50.8 \leq D^a \leq 58.4$[d]	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + 0.039\frac{\beta^4}{1-\beta^4} - 0.866\frac{\beta^3}{D^a}$	$91.71\beta^{2.5}$	0.
D and $D/2$ taps	$0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + 0.039\frac{\beta^4}{1-\beta^4} - 0.0158\beta^3$	$91.71\beta^{2.5}$	0.
$2\frac{1}{2}D$ and $8D$ taps[e]	$0.5959 + 0.461\beta^{2.1} + 0.48\beta^8 + 0.039\frac{\beta^4}{1-\beta^4}$	$91.71\beta^{2.5}$	0.
Eccentric orifice (flange taps)[f]			
180° taps $D \leq 4$ (100 mm)	$0.5975 + 0.3813\beta^{2.1} + 0.6898\beta^8 - 0.1963\frac{\beta^4}{1-\beta^4} - 0.3366\beta^3$	$7.3 - 15.7\beta + 170.8\beta^2 - 308.7\beta^3 + 332.2\beta^4$	0
$D > 4$ (100 mm)	$0.5949 + 0.4078\beta^{2.1} + 0.0547\beta^8 + 0.0955\frac{\beta^4}{1-\beta^4} - 0.5608\beta^3$	$-139.7 + 1328.8\beta - 4228.2\beta^2 + 5691.9\beta^3 - 2710.4\beta^4$	0
90° taps $D \leq 4$ (100 mm)	$0.6284 + 0.1462\beta^{2.1} - 0.8464\beta^8 + 0.2803\frac{\beta^4}{1-\beta^4} - 0.2286\beta^3$	$69.1 - 469.4\beta + 1245.8\beta^2 - 1287.5\beta^3 + 496.2\beta^4$	0
$D > 4$ (100 mm)	$0.6276 + 0.0822\beta^{2.1} + 0.2739\beta^8 - 0.0934\frac{\beta^4}{1-\beta^4} - 0.1133\beta^3$	$-108.2 + 898.3\beta - 2587.3\beta^2 + 2977\beta^3 - 1131.3\beta^4$	0

Table 9.1 Equations and Values for C_∞, b, and n of Eq. (9.49)[a] (*Continued*)

Primary device	Discharge coefficient C_∞ at infinite Reynolds number	Reynolds-number term: Coefficient b
Vena contracta taps[f]		
150° taps		
$D \le 4$ (100 mm)	$0.6261 + 0.1851\beta^{2.1} - 0.2879\beta^8 + 0.1170\frac{\beta^5}{1-\beta^5} - 0.2545\beta^5$	$23.3 - 307\beta + 821.5\beta^2 - 1398.6\beta^3 + 900.3\beta^4$
$D > 4$ (100 mm)	$0.6778 + 0.0822\beta^{2.1} + 0.2739\beta^8 - 0.0934\frac{\beta^5}{1-\beta^5} - 0.1132\beta^5$	$58.7 - 471.4\beta + 1721.8\beta^2 - 2722.6\beta^3 + 1569.4\beta^4$
90° taps		
$D \le 4$ (100 mm)	$0.5917 + 0.3061\beta^{2.1} + 0.3408\beta^8 - 0.1019\frac{\beta^5}{1-\beta^5} - 0.2715\beta^5$	$-69.3 + 556.9\beta - 1332.2\beta^2 + 1303.7\beta^3 - 394.8\beta^4$
$D > 4$ (100 mm)	$0.6016 + 0.3312\beta^{2.1} - 1.5581\beta^8 + 0.6510\frac{\beta^5}{1-\beta^5} - 0.7308\beta^5$	$52.8 - 434.2\beta + 1571.2\beta^2 - 2460.9\beta^3 + 1420.2\beta^4$
Segmental[f]		
Flange taps		
$D \le 4$ (100 mm)	$0.5986 + 0.3917\beta^{2.1} + 0.7586\beta^8 - 0.2273\frac{\beta^5}{1-\beta^5} - 0.3343\beta^5$	0
$D > 4$ (100 mm)	$0.6037 + 0.1580\beta^{2.1} - 0.2918\beta^8 + 0.0244\frac{\beta^5}{1-\beta^5} - 0.0790\beta^5$	0
Vena contracta		
$D \le 4$ (100 mm)	$0.5925 + 0.3380\beta^{2.1} + 0.4018\beta^8 - 0.1048\frac{\beta^5}{1-\beta^5} - 0.3212\beta^5$	0
$D > 4$ (100 mm)	$0.5932 + 0.3952\beta^{2.1} + 0.3412\beta^8 - 0.0569\frac{\beta^5}{1-\beta^5} - 0.4022\beta^5$	0
Quadrant (corner and flange taps)[f]		
$D \ge 1.5$ (40 mm)	$0.7746 - 0.1334\beta^{2.1} + 1.4085\beta^8 + 0.0975\frac{\beta^5}{1-\beta^5} + 0.3085\beta^5$	0
Conic orifice		
$D \ge 1$ (25 mm)	$250\beta \le R_D \le 500\beta$ 0.734 $500\beta < R_D \le 200{,}000\beta$ 0.720	0
Honed orifice meter runs		
Flange taps	$[0.5959 + 0.468(\beta^4 + 10\beta^{12})](1-\beta^4)^{0.5}$	$(0.67 + 8.1\beta^4)(1-\beta^4)^{0.5}$
$\frac{1}{2} \le D \le 1\frac{1}{2}$		
Corner taps (D in inches)	$\left[0.5991 + \frac{0.0044}{D} + \left(0.3155 + \frac{0.0175}{D}\right)(\beta^4 + 2\beta^{16})\right](1-\beta^4)^{0.5}$	$\left[\frac{0.52}{D} - 0.192 + \left(16.48\frac{1.16}{D}\right)(\beta^4 + 4\beta^{16})\right](1-\beta^4$
$\frac{1}{2} \le D \le 1\frac{1}{2}$		

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Table 2.6 Density and Viscosity of Water: U.S. and SI Units

Temperature		Density†		
°F	°C	lb_m/ft^3	kg/m^3	Viscosity‡ μ_w
32	0.00	62.41796	999.839	1.7869
33	0.56	62.42014	999.874	1.7536
34	1.11	62.42198	999.904	1.7212
35	1.67	62.42348	999.928	1.6896
36	2.22	62.42465	999.947	1.6592
37	2.78	62.42549	999.960	1.6295
38	3.33	62.42601	999.968	1.6005
39	3.89	62.42622	999.972	1.5724
40	4.44	62.42611	999.970	1.5450
41	5.00	62.42571	999.964	1.5183
42	5.56	62.42500	999.952	1.4923
43	6.11	62.42400	999.936	1.4670
44	6.67	62.42271	999.916	1.4424
45	7.22	62.42114	999.890	1.4184
46	7.78	62.41928	999.861	1.3950
47	8.33	62.41715	999.827	1.3722
48	8.89	62.41476	999.788	1.3499
49	9.44	62.41209	999.746	1.3283
50	10.00	62.40916	999.699	1.3071
51	10.56	62.40596	999.648	1.2865
52	11.11	62.40254	999.592	1.2664
53	11.67	62.39885	999.533	1.2468
54	12.22	62.39491	999.470	1.2276
55	12.78	62.39073	999.403	1.2089
56	13.33	62.38631	999.333	1.1907
57	13.89	62.38165	999.258	1.1729
58	14.44	62.37676	999.180	1.1555
59	15.00	62.37164	999.098	1.1385
60	15.56	62.36630	999.012	1.1219
61	16.11	62.36073	998.922	1.1057
62	16.67	62.35494	998.830	1.0899
63	17.22	62.34893	998.734	1.0745
64	17.78	62.34271	998.634	1.0592
65	18.33	62.33627	998.531	1.0444
66	18.89	62.32963	998.425	1.0299
67	19.44	62.32277	998.315	1.0158
68	20.00	62.31572	998.202	1.0019
69	20.56	62.30846	998.085	0.9884
70	21.11	62.30100	997.966	0.9753
71	21.67	62.29334	997.843	0.9624
72	22.22	62.28549	997.718	0.9499
73	22.78	62.27744	997.588	0.9374
74	23.33	62.26920	997.457	0.9253
75	23.89	62.26078	997.322	0.9134
76	24.44	62.25216	997.184	0.9018
77	25.00	62.24336	997.043	0.8904
78	25.56	62.23438	996.899	0.8793
79	26.11	62.22521	996.752	0.8685

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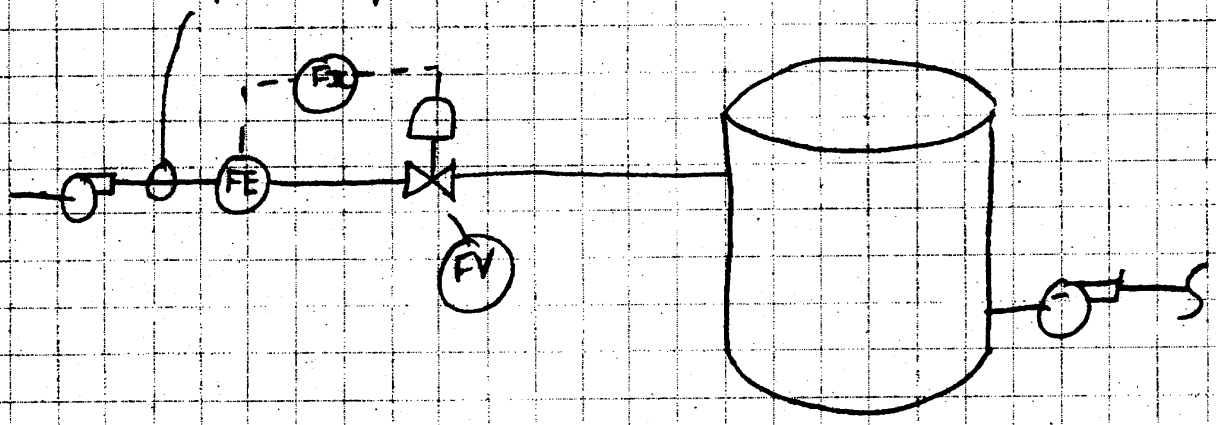
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Given:

Fluid 1

Flow = 390 GPM ± 10%



Add Fluid 2 to tank and ratio Fluid 2 to 10% of Fluid 1.

Fluid 2

Density = 57 lbm/Ft³
Viscosity = .9
Temp = 90 °F

(Clean Liquid)

Fluid 2 will have a new pump

1) Draw New Process Diagram using orfice Plate for the FE.

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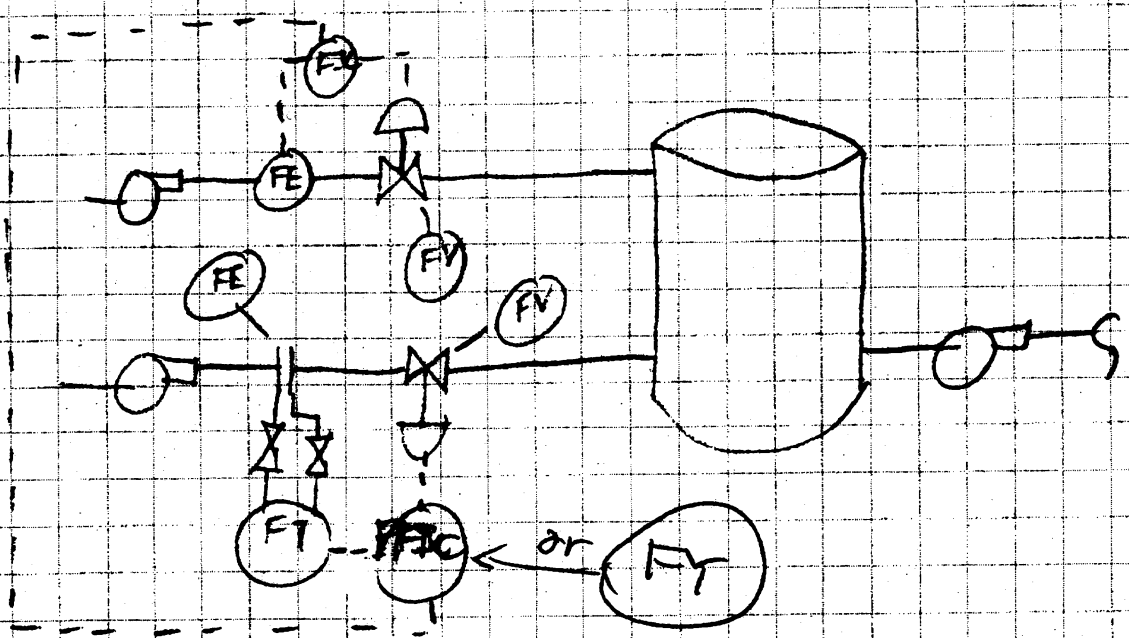
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(2) What is the Flow range for Fluid 2

Fluid 1 = 390 ± 10% = 429 + 10% = 42.9 Gpm
351 - 10% = 35.1 Gpm

(3) What should the scale of the Flow transmitter be?

$\frac{39}{.8} = 48.75$ Use 50 GPM.

Typically Normal flow is 80% of Range

3) What should the pipe size be for fluid 2. to keep the velocity less than 6 ft/sec. (use Standard weight pipe.

$$D = \sqrt{\frac{2.9(gpm)}{(2.448)(V_f)}}$$ (From Miller page C-6)

$$D = \sqrt{\frac{42.9}{(2.448)(6)}} = 1.71 \text{ in}$$

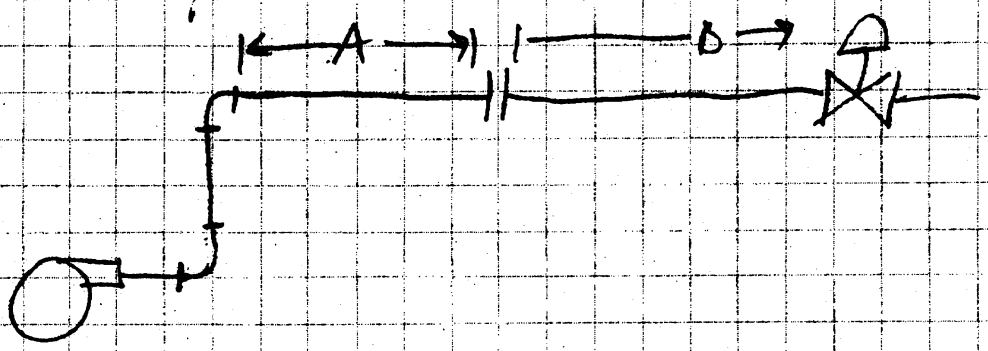
From pipe tables 1.5 in Schld 40 I.D. = 1.61 in

2.0 in schld 40 I.D. = 2.067 in

Select 2 in pipe.

(4) Calculate orifice bore using S.S. pipe + 100 in. H_2O as D.P. across the plate at Full Scale Flow. (Use miller eq.)

5) What should up & downstream piping be (A & B) assuming piping arrangement below per ISO 5167



A = 20 diameters or ≈ 40 in.

B = 6 diameters or ≈ 12 in.

(6) Calculate C_v of Control Valve at normal Flow using a Δp of 10 psid.

$S.G. = \frac{57}{62.4} = .913$

$Q\sqrt{\frac{S.G.}{\Delta P}} = C_v = 39\sqrt{\frac{.913}{10}}$

$C_v = 11.8$

7) What Factors are important when tuning new loop

1) Since Setpoint will change as Fluid Flow rate changes no derivitive should be used.

2) the period of the two loops should be close

↑ From Bump Test

From part 3 scale Flow = 50 GPM

a) Select Sm equation from table 9.23

Since density & volumetric flow are being used

$$S_m = \frac{\sqrt{F_p}\ \sqrt{\rho_F}\ q_v}{N_v \rho\ F_a\ D^2 \sqrt{h_w}}$$

b) Select N Factor for units ($N_{\rho v}$) from tables 9.14 - 9.19

for Gpm $N_{v\rho}$ = 44.74932

c) Find percent of Full Flow for normal Flow

Normal Flow = 39

Scale = 50

$\frac{39}{50}$ = 78%

d) Find P_p at Normal Flow

= 100 in H_2O x $(.78)^2$ = 60.84 in H_2O

e) calculate R_D

$$R_D = \left[2266.97 \frac{\rho_f}{\mu_{cp} D N_{vp}}\right] qv$$

$$R_p = \left[2266.97 \frac{57}{(.9)(2.067)(44.74932)}\right] 39 = 60,536$$

Check Table 9.27 to see if in range (for orifice $R_p > 19,00$

(f) assume Liquid compressibility factor (F_p) = 1 if unknown

(g) Calculate F_a From Eq 9.52

$$F_a = 1 + 2\alpha_{pE}(T_F - 68)$$

(α_{pE} = expansion factor for plate From Table B.4)

$$F_a = 1 + 2(.00000 96)(90 - 68) = 1.0004$$

(h) Calculate S_n

$$S_n = \frac{(\sqrt{1})(\sqrt{57})(39)}{(44.74932)(1.0004)(2.067)^2\sqrt{60.09}}$$

$$= .1974$$

(i) Calculate B_o From Table 9.2b for $R_D < 200{,}000$

$$B_o = \left[1 + \left(\frac{.6}{S_m} + .06\right)^2\right]^{-\frac{1}{4}}$$

$$= \left[1 + \left(\frac{.6}{.1974} + .06\right)^2\right]^{-\frac{1}{4}}$$

$$B_o = .568$$

(j) Select discharge coefficient from Table 9.1

$$C_\infty = .5959 + .0312\beta^{2.1} - .184\beta^8 + .039\frac{\beta^4}{1-\beta^4} - .0337$$

$$C = C_\infty + \frac{b}{R_D^n}$$

K) Calculate C_o using B_o

$$C_\infty = .605$$

$$C_o = .605 + \frac{91.71\beta^{2.5}}{R_D^{(.75)}} = .6107$$

L) recalculate B

$$B_1 = \left[1 + \left(\frac{C_o}{S_m}\right)^2\right]^{-\frac{1}{4}} = .5546$$

m) do steps k & L until change in $B < .001$ using new values

$C_1 = .61003$ $C_2 = .61005$ $C_3 = .61005$

$B_2 = .5549$ $B_3 = .5548$ $B_4 = .5548$

n) Calculate Bore

$d = DB = 2.067 \times .5548 = 1.147$ in

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Calculate Permanent Pressure loss at main Tie

$$h_1 = (1 - .24\beta - .52\beta^2 - .16\beta^3)h_w$$

From Pg 6-36 Table 6-3

$\beta = 0.554$ @

$h_1 = (1 - .24(.554) - .52(.554)^2 - .16(.554)^3)(79)$

$h_1 = (.6795)(79) = 53$ in H_2O

pressure drop @ normal flow

$\Delta P_{max} = 100$ in H_2O Given

@ 250 GPM

$= (100)\left(\frac{39}{50}\right) = 78$ in H_2O

Table 9.22 β_0 Approximate Sizing Equations (*continued*)

Type	Equation	
Segmental, all taps	$\beta_0 = \left[1 + \left(\frac{0.634}{S_M} - 0.062\right)^2\right]^{-1/4}$	(m)
Quadrant ($\beta \leq 0.6$)	$\beta_0 = \left[1 + \left(\frac{0.76}{S_M} + 0.26\right)^2\right]^{-1/4}$	(n)
Conic, corner ($\beta \leq 0.3$)	$\beta_0 = \left[1 + \left(\frac{0.734}{S_M}\right)^2\right]^{-1/4}$	(o)

†From BIF CALC 440/441; the manufacturer should be consulted for exact coefficient information.

‡Derived from Badger Meter, Inc. Lo-Loss flow-tube coefficient curve.

Table 9.23 Procedure for β_0 Sizing: Liquids

Procedure	Symbol: U.S. units	Symbol: SI units	Reference
1. Select flow rate,† line size, differential pressure, and S_M-factor equation			
a. Select the flow-rate value to be at the upper-range chart value, and the minimum far enough out on the chart for the desired readability (the flow unit may be mass or volume).	$(q)_{URV}$	$(q^*)_{URV}$	Figs. 9.7, 9.8
b. Select the S_M-factor equation for liquid or gas based on the flow-rate unit and the method of density determination (ρ_f, G_f).	S_M	S_M	Tables 9.23–9.24
c. Obtain the N factor for the desired flow-rate unit ($q_{ft^3/s}$, q_{GPM}, $q_{lbm/s}$, etc.).	N	N^*	Tables 9.14–9.17
d. Select the upper-range differential pressure for the upper-range flow rate. Use $h_w = 100$ in, $\Delta p^* = 25$ kPa, if not otherwise specified.	$(h_w)_{URV}$	$(\Delta p^*)_{URV}$	
e. Obtain the nominal pipe diameter from Table B.1. For SI units, $D^* = 25.4D$.	D	D^*	Table B.1

Table 9.29 Procedure for β_o Sizing: Liquids (*continued*)

Procedure	Symbol: U.S. units	Symbol: SI units	Reference
2. Scale to normal operating flow rate			
a. Multiply the URV flow rate by 0.8 *and use this in all subsequent calculations.*	$(q)_N$	$(q^*)_N$	
b. Multiply the upper-range differential pressure by 0.64 *and use this in all subsequent calculations.*	$(h_w)_N$	$(\Delta p^*)_N$	
3. Obtain fluid properties‡			
a. From the selected S_M-factor equation, tabulate the necessary fluid properties to solve for S_M.	S_M	S_M	Tables 9.23–9.24
b. Obtain the necessary density or specific gravity from measurements, tables, graphs, or prediction equations.	ρ, G_f	ρ^*, G_f,	App. E
c. Obtain the fluid viscosity from measurements, tables, or graphs; convert to centipoises if necessary (Table C.2).	μ_{cP}	μ_{cP}	App. F
d. Calculate the pipe Reynolds number to ensure it is above the minimum Reynolds-number range given in Table 9.27.	R_D	R_D	Tables 9.20–9.2 Tables C.4, C.5
4. Calculate S_M factor			
a. Set the liquid compressibility factor F_p to 1.0 if it is unknown or assumed to be negligible.	F_p	F_p	App. E, Eqs. (2.107), (2.110), (2.111)
b. Calculate or graphically obtain the thermal-expansion factor.	F_a	F_a^*	Eq. (9.52) (U.S. units), Eq. (9.54) (SI units), Fig. 9.5, Table B.4
c. Substitute values into the S_M-factor equation, and solve for S_M.	S_M	S_M	Tables 9.23–9.24
5. Calculate β_o: For the selected primary device, substitute the value of S_M into the β_o equation.	β_o	β_o	Table 9.28
6. Calculate the bore of the primary element as $d = \beta_o D$.	d	d^*	

†See Chap. 3.

‡See Chap. 2.

Table 9.23 Sizing-Factor S_M Equations for U.S. Flow Units

	Liquid	Gas (vapor)
MASS FLOW RATE		
Density	$S_M = \dfrac{q_M}{N_M F_a D^2 \sqrt{F_p}\sqrt{\rho_f}\sqrt{h_w}}$ (a)	$S_M = \dfrac{q_M}{N_M F_a D^2 \sqrt{\rho_{f1}}\sqrt{h_w}}$ (g)
Specific gravity	$S_M = \dfrac{q_M}{N_{MG} F_a D^2 \sqrt{F_p}\sqrt{G_f}\sqrt{h_w}}$ (b)	
pvT equation		$S_M = \dfrac{\sqrt{Z_{f1}}\sqrt{T_{f1}}q_M}{N_{MpT} F_a D^2 \sqrt{G}\sqrt{h_w p_{f1}}}$ (h)
VOLUMETRIC FLOW RATE AT FLOWING CONDITIONS		
Density	$S_M = \dfrac{\sqrt{F_p}\sqrt{\rho_f}\,q_v}{N_v F_a D^2 \sqrt{h_w}}$ (c)	$S_M = \dfrac{\sqrt{\rho_{f1}}q_v}{N_v F_a D^2 \sqrt{h_w}}$ (i)
Specific gravity	$S_M = \dfrac{\sqrt{F_p}\sqrt{G_f}\,q_v}{N_{vG} F_a D^2 \sqrt{h_w}}$ (d)	
pvT equation		$S_M = \dfrac{\sqrt{G}\sqrt{p_{f1}}q_v}{N_{vpT} F_a \sqrt{Z_{f1}}\sqrt{T_{f1}} D^2 \sqrt{h_w}}$ (j)
VOLUMETRIC FLOW RATE AT BASE CONDITIONS		
Density	$S_M = \dfrac{\rho_b q_v}{N_{v\rho} F_a D^2 \sqrt{F_p}\sqrt{\rho_f}\sqrt{h_w}}$ (e)	$S_M = \dfrac{\rho_b q_v}{N_{v\rho} F_a D^2 \sqrt{\rho_{f1}}\sqrt{h_w}}$ (k)
Specific gravity	$S_M = \dfrac{G_b q_v}{N_{vG} F_a D^2 \sqrt{F_p}\sqrt{G_f}\sqrt{h_w}}$ (f)	
pvT equation		
Standard base		$S_M = \dfrac{\sqrt{Z_{f1}}\sqrt{T_{f1}}\sqrt{G}\,q_v}{N_{vpT} F_a Z_b D^2 \sqrt{h_w p_{f1}}}$ (l)
Selected base		$S_M = \dfrac{\sqrt{Z_{f1}}\sqrt{T_{f1}}\sqrt{G}p_b q_{vb}}{(N_{vpT})_b F_a Z_b T_b D^2 \sqrt{h_w p_{f1}}}$ (m)

NOTE: Gas (vapor) equations are written for upstream pressure tap. For downstream pressure tap, change subscript 1 to subscript 2, in ρ_{f2}, p_{f2}, Z_{f2}, etc.

Table 9.14 N Factors for Mass Flow: U.S. Units†

N_M, Density equation, *liquid and gas* (vapor)

Time	Pound-mass (lb_m)	Kilogram (kg)§	Gram (g)§
s	0.09970190	0.04522402	45.22402
min	5.982114	2.713441	2713.441
h	358.9268	162.8065	162,806.5
24 h	8614.244	3907.36	3,907,356

N_{Ms} Specific-gravity‡ equation, *liquid*

Time	Pound-mass (lb_m)	Kilogram(kg)§	Gram (g)§
s	0.7873692	0.3571447	357.1447
min	47.24215	21.42868	21,428.68
h	2834.529	1285.721	1,285,721
24 h	68,028.70	30,857.30	30,857,300

N_{Mpr} pvT equation, *gas* (vapor)

Time	Pound-mass (lb_m)	Kilogram (kg)§	Gram (g)§
s	0.1637913	0.07429449	74.29449
min	9.827478	4.4576769	4457.669
h	589.6487	267.4602	267,460.2
24 h	14,151.57	6419.044	6,419,044

†The U.S. units are pressure p_f (psia), differential pressure h_w (inches of water at 68°F, 14.696 psia, and standard gravity, 32.17405 ft/s^2), temperature T_f (°R), dimensions d and D (in), and density ρ (lb_m/ft^3).

‡Specific-gravity base: water at 60°F; pressure = 14.69595 psia.

§For sizing and calculating mass flow in SI units, *but* with measurement in the U.S. units defined above.

units, the Reynolds number is calculated as

$$R_D = \frac{\rho_f \bar{V}_f D_P}{(\mu_m)_a} \tag{5.1}$$

The mass flow can be calculated as

$$q_{PPS} = \rho_f A_P \bar{V}_f \quad lb_m/s \tag{9.12}$$

Table 9.16 N **Factors for Volume Flow: U.S. Units†**

N_w, N_v, **Density equation,** ***liquid and gas*** **(vapor)**

Time	Cubic foot (ft^3)	Cubic meter (m^3)‡	Liter (L)‡	U.S. gallon (gal)	U.K. liquid (Imp. gal)	Barrel	
						42 gal	50 gal
s	0.09970190	0.002823244	2.823244	0.7458220	0.6210265	0.01775767	0.01491644
min	5.982114	0.1693946	169.3946	44.74932	37.26159	1.065460	0.8949864
h	358.9268	10.16368	10,163.68	2684.959	2235.696	63.92760	53.69919
24 h	8614.244	243.9283	243,928.3	64,439.02	53,656.69	1534.262	1288.780

N_{wa}, N_{va} **Specific-gravity equation,** ***liquid***

Time	Cubic foot (ft^3)	Cubic meter (m^3)	Liter (L)‡	U.S. gallon (gal)	U.K. liquid (Imp. gal)	Barrel	
						42 gal	50 gal
s	0.01262491	0.0003574978	0.3574978	0.09444092	0.07863849	0.002248593	0.001888819
min	0.7574946	0.02144987	21.44987	5.666455	4.718309	0.1349156	0.1133291
h	45.44968	1.286992	1286.992	339.9873	283.0986	8.094936	6.799747
24 h	1090.793	30.88781	30,887.81	8159.696	6794.365	194.2785	163.1939

Reynolds Number Eqs.

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASAB36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
1 1.315	...	....	5S	0.065	1.185
	...	....	10S	0.109	1.097
	40	Std	40S	0.133	1.049
	80	XS	80S	0.179	0.957
	160	....	...	0.250	0.815
	...	XXS	...	0.358	0.599
1¼ 1.660	...	....	5S	0.065	1.530
	...	....	10S	0.109	1.442
	40	Std	40S	0.140	1.380
	80	XS	80S	0.191	1.278
	160	....	...	0.250	1.160
	...	XXS	...	0.382	0.896
1½ 1.900	...	....	5S	0.065	1.770
	...	....	10S	0.109	1.682
	40	Std	40S	0.145	1.610
	80	XS	80S	0.200	1.500
	160	....	...	0.281	1.338
	...	XXS	...	0.400	1.100
2 2.375	...	....	5S	0.065	2.245
	...	....	10S	0.109	2.157
	40	Std	40S	0.154	2.067
	80	XS	80S	0.218	1.939
	160	....	...	0.344	1.687
	...	XXS	...	0.436	1.503
2½ 2.875	...	....	5S	0.083	2.709
	...	....	10S	0.120	2,635
	40	Std	40S	0.203	2.469
	80	XS	80S	0.276	2.323
	160	....	...	0.375	2.125
	...	XXS	...	0.552	1.771
3 3.500	...	....	5S	0.083	3.334
	...	....	10S	0.120	3.260
	40	Std	40S	0.216	3.068
	80	XS	80S	0.300	2.900
	160	....	...	0.438	2.624
	...	XXS	...	0.600	2.300

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
	...	....	5S	0.083	3.834
3½	...	....	10S	0.120	3.760
4.000	40	Std	40S	0.226	3.548
	80	XS	80S	0.318	3.364
	...	....	5S	0.083	4.334
	...	....	10S	0.120	4.260
4	40	Std	40S	0.237	4.026
4.500	80	XS	80S	0.337	3.826
	120	....	...	0.438	3.624
	160	....	...	0.531	3.438
	...	XXS	...	0.674	3.152
	...	....	5S	0.109	5.345
	...	....	10S	0.134	5.295
5	40	Std	40S	0.258	5.047
5.563	80	XS	80S	0.375	4.813
	120	....	...	0.500	4.563
	160	....	...	0.625	4.313
	...	XXS	...	0.750	4.063
	...	....	5S	0.109	6.407
	...	....	10S	0.134	6.357
6	40	Std	40S	0.280	6.065
6.625	80	XS	80S	0.432	5.761
	120	....	...	0.562	5.501
	160	....	...	0.719	5.187
	...	XXS	...	0.864	4.897
	...	....	5S	0.109	8.407
	...	....	10S	0.148	8.329
	20	....	...	0.250	8.125
	30	....	...	0.277	8.071
	40	Std	40S	0.322	7.981
8	60	....	...	0.406	7.813
8.625	80	XS	80S	0.500	7.625
	100	....	...	0.594	7.437
	120	....	...	0.719	7.187
	140	....	...	0.812	7.001
	...	XXS	...	0.875	6.875
	160	....	...	0.906	6.813

Table 9.20 Reynolds Number Related to Derived Flow-Rate Unit: U.S. Units

	Liquid		Gas (vapor)	
MASS FLOW RATE				
Density	$R_D = \left[2266.970 \frac{1}{\mu_a D N_{M_D}}\right] q_M$	(a)	$R_D = \left[2266.970 \frac{1}{\mu_a D N_{M_D}}\right] q_M$	(g)
Specific gravity	$R_D = 17{,}902.78 \frac{1}{\mu_a D N_{MG}} q_M$	(b)		
pvT equation			$R_D = \left[3724.200 \frac{1}{\mu_a D N_{M_D T}}\right] q_M$	(h)
VOLUMETRIC FLOW RATE AT FLOWING CONDITIONS				
Density	$R_D = \left[2266.970 \frac{\rho_f}{\mu_a D N_{v_D}}\right] q_o$	(c)	$R_D = \left[2266.970 \frac{\rho_n}{\mu_a D N_{v_D}}\right] q_o$	(i)
Specific gravity	$R_D = \left[17{,}902.78 \frac{F_p G_f}{\mu_a D N_{vG}}\right] q_o$	(d)		
pvT equation			$R_D = \left[3724.200 \frac{G p_n}{Z_n T_n} \frac{1}{\mu_a D N_{v_D T}}\right] q_o$	
VOLUMETRIC FLOW RATE AT BASE CONDITIONS				
Density	$R_D = \left[2266.970 \frac{\rho_b}{\mu_a D N_{v_D}}\right] q_v$	(e)	$R_D = \left[2266.970 \rho_b \frac{1}{\mu_a D N_{v_D}}\right] q_v$	(k)
Specific gravity	$R_D = \left[17{,}902.78 \frac{G_b}{\mu_a D N_{vG}}\right] q_v$	(f)		
pvT equation				
Standard base			$R_D = \left[3724.200 \frac{G}{Z_b} \frac{1}{\mu_a D N_{v_D T}}\right] q_v$	(l)
Selected base			$R_D = \left[3724.200 \frac{G p_b}{Z_b T_b} \frac{1}{\mu_a D (N_{v_D T})_b}\right] q_{vb}$	(m)

negligible. The simplified equations have been referred to by Spink (1967) as *plant equations.*

Over normal operating ranges for liquids and gases (vapors), the discharge coefficient does not significantly vary with Reynolds number, and it can be expressed with reasonable accuracy as

$$C = k_1 + k_2 S_M \tag{9.80}$$

where k_1 and k_2 are constants derived by fitting the discharge coefficient at either the infinite Reynolds number (C_∞) or over a selected Reynolds-number range to the value of S_M calculated from Eq. (9.78).

If the gas expansion factor Y is 1.0, the substitution of Eq. (9.80) into Eq. (9.78) gives β_0, the first approximation to β, as

$$\beta_0 = \left[1 + \left(\frac{k_1 + k_2 S_M}{S_M}\right)^2\right]^{-1/4} = \left[1 + \left(\frac{k_1}{S_M} + k_2\right)^2\right]^{-1/4} \tag{9.81}$$

This simplifying assumption thus allows β_0 to be calculated directly from the S_M factor.

Table 9.27 lists the limits on the variables for approximately 1 to 3 percent accuracy in sizing the bore. In Table 9.28 are the β_0 approximation equations; in Table 9.29, the calculation procedure for liquids; and in Table 9.30, the procedure for gas (vapor) sizing.

EXAMPLE 9.1

For the gasoline of Example 2.12, determine, by the β_0 method, the bore of a flange-tapped orifice required to measure 100 base gal/min (6.31 L/s) in a 2-in (50-mm) Schedule 80 pipe.

Table 9.27 Limits on β_0 Sizing Method for Approximately 2 Percent Accuracy†

	Liquid	Gas (vapor)
Reynolds number		
Orifice	$R_D \geq 10{,}000$	$R_D \geq 10{,}000$
Venturi nozzle	$R_D \geq 100{,}000$	$R_D \geq 10{,}000$
Lo-Loss	$R_D \geq 100{,}000$	$R_D \geq 10{,}000$
Expansion factor‡	$Y_1 = 1.0$	$\frac{h_w}{p_n} \leq 0.5; \frac{\Delta p^*}{p_1^*} \leq 0.02$
	$Y_2 = 1.0$	$\frac{h_w}{p_n} \leq 1.0; \frac{\Delta p^*}{p_1^*} \leq 0.04$

†Assumes pipe diameter D or D^* is measured.

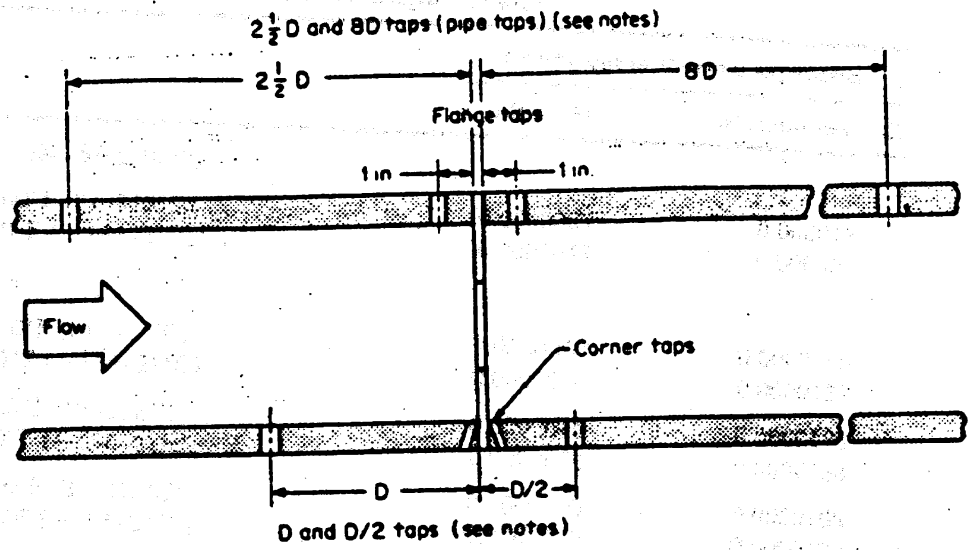
‡Ratios are based on upper-range differential pressure; operating flow rate is selected as 0.8 of upper-range flow rate, 0.64 of upper-range differential pressure.

Registered trade mark of Badger Meter, Inc. Manufacturer should be consulted for recommendations.

‡For SI units, substitute $p_2/p_1 = p_{r2}/p_{r1}$ in these equations.

Table 9.20 Reynolds Number Related to Derived Flow-Rate Units U.S. Units

	Liquid		Gas (vapor)	
MASS FLOW RATE				
Density	$R_D = \left[2266.970 \frac{1}{\mu_a D N_{M_2}}\right] q_M$	(a)	$R_D = \left[2266.970 \frac{1}{\mu_a D N_{M_2}}\right] q_M$	(g)
Specific gravity	$R_D = 17{,}902.78 \frac{1}{\mu_a D N_{MG}} q_M$	(b)		
puT equation			$R_D = \left[3724.200 \frac{1}{\mu_a D N_{M_2 T}}\right] q_M$	(h)
VOLUMETRIC FLOW RATE AT FLOWING CONDITIONS				
Density	$R_D = \left[2266.970 \frac{\rho_f}{\mu_a D N_{v_2}}\right] q_o$	(c)	$R_D = \left[2266.970 \frac{\rho_n}{\mu_a D N_{v_2}}\right] q_o$	(i)
Specific gravity	$R_D = \left[17{,}902.78 \frac{F_p G_f}{\mu_a D N_{vG}}\right] q_o$	(d)		
puT equation			$R_D = \left[3724.200 \frac{G p_n}{Z_n T_n} \frac{1}{\mu_a D N_{v_2 T}}\right] q_o$	(j)
VOLUMETRIC FLOW RATE AT BASE CONDITIONS				
Density	$R_D = \left[2266.970 \frac{\rho_b}{\mu_a D N_{v_2}}\right] q_v$	(e)	$R_D = \left[2266.970 \rho_b \frac{1}{\mu_a D N_{v_2}}\right] q_v$	(k)
Specific gravity	$R_D = \left[17{,}902.78 \frac{G_g}{\mu_a D N_{vG}}\right] q_v$	(f)		
puT equation				
Standard base			$R_D = \left[3724.200 \frac{G}{Z_b} \frac{1}{\mu_a D N_{v_2 T}}\right] q_v$	(l)
Selected base			$R_D = \left[3724.200 \frac{G p_b}{Z_b T_b} \frac{1}{\mu_a D (N_{v_2 T})_b}\right] q_{v_b}$	(m)



Notes:
(1) 2½D and 8D pipe taps are not recommended in ISO 5167 or ASME Fluid Meters.
(2) D and D/2 are radius taps now used in place of vena contracta taps.

Figure 9.4 Orifice pressure-tap locations and their names.

The generally small differences in the thermal-expansion coefficients between pipe and primary element material result in negligible error (<0.01%), even at high temperatures, if the effects of a beta ratio change are considered only for the dimensional terms in the flow-rate equation.

It is present U.S. practice to correct for thermal effects by introducing a multiplying term F_e. It is derived by partial differentiation of the theoretical flow rate equation to determine bore and pipe diameter sensitivity coefficients. The exact solution is presented in the "Generic Solution" section of this chapter.

When the pipe and primary element are of different material, the thermal-expansion-factor correction for measurements at 68°F is

$$F_e = 1 + \frac{2}{1 - \beta^4}(\alpha_{PE} - \beta^4\alpha_P)(T_F - 68) \tag{9.51}$$

where α_{PE} is the thermal-expansion coefficient of the primary element and α_P is the thermal-expansion coefficient of the pipe material. When the thermal-expansion coefficients of the primary element and pipe are approximately the same, which is usually the case, Eq. (9.51) reduces to

$$F_e = 1 + 2\alpha_{PE}(T_F - 68) \tag{9.52}$$

In this equation, the thermal-expansion coefficient of the primary element is used because the flow-rate calculation is more sensitive to bore than to pipe dimensions.

Table 6.3 Permanent Pressure-Loss Equations (U.S. Units)

Flowmeter	Liquid	Gas (vapor)		Liquid/gas (vapor)
Venturi:				
15° exit cone	→	$h_l = (0.436 - 0.86\beta + 0.59\beta^2)h_w$	(a)	←
7° exit cone	→	$h_l = (0.218 - 0.42\beta + 0.28\beta^2)h_w$	(b)	←
Universal Venturi Tube†	→	$h_l = (0.635 + 0.09\beta - 0.197\beta^2)h_w$	(c)	←
Lo-Loss tube‡	→	$h_l = (0.151 - 0.304\beta + 0.128\beta^2)h_w$	(d)	←
Nozzle	→	$h_l = (1 + 0.914\beta - 2.05\beta^2 + 1.18\beta^3)h_w$	(e)	←
Orifice	→	$h_l = (1 - 0.24\beta - 0.52\beta^2 - 0.16\beta^3)h_w$	(f)	←
Annubar: §				
		$h_l = \frac{k}{D} h_w$	(g)	
		Type 15/16 $k = 0.478$; 35/36 $k = 1.59$ 25/26 $k = 1.11$; 45/46 $k = 2.55$		
Pitot	→	$h_l = \frac{0.6}{D} h_w$	(h)	←
Target¶	→	$h_l = 0.000827 \frac{\rho_f V_f^2}{(1 - \beta_T)^{2.35}}$	(i)	←
	$h_l = \frac{F_p G_T}{(1 - \beta_T)^{2.35}} \left(\frac{q_{max}}{14.5D^2}\right)^2$ (k)	$h_l = \frac{Z_n G T_n}{p_{T1}(1 - \beta_T)^{2.35}} \left(\frac{q_{max}}{19,500D^2}\right)^2$	(o)	$h_l = \frac{1}{\rho_{T1}(1 - \beta_T)^{2.35}} \left($
	$h_l = \frac{G_f^2}{F_p G_T (1 - \beta_T)^{2.35}} \left(\frac{q_{max}}{14.5D^2}\right)^2$ (k)			
Turbine¶	$h_l = 9.00077 \rho_f V_f^2$	(l)	$h_l = 0.0128 \rho_{T1} V_f^2$	(r)	Liquid: $h_l = \frac{1}{\rho_T} \left(\frac{q}{25}\right.$
	$h_l = F_p G_T \left(\frac{q_{max}}{4.66D^2}\right)^2$	(m)	$h_l = \frac{Z_n G T_n}{p_{T1}} \left(\frac{q_{max}}{5714D^2}\right)^2$	(s)	Gas (vapor): $h_l = \frac{1}{\rho_{T1}}$
	$h_l = \frac{G_f^2}{F_p G_T} \left(\frac{q_{max}}{4.66D^2}\right)^2$	(n)			
Vortex¶	→		$h_l = 0.00084 \rho_{T1} V_f^2$	(t)	←
	$h_l = F_p G_T \left(\frac{q_{max}}{4.17D^2}\right)^2$	(o)	$h_l = \frac{Z_n G T_n}{p_{T1}} \left(\frac{q_{max}}{3600D^2}\right)^2$	(u)	$h_l = \frac{1}{\rho_{T1}} \left(\frac{q_{max}}{304D^2}\right)^2$
	$h_l = \frac{G_f^2}{F_p G_T} \left(\frac{q_{max}}{4.17D^2}\right)^2$	(p)			

†The manufacturer (BIF) should be consulted for exact information.

‡The manufacturer (Badger Meter Inc.) should be consulted for exact information.

§The manufacturer (Dieterich Standard Corp.) should be consulted for exact information.

MORGAN

QUESTION	DESCRIPTION	AREA
A15	PROCESS DYNAMICS	D

The response of a system to a 1-unit step input is shown in Figure A15.

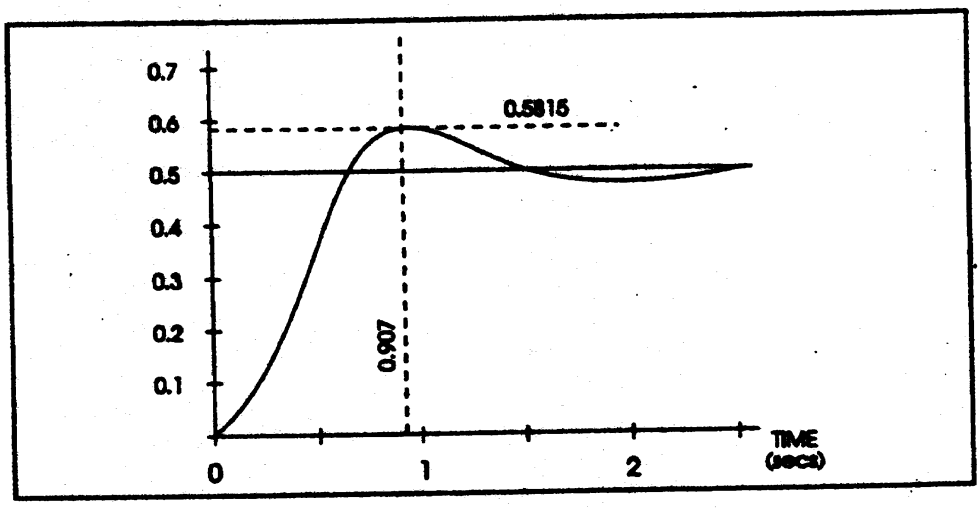


Figure A15

The data obtained from this test include:

1. Peak value of unit step response = 0.5815
2. Steady-state value of unit step response = 0.500
3. Time to peak value of unit step response = 0.907 seconds

From Bump Test

$\frac{Y}{U}$ Steady State Gain

QUESTION	DESCRIPTION	AREA
A15-17	PROCESS DYNAMICS	D

Assuming that the system can be described by a second-order differential equation:

A15. The damping ratio is most nearly:

(A) 0.4
(B) 0.5
(C) 0.6
(D) 0.7

A16. The undamped natural frequency of oscillation ω_0 in radians/second is most nearly:

(A) 0.551
(B) 1.103
(C) 3.464
(D) 4.000

A17. The transfer function of the closed-loop system is:

(A) $\dfrac{8}{s^2+8s+16}$

(B) $\dfrac{0.5}{s^2+8s+16}$

(C) $\dfrac{8}{s^2+4s+16}$

(D) $\dfrac{0.5}{s^2+4s+16}$

ANSWER	DESCRIPTION	AREA
A15-16	PROCESS DYNAMICS	D

A15. The overshoot is $\frac{0.5815 - 0.500}{0.500} * 100 = 16.3\%$

From standard response curves, the damping ratio is approximately 0.5, one-half of critical damping. Alternately, the damping ratio (ξ) can be calculated from the equation

Important
① − sign
② exponent

$$16.3 = 100\, e^{-(\pi\xi/\sqrt{1-\xi^2})}$$

$$e^{\pi\xi/\sqrt{1-\xi^2}} = \frac{100}{16.3} = 6.135$$

$$\pi\xi/\sqrt{1-\xi^2} = \ln 6.135 = 1.814$$

$$\pi^2\xi^2 = 3.29\,(1-\xi^2)\,;\ \xi^2\,(9.87 + 3.29) = 3.29$$

$$\xi^2 = 0.25\,;\ \xi = 0.5$$

The correct answer is (B).

Note: $\xi = G$ ... $\omega = G$ ...

A16. The time to the response peak, $t_p = 0.907$, is one-half of the period associated with the damped natural frequency:

$$\text{Damped period} = 2 * 0.907 = 1.814 \text{ seconds}$$

$$\therefore f_n = \frac{1}{1.814} = 0.551 \text{ cps}$$

$$\omega_n = 2\pi f_n = 3.464 \text{ rad/sec}$$

Alternately, ω_n could be calculated from the relation $t_p = \frac{\pi}{\omega_n}$, giving $\omega_n = \frac{3.1416}{0.907} = 3.464$

The undamped natural frequency ω_o is computed from $\omega_o = \frac{\omega_n}{\sqrt{1-\xi^2}} = \frac{3.464}{\sqrt{1-0.5^2}} = \frac{3.464}{0.866} = 4.0$ rad/sec.

The correct answer is (D).

ANSWER	DESCRIPTION	AREA
A17	PROCESS DYNAMICS	D

A17. This system is a second-order system with the general transfer function

$$\frac{K}{s^2 + 2\zeta\omega_0 s + \omega_0^2}$$

where $\zeta = 0.5$ and $\omega_0 = 4$, with K to be determined from the steady-state gain (0.5). ← Given in Problem Item (2)

$$2\zeta\omega_0 = (2)(0.5)(4) = 4$$

$$\omega_0^2 = 4^2 = 16$$

The transfer function is

$$\frac{K}{s^2 + 4s + 16}$$

To calculate K, note that the steady-state gain is obtained by setting $s = 0$; therefore

$$\frac{K}{\omega_0^2} = \frac{K}{16} = 0.5 \text{ or } K = 8.$$

The transfer function is

$$\frac{8}{s^2 + 4s + 16},$$

so the correct answer is (C).

~~0.1s+s~~

$$\frac{1.2k}{0.1s^2+s+1.2k}$$

$$0.1s^2+s+1.2k=0$$

$$s^2+10s+12k=0$$

$$s^2+2\xi\omega s+\omega^2$$

$$2\xi\omega=10 \qquad 2\xi\sqrt{12k}=10$$

$$\omega^2=12k \qquad 4\xi^2 12k=100$$

$$\omega=\sqrt{12k}$$

$$k=\frac{\omega^2}{12}$$

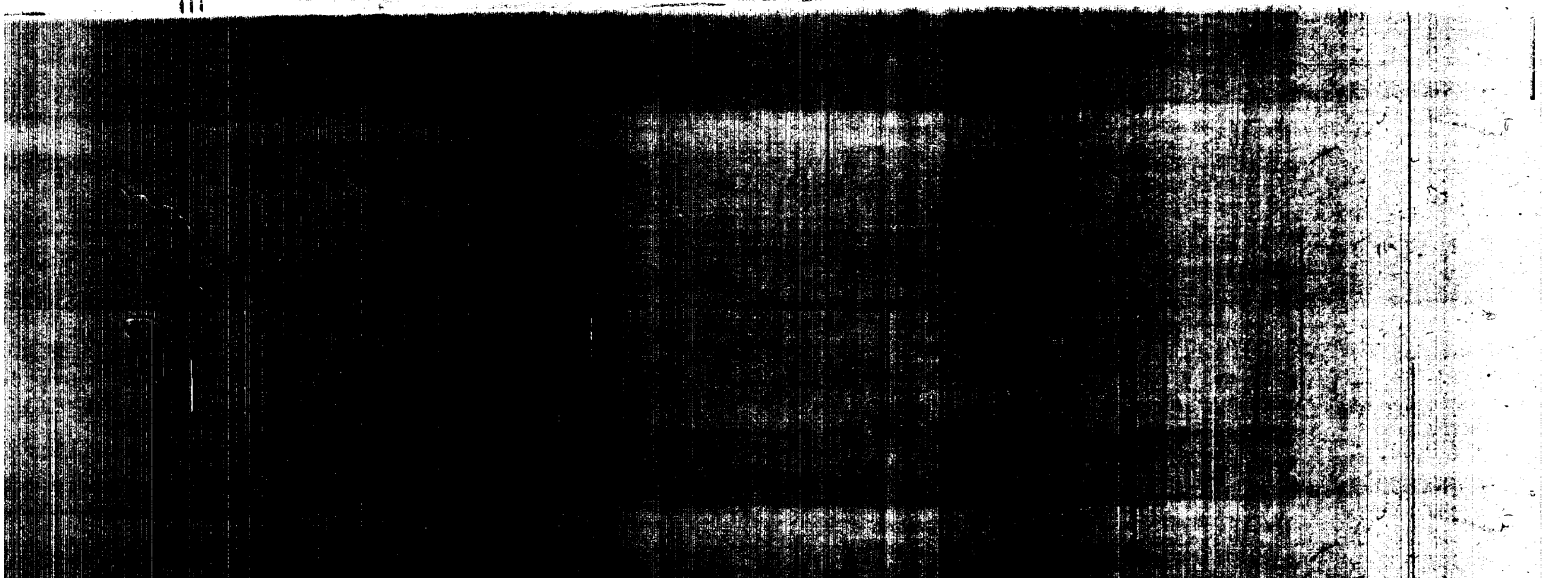
For Critical Damping

$\xi=1$, ~~$k=2.083$~~

$$4(1)^2 12k=100$$

$$k=\frac{100}{4(12)(1)^2}$$

$$k=2.083$$



QUESTION	DESCRIPTION	AREA
P16-17	PROCESS DYNAMICS	D

Use the following information to answer Questions P16 and P17.

Using a series of processes, a manufacturing plant makes a steel part that can be described as having a surface area of 80 square inches and a volume of 40 cubic inches. After a heat treating step, the temperature of the part is reduced to room temperature by immersing the object in water. The part is initially at 180 °F; the water is at 68 °F.

Assume the thermal conductivity of the part is high enough that the part can be described by a single temperature throughout its volume; also assume that the water volume is large enough that its temperature does not change significantly.

The following parameters can be assumed:

U = heat transfer coefficient
= 30 BTU/(hr)(sq ft)(°F)
SG = specific gravity of steel
= 7.7
c_p = specific heat of steel
= 0.12 BTU/(pound)(°F)

P16. From this data, the initial rate of change of temperature of the part (in degrees/minute) is estimated to be approximately:

(A) -2
(B) -23
(C) -1400
(D) -3360

P17. The time constant of this system (in minutes) is most nearly:

(A) 0.033
(B) 0.080
(C) 4.8
(D) 57.6

Substitute this page for an earlier version of these questions (see attached).

ANSWER	DESCRIPTION	AREA
P16-17	PROCESS DYNAMICS	D

From the system description, the differential equation is intended to be:

$$W c_p \frac{d\theta}{dt} = UA(\theta_w - \theta)$$

where θ = temperature of the part, °F;
θ_w = temperature of the water, °F;
and W, c_p, U and A are to be in consistent units.

$V = 40\ in^3$, so $W = \dfrac{(40\ in^3)(7.7\ \text{sp gr})(62.4\ \text{pounds/ft}^3)}{1728\ in^3/ft^3}$

$= 11.12$ pounds

$A = 80\ in^2 = \dfrac{80}{144} = 0.556\ ft^2$

$U = 30\ \text{BTU/(hr)(sq ft)(°F)} = 0.5\ \text{BTU/(min)(sq ft)(°F)}$

P16. $\left.\dfrac{d\theta}{dt}\right|_{t=0} = \dfrac{(0.5)(0.556)}{(11.12)(0.12)}(68-180) = \dfrac{UA}{W c_p}(\theta_w - \theta)$

$= -23.3$ deg/min

The correct answer is (B).

P17. If the differential equation is written

$$\frac{W c_p}{UA}\frac{d\theta}{dt} = \theta_w - \theta,$$

the coefficient of $d\theta/dt$ is

$$T = \frac{W c_p}{UA} = \frac{(11.12)(0.12)}{(0.5)(0.556)} = 4.8\ \text{min}$$

or $T = \dfrac{\text{Ultimate temp. change}}{\text{Initial rate of temp change}} = \dfrac{(68-180)}{-23.3} = 4.8$

The correct answer is (C).

$$\frac{30\ \text{BTU}}{°F\ hr\ ft^2} \left| \frac{1\ hr}{60\ min} \right| \frac{1\ ft^2}{144\ in^2} \left| \frac{80\ in^2}{} \right| \frac{lb\ °F}{0.12\ \text{BTU}} = 2.315\ \frac{lb}{min}$$

$$\frac{40\ in^3}{1728\ in^3/ft^3} \left| \frac{ft^3}{} \right| \frac{7.7\ SG}{} \left| \frac{62.4\ lb}{ft^3} \right| = 11.12\ lb$$

$$\frac{11.12\ lb}{2.315\ lb/min} = 4.8\ min$$

$$\frac{ft^2}{2.4\ lb} \left| \frac{30\ \text{BTU}}{°F\ hr\ ft^2} \right| \frac{1\ hr}{60\ min} \left| \frac{ft^2}{144\ in^2} \right| \frac{80\ in^2}{} \left| \frac{lb\ °F}{0.12\ \text{BTU}} \right| \frac{40\ in^3}{} \left| \frac{1728\ in^3/ft^3}{} \right| \frac{}{SG\ 7.7}$$

$1/C_P = 1/0.12$; $A = 0.0556$; $1/W = 1/11.12$

$$\frac{hr}{60\ min} \left| \frac{lb\ °F}{0.12\ \text{BTU}} \right| \frac{30\ \text{BTU}}{hr\ ft^2\ °F} \left| \frac{80\ in^2}{} \right| \frac{ft^2}{144\ in^2} \left| \frac{}{40\ in^3} \right| \frac{7.7\ SG}{} \left| \frac{62.4\ lb}{} \right| \frac{ft^3}{} \left| \frac{1728\ in^3}{ft^3} \right| \frac{68-80°}{}$$

$= -23.33\ °F/min$

$U = 0.5$

$$\boxed{4.8\ min} = \frac{68-180\ °F\ min}{-23.33\ °F}$$

QUESTION	DESCRIPTION	AREA
A20	CONTROLLERS/MODES/TUNING	F

The following questions relate to selection of controller parameters or tuning for control loops encountered in typical process applications.

A20. An alternative open-loop process testing for determining controller parameters is closed-loop testing: the controller is placed in AUTOMATIC, the integral and derivative action are set to zero, and the controller gain is increased gradually until a sustained oscillation is produced. Which of the following statements about this procedure are correct?

I The two data items obtained from a closed-loop test and used in tuning parameter calculation are the period and amplitude of oscillation.

II The tuning parameters obtained from a closed-loop test are likely to be more accurate than those determined from an open-loop test.

III It is necessary to observe the process for many cycles (say, 10 or more) to be sure that the oscillation is neither decaying nor increasing.

IV The engineer conducting a closed-loop test has no control over the amplitude of the oscillation.

(A) I and III

(B) I, II and IV

(C) II and III

(D) II and IV

QUESTION	DESCRIPTION	AREA
A21-22	CONTROLLERS/MODES/TUNING	F

A21. A poorly-tuned PID control loop has consistently responded too slowly to load disturbances because of a noise-free, but slow measurement device. An appropriate action to accelerate the disturbance response would be to:

I ~~II~~ Increase the controller's gain (decrease the proportional band).

II ~~III~~ Increase the controller's integral action (increase the reset rate).

III ~~IV~~ Decrease the controller's integral action (decrease the reset rate).

IV ~~V~~ Increase the controller's derivative action (increase the derivative time).

(A) I and II

(B) I and III

(C) III

Correct → (D) IV

A22. A poorly-tuned PID control loop has consistently overcompensated for low humidity conditions in a humidity-controlled room by injecting too much steam into the air supply duct. An appropriate action to reduce the overshoot problem would be to:

(A) Re-tune the loop for a critically-damped step response.

(B) Re-tune the loop for a under-damped step response.

(C) ~~(D)~~ Re-tune the loop for a 1/4-wave decay step response.

(D) ~~(E)~~ Re-tune the loop to minimize rise time.

QUESTION	DESCRIPTION	AREA
P21-22	CONTROLLERS / MODES / TUNING	F

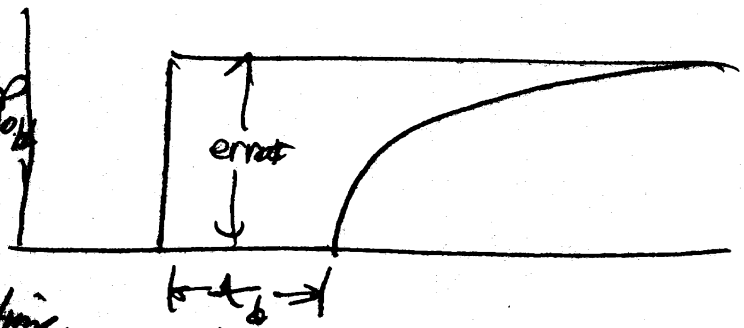
P21. Compared to a control loop with no dead time (pure time delay), a control loop with an appreciable dead time tends to require:

(A) ~~(B)~~ Less proportional gain and less integral action
(B) ~~(C)~~ ~~More proportional gain and less integral action~~
(C) ~~(D)~~ ~~More proportional gain and more integral action~~
(D) ~~(E)~~ Less proportional gain and more integral action

$OP_{NEW} = (error) \times (K) + OP_{old}$

gain

You must lower gain to minimize effect of deadtime
∴ c & d eliminated



P22. Which of the following tuning criteria would be most appropriate for designing a controller to regulate the temperature in the room where you are now sitting?

(A) ~~(B)~~ Minimize the response time for setpoint changes
(B) ~~(C)~~ Minimize the overshoot for setpoint changes
(C) ~~(D)~~ Follow varying setpoints with a minimum error
(D) ~~(E)~~ Maintain the ~~process~~ controlled variable at a constant value

ANSWER	DESCRIPTION	AREA
A20-22	CONTROLLERS/MODES/TUNING	F

A20.

I False–The parameters are the period of the oscillation and the gain needed to produce the oscillation.

II True

III False–3 or 4 cycles are sufficient.

IV True

The correct answer is (D).

A21.

(D)

The correct answer is (~~E~~) since derivative action in a relatively noise-free system allows the controller to anticipate the effects of a load disturbance and take pre-emptive action. Action I might also work, but there is nothing to indicate that action III is required as well.

A22.

The correct answer is (A) since all of the other tuning objectives would require overshoot which is stated to be undesirable. This question deals with important tuning criteria other than the classical 1/4-wave decay criteria favored by Ziegler and Nichols.

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A15

m6-97 next page

overshoot

$$\% \text{ max } O.S. = 100\, e^{-\left(\pi \zeta / \sqrt{1-\zeta^2}\right)}$$

$$\% \text{ max } O.S. = \frac{(.5815 - .5)}{.5} \times 100 = 16.3\%$$

$$16.3 = 100\, e^{-\left(\pi \zeta / \sqrt{1-\zeta^2}\right)}$$

$$\frac{16.3}{100} = e^{-\left(\pi \zeta / \sqrt{1-\zeta^2}\right)}$$

$$\frac{100}{16.3} = e^{+\left(\pi \zeta / \sqrt{1-\zeta^2}\right)}$$

Flip left side & remove (−) exponent from right side

$$\ln(6.135) = \frac{\pi \zeta}{\sqrt{1-\zeta^2}} = 1.814$$

$$1.814\sqrt{1-\zeta^2} = \pi\zeta$$

$$3.29(1-\zeta^2) = \pi^2\zeta^2$$

$$3.29 - 3.29\zeta^2 = \pi^2\zeta^2$$

$$3.29 = 9.87\zeta^2 + 3.29\zeta^2$$

$$3.29 = 13.16\zeta^2$$

$$\zeta = \sqrt{\frac{3.29}{13.16}} = \sqrt{.25} = .5$$

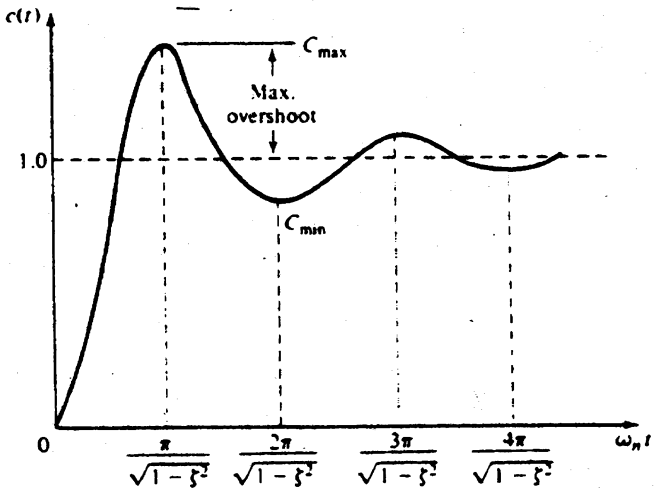


Figure 6-15 Step response illustrating that the maxima and minima occur at periodic intervals.

that, although the maxima and the minima of the response occur at periodic intervals, the response is a damped sinusoid and is not a periodic function.

The magnitudes of the overshoots and the undershoots can be obtained by substituting Eq. (6-92) into Eq. (6-84). Thus,

$$c(t)|_{\text{max or min}} = 1 + \frac{e^{-n\pi\zeta/\sqrt{1-\zeta^2}}}{\sqrt{1-\zeta^2}} \sin\left(n\pi - \tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta}\right) \qquad n = 1, 2, 3, \ldots \tag{6-94}$$

or

$$c(t)|_{\text{max or min}} = 1 + (-1)^{n-1} e^{-n\pi\zeta/\sqrt{1-\zeta^2}} \tag{6-95}$$

The maximum overshoot is obtained by letting $n = 1$ in Eq. (6-95). Therefore,

$$\text{maximum overshoot} = c_{max} - 1 = e^{-\pi\zeta/\sqrt{1-\zeta^2}} \tag{6-96}$$

and

$$\text{percent maximum overshoot} = 100e^{-\pi\zeta/\sqrt{1-\zeta^2}} \tag{6-97}$$

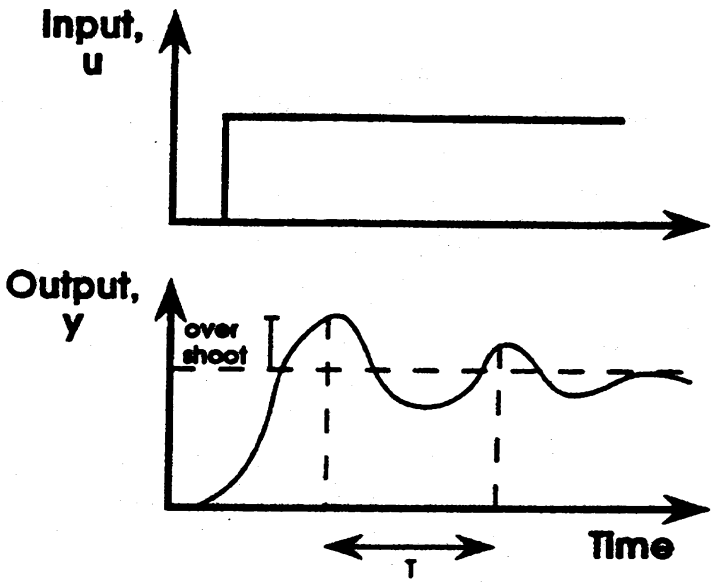
Note that for the second-order system, the maximum overshoot of the step response is only a function of the damping ratio. The relationship between the percent maximum overshoot and damping ratio for the second-order system is shown in Fig. 6-16.

From Eqs. (6-93) and (6-94) it is seen that for the second-order system under consideration, the maximum overshoot and the time at which it occurs are all exactly expressed in terms of ζ and ω_n. For the delay time, rise time, and settling time, however, the relationships are not so simple. It would be difficult to determine the exact expressions for these quantities. For instance, for the delay time, we would

DETERMINING POWER PLANT DYNAMICS FROM TIME HISTORY DATA

Second Order

$$\frac{y}{u} = \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$



K: Steady State Gain

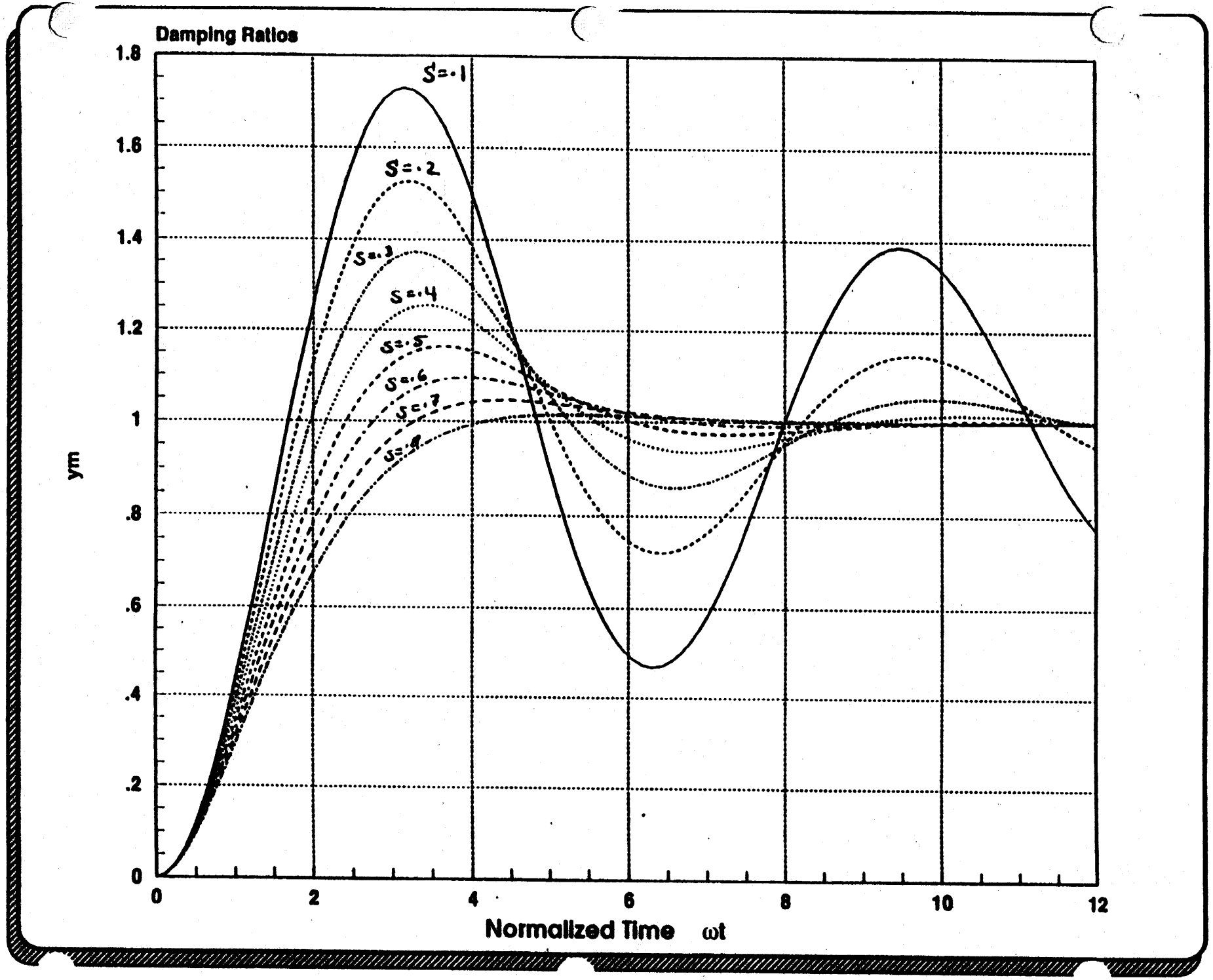
ζ: Damping Ratio

ω_n: Natural Frequency

Damping Ratio, ζ, can be approximated by estimating the amount of overshoot and using the table below. The period of oscillation, T, can be determined from the time history. Given T and ζ, the natural frequency can be determined from:

$$T = \frac{2\pi}{\omega_n\sqrt{1-\zeta^2}} \Longleftarrow \omega_n = \frac{2\pi/T}{\sqrt{1-\zeta^2}} \text{ rad/sec}$$

Overshoot, %	Damping Ratio
0	1.0
0.15	0.9
1.5	0.8
4.6	0.7
9.5	0.6
16	0.5
25	0.4
37	0.3
53	0.2
73	0.1


Damping Ratios
S=.1
S=.2
S=.3
S=.4
S=.5
S=.6
S=.7
S=.8
ym
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
0
0
2
4
6
8
10
12
Normalized Time ωt

A16

Eqn 6.93 on next page $t_{max} = \frac{\pi}{\omega_n \sqrt{1-\zeta^2}}$ (for 2nd order system)

$$.907 = \frac{\pi}{\omega_n \sqrt{1-.5^2}} = \frac{\pi}{\omega_n (.866)}$$

$$(.907)\omega_n = \frac{\pi}{(.866)}$$

$$\omega_n = \frac{\pi}{(.866)(.907)} = \frac{3.14159}{.785} = 4 \text{ rad/sec.}$$

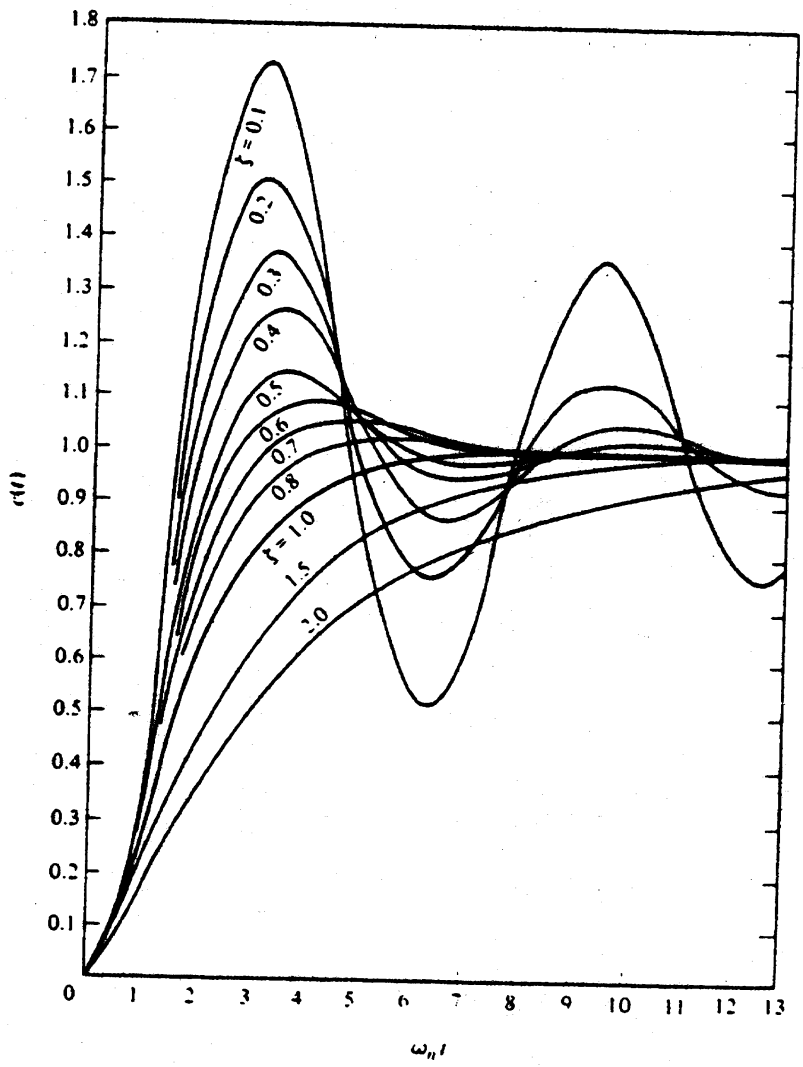


Figure 6-14 Transient response of a second-order system to a unit step function input.

time at which the maximum overshoot occurs is given by

$$t_{max} = \frac{\pi}{\omega_n \sqrt{1 - \zeta^2}} \tag{6-93}$$

In general, for all odd values of n, that is, $n = 1, 3, 5, \ldots$, Eq. (6-92) gives the times at which the overshoots occur. For all even values of n, Eq. (6-92) gives the times at which the undershoots occur, as shown in Fig. 6-15. It is interesting to note

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A17

2nd order system

$$= \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\frac{\Delta OP}{\Delta PV}$ = Steady-State Gain = K_{SS} = .5 from Bump Test

Given in Problem

Set $s = 0$ for steady state

$$.5 = \frac{K\omega_n^2}{\omega_n^2} = .5$$

$$\frac{(.5)(16)}{s^2 + 2(.5)(4)s + 16} = \frac{8}{s^2 + 4s + 16}$$

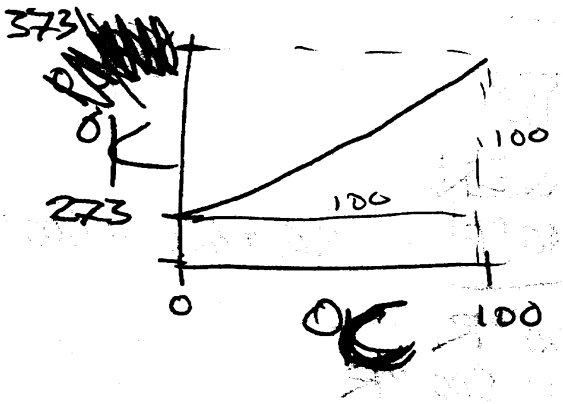
$2\zeta\omega = 4$ $\quad \omega^2 = 16$

$\omega = 4$

$2\zeta(4) = 4$

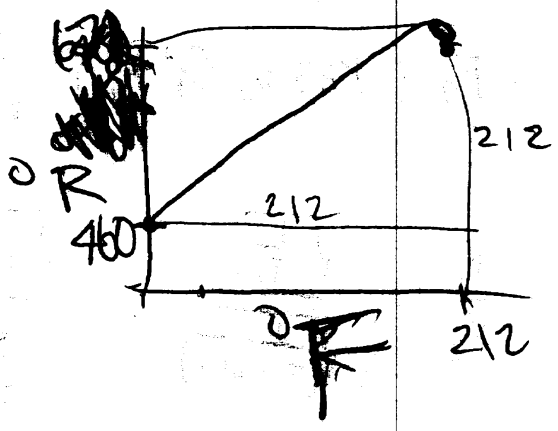
$\zeta = 0.5$

SI

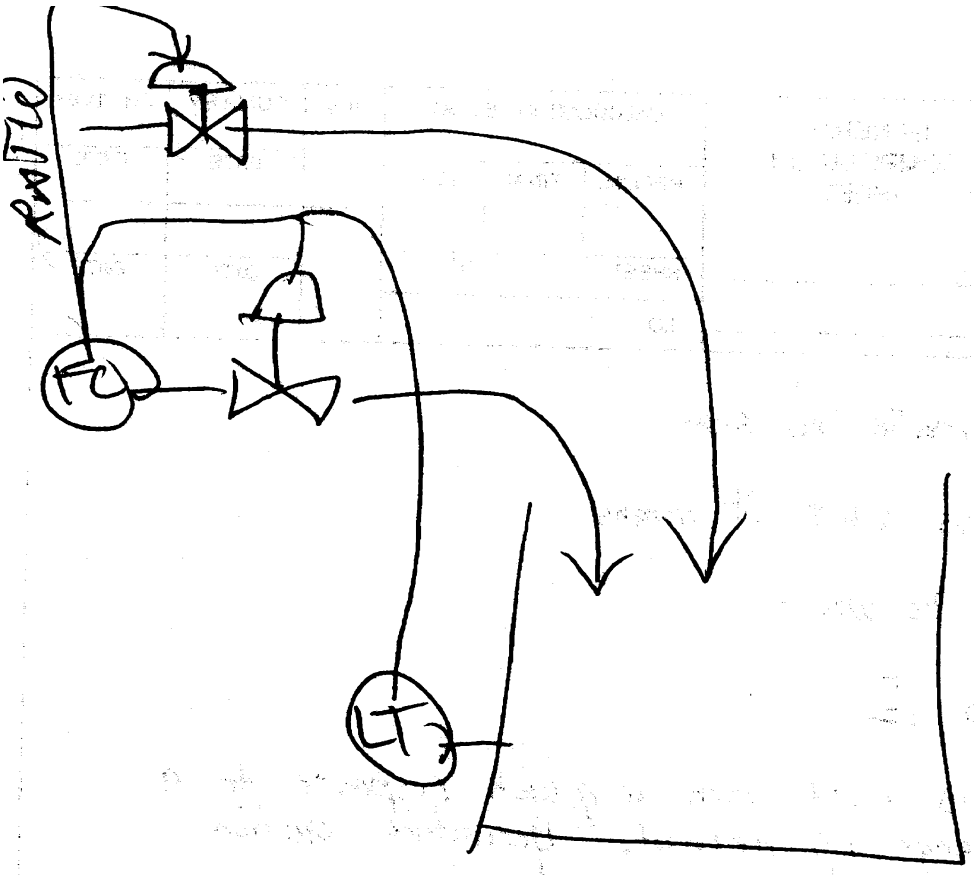


$^{\circ}K = {}^{\circ}C + 273$

English



$^{\circ}R = {}^{\circ}F + 460$



Lambda takes into account interacting loops

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J.O.					

PROJECT

SUBJECT

7) What is the requirer Chiller Capacity to cool the Clean water stream

$$\text{Chiller tons} = \frac{1628.96 \text{ lbs/min} \cdot (90-32)\,^{\circ}F}{200 \text{ lb/min TON}} \cdot \frac{12000 \text{ BTU/hr}}{60 \text{ min/hr}}$$

$$= 472.4 \text{ tons}$$

8) What should the pipe size be for the clean water Steam to keep the velocity to less than 6 ft/sec

$$\text{Velocity} = \frac{GPM}{2.448\, D^2}$$

$$6 = \frac{196.17}{2.448\, D^2}$$

$$D^2 = \frac{196.17}{(2.446)(6)}$$

$$D = \sqrt{13.356}$$

$D = 3.6$ inches — use 4 inch pipe

Form 5007 (Rev. 9/86)

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SHEET OF		DATE	DATE
J.O.			

PROJECT

SUBJECT

9) Calculate the C_v of the level Control Valve using a 20 psi Δp across the valve and a 3" V-ball valve. Assume - 1 size smaller than line

$$GPM = F_p C_v \sqrt{\frac{\Delta P}{S.G.}} \qquad C_v = \frac{GPM}{F_p \sqrt{\frac{\Delta P}{S.G}}}$$

$$F_p = \frac{1}{\sqrt{\frac{\Sigma K C_d^2}{890} + 1}}$$

$$C_d = \frac{C_v}{d^2}$$

$$\Sigma K = 1.5\left(1 - \left(\frac{d}{D}\right)^2\right)^2$$

Calculate C_v (using $F_p = 1$ ← swage factor; $F_p = 1$ if valve size = line size; As first guess to get C_d)

$$C_v = \frac{196.17}{1\left(\sqrt{\frac{20}{1.001}}\right)} = 43.89$$

Calculate Cd

$$C_d = \frac{43.89}{3^2} = 4.87$$

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PROJECT

SUBJECT

Calculate ΣK

$$\Sigma K = 1.5\left(1 - \left(\frac{3}{4}\right)^2\right)^2$$

$$= 0.287$$

$$F_p = \frac{1}{\sqrt{\frac{(0.287)(4.87)^2}{890}} + 1}$$

$$F_p = .996$$

$$C_v = \frac{196.17}{(.996)\left(\sqrt{\frac{20}{1,001}}\right)} = 44.06$$

VALVES AND FINAL CONTROL ELEMENTS

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SAFETY RELIEF VALVES

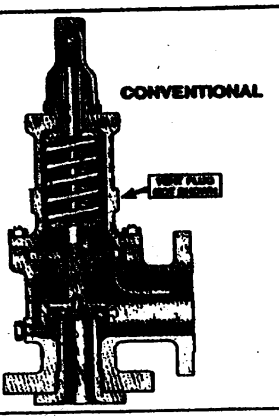
FOR CSEX REVIEW COURSE

AUBURN/ ISA, BIRMINGHAM SECTION

BY ED ANDREWS, ENGINEER

PROCESS SPECIALTIES INC.

CSEX 1



2

DEFINITIONS

RELIEF VALVE: Relieves upstream pressure in proportion to that pressure. Liquid usually.

SAFETY VALVE: Relieves upstream pressure with rapid full opening, or POP action.

SAFETY RELIEF VALVE: Either of above, but to protect personnel and equipment by preventing excessive pressure buildup.

Our example is last one above.

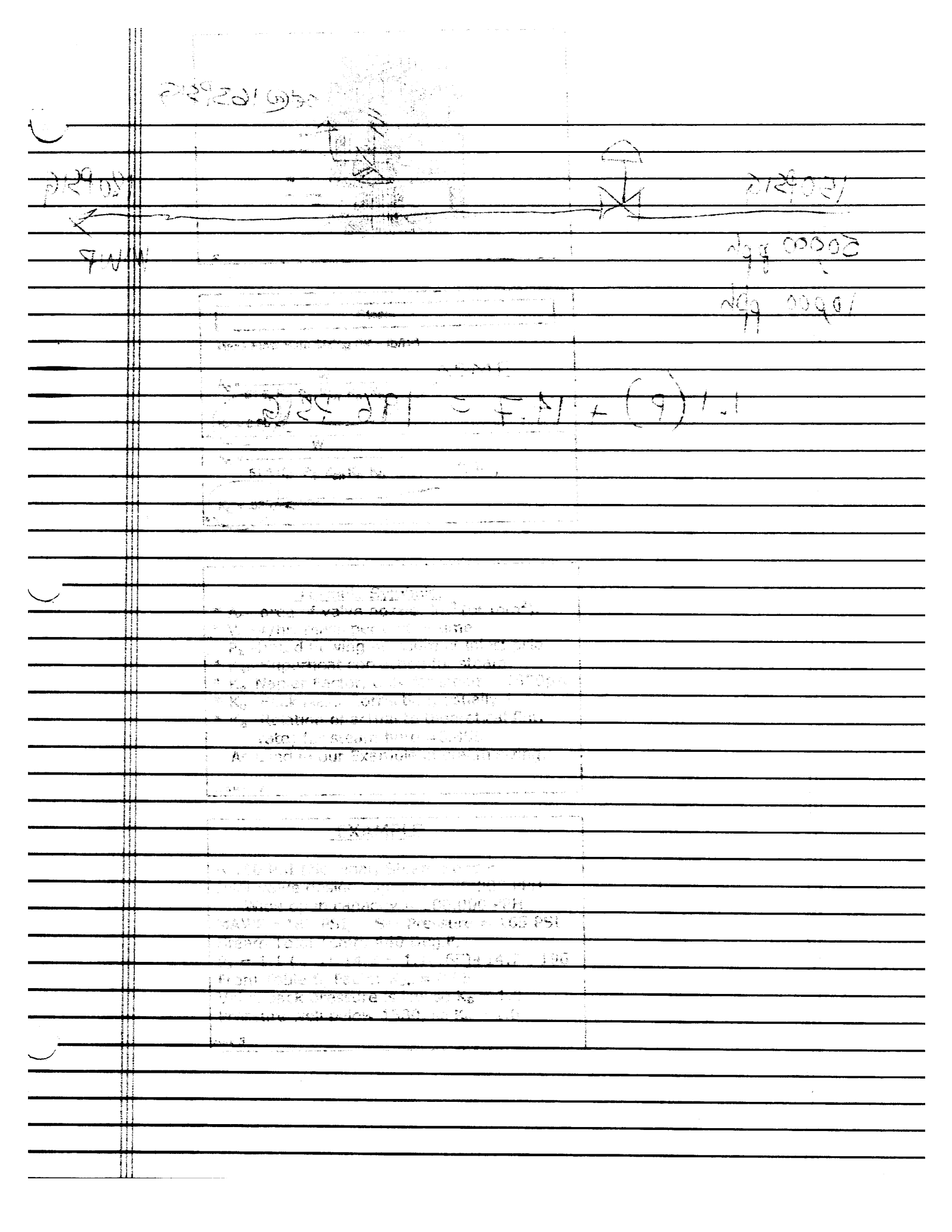
3

DEFINITIONS 2

* Operating Pressure: normal vessel pressure
* Max Allowable Working Pressure: Max permissible pressure at design pressure
* Set Pressure: Inlet pressure to which the valve is set
* Rated Capacity: Flow at given % over pressure pemitted by the code
*Operating VS Set Pressure Diff.: Best if 10% or 25psi Minimum
* Cold Differential Test Pressure (CSD): The cold test stand set below operating Temp.

CSEX 4

} Or you get chatter, seat w & leakage



CALCULATION

Set pressure

$A_C = W / 51.5 (.855) \times P_1 \times K_{SH} \times 1 \times 1$
$= 100000 / 51.1 (.855) \times 196 \times 0.98$
$= 100000 / 8458 = 11.82$ sq. in.

From capacity table: Steam, ASME (Consolidated 4-3)
Orifice Q has area of 12.85 sq. in. (next higher).
To check capacity for 160psi set pressure (nearest) we see a capacity of 104,901 which proves it is big enough.
This is an 6"x 8" valve (in/out) (Consolidated pg.2-2)
It could be an ANSI 150 OR 300 Rating

9

ASME Orifice Area

D – smallest

↓ ↓

T – Largest

17 sizes

MULTIPLE VALVE USE

* When capacity of largest valve is too small, 2 or 3 should be used.
* Price or availability show 2 or 3 would be less cost.
* Use short inlet manifold, vents can be separate or " y " joined.
* In p_1 calc use 1.16 for second valve
1.21 for third valve.

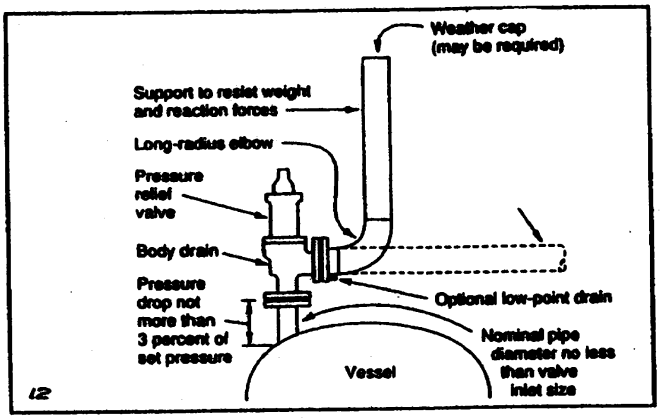
This lets them open in sequence, not all at once. 1st valve can be smaller, never larger.

10

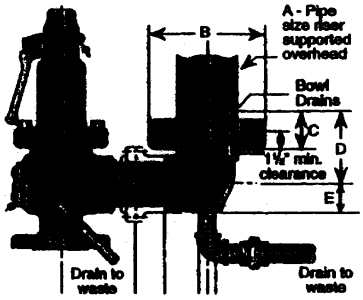
INSTALLATION GUIDE

* MOUNT CLOSE TO VESSEL, VERTICALLY.
* USE SAME SIZE INLET PIPE AS VALVE INLET.
* USE SAME SIZE OUTLET PIPE, OR LARGER, AS VALVE OUTLET.
* NO ISOLATION VALVES ON INLET OR OUTLET.
* ALLOW FOR LARGE REACTION FORCES AND THERMAL STRESSES IN OUTLET PIPING.
* OPTIONAL DRIP ELBOW IS GOOD PRACTICE.
* CHECK NOISE LEVEL OF VENT STACK EXIT.
* VENT PIPE MUST HAVE RAIN HOOD & DRAIN.

11



12



13

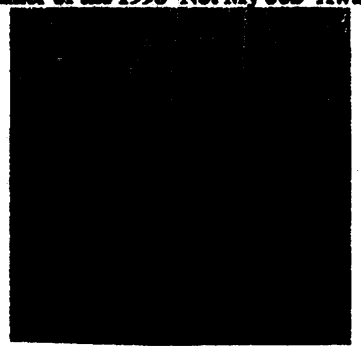
SOURCES OF SIZING, TABLES AND ASME CODE SECTION VIII

1. Consolidated Div. Dresser, Alexandria,LA
   FAX 318-640-6222
2. Conbraco Industries, Mathews, NC
   Fax 704-841-6000
3. Kunkle, Black Mtn. NC FAX 704-669-0586
4. North American S. V. Industries, N.K.C.MO
   FAX 816-421-0297

Or call your friendly Safety Valve Representative

14

Winner of the 1998 'Not My Job' Award



15

CONTROL SYSTEMS ENGINEERING EXAM REVIEW

FINAL CONTROL ELEMENTS

1

ED ANDREWS

CONTROL VALVE SIZING AND SELECTION

1. REVIEW DATA GIVEN
2. SELECT SIZING EQUATION TO USE
3. CONVERT DATA SO UNITS FIT EQUATION
   ?PER HR. OR PER MIN.
   ACFH TO SCFH (REM. PV=nRT)
4. CALCULATE C_V
5. CHOOSE VALVE STYLE AND SIZE
   - A. CAPACITY
   - B. UNIQUE REQUIREMENTS

H. COMMON SENSE

   - C. FLOW CHARACTERISTICS
   - D. BODY AND TRIM MATERIAL
   - E. BODY RATING & END CONNECTIONS
   - F. TRIM RATING FOR dP & LEAKAGE
   - G. COST

2

FROM BERNOULLI'S EQUATION FLUID FLOW

$$Q = C_D * \sqrt{P_1 - P_2}$$

FOR CONTROL VALVES

$$Q = C_V * \sqrt{dP/G} \quad \& \quad C_V = Q * \sqrt{G/dP}..$$

C_V IS VALVE COEFFICIENT, DEFINED AS:

CAPACITY OF 1 GPM OF 1 SPEC GRAV. WATER AT 1 PSI DIFFERENTIAL

3

Cv experimentally determined by vendor

RULES OF THUMB

1. MAKE CONTROL VALVE ONE SIZE SMALLER THAN LINE SIZE } 95% of time works OK

2. IF IN DOUBT ABOUT TRIM:
   FOR LIQUID FLOW CHOOSE EQUAL PERCENTAGE.

   FOR GAS OR STEAM FLOW CHOOSE LINEAR

4

LIQUID FLOW EQUATIONS

NON-COMPRESSIBLE FLOW SIZING

The basic formulas expressed in English units are:

$$C_v = \frac{Q\sqrt{G}}{\sqrt{\Delta p}}$$

$$C_v = \frac{W}{500\sqrt{G\Delta p}}$$

Where
- Q = Flow in U.S. gallons per minute
- G = Specific gravity
- Δp = Pressure drop in pounds per square inch
- W = Flow in pounds per hour

500 GPM / lb/hr

5

PROCEDURE

1. PUT DATA IN FORMULA UNITS
   ie, SCFM NOT ACFM (Standard / Actual)
2. CALCULATE C_V FROM DATA
3. REVIEW LIMITATIONS
   - A. CAVITATION/FLASHING
   - B. VISCOSITY CORRECTION
   - C. SLURRY; PULP STOCK OR?
4. RECALCULATE PER LIMITATIONS

6

Factors Affecting Cavitation

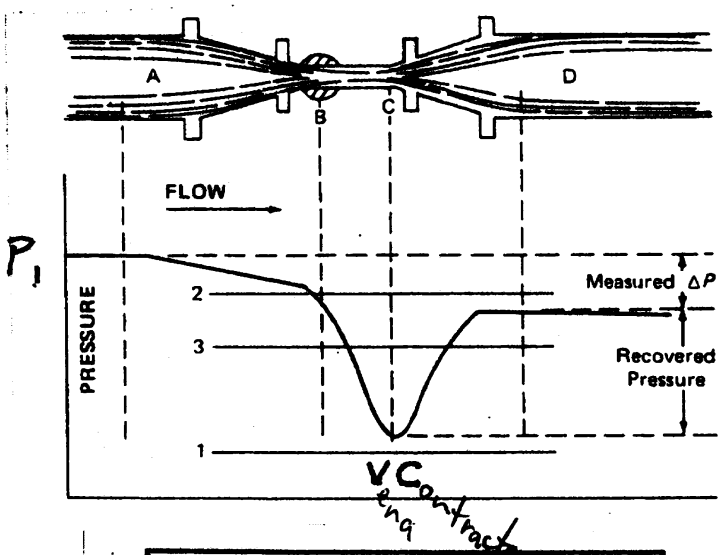
- **Inlet pressure**
- **Vapor pressure**
- **Pressure drop**

(FROM FLOW DATA)

- **Pressure recovery factors K_C & F_L^2**

FROM VALVE DATA TABLES

7



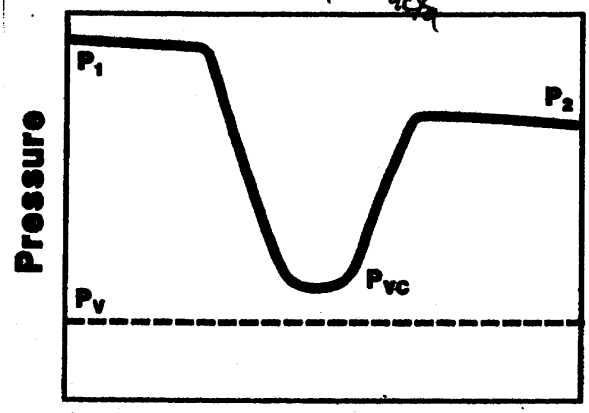
FLOW THRU VALVE

VENA CONTRACTA (SMALLEST VEIN)

HIGHEST VELOCITY

LOWEST PRESSURE

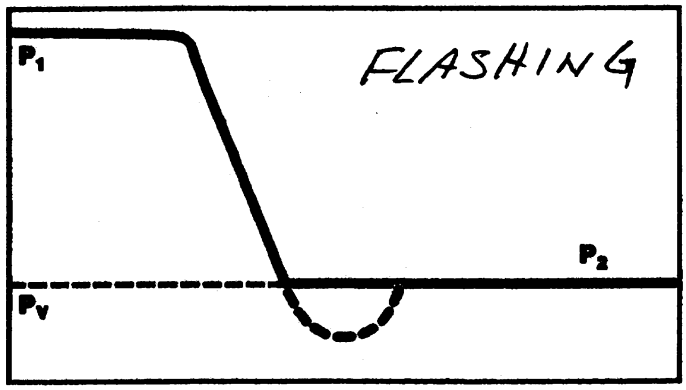
8



NO PROBLEM!

Vapor Pressure

9



A PROBLEM,

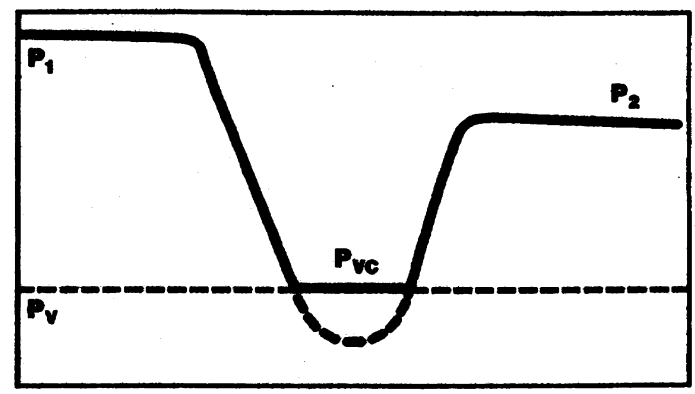
2 PHASE FLOW

DOWN STREAM Choke Flow

& POSSIBLE EROSION DAMAGE

HIGH VELOCITY.

10



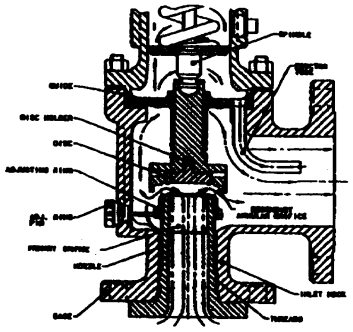
CAVITATION PROBLEM

NOISE

DAMAGE

VIBRATION

11



5

Steam

Mass Flow Rate Sizing (W = lb/Hr)

$$A_c = \frac{W}{51.5\ K_d\ P_1\ K_{sh}\ K_n\ K_b}$$

ASME

$K_d = 0.85$

$$A_c = \frac{W}{51.5\ K_d\ P_1\ K_{sh}\ K_n\ K_b}$$

API

$K_d = .625$

6

Formula Symbols:

* A_c—area of valve nozzle; in.^{2} (or mm^2).
* W -#/hr. mass per unit of time.
* P_1 -Rated flowing pressure at inlet; psia
* K_{SH} Superheat correction for steam.
* K_n- Napier Factor, only for steam >1580psi.
* K_b- Back Pressure Correction; usually 1
* K_d- Relation of actual to theoretical flow rate; for steam here =0.855

As used in our Example of steam sizing.

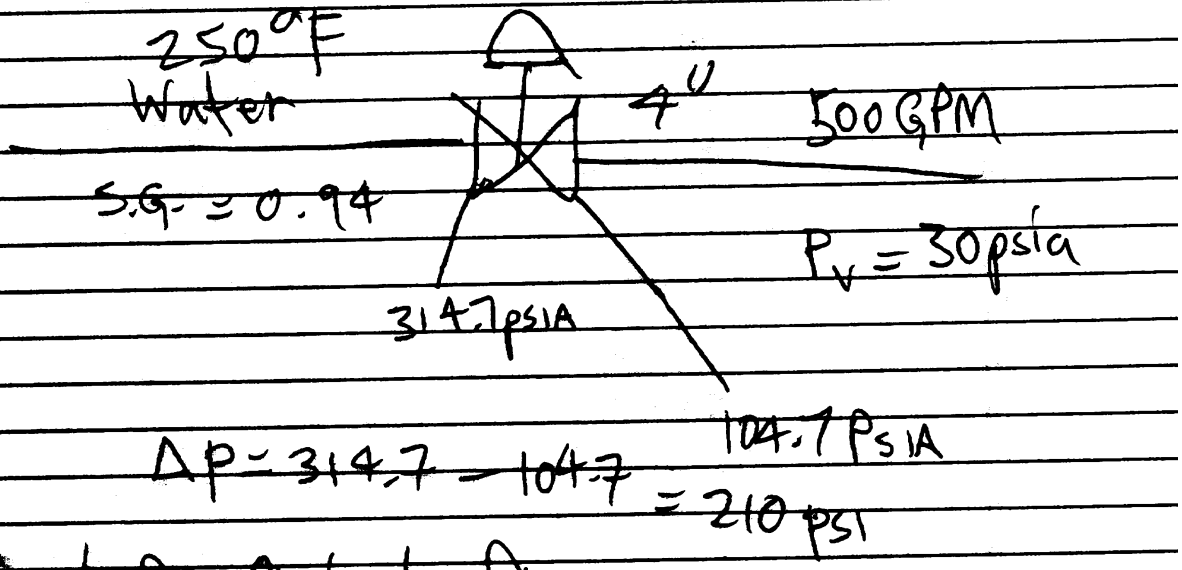
CSEX 7

EXAMPLE

A 150 PSI (Nominal) Steam Header
Inlet valve design capacity = 50,000 PPH
Wide open capacity = 100,000 PPH
MAWP =180 PSI, Set Pressure = 165 PSI
Steam Total Temp. 440 Deg.F,
P_1 = 1.1 (P)+ 14.7 = 1.1(165)+14.7= 196
From Table 6, Factor K_{SH} = 0.98
Valve back pressure is low so K_B = 1.0
Pressure well below 1580, so K_n = 1.0

csex 8

$P_c = 3206.2$



$\Delta P = 314.7 - 104.7 = 210$ psi

Check for Choked flow

$\Delta P_{allowable} = F_L^2 (P_1 - F_F P_v)$ $\quad F_L = 0.9$

$F_F = 0.96 - 0.28\sqrt{\frac{30}{3206.2}} = 0.93$

$\Delta P_a = (0.9)^2 \left(314.7 - (0.93)(30)\right) = 232.3$ psi

Since $\Delta P < \Delta P_{allowable}$, we're not into choked flow

$210 < 232$

$C_v = 500\sqrt{\frac{0.94}{210}} = 33.4$

$K = F_1^2$

$\Delta P_{critical} = (F_L)^2 (P_1 - P_v) = 187$ psi

CAVITATION STA
At $\Delta P_{critica}$

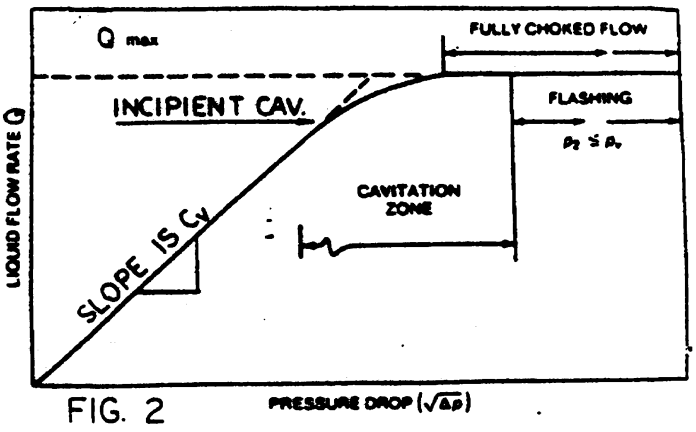


FIG. 2

MAX. FLOW OCCURS AT

$\Delta P_T = F_L^2 (P_1 - F_F P_V)$

INCIPIENT CAVITATION OCCURS AT OR ABOUT

$\Delta P_C = K_C (P_1 - P_V)$

BUT K_C data scarce

12

Cavitation can generate destructive forces that cause problems, some of them severe:

Noise, like gravel in the pipe
Vibration in pipe
Destruction of the valve trim
Destruction of the downstream pipe
All of the above

13

TO AVOID CAVITATION

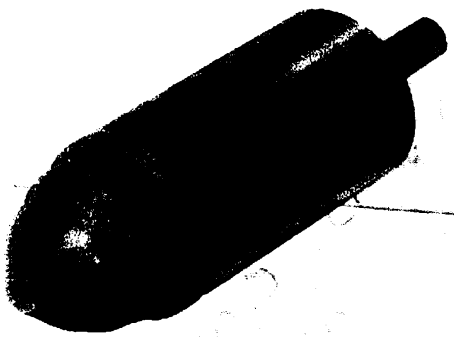
1. IMPROVE SERVICE CONDITIONS
2. SELECT LARGER VALVE, IF ROTARY (Ball Valve)
3. GO TO GLOBE STYLE , IF OK
4. GO TO SPECIAL TRIM;
   A. ANTI-CAVITATION
   B. HARDER TRIM

14

Materials Choice Cavitation Resistance

440C stainless steel
Stellite over 316 SS
17-4 PH SS
316 SS
Cast Iron
Chrome moly, C5
Modular Iron
Carbon steel
Brass (B-16)

15



W2642

Figure 8. Typical Flashing Damage

FLASHING WATER
HIGH VELOCITY
"WASH", SMOOTH
DROPLETS OF
LIQUID IN HIGH
VELOCITY VAPOR

16



W1360

Figure 5. Typical Cavitation Damage

CAVITATING WATER
ROUGH AS A CINDER
IMPLOSION PITS

SOUNDS LIKE GRAVEL
IN FLOW STREAM

17 VERY HIGH ENERGY
RELEASE AT A POINT

Predicting and Avoiding Cavitation

Predicting cavitation can be accomplished by solving the following equation:

$$\Delta P_T = F_L^2 (P_1 - F_F P_v)$$

Where:
F_L = Liquid pressure recovery factor (From Table)
P_1 = Inlet pressure psia
P_v = Vapor pressure at inlet temperature in psia
ΔP_T = Maximum pressure drop at which increased flow results at given P_1
F_F = Liquid critical pressure ratio factor

Terminal Pressure Drop

It can be assumed, for most practical applications, that the value of F_F for water is 0.96. Table 34 is included to give some values for critical pressure for some of the more common liquids.

F_L A FUNCTION OF
VALVE STYLE AND
PER CENT OPEN

P_1, P_V AS SERVICE
CONDITIONS - DATA

18

$$F_F = 0.96 - .28\sqrt{\frac{P_V}{P_C}}$$

A CURVE IS ALSO
OFFERED, FIG 9 IN
NJ; T-150-1 & OTHER.

P_C, CRITICAL PRESSURE
OF FLUID; 3206 FOR
WATER

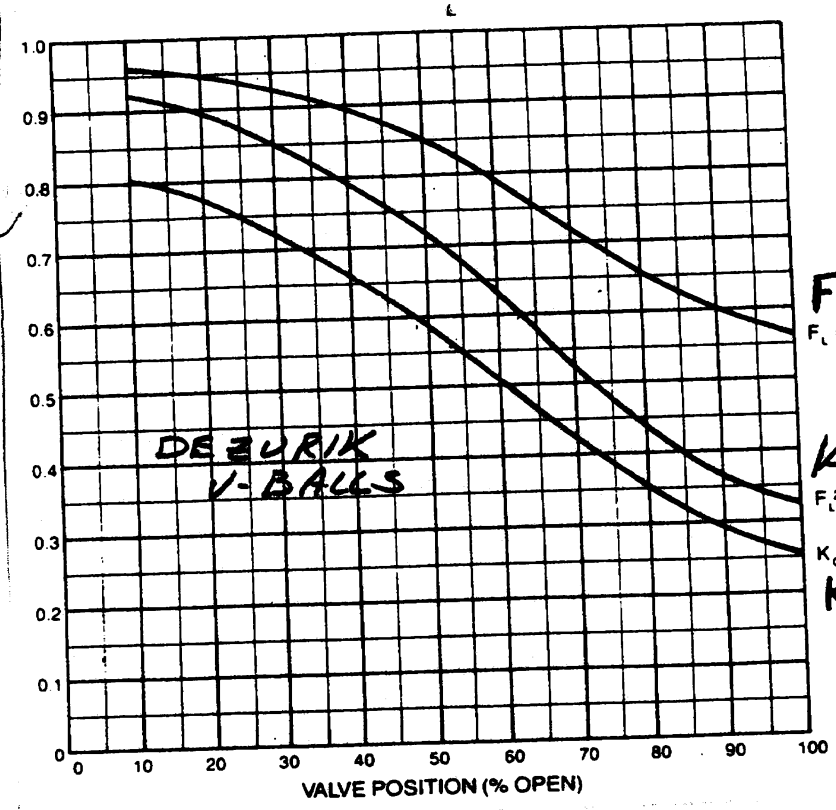
THE LEAST EFFECT
OF ANY VARIABLE

SOURCE: 5 & 8, FISHER

Ideal Throttling Range

10 — 90% Open GLOBE

20 — 65% Open B'FLY



GLOBE VALVES
F_L : .90 - .98
(LOW RECOVERY)

F_L
F_L = PRESSURE RECOVERY FACTOR

$K_m = F_L^2$
F_L^2 = CRITICAL FLOW FACTOR

K_c = CAVITATION INDEX
K_c

BUTTERFLY VALVES
F_L ; .35 - .45

19

CALCULATE & SELECT

1. SELECT A TYPE OF VALVE & IT'S F_L
2. CALCULATE C_V, NOTE F_L FOR THIS C_V
3. RECALCULATE C_V
4. REPEAT. IF NOT OK GO TO OTHER VALVE STYLE
5. DO NOT USE DATA dP, USE dP_T

20

VISCOSITY CORRECTION

2nd LIMITATION)

Calculate the C_V as shown before without taking viscosity into account. Now calculate the C_V again using the formula below.

$$C_v = \frac{1}{F_s}\left(\frac{Q_\mu}{47\Delta p}\right)^{2/3}$$

Where
μ = Viscosity in centipoise
Q = Flow rate in gpm
Δp = Pressure drop in psi
F_s = 1.25 for ball valves
1.03 for butterfly valves
1.05 for globe valves
(valve style correction factor)
Centipoise = Centistokes X specific gravity
100 centipoise = 1 poise

C_V LAMINAR FLOW

CALC. C_V TURBULENT

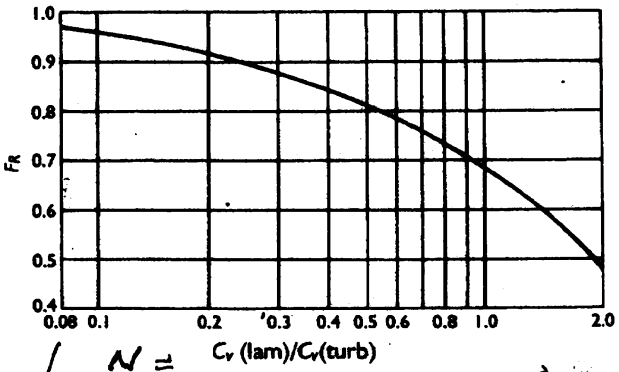
CALC C_V LAMINAR

DIVIDE $\frac{C_V \text{ LAM.}}{C_V \text{ TUR.}} = \text{"N"}$

21

SEVERAL DIFFERENT EQUATIONS

F_R—REYNOLDS NUMBER CORRECTION FACTOR



SEE BULL. T-150-1 BY N-J. FOR COMPLETE WORK OR: OTHER VENDOR DATA OR: A GOOD SIZING PROGRAM!

22

ABOVE 2.0 USE C_v (LAM)

THIS IS TRANSITIONAL FLOW

BELOW 0.08 USE C_v (turb)

SLURRIES & NON NEWTONIAN FLUIDS

EXAMPLES: PULP STOCK
WASTE TREATMENT SLUDGE
ASPHALTS, GLUES, MOLASSES, PAINTS
CLAY SLURRIES

GET RECOMMENDATIONS FROM CONTROL VALVE MANUFACTURER'S REPS

23

FOR ABRASIVE SLURRIES VERY HARD BODY AND TRIM MATERIALS MAY BE NEEDED OR SOFT MATERIAL; POLYURETHANE LINER IN A PINCH OR "BOOT" VALV

STEAM & COMPRESSIBLE FLUIDS SIZING

Any vapor:

$$C_v = \frac{W}{63.3Y}\sqrt{\frac{V_1}{XP_1}}$$

V_1 = Specific volume cu. ft. per lb; see steam tables
W = Flow rate, lb./hr.
X = Actual pressure drop ratio, $\Delta p/P_1$
X_T = Rated pressure drop ratio of valve $\Delta p/P_1$ (see section on choked flow and Fig. 10)
Y = Expansion factor, dimensionless = $1 - (X/3F_KX_T)$

STEAM, ANY PRESSUR

V_1; SPECIFIC VOLUME FROM STEAM TABLES

Y; EXPANSION FACTOR IS A COMPLICATION

24

NAT GAS.

$P_1 = 1314.7$ PSIA

$P_2 = 99.7$ PSIA

Flow = 2,000,000 SCFH

$P_c = 672.92$

$T_c = -115.8$ °F

Molecular Weight = MW = 16.042

$K = 1.32$

(Volume Basis) $C_v = \frac{Q}{1360 P_1 Y \sqrt{\frac{GT}{X}}}$

$Q = 7320 C_v P_1 Y \sqrt{\frac{X}{MT_1 Z}}$

$C_v = \frac{Q}{7320 P_1 Y \sqrt{\frac{MTZ}{X}}}$

Volumetric flow / Molecular Wt.

Air @ 60°F

$Q = 900{,}000$ SCFH

$P_1 = 85$ PSIA

$\Delta P = 10$ PSI

$T_1 = 60 + 460 = 520$

$X_T = 0.31$

$F_L = 0.6$

$M = 28.97$

$X = \frac{\Delta P}{P_1} = \frac{10}{85} = 0.$

$Y = 1 - \frac{X}{3X_T} = 1 - \frac{.118}{3(0.$

$Y = 0.873$

$C_v = 592$

for split phase calculate percentage of flow in each phase, calculate a C_v & add them

Since $X < X_T \Rightarrow$ Not choke flow

$0.118 < 0.31$

COMPRESSIBLE FLOW SIZING, GAS

Volume Basis:

$$C_v = \frac{Q}{1360 P_1 Y}\sqrt{\frac{GT}{X}}$$

Weight Basis:

$$C_v = \frac{W}{19.3 P_1 Y}\sqrt{\frac{T}{XM}}$$

X_T = Rated pressure drop ratio of valve $\Delta p/P_1$ (see section on choked flow and Fig. 10)

Y = Expansion factor, dimensionless $= 1 - (X/3F_K X_T)$ (see section on choked flow)

F_K = Ratio of specific heats factor = $K/1.40$ (see Table I)

G = Specific gravity at standard conditions (Air = 1; see Table 38 for other gases)

M = Molecular weight (Air = 29; see Table 38 for other gases)

P_1 = Upstream pressure in psia

Δp = Pressure drop ($P_1 - P_2$)

Q = Flow rate, scfh

T = Absolute temperature °R = (°F + 460)

V_1 = Specific volume cu. ft. per lb; see steam tables

W = Flow rate, lb./hr.

X = Actual pressure drop ratio, $\Delta p/P_1$

25

CONSTRAINTS--STEAM AND GAS

CRICITAL DROP: $dP = F_K * X_T$

1st ESTIMATE: $dP = 0.5 * P_1$ = Inlet Pressure

CRITICAL DROP GENERATES SONIC VELOCITY IN V.C.
THIS IS KNOWN AS CHOKED FLOW

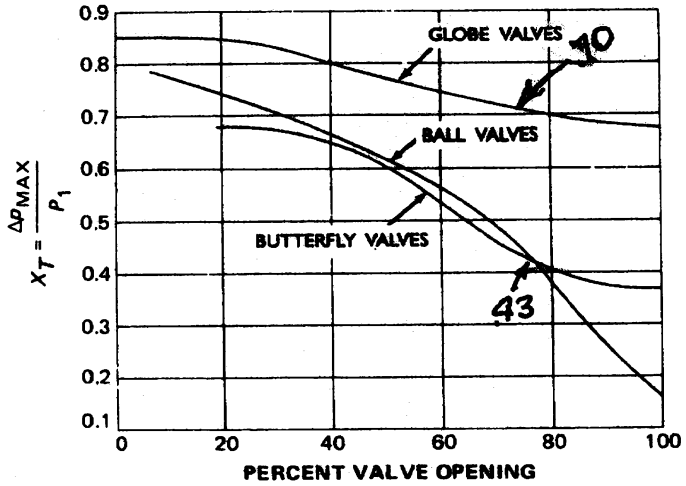
HIGHER dP CAUSES NO HIGHER FLOW
BUT HIGHER NOISE LEVEL

CALCULATE LIMITING dP/P_1 OR X_T (TERMINAL dP/P_1)
SEE X_T CURVES IN FIG. 10

26

$$Y = 1 - \frac{X}{3F_K X_T}$$

PRESSURE DROP RATIO FACTOR X_T AS A FUNCTION OF VALVE OPENING FOR NELES-JAMESBURY CONTROL VALVES LINE SIZE = VALVE SIZE



27

CALCULATE EXPANSION FACTOR: $Y=1-X/3F_KX_T$

AT CHOKED FLOW: $X= F_KX_T$; SO Y= 1-1/3 =.667

AT NON-CRITICAL FLOW CALCULATE Y FROM DATA
AND F_K FROM TABLE 1: FOR AIR IT'S 1.0
X_T FROM VENDOR SIZING TABLES, FIG. 10,
OR 0.43 FOR ROTARY
0.70 FOR GLOBE VALVES

28

SPECIFIC HEATS CORRECTION

When dealing with gases other than air at pressure drop ratios close to X_T, a correction factor (Table 1) must be applied to X_T to compensate for the difference in ratio of specific heats between air and the given gas.

$$K = \frac{\text{Specific heat at constant pressure}}{\text{Specific heat at constant volume}}$$

$$F_K = \frac{K}{1.40}$$

29

TABLE 1 – K FOR TYPICAL GASES

GAS	K	GAS	K
Acetylene	1.26	Helium	1.67
Air	1.40	Hydrogen	1.41
Ammonia	1.29	Methane	1.31
Argon	1.67	Nitrogen	1.40
Carbon Dioxide	1.30	Nitrous Oxide	1.30
Chlorine (Dry)	1.34	Oxygen	1.40
Ethane	1.19	Sulphur Dioxide	1.26
Ethylene	1.25	Steam	1.31

30

CALCULATE C_V WITH GIVEN DATA & Y FROM ABOVE

SELECT A VALVE AT 60 OR 70% OPEN THEN
USE ITS X_T TO RECALCULATE A NEW C_V

IF FLOW OR AND/OR dP IS HIGH CALCULATE NOISE
LEVEL WITH VENDOR PC PROGRAM.

IF ABOVE 85dBA GO TO SPECIAL TRIM, USUALLY IN
A GLOBE STYLE BODY.

RECALCULATE C_V AND NOISE LEVEL

31

EFFECT OF PIPE REDUCEERS F_p OR " SWAGE FACTOR "

ALL MANUALS FROM VENDOR ASSUME LINE SIZE = VALVE SI

$F_p \leq 1.0$

PRESSURE LOSS IN PIPE REDUCERS IS ACCOUNTED FOR BY CALCULATING F_p USING EQUATIONS BELOW OR FROM VENDOR TABLES, THEN:

REQUIRED C_V = CALC. C_V / F_p

APPLY ONLY TO ROTARY VALVES

32

$$F_p = \left[\frac{\sum K (C_d)^2}{890} + 1 \right]^{-1/2}$$

$$C_d = \frac{C_v}{d^2}$$

$$\sum K = 1.5 \left[1 - \left(\frac{d}{D} \right)^2 \right]^2$$

33

F_p

PIPE REDUCER FACTORS

STANDARD PORT VALVES.

DEBURIK V-BALL

VALVE SIZE INCHES	MM	C_v	PIPE SIZE INCHES	MM	F_p	PIPE SIZE INCHES	MM	F_p	PIPE SIZE INCHES	MM	F_p
1	25	—	1.25	32	—	1.5	40	—	2	50	—
1.5	40	25	2	50	.980	2.5	60	.959	3	80	.946
2	50	90	2.5	60	.948	3	80	.889	4	100	.822
2.5	65	145	3	80	.960	4	100	.864	5	125	.813
3	80	245	4	100	.898	5	125	.813	6	150	.766
4	100	380	5	125	.948	6	150	.889	8	200	.822
5	125	550	6	150	.963	8	200	.876	10	250	.827
6	150	1070	8	200	.882	10	250	.788	12	300	.737
8	200	1500	10	250	.944	12	300	.881	14	350	.839
—	—	—	—	—	—	—	—	—	16	400	.810

34

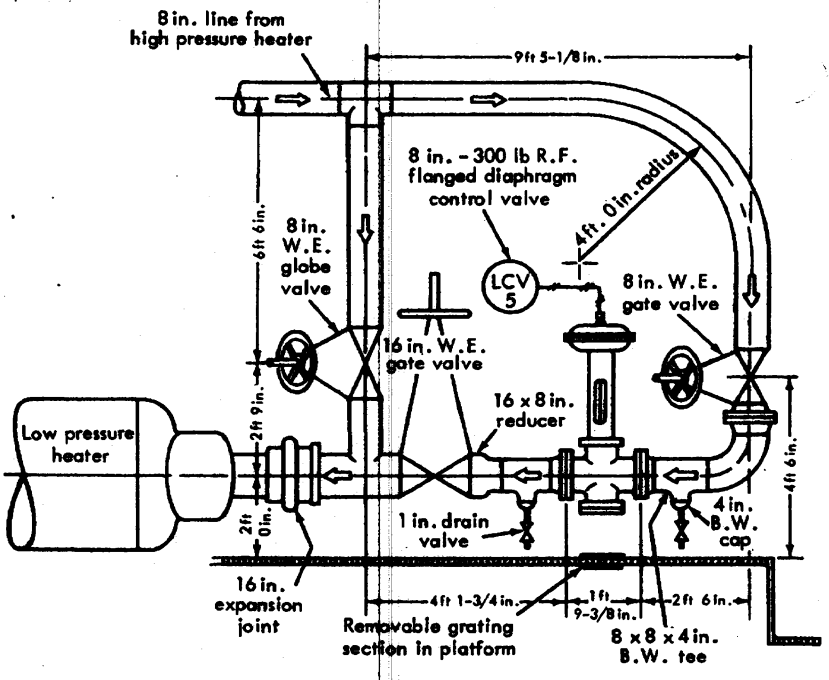


Figure 32. MANIFOLDING OF CONTROL VALVE FOR LOOPED ENTRY TO HEATER FROM OVERHEAD SUPPLY LINE.

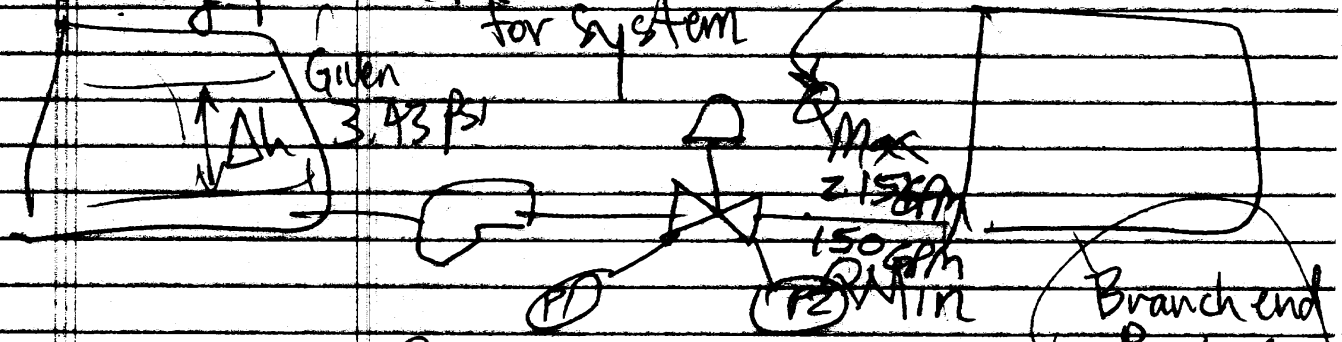
35

Direct ΔP

① Δh, suction head 8.47 PSI

② friction losses

③ backing up on curve Assume 16.43 ft. friction loss @ for system



$P_1 = 29.29$ $P_2 = 23.83$

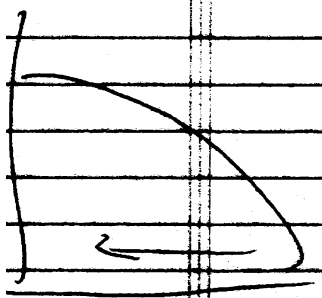
$\Delta P = P_1 - P_2 = 5.46$ @ 215 GPM

$S.G. = 1.22$

$$C_V = Q\sqrt{\frac{G}{\Delta P}} = 215\sqrt{\frac{1.22}{5.46}}$$

$C_V = 101.63$ @ Q_{max}

$$h_{f\,norm} = \left(\frac{150}{210}\right)^2 (8.67) = 4.22 \text{ psi}$$



See work

$h_f = 8.67 - 4.22 = 4.45$ PSIG

new level + backing up on pump curve + friction losses

@ 150 GPM $P_1 = 29.29 + 3.43 + 4.22 + 4.45$

$P_1 = 41.39$

$P_2 = 23.83$

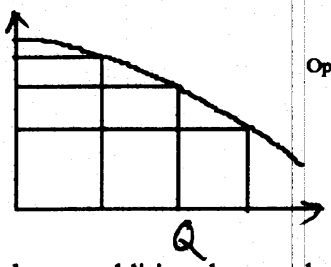
$\Delta P_{min} = 17.56$

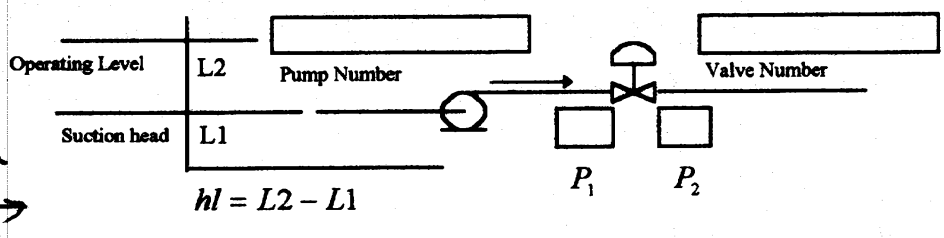
$C_{V\,min} = 150\sqrt{\frac{1.22}{17.56}} = 39.54$

PROJECT_____ DESCRIPTION_____

VALVE TAG_____ CALC. BY_____ CHK'D_____

CONTROL VALVE SIZING WORKSHEET					
Process Condition	**Flow Rate GPM**	**Friction Loss FT (PSIG)**	**Inlet Pressure FT (PSIG)** P_1	**Outlet Pressure FT (PSIG)**	**Valve Differential PSI**
MAXIMUM FLOW (1)		h_f max			
MAXIMUM FLOW (2)			$P_1 + hl + ha$	P_2	$P_1 - P_2$
NORMAL FLOW		$h_f norm$	$P_1 + hl + hp_n + h_f + ha$	p_2	$P_1 - P_2$
MINIMUM FLOW		h_f min	$P_1 + hl + hp_m + h_f + ha$	P_2	$P_1 - P_2$





hp_n = additional pump head @ normal flow conditions (head @ norm. flow-head @ max. flow)

hp_n =

hp_m = additional pump head @ minimum flow conditions (head @ min. flow-head @ max. flow)

hp_m =

h_f = additional valve differential required due to the reduction in piping friction losses.

$$h_f norm = \left(\frac{GPM_{norm.}}{GPM_{max.}}\right)^2 \left(h_f \text{ max}\right) = \qquad \therefore h_f = h_f \text{ max} - h_f norm =$$

$$h_f \text{ min} = \left(\frac{GPM_{min.}}{GPM_{max.}}\right)^2 \left(h_f \text{ max}\right) = \qquad \therefore h_f = h_f \text{ max} - h_f \text{ min} =$$

ha = additional head added to the pump for wear, tolerance, velocity and elevation.

ha = (Pump Head for Selection - Pump Head)

EXAMPLE : STEAM APPLICATION

FLOW = 40,000 PPH: P_1 = 150 PSI, SATURATED
P_2 =50 PSI, PIPE SIZE IS 6 IN. ,V_1=2.752 (STEAM TABLE)

A. dP = 100>.5*P_1---- CRITICAL DROP, CHOKED FLOW
B. PRESELECT A LINEAR TRIM GLOBE VALVE ----X_T = 0.70
C. SEE TABLE 1; K = 1.31; F_K = .131/1.40 = 0.936
D. X *MUST* = $F_K * X_T$ = .936*.70 = .655

AND Y = 1 - $X/F_K * X_T$ = 1 - 1/3 = .667

E. $C_V = \frac{W}{63.3\,Y\sqrt{\frac{V_1}{X\,P_1}}} = \frac{40{,}000}{63.3*.667\sqrt{\frac{2.752}{.655*165}}} = 151$

F. FROM TABLE 14, SELECT A 4 IN. VALVE. AT 60%
C_V IS 147 & X_T IS .71 CLOSE ENOUGH!

37

INSTALLATION (see slides) (36)

ASME CODE Excerpts Section VIII - 1989 Edition with 1990 Addenda

PRESSURE RELIEF DEVICES

UG-125 GENERAL

(a) All pressure vessels within the Scope of this Division, irrespective of size or pressure, shall be provided[39] with protective devices in accordance with the requirements of UG-125 through UG-136. Unless otherwise defined in this Division, the definitions relating to pressure relief devices in Appendix I of ASME/ANSI PTC 25.3 Safety and Relief Valves shall apply.

(b) An unfired steam boiler, as defined in U-1 (g), shall be equipped with pressure relief devices required by Section I insofar as they are applicable to the service of the particular installation.

(c) All pressure vessels other than unfired steam boilers shall be protected by a pressure relieving device that shall prevent the pressure from rising more than 10% or 3 psi, whichever is greater, above the maximum allowable working pressure except as permitted in (1) and (2) below. (See UG 134 for pressure settings.)

(1) When multiple pressure relieving devices are provided and set in accordance with UG-134(a), they shall prevent the pressure from rising more than 16% or 4 psi, whichever is greater, above the maximum allowable working pressure.

(2) Where an additional hazard can be created by exposure of a pressure vessel to fire or other unexpected sources of external heat, supplemental pressure relieving devices shall be installed to protect against excessive pressure. Such supplemental pressure relieving devices shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pressure. The same pressure relieving devices may be used to satisfy the capacity requirements of (c) or (c) (1) above and this paragraph provided the pressure setting requirements of UG 134(a) are met.

(3) Pressure relief devices, intended primarily for protection against exposure of a pressure vessel to fire or other unexpected sources of external heat installed on vessels having no permanent supply connection and used for storage at ambient temperatures of nonrefrigerated liquefied compressed gases,[40] are excluded from the requirements of (c) (1) and (c)(2) above, provided:

(a) the relief devices are capable of preventing the pressure from rising more than 20% above the maximum allowable working pressure of the vessels;

(b) the set pressure of these devices shall not exceed the maximum allowable working pressure of the vessels;

(c) the vessels have sufficient ullage to avoid a liquid full condition;

(d) the maximum allowable working pressure of the vessels on which these devices are installed is greater than the vapor pressure of the stored liquefied compressed gas at the maximum anticipated temperature[41] that the gas will reach under atmospheric conditions; and

(e) pressure relief valves used to satisfy these provisions also comply with the requirements of UG-129(a)(5), UG-131(c)(2), and UG-134(d) (2).

(d) Pressure relieving devices shall be constructed, located, and installed so that they are readily accessible for inspection and repair and so that they cannot be readily rendered inoperative (see Appendix M), and should be selected on the basis of their intended service.

(e) Pressure relief valves or non-reclosing pressure relief devices[42] may be used as protective devices. Non-reclosing pressure relief devices may be used either alone or, if applicable, in combination with safety or safety relief valves on vessels.

NOTE: Use of nonreclosing devices of some types may be advisable on vessels containing substances that may render a safety or safety relief valve inoperative, where a loss of valuable material by leakage should be avoided, or where contamination of the atmosphere by leakage of noxious fluids must be avoided. The use of rupture disk devices may also be advisable when very rapid rates of pressure rise may be encountered.

(f) Vessels that are to operate completely filled with liquid shall be equipped with liquid relief valves, unless otherwise protected against overpressure.

(g) The protective devices required in (a) above need not be installed directly on a pressure vessel when the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the maximum allowable working pressure at the operating temperature except as permitted in (c) above (see UG-98).

NOTE: Pressure reducing valves and similar mechanical or electrical control instruments, except for pilot operated valves as permitted in UG- 126(b), are not considered as sufficiently positive in action to prevent excess pressures from being developed.

(h) Safety and safety relief valves for steam service shall meet the requirements of UG-131 (b).

UG-126 PRESSURE RELIEF VALVES[43]

(a) Safety, safety relief, and relief valves shall be of the direct spring loaded type.

(b) Pilot operated pressure relief valves may be used, provided that the pilot is self-actuated and the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot should fail.

(c) The spring in a safety valve or safety relief valve shall not be set for any pressure more that 5% above or below that for which the valve is marked, unless the setting is within the spring design range established by the

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[39] Safety devices need not be provided by the vessel manufacturer, but over pressure protection shall be provided prior to placing the vessel in service.

[40] For the purpose to these rules, gases are considered to be substances having a vapor pressure greater than 40 psia at 100°F

[41] Normally this temperature should not be less than 115°F.

[42] A *pressure relief valve* is a pressure relief device which is designed to reclose and prevent the further flow to fluid after normal conditions have been restored; *A nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.

[43] A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action A *relief valve* is a pressure relief valve actuated by inlet static pressure which opens in proportion to the increase in pressure over the opening pressure. A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure, depending on application. A *pilot operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.

valve manufacturer or is determined to be acceptable to the manufacturer. The initial adjustment shall be performed by the manufacturer, his authorized representative, or an assembler, and a valve data tag shall be provided that identifies the set pressure capacity and date. The valve shall be sealed with a seal identifying the manufacturer, his authorized representative, or the assembler performing the adjustment.

(d) The set pressure tolerances, plus or minus, of pressure relief valves shall not exceed 2 psi for pressures up to and including 70 psi and 3% for pressures above 70 psi.

UG-127 NON-RECLOSING PRESSURE RELIEF DEVICES

(a) *Rupture Disk Devices*[44]

(1) *General*

(a) Every rupture disk shall have a stamped burst pressure established by rules of (a)(1)(b) below within a manufacturing design range[45] at a specified disk temperature[46] and shall be marked with a lot number. The burst pressure tolerance at the specified disk temperature shall not exceed ± 2 psi for stamped burst pressure up to and including 40 psi and ± 5% for stamped burst pressure above 40 psi.

(b) The stamped bursting pressure within the manufacturing design range at the coincident disk temperature shall be derived by one of the following methods. All the tests of disks for a given lot shall be made in a holder of the same form and dimensions as that with which the disk is to be used.

(1) At least two sample rupture disks from each lot of rupture disks, made from the same materials and of the same size as those to be used, shall be burst to verify that the stamped bursting pressure falls within the manufacturing design range at the coincident disk temperature. At least one disk shall be burst at room temperature. The stamped rating at the specified disk temperature shall be the average of the bursts at coincident disk temperature.

(2) At least four sample rupture disks, but not less than 5%, from each lot of rupture disks, made from the same material and of the same size as those to be used, shall be burst at four different temperatures, distributed over the applicable temperature range for which the disks will be used. These data shall be used to establish a curve of bursting pressure versus temperature for the lot of disks. The stamped rating at the coincident disk temperature shall be interpolated from this curve.

(3) For prebulged, solid metal disks or graphite disks only, a curve of percentage ratio at temperatures other than ambient may be established as in (2) above, using one size of disk for each lot of material. At least four bursts at four different temperatures shall be used to establish the above curve over the applicable temperature range. At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at ambient temperature to establish the room temperature rating of the lot of disks.

The percent change of bursting pressure taken from the above curve shall be used to establish the stamped rating at the coincident disk temperature for the lot of disks.

(2) *Capacity Rating*

(a) The calculated capacity rating of a rupture disk device shall not exceed a value based on the applicable theoretical formula (see UG-131) for the various media multiplied by K=coefficient=0.62. The area A (square inches) in the theoretical formula shall be the minimum net area existing after disk burst. [47]

(b) In lieu of the method of capacity rating in (a) above, a Manufacturer may have the capacity of a given rupture disk device design determined for the K_D coefficient in general accordance with the procedures of UG-131, as applicable.

(3) *APPLICATION OF RUPTURE DISKS*

(a) A rupture disk device may be used as the sole pressure relieving device on a vessel.

NOTE: When rupture disk devices are used, it is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure to the rupture disk due to fatigue or creep.
Application of rupture disk devices to liquid service should be carefully evaluated to assure that the design of the rupture disk device and the dynamic energy of the system on which it is installed will result in sufficient opening of the rupture disk.

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[44] A *rupture disk* device is a non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk. A *rupture disk* is the pressure containing and pressure sensitive element of a rupture disk device. A *rupture disk holder* is the structure which encloses and clamps the rupture disk in position. Rupture disks may be designed in several configurations, such as plain flat, prebulged or reverse buckling, and may be made of either ductile or brittle material; rupture disk material is not required to conform to an ASME specification. The material of the rupture disk holder shall be listed in Section II and this Division.

[45] The *manufacturing design range* is a range of pressure within which the average burst pressure of test disks must fall to be acceptable for a particular requirement as agreed upon between the rupture disk Manufacturer and the user or his agent. The disk shall be marked at the average burst pressure of all test disks.

[46] The specified disk temperature supplied to the rupture disk Manufacturer shall be the expected temperature of the disk when an emergency condition exists and the disk is expected to rupture.

[47] The *minimum net flow area* is the calculated net area after a complete burst of the disk with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

(b) A rupture disk device may be installed between a pressure relief valve[48] and the vessel provided:

(1) the combination of the spring loaded safety or safety relief valve and the rupture disk device is ample in capacity to meet the requirements of UG-133 (a) and (b);

(2) the stamped capacity of a spring loaded safety or safety relief valve (nozzle type) when installed with a rupture disk device between the inlet of the valve and the vessel shall be multiplied by a factor of 0.90 of the rated relieving capacity of the valve alone, or alternatively, the capacity of such a combination shall be established in accordance with (3) below;

(3) the capacity of the combination of the rupture disk device and the spring loaded safety or safety relief valve may be established in accordance with the appropriate paragraphs of UG-132, Certification of Capacity of Safety and Safety Relief Valves in Combination with Non-reclosing Pressure Relief Devices;

(4) the space between a rupture disk device and a safety or safety relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detection of disk rupture or leakage. [49]

(5) the opening [47] provided through the rupture disk, after burst, is sufficient to permit a flow equal to the capacity of the valve [(2) and (3) above], and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with UG-132.

(C) A rupture disk device may be installed on the outlet side [50] of a spring loaded safety relief valve which is opened by direct action of the pressure in the vessel provided:

(1) the valve is so designed that it will not fail to open at its proper pressure setting regardless of any back pressure that can accumulate between the valve disk and the rupture disk. The space between the valve disk and the rupture disk shall be vented or drained to prevent accumulation of pressure due to a small amount of leakage from the valve.[51]

(2) the valve is ample in capacity to meet the requirements of UG-133 (a) and (b);

(3) the stamped bursting pressure of the rupture disk at the coincident disk temperature plus any pressure in the outlet piping shall not exceed the design pressure of the outlet portion of the safety or safety relief valve and any pipe or fitting between the valve and the rupture disk device. However, in no case shall the stamped bursting pressure of the rupture disk at the coincident operating temperature plus any pressure in the outlet piping exceed the maximum allowable working pressure of the vessel or the set pressure of the safety or safety relief valve.

(4) the opening provided through the rupture disk device after breakage is sufficient to permit a flow equal to the rated capacity of the attached safety or safety relief valve without exceeding the allowable overpressure;

(5) any piping beyond the rupture disk cannot be obstructed by the rupture disk or fragment;

(6) the contents of the vessel are clean fluids free from gumming or clogging matter, so that accumulation in the space between the valve inlet and the rupture disk (or in any other outlet that may be provided) will not clog the outlet;

(7) the bonnet of the safety relief valve shall be vented to prevent accumulation of pressure.

(b) Breaking Pin Device [52]

(1) Breaking pin devices shall not be used as single devices but only in combination between the safety or safety relief valve and the vessel.

(2) The space between a breaking pin device and a safety or safety relief valve shall be provided with a pressure gage, a try cock, a free vent, or suitable telltale indicator. This arrangement permits detection of breaking pin device operation or leakage.

(3) Each breaking pin device shall have a rated pressure and temperature at which the pin will break. The breaking pin shall be identified to a lot number and shall be guaranteed by the Manufacturer to break when the rated pressure, within the following tolerances, is applied to the device:

Rated Pressure, psi		
Minimum	Maximum	Tolerance, Plus or Minus, psi
30	150	5
151	275	10
276	375	15

(4) The rated pressure of the breaking pin plus the tolerance in psi shall not exceed 105% of the maximum allowable working pressure of the vessel to which it is applied.

(5) The rated pressure at the coincident operating temperature [53] shall be verified by breaking two or more sample breaking pins from each lot of the same material and the same size as those to be used. The lot size shall not exceed 25. The test shall be made in a device of the

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[48] Use of a rupture disk device in combination with a safety relief valve shall be carefully evaluated to ensure that the media being handled and the valve operational characteristics will result in pop action of the valve coincident with the bursting of the rupture disk.

[49] Users are warned that a rupture disk will not burst at its design pressure if back pressure builds up in the space between the disk and the safety or safety relief valve which will occur should leakage develop in the rupture disk due to corrosion or other cause.

[50] This use of a rupture disk device in series with the safety or safety relief valve is permitted to minimize the loss by leakage through the valve of valuable or of noxious or otherwise hazardous materials, and where a rupture disk alone or disk located on the inlet side of the valve is impracticable, or to prevent corrosive gases from a common discharge line from reaching the valve internals.

[51] Users are warned that an ordinary spring loaded safety relief valve will not open at its set pressure if back pressure builds up in the space between the valve and rupture disk. A specially designed valve is required, such as a diaphragm valve or a valve equipped with a bellows above the disk.

[52] A *breaking pin device* is a non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the breakage of a load-carrying section of a pin which supports a pressure containing member. A *breaking pin* is the load-carrying element of a breaking pin device. A *breaking pin housing* is the structure which encloses the breaking pin mechanism. The material of the housing shall be listed in Section II and be permitted for use in this Division.

[53] The specified temperature supplied to the breaking pin manufacturer shall be the temperature of the breaking pin when an emergency condition exists and the pin is expected to break.

same form and pressure dimensions as that in which the breaking pin is to be used.

(c) Spring Loaded Non-reclosing Pressure Relief Device

(1) A spring loaded non-reclosing pressure relief device, pressure actuated by means which permit the spring loaded portion of the device to open at the specified set pressure and remain open until manually reset, may be used provided the design of the spring loaded non reclosing device is such that if the actuating means fail, the device will achieve full opening at or below its set pressure. Such a device may not be used in combination with any other pressure relief device. The tolerance on opening point shall not exceed ±5%.

(2) The calculated capacity rating of a spring loaded non-reclosing pressure relief device shall not exceed a value based on the applicable theoretical formula (see UG-131) for the various media, multiplied by: *K*=coefficient=0.62.

The area *A* (square inches) in the theoretical formula shall be the flow area through the minimum opening of the non-reclosing pressure relief device.

(3) In lieu of the method of capacity rating in (2) above, a Manufacturer may have the capacity of a spring loaded non-reclosing pressure relief device design certified in general accordance with the procedures of UG-131, as applicable.

UG-128 LIQUID RELIEF VALVES

Any liquid relief valve used shall be at least NPS 1/2.

UG-129 MARKING

(a) Safety, Safety Relief, Liquid Relief, and Pilot Operated Pressure Relief Valves. Each safety, safety relief, liquid relief, and pilot operated valve NPS 1/2 and larger shall be plainly marked by the manufacturer or assembler with the required data in such a way that the marking will not be obliterated in service. The marking may be placed on the valve or on a plate or plates that satisfy the requirements of UG-119:

(1) the name, or an acceptable abbreviation, of the Manufacturer and the assembler;
(2) Manufacturer's design or type number;
(3) NPS size_____ (the nominal pipe size of the valve inlet);
(4) set pressure_____psi;
(5) certified capacity (as applicable):

(a) lb/hr of saturated steam at an overpressure of 10% or 3 psi, whichever is greater for valves certified on steam complying with UG-131 (b); or

(b) gal/min of water at 70°F at an overpressure of 10% or 3 psi, whichever is greater for valves certified on water; or

(c) SCFM (standard cubic feet per minute at 60°F and 14.7 psia) or lb/min. of air at an overpressure of 10% or 3 psi, whichever is greater. Valves that are capacity certified in accordance with UG-131 (c)(2) shall be marked "at 20% overpressure."

*(d)*In addition, to one of the fluids specified, the Manufacturer may indicate the capacity in other fluids (see Appendix 11).

(6) year built, or alternatively, a coding may be marked on the valve such that the valve Manufacturer or assembler can identify the year built;

(7) ASME Symbol as shown in Fig. UG-129.

On valves smaller than NPS 1/2, the markings may be made on a metal tag attached by wire or adhesive meeting the requirements of UG-119 or other means suitable for the service conditions.

(b) Safety and safety relief valves certified for a steam discharging capacity under the provision of Section I and bearing the official Code Symbol Stamp of Section I for safety valves may be used on pressure vessels. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Appendix 11. [see UG-131 (h).]

(c) Pressure Relief Valves in Combination With Rupture Disk Devices. Pressure relief valves in combination with rupture disk devices shall be marked with the capacity as established in accordance with UG-127 (a)(3)(b)(2) (using 0.90 factor) or the combination capacity factor established by test in accordance with UG-132 (a) or (b), in addition to the marking of UG-129 (a) and (f) below.



FIG. UG-129 OFFICAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

The marking may be placed on the valve or rupture disk device or on a plate or plates that satisfy the requirements of UG-119 or rupture disk device. The marking shall include the following:

(1) name of Manufacturer of valve;
(2) design or type number of valve;
(3) name of Manufacturer of rupture disk device;
(4) design or type number of rupture disk device;
(5) capacity or combination capacity factor;
(6) name of organization responsible for this marking.

This shall be either the vessel user, vessel Manufacturer, rupture disk Manufacturer, or pressure relief valve Manufacturer.

(d) Pressure Relief Valves in Combination With Breaking Pin Devices. Pressure relief valves in combination with breaking pin devices shall be marked in accordance with (a) above. In addition, the rated pressure shall be marked on the breaking pin and the breaking pin housing.

(e) Rupture Disk Devices. Every rupture disk shall be plainly marked by the Manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the disk or on a metal tab that satisfies the requirements of UG-119. The marking shall include the following:

(1) the name or identifying trademark of the Manufacturer;
(2) Manufacturer's design or type number;
(3) lot number;
(4) disk material;
(5) size____(NPS Designator at valve inlet)
(6) stamped bursting pressure_____psi;
(7) coincident disk temperature_____°F;
(8) capacity_____lb of saturated steam/hr, or _____cu ft of air/min (60°F and 14.7 psia).

NOTE: In addition, the Manufacturer may indicate the capacity in other fluids (see Appendix 11).

Items (1), (2), and (5) above shall *also* be marked on the rupture disk holder.

(f) Spring Loaded Non-reclosing Pressure Relief Devices. Spring loaded non-reclosing pressure relief devices shall be marked in accordance with (a) above

except that the Code Symbol Stamp is to be applied only when the capacity has been established and certified in accordance with UG-127 (c)(3) and all other requirements of UG-130 have been met.

UG-130 USE OF CODE SYMBOL STAMP

Each pressure relief valve[54] to which the Code Symbol (see Fig. UG-129) will be applied shall have been fabricated or assembled by a Manufacturer or Assembler holding a valid Certificate of Authorization (UG-117) and capacity certified in accordance with the requirements of this Division.

UG-131 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF VALVES

(a) Before the Code Symbol is applied to any pressure relief valve, the valve Manufacturer shall have the capacity of his valves certified in accordance with the provisions of this paragraph.

(b) (1) Capacity certification tests for pressure relief valves for compressible fluids shall be conducted on dry saturated steam, or air, or natural gas. When dry saturated steam is used, the limits for test purposes shall be 98% minimum quality and 20°F maximum superheat. Correction from within these limits may be made to the dry saturated condition. Valves for steam service may be rated as above, but at least one valve of each series shall be tested on steam to demonstrate the steam capacity and performance.

(2) Capacity certification tests for pressure relief valves for incompressible fluids shall be conducted on water at a temperature between 40°F and 125°F.

(c) (1) Capacity certification tests shall be conducted at a pressure which does not exceed the pressure for which the pressure relief valve is set to operate by more than 10% or 3 psi, whichever is greater, except as provided in (c) (2) below. Minimum pressure for capacity certification tests shall be at least 3 psi above set pressure. The reseating pressure shall be noted and recorded.

(2) Capacity certification tests of pressure relief valves for use in accordance with UG-125 (c) (3) may be conducted at a pressure not to exceed 120% of the stamped set pressure of the valve.

(3) *(a)* Pressure relief valves for compressible fluids having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure or 3 psi, whichever is greater.

(b) The blowdown of pressure relief valves for incompressible fluids and pressure relief valves for compressible fluids having nonadjustable blowdown shall be noted and recorded.

(4) Capacity certification of pilot operated pressure relief valves may be based on tests without the pilot valves installed, provided prior to capacity tests it has been demonstrated by test to the satisfaction of the Authorized Observer that the pilot valve will cause the main valve to open fully at a pressure which does not exceed the set pressure by more than 10% or 3 psi, whichever is greater, and that the pilot valve in combination with the main valve will meet all the requirements of this Division.

(c) (1) A capacity certification test is required on a set of three valves for each combination of size, design, and pressure setting. The stamped capacity rating for each combination of design, size, and test pressure shall not exceed 90% of the average capacity of the three valves tested. The capacity for each set of three valves shall fall within a range of ±5% of the average capacity. Failure to meet this requirement shall be cause to refuse certification of that particular safety valve design.

(d) (2) If a Manufacturer wishes to apply the Code Symbol to a design of pressure relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the approximate range of pressures for which the valve will be used or covering the range available at the certified test facility that shall conduct the tests. The capacities based on these four tests shall be as follows.

(a) For compressible fluids, the slope W/P of the actual measured capacity versus the flow pressure for each test point shall be calculated and averaged:

$$\text{slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow pressure, psia}}$$

All values derived from the testing must fall with ±5% of the average value:

minimum slope = 0.95 X average slope

maximum slope = 1.05 X average slope

If the values derived from the testing do not fall between the minimum and maximum slope values, the Authorized Observer shall require that additional valves be tested at the rate of two for each valve beyond the maximum and minimum values with a limit of four additional valves.

The relieving capacity to be stamped on the valve shall not exceed 90% of the average slope times the absolute accumulation pressure:

rated slope = 0.90 X average slope

stamped capacity ≤ rated slope (1.10 X set pressure + 14.7) or (set pressure + 3 psi +14.7), whichever is greater

For valves certified in accordance with (c) (2) above,

stamped capacity ≤ rated slope (1.20 X set pressure + 14.7) or (set pressure + 3 psi + 14.7), whichever is greater

(b) For incompressible fluids, the capacities shall be plotted on log-log paper against the differential (inlet

[54] Vacuum relief valves are not covered by Code Symbol Stamp requirements.

minus discharge pressure) test pressure and a straight line drawn through these four points. If the four points do not establish a straight line, two additional valves shall be tested for each unsatisfactory point, with a limit of two unsatisfactory points. Any point that departs from the straight line by more than 5% should be considered an unsatisfactory point. The relieving capacity shall be determined from this line. The certified capacity shall not exceed 90% of the capacity taken from the line.

(e) Instead of individual capacity certification as provided in (d) above, a coefficient of discharge K may be established for a specific safety valve design according to the following procedure.

(1) For each design, the pressure relief valve manufacturer shall submit for test at least three valves for each of three different sizes (a total of nine valves) together with detailed drawings showing the valve construction. Each valve of a given size shall be set at a different pressure.

(2) Tests shall be made on each pressure or relief valve to determine its capacity-lift, popping and blowdown pressures, and actual capacity in terms of the fluid used in the test. A coefficient K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where actual flow is determined quantitatively by test, and theoretical flow is calculated by the appropriate formula which follows:

For tests with dry saturated steam,

$$W_T = 51.5\,AP$$

NOTE: For dry saturated steam pressures over 1500 psig and up to 3200 psig, the value of W_T, calculated by the above equation, shall be corrected by being multiplied by the following factors:

$$\left(\frac{0.1906P - 1000}{0.2292P - 1061}\right)$$

For tests with air,

$$W_T = 356AP\sqrt{\frac{M}{T}}$$

For tests with natural gas,

$$W_T = CAP\sqrt{\frac{M}{ZT}}$$

For tests with water,

$$W_T = 2407A\sqrt{(P - P_d)\,w}$$

where

W_T = theoretical flow, lb/hr
A = actual discharge area through the valve at developed lift, sq. in.,
P = (set pressure X 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater
P_d = pressure at discharge from valve, psia
M = molecular weight
T = absolute temperature at inlet °F + 460 °F
C = constant for gas or vapor based on the ratio of specific heats
$k = C_P/C_V$ (see Fig. 11-1)
Z = compressibility factor corresponding to P and T
w = specific weight of water at valve inlet conditions

The average of the coefficient K_D of the nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.879 (the product of 0.9 x 0.975).

NOTE: All experimentally determined coefficients K_D shall fall within a range of ± 5% of the average K_D found. Failure to meet this requirement shall be cause to refuse certification of that particular valve design.

To convert lb/hr of water to gal/min of water, multiply the capacity in lb/hr by 1/500.

(3) The official relieving capacity of all sizes and pressures of a given design, for which K has been established under the provisions of (e)(2) above, that are manufactured subsequently shall not exceed the value calculated by the appropriate formula in (e)(2) above multiplied by the coefficient K (see Appendix 11).

(4) The coefficient shall not be applied to valves whose beta ratio (ratio of valve throat to inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that the individual coefficient of discharge K_D for valves at the extreme ends of a larger range is within ±5% of the average coefficient K. For designs where the lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio *(L/D)*.

(f) Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25.3. The tests shall be made under the supervision of, and certified by, an authorized observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME on recommendation of an ASME Designee. Acceptance of the testing facility is subject to review within each 5 year period.

(g) Capacity test data reports for each valve model, type, and size, signed by the manufacturer and the Authorized Observer witnessing the tests shall be submitted to the ASME Designee for review and acceptance.[55] Where changes are made in the design, capacity certification tests shall be repeated.

(h) For absolute pressures up to 1500 psia, it is permissible to rate safety valves under PG-69.1.2 of Section I with capacity ratings at a flow pressure of 103% of the set pressure, for use on pressure vessels, without further tests. In such instances, the capacity rating of the valve may be

[56] Valve capacities are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.

increased to allow for the flow pressure permitted in (c)(1) and (c)(3) above, namely, 110% of the set pressure, by the multiplier

$$\frac{1.10p + 14.7}{1.03p + 14.7}$$

where P = set pressure, psig

Such valves shall be marked in accordance with UG-129. This multiplier shall not be used as a divisor to transform test ratings from a higher to a lower flow.

(*i*) Rating of nozzle type pressure relief valves, i.e., coefficient K_D, greater than 0.90 and nozzle construction, for saturated water shall be according to 11-2.

(*j*) When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Division shall be performed.

UG-132 CERTIFICATION OF CAPACITY OF SAFETY AND SAFETY RELIEF VALVES IN COMBINATION WITH NONRECLOSING PRESSURE RELIEF DEVICES

(a) Capacity of Safety or Safety Relief Valves in Combination With a Rupture Disk Device at the Inlet

(1) For each combination of safety or safety relief valve design and rupture disk device design, the safety valve manufacturer or the rupture disk device manufacturer may have the capacity of the combination certified as prescribed in (3) and (4) below.

(2) Capacity certification tests shall be conducted on saturated steam, air or natural gas. When saturated steam is used, corrections for moisture content of the steam shall be made.

(3) The valve manufacturer or the rupture disk device manufacturer may submit for tests the smallest rupture disk device size with the equivalent size of safety or safety relief valve that is intended to be used as a combination device. The safety or safety relief valve to be tested shall have the largest orifice used in the particular inlet size.

(4) Tests may be performed in accordance with the following subparagraphs. The rupture disk device and safety or safety relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(a) The test shall embody the minimum burst pressure of the rupture disk device design which is to be used in combination with safety or safety relief valve design. The stamped bursting pressure shall be between 90% and 100% of the stamped set pressure of the valve.

(b) The test procedure to be used shall be as follows. The safety or safety relief valve (one valve) shall be tested for capacity as an individual valve, without the rupture disk device at a pressure 10% above the valve set pressure. The rupture disk device shall then be installed ahead of the safety or safety relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the individual safety or safety relief valve capacity test.

(c) Tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(d) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity determined by the combination tests to the capacity determined on the individual valve.

The Combination Capacity Factor shall be used as a multiplier to make appropriate changes in the ASME rated relieving capacity of the safety or safety relief valve in all sizes of the design. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design of safety or safety relief valve and the same design of rupture disk device as those tested.

(e) The test laboratory shall submit the test results to the ASME Designee for acceptance of the Combination Capacity Factor.

(b) *Optional Testing of Rupture Disk Devices and Safety or Safety Relief Valves*

(1) If desired, a valve manufacturer or a rupture disk manufacturer may conduct tests in the same manner as outlined in (a)(4)(c) and (a)(4)(d) above using the next two larger sizes of the design of rupture disk device and safety or safety relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be certified, it may be used for all larger sizes of the combination, but shall not be greater than one.

(2) If desired, additional tests may be conducted at higher pressures in accordance with (a)(4)(c) and (a)(4)(d) above to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but shall not be greater than one.

(c) Capacity of Breaking Pin Devices in Combination With Safety Relief Valves

(1) Breaking pin devices in combination with safety relief valves shall be capacity tested in compliance with UG-131(d) or UG-131(e) as a combination.

(2) Capacity certification and Code Symbol stamping shall be based on the capacity established in accordance with these paragraphs.

UG-133 DETERMINATION OF PRESSURE RELIEVING REQUIREMENTS

(a) Except as permitted in (b) below, the aggregate capacity of the pressure relieving devices connected to any vessel or system of vessels for the release of a liquid, air, steam, or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the vessel of more than 16% above the maximum allowable working pressure when the pressure relieving devices are blowing.

(b) Protective devices as permitted in UG-125(c)(2), as protection against excessive pressure caused by exposure to fire or other sources of external heat, shall have a relieving capacity sufficient to prevent the pressure from rising more than 21% above the maximum allowable working pressure of the vessel when all pressure relieving devices are blowing.

(c) Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel may be considered as one unit in figuring the required relieving capacity of pressure relieving safety devices to be furnished.

(d) Heat exchangers and similar vessels shall be protected with a relieving device of sufficient capacity to avoid overpressure in case of an internal failure.

(e) The official rated capacity of a pressure relieving safety device shall be that which is stamped on the device and guaranteed by the manufacturer.

(f) The rated pressure relieving capacity of a pressure relief valve for other than steam or air shall be determined by the method of conversion given in Appendix 11.

(g) To prorate the relieving capacity at any relieving pressure greater than 1.10*p*, as permitted under UG-125, a multiplier may be applied to the official relieving capacity of a pressure relieving device as follows:

$$\frac{P + 14.7}{1.10p + 14.7}$$

where

P = relieving pressure, psig

p = set pressure, psig

UG-134 PRESSURE SETTING OF PRESSURE RELIEF DEVICES

(a) When a single pressure relieving device is used, it shall be set to operate[57] at a pressure not exceeding the maximum allowable working pressure of the vessel. When the required capacity is provided in more than one pressure relieving device, only one device need be set at or below the maximum allowable working pressure, and the additional devices may be set to open at higher pressures but in no case at a pressure higher than 105% of the maximum allowable working pressure, except as provided in (b) below.

(b) Protective devices permitted in UG-125(c)(2) as protection against excessive pressure caused by exposure to fire or other sources of external heat shall be set to operate at a pressure not in excess of 110% of the maximum allowable working pressure of the vessel. If such a device is used to meet the requirements of both UG-125(c) and UG-125(c)(2), it shall be set to operate at not over the maximum allowable working pressure.

(c) The pressure at which any device is set to operate shall include the effects of static head and constant back pressure.

(d) (1) The set pressure tolerance for pressure relief valves shall not exceed ±2 psi for pressures up to and including 70 psi and 3% for pressures above 70 psi, except as covered in (d)(2) below.

(2) The set pressure tolerance of pressure relief valves which comply with UG-125(c)(3) shall be within -0%, +10%.

UG-135 INSTALLATION

(a) Safety, safety relief and pilot operated pressure relief valves, and nonreclosing pressure relief devices shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected.

(b) The opening through all pipe and fittings between a pressure vessel and its pressure relieving device shall have at least the area of the pressure relieving device inlet, and the flow characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relieving device. The opening in the vessel wall shall be designed to provide direct and unobstructed flow between the vessel and its pressure relieving device. (See Appendix M.)

(c) When two or more required pressure relieving devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be either sized to avoid restricting flow to the pressure relief devices or made at least equal to the combined inlet areas of the safety devices connected to it. The flow characteristics of the upstream system shall satisfy the requirements of (b) above. (See Appendix M.)

(d) Liquid relief valves shall be connected below the normal liquid level.

(e) There shall be no intervening stop valves between the vessel and its protective device or devices and the point of discharge, except:

(1) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected relieving devices below the required relieving capacity; or

(2) under conditions set forth in Appendix M.

(f) The safety devices on all vessels shall be so installed that their proper functioning will not be hindered by the nature of the vessel's contents.

(g) Discharge lines from pressure relieving safety devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from lodging in the discharge side of the safety device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the relieving devices below that required to properly protect the vessel. (See UG-136(a)(8) and Appendix M.)

UG-136 MINIMUM REQUIREMENTS FOR PRESSURE RELIEF VALVES

(a) Mechanical Requirements

(1) The design shall incorporate guiding arrangements necessary to ensure consistent operation and tightness.

(2) The spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 0.5% of the free height.

[57] Set to operate means the set pressure to a pressure relief valve or a spring loaded nonreclosing device; the bursting pressure of a rupture disk device; or, the breaking pressure of a breaking pin device.

(3) Each pressure relief valve on air, water over 140°F, or steam service shall have a substantial lifting device which when activated will release the seating force on the disk when the valve is subjected to a pressure of at least 75% of the set pressure of the valve. Pilot operated pressure relief valves used on these services shall be provided with either a lifting device as described above or means for connecting and applying pressure to the pilot adequate to verify that the moving parts critical to proper operation are free to move.

(4) The seat of a pressure relief valve shall be fastened to the body of the valve in such a way that there is no possibility of the seat lifting.

(5) In the design of the body of the valve, consideration shall be given to minimizing the effects of deposits.

(6) Valves having screwed inlet or outlet connections shall be provided with wrenching surfaces to allow for normal installation without damaging operating parts.

(7) Means shall be provided in the design of all valves for use under this Division for sealing all initial adjustments which can be made without disassembly of the valve. Seals shall be installed by the manufacturer or assembler at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment without breaking the seal. For valves larger than NPS 1/2 in. pipe size, the seal shall serve as a means of identifying the manufacturer or assembler making the initial adjustment.

(8) If the design of a pressure relief valve is such that liquid can collect on the discharge side of the disk, the valve shall be equipped with a drain at the lowest point where liquid can collect (for installation see UG-135).

(b) Material Selections

(1) Cast iron seats and disks are not permitted.

(2) Adjacent sliding surfaces such as guides and disks or disk holders shall both be of corrosion resistant material. Springs of corrosion resistant material or having a corrosion resistant coating are required. The seats and disks of pressure relief valves shall be of suitable material to resist corrosion by the fluid to be contained.

NOTE: The degree of corrosion resistance, appropriate to the intended service, shall be a matter of agreement between the manufacturer and the purchaser.

(3) Materials used in bodies and bonnets or yokes shall be listed in Section II and this Division. Materials used in nozzles, disks,and other parts contained within the external structure of the pressure relief valves shall be one of the following categories:

(a) listed in Section II;

(b) listed in ASTM Specifications

(c) controlled by the manufacturer of the pressure relief valve by a specification insuring control of chemical and physical properties and quality at least equivalent to ASTM Standards .

(c) Inspection of Manufacturing and/or Assembly of Pressure Relief Valves

(1) A Manufacturer or assembler shall demonstrate to the satisfaction of a designated representative of the ASME that his manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance of random production samples and the performance of those valves submitted for Capacity Certification.

(2) Manufacturing, assembly, inspection, and test operations including capacity are subject to inspections at any time by a designated representative of the ASME.

(3) The following schedule of tests applies to production pressure relief valves certified under this Division, produced, assembled, tested, sealed, and shipped by the Manufacturer and having a normal scope of size and capacity within the capability of ASME accepted laboratories. Production valves for capacity and operational testing shall be selected by a designated representative of the ASME and the testing shall be carried out in the presence of a representative of the same organization at an ASME accepted laboratory in accordance with the following:

(a) Initial capacity certification shall be valid for 1 year during which time two production valves shall be tested for operation and stamped capacity verification. Should any of these valves fail to relieve at or above its stamped capacity, or should it fail to meet performance requirements, the test shall be repeated at the rate of two valves for each valve that failed. Initial capacity verification may be extended for 1 year intervals until the valve is in production. Valves having an adjustable blowdown construction shall be adjusted by the Manufacturer following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi, whichever is greater. This adjustment may be made on the flow test facility.

(b) Thereafter, two valves shall be tested within each 5 year period of time. The valve manufacturer shall be notified of the time of the test and may have a witness present during the test. Should any of these valves fail to relieve at or above its stamped capacity or should it fail to meet performance requirements of this Division, the test shall be repeated at the rate of two valves for each valve that failed. Valves having an adjustable blowdown construction shall be adjusted by the manufacturer following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi, whichever is greater. This adjustment may be made on the flow test facility. These valves shall be furnished by the manufacturer or assembler. Failure of any of these valves to meet the stamped capacity or the performance requirements of this Division shall be cause for revocation within 60 days of the authorization to use the Code Symbol on that particular type of valve. During this period, the manufacturer shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence, and the requirements of (c)(3)(a) above shall apply.

(4) An assembler may be granted permission to use a Code Symbol Stamp after demonstrating to the satisfaction of a designated representative of the ASME that his quality control procedures will insure that the assembled valves meet the requirements of this Division, including the following.

(a) Initially, two valves of each type or series to which the Code stamp is to be applied and which have been assembled, tested, and sealed by the assembler shall be selected by a designated representative of the ASME and tested for operation and stamped capacity verification.

Should any valve fail to relieve at or above its stamped capacity, or should it fail to meet performance requirements, the test shall be repeated at the rate of two valves for each valve that failed. Valves having an adjustable blowdown construction shall be adjusted by the assembler following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi, whichever is greater. This adjustment may be made on the flow test facility.

(b) Thereafter, within each 5 year period of time, two valves of each type or series shall be selected by a designated representative of the ASME and tested for operation and stamped capacity verification. The assembler shall be notified of the time of the test and may have a witness present during the test. Should any valve fail to relieve at or above its stamped capacity or should it fail to meet performance requirements of this Division, the test shall be repeated at the rate of two valves for each valve that failed. Valves having an adjustable blowdown construction shall be adjusted by the manufacturer following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi, whichever is greater. This adjustment may be made on the flow test facility. These valves shall be furnished by the assembler. Failure of any valve to meet the performance requirements of this Division shall be cause for revocation within 60 days of the assembler's authorization to use the Code Symbol on that particular type or series of valve. During this period, the assembler shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence.

(c) All tests shall be carried out in the presence of a designated representative of the ASME at an ASME accepted laboratory.

(d) Use of the Code Symbol Stamp by an assembler indicates the use of original, unmodified parts in strict accordance with the instructions of the manufacturer of the valve.

(e) In addition to the requirements of UG-129, the name plate marking shall include the name of the manufacturer and the assembler. The Code Symbol Stamp shall be that of the assembler.

NOTE: Within the requirements of UG-136(c) and UG-136(d): A manufacturer is defined as a person or organization who is completely responsible for design, material selection, capacity certification, manufacture of all component parts, assembly, testing, sealing, and shipping of pressure relief valves certified under this Division. An assembler is defined as a person or organization who purchases or receives from a manufacturer the necessary component parts or valves and assembles, adjusts, tests, seals, and ships pressure relief valves certified under this Division, at a geographical location other than and using facilities other than those used by the manufacturer. An assembler may be organizationally independent of a manufacturer or may be wholly or partly owned by a manufacturer.

(d) Production Testing by Manufacturers and Assemblers

(1) Each pressure relief valve to which the Code Symbol Stamp is to be applied shall be subjected to the following tests by the manufacturer or assembler. A manufacturer or assembler shall have a documented program for the application, calibration,and maintenance of gages and instruments used during these tests.

(2) The primary pressure parts of each valve exceeding NPS 1 inlet size or 300 psi set pressure where the materials used are either cast or welded shall be tested at a pressure of at least 1.5 times the design pressure of the parts. These tests shall be conducted after all machining operations on the parts have been completed. There shall be no visible sign of leakage.

(3) The secondary pressure zone of each closed bonnet valve exceeding NPS 1 inlet size when such valves are designed for discharge to a closed system shall be tested with air or other gas at a pressure of at least 30 psi. There shall be no visible sign of leakage.

(4) Each valve shall be tested to demonstrate its popping or set pressure. Valves marked for steam service or having special internal parts for steam service shall be tested with steam, except that valves beyond the capability of the production steam test facility either because of size or set pressure may be tested on air. Necessary corrections for differentials in popping pressure between steam and air shall be established by the manufacturer and applied to the popping point on air. Valves marked for gas or vapor may be tested with air. Valves marked for liquid service shall be tested with water or other suitable liquid. Test fixtures and test drums where applicable shall be of adequate size and capacity to ensure that valve action is consistent with the stamped set pressure within the tolerances required by UG-134(e).

(5) A seat tightness test shall be conducted at a maximum expected operating pressure, but at a pressure not exceeding the reseating pressure of the valve. When testing with either water or steam, a valve exhibiting no visible signs of leakage shall be considered adequately tight. Leakage tests conducted with air shall be in accordance with industry accepted standards.

(6) Testing time on steam valves shall be sufficient, depending on size and design, to insure that test results are repeatable and representative of field performance.

(e) Design Requirements. At the time of the submission of valves for capacity certification, or testing in accordance with (c)(3) above, the ASME Designee has the authority to review the design for conformity with the requirements of UG-136(a) and UG-136(b) and to reject or require modification of designs which do not conform, prior to capacity testing.

(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of bodies, bonnets, and yokes shall be performed in accordance with the applicable requirements of this Division.

APPENDIX 11
CAPACITY CONVERSIONS FOR SAFETY VALVES

11.1

The capacity of a safety or relief valve in terms of a gas or vapor other than the medium for which the valve was officially rated shall be determined by application of the following formulas:[1]

For steam,

$$W_S = 51.5KAP$$

For air,

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

$C = 356$

$M = 28.97$

$T = 520$ when W_a is the rated capacity

For any gas or vapor,

$$W = CKAP\sqrt{\frac{M}{T}}$$

where

W_S = rated capacity, lb/hr of steam
W_a = rated capacity, converted to lb/hr of air at 60°F, inlet temperature.

[1]Knowing the official rating capacity of a safety valve which is stamped on the valve, it is possible to determine the overall value of K_A in either of the following formulas in cases where the value of these individual terms is not known:

Official Rating in Steam

$$K_A = \frac{W_S}{51.5P}$$

Official Rating in Air

$$K_A = \frac{W_a}{CP}\sqrt{\frac{T}{M}}$$

This value for K_A is then substituted in the above formulas to determine the capacity of the safety valve in terms of the new gas or vapor.

W = flow of any gas or vapor, lb/hr
C = constant for gas or vapor which is function of the ratio of specific heats, $K = C_P/C_V$ (see Fig. 11-1)
K = coefficient of discharge [see UG-131(d) and (e)]
A = actual discharge area of the safety valve, sq in.
P = (set pressure X 1.10) plus atmospheric pressure, psia
M = molecular weight
T = absolute temperature at inlet (°F + 460)

These formulas may also be used when the required flow of any gas or vapor is known and it is necessary to compute the rated capacity of steam or air.
Molecular weights of some of the common gases and vapors are given in Table 11-1.

For hydrocarbon vapors, where the actual value of K is not known, the conservative value, $K = 1.001$ has been commonly used and the formula becomes

$$W = 315KAP\sqrt{\frac{M}{T}}$$

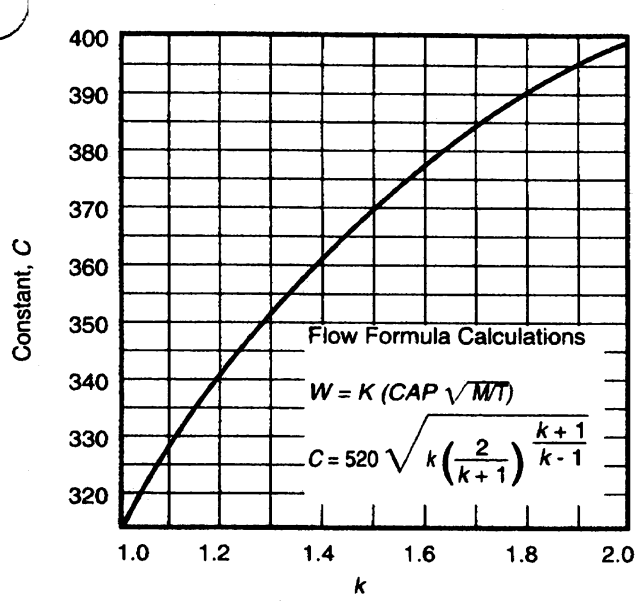
When desired, as in the case of light hydrocarbons, the compressibility factor Z may be included in the formulas for gases and vapors as follows:

$$W = CKAP\sqrt{\frac{M}{ZT}}$$

Example 1

GIVEN: A safety valve bears a certified capacity rating of 3020 lb/hr of steam for a pressure setting of 200 psi.

PROBLEM: What is the relieving capacity of that valve in terms of air at 100°F for the same pressure setting?



k	Constant C	k	Constant C	k	Constant C
1.00	315	1.26	343	1.52	366
1.02	318	1.28	345	1.54	368
1.04	320	1.30	347	1.56	369
1.06	322	1.32	349	1.58	371
1.08	324	1.34	351	1.60	372
1.10	327	1.36	352	1.62	374
1.12	329	1.38	354	1.64	376
1.14	331	1.40	356	1.66	377
1.16	333	1.42	358	1.68	379
1.18	335	1.44	359	1.70	380
1.20	337	1.46	361	2.00	400
1.22	339	1.48	363	2.20	412
1.24	341	1.50	364	•••	•••

Fig. 11-1 CONSTANT *C* FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($K = C_p/C_v$)

SOLUTION:

For steam

$$Ws = 51.5KAP$$

$$3020 = 51.5KAP$$

$$KAP = \frac{3020}{51.5} = 58.5$$

For air

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

$$= 356KAP\sqrt{\frac{28.97}{460 + 100}}$$

$$= (356)\ (58.5)\ \sqrt{\frac{28.97}{560}}$$

$$= 4750 \text{ lb/hr}$$

Example 2

GIVEN: It is required to relieve 5000 lb/hr of propane from a pressure vessel through a safety valve set to relieve at a pressure of P_s, psi, and with an inlet temperature at 125°F.

PROBLEM: What total capacity in pounds of steam per hour in safety valves must be furnished.

SOLUTION:

For Propane,

$$W = CKAP\sqrt{\frac{M}{T}}$$

The value of *C* is not definitely known. Use the conservative value, $C = 315$.

$$5000 = 315KAP\sqrt{\frac{44.09}{460 + 125}}$$

$$KAP = 57.7$$

TABLE 11-1
MOLECULAR WEIGHTS OF GASES AND VAPORS

Air	28.97	Freon 22	86.48
Acetylene	26.04	Freon 114	170.90
Ammonia	17.03	Hydrogen	2.02
Butane	58.12	Hydrogen Sulfide	34.08
Carbon Dioxide	44.01	Methane	16.04
Chlorine	70.91	Methyl Chloride	50.48
Ethane	30.07	Nitrogen	28.02
Ethylene	28.05	Oxygen	32.00
Freon 11	137.371	Propane	44.09
Freon 12	120.9	Sulphur Dioxide	64.06

For steam,

$$W_S = 51.5\ KAP = (51.5)(57.7)$$
$$= 2970 \text{ lb/hr set to relieve at } P_S, \text{ psi}$$

Example 3

GIVEN: It is required to relieve 1000 lb/hr of ammonia from a pressure vessel at 150°F.

PROBLEM: What is the required total capacity in pounds of steam per hour at the same pressure setting?

SOLUTION:

For ammonia,

$$W = CKAP\sqrt{\frac{M}{T}}$$

Manufacturer and user agree to use k= 1.33; from Fig.11-1, C= 350.

$$1000 = 350KAP\sqrt{\frac{17.03}{460 + 150}}$$

$$KAP = 17.10$$

For steam,

$$W_S = 51.5\ KAP = 51.5 \times 17.10$$

$$= 880 \text{ lb/hr}$$

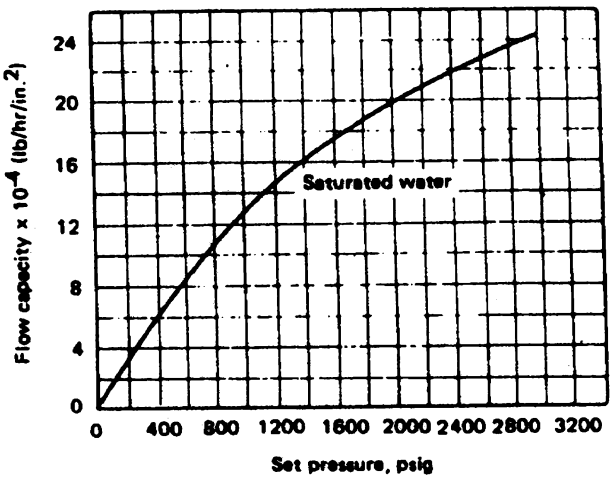


FIG. 11-2 FLOW CAPACITY CURVE FOR RATING NOZZLE TYPE SAFETY VALVES ON SATURATED WATER (BASED ON 10% OVERPRESSURE)

EXAMPLE 4

GIVEN: A safety valve bearing a certified rating of 10,000 cu ft/min of air at 60°F and 14.7 psia (atmospheric pressure).

PROBLEM: What is the flow capacity of this safety valve in pounds of saturated steam per hour for the same pressure setting?

SOLUTION:

For air: Weight of dry air at 60°F and 14.7 psia is 0.0766 lb/cu ft.

$$Wa = 10{,}000 \times 0.0766 \times 60 = 45{,}960 \text{ lb/hr}$$

$$45{,}960 = 356\ KAP\sqrt{\frac{28.97}{460 + 60}}$$

$$KAP = 546$$

For steam,

$$Ws = 51.5\ KAP = (51.5)(546)$$

$$= 28{,}200 \text{ lb/hr}$$

NOTE: Before converting the capacity of a safety valve from any gas to steam, the requirements of UG-131 (b) must be met.

11-2

(a) Since it is realized that the saturated water capacity is configuration sensitive, the following applies only to those safety valves that have a nozzle type construction (throat to inlet diameter ratio of 0.25 to 0.80 with a continuously contoured change and have exhibited a coefficient K_D in excess of 0.90.) No saturated water rating shall apply to other types of construction.

Note: The manufacturer, user, and inspector are all cautioned that for the following rating to apply, the valve shall be continuously subjected to saturated water. If, after initial relief the flow media changes to quality steam, the valve shall be rated as per dry saturated steam. Valves installed on vessels or lines containing steam-water mixture shall be rated on dry saturated steam.

(b) To determine the saturated water capacity of a valve currently rated under UG-131 and meeting the requirements of (a) above, refer to Fig. 11-2. Enter the graph at the set pressure of the valve, move vertically upward to the saturated water line and read horizontally the relieving capacity. This capacity is the theoretical, isentropic value arrived at by assuming equilibrium flow and calculated values for the critical pressure ratio.

APPENDIX M
INSTALLATION AND OPERATION

M-1 INTRODUCTION

(a) The rules in this Appendix are for general information only, because they pertain to the installation and operation of pressure vessels, which are the prerogative and responsibility of the law enforcement authorities in those states and municipalities which have made provision for the enforcement of Section VIII.

(b) It is permissible to use any departures suggested herein from provisions in the mandatory parts of this Division when granted by the authority having legal jurisdiction over the installation of pressure vessels.

M-2 CORROSION

(a) Vessels subject to external corrosion shall be so installed that there is sufficient access to all parts of the exterior to permit proper inspection of the exterior, unless adequate protection against corrosion is provided or unless the vessel is of such size and is so connected that it may readily be removed from its permanent location for inspection.

(b) Vessels having manholes, handholes, or cover plates to permit inspection of the interior shall be so installed that these openings are accessible.

(c) In vertical cylindrical vessels subject to corrosion, to insure complete drainage, the bottom head, if dished, should preferably be concave to pressure.

M-3 MARKING ON THE VESSEL

The marking required by this Division shall be so located that it will be accessible after installation and when installed shall not be covered with insulation or other material that is not readily removable [see UG-116(j)].

M-4 PRESSURE RELIEVING SAFETY DEVICES

The general provisions for the installation of pressure relieving devices are fully covered in UG-135. The following paragraphs contain details in arrangement of stop valves for shutoff control of safety pressure relief devices which are sometimes necessary to the continuous operation of processing equipment of such a complex nature that the shutdown of any part of it is not feasible. There are also rules with regard to the design of inlet and discharge piping to and from safety and relief valves, which can only be general in nature because the design engineer must fit the arrangement and proportions of such a system to the particular requirements in the operation of the equipment involved.

M-5 STOP VALVES BETWEEN PRESSURE RELIEVING DEVICE AND VESSEL

(a) A vessel, in which pressure can be generated because of service conditions, may have a full area stop valve between it and its pressure relieving device for inspection and repair purposes only. When such a stop valve is provided, it shall be so arranged that it can be locked or sealed open, and it shall not be closed except by an authorized person who shall remain stationed there during that period of the vessel's operation within which the valve remains closed, and who shall again lock or seal the stop valve in the open position before leaving the station.

(b) A vessel or system [see UG-133(c)] for which the pressure originates from an outside source exclusively may have individual pressure relieving devices on each vessel, or connected to any point on the connecting piping, or on any one of the vessels to be protected. Under such an arrangement, there may be a stop valve between any vessel and the pressure relieving devices, and this stop valve need not be locked open, provided it also closes off that vessel from the source of pressure.

M-6 STOP VALVES ON THE DISCHARGE SIDE OF A PRESSURE RELIEVING DEVICE [SEE UG-135(e)]

A full-area stop valve may be placed on the discharge side of a pressure relieving device when its discharge is connected to a common header with other discharge lines from other pressure relieving devices on nearby vessels that are in operation, so that this stop valve when closed will prevent a discharge from any connected operating vessels from backing up beyond the valve so closed. Such a stop valve shall be so arranged that it can be locked or sealed in either the open or closed position, and it shall be locked or sealed in either position only by an authorized person. When it is to be closed while the vessel is in operation, an authorized person shall be present, and he shall remain stationed there; he shall again lock or seal the stop valve in the open position before leaving the station. Under no condition should this valve be closed while the vessel is in operation except when a stop valve on the inlet side of the safety relieving device is installed and is first closed.

M-7 INLET PRESSURE DROP FOR HIGH LIFT, TOP GUIDED SAFETY, SAFETY RELIEF, AND PILOT OPERATED PRESSURE RELIEF VALVES IN COMPRESSIBLE FLUID SERVICE

(a) The nominal pipe size of all piping, valves and fittings, and vessel components between a pressure vessel and its safety, safety relief or pilot operated pressure relief valves shall be at least as large as the nominal size of the device inlet, and the flow characteristics of the upstream system shall be such that the cumulative total of all nonrecoverable inlet losses shall not exceed 3% of the valve set pressure. The inlet pressure losses will be based on the valve nameplate capacity corrected for the characteristics of the flowing fluid.

(b) When two or more required safety, safety relief, or pilot operated pressure relief valves are placed on one connection, the internal cross-sectional area of the inlet of this connection shall be either sized to avoid restricting flow or made at least equal to the combined areas of the nominal pipe size inlets of the valves connected to it, and the flow characteristics of the upstream system shall meet the requirements of (a) above with all valves relieving simultaneously.

M-8 DISCHARGE LINES FROM SAFETY DEVICES

(a) Where it is feasible, the use of a short discharge pipe or vertical riser, connected through long-radius elbows from each individual device, blowing directly to the atmosphere, is recommended. Such discharge pipes shall be at least of the same size as the valve outlet. Where the nature of the discharge permits, telescopic (sometimes called "broken") discharge lines, whereby condensed vapor in the discharge line, or rain, is collected in a drip pan and piped to a drain are recommended.[1]

(b) When discharge lines are long, or where outlets of two or more valves having set pressures within a comparable range are connected into a common line, the effect of the back pressure that may be developed therein when certain valves operate must be considered [see UG-135 (g)]. The sizing of any section of a common-discharge header downstream from each of the two or more pressure relieving devices that may reasonably be expected to discharge simultaneously shall be based on the total of their outlet areas, with due allowance for the pressure drop in all downstream sections. Use of specially designed valves suitable for use on high or variable back pressure service should be considered.

(c) The flow characteristics of the discharge system of high lift, top guided safety, safety relief, or pilot operated pressure relief valves in compressible fluid service shall be such that the static pressure developed at the discharge flange of a conventional direct spring loaded valve will not exceed 10% of the set pressure when flowing at stamp capacity. Other valve types exhibit various degrees of tolerance to back pressure and manufacturer's recommendation should be followed.

(d) All discharge lines shall be run as direct as is practicable to the point of final release for disposal. For the longer lines, due consideration shall be given to the advantage of long-radius elbows, avoidance of closeup fittings, and the minimizing of excessive line strains by expansion joints and well-known means of support to minimize line-sway and vibration under operating conditions.

(e) Provisions should be made in all cases for adequate drainage of discharge lines.

NOTE: It is recognized that no simple rule can be applied generally to fit the many installation requirements which vary from simple short lines that discharge directly to the atmosphere to the extensive manifold discharge piping systems where the quantity and rate of the product to be disposed of requires piping to a distant safe place.

[1] This construction has the further advantage of not transmitting discharge-pipe strains to the valve. In these types of installation, the back pressure effect will be negligible, and no undue influence upon normal valve operation can result.

M-9 PRESSURE DROP, NONRECLOSING PRESSURE RELIEF DEVICES

Piping, valves and fittings, and vessel components comprising part of a nonreclosing device pressure relieving system shall be sized to prevent the vessel pressure from rising above the allowable overpressure.

M-10 GENERAL ADVISORY INFORMATION ON THE CHARACTERISTICS OF SAFETY RELIEF VALVES DISCHARGING INTO A COMMON HEADER

Because of the wide variety of types and kinds of safety relief valves, it is not considered advisable to attempt a description in this Appendix of the effects produced by discharging them into a common header. Several different types of valves may conceivably be connected into the same discharge header and the effect of back pressure on each type may be radically different. Data compiled by the manufacturers of each type of valve used should be consulted for information relative to its performance under the conditions anticipated.

M-11 PRESSURE DIFFERENTIALS FOR PRESSURE RELIEF VALVES

Due to the variety of service conditions and the various designs of safety and safety relief valves, only general guidance can be given regarding the differential between the set pressure of the valve (see UG-134) and the operating pressure of the vessel. Operating difficulty will be minimized by providing an adequate differential for the application. The following is general advisory information on the characteristics of the intended service and of the safety or safety relief valves that may bear on the proper pressure differential selection for a given application. These considerations should be reviewed early in the system design since they may dictate the MAWP of the system.

(a) Consideration of the Process Characteristics in the Establishment of the Operating Margin to Be Provided. To minimize operational problems, it is imperative that the user consider not only normal operating conditions of fluids, pressures, and temperatures, but also start-up and shutdown conditions, process upsets, anticipated ambient conditions, instrument response times, pressure surges due to quick closing valves, etc. When such conditions are not considered, the pressure relieving device may become, in effect, a pressure controller, a duty for which it is not designed. Additional consideration should be given to hazard and pollution associated with the release of the fluid. Larger differentials may be appropriate for fluids which are toxic, corrosive, or exceptionally valuable.

(b) Consideration of Safety Relief Valve Characteristics. The blowdown characteristic and capability is the first consideration in selecting a compatible valve and operating margin. After a self-actuated release of pressure, the valve must be capable of reclosing above the normal operating pressure. For example, if the valve is set at 100 psig with a 7% blowdown, it will close at 93 psig. The operating pressure must be maintained below 93 psig in order to prevent leakage or flow from a partially open valve. Users should exercise caution regarding the blowdown adjustment of large springloaded valves. Test facilities, whether owned by Manufacturers, repair houses or users, may not have sufficient capacity to accurately verify the blowdown setting. The settings cannot be considered accurate unless made in the field on the actual installation.

Pilot-operated valves represent a special case from the standpoints of both blowdown and tightness. The pilot portion of some pilot-operating valves can be set at blowdowns as short as 2%. This characteristic is not, however, reflected in the operation of the main valve in all cases. The main valve can vary considerably from the pilot depending on the location of the two components in the system. If the pilot is installed remotely from the main valve, significant time and pressure lags can occur, but reseating of the pilot assures reseating of the main valve. The pressure drop in the connecting piping between the pilot and the main valve must not be excessive; otherwise, the operation of the main valve will be adversely affected.

The tightness of the main valve portion of these combinations is considerably improved above that of conventional valves by pressure loading the main disc or by the use of soft seats or both.

Despite the apparent advantages of pilot-operated valves, users should be aware that they should not be employed in abrasive or dirty service, in applications where coking, polymerization, or corrosion of the wetted pilot parts can occur, or where freezing or condensation of the lading fluid at ambient temperatures is possible. For all applications the valve Manufacturer should be consulted prior to selecting a valve of this type.

Tightness capability is another factor affecting valve selection, whether spring loaded or pilot operated. It varies somewhat depending on whether metal or resilient seats are specified, and also on such factors as corrosion or temperature. The required tightness and test method should be specified to comply at a pressure no lower than the normal operating pressure of the process. A recommended procedure and acceptance standard is given in ANSI B147.1. It should also be remembered that any degree of tightness obtained should not be considered permanent. Service operation of a valve almost invariably reduces the degree of tightness.

Application of special designs such as O-rings or resilient seats should be reviewed with the valve Manufacturer.

The anticipated behavior of the valves includes allowance for a plus-or-minus tolerance on set pressure which varies with the pressure level. Installation conditions, such as back pressure, variations, and vibrations, influence selection of special types and increase in differential pressure.

(c) General Recommendations. The following pressure differentials are recommended unless the safety or safety relief valve has been designed or tested in a specific or similar service and a small differential has been recommended by the Manufacturer.

A minimum difference of 5 psi is recommended for set pressures to 70 psi. In this category, the set pressure tolerance is ±2 psi [UG-134(d)(1)], and the differential to the leak test pressure is 10% or 5 psi, whichever is greater.

A minimum differential of 10% is recommended for set pressures from 71 psi to 1000 psi. In this category, the set pressure tolerance is ±3% and the differential to the leak test pressure is 10%.

A minimum differential of 7% is recommended for set pressures above 1000 psi. In this category, the set pressure tolerance is ±3% and the differential to the leak test pressure should be 5%. Valves having small seat sizes will require additional maintenance when the pressure differential approaches these recommendations.

M-12 INSTALLATION OF SAFETY AND SAFETY RELIEF VALVES

Spring loaded safety and safety relief valves normally should be installed in the upright position with the spindle vertical. Where space or piping configuration preclude such an installation, the valve may be installed in other than the vertical position provided that:

(a) the valve design is satisfactory for such position;

(b) the media is such that material will not accumulate at the inlet of the valve; and

(c) drainage of the discharge side of the valve body and discharge piping is adequate.

M-13 REACTION FORCES AND EXTERNALLY APPLIED LOADS

(a) Reaction Thrust. The discharge of a pressure relief valve imposes reactive flow forces on the valve and associated piping. The design of the installation may require computation of the bending moments and stresses in the piping and vessel nozzle. There are momentum effects and pressure effects at steady state flow as well as transient dynamic loads caused by opening.

(b) External Loads. Mechanical forces may be applied to the valve by discharge piping as a result of thermal expansion, movement away from anchors, and weight of any unsupported piping. The resultant bending moments on a closed pressure relief valve may cause valve leakage and excessive stress in inlet piping. The design of the installation should consider these possibilities.

M-14 SIZING OF PRESSURE RELIEF DEVICES FOR FIRE CONDITIONS

(a) Excessive pressure may develop in pressure vessels by vaporization of the liquid contents and/or expansion of vapor content due to heat influx from the surroundings particularly from a fire. Pressure relief systems for fire conditions are usually intended to release only the quantity of product necessary to lower the pressure to a predetermined safe level, without releasing an excessive quantity. This control is especially important in situations where release of the contents generates a hazard because of flammability or toxicity. Under fire conditions, consideration must also be given to the possibility that the safe pressure level for the vessel will be reduced due to heating of the vessel material, with a corresponding loss of strength.

(b) Several formulas have evolved over the years for calculating the pressure relief capacity required under fire conditions. The major differences involve heat flux rates. There is no single formula yet developed which takes into account all of the many factors which could be considered in making this determination. When fire conditions are a consideration in the design of a pressure vessel, the following references which provide recommendations for specific installations may be used:

API RP 520, Recommended Practice for the Design and Installation of Pressure-Relieving Systems in Refineries, Part I - Design, 1976, American Petroleum Institute, Washington DC

API Standard 2000, Venting Atmospheric and Low Pressure Storage Tanks (nonrefrigerated and refrigerated), 1973, American Petroleum Institute, Washington, DC

AAR Standard M-1002, Specification for Tank Cars, 1978, Association of American Railroads, Washington, DC

Safety Relief Device Standards:S-1.1, Cylinders for Compressed Gases; S-1.2, Cargo and Portable Tanks; and S-1.3, Compressed Gas Storage Containers. Compressed Gas Association, New York

NFPA Code Nos. 30, 59 and 59A, National Fire Protection Association, Boston, MA

Pressure-Relieving Systems for Marine Cargo Bulk Liquid Containers, 1973, National Academy of Sciences, Washington, DC

Bulletin E-2, How to Size Safety Relief Devices, Phillips Petroleum Company, Bartlesville, OK

A Study of Available Fire Test Data as Related to Tank Car Safety Device Relieving Capacity Formulas, 1971, Phillips Petroleum Company, Bartlesville, OK

M-15 PRESSURE INDICATING DEVICE

If a pressure indicating device is provided to determine the vessel pressure at or near the set pressure of the relief device, one should be selected that spans the set pressure of the relief device and is graduated with an upper limit that is neither less than 1.25 times the set pressure of the relief device nor more than twice the maximum allowable working pressure of the vessel. Additional devices may be installed if desired.

REFERENCE BOOKS FOR CSEX REVIEW CONTROL VALUES ETC

✓ "CAMERON HYDRAULIC DATA" $15.-
SBN 193143162 C.C. HEALD, 17TH ED, 1ST PRINTING JUNE, 199
INGERSOLL-RAND, WOODCLIFF, NJ 07675

"FLOWMETER ORIFICE SIZING HANDBOOK"
10B9000 FISCHER AND PORTER CO.
WARMINSTER, PA 18974.

"MASONEILAN CONTROL VALVE SIZING AND SELECTION HANDBOOK" BULL. 02 1000 6/9
MASONEILAN N.A. OPERATIONS
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HOUSTON, TX 77084

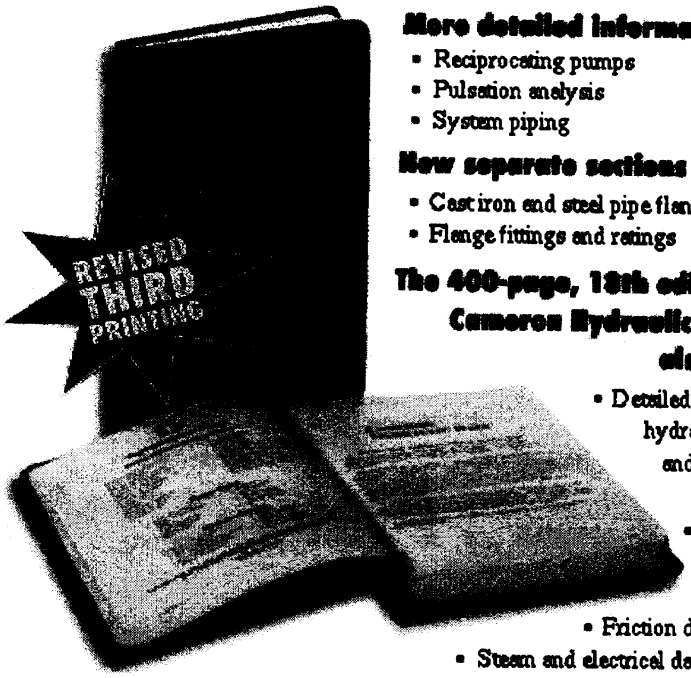
✓ "FLOW METER ENGINEERING HANDBOOK"
C. F. CUSICK, FIFTH ED. $3.00
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PROFILES AND PIPING

Reynolds Number is a dimensionless value expressing relative turbulence:

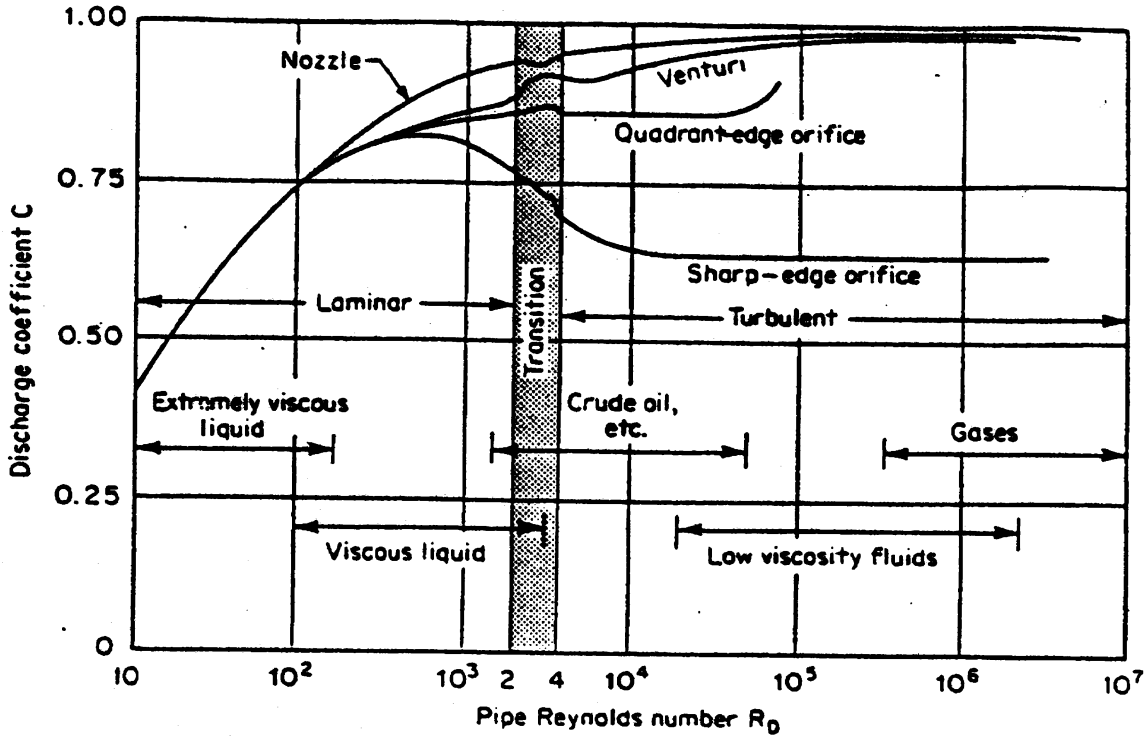
$$R_D = K \frac{\rho x V x ID}{\mu}$$

Where: K = units correction factor

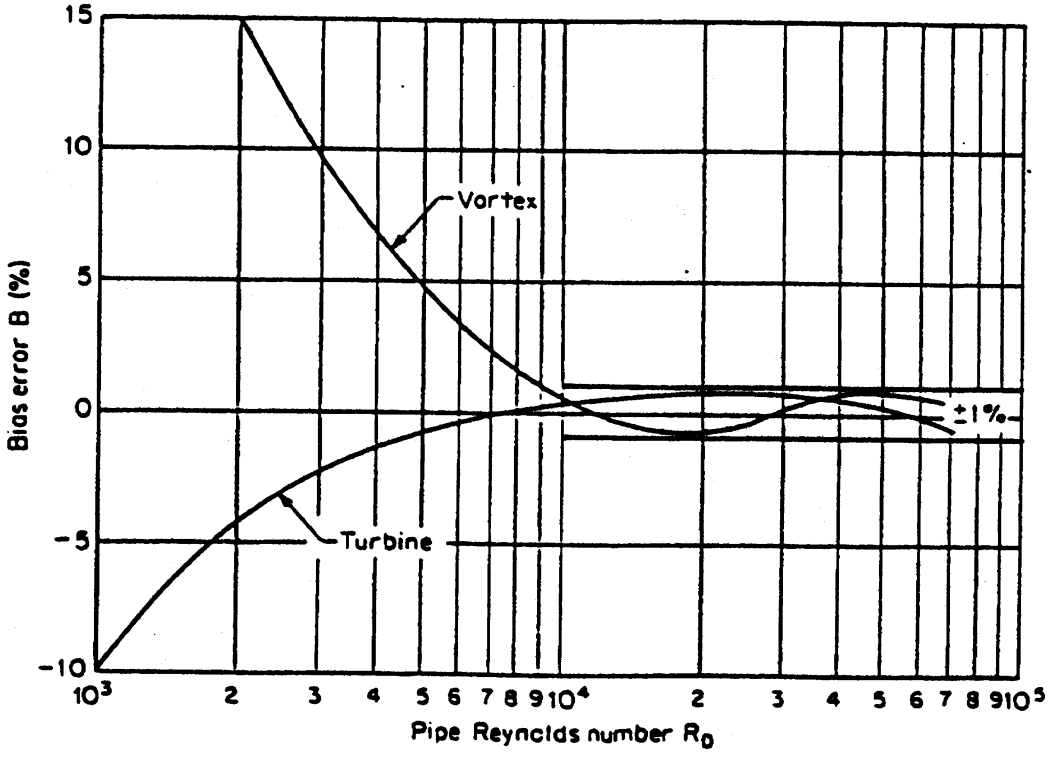
Values below 2000 are laminar, above 5000 are turbulent, and between are transitional. Industrial meters are designed for turbulent conditions. This is one of the reasons why flowmeter measurement ranges do not include the value 'zero'. In point of fact, many meters operate poorly if at all when R_D is less than 20,000.

Size Flow Meters on flow rate, not pipe size. Piping is sized to reduce pumping horsepower by minimizing pressure drops, which means that fluid velocity is often low and the profile laminar or transitional. Like control valves, meters often require pipe size reductions to increase fluid velocity.

As an aside, the piping engineer often resists reducing his 6" pipe to 4 or even 3" for the meter but will allow a 6" orifice plate with a 2" bore. This is one of several reasons why orifices are so common.

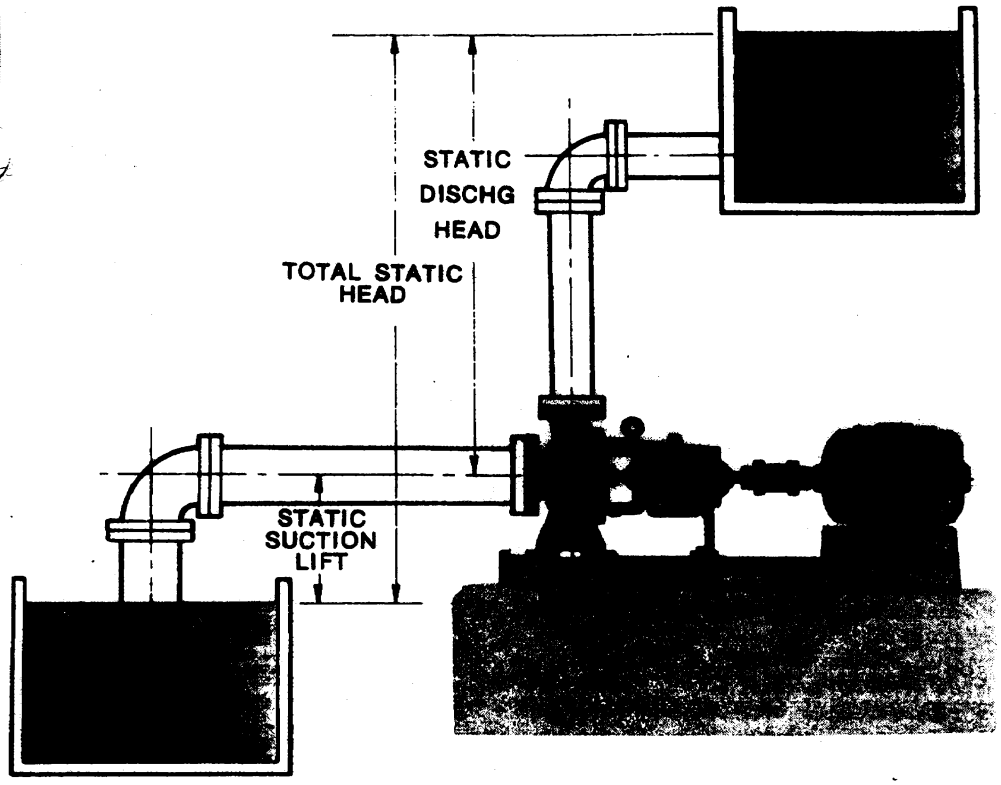


(a)

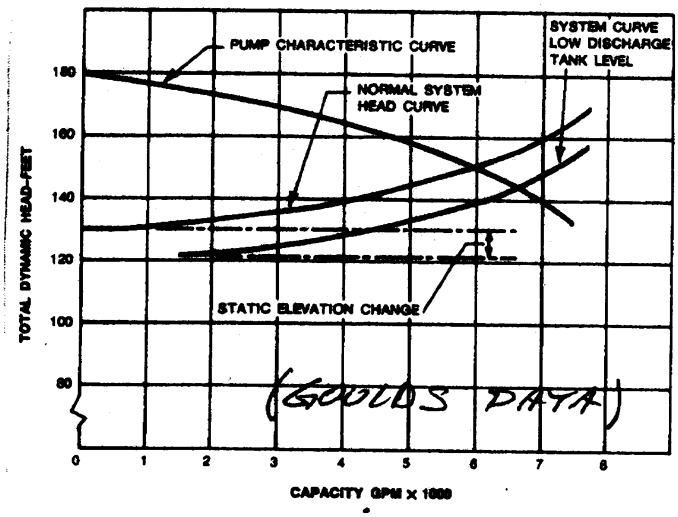


(b)

Figure 5.50 Typical flowmeter signature curves. (a) Differential producer. (*b*) Turbine and vortex flowmeters.

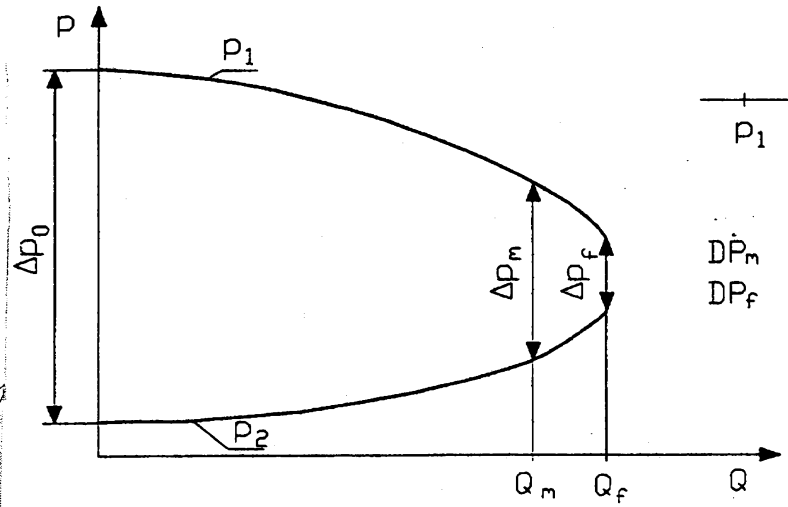


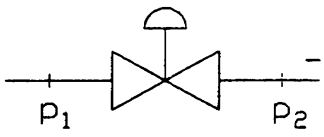
STATIC HEAD IS CONSTANT EXCEPT FOR LEVEL CHANGES



TYPICAL PUMP HEAD CURVE & TYPICAL SYSTEM HEAD CURVE DUE TO PIPE FLOW FRICTION LOSS. NOTE POINTED "BULLET"

SOURCE: BOTH GOULDS PUMP



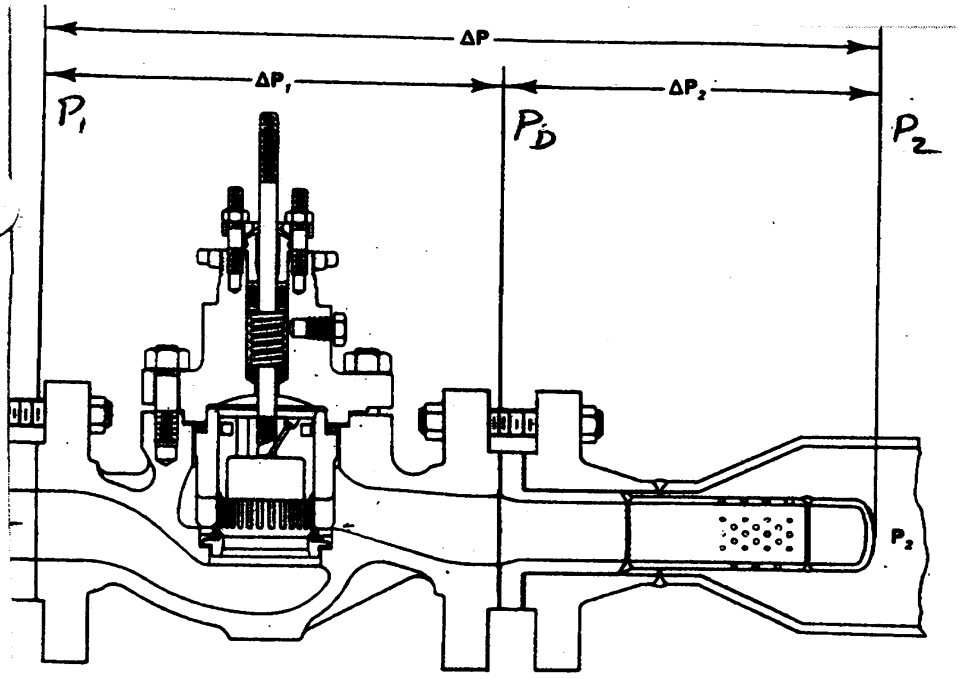


BULLET CURVE WITH CONTROL VALVE.

$DP_m = \Delta P_m / \Delta P_0$ ← PART OF MATH MODEL OF SYSTEM FOR INSTALLED CHARACTERISTICS

$DP_f = \Delta P_f / \Delta P_0$

Figure 7. The process pressure model. Neles-Jamesbury



NOISE REDUCTI

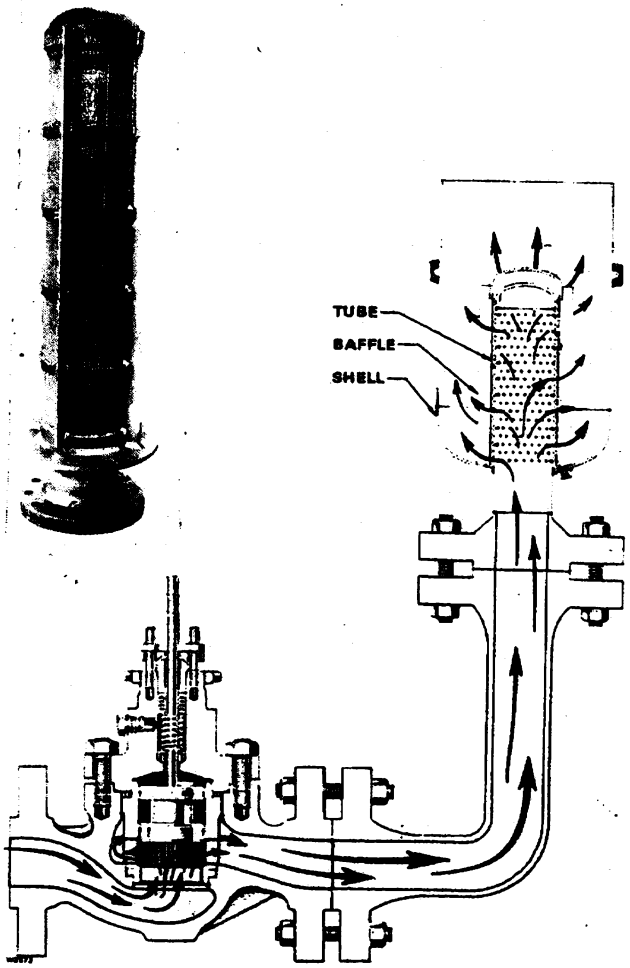
FOR HIGH ΔP DIVIDE IT UP IN Z

X_T LIMITS FLOW BU NOT NOISE SO ADD A DIFFUSER DOWN STREAM

$\Delta P_1 \simeq X_T$

$\Delta P_2 \simeq$ BALANCE OF TOTAL

$\Delta P/P$ TOTAL $= 0.75$; $\Delta P_1/P_1 = 0.5$; $\Delta P_2/P_2 = 0.5$

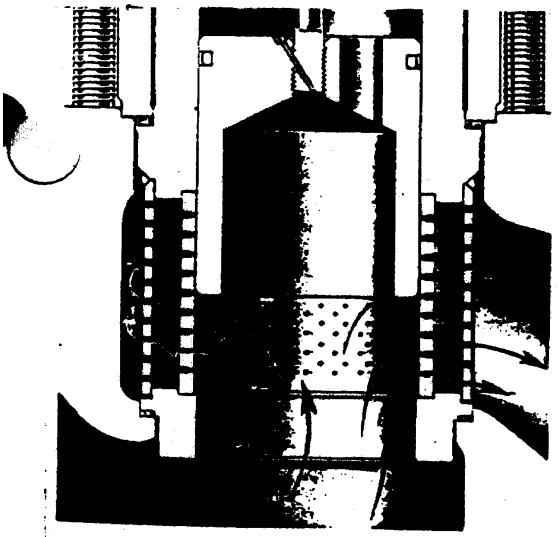


ROOF VENTS:

VALVE IN PLANT, VENT ON ROOF. ABOUT 25dB

NOISE IS CONTAINED INSID PIPE AND ESCAPES WITH AN OPEN VENT.

SOURCE: FISHER



6. Unique Severe Service globe valve for high pressure drops and high noise reduction. Uses 2 drilled hole cages and long stroke. Balanced plug shown.

CAVITATION REDUCTION CAGE IS SIMILIAR BUT FLOW IS DOWN

NOISE CALCULATIONS

ISA HAS A METHOD OF CALCULATION BUT- IT DOES NOT COVER THE MANY UNIQUE VALVE DESIGNS OFFERED BY THE VALVE MANUFACTURERS TO REDUCE NOISE LEVELS.

USE A GOOD CONTROL VALVE SIZING AND NOISE PROGRAM. USE IT FOR DESIGN BUT GET REP TO PROVIDE THEIR SOLUTION WITH PROPOSAL BEFORE PURCHASE.

THERE HAVE BEEN NO NOISE PROBLEMS ON FIRST 2 EXAMS

(No cut of Slide) a computer

USE A COMPUTER PROGRAM BY VALVE MANUFACTURER

SOURCE: TOP, FISHER

Pressure-Temperature Ratings for Standard Class Valves
(In accordance with ANSI B16.34-1977)

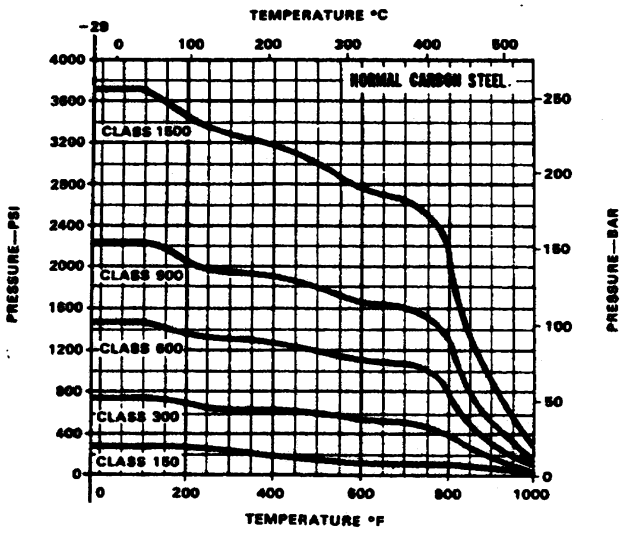


Figure 3-1. Ratings for Normal Carbon Steel Valves

18. Valve must meet [illegible] piping code, or exceed [illegible] Chrome-moly pipe and valves go to higher temps. Many makers limit WCB steel to 800 F. SS stands lower temperatures better.

TYPICAL SPECS.

SCREWED: ≤ 2"

FLANGED: 2-2½ & UP

WELDED:

SOCKET: ≤ 2"

BUTT: ≥ 2½"

Control Valve Seat Leakage Classifications
(In accordance with ANSI B16.104-1976)

Leakage Class Designation	Maximum Leakage Allowable	Test Medium	Test Pressures	Testing Procedures Required for Establishing Rating
I	...	...	...	No test required provided user and supplier so agree.
II	0.5% of rated capacity	Air or water at 50-125°F (10-52°C)	45-60 psig or max. operating differential, whichever is lower	Pressure applied to valve inlet, with outlet open to atmosphere or connected to a low head loss measuring device, full normal closing thrust provided by actuator.
III	0.1% of rated capacity	As above	As above	As above
IV	0.01% of rated capacity	As above	As above	As above
V	0.0005 ml per minute of water per inch of port diameter per psi differential	Water at 50-125°F (10-52°C)	Max. service pressure drop across valve plug, not to exceed ANSI body rating. (100 psi pressure drop minimum)	Pressure applied to valve inlet after filling entire body cavity and connected piping with water and stroking valve plug closed. Use net specified max. actuator thrust, but no more, even if available during test. Allow time for leakage flow to stabilize.
VI	Not to exceed amounts shown in following table based on port diameter	Air or Nitrogen at 50-125°F (10-52°C)	50 psig or max. rated differential pressure across valve plug, whichever is lower.	Actuator should be adjusted to operating conditions specified with full normal closing thrust applied to valve plug seat. Allow time for leakage flow to stabilize and use suitable measuring device.

19. Some leakage is OK in many systems; in steam piping it keeps thing hot. Leakage is subject reps avoid unless user brings up.

CHECK ΔP LIMIT ON TRIM SELECTED

20. Few metal seats are Class V Soft seats are needed to meet Class VI and some makers offer "bubble tight" tests for TFE.

SOURCE: ANSI & FISHER

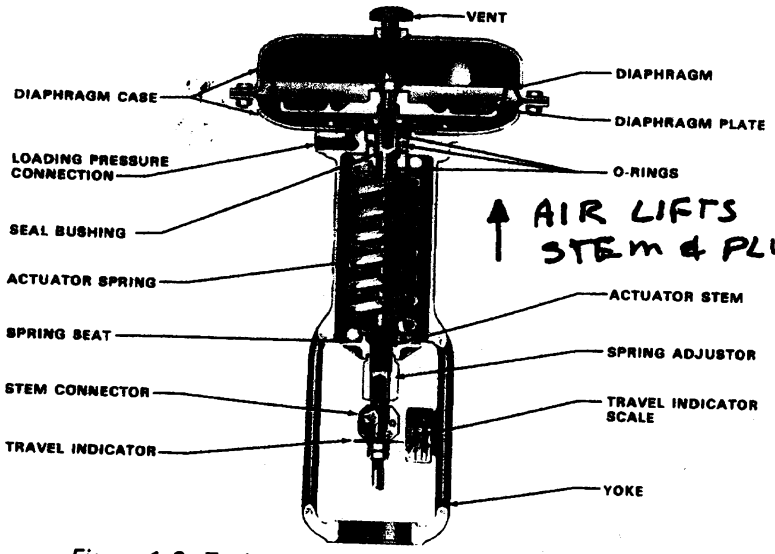
FAIL — CLOSED MOST COMMON

CONTROL VALVE ACTUATORS

SPRING AND DIAPHRAM - GLOBE VALVES
  SINGLE ACTION - POSITIVE FAIL ACTION

PISTONS - ROTARY VALVES
  DOUBLE ACTION, CAN FAIL (ON POWER AIR FAILURE)
    1. LAST POSITION, INHERENTLY
    2. LOCKED IN LAST POSITION
    3. WHERE VALVE FORCES ACT

POSITIONER CONTROLS IT ON SIGNAL FAILURE



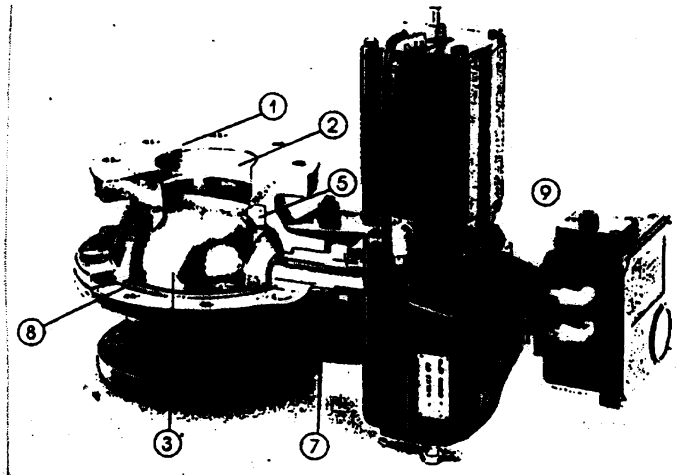
AIR LIFTS STEM & PLUG

Figure 1-2. Typical Reverse-Acting Diaphragm Actuator

POSITIONER NOT REQUIRED

FAIL CLOSED FOR TYPICAL PUSH DOWN TO CLOSE VALVE BODY

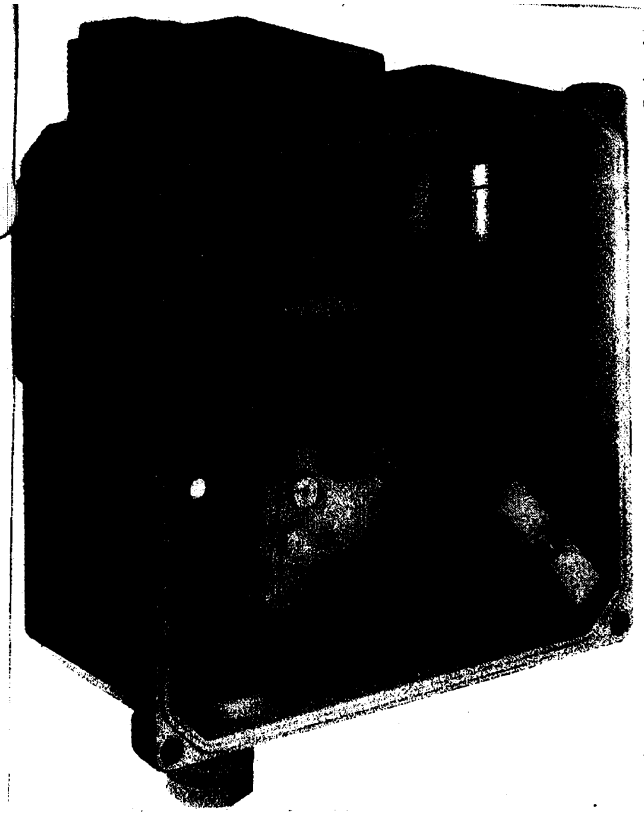
MANY ACTUATORS ARE REVERSABLE ACTION IN FIELD



POSITIONER REQUIRED FOR THROTTLING CONTROL; DOUBLE ACTION PISTONS REQUIRED ON LARGE BALL AND BUTTERFLYS, ESPECIALLY THOSE WITH METAL SEATS.

SOURCE: FISHER

POSITIONERS



51. Positioner with cam that can be changed. Though offered by most positioners, as a changeable item to alter control valve characteristics, Neles-Jamesbury does not recommend it. It is better to make other changes such as putting a function block, f(x) in the final signal output of a digital controller. Then any curve required can be configured later if needed.

CAM FILERS HAVE ALL DIED OUT.

DIGITAL SYSTEM ENGINEERS HAVE TAKEN OVER.

THE GUIDELINES

A. As a first guideline, previous rules based on actuator loading, valve unbalance and stem friction should be discarded.

B. It should be realized that a simple spring and diaphragm actuator, if properly sized, will often do an excellent job without the aid of auxiliaries such as either a positioner or an amplifier.

C. Three cases are recognized, however, where one of the two auxiliary devices should be considered. They are:

1. Where the loading pressure to the actuator must be increased above the standard 3-15 psi range to obtain adequate thrust or stiffness.
2. Where split-range signals are required.
3. Where the best possible control is desired; i.e., the minimum overshoot and fastest recovery of the system is wanted, following a disturbance or load change.

D. The cases cited above only indicate that a positioner or pneumatic amplifier should be considered, the choice of which should be used depends on the system dynamics.

FOR EXPLANATION CONTACT ED ANDREWS

1. If the system is relatively fast, such as is typical of liquid pressure, most flow and some gas pressure control loops, the proper auxiliary choice is a pneumatic amplifier.
2. If the system is relatively slow, such as is typical of liquid level, blending, temperature and some reactor control loops, the proper auxiliary choice is a positioner.

SOURCE: FISHER TM 23

ADD ONE MORE:

E. ANY CONTROL VALVE WITH HIGH FRICTION, SUCH AS BALL VALVES WITH METAL SEATS

SOURCE: POSIT. NJ

OTHER THAN AIR OPERATED ACTUATORS

ELECTRO- HYDRAULIC
- POWER AND OR SPEED
- EXPENSIVE

ELECTRIC MOTORIZED
- LIMITED DUTY CYCLE
- SLOW RESPONSE
- EXPENSIVE

SELF ACTUATED
- DIRECT PRV'S, RELIEF VALVES
- GAS OR STEAM PILOTED

VARIABLE SPEED PUMPS OR CONVEYORS

INSTALLATION PRACTICES

HYDRAULICS MUST BE CORRECT
ACCESSIBLE TO OPERATORS ON MANUAL
ACCESSIBLE FOR MAINTENANCE
CLEARANCE TO DISASSEMBLE
3 VALVE MANIFOLDS
AVOID LOW QUALITY STEAM ON START-UP

ISA HAS STANDARD COVERING 3VALVE MANIFOLDS & CLEARANCES REQ'D.

THE END

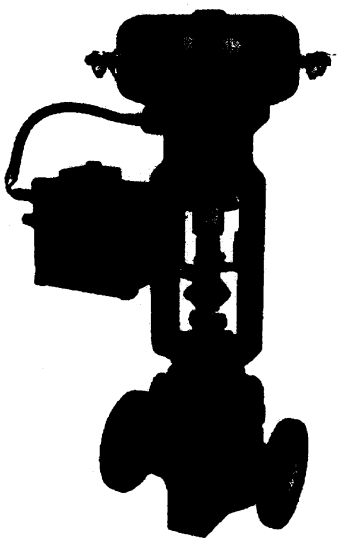
ENGINEERING HANDBOOK FOR NELES-JAMESBURY CONTROL VALVES

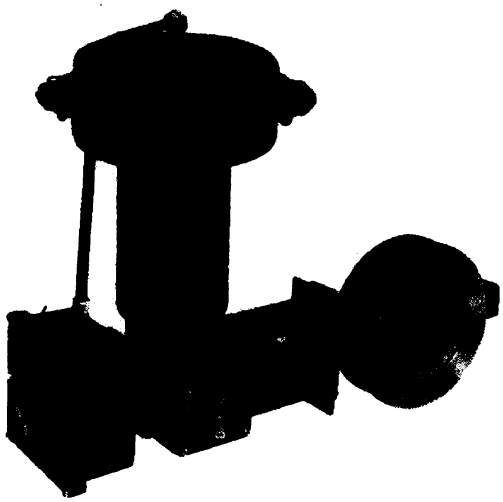
GENERAL

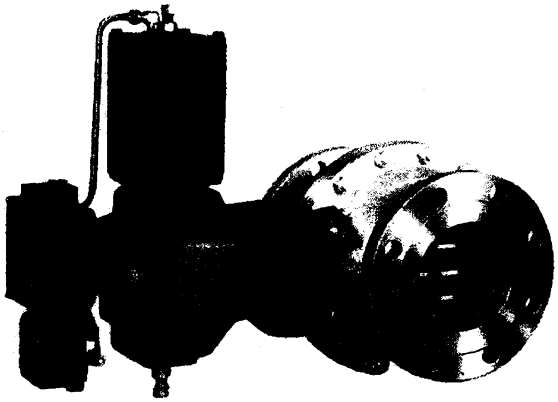
This bulletin provides all information necessary for the proper sizing and selection of Neles-Jamesbury control valves. It contains the most recent information available, including close adherence to current ANSI/ISA S75.01 Control Valve Sizing Equations.

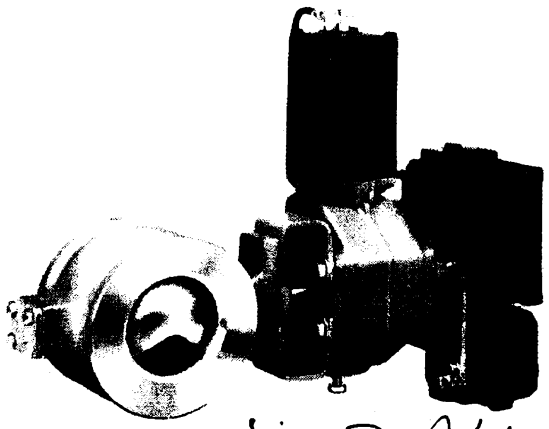
In view of the increasing importance today of accurate valve sizing, information contained in this bulletin is extensive, so that anyone selecting a valve for a specific application can readily determine the proper type of valve and correct valve size for the service conditions involved.

Circumstances may arise where additional assistance might be needed in sizing a valve. In such cases, help may be obtained either from the nearest Neles-Jamesbury control valve representative or from Neles-Jamesbury's office.









V-BALL

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DEFINITIONS

To understand the behavior of a valve under actual flow conditions, it is essential to know its flow characteristic. To fully describe this characteristic, special terminology has been developed. Definitions of this terminology are given below.

Inherent Flow Characteristic

The inherent flow characteristic of a valve describes the relationship between flow capacity of the valve and the percentage of opening of the valve while the pressure drop across the valve remains constant. The relationship may be described graphically by plotting the percentage of maximum flow capacity against the degree of opening expressed as percent opening (see Figure 1).

Installed Flow Characteristic

The installed flow characteristic of a valve is the relationship between actual flow through the valve and the percent opening of the valve. The installed flow characteristic is usually significantly different than the inherent characteristic because in actual practice the pressure drop across the valve usually varies with the flow through the system. The inherent characteristic is found with the pressure drop held constant as the flow changes.

Linear Flow Characteristic

The linear flow characteristic is defined as that characteristic which produces changes in flow directly in proportion to degree of valve opening. If such a valve is moved from thirty percent to forty percent open, the flow capacity also increases from thirty percent to forty percent of maximum. If a graph is plotted with percent valve opening on one axis and percent of maximum flow along the other axis, a linear flow characteristic will be represented by a straight line (see curve 1 below).

Equal Percentage Characteristic

The equal percentage flow characteristic is defined as that characteristic which will produce equal percentage increments in flow for equal increments in openings. If the Neles-Jamesbury ball valve is moved from twenty percent to thirty percent open the flow capacity changes from four percent of maximum to six percent of maximum, a fifty percent increase. If this valve is then moved from thirty percent to forty percent open the flow capacity increases from six percent to nine percent of maximum, again a fifty percent increase (see curve 3 below).

A perfect equal percentage characteristic can be represented on semi-log graph paper as a straight line. A valve with an equal percentage inherent flow characteristic is by far the most common type of flow control valve used.

Other Flow Characteristics

Other types of control valves may have characteristics which lie between linear and equal percentage and which are often described as parabolic, modified parabolic, or modified linear. Any valve where the flow increase per degree of opening is greater than for a linear valve is known as a quick opening valve and is suitable primarily for on-off control only.

Flow Coefficient (C_v)

The flow coefficient of a valve is also referred to as the sizing coefficient or the valve constant. It is used to describe the flow capacity of the valve and is an empirically determined constant equal to the flow capacity of the valve in U.S. gallons per minute of water at 60 degrees F when a pressure drop of 1 psi is applied across it in the wide open position. For convenience in control valve terminology, the flow capacity of control valves in partially open positions is also stated in terms of the effective C_v. In this way, partially open flow capacities may be related directly to the flow coefficient under the same standard set of conditions.

Rangeability

The term is intended to express the ratio between the maximum flow coefficient and the minimum flow coefficient at which it is practical to throttle the valve continuously. In other words, if a valve will perform well from the point of view of both accuracy and longevity at one percent of its maximum C_v, then the rangeability of that valve is a hundred to one.

THROTTLING CHARACTERISTICS

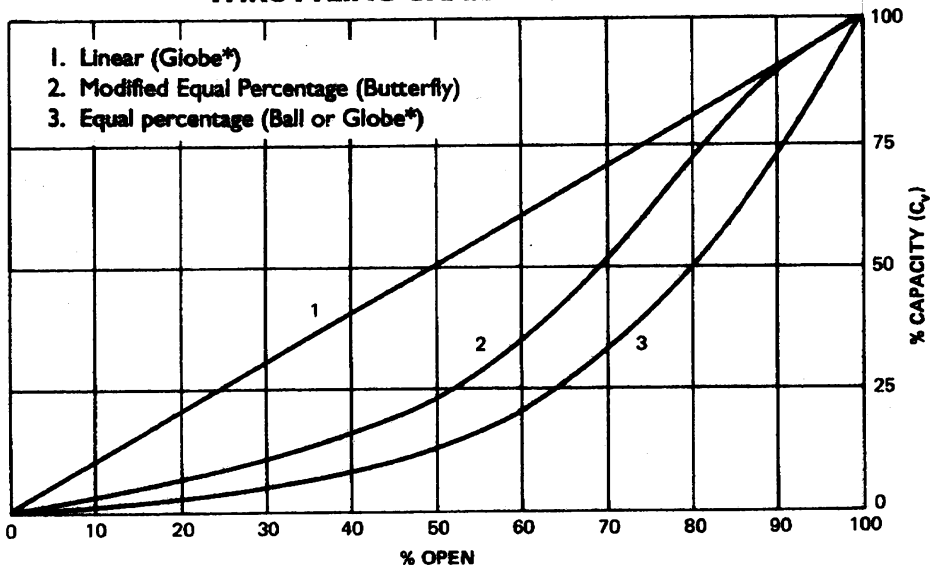


Figure 1

* Neles-Jamesbury globe valves are available with linear or equal percentage characteristics.

VALVE CHARACTERISTICS

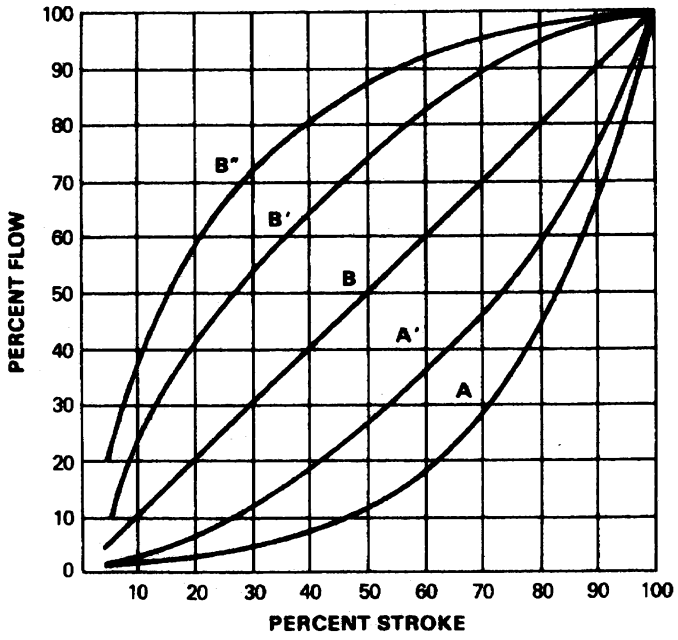
The selection of the proper valve characteristic is one of the most important phases of designing a control loop. It is not enough to assume that a stable process with a wide proportional band plus integral (reset) controller will cover up any mismatch between the process and the valve characteristic. While it is true that an exact match between valve and process would require a characteristic especially designed for the process, it is possible to choose the better of two standard characteristics (linear or equal percentage) for the process. This is important since a serious mismatch will cause the system to be unstable and difficult to control effectively.

The linear flow characteristic produces a flow rate which varies in direct proportion to change in valve stem position at a constant pressure drop. That is, for 10 percent of valve stem travel, the valve will pass 10 percent of its rated C_v; for 20 percent of travel, 20 percent of its rated C_v, and so on.

The equal percentage characteristic is so named because for equal increments of stem travel, at constant pressure drop, an equal percentage change in existing flow occurs. This means that the same *percentage* increase in flow will occur when the stem position changes from 40 to 50 percent of travel, for example, as would occur when stem position changes from 70 to 80 percent of travel.

In actual practice, a valve has two characteristics. One is the design or inherent characteristic, which the valve exhibits in laboratory conditions where the pressure drop (ΔP) is held constant. The second characteristic is the most important one, and can be called the resultant or installed characteristic. This is the relationship between flow and stroke when the valve is subjected to the pressure conditions of the process. While C_v is an expression for liquid flow at a constant pressure differential, Figure 3, flow versus stroke, shows how the design or inherent characteristic is changed by variations in pressure differential. This occurs as the process changes from high flows, where pressure differential is distributed throughout the system, to low flows, where most of the pressure differential is concentrated at the control valve. This variation in pressure differential concentration is one of the most important aspects in choosing the proper characteristics for a given process.

DIFFERENTIAL PRESSURE EFFECTS



A — EQUAL PERCENTAGE CHARACTERISTIC

$$\frac{\text{MAX}\,\Delta p}{\text{MIN}\,\Delta p} = 1$$

A' — EQUAL PERCENTAGE CHARACTERISTIC

$$\frac{\text{MAX}\,\Delta p}{\text{MIN}\,\Delta p} = 2\tfrac{1}{2}$$

B — LINEAR CHARACTERISTIC

$$\frac{\text{MAX}\,\Delta p}{\text{MIN}\,\Delta p} = 1$$

B' — LINEAR CHARACTERISTIC

$$\frac{\text{MAX}\,\Delta p}{\text{MIN}\,\Delta p} = 2\tfrac{1}{2}$$

B" — LINEAR CHARACTERISTIC

$$\frac{\text{MAX}\,\Delta p}{\text{MIN}\,\Delta p} = 5$$

Figure 3

The net effect of the phenomena shown in figure 3 is that as the percentage of system pressure drop across the valve decreases, the valve responds more like a linear valve in the case of equal percentage, and quick opening in the case of a linear inherent valve. As an example, curve A is an inherent equal percentage characteristic. Curve A' can be considered the response of the same equal percentage valve when the total system was 100 psi and the valve takes a 40 psi pressure drop.

RANGEABILITY CONSIDERATIONS

The term "rangeability" is defined as "the ratio of maximum controllable flow to minimum controllable flow." Thus a valve with a characteristic curve as shown will have a rangeability of $\frac{100}{2}$, or 50:1.

Valve rangeability must be based on controllable flow. It is impractical, from a manufacturing standpoint, to characterize flow when the valve is barely open. Likewise, at shutoff it is impossible to characterize any leakage flow that may occur. If minimum flow, not minimum controllable flow, were used, a valve with bubble-tight shutoff would have infinite rangeability. Such reasoning is logical, but unrealistic.

Since C_v is an expression of flow capacity, the definition of rangeability can be restated to be "the ratio of rated C_v to minimum controllable C_v." (See Figure 4.)

To determine the required rangeability needed in a control valve for a particular set of flow conditions, merely take the ratio of maximum required C_v to minimum required C_v.

If this ratio is less than the available rangeability in the valve, you will be able to control properly.

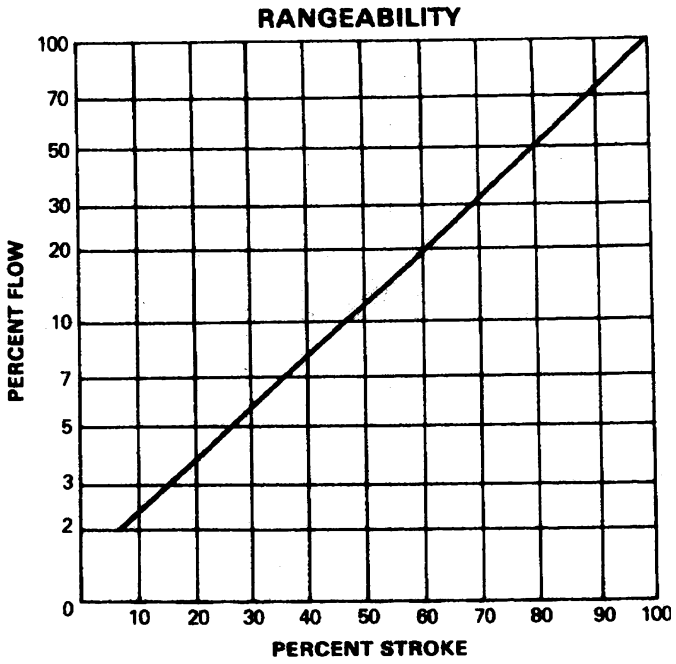


Figure 4

DETERMINING PRESSURE DROP ACROSS THE VALVE

The desired flow rate, specific gravity, temperature, and upstream specific volume are quantities that are easily determined. What is not so readily available is the throttling pressure drop. It is most important to realize that a control valve does not define the pressure drop across it. It will absorb whatever excess pressure is left in the system. This point can be illustrated graphically by the hydraulic gradient method. At maximum flow rate, plot fluid static pressure vs. physical location in the system.

Plot delivered and remaining pressure from left to right, and stop at the control valve. Then plot required pressure from right to left, stopping at the control valve. The difference between these final points is the pressure drop which the control valve must maintain at maximum flow. (See Figure 5.)

A similar analysis can be made for minimum flow. From a pump curve, outlet pressure is higher at low flow. Because of the lower fluid velocity, the pressure loss through the pipe and fittings will be much less than at maximum flow. This greatly increases the delivered pressure at the inlet of the control valve and also decreases the required pressure at the outlet of the control valve. As a result, the pressure drop which must be maintained across the control valve is much greater at the low flow rate than it is at the high flow rate. (See Figure 5.)

To make sure that valve size is properly calculated, sizing is always done at maximum flow rate and minimum pressure drop to determine maximum C_v requirements, and at minimum flow and maximum ΔP to determine minimum C_v requirements.

PRESSURE DROP THROUGH CONTROL VALVES (MAX. AND MIN.)

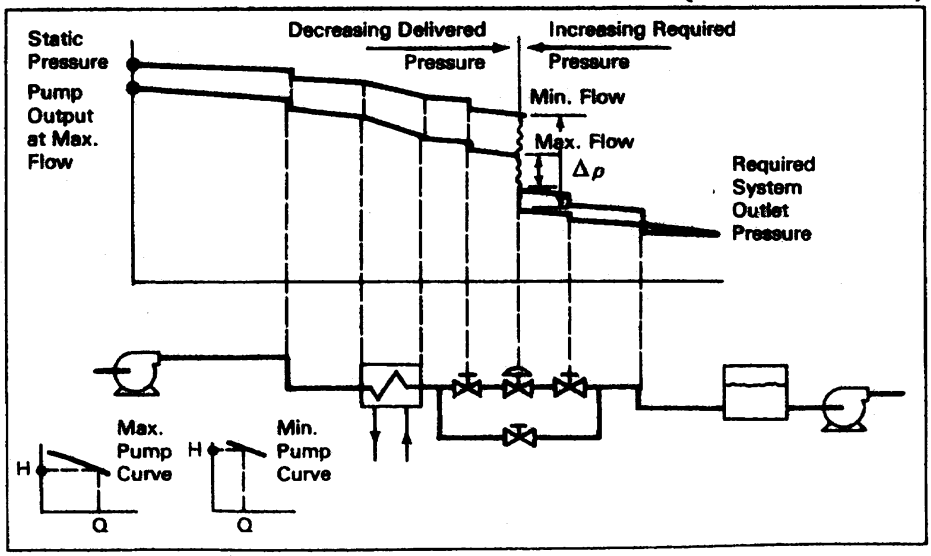


Figure 5

NON-COMPRESSIBLE FLOW SIZING

The basic formulas expressed in English units are:

$$C_v = \frac{Q\sqrt{G}}{\sqrt{\Delta p}}$$

$$C_v = \frac{W}{500\sqrt{G\Delta p}}$$

Where
- Q = Flow in U.S. gallons per minute
- G = Specific gravity
- Δp = Pressure drop in pounds per square inch
- W = Flow in pounds per hour

The above formulas using metric units are:

$$C_v = \frac{1.16W}{\sqrt{G}\sqrt{\Delta p}}$$

$$C_v = \frac{1.16V\sqrt{G}}{\sqrt{\Delta p}}$$

Where
- W = Flow in thousands of kilograms per hour
- G= Specific gravity
- Δp = Pressure drop in bars
- V = Flow in cubic meters per hour

A coefficient, A_v, using international units has been adopted by I.S.O.

$$A_v = \frac{Q\sqrt{\gamma}}{\sqrt{\Delta p}}$$

Where
- Q = Flow, m^3/Sec.
- Δp = Pressure drop N/m^2
- γ = Density kg/m^3
- $A_v = 24.0 \times 10^{-6} C_v$

These formulas assume single phase non-viscous and non-cavitating flow. The following sample calculation is expressed in English units. The same method, however, applies to any C_v calculation.

Each formula can be rewritten to solve for flow or pressure drop as shown.

For flow Q $Q = C_v\sqrt{\frac{\Delta p}{G}}$

For pressure drop Δp $\Delta p = \frac{Q^2 G}{C_v^2}$

Sample Calculation $\sqrt{\Delta P} = \frac{Q}{C_V} \times \sqrt{G}$

32	SERVICE CONDITIONS FLUID		SUGAR SOL.	
33	QTY. MIN.	QTY. MAX.	100	800
34	QTY. NORM. @ F. T.		300	
35	PRESS. MAX. IN	NORM. OUT	50	25
36	Δp @ MIN. FLOW	Δp @ MAX. FLOW	30	4.0
37	TEMP. MAX.	NORM.	100°F	75°F
38	SP. GR. @ 60°F	@ F. T.	N/A	1.2
39	VISCOSITY @ F. T.		N/A	
	NOTES:			

For maximum required C_v, use maximum flow and Δp sizing as these conditions exist when valve is fully open.

$$C_v = \frac{Q\sqrt{G}}{\sqrt{\Delta p}} \qquad C_v = \frac{800\sqrt{1.2}}{\sqrt{4.0}} \qquad C_v = 438$$

C_v at min. flow condition is:

$$C_v = \frac{Q\sqrt{G}}{\sqrt{\Delta p}} \qquad C_v = \frac{100\sqrt{1.2}}{\sqrt{30}} \qquad C_v = 20$$

After calculating C_v refer to tables 2 through 33 to determine valve size, type, and pressure class.

VISCOSITY CORRECTION

Calculate the C_v as shown before without taking viscosity into account. Now calculate the C_v again using the formula below.

$$C_v = \frac{1}{F_s}\left(\frac{Q_\mu}{47\Delta p}\right)^{2/3}$$

Where
- μ = Viscosity in centipoise
- Q = Flow rate in gpm
- Δp = Pressure drop in psi
- F_s = 1.25 for ball valves
  1.03 for butterfly valves
  1.05 for globe valves
  (valve style correction factor)

Centipoise = Centistokes X specific gravity

100 centipoise = 1 poise

The equation above is for laminar flow which is induced by high viscosity and/or low flow rate.

Divide the C_v for laminar flow from the equation above by the C_v for turbulent flow from the standard equation. If the result is between 0.08 and 2.0 refer to Figure 6 to determine the Reynolds number correction factor, F_R, for transitional flow. Divide the C_v for turbulent flow by F_R to arrive at the corrected C_v.

$$C_{v\,(corrected)} = \frac{C_v\,(turb)}{F_R}$$

If the result of C_v(lam)/C_v(turb) is less than 0.08, use the C_v for turbulent flow. If the result is greater than 2.0 use the C_v for laminar flow.

F_R—REYNOLDS NUMBER CORRECTION FACTOR

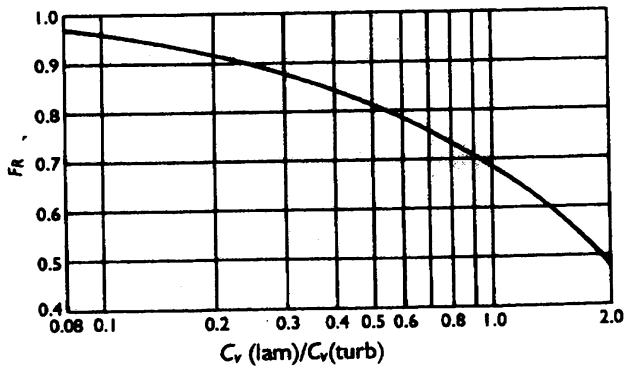


Figure 6

CAVITATION

One of the prime advantages of the ball valve is its extremely high flow capacity - two to three times that of a conventional globe or cage valve. The consequent disadvantage is the ball valve's greater tendency to cavitate. This section explains cavitation, what causes it, and how to avoid it in control valve applications.

What Is Cavitation?

Cavitation is a phenomenon which may be found in any fluid process where low and higher pressure areas exist. In the low pressure area, liquids boil, forming vapor bubbles, which then move into an area of high pressure where the vapor condenses and the bubbles collapse. The liquid surfaces come together with considerable velocity, sending out severe shock waves through the liquid. The shock waves are radiated equally in all directions, but if the implosion occurs at a metal surface, half the energy of the shock wave is imparted to the adjacent metal. Under repeated implosions, severe damage to the metal surface may occur.

The Causes of Cavitation in Control Valves

In order to satisfy the law of conservation of energy, the total energy, that is, the sum of the potential and kinetic energy which a liquid possesses, must remain constant, except for the losses due to friction. The kinetic energy of the liquid is dependent on its velocity. The potential energy is dependent on the pressure of the liquid. Therefore, if over a very short distance (where friction losses can be neglected), the velocity of a fluid is increased, the pressure must decrease to maintain the same total energy level. Conversely, if the velocity is decreased, the pressure must increase.

As liquid passes through a control valve, the total volume of liquid flows through an orifice which is far smaller than the size of the pipe in which the valve is installed. In order for the liquid to pass through the small area, its velocity must increase. In Figure 7, the velocity at point B is far greater than at point A. In actual fact, the liquid reaches maximum velocity at point C, known as the *Vena Contracta*. At the *Vena Contracta*, the cross sectional area of the stream is actually less than in the narrowest portion of the valve. It is fairly clear that between points C and D, the liquid slows down back to line velocity and, therefore, recovers a considerable amount of pressure. Hence, the term "high recovery" valve.

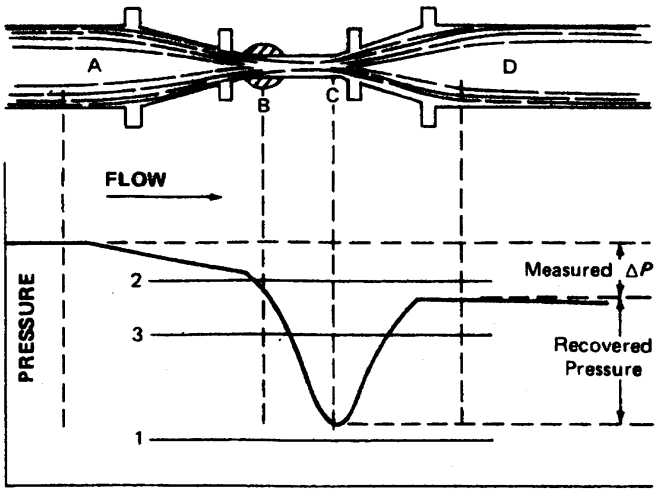


Figure 7

In the pressure profile curve (Figure 7), the vapor pressure of the liquid may be in the position 1, 2, or 3. If the vapor pressure is in position 1, the pressure at point C is never below the vapor pressure and consequently the liquid does not boil. If the vapor pressure is in position 2, the fluid pressure drops below it somewhere in the valve and the liquid boils but never recovers enough pressure to recondense. This is referred to as flashing, not cavitation.

Cavitation occurs when the vapor pressure is in position 3. At point C, the pressure of the liquid is below the vapor pressure and the liquid flashes. At point D, however, the pressure of the liquid is again above its vapor pressure and recondensation occurs, resulting in severe cavitation.

Ball valves cavitate at lower pressure drops than globe and cage valves because of their greater flow capacity and similar port areas (see Figure 8). The resulting higher velocities at the *Vena Contracta* contribute to a greater pressure recovery. It is interesting, however, to note that if a comparison is made of the ball valve's cavitation index (F_L) or point at which cavitation begins versus the valve's flow coefficient (C_v) at that opening which is essentially equivalent to a fully open globe valve of equal size, the values of F_L will be approximately the same.

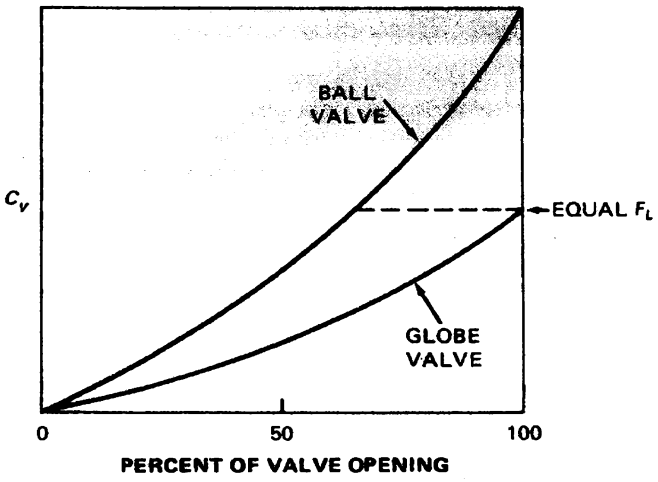


Figure 8

Predicting and Avoiding Cavitation

Predicting cavitation can be accomplished by solving the following equation:

$$\Delta P_T = F_L^2 (P_1 - F_F P_v)$$

Where:
- F_L = Liquid pressure recovery factor
- P_1 = Inlet pressure psia
- P_v = Vapor pressure at inlet temperature in psia
- ΔP_T = Maximum pressure drop at which increased flow results at given P_1
- F_F = Liquid critical pressure ratio factor

It can be assumed, for most practical applications, that the value of F_F for water is 0.96. Table 34 is included to give some values for critical pressure for some of the more common liquids.

The value of F_F can be determined from Figure 9, where F_F is plotted versus vapor pressure divided by critical pressure.

If the value of ΔP_T determined above is greater than the ΔP used the equations on page 8 (ΔP for actual flow conditions), ed flow does not exist. If ΔP_T is less than ΔP across the valve, a cavitating condition.

The intent, of course, is to size the control valve into a system to provide maximum length of service and still provide good

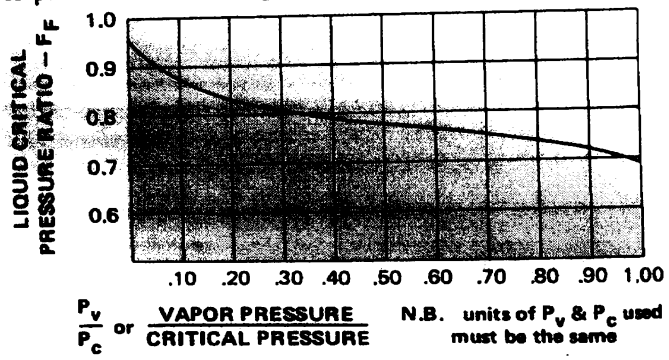


Figure 9

throttling characteristics. Looking at the equation on page 9, which determines the maximum allowable pressure drop, it can be seen that increasing F_L or P_1 or decreasing P_v will increase allowable pressure drop. To increase F_L use a larger size valve at a smaller opening in order to provide the same C_v, i.e., a 2" valve at 80% open has a C_v of 78 and F_L of 0.65, a 3" valve is 62% open at a C_v equal to 78 where F_L is 0.79, while a 6" valve is 45% open and has an F_L of 0.87.

Upstream pressure can be increased by placing the valve at the lowest possible elevation or close to the pressure source. Vapor pressure, P_v, is a function of temperature and can be reduced only by placing the valve at a location of lower fluid temperature.

Although F_L is an accurate measurement of choked flow, it is not a good indicator of potential damage and noise. Using a lower pressure drop ratio than F_L is recommended to avoid these undesirable effects. Consult a Neles-Jamesbury field representative or Neles-Jamesbury's home office for recommendations on specific applications.

The vapor pressure of water in relation to temperature is shown in Table 36.

COMPRESSIBLE FLOW SIZING

Valve sizing for compressible flow is performed in a manner similar to liquid sizing. Equations below are used to solve for C_v required whereby one refers to the C_v listing for valves and chooses the appropriate size for the conditions as described viously.

e basic formulas expressed in English units are:

Volume Basis:

$$C_v = \frac{Q}{1360 P_1 Y}\sqrt{\frac{GT}{X}}$$

Weight Basis:

$$C_v = \frac{W}{19.3 P_1 Y}\sqrt{\frac{T}{XM}}$$

Any vapor:

$$C_v = \frac{W}{63.3Y}\sqrt{\frac{V_1}{XP_1}}$$

F_K = Ratio of specific heats factor = $K/1.40$ (see Table 1)
G = Specific gravity at standard conditions (Air = 1; see Table 38 for other gases)
M = Molecular weight (Air = 29; see Table 38 for other gases)
P_1 = Upstream pressure in psia
Δp = Pressure drop ($P_1 - P_2$)
Q = Flow rate, scfh
T = Absolute temperature °R = (°F + 460)
V_1 = Specific volume cu. ft. per lb; see steam tables
W = Flow rate, lb./hr.
X = Actual pressure drop ratio, $\Delta p/P_1$
X_T = Rated pressure drop ratio of valve $\Delta p/P_1$ (see section on choked flow and Fig. 10)
Y = Expansion factor, dimensionless = $1 - (X/3F_KX_T)$ (see section on choked flow)

These formulas using metric units are:

Volume Basis:

$$C_v = \frac{Q}{417 P_1 Y}\sqrt{\frac{GT}{X}}$$

Weight Basis:

$$C_v = \frac{W}{94.8 P_1 Y}\sqrt{\frac{T}{XM}}$$

Any vapor:

$$C_v = \frac{W}{27.3Y}\sqrt{\frac{V_1}{XP_1}}$$

F_K = Ratio of specific heats factor = $K/1.40$ (see Table 1)
G = Specific gravity at standard conditions (Air = 1; see Table 38 for other gases)
M = Molecular weight (Air = 29; see Table 38 for other gases)
P_1 = Upstream pressure in bars absolute
Δp = Pressure drop ($P_1 - P_2$)
Q = Flow rate, m^3/hr
T = Absolute temperature °K = (°C + 273)
V_1 = Specific volume m^3/kg
W = Flow rate, kg/hr.
X = Actual pressure drop ratio, $\Delta p/P_1$
X_T = Rated pressure drop factor of valve $\Delta p/P_1$ (see section on choked flow and Fig. 10)
Y = Expansion factor, dimenless = $1 - (X/3F_KX_T)$ (see section on choked flow)

Solving Compressible Flow Equations

Before solving any of the compressible flow equations, a number of variables must be known. They are flow rate, upstream pressure, pressure drop, temperature and either specific gravity or molecular weight. These variables are a function of system design and must be supplied by those familiar with the application. Once these parameters have been established, the C_v can be found by the method shown below.

$$C_v = \frac{Q}{1360 P_1 Y}\sqrt{\frac{GT}{X}} \qquad \text{where: } Y = 1 - \frac{X}{3F_K X_T}$$

$$X = \frac{\Delta p}{P_1}$$

NOTE:

Under choked flow conditions, the actual pressure drop ratio may exceed X_T in the sizing equations, however, $\Delta P/P_1$ or X must be numerically limited to $F_K X_T$. This means that at choked flow, the expansion factor, Y, reduces to 0.667.

Write the above equations down as shown. Now rewrite each again with the process conditions with appropriate units as shown above. It can be seen now that the expansion factor, Y, includes two terms for which there is no value as part of the conditions. These terms are derived as follows:

1. F_K is the ratio of specific heats factor which is described on page 12. The value of F_K for air is one and can be assumed as one for most other common gases without incurring any significant error.

2. X_T is the limiting pressure drop ratio and is a function of valve opening. When sizing a butterfly or ball control valve, use a value of 0.43 for X_T. This corresponds to a valve opening of 75%. When sizing an on-off valve, use 0.16 for ball valves and 0.37 for butterfly valves. These correspond to the fully open position.

The choice of 0.43 as the value of X_T for rotary control valve sizing is a conservative starting point for solving the equation and reduces the expansion factor equation to the form below (for $F_K = 1.0$):

$$Y = 1 - \frac{X}{1.29}$$

As an example, assume that solving for C_v as described yields a required value of 165. Referring to the ball valve sizing coefficient chart it can be seen that the required C_v corresponds to a 6" valve at 60% open, a 3" at about 80%, or an 8" at about 40% open. All are within the recommended throttling range. If the 3" or 8" valve in the example above was chosen, recalculate the required C_v with the value of X_T which corresponds to the actual valve opening from Figure 10.

Also check to be sure that the pressure drop ratio, X, used in the C_v calculation does not exceed $F_K X_T$.

CHOKED FLOW AND SONIC VELOCITY

When a compressible fluid at a constant upstream pressure is flowing through a restriction, the flow will increase when the downstream pressure is reduced. This change in downstream pressure is communicated by a pressure wave which travels at sonic velocity relative to the stream. The downstream pressure may be gradually reduced until the maximum fluid velocity reaches the speed of sound. After this point a greater reduction in downstream pressure cannot be sensed upstream because the velocity of the pressure wave relative to the stream becomes zero. This condition is known as choked flow and occurs when the pressure drop ratio $X = \Delta P/P_1$ equals $F_K X_T$. A *further* reduction in downstream pressure will not increase the flow rate. The geometry of the flow path varies with the percent of opening, and therefore X_T could be expected to vary in a similar manner. A substantial amount of flow testing with air was performed by an independent laboratory to determine the variation of X_T with percent opening in Neles-Jamesbury control valves. This characteristic is presented in Figure 10. Although X_T limits the flow capacity of a given valve it should be noted that physical damage to valve or piping does not result from exceeding these limits as it does in the case of cavitation.

The expansion factor, Y, accounts for the change in fluid density, as it passes from the valve inlet to the *Vena Contracta* which is the point of minimum jet cross sectional area just beyond the orifice. It also accounts for the change in area of the *Vena Contracta* as the pressure drop is varied. The factor, Y, is a function of F_K, X, and X_T and is expressed as:

$$Y = 1 - \frac{X}{3F_K X_T}$$

PRESSURE DROP RATIO FACTOR X_T AS A FUNCTION OF VALVE OPENING FOR NELES-JAMESBURY CONTROL VALVES LINE SIZE = VALVE SIZE

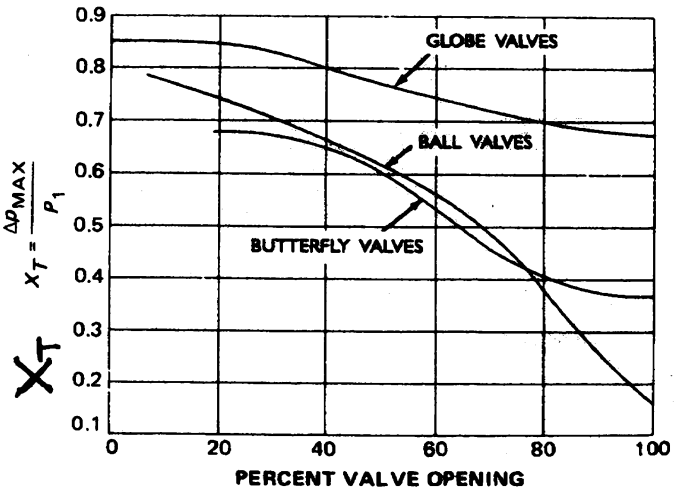


Figure 10

COMPRESSIBILITY

Compressibility is a term used to describe the departure of a real gas from a thermally perfect gas. For a thermally perfect g[illegible]ompressibility is 1.0. Applications where compressibility [illegible]s from 1.0 depend on the gas, the temperature, and the p[illegible]re.

For the majority of ball and butterfly valve applications, compressibility need not be taken into account because the temperatures and pressures are such that the error incurred by omission will be very small.

SPECIFIC HEATS CORRECTION

When dealing with gases other than air at pressure drop ratios close to X_T, a correction factor (Table 1) must be applied to X_T to compensate for the difference in ratio of specific heats between air and the given gas.

$$K = \frac{\text{Specific heat at constant pressure}}{\text{Specific heat at constant volume}}$$

$$F_K = \frac{K}{1.40}$$

TABLE 1 – K FOR TYPICAL GASES

GAS	K	GAS	K
Acetylene	1.26	Helium	1.67
Air	1.40	Hydrogen	1.41
Ammonia	1.29	Methane	1.31
Argon	1.67	Nitrogen	1.40
Carbon Dioxide	1.30	Nitrous Oxide	1.30
Chlorine (Dry)	1.34	Oxygen	1.40
Ethane	1.19	Sulphur Dioxide	1.26
Ethylene	1.25	Steam	1.31

EFFECT OF REDUCERS

In many cases control valves are less than line size, and adjustments must be made for reducer and expander losses. C_v's for ball valves installed in larger-than-body line sizes are shown in Table 2A.

These values are derived from the formula:

$$F_p = \frac{1}{\sqrt{1 + \frac{1.5(1 - [d^2/D^2])^2}{890}\left(\frac{C_v}{d^2}\right)^2}}$$

Where:

C_v = Rated sizing coefficient of valve without reducers
d = Nominal valve size in inches
D = Inside diameter of pipe in inches
C_{v_c} = Sizing coefficient of valve when installed with reducers
$C_{v_c} = C_v F_p$

[illegible]OISE PREDICTION

Pressure drop through a control valve is the dissipation of energy. Some of this energy is converted to acoustic energy or noise. Noise can be generated in both liquid and compressible flow streams and can be of concern when the noise level exceeds acceptable limits. A limit of 85 dB has been established as the maximum allowed for long term worker exposure. Furthermore, noise can result in equipment vibration which can cause mechanical failure.

Noise prediction, therefore, is an important part of control valve sizing and selection. Neles-Jamesbury has developed the necessary data for noise prediction which uses methods based on VDMA 24422. Calculation methods for determining sound pressure levels are included on the Neles-Jamesbury control valve sizing program for IBM and compatible computers.

FINDING ΔP ACROSS AN OPEN VALVE

To determine pressure drop of valves in the wide open position for compressible flow:

Step 1. Using the following equations, solve for $Y\sqrt{X}$.

For gases: $$Y\sqrt{X} = \frac{Q\sqrt{GT}}{1360\,C_v P_1}$$

For vapors: $$Y\sqrt{X} = \frac{W}{63.3C_v}\sqrt{\frac{V_1}{P_1}}$$

Where:

C_v = Wide open valve
W = Flow rate, lb./hr
Q = Flow rate, scfh
G = Specific gravity at standard conditions
T = Absolute temperature °R = (°F + 460)
P_1 = Inlet pressure in psia
V_1 = Specific volume cu. ft. per lb.

Step 2: Utilizing Figure 11, the graphic plot of $Y\sqrt{X}$ versus X for various values of X_T; determine the value of X for the given value of X_T.

Step 3: Determine ΔP using the expression $\Delta P = XP_1$.

If the determined value of $Y\sqrt{X}$ is greater than the terminal value shown on the graph ($Y\sqrt{X} = 0.667X_T$), one can conclude that a valve of the same type having a greater C_v than that given would be required to pass the given flow rate.

If the determined rate of $Y\sqrt{X}$ is equal to the terminal value shown on the graph, one can conclude that the pressure drop (ΔP) will be equal to or greater than the value established by Step 3. (Since the ΔP will be critical and is $\geq P_1X_T$.)

TABLE 2 – SIZING TABLES (C_V) FOR NELES JAMESBURY SERIES 5000 STANDARD PORT FLANGED BALL CONTROL VALVES

VALVE SIZE IS LINE SIZE										
	BALL ROTATION (Percent)									
Valve Size	10	20	30	40	50	60	70	80	90	100
1/2"	0.1	0.2	0.4	0.7	1.2	1.9	2.7	4.2	6.3	9
3/4"	0.2	0.4	0.9	1.4	2.5	4.0	5.7	9.0	13	19
1"	0.4	0.9	2.0	3.4	5.8	9.5	13.5	21	32	45
1-1/2"	1.1	2.4	5.6	9.4	16	26	38	58	88	125
2"	1.5	3.1	7.5	12	21	35	50	78	115	165
3"*	3	7	15	26	45	74	105	165	245	350
4"*	2	5	17	32	54	90	135	201	301	550
6"	7	15	35	57	100	160	230	360	535	765
8"	12	36	85	140	245	395	570	890	1325	1890
10" 5150	30	74	175	295	507	820	1170	1830	2730	3900
10" 5300	40	84	195	330	570	925	1320	2070	3080	4400
12"	60	127	300	505	870	1400	2010	3150	4690	6700
12" 5150	40	95	230	380	660	1070	1530	2400	3570	5100
14" 5300	45	104	240	400	700	1130	1620	2540	3780	5400
16" 5150	70	155	365	605	1050	1700	2430	3805	5670	8100
16" 5300	70	155	375	630	1100	1785	2550	3990	5950	8500
18" 5150	100	210	470	825	1430	2310	3300	5170	7700	11,000
18" 5300	100	200	440	760	1275	2050	2940	4600	6860	9800
20" 5150	145	304	720	1200	2080	3360	4800	7520	11,200	16,000
20" 5300	125	260	610	990	1700	2750	3900	6110	9100	13,000
F_L	0.91	0.91	0.90	0.88	0.85	0.80	0.74	0.65	0.55	0.46
X_T	0.82	0.82	0.80	0.75	0.67	0.57	0.42	0.28	0.20	0.15

TABLE 2A

VALVE IN LARGER LINE SIZES											
		BALL ROTATION (Percent)									
Valve Size	Line Size	10	20	30	40	50	60	70	80	90	100
1"	1-1/2"	0.4	0.9	2.0	3.4	5.8	9.3	12.9	19	26	31
	2"	0.4	0.9	2.0	3.4	5.8	9.1	12.5	17.6	23	26
1½"	2"	1.1	2.4	5.6	9.4	16	25	36	53	72	88
	3"	1.1	2.4	5.6	9.4	16	25	34	45	56	63
2"	3"	1.5	3.1	7.5	12	21	34	48	71	96	120
	4"	1.5	3.1	7.5	12	21	34	47	67	86	102
3"*	4"	3	7	15	26	45	73	103	157	220	287
	6"	3	7	15	26	45	72	99	144	188	224
4"*	6"	2	5	17	32	54	88	132	193	275	430
	8"	2	5	17	32	54	85	130	187	260	378
6"	8"	7	15	35	57	100	160	229	354	517	715
	10"	7	15	35	57	100	160	227	348	500	670
	12"	7	15	35	57	100	160	226	344	485	640
8"	10"	17	36	85	140	245	393	565	870	1265	1730
	12"	17	36	85	140	245	391	560	850	1195	1570
	14"	17	36	85	140	245	389	555	830	1150	1465
	16"	17	36	85	140	245	388	550	820	1115	1395
10"	12"	30	74	175	295	507	816	1158	1785	2580	3500
	14"	30	74	175	295	505	810	1140	1720	2395	3070
	16"	30	74	175	295	500	803	1125	1665	2255	2790
	18"	30	74	175	295	497	795	1100	1595	2090	2495
12"	14"	60	127	300	505	870	1392	1985	3065	4420	5975
	16"	60	127	300	505	865	1380	1950	2930	4050	5140
	20"	60	127	300	500	859	1355	1885	2730	3565	4240
	24"	60	127	300	495	855	1340	1845	2615	3310	3835
14"	16"	40	95	230	380	660	1070	1525	2385	3515	4950
	18"	40	95	230	380	660	1065	1520	2355	3425	4700
	20"	40	95	230	380	660	1065	1510	2325	3335	4480
	24"	40	95	230	380	655	1060	1495	2280	3200	4170
16"	18"	70	155	365	605	1050	1695	2420	3775	5570	7815
	20"	70	155	365	605	1050	1690	2405	3715	5390	7335
	24"	70	155	365	605	1045	1680	2375	3605	5060	6570
	30"	70	155	365	605	1040	1670	2340	3485	4750	5935
18"	20"	100	210	470	825	1430	2305	3290	5130	7570	10,635
	24"	100	210	470	825	1425	2290	3245	4970	7080	9390
20"	24"	145	304	720	1200	2075	3340	4745	7320	10,570	14,300
	30"	145	304	720	1195	2065	3300	4630	6910	9440	11,820

* Series MBV Standard-Bore Ball Valves

TABLE 9 – SIZING TABLES (C_v) FOR NELES-JAMESBURY 3-WAY REDUCED PORT FLANGED BALL CONTROL VALVES

FLOW INTO COMMON (SIDE) PORT

VALVE SIZE IS LINE SIZE											
Ball Stroke (Percent) – Port C to A and B*											
Valve Size	0	10	20	30	40	50	60	70	80	90	100
2"	50	49	48	43	36	30	36	43	48	49	50
3"	155	153	147	132	105	93	105	132	147	153	155
4"	270	264	256	230	184	162	184	230	256	264	270
6"	440	431	418	374	300	264	300	374	418	431	440
8"	880	862	836	748	600	328	600	748	836	862	880
10"	1500	1470	1420	1275	1020	900	1020	1275	1420	1470	1500
12"	2300	2260	2180	1960	1500	1380	1500	1960	2180	2260	2300

*NOTE: Flow entering common port (C) and exiting ports A and B for equal piping on A and B ports.

TABLE 9A

FLOW INTO END PORTS

Ball Stroke (Percent)												
Valve Size	B to C	0	10	20	30	40	50	60	70	80	90	100
	A to C	100	90	80	70	60	50	40	30	20	10	0
2"		50	48	45	37	25	15.0	9.0	5.0	2.5	1.0	0
3"		155	149	140	115	78	47	28	15.5	7.8	3.1	0
4"		270	259	243	200	135	81	49	27	13.5	5.4	0
6"		440	422	396	326	220	132	79	44	22	8.8	0
8"		880	844	792	652	440	164	158	88	44	17.6	0
10"		1500	1440	1350	1110	750	450	270	150	75	30	0
12"		2300	2200	2080	1700	1150	690	414	230	115	46	0

TABLE 10 – SIZING TABLE (C_v) FOR NELES-JAMESBURY SERIES R SEGMENT BALL VALVES

BALL ROTATION (Percent)										
Valve Size	10	20	30	40	50	60	70	80	90	100
1"	0.52	1.13	2.23	3.83	5.95	8.58	11.7	16.2	24.1	45
1" w/ C15 Trim	0.48	0.89	1.40	2.09	2.91	4.06	5.63	7.66	10.7	15
1" w/ C05 Trim	0.24	0.45	0.65	0.88	1.17	1.54	2.04	2.77	3.76	5
1" w/ C015 Trim	0.10	0.20	0.31	0.41	0.54	0.67	0.83	1.02	1.26	1.55
1" w/ C005 Trim	0.03	0.06	0.10	0.14	0.19	0.24	0.29	0.35	0.42	0.5
1-1/2"	1.33	3.27	6.44	11.1	17.2	24.8	33.9	46.5	69.3	110
2"	2.05	5.07	10.0	17.2	26.6	38.4	52.5	72.4	108	180
3"	4.73	11.6	23.0	39.4	61.0	88.2	121	165	246	420
4"	7.57	18.6	36.8	63.1	97.7	141	193	264	393	620
6"	13.9	34.1	67.2	115	178	258	352	484	719	1260
8"	22.5	55.3	109	187	290	418	571	784	1164	2030
10"	35.3	86.9	171	294	455	658	900	1236	1831	3210
12"	49.8	123	243	418	648	937	1278	1754	2601	4490
14"	63.9	158	311	534	827	1193	1628	2237	3320	6440
16"	85.4	210	414	713	1106	1599	2180	2989	4432	8510
F_L	0.94	0.93	0.92	0.88	0.85	0.81	0.78	0.72	0.61	0.42
X_T	0.64	0.64	0.63	0.62	0.59	0.54	0.49	0.40	0.32	0.16

TABLE 11 – SIZING TABLE (Cv) FOR NELES-JAMESBURY SERIES R SEGMENT BALL VALVES WITH Q-TRIM

BALL ROTATION (Percent)										
Valve Size	10	20	30	40	50	60	70	80	90	100
2"	1.07	2.51	4.52	6.9	10.2	14.2	19	26	35.6	47
3"	3.59	8.4	15.2	23.2	34.3	47.6	64	87.5	120	160
4"	5.68	13.3	24.1	36.8	54.3	75.3	101	139	190	250
6"	12.3	28.9	52.2	79.6	118	163	219	300	412	540
8"	20.0	47.0	84.8	130	191	265	357	488	669	880
10"	34.3	80.4	145	222	328	455	611	836	1146	1510
12"	49	114	206	315	466	646	868	1190	1630	2140
14"	72	167	303	462	684	948	1273	1746	2371	3160
16"	95	221	401	611	905	1254	1685	2310	3164	4180
F_L	0.95	0.95	0.95	0.95	0.95	0.93	0.90	0.86	0.79	0.64
X_T	0.82	0.83	0.83	0.82	0.79	0.74	0.67	0.60	0.51	0.40

TABLE 12A – SIZING TABLES (C_V) FOR L11C/L21C NELDISC® METAL-SEATED BUTTERFLY VALVES

	DISC ROTATION (Percent)									
Valve Size	10	20	30	40	50	60	70	80	90	100
3"	12.5	31.3	51.0	75.0	103	137	174	208	238	245
4"	17.0	40.4	73.0	108	152	198	255	321	413	450
6"	37.8	82.6	139	212	306	430	596	820	1116	1500
8"	76.8	168	283	432	622	874	1212	1668	2268	3050
10"	123	269	453	691	995	1398	1939	2669	3622	4870
12"	184	403	680	1037	1492	2097	2909	4003	5429	7300
14"	265	580	978	1492	2147	3018	4186	5762	7809	10,500
16"	346	756	1274	1944	2797	3931	5454	7506	10,189	13,700
18"	442	966	1628	2484	3574	5023	6969	9591	13,089	17,600
20"	550	1204	2030	3096	4455	6261	8686	11,954	16,287	21,900
24"	781	1708	2879	4392	6320	8882	12,322	16,958	23,055	31,000
30"	1180	2583	4354	6642	9557	13,432	18,635	25,646	34,880	46,900
36"	1674	3661	6171	9414	13,546	19,037	26,412	36,349	49,382	66,400
40"	2086	4564	7694	11,736	16,887	23,733	32,926	45,314	61,578	82,800
F_L	0.87	0.85	0.83	0.81	0.77	0.73	0.67	0.60	0.49	0.36
X_T	0.53	0.53	0.53	0.52	0.47	0.41	0.35	0.27	0.19	0.11

TABLE 12B – SIZING TABLES (C_V) FOR L11D/L1D/L21D/L2D NELDISC® METAL-SEATED BUTTERFLY VALVES

	DISC ROTATION (Percent)									
Valve Size	10	20	30	40	50	60	70	80	90	100
3"	12.5	31.3	51.0	75.0	103	137	174	208	238	245
4"	17.0	40.4	73.0	108	152	198	255	321	413	450
6"	41.6	87.4	144	213	304	422	576	757	1013	1240
8"	71.6	150	247	367	523	727	992	1300	1734	2130
10"	107	225	370	549	783	1088	1485	1951	2581	3180
12"	172	360	592	879	1250	1740	2380	3120	4171	5090
14"	252	528	870	1290	1835	2550	3480	4580	6152	7470
16"	307	644	1058	1570	2240	3110	4250	5580	7444	9100
18"	408	857	1408	2090	2980	4140	5650	7425	9941	12,100
20"	488	1025	1680	2500	3560	4950	6760	8880	11,828	14,400
24"	616	1290	2130	3160	4500	6250	8530	11,200	14,794	22,000
F_L	0.86	0.85	0.83	0.81	0.78	0.75	0.71	0.65	0.56	0.49
X_T	0.53	0.53	0.53	0.52	0.50	0.44	0.39	0.33	0.25	0.17

TABLE 13A – SIZING TABLES (C_V) FOR SERIES L6C NELDISC® METAL-SEATED BUTTERFLY VALVES

	DISC ROTATION (Percent)									
Valve Size	10	20	30	40	50	60	70	80	90	100
4"	11.3	22.7	40.5	61.2	86.4	115	148	167	176	180
5"	17	34	60.8	91.8	130	173	221	251	265	270
6"	32.1	64.3	115	173	245	326	418	474	500	510
8"	36.5	85.1	146	231	328	462	621	828	1156	1350
10"	73.7	172	295	467	663	934	1256	1673	2337	2730
12"	118	275	471	746	1059	1491	2006	2673	3732	4360
14"	177	413	707	1120	1592	2240	3013	4015	5607	6550
16"	254	593	1017	1611	2289	3222	4333	5774	8064	9420
18"	332	775	1328	2103	2989	4207	5658	7540	10529	12300
20"	424	989	1696	2685	3815	5369	7222	9624	13439	15700
24"	532	1241	2128	3369	4787	6737	9062	12076	16863	19700
28"	751	1751	3002	4754	6755	9508	12788	17041	23797	27800
32"	953	2224	3812	6036	8578	12073	16238	21639	30217	35300
36"	1296	3024	5184	8208	11664	16416	22080	29424	41088	48000
40"	1607	3749	6426	10175	14459	20349	27370	36474	50932	59500
48"	2006	4681	8024	12705	18055	25411	34178	45546	63601	74300
52"	2808	6552	11232	17784	25272	35568	47840	63752	89024	104000
56"	2808	6552	11232	17784	25272	35568	47840	63752	89024	104000
60"	2808	6552	11232	17784	25272	35568	47840	63752	89024	104000
F_L	0.87	0.85	0.83	0.81	0.77	0.73	0.67	0.60	0.49	0.36
X_T	0.53	0.53	0.53	0.52	0.47	0.41	0.35	0.27	0.19	0.11

TABLE 13B – SIZING TABLES (C_V) FOR SERIES L6D NELDISC® METAL-SEATED BUTTERFLY VALVES

	DISC ROTATION (Percent)									
Valve Size	10	20	30	40	50	60	70	80	90	100
4"	11.3	22.7	40.5	61.2	86.4	115	148	167	176	180
5"	17.0	34.0	60.8	91.8	130	173	221	251	265	270
6"	32.1	64.3	115	173	245	326	418	474	500	510
8"	33.0	83.4	139	213	297	412	548	705	927	1030
10"	57.0	144	240	368	513	712	947	1218	1602	1780
12"	85.1	215	359	551	766	1064	1415	1819	2394	2660
14"	136	345	575	882	1227	1704	2266	2914	3834	4260
16"	200	505	842	1292	1797	2496	3320	4268	5616	6240
18"	244	617	1029	1577	2195	3048	4054	5212	6858	7620
20"	323	818	1364	2091	2909	4040	5373	6908	9090	10100
24"	387	980	1634	2505	3485	4840	6437	8276	10890	12100
28"	589	1490	2484	3809	5299	7360	9789	12586	16560	18400
F_L	0.86	0.85	0.83	0.81	0.78	0.75	0.71	0.65	0.56	0.49
X_T	0.53	0.53	0.53	0.52	0.50	0.44	0.39	0.33	0.25	0.17

TABLE 14 – SIZING TABLES (C_V) FOR NELES-JAMESBURY *WAFER-SPHERE*® SOFT-SEATED BUTTERFLY CONTROL VALVES

		VALVE SIZE IS LINE SIZE									
		DISC ROTATION (Percent)									
Valve Size	Valve Series	10	20	30	40	50	60	70	80	90	100
2-1/2"	815	3	6	18	32	45	57	70	73	76	78
3"	ALL	4	12	21	35	46	66	90	125	153	165
4"	ALL	8	25	55	87	120	165	225	310	380	400
5"	815	10	38	87	143	193	263	356	492	606	650
6"	ALL	10	58	137	235	310	415	560	745	960	1050
8"	830	12	115	260	390	570	795	1120	1525	1650	1800
8"	815	15	130	315	475	695	970	1370	1865	2015	2200
10"	830	20	145	325	515	795	1155	1590	2125	2890	3150
10"	815	25	155	340	540	835	1210	1665	2225	3030	3300
12"	830	45	280	550	835	1315	1880	2600	3590	4570	4750
12"	815	55	310	590	895	1410	2020	2790	3855	4900	5100
14"	830	90	430	750	1200	1580	2250	3100	4300	5100	5200
14"	815	100	435	755	1220	1625	2320	3190	4410	5395	5800
16"	830	150	620	1030	1500	2100	2950	4050	5450	6750	6900
16"	815	165	630	1050	1530	2190	3080	4350	6100	7600	8000
18"	830	280	780	1350	2100	2790	4000	5450	7350	8900	9300
18"	815	285	790	1365	2200	2940	4200	5760	7970	9750	10,500
20"	830	340	870	1550	2510	3250	4800	6550	8250	10,600	11,300
20"	815	350	880	1570	2540	3400	5080	7150	9450	12,650	14,000
24"	830	400	1020	1920	2960	4300	6200	9000	12,700	17,400	18,500
24"	815	405	1070	1980	3050	4430	6500	9550	13,950	19,100	21,600
30"	815	650	1770	3150	4760	6800	9860	14,620	21,400	29,920	34,000
36"	815L	1220	2980	5230	7650	11,150	16,100	23,500	34,100	49,200	55,500
42"	815L	1600	4290	7700	11,550	16,550	23,900	35,400	52,100	72,600	82,650
48"	815L	2100	5600	10,100	15,200	21,700	31,400	46,600	68,200	95,300	108,300
54"	815L	2540	6950	12,400	18,700	26,700	38,700	57,400	84,100	117,500	133,500
60"	815L	3020	8270	14,800	22,250	31,800	46,100	68,370	100,200	139,900	159,000
F_L		0.75	0.83	0.84	0.81	0.77	0.72	0.65	0.55	0.48	0.46
X_T		0.42	0.42	0.43	0.44	0.45	0.42	0.40	0.34	0.27	0.24

TABLE 15 – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G110/G111 EQUAL PERCENT FLOW CHARACTERISTIC

		OPENING (Percent)									
Valve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
1½"	Full Size	0.5	1.1	2.1	3.6	5.6	9.2	14	23	33	37
	1 Reduction	0.5	0.8	1.4	2.1	3.2	4.9	7.5	12	18	24
	2 Reduction	0.3	0.4	0.7	1.2	1.9	3.0	4.5	7.0	11	14
2"	Full Size	1.0	2.0	3.0	5.0	9.0	17	30	45	56	60
	1 Reduction	1.0	2.0	2.5	3.0	5.0	7.5	14	23	33	38
	2 Reduction	1.0	1.5	2.0	2.5	3.0	5.5	8.0	13	18	23
3"	Full Size	2.5	5.0	7.5	12	21	38	63	91	109	128
	1 Reduction	1.0	2.0	3.0	5.0	10	17	30	49	65	77
	2 Reduction	1.0	2.0	2.5	3.0	5.0	8.0	14	22	32	41
4"	Full Size	2.0	4.0	6.0	12	19	38	68	106	144	170
	1 Reduction	2.0	4.0	5.0	8.0	14	25	42	65	87	109
	2 Reduction	2.0	2.5	3.0	5.0	8.0	15	24	37	50	64
6"	Full Size	5.9	8.7	13	23	44	89	164	253	320	362
	1 Reduction	3.8	6.8	13	20	40	72	116	166	215	258
	2 Reduction	2.7	4.1	6.9	11	23	45	72	98	125	151
8"	Full Size	11	14	22	47	84	142	246	420	546	650
	1 Reduction	8.5	13	19	26	42	70	117	202	325	415
	2 Reduction	5.2	10	16	24	35	50	76	124	195	230
10"	Full Size	17	29	42	62	98	170	293	566	840	950
	1 Reduction	9.8	17	25	37	58	101	174	336	498	540
	2 Reduction	6.6	11	17	25	39	68	117	226	336	400
12"	Full Size	22	38	56	82	130	226	390	754	1120	1275
	1 Reduction	13	22	33	48	77	133	230	445	661	725
	2 Reduction	9.0	16	23	34	53	93	160	309	458	545
16"	Full Size	41	71	104	153	242	420	725	1400	2080	2500
	1 Reduction	23	40	58	85	135	235	406	784	1160	1400
	2 Reduction	17	30	44	65	103	179	308	596	882	1060
F_L		0.97	0.97	0.97	0.97	0.96	0.95	0.94	0.92	0.90	0.90
X_T		0.79	0.79	0.79	0.79	0.78	0.76	0.74	0.71	0.69	0.68

TABLE 16 – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G110/G111 LINEAR FLOW CHARACTERISTIC

		OPENING (Percent)									
lve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
1½"	Full Size	2.0	7.3	13	19	24	29	34	38	39	40
	1 Reduction	1.9	5.2	9.0	12	16	20	25	30	32	34
	2 Reduction	1.2	3.3	5.9	8.8	12	15	18	22	24	27
2"	Full Size	4.0	14	24	34	43	51	56	59	62	65
	1 Reduction	3.0	8.0	14	20	25	32	37	43	47	49
	2 Reduction	2.0	5.0	8.0	12	17	22	27	31	35	38
3"	Full Size	11	33	55	72	86	97	108	117	125	132
	1 Reduction	5.0	16	28	40	51	61	73	84	92	97
	2 Reduction	4.0	12	18	26	33	41	51	59	65	71
4"	Full Size	14	46	76	102	126	147	168	186	202	212
	1 Reduction	10	26	43	59	75	80	106	126	143	156
	2 Reduction	5.0	13	22	33	43	54	66	78	90	100
6"	Full Size	41	112	182	248	304	349	390	428	450	461
	1 Reduction	23	60	100	141	182	225	268	303	332	355
	2 Reduction	8.9	22	33	53	72	91	118	145	171	195
8"	Full Size	47	121	205	284	368	452	536	614	682	735
	1 Reduction	23	70	122	176	234	286	341	387	425	455
	2 Reduction	12	33	62	92	123	153	186	218	250	280
10"	Full Size	68	173	287	410	524	645	767	879	968	1050
	1 Reduction	40	102	174	241	311	380	458	521	574	610
	2 Reduction	21	67	112	161	212	267	316	358	394	420
12"	Full Size	70	210	382	546	720	886	1050	1190	1295	1400
	1 Reduction	53	133	225	301	413	505	596	690	761	820
	2 Reduction	29	71	135	207	279	349	422	484	526	565
16"	Full Size	130	391	696	1004	1321	1637	1934	2213	2437	2600
	1 Reduction	73	216	389	562	738	926	1092	1238	1352	1450
	2 Reduction	62	174	300	422	545	672	796	918	1027	1100
F_L		0.97	0.97	0.96	0.94	0.93	0.92	0.92	0.90	0.90	0.90
X_T		0.79	0.79	0.77	0.75	0.73	0.71	0.71	0.69	0.68	0.68

TABLE 21B – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G410 (PLUG SERIES 68) LINEAR FLOW CHARACTERISTIC

		OPENING (Percent)									
e Size	Trim Size	10	20	30	40	50	60	70	80	90	100
½"	Full Size	1.00	1.90	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00
	1 Reduction	0.40	0.55	0.70	1.02	1.31	1.60	2.10	2.65	3.30	4.00
	3 Reduction	0.50	0.75	1.00	1.30	1.50	1.70	1.90	2.10	2.30	2.50
	4 Reduction	0.20	0.30	0.50	0.60	0.73	0.87	1.02	1.15	1.30	1.50
	5 Reduction	0.12	0.23	0.34	0.45	0.55	0.64	0.73	0.82	0.90	1.00
¾"	Full Size	1.00	1.90	2.80	3.90	4.80	5.40	6.10	6.90	7.50	8.00
	1 Reduction	0.40	0.55	0.70	1.02	1.31	1.60	2.10	2.65	3.30	4.00
	3 Reduction	0.50	0.75	1.00	1.30	1.50	1.70	1.90	2.10	2.30	2.50
	4 Reduction	0.20	0.30	0.50	0.60	0.73	0.87	1.02	1.15	1.30	1.50
	5 Reduction	0.12	0.23	0.34	0.45	0.55	0.64	0.73	0.82	0.90	1.00
1"	Full Size	1.30	2.60	4.20	5.50	6.80	8.10	9.40	10.70	12.00	13.00
	1 Reduction	1.00	1.90	2.80	3.90	4.80	5.50	6.30	7.20	8.10	9.00
	2 Reduction	0.40	0.55	0.70	1.02	1.31	1.60	2.10	2.65	3.30	4.00
	3 Reduction	0.50	0.75	1.00	1.30	1.50	1.70	1.90	2.10	2.30	2.50
	4 Reduction	0.20	0.30	0.50	0.60	0.73	0.87	1.02	1.15	1.30	1.50
	5 Reduction	0.12	0.23	0.34	0.45	0.55	0.64	0.73	0.82	0.90	1.00
1¼"	Full Size	2.20	3.90	5.50	8.50	10.50	12.00	14.00	16.00	18.00	20.00
1½"	Full Size	3.00	6.00	9.00	12.00	15.00	18.00	20.00	23.00	26.00	28.00
	1 Reduction	0.90	1.60	2.50	3.60	4.50	5.60	6.50	7.50	8.70	10.00
2"	Full Size	6.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
F_L		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
X_T		0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

TABLE 21C – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G410 SOFT SEAT (PLUG SERIES 67) LINEAR FLOW CHARACTERISTIC

		OPENING (Percent)									
Valve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
½"	Full Size	0.45	0.82	1.30	1.80	2.20	2.60	3.10	3.80	4.50	5.00
	2 Reduction	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	3 Reduction	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	4 Reduction	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
	5 Reduction	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
¾"	Full Size	0.45	0.82	1.30	1.80	2.20	2.60	3.10	3.80	4.50	5.00
	2 Reduction	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	3 Reduction	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	4 Reduction	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
	5 Reduction	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
1"	Full Size	0.45	0.82	1.30	1.80	2.20	2.60	3.10	3.80	4.50	5.00
	2 Reduction	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	3 Reduction	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	4 Reduction	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
	5 Reduction	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
2"	Full Size	6.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
F_L		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
X_T		0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

TABLE 21D – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G410 MICRO (PLUG SERIES 10) LINEAR FLOW CHARACTERISTIC

		OPENING (Percent)									
Valve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
½"–1"	Full Size	0.03	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
F_L		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
X_T		0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76

TABLE 22 – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G420 (PLUG SERIES 58) EQUAL PERCENT FLOW CHARACTERISTIC

		OPENING (Percent)									
Valve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
½"	2 Reduction	0.03	0.06	0.10	0.20	0.35	0.60	0.90	1.30	1.80	2.50
	3 Reduction	0.015	0.03	0.05	0.07	0.14	0.25	0.41	0.65	1.00	1.50
	4 Reduction	0.01	0.02	0.04	0.06	0.12	0.20	0.35	0.50	0.82	1.00
	5 Reduction	0.003	0.006	0.015	0.03	0.04	0.06	0.10	0.17	0.25	0.50
1"	Full Size	0.24	0.38	0.70	1.10	1.70	2.60	3.80	5.70	8.50	9.50
	1 Reduction	0.15	0.39	0.60	0.88	1.20	1.60	2.10	2.71	3.25	4.00
	2 Reduction	0.03	0.06	0.10	0.20	0.35	0.60	0.90	1.30	1.80	2.50
	3 Reduction	0.015	0.03	0.05	0.07	0.14	0.25	0.41	0.65	1.00	1.50
	4 Reduction	0.01	0.02	0.04	0.06	0.12	0.20	0.35	0.50	0.82	1.00
	5 Reduction	0.003	0.006	0.015	0.03	0.04	0.06	0.10	0.17	0.25	0.50
1½"	Full Size	0.90	1.70	2.60	3.70	5.30	7.60	11.00	13.50	16.00	17.50
	1 Reduction	0.50	0.70	1.00	1.40	2.00	2.80	3.60	5.00	7.00	9.00
2"	Full Size	1.00	1.90	3.00	5.00	7.70	11.00	15.00	20.00	24.00	30.50
	1 Reduction	1.10	1.70	2.70	4.10	6.10	8.90	11.00	14.00	16.00	17.50
	2 Reduction	0.50	1.10	1.60	2.20	2.80	3.60	4.70	6.40	8.10	10.00
3"	Full Size	1.25	3.20	6.00	12.00	19.00	30.00	38.00	46.00	52.00	61.00
F_L		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
X_T		0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

TABLE 22A – NELES-JAMESBURY GLOBE CONTROL VALVE FLOW COEFFICIENTS SERIES G420 SOFT SEAT (PLUG SERIES 57) EQUAL PERCENT FLOW CHARACTERISTIC

		OPENING (Percent)									
Valve Size	Trim Size	10	20	30	40	50	60	70	80	90	100
½"	2 Reduction	0.09	0.14	0.25	0.38	0.55	0.70	1.00	1.30	1.70	2.50
1"	Full Size	0.24	0.38	0.60	0.95	1.50	2.40	3.70	5.30	7.50	8.50
	1 Reduction	0.22	0.28	0.40	0.75	1.30	2.10	2.70	3.10	3.60	4.00
	2 Reduction	0.09	0.14	0.25	0.38	0.55	0.70	1.00	1.30	1.70	2.50
1½"	Full Size	1.00	1.70	2.60	3.70	5.30	7.60	11.00	13.50	16.00	17.50
2"	Full Size	1.00	1.90	3.00	5.00	7.70	11.00	15.00	20.00	24.00	30.50
	1 Reduction	1.00	1.60	2.80	4.20	6.00	8.80	11.20	14.20	15.80	18.00
F_L		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
X_T		0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

TABLE 33

ANSI PRESSURE-TEMPERATURE VALVE RATINGS FOR ASTM A126 CLASS B CAST IRON		
TEMPERATURE IN °F	WORKING PRESSURES IN psi	
	CLASS 125	250
-20 TO 150	200	500
200	190	460
250	175	415
300	165	375
350	150	335
400	140	290
450	125	250

Most control valves are rated according to the ANSI flange and fitting ratings. Tables 31, 32, and 33 show the pressure-temperature limitations for valves made of cast iron, carbon steel, and 316 SS. The ratings for cast iron valves correspond to ratings of ANSI B16.1-1975 while those for carbon steel and 316 SS correspond to ratings of ANSI B16.34-1988

TABLE 34

ANSI PRESSURE-TEMPERATURE FLANGE RATINGS FOR ASTM A216-WCB CAST STEEL			
TEMPERATURE IN °F	WORKING PRESSURES IN psi		
	CLASS 150	300	600
-20 TO 100	285	740	1480
200	260	675	1350
300	230	655	1315
400	200	635	1270
500	170	600	1200
600	140	550	1095
650	125	535	1075
700	110	535	1065
750	95	505	1010
800	80	410	825
850	65	270	535
900	50	170	345
950	35	105	205
1000	20	50	105

TABLE 35

ANSI PRESSURE-TEMPERATURE FLANGE RATINGS FOR ASTM A351-CF8M 316 SS			
TEMPERATURE IN ° F	WORKING PRESSURES IN psi		
	CLASS 150	300	600
-20 TO 100	275	720	1440
200	240	620	1240
300	215	560	1120
400	195	515	1030
500	170	480	955
600	140	450	905
650	125	445	890
700	110	430	865
750	95	425	845
800	80	415	830
850	65	405	810
900	50	395	790
950	35	385	775
1000	20	365	725

TABLE 36 – CRITICAL PRESSURES OF SOME COMMON LIQUIDS

Liquid	psia	Bar Absolute	Liquid	psia	Bar Absolute
Acetic Acid	840	58.0	Hexane	433	29.9
Acetic Anhydride	676	46.6	Hydrogen	188	13.0
Acetone	691	47.6	Hydrogen Sulphide	1308	90.1
Acetylene	911	62.9	Isopropyl Alcohol	779	53.8
Air	547	37.7	Methane	673	46.4
Ammonia	1638	113.0	Methyl Alcohol	1156	79.8
Benzene	701	48.3	Methyl Chloride	967	66.7
Bromine	1485	102.3	Nitrogen	492	33.9
Butadiene	627	43.3	Octane	362	25.0
Butane	529	36.5	Oxygen	730	50.4
Butyl Alcohol	711	49.0	Pentane	485	33.5
Carbon Dioxide	1072	74.0	Phenol	889	61.3
Carbon Tetrachloride	661	45.6	Propane	617	42.6
Dowtherm A	465	32.1	Propylene	661	45.6
Dowtherm E	465	32.1	Propyl Alcohol	735	50.7
Ethane	717	49.5	Propyl Chloride	664	45.8
Ethyl Alcohol	927	64.0	Pyridine	882	60.8
Ethyl Chloride	2750	190.0	Pyridine Pure	882	60.8
Ethylene	742	51.2	Toluene	611	42.1
Heptane	394	27.2	Water	3206	221

TABLE 37 – PROPERTIES OF STEAM

SATURATED STEAM			
Absolute Pressure	Gage Pressure	Temperature °F	V_1-Specific Volume-ft.^{3}/lb.
14.7	0	212	26.80
25.0	10	240	16.30
35.0	20	259	11.90
45.0	30	274	9.40
55.0	40	287	7.79
65.0	50	298	6.66
75.0	60	308	5.82
85.0	70	316	5.17
95.0	80	324	4.65
105.0	90	331	4.23
115.0	100	338	3.88
140.0	125	353	3.22
165.0	150	366	2.752
190.0	175	378	2.404
215.0	200	388	2.135
240.0	225	397	1.918
265.0	250	406	1.742
290.0	275	414	1.60
315.0	300	422	1.45
340.0	325	429	1.37
365.0	350	436	1.27
390.0	375	442	1.19
415.0	400	448	1.11
440.0	425	454	1.06
465.0	450	460	0.99

CORROSION CONSIDERATIONS

The corrosive effect of a given chemical upon materials of construction depends heavily upon its concentration and temperature. It also depends upon the presence of other chemicals, either as impurities or as part of the stream composition. EACH APPLICATION MUST BE CONSIDERED COMPLETELY, AND SINCE THE NECESSARY INFORMATION FOR SUCH CONSIDERATION CAN ONLY BE KNOWN BY THE USER, HE MUST BE RESPONSIBLE FOR THE ACTUAL SELECTION OF MATERIALS OF CONSTRUCTION. Table 37 is a *general* guide to materials found adequate under conditions often encountered. Before selecting a material, particularly for a new application, the user should consult a competent corrosion engineer or tables denoting or containing more detailed temperature and concentration data.

TABLE 38 – VAPOR PRESSURE OF WATER

VAPOR PRESSURE OF WATER (psia)					
°F	psia	°F	psia	°F	psia
32	.088	100	.950	160	4.741
40	.122	105	1.102	165	5.335
45	.148	110	1.275	170	5.992
50	.178	115	1.470	175	6.715
55	.214	120	1.693	180	7.510
60	.256	125	1.942	185	8.383
65	.306	130	2.223	190	9.339
70	.363	135	2.537	195	10.385
75	.430	140	2.889	200	11.526
80	.507	145	3.281	205	12.769
85	.596	150	3.718	210	14.123
90	.698	155	4.203	212	14.696
95	.815				

TABLE 40 – PHYSICAL CONSTANTS OF VARIOUS FLUIDS

Fluid	Formula	Molecular Weight	Boiling Point at 14.696 psia °F	Specific Gravity	
				Liquid (Water=1.00)	Gas (Air=1.00)
Acetic Acid	$HC_2H_3O_2$	60.05	245	1.05	
Acetone	C_3H_6O	58.08	133	0.79	2.01
Acetylene	C_2H_2	26.03	−119	0.62	0.90
Air	N_2O_2	28.97	−317	0.86	1.00
Alcohol, Ethyl	C_2H_6O	46.07	173	0.789	1.59
Alcohol, Methyl	CH_4O	32.04	148	0.791	1.11
Ammonia	NH_3	17.03	−28	0.62	0.59
Ammonium Chloride*	NH_4Cl			1.07	
Ammonium Hydroxide*	NH_3OH			0.91	
Ammonium Sulfate*	$(NH_4)_2SO_4$			1.15	
Aniline	C_6H_7N	93.12	365	1.02	
Argon	A	39.94	−302	1.65	1.38
Benzene	C_6H_6	78.08	176	0.88	2.70
Bromine	Br_2	159.84	138	2.93	5.52
Butane	C_4H_{10}	58.10	31	0.58	2.07
Calcium Carbonate*	$CaCO_3$			1.48	
Calcium Chloride*	$CaCl_2$			1.23	
Calcium Hydroxide*	$Ca(OH)_2$			1.31	
Carbon Dioxide	CO_2	44.01	−109		1.52
Carbon Disulfide	CS_2	76.10	115	1.29	2.63
Carbon Monoxide	CO	28.01	−314	0.80	0.97
Carbon Tetrachloride	CCl_4	153.84	170	1.59	5.31
Chlorine	Cl_2	70.91	−30	1.42	2.45
Chromic Acid	H_2CrO_4	118.03		1.21	
Citric Acid	$C_6H_8O_7$	192.12		1.54	
Copper Sulfate*	$CuSO_4$			1.17	
Cyclohexane	C_6H_{12}	84.13	177	0.78	2.91
Cyclopentane	C_5H_{10}	70.10	121	0.75	2.42
Diethylamine	$(C_2H_5)_2NH$	73.12	133	0.71	
Ethane	C_2H_6	30.05	−128	0.57	1.05
Ethyl Chloride	C_2H_5Cl	64.50	55	0.90	2.22
Ethylene	C_2H_4	28.04	−155		0.97
Ferric Chloride*	$FeCl_3$			1.23	
Fluorine	F_2	38.00	−305	1.11	1.31
Formaldehyde	H_2CO	30.03	−6	0.82	1.08
Formic Acid	HCO_2H	46.03	214	1.23	
Freon	CCl_2F_2	120.90	−18	1.35	4.17
Furfural	$C_5H_4O_2$	96.08	324	1.16	
Gasoline	C_6H_{14}	86.20	145		
Glycerine	$C_3H_8O_3$	92.09	554	1.26	
Glycol	$C_2H_6O_2$	62.07	387	1.11	
Helium	He	4.003	−454	0.18	0.14
Heptane	C_7H_{16}	100.20	209	0.69	3.46
Hexane	C_6H_{14}	86.14	156	0.66	2.98
Hydrochloric Acid	HCl	36.47	−115	1.64	
Hydrofluoric Acid	HF	20.01	66	0.92	
Hydrogen	H_2	2.016	−422	0.07	0.07
Hydrogen Chloride	HC	36.47	−115		1.26
Hydrogen Peroxide	H_2O_2	34.016	185	1.44	
Hydrogen Sulfide	H_2S	34.07	−76	0.79	1.17

TABLE 40 – PHYSICAL CONSTANTS OF VARIOUS FLUIDS (Continued)

Fluid	Formula	Molecular Weight	Boiling Point at 14.696 psia °F	Specific Gravity	
				Liquid (Water=1.00)	Gas (Air=1.00)
Isopropyl Alcohol	C_3H_8O	60.09	180	0.78	2.08
Kerosene	C_9H_{20}	128.30	278	0.75	
Magnesium Chloride*	$MgCl_2$			1.22	
Magnesium Hydroxide*	$Mg(OH)_2$			1.34	
Mercury	Hg	200.61	670	13.60	6.93
Methane	CH_4	16.04	–259	0.43	0.56
Methyl Bromide	CH_3Br	94.95	38	1.73	3.27
Methyl Chloride	CH_3Cl	50.49	–11	0.99	1.74
Methyl Ethyl Ketone	C_4H_8O	72.10	176	0.81	
Naphthalene	$C_{10}H_8$	128.16	424	1.14	4.43
Nitric Acid	HNO_3	63.02	248	1.50	
Nitrobenzene	$C_6H_5NO_2$	123.08	412	1.20	
Nitrogen	N_2	28.02	–320		0.97
Nitrous Oxide	N_2O	44.10	–128		
Octane	C_8H_{18}	114.20	258	0.70	
Oxygen	O_2	32.00	–297	1.14	
Pentane	C_5H_{12}	72.12	97	0.63	2.49
Phenol	C_6H_5OH	94.10	358	1.07	
Phosphoric Acid	H_3PO_4	98.00	415	1.83	
Potassium Chloride*	KCl			1.16	
Potassium Hydroxide*	KOH			1.24	
Propane	C_3H_8	44.10	–44	0.59	1.55
Sodium Carbonate*	Na_2CO_3			1.38	
Sodium Chloride*	NaCl			1.19	
Sodium Hydroxide*	NaOH			1.27	
Sodium Sulfate*	Na_2SO_4			1.24	
Sodium Thiosulfate*	$Na_2S_2O_3$			1.23	
Starch	$(C_6H_{10}O_5)x$			1.50	
Styrene	C_8H_8	104.10	293	0.91	3.60
Sugar Solutions*	$C_{12}H_{22}O_{11}$			1.10	
Sulfur Dioxide	SO_2	64.60	14	1.39	2.21
Sulfuric Acid	H_2SO_4	98.08	626	1.83	
Tetraethyl Lead	$Pb(C_2H_5)_4$	323.40	195	1.66	
Toluene	C_7H_8	92.10	231	0.87	3.18
Trichloroethylene	$CHCl:CCl_2$	131.40	188	1.46	
Water	H_2O	18.016	212	1.00	0.62
Zinc Chloride*	$ZnCl_2$			1.24	
Zinc Sulfate*	$ZnSO_4$			1.31	

Aqueous solution—25% by weight of compound

VELOCITY AND PRESSURE DROP THROUGH PIPE

To further assist in the use of the hydraulic gradient method, Tables 41 and 42 show velocity and pressure drop through Schedule 40 pipe. For Table 41, liquid flow, specific gravity = 1, viscosity = 1 centistoke.

Note: 1. If actual specific gravity is other than 1.0, multiply pressure loss by actual specific gravity.

2. Generally no correction for viscosity is required.

Table 42 is a tabulation of pressure drop/100 ft of Schedule 40 pipe for compressed air at 100 psig and 60° with flow rate expressed in standard cubic feet per minute.

TABLE 41 – VELOCITY AND PRESSURE DROP THROUGH PIPE (WATER)

VELOCITY (ft/s)	ΔP (per 100ft)	FLOW (U.S. gpm)	VELOCITY (ft/s)	ΔP (per 100ft)
3/4" PIPE		4" PIPE		
1.20	0.456	50	1.26	0.077
1.81	0.68	100	2.52	0.277
2.41	1.62	150	3.78	0.59
3.01	2.47	200	5.05	1.0
3.61	3.43	300	7.57	2.1
4.82	5.83	500	12.6	5.5
6.02	8.83	700	17.6	5.8
7.22	12.37	800	20.2	13.0
9.83	21.06	900	22.7	16.2
10.8	25.9	1000	25.2	19.6
1" PIPE		6" PIPE		
1.86	0.76	100	1.11	0.037
2.97	1.81	200	2.22	0.136
3.71	2.73	300	3.33	0.289
5.20	5.1	500	5.56	0.74
6.68	8.1	600	6.66	1.04
8.17	11.72	750	8.34	1.58
9.66	15.98	900	10.0	2.2
11.1	20.8	1000	11.1	2.7
13.0	27.8	1500	16.7	5.7
14.9	35.5	2000	22.2	9.7
1-1/2" PIPE		8" PIPE		
1.58	0.34	300	1.92	0.076
2.37	0.82	500	3.20	0.196
3.56	1.73	750	4.81	0.414
4.10	2.0	1000	6.41	0.71
5.26	3.2	1500	9.61	1.5
7.88	6.7	2000	12.8	2.5
11.88	17.6	2600	16.7	4.1
15.8	24.1	3000	19.2	5.37
23.6	50.7	4000	25.6	9.2
28.4	71.3	5000	32.0	13.9
2" PIPE		10" PIPE		
1.91	0.36	500	2.04	0.065
3.82	1.31	700	2.85	0.120
4.78	1.97	1000	4.07	0.233
7.17	4.18	1500	6.10	0.494
9.56	7.13	2000	8.14	0.84
11.5	10.0	3000	12.2	1.78
14.3	15.1	4000	16.3	3.03
19.1	25.6	5000	20.3	4.6
24.9	41.8	6000	24.4	10.3
28.7	54.5	7000	28.5	8.53
3" PIPE		12" PIPE		
1.30	0.112	700	1.99	0.047
2.17	0.289	1000	2.84	0.097
3.25	0.610	2000	5.68	0.35
4.34	1.04	3000	8.52	0.74
6.51	2.2	5000	14.2	1.91
8.68	3.7	7000	19.9	3.55
13.0	7.9	9000	25.6	5.67
17.4	13.5	10000	28.4	6.86
21.7	20.5	12000	34.1	9.61
26.0	28.7	14000	39.8	12.8

TABLE 42 – PRESSURE DROP THROUGH PIPE (AIR)

Flow Rate (acfm)	ΔP (per 100ft)	Flow Rate (acfm)	ΔP (per 100ft)
3/4" PIPE		4" PIPE	
6	0.037	[illegible]	[illegible]
10	0.094	[illegible]	[illegible]
20	0.345	[illegible]	[illegible]
25	0.525	[illegible]	[illegible]
35	1.0	[illegible]	[illegible]
45	1.62	2000	0.757
60	2.85	4000	2.94
80	4.96	7000	8.94
100	7.69	11000	22.2
150	17.0	14000	36.0
1" PIPE		6" PIPE	
10	0.029	950	0.023
25	0.156	1300	0.041
35	0.293	1600	0.061
50	0.578	3000	0.204
70	1.10	4500	0.450
100	2.21	7000	1.07
150	4.87	11000	2.62
225	10.8	14000	4.21
275	16.0	18000	6.96
350	25.8	26000	14.5
1-1/2" PIPE		8" PIPE	
35	0.035	2000	0.023
60	0.094	3500	0.068
90	0.203	4500	0.111
175	0.727	7000	0.262
225	1.19	9000	0.427
325	2.42	12000	0.753
425	4.09	14000	1.02
500	5.61	18000	1.68
700	10.9	22000	2.50
900	18.0	28000	4.04
2" PIPE		10" PIPE	
70	0.036	3500	0.022
125	0.107	5000	0.043
200	0.264	7000	0.082
300	0.573	10000	0.164
375	0.887	12000	0.234
475	1.40	15000	0.364
600	2.21	18000	0.520
800	3.90	24000	0.918
950	5.47	28000	1.25
1300	10.1	30000	1.42
3" PIPE		12" PIPE	
225	0.045	5000	0.018
325	0.090	6000	0.025
425	0.151	8000	0.044
550	0.248	10000	0.067
750	0.451	12000	0.096
950	0.715	14000	0.129
1300	1.32	16000	0.167
1800	2.50	20000	0.250
3500	9.23	24000	0.371
6000	27.1	28000	0.505

DIGITAL CONTROL SYSTEMS

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1. DIGITAL CONTROL DEVICES

2. SYSTEMS RELIABILITY

3. PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS

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BIRMINGHAM, ALABAMA

PRESENTATION OUTLINE

1. Types and Characteristics of Digital Control Devices

- Distributed Control Systems (DCS)
- Supervisory Control & Data Acquisition Systems (SCADA)
- Programmable Logic Controllers (PLC)
- Single Loop Controllers (SLC)
- Personal Computer Controllers (PCC)

PRESENTATION OUTLINE (cont.)

2. Digital Control Systems Major Components & Functions

- Process I/O "Front End"
- Controllers
- Operator Stations
- Software
- Data Communications

PRESENTATION OUTLINE (cont.)

3. Selection & Configuration of Digital Control Systems

   - Requirements Specification

   - Systems Evaluations

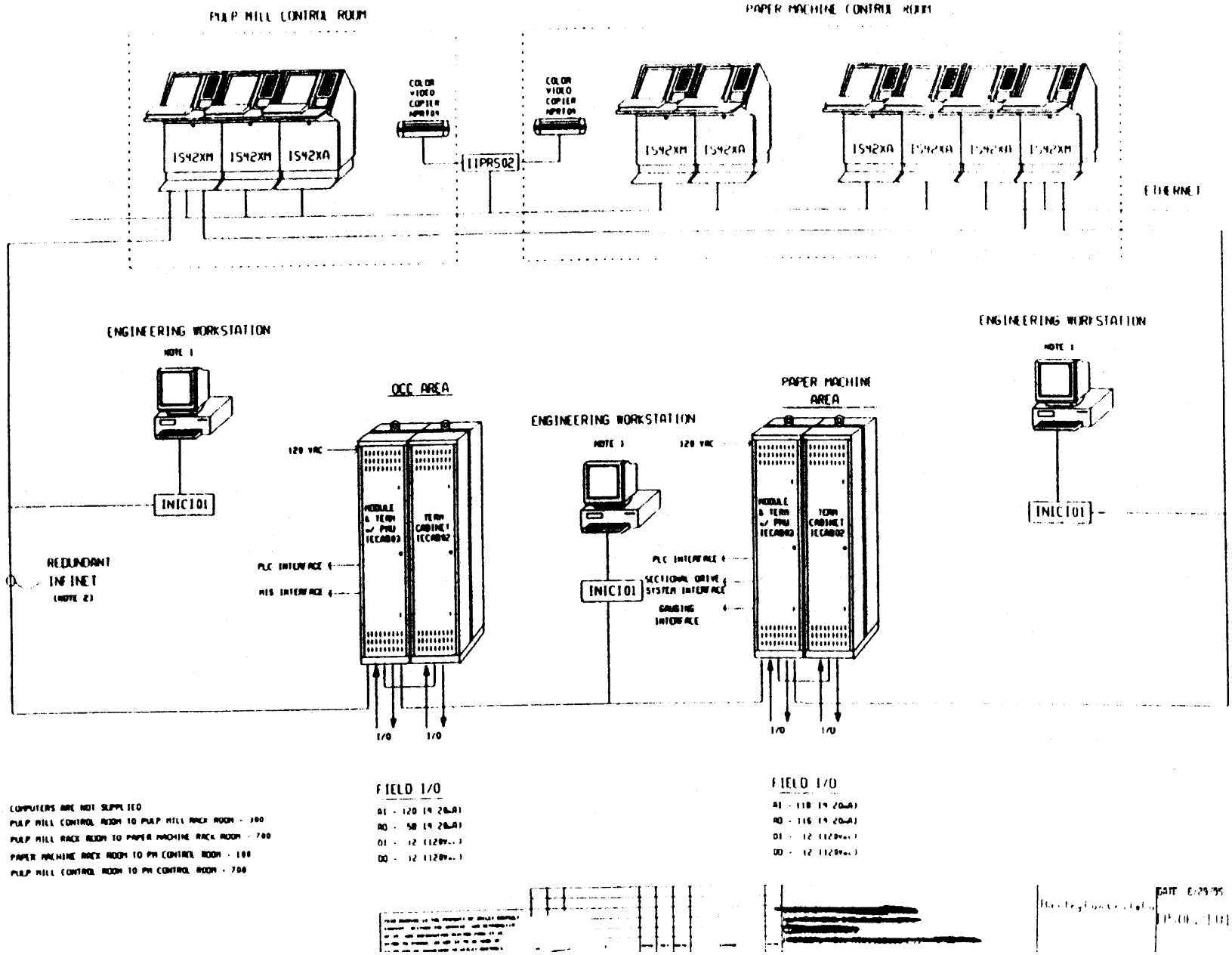
   - Configuration Engineering Steps

4. Problem Exercise

5. References

1. TYPES & CHARACTERISTICS OF DIGITAL CONTROL SYSTEMS

DCS EXAMPLE SYSTEM ARCHITECTURE



NOTE 1: COMPUTERS ARE NOT SUPPLIED

NOTE 2: PULP MILL CONTROL ROOM TO PULP MILL RACK ROOM - 300
PULP MILL RACK ROOM TO PAPER MACHINE RACK ROOM - 700
PAPER MACHINE RACK ROOM TO PM CONTROL ROOM - 100
PULP MILL CONTROL ROOM TO PM CONTROL ROOM - 700

FIELD I/O

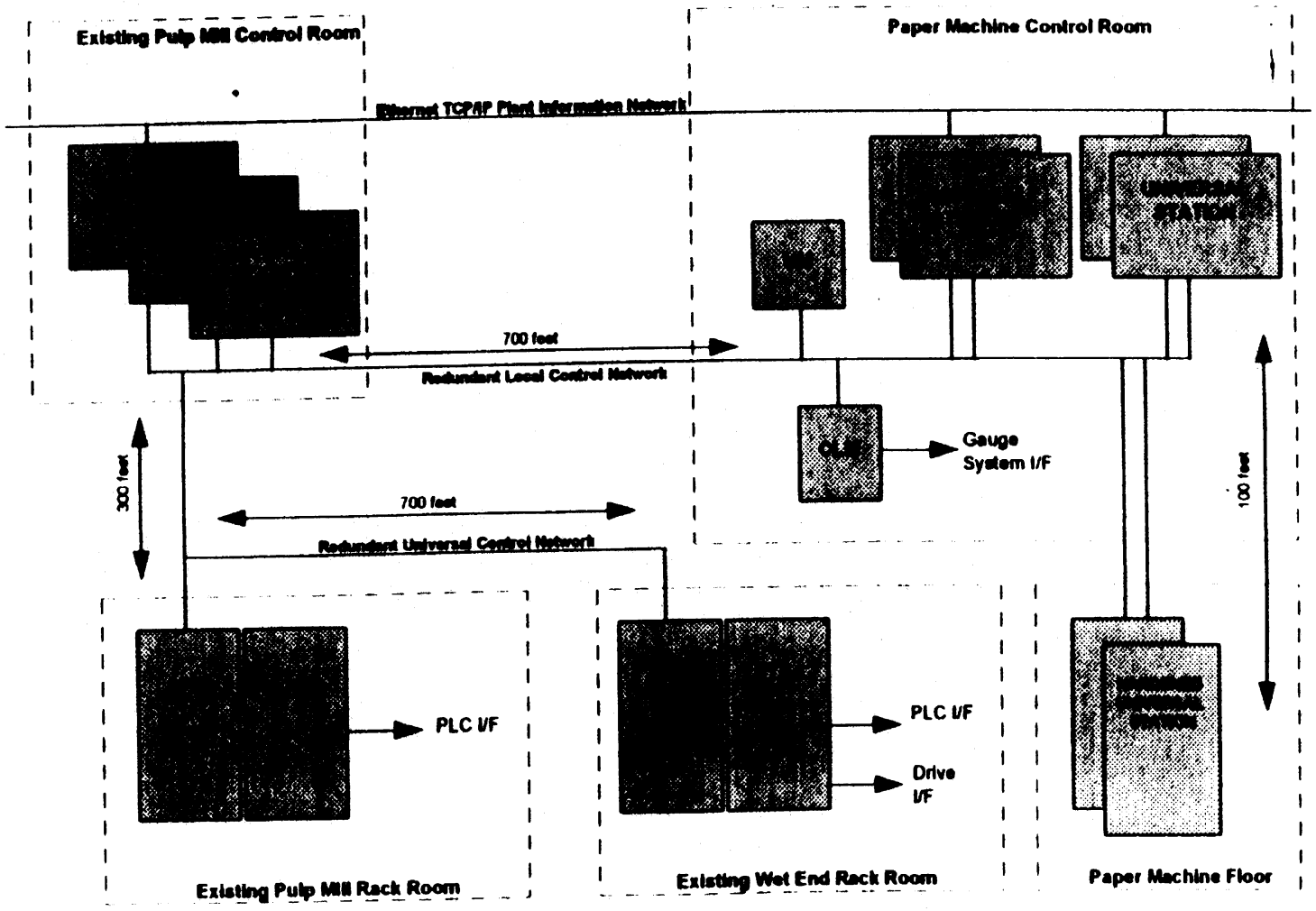
AI - 120 (4-20mA)
AO - 50 (4-20mA)
DI - 12 (120V~)
DO - 12 (120V~)

FIELD I/O

AI - 110 (4-20mA)
AO - 115 (4-20mA)
DI - 12 (120V~)
DO - 12 (120V~)

DATE 6/29/95

DCS EXAMPLE SYSTEM ARCHITECTURE



CHARACTERISTICS OF A DISTRIBUTED CONTROL SYSTEM (DCS)

1. PROCESS CONTROL PERFORMED BY MULTIPLE MICRO PROCESSOR BASED MULTI-LOOP CONTROLLERS.
2. CONTROL LOOPS & CONTROLLERS DISTRIBUTED FUNCTIONALLY & GEOGRAPHICALLY.
3. CONTROLLERS TYPICALLY CONFIGURED/PROGRAMMED VIA CONTROL FUNCTION ORIENTED OR STRUCTURED PROGRAMMING LANGUAGE.
3. OPERATOR INTERFACING ACCOMPLISHED VIA CRT-BASED WORKSTATIONS.
4. CONTROLLERS LINKED WITH OPERATOR INTERFACE STATIONS & OTHER NODES VIA SHARED HIGH-SPEE COMMUNICATIONS NETWORK.
5. SYSTEMS BACK-UP ACHIEVED VIA SELECTED REDUNDANT DCS COMPONENTS.
6. TYPICALLY UTILIZED ON MEDIUM TO LARGE APPLICATIONS INVOLVING CONTINUOUS, BATCH, & DISCONTINUOUS PROCESSES.

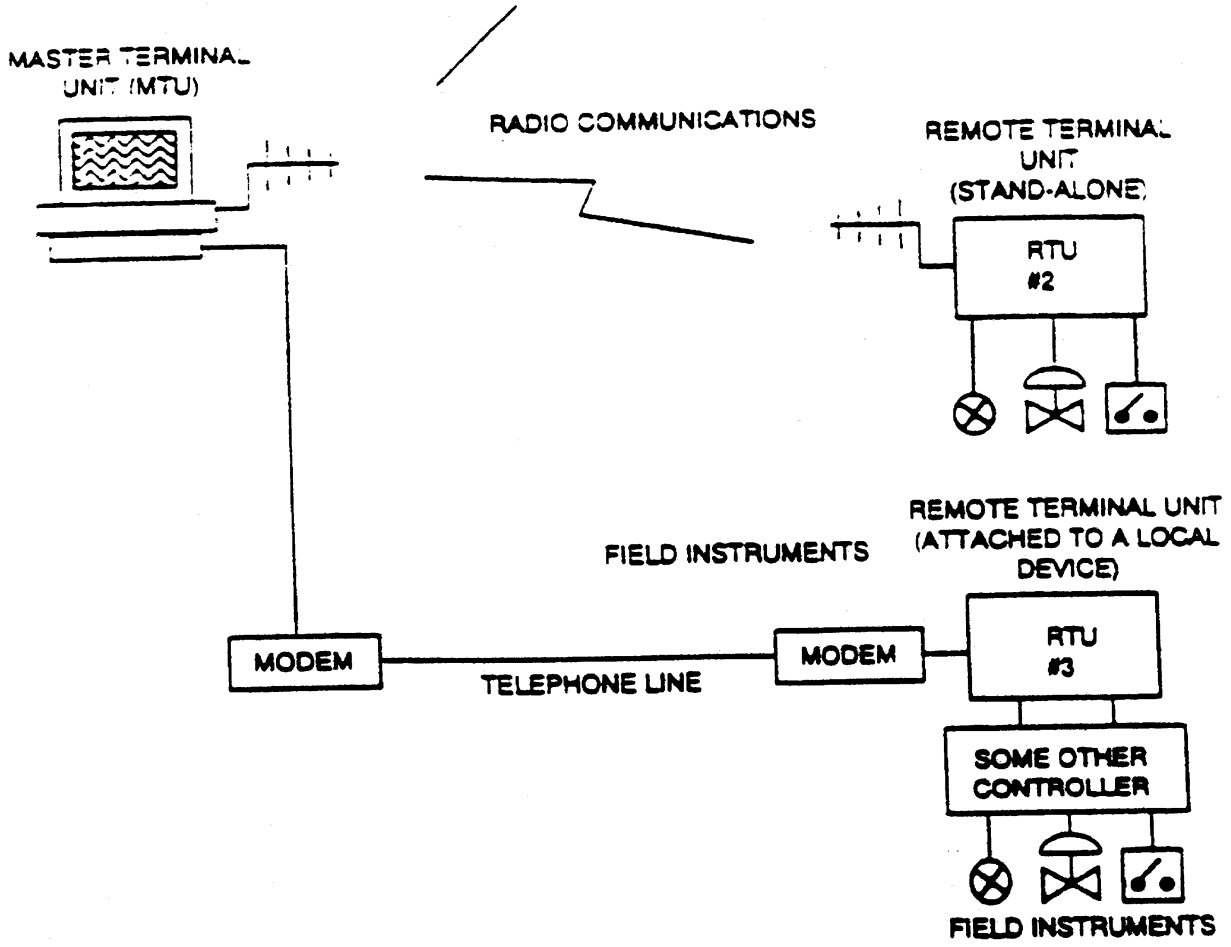


Figure 2 A typical SCADA system

CHARACTERISTICS OF A SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM (SCADA)

1. TYPICALLY A SYSTEM THAT GATHERS AND SENDS INFORMATION FROM/TO DISTANT LOCATIONS.
2. ONE COMPUTER SUPERVISES & COORDINATES OPERATION OF SEVERAL REMOTE CONTROLLERS.
3. ABLE TO COMMUNICATE WITH REMOTE UNITS OVER TELEPHONE LINES, UHF/VHF RADIOS, MICROWAVE SYSTEMS, & SATELLITES.
4. TYPICAL SYSTEM CONSISTS OF MASTER TERMINAL UNIT (MTU) WHICH COMMUNICATES WITH SEVERAL REMOTE TERMINAL UNITS (RTU).
5. FREQUENTLY USED IN GAS & OIL GATHERING & DISTRIBUTION & ELECTRICAL POWER TRANSMISSION APPLICATIONS.

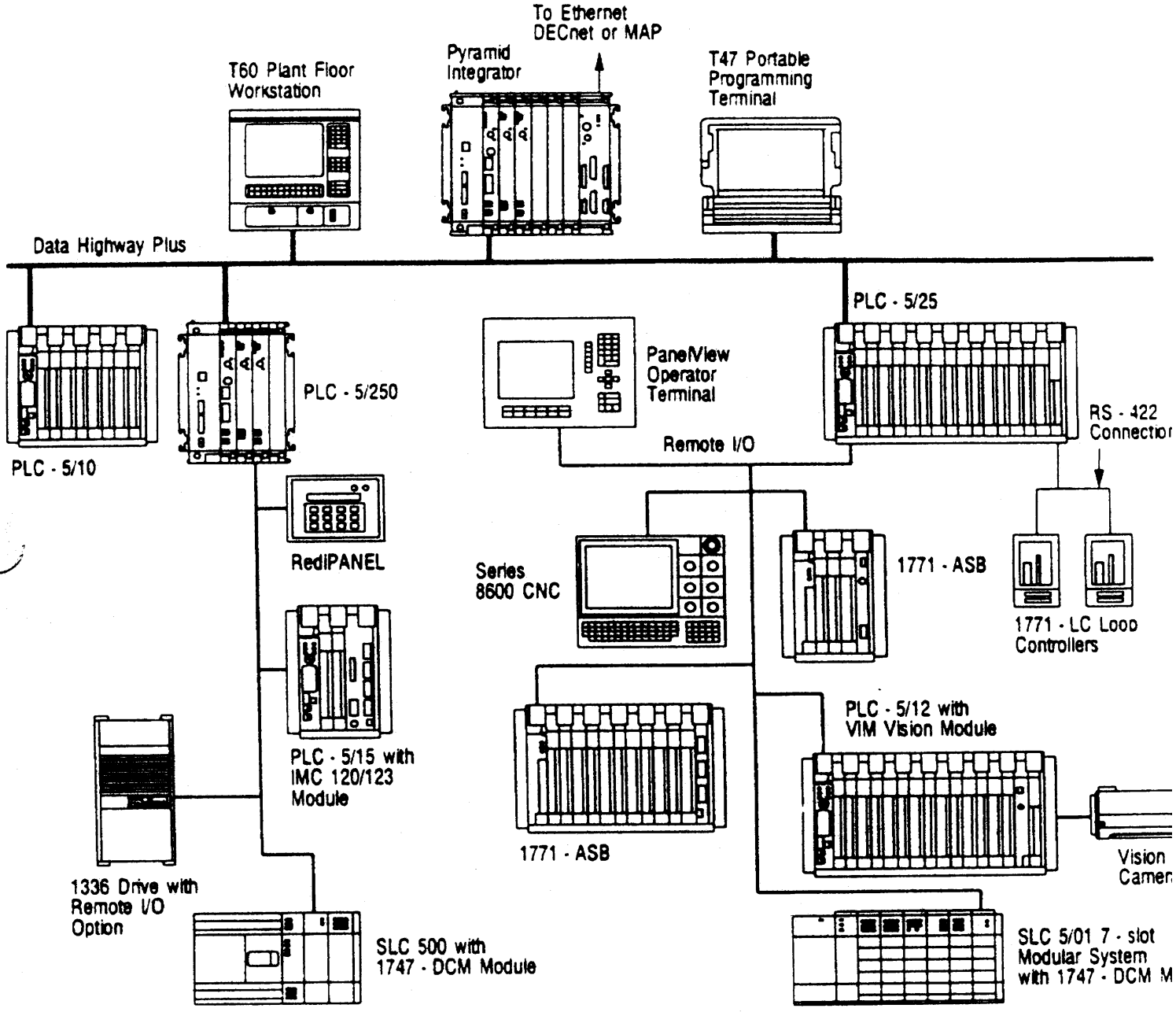


Figure 3
PROGRAMMABLE LOGIC CONTROLLERS

CHARACTERISTICS OF PROGRAMMABLE LOGIC CONTROLLERS (PLC)

1. ORIGINALLY DESIGNED AS REPLACEMENT FOR HARD-WIRED RELAY SYSTEMS.
2. VERY FAST & EFFICIENT AT EXECUTING DISCRETE LOGIC (E.G., MOTOR CONTROLS)..
3. COMMONLY (BUT NOT ALWAYS) PROGRAMMED IN LADDER LOGIC.
4. REPUTATION FOR BEING RUGGED & RELIABLE IN TOUGH INDUSTRIAL APPLICATIONS.
5. FREQUENTLY USED IN CONJUNCTION WITH HOST OR SUPERVISORY COMPUTER SYSTEMS.
6. TYPICALLY LOWER COST PER DISCRETE POINT THAN DCS.

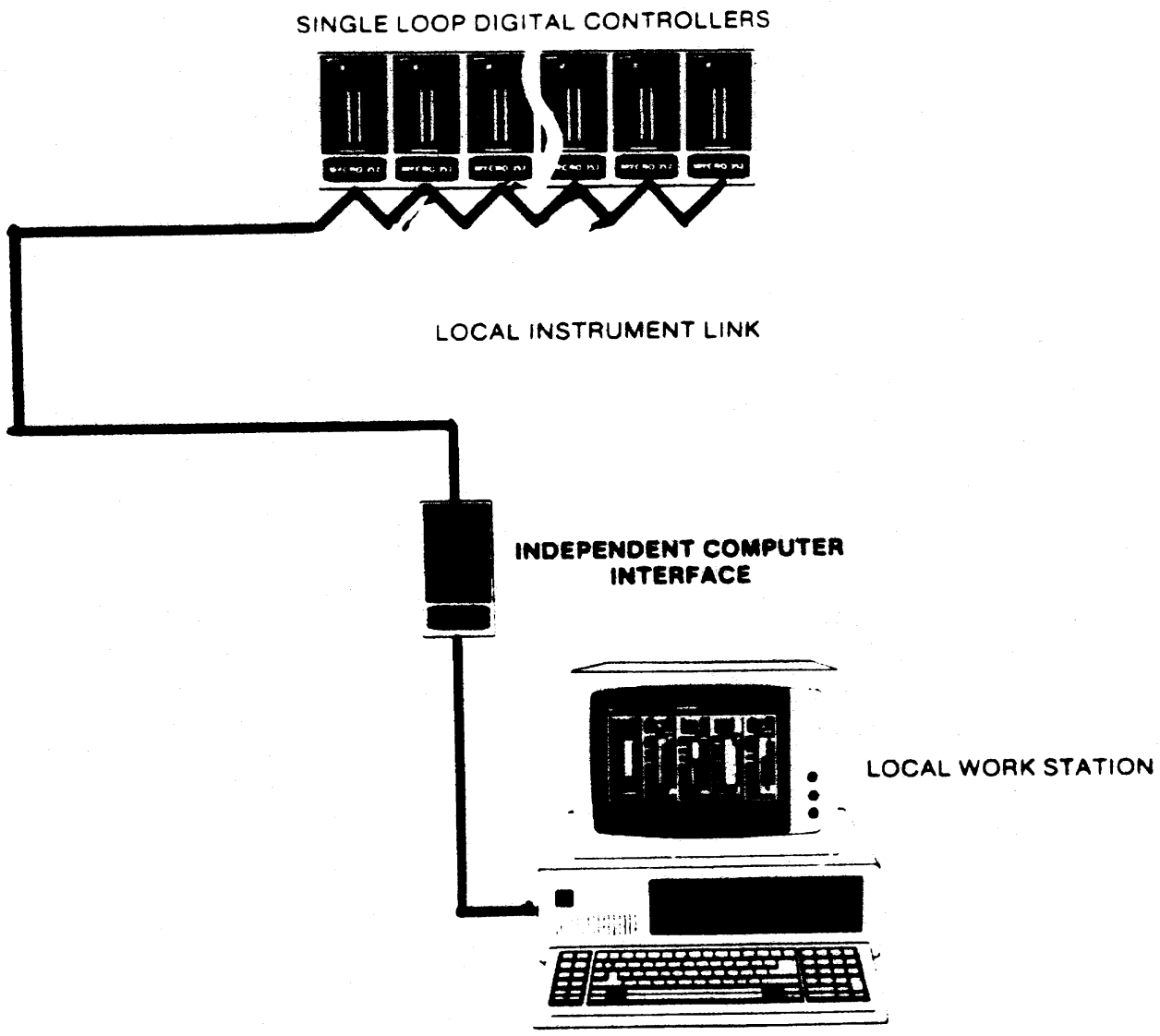


Figure 4

Single-Loop Digital Controller

CHARACTERISTICS OF SINGLE LOOP CONTROLLERS (SLC)

1. INCLUDE OWN ANALOG & DISCRETE I/O SIGNAL PROCESSING HARDWARE.
2. PHYSICAL REPLACEMENT FOR BUT GREATER FUNCTIONALITY THAN ANALOG CONTROLLERS.
3. INHERENTLY PROVIDE SINGLE LOOP INTEGRITY.
4. TYPICALLY PROGRAMMED IN BLOCK-ORIENTED CONTROL SOFTWARE.
5. CAN BE DAISY-CHAIN LINKED TO CENTRAL CONTROL STATION.

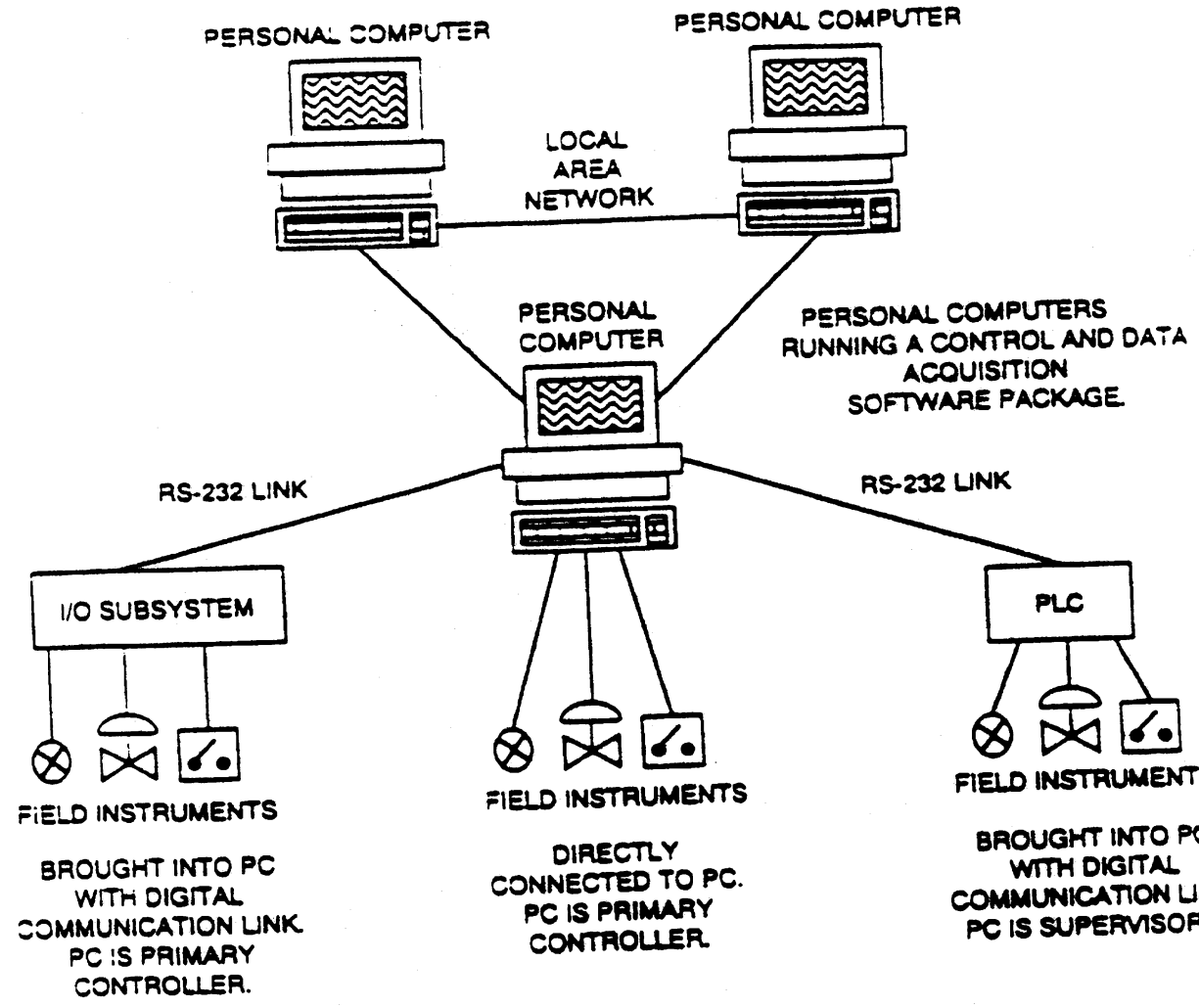


Figure 5 A PC-based control and data acquisition system

CHARACTERISTICS OF A PERSONAL COMPUTER BASED CONTROL SYSTEM (PCC)

1. UTILIZE GENERAL PURPOSE PC WHICH MAY NOT BE DESIGNED SPECIFICALLY FOR INDUSTRIAL DATA ACQUISITION & CONTROL.
2. MANY THIRD-PARTY SOFTWARE PACKAGES TO PERFORM DATA ACQUISITION, CONTROL, GRAPHICS, ALARMING, TRENDING, & NETWORKING AVAILABLE.
3. FREQUENTLY UTILIZED IN SMALLER NON-CRITICAL PROCESS APPLICATIONS.
4. ALSO USED IN CONJUNCTION WITH DCS & PLC SYSTEMS AS OPERATOR INTERFACE.
5. RELATIVELY LOW COST & EASY TO USE.

2. DIGITAL CONTROL SYSTEMS

TYPICAL EQUIPMENT & FUNCTIONS

PROCESS CONTROL SUBSYSTEM
TYPICAL PROCESS INPUTS AND OUTPUTS
"FRONT-END" HARDWARE

- FIELD WIRING TERMINATION RACKS
- FIELD SIGNAL PROTECTION DEVICES
- HIGH-LEVEL ANALOG INPUT SIGNAL CARDS
- LOW-LEVEL ANALOG INPUT SIGNAL CARDS
- CONTACT INPUT SIGNAL CARDS
- INTERRUPT INPUT SIGNAL CARDS
- PULSE INPUT SIGNAL/INTEGRATOR CARDS
- ANALOG TO DIGITAL CONVERTERS
- MULTIPLEXERS

PROCESS CONTROL SUBSYSTEM
TYPICAL PROCESS INPUTS AND OUTPUTS
"FRONT-END" HARDWARE
(CONTINUED)

- PROCESS I/O FRONT-END BUS
- DIGITAL TO ANALOG CONVERTERS
- ANALOG OUTPUT SIGNAL CARDS
- MOMENTARY CONTACT CLOSURE OUTPUT SIGNAL CARDS
- SUSTAINED CONTACT CLOSURE OUTPUT SIGNAL CARDS
- PULSE TRAIN OUTPUT SIGNAL CARDS
- POWER SUPPLIES

PROCESS I/O SIGNALS PROCESSING HARDWARE FUNCTIONS

- ELECTRICAL EXCITATION OF FIELD DEVICES (E.G., RTD EXCITATION)
- FIELD SIGNAL FUSING (E.G., INPUT CIRCUITS PROTECTION)
- FIELD SIGNAL ISOLATION (E.G., OPTICAL ISOLATION)
- FIELD SIGNAL TYPE CONVERSION (E.G., MA DC TO VDC)
- FIELD SIGNAL FILTERING (E.G., NOISE REJECTION)
- FIELD SIGNAL DEBOUNCING (E.G., CHATTERING CONTACTS)
- ELECTRICAL SHIELDING AND GROUNDING

PROCESS I/O SIGNALS PROCESSING HARDWARE FUNCTIONS, CON'T.

- SIGNAL MULTIPLEXING (E.G., ANALOG INPUTS SWITCHING TO SHARED A/D CONVERTER)
- SIGNAL AMPLIFICATION (E.G., THERMOCOUPLE MV SIGNAL TO VDC SIGNAL)
- ANALOG SIGNAL TO DIGITAL VALUE CONVERSION (E.G., 1-5VDC SIGNAL TO DIGITAL/BINARY VALUE EQUIVALENT)

  NOTE: TYPICAL A/D RESOLUTION (CONVERSION ACCURACY) = 12 BITS = 1 PART IN 4095 = 0.025%

PROCESS I/O SIGNALS PROCESSING HARDWARE FUNCTIONS, CON'T.

- PULSE SIGNAL TO DIGITAL VALUE CONVERSION (E.G., INTEGRATION OF PULSE TRAIN SIGNAL)

- DIGITAL VALUE TO ANALOG SIGNAL CONVERSION (E.G. BINARY VALUE TO 4-20 MA. OUTPUT SIGNAL)

  NOTE: TYPICAL D/A RESOLUTION (CONVERSION ACCURACY) = 8 BITS = 1 PART IN 255 = 0.4%

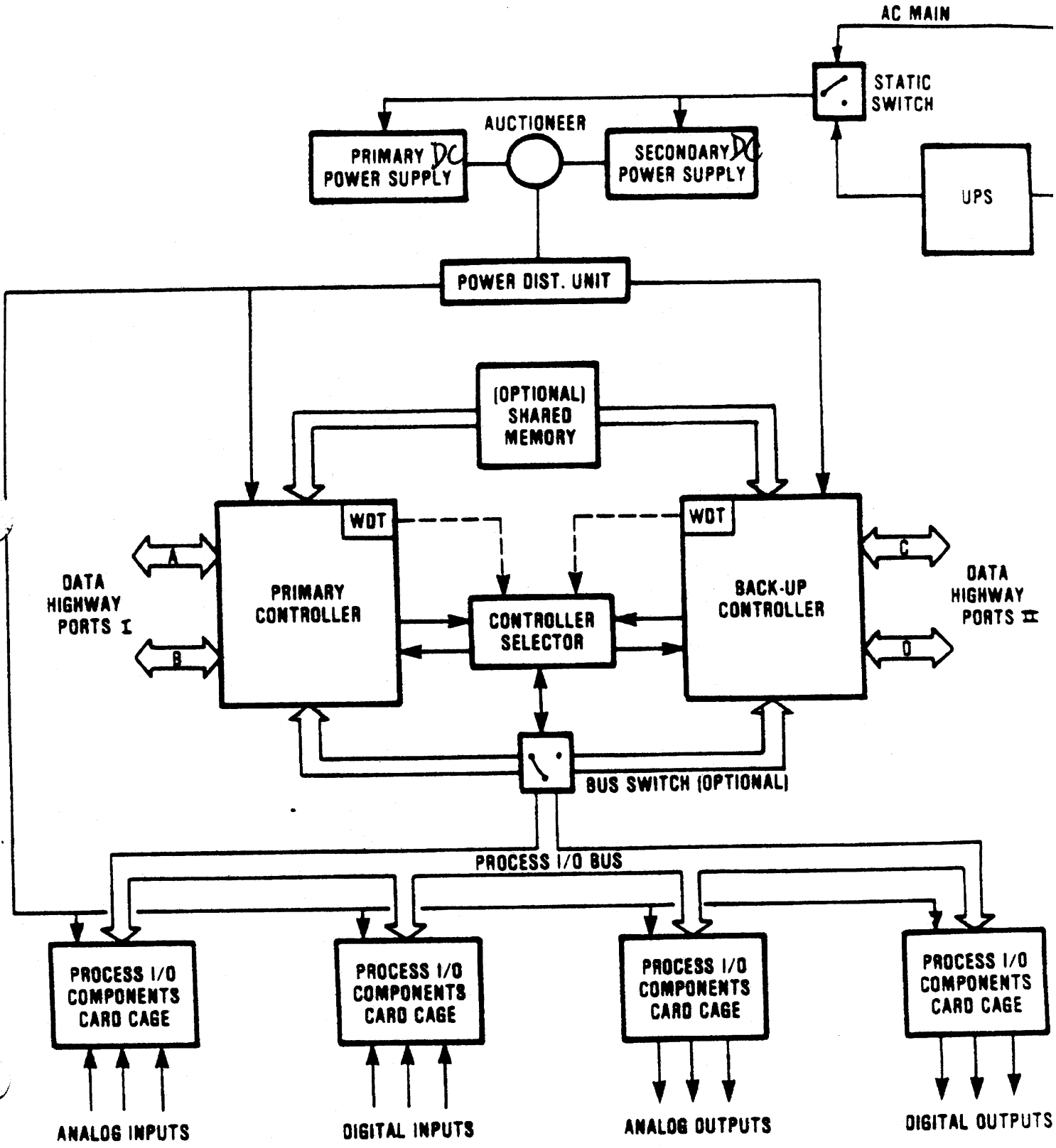
- DIGITAL VALUE TO PULSE SIGNAL CONVERSION (E.G., BINARY VALUE TO PULSE TRAIN OUTPUT SIGNAL)

PROCESS CONTROL SUBSYSTEM
TYPICAL PROCESS CONTROLLER HARDWARI
(SINGLE- OR MULTI-LOOP)

- CENTRAL PROCESSING UNIT (MICROPROCESSOR)
- MATH CO-PROCESSOR (OPTIONAL)
- REAL-TIME CLOCK
- READ ONLY MEMORY
- RANDOM ACCESS MEMORY (WITH BATTERY BACKUP VOLATILE)
- INTERNAL BUS
- BUS CONTROLLER
- SERIAL COMMUNICATIONS INTERFACE
- LOCAL CONFIGURATOR* (OPTIONAL)—VS. VIA OPERATOR/ENGINEER CONSOLE
- LOCAL DISPLAY/CONTROL STATIONS
- SECURITY MODULE
- DATA HIGHWAY INTERFACE

**EXAMPLES INCLUDE PLUG-IN, HAND-HELD, CALCULATOR-LIKE UNITS OR MODIFIED, PORTABLE PERSONAL COMPUTERS*

REDUNDANT DCS CONTROLLER BLOCK DIAGRAM



TYPICAL DIGITAL CONTROLLER FUNCTIONS

1. PROCESS INPUT SIGNALS SCANNING
2. SIGNAL QUALITY CHECKING
3. CONVERSION TO ENGINEERING UNITS
4. CHECKING AGAINST ALARM LIMITS
5. GENERATION OF ALARMS TO OPERATOR STATION
6. PERFORMING "LOOP" CALCULATIONS & EXECUTING CONTROL ALGORITHMS
7. OUTPUTTING RESULTS TO OUTPUT SIGNAL HARDWARE
8. COMMUNICATING WITH OTHER NETWORKED CONTROL SYSTEM DEVICES.

DIGITAL CONTROL LOOP PROCESSING BASICS

1. ANALOG & DIGITAL INPUT SIGNALS SAMPLED AT VARIOUS SELECTABLE RATES (I.E., SCAN RATES).
2. RESULTING DISCRETE-TIME ANALOG VALUES ARE CONVERTED TO DIGITAL REPRESENTATIONS BY MEANS OF A/D CONVERTERS.
3. CONTROL ALGORITHMS MAY BE EXECUTED AT USER SELECTED FREQUENCY AS INPUTS ARE "SCANNED" OR AFTER ALL INPUTS HAVE BEEN PROCESSED.
4. CONTROL OUTPUT COMMANDS ARE CONVERTED BACK FROM DIGITAL DISCRETE-TIME FORM TO ANALOG FORM VIA D/A CONVERTER & RECONSTRUCTED INTO CONTINUOUS SIGNAL USING HOLD ELEMENTS.
5. SAMPLING & LOOP EXECUTION RATES & ORDER MUST BE PROPERLY SELECTED SO THAT DIGITAL FORM OF CONTROL LOOP DOES NOT BECOME UNSTABLE.
6. MULTI-LOOP CONTROLLER LOADING MUST CONSIDER PEAK LOOP PROCESSING INTERVALS.

DCS OPERATOR STATION HARDWARE COMPONENTS

1. NODE CONTROLLER (MICROCOMPUTER)
   - DISK(S)
   - ALARM/REPORT PRINTER(S)
   - DATA HIGHWAY INTERFACE
2. OPERATOR CONSOLES (USUALLY MORE THAN ONE)
   - COLOR CRT (WITH OPTIONAL TOUCH-SCREEN OVERLAY OR LIGHT PEN)
   - KEYBOARD (WITH HARD AND "SOFT" KEYS, CURSOR, "JOYSTICK", ETC.)
   - PUSHBUTTON/ANNUNICATOR PANEL
   - DIGITIZER TABLET (UNLESS PART OF ENGINEER'S CONSOLE)
   - VIDEO COPIER
3. UPS (OPTIONAL)

TYPICAL OPERATOR STATION FUNCTIONS

1. OVERVIEW, AREA, GROUP, & LOOP DISPLAYS.
2. DYNAMIC INTERACTIVE PROCESS GRAPHICS.
3. PROCESS ALARMS MANAGEMENT.
4. AUTOMATIC LOGGING OF OPERATOR ACTIONS.
5. REAL-TIME & HISTORICAL TREND DISPLAYS.
6. ON-DEMAND/SCHEDULED REPORTS PRINTING.
7. CONTROL LOOPS TUNING (RESTRICTED ACCESS)
8. DIGITAL CONTROL SYSTEM EQUIPMENT STATUS MONITORING & REPORTING.

DCS

PROCESS CONTROL SOFTWARE

DCS CONTINUOUS PROCESS CONTROL SOFTWARE

1. TYPICAL PERSPECTIVE:
   - TRANSLATION OF ANALOG (CONTINUOUS DOMAIN) CONTROL LOOP INTO DIGITAL (DISCRETE SAMPLING DOMAIN) CONTROL LOOP EQUIVALENT.
2. TYPICAL MAJOR FUNCTIONS:
   - CONFIGURATION/PROGRAMMING OF CONTROL STRATEGIES IN TARGET IMPLEMENTATION LANGUAGE (USUALLY DONE AT ENGINEERING WORKSTATION).
   - CHECKING & ALARMING PROCESS VARIABLES.
   - GENERATING ALARMS TO OPERATOR STATIONS.
   - MANAGING EXECUTION OF CONTROL LOOPS IN SPECIFIED ORDER & FREQUENCY.
   - COMMUNICATING WITH OTHER DEVICES VIA DCS NETWORK AS WELL AS DIRECT SERIAL DATA LINKS.
   - RUNNING SELF-DIAGNOSTICS & REPORTING STATUS TO OPERATOR STATION.

DCS CONTINUOUS PROCESS CONTROL SOFTWARE

3. TYPICAL CONTINUOUS CONTROL ALGORITHMS LIBRARY (HONEYWELL —ISA FUNCTIONALITY

SCAN	DATA ACQUISITION
PID NORMAL	BASIC CONTROL ALGORITHM
PID RATIO	PID WITH RATIO/BIAS ON SETPOINT
PID ERROR^2 ON GAIN	NON-LINEAR PID, GAIN = F(ERROR)
PID ERROR^2 ON INTEGRAL	NON-LINEAR PID, INTEGRAL = F(ERROR)
PID GAP	NON-LINEAR PID, NO CONTROL ACTION WITHIN GAP
LEAD LAG	OUTPUT = F(INPUT, TIME)
OVERRIDE HI SELECTOR	MULTI-INPUT HI SELECTOR WITH FEEDBAC TO NON-SELECTED CONTROLLER
OVERRIDE LO SELECTOR	MULTI-INPUT LO SELECTOR WITH FEEDBA TO NON-SELECTOR CONTROLLER
SUMMER	MULTI-INPUT SUMMATION
MULTIPLIER	MULTIPLIES TWO INPUTS
AUTO-MANUAL SWITCH	AUTO OR MANUAL TRANSFER OF OUTPU SINGLE POLE DOUBLE THROW SWITCHING OF TWO INPUTS
DIVIDER	DIVIDES TWO INPUTS
SQUARE ROOT	TAKES SQUARE ROOT OF INPUT
HI SELECTOR	MULTI-INPUT HI SELECTOR
LO SELECTOR	MULTI-INPUT LO SELECTOR

NOTES:

1. SUCH ALGORITHMS MAY BE IMPLEMENTED VIA BLOCK OR SUBROUTIN CONSTRUCTION
2. SAMA-BASED ALGORITHMS MORE NUMEROUS THAN ISA-BASED ALGORITHMS, SINCE SAMA FUNCTIONS ENCOMPASS SMALLER CONTROL ELEMENTS

TRANSFER FUNCTION IMPLEMENTATION

1. Substitute $\frac{d}{dt}$ operator for s

2. Convert to difference equation

Example: First order filter (lag):

$$\frac{output}{input} = \frac{y}{x} = \frac{1}{1+\tau s} \quad \Rightarrow \quad x = y(1+\tau s)$$

$$x = y + \tau s y$$

$$x = y + \tau \frac{dy}{dt}$$

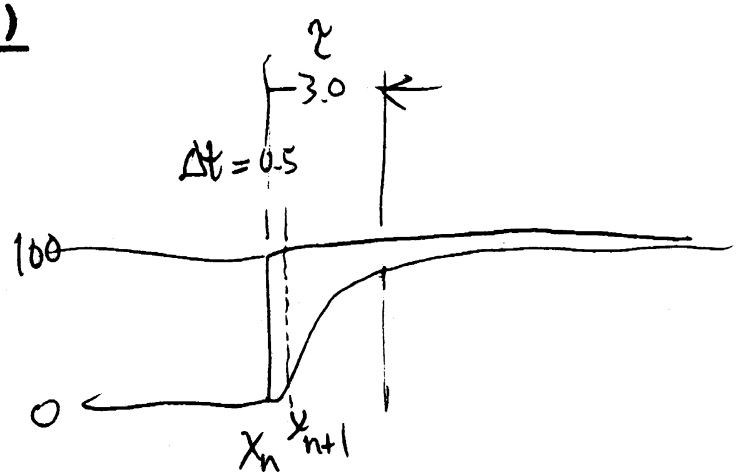
TRANSFER FUNCTION IMPLEMENTATION (cont.)

$$x = y + \tau \frac{dy}{dt}$$

$$\frac{dy}{dt} = \frac{1}{\tau}(x - y)$$

$$\frac{y_{n+1} - y_n}{\Delta t} = \frac{1}{\tau}(x_{n+1} - y_{n+1})$$

$$y_{n+1} = \left(1 - \frac{\Delta t}{\tau + \Delta t}\right) y_n + \frac{\Delta t}{\tau + \Delta t} x_{n+1}$$



$$0.14 \simeq \frac{\Delta t}{\tau + \Delta t} = \frac{0.5}{3.0 + 0.5} = \frac{0.}{3.5}$$

1st scan $y_{n+1} = (100)(0.14) + (0)(1 - 0.14) = 14$

2nd scan $(100)(0.14) + 14(0.86) \simeq 26$

first-order lag filter

fixed sampling interval

time (in seconds) to reach 62.3% of Step Respons

TRANSFER FUNCTION IMPLEMENTATION (cont.)

Exercise:

Derive the difference equation for a direct acting, interactive, PI controller, with *error* equal to *PV-SP*(error)

Both Normalized to Percent

$$\frac{controller_output}{error} = \frac{y}{x} = K\left(1 + \frac{1}{\tau_I s}\right)$$

error ↖ PV-SP

Solution:

See separate handout

TRANSFER FUNCTION OF AN INTERACTIVE PI CONTROLLER

The interactive PI controller algorithm is

$$\frac{y}{x} = K\left(1 + \frac{1}{\tau_I s}\right)$$

$$\frac{y}{x} = K\frac{\tau_I s + 1}{\tau_I s}$$

$$\tau_I \frac{dy}{dt} = K\left(\tau_I \frac{dx}{dt} + x\right)$$

$$dy = K\left(dx + \frac{x dt}{\tau_I}\right)$$

where:

K = Controller Gain (100/PB)

τ_I = Integral Time Constant (1/RESET)

As a difference equation this is

$$y_{n+1} = y_n + K\left(x_{n+1} - x_n + \frac{x_{n+1} \cdot \Delta t}{\tau_I}\right)$$

$$\frac{X}{Y} = K\left(\frac{\tau_I s + 1}{\tau_I s}\right) = \frac{K\tau_I s + K}{\tau_I s}$$

$$\tau_I s X = Y(K\tau_I s + K)$$

$$\frac{d}{dt} = s$$

$$\tau_I s X = Y K \tau_I s + Y K$$

$$Y = \frac{\tau_I s X}{K\tau_I s + K}$$

$$\frac{Y}{X} = \frac{\tau_I s K + K}{\tau_I s} = \frac{(\tau_I s K + K)}{\tau_I s}$$

$$Y = \frac{(\tau_I K s + K)X}{\tau_I s}$$

$$Y = \frac{(\tau_I s + 1)KX}{\tau_I s}$$

$$\tau_I s Y = (\tau_I s + 1)KX$$

$$\tau_I \frac{dy}{dt} = \tau_I K s X + KX = \tau_I K \frac{dx}{dt} + KX$$

$$sx = \frac{dx}{dt}$$

$$s = \frac{d}{dt}$$

$$sy = \frac{dy}{dt}$$

DCS DISCRETE/SEQUENCE CONTROL SOFTWARE

1. TYPICAL PERSPECTIVE
   - DIGITIZED COUNTERPART OF TRADITIONAL HARD-WIRED RELAY CONTROL LOGIC (E.G., FOR MOTOR CONTROL)
2. MAJOR FUNCTIONS
   - CONFIGURATION/SET-UP OF DISCRETE CONTROL LOGIC
   - SCANNING AND ALARMING DIGITAL INPUTS
   - PERFORMING TESTING/TIMING/ARITHMETIC/CONTROL LOGIC
   - DRIVING DIGITAL OUTPUTS
   - INTERACTING WITH OPERATOR
   - LOGGING (LIMITED)

DCS DISCRETE/SEQUENCE CONTROL SOFTWARE

3. TYPICAL DISCRETE CONTROL INSTRUCTIONS "LIBRARY" (ALLEN-BRADLEY)

—| |—	EXAMINE ON
—|/|—	EXAMINE OFF
—( )—	ENERGIZE
—(L)—	OUTPUT LATCH
—(U)—	OUTPUT UNLATCH
—(TON)—	TIMER ON DELAY
—(TOF)—	TIMER OFF DELAY
—(RTO)—	RETENTIVE TIMER
—(RTR)—	RETENTIVE TIMER RESET
—(CTU)—	UP COUNTER
—(CTR)—	COUNTER RESET
—(CTD)—	DOWN COUNTER
—(SCT)—	SCAN COUNTER
—[G]—	GET
—(PUT)—	PUT
—[<]—	LESS THAN
—[=]—	EQUAL TO
—(+)—	ADD
—(-)—	SUBTRACT
—(X)—	MULTIPLY
—(÷)—	DIVIDE
—(JMP)—	JUMP
—(JSR)—	JUMP TO SUBROUTINE
—(RET)—	RETURN
⋮	

DCS BATCH PROCESS CONTROL SOFTWARE

1. TYPICAL PERSPECTIVE
   - AUTOMATION AND INTEGRATION OF RESOURCES/RECIPES MANAGEMENT, SEQUENCE (STEP) CONTROL, AND CONTINUOUS CONTROL TASKS

2. MAJOR FUNCTIONS
   - RECIPES HANDLING AND MAINTENANCE
   - PROCESS MATERIALS AND EQUIPMENT MANAGEMENT
   - BATCH SCHEDULING
   - EQUIPMENT ALLOCATION

   } USUALLY HOST COMPUTER FUNCTIONS

   - OPERATING SEQUENCE/PROCEDURES DEFINITION
   - BATCH OPERATION CONTROL
     - — SEQUENTIAL CONTROL "LOOPS"
     - — CONTINUOUS CONTROL LOOPS (EMBEDDED)
   - ERROR HANDLING AND RECOVERY
   - INTERACTING WITH OPERATOR
   - LOGGING AND REPORTING

   } CONTROLLER FUNCTIONS

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4/26/84

DCS BATCH PROCESS CONTROL SOFTWARE

6. TYPICAL BATCH SOFTWARE ALGORITHM LIBRARY (WESTINGHOUSE)

CAPTURE	CAPTURE A DEVICE FOR EXCLUSIVE USE
DEVICE	OPEN OR CLOSE A DEVICE
RELEASE	RELEASE A DEVICE FROM CONTROL
⋮	
CONTROL	SET THE MODE, ETC., OF A CONTROL LOOP
FUNCTION	SET A VARIABLE TO THE RESULT OF A CALCULATION
HOLD	HOLD A SEQUENCE FOR A PERIOD OF TIME
IF	COMPARE TRUE/FALSE RELATIONSHIP OF TWO VARIABLES
JUMP	JUMP TO ANOTHER STEP OR PHASE
LOGIC	SET A VARIABLE TO RESULT OF LOGICAL OPERATION
MATH	SET A VARIABLE TO RESULT OF ARTHMETIC CALCULATION
RAMP	RAMP A VARIABLE TO A VALUE IN A PERIOD OF TIME
SET	SET A VARIABLE TO A VALUE
WAIT—TIL	HOLD IN SEQUENCE UNTIL A SPECIFIED EVENT OCCURS
⋮	
OP—ENTRY	SEND MESSAGE TO OPERATOR REQUESTING RESPONSE
MSG	SEND A MESSAGE TO A DESTINATION
⋮	
LOG—PRT	PRINT LOG OUT AT SPECIFIED PRINTING DEVICE
⋮	
END—PATH	DEFINE THE END OF A PATH PHASE
⋮	
HALT	HALT RECIPE AT CURRENT INSTRUCTION PENDING OPERATOR COMMAND
⋮	
END	END A RECIPE SEQUENCE

Baud Rate Does not equal Bits/Sec due to Multiplexing at Baud Rate > 600

DATA COMMUNICATIONS & DATA NETWORKS

Basic Data Channels

- Simplex, Half Duplex, Full Duplex
  - Simplex: one direction communication
  - Half Duplex: both directs take turns
  - Full Duplex: Both directions simultaneously
- Bandwidth, ~~Baud rate~~ Bits/Sec
  - Hz
  - Bandwidth vs. Baud
  - eg. 300–3000Hz
- Synchronous or Asynchronous
  - Sample method
  - must match
  - sampling rates don't have to match
- RS-232C, RS-422, RS485
  - RS-232C: unbalanced
  - RS-422: balanced
  - RS485/RS422 vs. RS232 — longer distances with less noise for RS485/422
- Protocol, Flow Control
- Modems

Networks

- Architecture, Topology - - Bus, Ring, Star
- Protocol, e.g. IEEE 802.3 (Ethernet), OSI 7-Layer Model
- Cabling, e.g. 10Base5

(See References 3 and 4)

(See Primer Pg. 2)

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

DATA COMMUNICATIONS & DATA NETWORKS

Exercise Problem

Answer questions A08 and A09 in Area B of the study guide.

3. SELECTION & CONFIGURATION OF DIGITAL CONTROL SYSTEMS

SPECIFICATION NO. 1849/51

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	ATTACHMENTS	

DCS Vendor Proposal Evaluation
Technical Review

Bid Sect'n	Bid Catagory	Wt Fctr	FOXBORO Raw Score	FOXBORO Wt Score	TAYLOR Raw Score	TAYLOR Wt Score
-	Special Conditions	5	6.83	34.15	5.40	27.00
3	Vendor Responsibilit	2	10.00	20.00	10.00	20.00
5	Standards & Codes	2	10.00	20.00	10.00	20.00
6	Concepts & Philos.	4	9.70	38.80	9.70	38.80
7a	Process I/O	8	8.00	64.00	7.19	57.52
7b	Distrib. Cntrls.	10	9.25	92.50	9.24	92.40
7c	Oper & Eng Interface	12	9.22	110.64	9.07	108.84
7d	Data Commun.	4	9.22	36.88	9.66	38.64
7e	Other Applic.	4	9.46	37.84	6.80	27.20
8	Elect. Require.	3	9.19	27.57	9.05	27.15
9	Environmental Req.	3	9.22	27.66	9.50	28.50
10	Reliab.Maint.Expan.	6	9.28	55.68	9.61	57.66
11	Training	3	9.50	28.50	10.00	30.00
12	Factory Accept. Test	4	10.00	40.00	10.00	40.00
13	Inst & Strt-up Suprt	4	10.00	40.00	10.00	40.00
14	Maint. Serv/Spares	3	10.00	30.00	10.00	30.00
15	System Docum.	3	8.75	26.25	10.00	30.00
16	Proj Manage. Coord.	4	9.25	37.00	9.38	37.52
17	Guarantees	3	8.50	25.50	9.00	27.00
	Sub-Total		175.37	792.97	173.60	778.23
	Judgement Values					
-	Schedule/Del	4	7.00	28.00	9.50	38.00
-	Sys Cost Effect	3	10.00	30.00	8.75	26.25
-	Probability Success	4	6.85	27.40	9.40	37.60
-	Plant Acceptance	2	9.00	18.00	7.25	14.50
	Sub-Total		32.85	103.40	34.90	116.35
	Evaluation Total	100	208.22	896.37	208.50	894.58

DCS CONFIGURATION STEPS

	DESCRIPTION	PRECURSOR SCHEDULE	DELIVERABLE WORK PLAN
1.	IDENTIFY TEAM MEMBERS & ASSIGN CONFIGURATION TASK RESPONSIBILITIES		
2.	ESTABLISH CONFIGURATION INFORMATION HANDLING PROCEDURES	PROJECT PROC'S MANUAL	
3.	DEFINE WORK AREA REQ'MENTS, ARRANGE SPACE FOR CONFIGURATION SYSTEMS, & LAYOUT FLOOR PLAN	DCS CONFIGURE EQUIPMENT LIST	FLOOR PLAN
4.	PREPARE CONFIGURATION 'HOUSE-KEEPING' & BACKUP PROCEDURES		PROCEDURES MEMO
5.	DEFINE OPERATOR/USER CHANGE ACCESS ENVIRONMENTS/LEVELS	OPERATOR RESP'S LIST	OPER/USER CHANGE ACCESS REQ'MENTS
6.	PREPARE PROCESS ALARMS MANAGEMENT GUIDELINES	OPERATOR INTF PHILOSOPHY	PROCESS ALARM MGMT. STD.
7.	ESTABLISH CONTROL LOOP CONFIG STD'S & CONVENTIONS FOR SELECTED DCS; PREPARE TYPICAL CONTROL LOOP CONFIG'S	CONTROL STD'S & PHILOSOPHY	LOOP CONFIG STD'S, CONV'S, EXAMPLE CONFIG'S
8	ESTABLISH PROCESS DISPLAYS, GRAPHICS DESIGN STANDARDS	PLANT SYMBOLS STANDARD	PROCESS GRAPHICS DESIGN STD'S.
9.	PREPARE SYSTEMS & SUB-SYSTEMS INTEGRATION REQUIREMENTS	SYSTEM SPEC'S, VENDOR INFO	SYSTEMS INTEGRATE SPEC
10.	REVIEW LATEST P&ID'S & PREPARE CURRENT PROCESS I/O COUNT	P&ID'S, INST. INDEX	I/O LIST
11.	PARTITION PROCESS INPUTS, OUTPUTS, SUB-SYSTEM INTERFACES	P&ID'S, SAMA'S SUB-SYS SPECS	CONTROLLER LOOP ASSIGNS
12.	ALLOCATE CONTROLLER, I/O HARDWARE, SUB-SYS INTERFACES, & POWER SUPPLIES IN DCS CABINETS	LOOP ASSIGNS, HDWR CAPACITY	RACK LOADINGS
13.	PREPARE I/O WIRING ASSIGNMENTS	CONTROLLER LOOP ASSIGNS	I/O WIRING ASSIGN LIST
14.	ALLOCATE GRAPHICS, NON-CONTROL FUNCTIONS, ETC. TO TARGET DEVICES	FUNCTIONAL REQ'MENTS	
15.	FINALIZE OPERATOR CONSOLES LAYOUTS		CONSOLE DRAWINGS
16.	LAYOUT CONTROL RM, RACK RM, & COMPUTER ROOM EQUIPMENT	RM EQUIP LIST	FLOOR PLANS

17. REVIEW & FINALIZE SYSTEM OVERALL ARCHITECTURES		SYSTEM ARCH DIAGRAMS
18. RELEASE DCS FOR MANUFACTURING		
19. SET UP CONFIGURATION ENGINEERING SYSTEMS EQUIPMENT & LOAD & SYS-GEN/ INITIALIZE CONFIGURE SOFTWARE	EQUIPMENT, WORK AREA, LAYOUT SKETCH	
20. CONFIGURE PROTOTYPE INPUTS, CONTROL LOOPS, ETC.	CONFIG STD'S & CONVENTIONS	
21. CONFIGURE CONTROLLER INPUTS, MONITOR-ONLY POINTS, DATABASES	INDEX, ASSIGN LIST, P&I'S	INPUTS DATA BASE
22. CONFIGURE CONTROL LOOPS & INTERLOCKS	P&I'S, SAMA'S, LOGICS	LOOP CONFIG'S
23. CONFIGURE COMPUTED PROCESS VARIABLES	COMPUTED VARIABLES EQUATIONS	
24. CONFIGURE PROCESS DATA VALIDATION LOOPS	DATA VALIDATION EQUATIONS	
25. CONFIGURE SMART TRANSMITTERS CALIBRATION AIDS	INST DATA SHEETS	
CONFIGURE PROCESS SUBSYSTEMS (BMS) COMMUNICATION INTERFACES	SYSTEMS INTEGRATE SPEC, VARIABLES LISTS	
27. CONFIGURE 'USER' ACCESS ENVIRONMENTS, KEYLOCKS, PASSWORDS SCHEMES	USER CHANGE ACCESS REQ'S	
28. CONFIGURE ALARMS MANAGEMENT SCHEME	ALARM MGMT DESIGN STD	
29. DESIGN CRT DISPLAYS HIERARCHY	GRAPHICS STDS, SKETCHES	DISPLAYS HIERARCHY DIAG
30. CONFIGURE GROUP TEMPLATE DISPLAYS		
31. BUILD CUSTOM PROCESS GRAPHIC DISPLAYS	PROCESS GRAPHICS DESIGN STD'S, SKETCHES	GRAPHICS PRINT-OUTS
32. CONFIGURE CRT DISPLAYS HIERARCHY	DISPLAYS HIERARCHY DIAGRAM	
33. CONFIGURE HISTORICAL DATA BASE	HIST VAR'S LIST, COLLECT PARM'S	
34. CONFIGURE HISTORICAL TRENDS DISPLAYS		

35. CONFIGURE SPC CHARTS	SPC VARIABLES SPEC'S	
36. CONFIGURE LOGS & REPORTS	FORMAT & CONTENT DEF.	REPORT PRINT-OUTS
37. CONFIGURE PROGRAMMABLE BUTTON PANELS		BUTTON ASSIGNS
38. CONFIGURE HOST COMPUTER INTFACE (CHIP) TO DCS (CELCO ONLY)	PROCESS DATA R/W REQ'MENTS	
39. REVIEW VENDOR DCS FAT PLAN	FAT PLAN	COMMENTS
40. WITNESS AS MANUFACTURED DCS FACTORY ACCEPTANCE TEST	DCS BUILD BOOK, FAT PLAN	FAT RESULTS, VDR PUNCH LIST
41. RESOLVE FAT 'PUNCH LISTS' ITEMS	PUNCH LISTS	
42. REVIEW VENDOR DCS FIELD ACCEPT TEST PLAN	VDR FIELD TEST PLAN	COMMENTS
43. DEVELOP FIELD INSTALL, INTEGRATE, COMMISSION, & APPLY ACCEPT TEST PLANS		FIELD TEST/ ACCEPT PLANS
44. PREPARE DCS 'SYSTEM CONFIG MANUAL'		CONFIG MANUAL
45. PREPARE DCS 'OPERATOR APPLY MANUAL'		APPLY MANUAL

4. PROBLEM EXERCISES

Work problem P301 C.S.E. Study Guide 2nd Edition ➢ (Copy in **Section 5. References**).

For Question 7, did you use the interactive PID algorithm from the previous exercise? Explain the difference between that algorithm and the answer in the Study Guide.

Note that Questions 5-10 show the controller "programmed" in a procedural language. What technique would be more typical for a modern DCS.

4. PROBLEM EXERCISES (cont.)

Work problem A301 C.S.E. Study Guide 2nd Edition. (Copy in **Section 5. References**)

In addition to processing time, what other controller resources are possibly relevant as a loading consideration?

4. PROBLEM EXERCISES (cont.)

Work problem A302 C.S.E. Study Guide 2nd Edition. (Copy in **Section 5. References**)

Sample @ at least double the frequency of the highest frequency

S

5. REFERENCES

1. Amy, L. T., *Automation Systems for Control and Data Acquisition*, Instrument of America, 1992.
2. Smith, Cecil L., *Digital Computer Process Control*, Intext Educational Publishers, New York, 1972.
3. Capano, Daniel E., *Computer Networks: A Primer*, Intech, December 1995. (Copy Attached)
4. *Technical Overview: Data Communications Terms*, Black Box .pdf Internet Download. (Copy Attached)

5. REFERENCES (Cont.)

5. Control Systems Engineering Study Guide 2nd Edition Problems P301, A301, and A302. (Copies, with Solutions Attached)

Applying Technology

Computer networks: a primer

By Daniel E. Capano

Need to brush up on data communications terminology? Here are some basics.

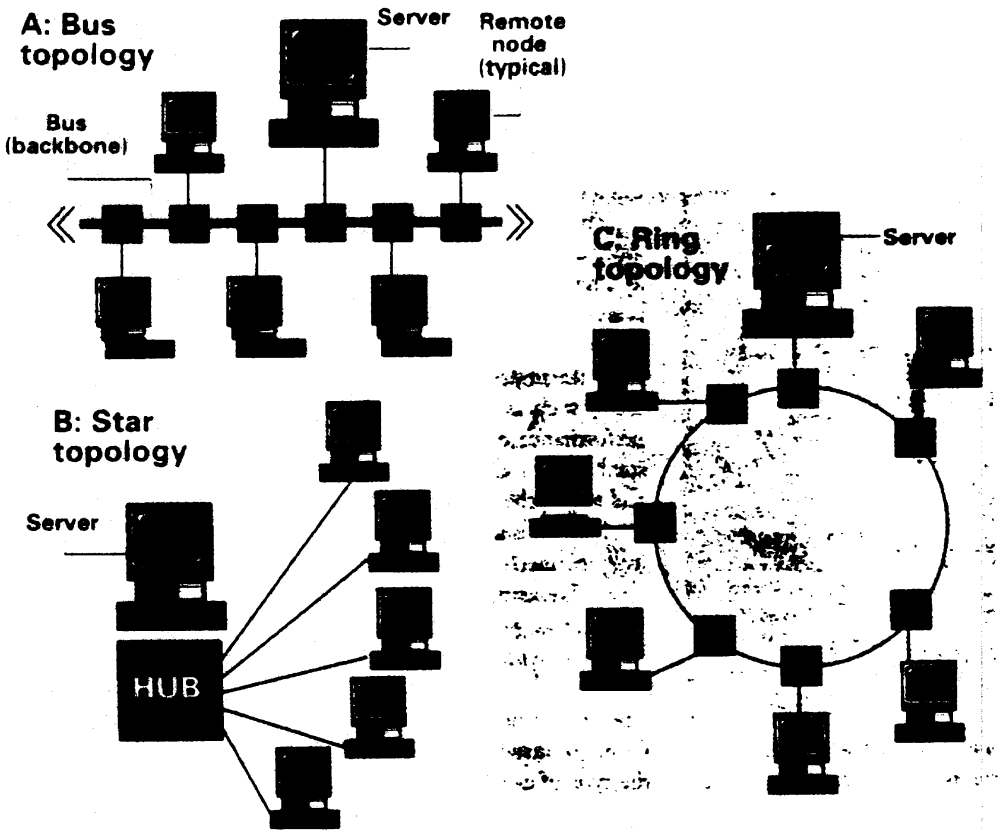


Figure 1. Network topologies

A computer network is arranged so any computer node can utilize any network resources such as printers, modems, mass storage devices, memory, and other computers. Ideally, any PC can access a vast amount of data and services as if the extended resources existed on that same PC. In other words, the connection to resources is seamless and transparent to the user or application. The network, in effect, becomes a virtual computer.

Networks are classified by architecture, data transmission protocol, and, to a lesser extent, physical cabling. Architecture, or topology, refers to the physical configuration of the network. Three network topologies are in general use as of this writing: bus, ring, and star (see Figure 1).

InTech magazine frequently receives requests to run articles on "technology basics." This "data communications primer" is the first in what we hope will become a periodic series responding to that need.
— The Editors

Data transmission protocols are the "language" the network speaks between nodes in order to establish connections, transfer data, regulate the use of the network, and avoid contention for resources. There are three protocols in common use: IEEE-802.3 or "Ethernet," IEEE-802.5 or "token ring," and Attached Resource Computer network (ARCnet).

The third parameter used to describe a network is the cabling used to physically connect the nodes together and to resources. A variety of cable is used; the type used is determined by distance between nodes, data throughput, data transmission protocol, and cost.

Topologies

The *bus* is the prevalent type, due in part to low installation and maintenance costs. It is suited to applications where nodes are separated by a large physical distance and is known as a "backbone" network. It is capable of high node density, but has the drawback of flat performance (throughput) at high traffic volumes. Isolation of network segments can occur from accidental cable breakage, but a node failure affects only that node.

The *ring* is most common in installations built around IBM mainframes. While often perceived as a physical ring, its physical installation usually is arranged in a star topology, but that's where the resemblance to a star ends. The protocol establishes the nodes in a logical ring. With a ring protocol, such as IEEE-802.5 (token-passing ring), performance on the network is essentially constant. Major drawbacks are high cost per node and loss of the entire network with a node failure.

The *star* is arranged so that each node is physically connected via cabling back to the network server. Depending on the protocol used, the network can be reconfigured at any time for number of users without "downing" the server. The ARCnet system reconfigures itself automatically whenever a node enters or leaves the system. Costs for installation and maintenance vary with the type of cabling and protocol used.

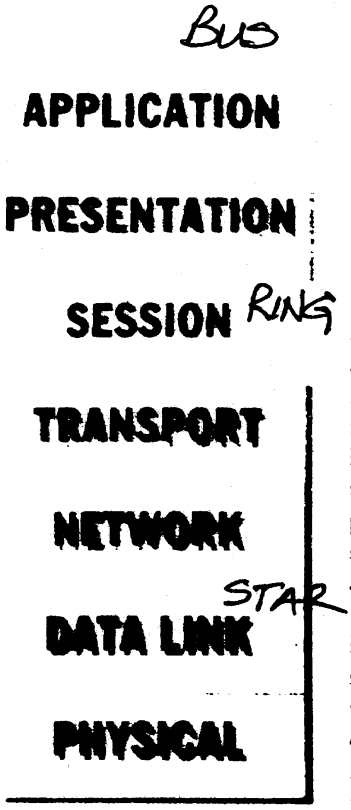


Figure 2. The ISO Open Systems Interconnect (OSI) model

Two broad protocols

Protocols are logical agreements that enable each node to communicate with another node. In the most general sense, data transmission protocols fall into two broad categories: synchronous and asynchronous.

Synchronous protocols are based on clearly defined steps initiated by a timing pulse or signal, such as the pulse generated by the system clock. The timing signals, transmitted with the data, allow the receiving node to synchronize with the transmitting node. Typically, the sending node sends a *preamble* before the data to achieve synchrony. The effect of synchrony is higher throughput, reliable error detection and correction, and fault-tolerant network control. Examples of this type of protocol are Ethernet and token ring.

Asynchronous protocols transmit the data without establishing synchrony. The transmitting node sends the data through the medium and performs the next operation without regard to whether the message was received or lost. Asynchronous protocols do not establish a "connection" in the sense that the synchronous protocols do.

Some error correction schemes are in use such as Cyclical Redundancy Check (CRC). The transmission of data can happen at any time between the communicating nodes when an asynchronous protocol is used. This type of protocol is used on systems where the communicating devices are wired together directly and utilize a single communicating channel exclusively. An example would be the EIA/TIA RS-232-D serial communications standard.

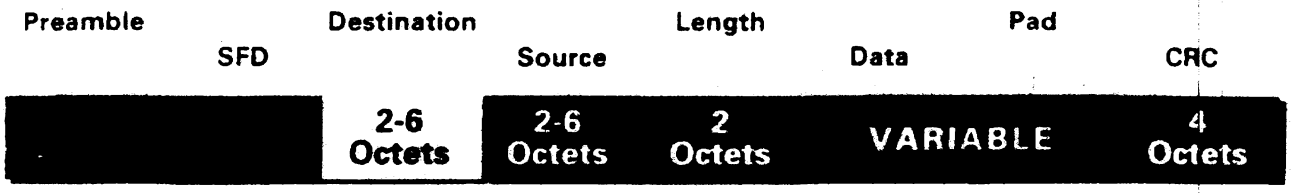
In order for two nodes to communicate, both must follow an agreed-upon method for reading and decoding the data. The communication protocol forms an "envelope" around the transmitted data according to agreed-upon conventions. The envelope consists of leading and trailing data fields that mark the start and end of the transmission. Within the data fields, decoding and routing information is also provided. This information permits the receiving node to do any required special handling such as the transmission to another node or network.

Another important protocol function is establishing a standard communication path. Services such as flow control and error handling must be provided. Flow control establishes a virtual path after assuring there is no contention for the network resource. Error handling provides for loss of or corruption of data and the subsequent retransmission of that data.

The International Standards Organization (ISO) has developed what has come to be known as the Open Systems Interconnect (OSI) model (see Figure 2). The model was developed to provide a framework within which logical and ordered interfaces could be achieved.

The model is defined by seven layers, each of which contains protocols performing different services. Theoretically, each layer interfaces seamlessly with the layer above and below it. Using this method, specialized protocols can be developed and incorporated into a network protocol suite in order to provide such services as transmission control and internetworking.

The user, at the application layer, enters data at the terminal interface. The application layer passes the data stream to the presentation layer which envelopes the data stream with a header and trailer unique to this layer. It should be noted that entire layers may be ignored and the data passed through those layers if the functions provided are not needed.



1 octet = 8 bits = 1 byte **SFD = start frame delimiter** **CRC = cyclical redundancy check**

Bits within frame transmitted left-to-right

Figure 3. Data frame

The data is ultimately passed through to the lowest, or physical, layer after each layer has appended or passed the data through. The data link and physical layers of the model provide the services needed to establish and control communication between sending and receiving nodes.

The data link layer provides facilities for the control of the transmission of data blocks and the recovery from errors. This layer also controls the rate at which packets are received from the physical layer. Control of the physical layer is continued or shared in this layer in order to achieve an error-free interface with the network layer.

The physical layer supplies and controls the physical communication medium used for the transmission of data. This layer is responsible for the actual signal transmission over the network. Upon receiving data, the physical layer is charged with maintaining proper interfacing with the data link layer and effecting the transfer of data from the physical medium to the data link layer. The data link layer uses the physical layer to form its connection.

Ethernet evolved in 1970s

Ethernet was developed in 1969 at the University of Hawaii's Computer Science Department to link the resources of the school's seven campuses on four different islands. Radio was the physical medium used for transmission, hence the term *Ether*net. The technology was developed further between 1973 and 1976 at the Xerox Palo Alto Research Center (PARC).

IEEE-802.3 is a physical layer protocol standard and is the result of work by the committee of the same designation. Physical media, primarily cable specifications, are defined as is the data transmission format or "frame" and the medium control technique.

There are several transmission medium options. Besides radio, there is increasing use of cellular technology for wide area networks. But the vast majority of networks use copper or optical cables. IEEE-802.3 uses a coaxial cable with a diameter of .405 in. with taps or terminations every 8.3 meters. The maximum allowable segment length is 1,762 ft. or 500 meters. Data throughput or bandwidth is limited to 10 Mbps.

Data is broadcast over the network to all nodes on a single frequency-modulated channel. In radio parlance, this is known as baseband transmission. Broadband transmission, by comparison, uses more than one frequency to transfer data. IEEE 802.3 defines the use of this technology.

As previously mentioned, data transmission format is commonly known as a data frame, data packet, or packet frame. This frame is the agreed-upon format that defines a standard data element. The original Ethernet frame differs from the 802.3, which enlarged the minimum data field.

A data frame contains the following elements (see Figure 3):

The 48-bit preamble synchronizes the listening nodes to the new transmission. Following the preamble is the start frame delimiter (SFD), which signals the start of a message with the bit sequence 10101011. Then there is the destination address field with the data necessary to route the message to the proper node.

This information is supplied by the network layer of the ISO stack using a protocol such as the Internet Protocol (IP) portion of the TCP/IP protocol suite. The network layer protocols handle establishment of connection between nodes. This involves routing the message regardless of the actual physical location of the receiving node. The protocol establishes the connection, handles any acknowledgment from the receiving node(s), and then turns the data over to the link or transport layers, depending on the direction of travel in the stack.

The next field is the source address field and is used during the connection establishment or "handshaking." The data field follows and is limited to a minimum of 48 bytes by convention, thereby determining a minimum frame length. Finally, a stop frame delimiter is sent, signaling the end of the frame. The stop frame delimiter typically performs an error-checking function, usually a CRC calculation.

Besides radio, there is increasing use of cellular technology for wide area networks, but the vast majority of networks use copper or optical cables.

For further reading:

IEEE 802.3: Carrier Sense Multiple Access with Collision Detection

IEEE-802.5: Token Ring Access Method

(Contact: IEEE, 445 Hoes Lane, Piscataway, NJ 08855-1331)

Industrial Data Communications: Fundamentals and Applications
Lawrence M. Thompson, ISA

Handbook of LAN Technology, 2nd edition, Paul J. Fortier
McGraw-Hill Publishing
ISBN 0-07-021625-8

Guide to Connectivity, 2nd edition, Frank J. Derfler
Ziff-Davis Press
ISBN 1-56276-047-5

TCP/IP and Related Protocols
Uyless Black
McGraw-Hill Publishing
ISBN 0-07-005553-X

DEC Networks and Architectures
Carl Malamud
McGraw-Hill Publishing
ISBN 0-07-039822-4

LAT Network Concepts
Digital Equipment Corporation
Order number: AA-LD84B-TK

Technical Aspects of Data Communication
John E. McNamara
Digital Press
ISBN 1-55558-007-6

Advanced Ethernet/802.3 Management & Performance
Bill Hancock
Network-1, Inc., L.I.C., NY.
800\NETWRK1

Recommended reading (via Internet) for TCP/IP is as follows:

Request for Comment RFC 793 — Transmission Control Protocol

RFC 791 — Internet Protocol

RFC 1011 — Official Protocols

Medium control

IEEE-802.3 describes a method of medium access control designated as Carrier Sense Multiple Access with Collision Detection (CSMA/CD), which is used exclusively on backbone networks. Essentially, a node's network layer protocol receives data from a layer above it and signals the link and physical layers that it has a message to send.

The message is encapsulated with routing information as previously described and is passed to the link layer. The link layer protocol has been monitoring the network for traffic, and when a break in traffic is detected, the link layer instructs the physical layer to seize and assert a busy signal on the network.

The other nodes see the busy signal and refrain from attempting transmission. Transmission of data then begins. If, at the same moment, another node has begun to send data by the above method, a BUS error or JAM signal is generated by both nodes, aborting both transmission attempts. Both nodes then back off for a randomly selected delay time and retry the above sequence.

Once a message is successfully transmitted to the network, the preamble signals the start of a new message and allows all listening nodes to get into synchronization with the sending node. The start frame delimiter and destination address are then transmitted. The nondestination nodes ignore the message.

The receiving node accepts the message and, using the source address, acknowledges receipt to the sending (source) node. The network medium is then released for use by other nodes. The receiving node then decodes any special routing or control information included and passes the data up the stack to the appropriate level.

This transmission method works very well with small traffic volumes. As traffic increases, collisions become more frequent. These add propagation time delays in the form of cumulative transmission retries and reduce network performance. Performance is directly related to medium bandwidth, which is dependent upon the physical characteristics of the physical layer devices.

Token ring

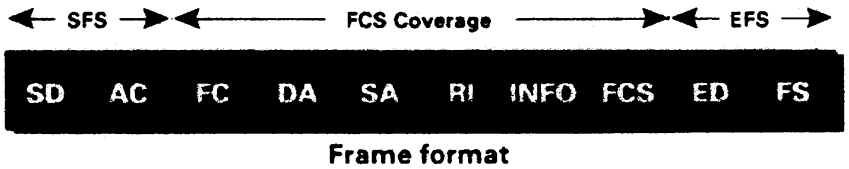
The second major network type is the token ring, developed by IBM from a system of network control being used in the Netherlands in the mid-1980s. This class of network access and control is known as sequential control. Each node or station is allowed to transmit data over the network only when the node is given exclusive permission to do so.

Any other nodes on the network are blocked from transmitting and must wait their turn to transmit. The so-called token is the device that gives nodes the right to transmit. The technique used to transfer control is called token passing. This protocol is defined as a physical layer standard by IEEE 802.5.

The token is a bit sequence, as illustrated in Figure 4. A node is inactive until it receives the token. The node examines the token and, based on the data it contains, takes action or passes on the token and any information it contains. If no data addressed to another node are present, the node retransmits the information to the next node. If the data is addressed to that node, the node begins to receive and passes the data to the appropriate level of the stack.



Token format



Frame format

AC	Access control
DA	Destination address (2 or 6 octets)
ED	Ending delimiter (1 octet)
EFS	End-of-frame sequence
FC	Frame control (1 octet)
FCS	Frame check sequence (4 octets)
FS	Frame status (1 octet)
RI	Routing information (0 to 30 octets)
SA	Source address (2 or 6 octets)
SD	Starting delimiter (1 octet)
INFO	Information (0 or more octets)
SFS	Start-of-frame sequence

Figure 4. Token bit sequence

The node can use a token to pass data of its own if there are no data appended to the token. This is accomplished by appending a data frame to the token. The data travels over the network until the addressed node is reached. The receiving node acknowledges the receipt of the data and sends the token frame back to the transmitting node, which checks for successful and error-free transmission and ultimately deletes it.

Token-ring networks operate at 16 Mbps and support both synchronous (real-time video) and asynchronous (real-time control) classes of service. Lack of collisions and subsequent recovery allow this type of network to perform at consistent transfer speeds independent of traffic volume.

Factors affecting network performance include the server bus and hard disk access and transfer speeds and, to a lesser extent, data frame length. A major drawback to this type of network is the loss of the whole network with a node failure. Token-ring networks require an active network management scheme which adds to the cost of setting up and operating the network.

Other control techniques

Several other network access and control techniques should be mentioned briefly. The other major sequential control techniques are token bus and ARCnet. Token bus resembles token ring in that a token is passed between nodes sequentially. Manufacturing Automation Protocol (MAP) was a variant of the token-passing bus.

ARCnet, developed by the Datapoint Corporation, uses a broadcast-type signaling technique which sequentially sends transmission permission to the star-connected nodes. ARCnet has the advantage of being able to communicate over large geographical areas.

The third major class of network access and control protocol is known as the reservation type in which the network resources are allocated time slots. The total number of available slots is some multiple of the number of stations using the network. Each node has a set of numbers stored in memory which correspond to the time slots the node "owns."

The network server sends a periodic slot synchronization signal that serves to increment a counter in each node. When the counter value equals a number in the node's memory, the node has permission to transmit. A node typically owns more than one slot and may use more than one to transmit a frame of data. While not in common use on Earth, this system finds extensive use in the aerospace industry, particularly in the space shuttle fleet. An example of this protocol is the Honeywell Experimental Data Processing System (HXDP).

Cable types

A shorthand has been developed to describe the types of cabling used. 10Base5 is a coaxial cable used in 802.3 networks. The cable is referred to as trunk or "thickwire" because of its relatively large diameter of .405 in. The designation describes the cable as having a bandwidth of 10 Mbps using baseband transmission on cable segments of 500 meters.

10Base2 describes a cable with a diameter of .188 in. and is referred to as "thinwire" or "thinnet." Following the naming convention, this cable supports a 10-Mbps throughput using baseband transmission. This cable is limited to a segment length of 200 meters.

10BaseT cable designates unshielded eight-conductor twisted-pair cable. While this cable is used with the Ethernet, or standard 802.3 for data frame format, the physical medium specification widely used is EIA/TIA 568, which specifies cable characteristics and physical interfaces such as RJ45 modular plug terminations. Segment lengths are limited to 100 meters and connections are point-to-point. This type of cable is used in star-type networks. 10BaseT does not support broadband transmission. The cable specification is further broken down in categories based on throughput or bandwidth.

Level 1 or category 1 cable is analogous to telephone cable, commonly known as "quad" or unshielded four-conductor twisted pair. It is commonly used in residential telephone installations. The bandwidth is <5,000 Hz. Later implementations of this definition do not consider quad as a suitable medium. Quad can be used, however, if the cable is already installed.

Category 3 cable is an unshielded eight-conductor twisted pair commonly used in small office networks which supports a bandwidth to 10 Mbps.

Category 5 cable is physically similar to category 3 cable, but allows throughputs of up to 100 Mbps. This permits real-time video services such as conferencing, surveillance, and commercial video feeds.

100BaseT and 100BaseVG are emerging technologies being developed in order to effect faster data transfer over existing cabling.

100BaseF describes an optical fiber cable supporting 100 Mbps of data throughput. An addendum to the IEEE-802.3 standard is being prepared for IEEE which describes optical transmission. IT

Token-ring networks require an active network management scheme which adds to the cost of setting up and operating the network.

IEEE 802.5
TOKEN RING
16 Mbps

10Base5 – Coaxial Cable
200M 10Mbps

10BaseT
RJ45 100 M

CAT 1 = Telephone

CAT 3 10Mbps
8 Conductor Twisted Pair
CAT 5 100Mbps
100BaseT NEW

Behind the byline

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100BaseF Fiberoptic

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Technical Overview: Data-Communication Terms

This Technical Overview defines a few of the terms you'll often see in our catalog. For a much more comprehensive list, try our Pocket Glossary—call for ordering information.

10BASE2 — A 10-Mbps Ethernet network implemented on thin RG58 coaxial cable, commonly known as "Thin Ethernet" or "ThinNet."

10BASE5 — The original 10-Mbps Ethernet network standard defined by DEC™, Xerox®, and Intel®, and implemented on thick, yellow-jacketed cable. Also called "Thick Ethernet" or "ThickNet."

10BASE-T — A 10-Mbps *Ethernet* network implemented on twisted-pair cable.

100BASE-T — A 100-Mbps Ethernet network implemented on twisted-pair cable.

100VG-AnyLAN — A 100-Mbps LAN using demand-priority technology and implemented on twisted-pair cable.

ANSI (American National Standards Institute) — The principal standards-development organization in the U.S.

ASCII (American Standard Code for Information Interchange, pronounced "ASK key") — A 7-bit binary data code used in communications with most minicomputers and personal computers.

Asynchronous (async) transmission — A transmission method in which time intervals between transmitted characters may be of unequal length. Transmission is controlled by *start* and *stop bits* on each character, rather than by clocking as in *synchronous transmission*.

AT command set — The standard control language for modems, in which commands begin with an "attention string" made up of the two letters "AT."

ATM (Asynchronous Transfer Mode) — A high-bandwidth networking standard based on cell-relay services. As defined by the ITU-T, ATM is a type of cell relay based on a data unit of 53 bytes.

AUI (Attachment Unit Interface) — The interface between a *transceiver* and a *NIC* or other network node in a *10BASE5* Ethernet network.

AWG (American Wire Gauge) — A standard method of defining the cross-sectional area of a wire.

Backbone — In *10BASE5* Ethernet, the main network cable, to which nodes are attached through transceivers.

Balanced — A type of line that carries pairs of equal but oppositely polarized signals to minimize crosstalk and eliminate the need for signal ground reference.

Balun (BALanced/UNbalanced) — An impedance-matching transformer device used to connect *balanced* twisted-pair cabling to unbalanced coaxial (or other) cabling. Common in IBM cabling systems.

Baud — Unit of signaling speed. The speed in baud is the number of line changes (in frequency, amplitude, etc.) or events per second. At low speeds, each event represents only one bit condition, and *baud rate* equals *bps*. As speed increases, each event represents more than one bit, and *baud rate* does not truly equal *bps*. But in common usage, *baud rate* and *bps* are often used interchangeably.

BERT/BLERT (Bit Error Rate Test/Block Error Rate Test) — Tests that measure the quality of a data transmission. Both tests compare received data with an established data pattern, then count the number of mismatches (errors).

BNC (bayonet-Neill-Concelman) — A bayonet-locking connector for miniature coax. Contrast with *TNC*.

bps (bits per second) — The basic unit of measurement for serial data-transmission capacity.

Bridge — A device that connects LANs running the same protocols and cabling. Compare *router*, *gateway*.

Browser — A program that can be used to view and download information from the *World Wide Web*.

Buffer — A memory area in which data is temporarily stored until it can be processed or transmitted.

Bus — 1) A transmission path or channel; an electrical connection, with one or more conductors, by which all attached devices receive all transmissions at the same time. 2) A linear LAN topology, used by Ethernet, in which every network node listens to all transmissions, selecting certain ones based on address identification. 3) In computer architecture, a data path shared by devices within a system; for example, a computer's input/output bus.

Cascade — To connect a multiple-port device to an identical device, increasing the total number of ports available.

Category 3 — A cabling standard for UTP wiring with a 16-MHz bandwidth. Used for *10BASE-T* networks or 4-Mbps *Token Ring* networks.
Category 4 — A cabling standard for UTP wiring with a 20-MHz bandwidth. Used for 16-Mbps *Token Ring* networks.
Category 5 — A cabling standard for UTP wiring with a 100-MHz bandwidth. Used for 100-Mbps data transmission.
CCITT (Comité Consultatif Internationale de Télégraphique et Téléphonique) — An international consultative committee that set worldwide communications standards such as V.32, V.34, and X.25. Replaced by the *ITU-TSS*.
Centronics® parallel — A de-facto standard 36-pin interface for connecting parallel printers to PCs.
Cladding — In fiberoptic cable, a low-refractive-index material that surrounds, insulates, and protects the *core*.
Coaxial cable — Cable in which a solid piece of copper is surrounded by insulation and a tubular piece of copper braid. Comes in many varieties, depending on the degree of EMI shielding afforded and voltages and frequencies accommodated. Has high bandwidth but is cumbersome to install, making it most suitable for more permanent installations. Typically supports RF frequencies from 50 to about 500 MHz. Also called "coax."
Collision — 1) In LAN technology, two stations attempting to use the same transmission medium at the same time. 2) In a half-duplex system, the result of both ends trying to transmit at the same time.
Connectivity — The components and technology that enable devices to exchange data across electronic links.
Contention — A first-come, first-served method of access used in public telecommunication or PBX systems in which multiple devices must access a limited number of communication ports.
Core — The central region of an optical waveguide through which light is transmitted; typically 8 to 12 microns in diameter for single-mode fiber, and 50 to 100 microns for multimode fiber.
CPU (Central Processing Unit) — 1) The heart of a computer; the processor or processors that do the computing. 2) The enclosure that houses a PC's motherboard, as opposed to its monitor and/or external peripherals.
Cross-pinned cable, crossover cable — A cable configured to allow two DTE devices or two DCE devices to communicate. Also called a "null-modem cable" or "modem-eliminator cable."
Crosstalk — The unwanted coupling of a signal from one circuit to another, measured in dB as a negative number. A measurement of 0 dB represents full coupling; as the measured value increases, the amount of coupling decreases.
CSU (Channel Service Unit) — A digital *DCE* used to terminate digital circuits (such as *DDS* or *T1* lines) at the customer site. It conditions the line, ensures network compliance with FCC rules, and responds to loopback commands from the central office.
Daisychaining — An arrangement of devices connected in a series, one after the other. Any signal transmitted to the devices goes to the first device, and from the first to the second, and so on.
Data rate, data-signaling rate — A measure of how quickly data is transmitted, expressed in bps. Also commonly, but often incorrectly, expressed in baud. Synonymous with "speed."
dB (decibel) — A comparative (logarithmic) measure of signal power (strength or level): +10 dB (or +1 Bel) represents a gain of 10 to 1; -3 dB represents a 50 percent loss of power. Contrast with *dBm*.
dBm (decibels referenced to one milliwatt) — An absolute measure of signal power, where 0 dBm is equal to one milliwatt. Contrast with *dB*.
DB9, DB15, DB15HD, DB25, DB37, DB50 — Common names for D-shaped connectors used in data communications. The number indicates the number of possible pins in sockets in the connector.
DCE (Data-Communications Equipment) — Devices such as modems that enable *DTEs* to communicate over phone lines or data circuits. They establish, maintain, and terminate connections, and perform the conversions necessary for communication. In *RS-232*, designation as either DCE or DTE determines the signaling role in handshaking.
DDS (Dataphone Digital Service) — A private-line digital service with typical data rates of 2.4, 4.8, 9.6, and 56 Kbps.
Decibel — See *dB*.
Dedicated line — A nonswitched channel or circuit dedicated to a single communication link; see *leased line*.
Dialup line, dial-in line, dial line — A temporary data connection activated by establishing a direct-dialed telephone link between two modems. Compare with *leased line*.
DIN — 1) The Deutsches Institut für Normung (German Institute for Standardization). 2) A type of rounded connector standardized by this organization.
DIP (Dual In-Line Package) switch — A switch for opening and closing leads between two points. Often used to configure devices.
Driver — A software module that, under control of the processor, manages peripheral I/O.
DSU (Data Service Unit) — A component of customer premise equipment used to interface to a digital circuit (*DDS* or *T1*); combined with a *CSU*, it converts a customer's data stream to bipolar format for transmission.
DTE (Data Terminal Equipment) — User devices such as terminals and computers that connect to *DCEs*; they either generate or receive the data carried across the link or network. In *RS-232*, designation as either DTE or DCE determines the signaling role in handshaking; in *X.25*, it determines the device or equipment that manages the interface at the user's premises.
E1 — A European standard for digital transmission at 2.048 Mbps. It has 31 64-KB channels available for traffic.
EBCDIC (Extended Binary Coded Decimal Interchange Code, pronounced "EBB-see-dick") — An 8-bit character code used primarily in IBM equipment; the code provides for 256 different bit patterns. Compare with *ASCII*.

EIA (Electronic Industries Association) — A standards organization in the U.S. specializing in the electrical and functional characteristics of interface equipment. It used to designate its recommended standards with the "RS-" prefix ("RS-232," "RS-485," etc.); now it designates them with the "EIA-" or "EIA/TIA-" prefix.

EIA/TIA-568 — A wiring standard for commercial buildings supported by both the EIA and the TIA, as well as by ANSI. It describes every aspect of cable installation for both voice and data communication.

EIA/TIA-568A — One of two similar but noninteroperable ways to attach the wires in twisted-pair cable to RJ-45 connectors, specified in the *EIA/TIA-568* standard. Used for *ISDN*, 568A assigns Pair 2 to Pins 3 and 6 and Pair 3 to Pins 1 and 2. Not as popular as its counterpart *EIA/TIA-568B*.

EIA/TIA-568B — One of two similar but noninteroperable ways to attach the wires in twisted-pair cable to RJ-45 connectors, specified in the *EIA/TIA-568* standard. Used for *10BASE-T*, 568B assigns Pair 2 to Pins 1 and 2 and Pair 3 to Pins 3 and 6. More popular than its counterpart *EIA/TIA-568A*.

Emulation — The imitation of all or part of one device by another, so that the emulating device accepts the same data, performs the same functions, and appears to other network devices as if it were the emulated device.

Ethernet — A network standard first developed by Xerox, refined by DEC and Intel, and codified as the *IEEE 802.3* standard. It interconnects up to 1,024 personal computers in a bus topology on each network. In its original form, it supports a 10-Mbps data rate.

Fallback — The ability to default to an alternate line or device if the primary unit fails.

Fast Ethernet — Any 100-Mbps Ethernet-based networking scheme.

FDDI (Fiber Distributed Data Interface) — An ANSI standard for fiberoptic links with data rates up to 100 Mbps.

FEP (Front-End Processor) — A dedicated computer linked to one or more host computers or multi-user minicomputers; performs data-communications and network-processing functions for the attached computers; in IBM *SNA* networks, an IBM 3704, 3705, 3725, or 3745 communications controller.

Filtering — In LAN technology, discarding packets that do not meet the criteria for *forwarding*.

Firmware — Operating instructions stored for the long term in a device's read-only memory.

Flow control — A method of regulating the flow of data between two devices; prevents the loss of data once a device's buffer has reached its capacity.

Forwarding — In LAN technology, sending a packet from one LAN to another through a bridge or router.

Fractional T1 — A service aimed at customers who don't need or can't afford all 24 channels of a full T1 line. Fractional T1 service offers one or more channels; customers pay only for the channels they use.

FRAD (Frame-Relay Assembler/Disassembler) — A device that acts as the interface between a LAN and a Frame Relay network.

Frame Relay — A packet network service, relying on the data integrity inherent in digital transmissions to speed up transmission. Unlike old *X.25* networks, Frame Relay "assumes" the data is correct and starts error checking as soon as it receives the header. Frame Relay services are offered with *T1* and *DDS* connections.

Front-end processor — See *FEP*.

FTP (File Transfer Protocol) — An upper-level *TCP/IP* service that allows copying of files across a network.

Full duplex (FDX) — Simultaneous, two-way, independent transmission in both directions. Compare with *half-duplex*.

G.703 — The general standard for interfacing to digital high-speed circuits. It now includes specifications for both 1.544 Mbps and 2.048 Mbps data rates; however, G.703 is normally referred to for 2.048-Mbps applications.

Gateway — A hardware-software combination that connects two LANs (or a LAN and a host computer) that run different protocols—for example, a TCP/IP LAN and an SNA mainframe. The gateway provides the protocol conversion. Compare with *bridge*, *router*.

Half-duplex (HDX) — Transmission in either direction, but not both simultaneously. Compare with *full duplex*.

Handshaking — Exchange of predetermined signals between two devices, establishing a connection or providing *flow control*. Usually part of a communications protocol.

HDLC (High-Level Data-Link Control) — An international standard communication protocol defined by the ISO.

Host computer — The central computer (or one of a collection of computers) in a data-communications system. It handles the system's primary data-processing functions such as computing, mediating database access, and running special system-specific programs; often shortened to "*host*."

HTML (Hypertext Markup Language) — The standard set of codes that allows documents on the *World Wide Web* to be read by any system.

HTTP (Hypertext Transfer Protocol) — The protocol used to transfer documents on the *World Wide Web*.

Hub — The core of a star-topology network or cabling system.

IEC (International Electrotechnical Commission) — An organization that cooperates with the ISO in setting technology standards.

IEEE (Institute of Electrical and Electronic Engineers) — An international society of professional engineers that issues widely used networking standards.

IEEE 802.3 — The IEEE standard for *Ethernet*: a physical-layer standard that uses the CSMA/CD access method on a bus-topology LAN.

IEEE 802.5 — The IEEE standard for *Token Ring*: a physical-layer standard that uses the token-passing access method on a ring-topology LAN.

IEEE-488 — Standard interface commonly used by HP plotters and in industrial applications.

Impedance — The resistance to the flow of alternating current in a circuit.

Interface converter — A device that allows communication between two systems with incompatible electrical signals, connectors, and/or handshaking.

International Telecommunications Union (ITU) — See *ITU-TSS*.

Internet — 1) Any large network made up of several smaller networks. 2) Capitalized, the international network of networks that connects educational, scientific, and commercial institutions.

ISDN (Integrated Services Digital Network) — A CCITT standard for a network that accommodates a variety of mixed digital-transmission services at 144 Kbps and 1.544 Mbps.

ISO (International Standards Organization) — The international "master organization" responsible for developing and maintaining worldwide standards for computers, data communications, and many other fields.

ISO 9000 — An umbrella group of international standards (including ISO-9001, -9002, -9004, etc.) for quality assurance in business practices, ratified by the ISO beginning in 1987. Certification of ISO 9000 compliance is rapidly becoming a prerequisite for selling many types of goods and services (including data-communications equipment and services), especially to government bodies. Black Box Corporation and many of its subsidiaries are ISO-9001 certified.

ISP (Internet Service Provider) — A company or organization that provides dialup Internet access.

ITU-TSS — The United Nations organization responsible for setting telecommunications standards. Replaced the *CCITT*.

Kbps (Kilobits per second) — A standard measurement of data rate and transmission capacity, equal to 1000 bits per second.

LAN (Local Area Network) — A switched multipoint data-communications system confined to a limited geographic area—up to 6 miles (10 kilometers)—with 100-Kbps to 155-Mbps data rates. It does not use common-carrier circuits, although it may have gateways or bridges to other public or private networks.

Leased line — A telephone line reserved for the exclusive use of a leasing customer without interexchange switching arrangements. A leased line may be *point-to-point* or *multipoint*. (Also called a "private line.")

Line driver — A DCE device that amplifies a data signal for transmission over lengths of cable beyond the RS-232 limit of 50 feet (15.2 m)—even up to several miles. It also conditions the signal by reshaping distorted pulses. Also called a "limited-distance modem (LDM)" or "short-haul modem (SHM)."

Local area network — See *LAN*.

Loopback — A diagnostic procedure used for transmission devices. A test message is sent to a device being tested. The message is then sent back to the originator and compared with the original transmission. Loopback testing may be performed with a locally attached device or conducted remotely over a communications circuit.

MAU (Multistation Access Unit) — A wiring concentrator used in Token Ring LANs.

Mbps (Megabits per second) — A standard measurement of data rate and transmission capacity, equal to 1,000,000 bits per second.

Mini-DIN — A small type of *DIN* connector most often used for keyboard and mouse connections.

Modem eliminator — A device used to connect a pair of *DTE*s in lieu of the pair of modems that would otherwise be necessary. See *SME*.

Multiplexor — A device that uses any of several methods to transmit and receive multiple signals across a single communication channel at the same time. Often shortened to "mux."

Multipoint — Describes communications lines or circuits that connect more than two stations, thus supporting terminals in several different locations. Compare with *point-to-point*.

Mux — See *multiplexor*.

NIC (network interface controller, network interface card) — Electronic circuitry that connects a workstation to a network; usually in the form of a card that fits into one of the expansion slots inside a personal computer.

Node — On a network, a terminal point at which data is transmitted, received, or repeated. Usually corresponds to an attached device such as a computer, network modem, or router.

NOS (network operating system) — Master software installed on a network to control all network functions, such as connecting devices, sharing resources, and transferring files.

Packet — A sequence of data, with associated control information, that is switched and transmitted as a whole; refers mainly to the field structure and format defined with the CCITT *X.25* recommendation.

Packet-switched network — A data-communications network such as *X.25* that takes packets from different sources, routes them according to addresses, interleaves them, and sends them to their destinations.

Parallel transmission — Transmitting a number of bits of data simultaneously over separate lines (for example, eight bits over eight lines); usually unidirectional. Compare with *serial transmission.*

PC Card — A credit-card-sized device that can be easily plugged into and removed from portable or laptop computers to provide temporary memory enhancements, modem or LAN capability, or even disk storage. Originally called "PCMCIA cards."

PCMCIA (Personal Computer Memory Card International Association) — See *PC Card.*

Pixel (picture element) — The smallest indivisible part of a video image.

Plenum rated — In cabling, approved by the NEC for installation in air spaces ("plenums"). Plenum-rated cable does not give off toxic fumes when it burns. Compare with *PVC.*

Point-to-point — Describes communications lines or circuits that connect just two locations. Compare with *multipoint.*

Protocol — The procedures used to control the orderly exchange of information between stations on a data link or on a data-communications network or system.

Protocol converter — A device that translates from one communications protocol into another, such as IBM SNA/SDLC to ASCII; compare with *gateway.*

PVC (Polyvinyl chloride) — The type of plastic from which cable jackets and wire insulation are usually made. Produces toxic fumes when it burns. Compare with *plenum rated.*

RAID (Redundant Array of Inexpensive Disks) — A method of storing data on multiple hard-disk drives, for faster access, greater reliability, or both. There are six officially defined "levels," each designed for a specific kind of application.

Repeater — In digital transmission, equipment that receives a signal, amplifies it, retimes it, and then reconstructs the signal for retransmission; in fiberoptics, a device that decodes a low-power light signal, converts it to electrical energy, and then retransmits it via an LED or laser source. Also called a "regenerative repeater."

RJ-11 — Wiring with 4- or 6-wire modular connectors; commonly used for standard telephone lines.

RJ-45 — Wiring with 8-wire modular connectors; commonly used for serial data transmission.

Router — A network device that examines the network addresses within a given protocol, determines the most efficient pathway to the destination, and routes the data accordingly. Compare with *bridge, gateway.*

Routing — The process of selecting the correct circuit path for a message.

RS-232 — The industry's most common serial interface standard; an *EIA*-recommended standard for the interface between computer devices. It is identical in function to the combined CCITT standards *V.24* and *V.28.*

RS-422, RS-423 — *EIA* serial transmission standard that extends transmission speeds and distances beyond those of *RS-232.* RS-423 is an unbalanced system; RS-422 is a balanced system with a higher level of noise immunity.

RS-449 — *EIA* standard specifying the pinning for *RS-422* and *RS-423* when a DB37 or DB9 connector is used.

RS-485 — *EIA* serial interface standard for multipoint lines.

RS-530 — *EIA* standard specifying the pinning for *RS-422* when a DB25 connector is used.

SCSI (Small Computer Standard Interface, pronounced "scuzzy") — An interface that provides high-speed bus connections between small computers and intelligent peripherals such as hard disks, printers, and optical disks.

Serial transmission — Transmitting data one bit at a time. Contrast with *parallel transmission.*

Session — 1) A connection between two stations that allows them to communicate. 2) The time period during which a user engages in a dialogue with an interactive computer. 3) In the IBM *SNA*, the logical connection between two network-addressable units.

Shielding — Surrounding a cable with grounded metal so that there is less chance that electrical signals carried by that cable will interfere with, or be interfered with by, external electrical signals.

Short-haul modem — See *line driver.*

SME (synchronous modem eliminator) — A *modem eliminator* that operates synchronously rather than asynchronously; that is, it uses clocking rather than *start* and *stop bits.*

SNA (Systems Network Architecture) — The total description of the logical structure, formats, protocols, and operating sequences for transmitting information between IBM software and hardware devices.

Splitter — A device that multiplies one input into a number of identical outputs.

Spool (Simultaneous Peripheral Operation On Line) — A program or device, usually with a large *buffer,* that controls data going to an output device; also called "spooler."

Spread spectrum — The process of modulating a signal over a significantly larger bandwidth than is necessary for the given data rate, in order to reduce the number of errors caused by interference.

Start bit — In *asynchronous transmission,* an extra bit added to signal the start of a byte or character.

Stop bits — In *asynchronous transmission,* one or more extra bits added to signal the end of a byte or character.

STP (Shielded Twisted Pair) — Twisted-pair cable that has a foil and/or braided shield to minimize interference.

Super VGA (SVGA) — A refinement of *VGA* that offers higher resolution, at least 800 x 600 pixels.

Switched 56 (SW56) — A dialup version of *DDS* that provides for 56-Kbps transmission across 2- or 4-wire circuits.

Sync — Short for *synchronous, synchronous transmission,* or *synchronization.* In video, a means of synchronizing signals with timing pulses so that each step in a process occurs at exactly the right time.

Synchronous (sync) transmission — Data transmission in which characters and bits are transmitted at a fixed rate, with the transmitter and receiver synchronized by a clock source. This eliminates the need for individual *start bits* and *stop bits* surrounding each byte, thus providing greater efficiency than *asynchronous transmission*.

T1 — A digital carrier facility used to transmit a formatted digital signal at an aggregate data rate of 1.544 Mbps. A T1 carrier uses *multiplexing* to transmit large volumes of information across great distances at high speeds at a (potentially) lower cost than that provided by traditional analog service. It consists of one 4-wire circuit providing 24 separate 64-Kbps logical channels.

TCP/IP (Transmission Control Protocol/Internet Protocol) — A layered set of protocols that allows sharing of applications among PCs, hosts, or workstations in a high-speed communications environment; it governs data communication on the *Internet*.

Telco — A generic abbreviation for "telephone company"; also an abbreviation for "telephone central office." Used to describe certain interfaces and equipment typically used by telephone companies.

Telnet™ — A virtual terminal service available through the *TCP/IP* protocol suite.

Thick Ethernet, Thicknet — See *10BASE5*.

Thin Ethernet, ThinNet — See *10BASE2*.

TNC (threaded Neill-Concelman): A threaded connector for miniature coax. Contrast with *BNC*.

Token — A continuously repeating frame, transmitted onto the network by the controlling computer; the frame that polls for network transmissions. See *Token Ring*.

Token Ring — A LAN-access mechanism and topology, developed by IBM and standardized as *IEEE 802.5*, in which a supervisory frame or token is passed from station to station in sequential order. Stations wishing to gain access to the network must wait for the token to arrive before transmitting data.

Transceiver — A device that links a node to a network cable, functioning as both a transmitter and receiver.

Twinaxial cable — A cable that is similar to *coaxial cable*, but has two inner conductors instead of one. Used in IBM minicomputer and midrange systems such as Systems 34, 36, and 38, and AS/400.

Twisted pair — Two insulated copper conductors that are wound around each other, mainly to cancel the effects of electrical noise; typical of standard telephone wiring.

Twisted-pair cable — Cable made up of one or more *twisted pairs*.

TIA (Telecommunication Industries Association) — Sister organization to the *EIA* that collaborates with it in setting standards for data communication (*EIA/TIA-568*, for example).

URL (Uniform Resource Locator) — A standard Internet-location address; for example, "http://www.blackbox.com."

USB (Universal Serial Bus) — Serial 4-wire bus architecture for peripheral I/O developed by Compaq, Intel, and Microsoft. It autosenses up to 128 peripherals and supports a maximum distance of 5 m (16.4 ft.) and a maximum data rate of 12 Mbps.

UTP (Unshielded Twisted Pair) — Twisted-pair cabling without EMI/RFI shielding. Compare *STP*.

V.24 — A CCITT interface recommendation defining interchange circuits; similar to and compatible with RS-232.

V.28 — A CCITT interface recommendation defining electrical characteristics for *V.24* interchange circuits; similar to and compatible with RS-232.

V.32 — A CCITT 9600-bps dial- or 2-wire leased-line modem recommendation.

V.32 bis — A CCITT 14.4-Kbps dial- or 2-wire leased-line modem recommendation.

V.34 — An ITU-TSS modem standard for data transmission at 28.8 Kbps.

V.34 bis (V.34+) — An ITU-TSS modem standard for data transmission at 33.6 Kbps.

V.35 — A CCITT interface standard for high-speed communication. V.35 specifies a 34-pin connector and can transmit at speeds into the millions of bits per second. It can't connect, physically or electrically, to any other interface without the aid of a converter.

V.42 — A CCITT standard for error correction by modems.

V.42 bis — A CCITT standard for data compression by modems.

VGA (Video Graphics Array) — A video standard for IBM PC and compatible computers. Standard VGA has a resolution of 640 x 480 and supports 16 colors.

WAN (Wide-Area Network) — A network that serves an area of anywhere from several to thousands of miles, using common-carrier-provided lines; contrast with *LAN*.

Web page — A single location on the *World Wide Web*; for example, an article in an online magazine.

Web site — A group of related pages on the *World Wide Web*.

World Wide Web — The collection of tens of millions of Internet *HTML* sites around the world that can be accessed with a *browser*. Information on the Web can be in the form of text or a combination of text and graphics.

X.21 — A CCITT standard that defines a synchronous DCE-to-DTE interface for public data networks.

X.25 — The main CCITT standard interface for *packet-switched* data-communications networks.

X-ON/X-OFF (Transmitter On/Transmitter Off) — Special characters used for flow control; they signal a device to start transmission (X-ON) and stop transmission (X-OFF).

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Questions 1-4 concern a supervisory control system shown in Figure P301.

The system in Figure P301 reads and records the controller output, setpoint, and process variable for the four controllers.

A small computer requires 4 microseconds (μsec) per instruction and 100 instructions to address a multiplexer line and to read in and process the data on that line. The ADC requires 30 μsec to perform the conversion and capture the value of an input, and the multiplexer requires 20 μsec to select an input.

Flow loops are sampled and recorded five times as often as the level loop, and the pressure loop twice as often as the level loop.

2ea F5x
1ea L x
1ea P2x

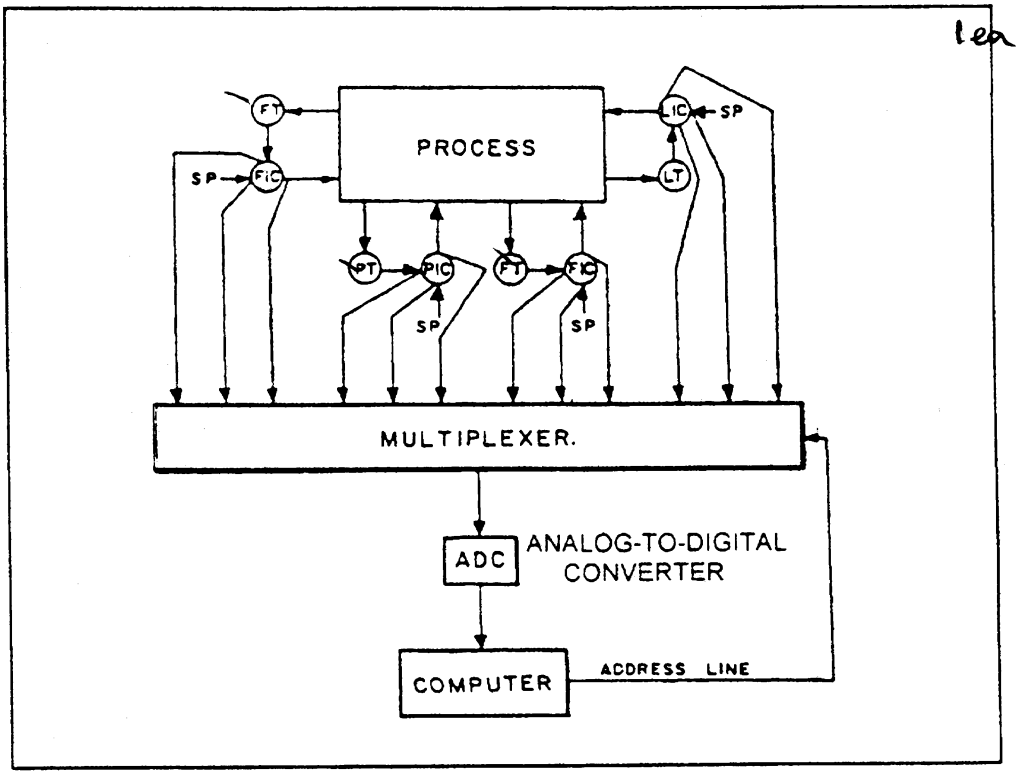


Figure P301

1. As an independent system, the multiplexer and ADC would have a maximum conversion rate (in conversions per second) that is most nearly equal to:

   (A) 2,220
   (B) 2,500
   (C) 20,000
   (D) 33,330
   (E) 50,000

$\frac{10^6 \mu s/sec}{(20+30)\mu sec} = 20{,}000$

2. For the system as shown, the total time (in microseconds) to process all of the controllers is most nearly equal to:

   (A) 1,600
   (B) 4,800
   (C) 5,400
   (D) 5,850
   (E) 17,550

3. If all of the controllers were used for level control and the group of inputs was scanned once every 30,000 microseconds, the total time (in microseconds) available for other functions would be most nearly

   (A) 12,450
   (B) 24,600
   (C) 25,200
   (D) 26,000
   (E) 29,400

4. If all of the controllers were used for flow control and the scanning requirements were the same as defined previously, how many controllers could be handled in 30,000 microseconds?

   (A) 4
   (B) 5
   (C) 22
   (D) 25
   (E) 66

$\frac{30000}{(3)(5)(450)} = 4.44$

Questions 5-10 concern a key program for a process control computer. The program provides for translation of a binary count from an analog-to-digital converter into engineering units, checking the resulting value against high and low limits, calculation of an associated controller output using a proportional-plus-integral algorithm, and checks of the controller output against appropriate limits.

In the program, the following nomenclature is used:

XE	Error - current value
XEP	Error - previous value
XDE	Error - diff of current and previous value
XSE	Error - sum of current and previous values
XDM	Manipulated variable - calculated change
XMP	Manipulated variable - previous value
XMMAX	Manipulated variable - upper limit
XMMIN	Manipulated variable - lower limit
XDMMAX	Manipulated variable - maximum change (absolute)
XM	Manipulated variable - new value
GAINX	Proportional gain for PI control algorithm
TIX	Integral time for PI control Algorithm
T	Control time interval

You can assume that past values of the variables, constant parameters, etc., are correctly stored in a data base in the computer memory, with suitable indexing so that "X" can refer to any one of the many system variables.

Program instruction (Questions 7-9) are written in a half-English, half-mathematical form to avoid use of a particular programming language. In evaluating the program instructions, consider their intended purpose, not their conformity to the rules or syntax of a particular language.

5. For conversion of the input variable count (e.g., 0 to 1023) to engineering units, the program should contain provisions for using which of the following relationships?

   (A) Linear

   (B) Square

   (C) General polynomial

   (D) Square root

   (E) All of the above

6. When a limit check shows an input signal outside its high or low limits, the program should:

   (A) Go directly to the END of the program, skipping execution of the control algorithm.

   (B) Print an alarm message, and go directly to the END of the program.

   (C) Turn on a horn and flashing light, and go directly to the END of the program.

   (D) Enter the time, variable identification and calculated value (in engineering units) in an alarm list for later processing, and continue execution of the program.

   (E) Substitute the limit value for the calculated value of the variable and continue execution of the program.

7. The correct formula for calculating the change in the controller output (manipulated variable) is:

   (A) XDM = GAINX * XE + XSE/TIX

   (B) XDM = GAINX * XDE + XE/TIX

   (C) XDM = GAINX * (XDE + XE/TIX)

   (D) XDM = GAINX * (XDE + (T/TIX)(XEP))

   (E) XDM = GAINX * (XE + (T/TIX)(XSE))

8. After calculating the change in the controller output, the intent is to compare the change (XDM) with a maximum allowable change (XDMMAX, a positive quantity). In order to constrain the amount of change in the controller output in one execution of the control algorithm, the program will adopt the calculated change or the maximum allowable change, whichever is smaller. Which of the following sets of instructions will produce the intended result?

I If XDM < XDMMAX, go to next step.

II If XDM > XDMMAX, XDM = XDMMAX; go to next step.

III If ABS (XDM) < XDMMAX, go to next step.

IV If ABS (XDM) > XDMMAX, XDM = XDMMAX; go to next step.

V If ABS (XDM) > XDMMAX, XDM = (XDM/ABS (XDM)) * XDMMAX); go to next step.

(A) I

(B) I, followed by II.

(C) III

(D) III, followed by IV.

(E) III, followed by V.

9. After checking the magnitude of the change in the controller output, the program next calculates the new controller output (XM = XMP + XDM) and compares the result with upper and lower limits (XMMAX and XMMIN, respectively). If the calculated controller output is outside the limits, the limits are adopted. Which of the following instructions should be executed by the program?

I If XM > XMMAX, XM = XMMAX; go to END

II If XM < XMMIN, XM = XMMIN; go to END.

III If XDM < (XMMAX - XMMIN), go to END.

IV If ABS (XDM) < (XMMAX - XMMIN), go to END.

V If (XM < XMMAX) and (XM > XMMIN), go to END.

(A) I and II
(B) III
(C) IV
(D) V
(E) I, II and V.

10. A program like the one considered here should contain which of the following features?

I Filtering or averaging for inputs

II Halt on division by zero

III Halt if controller parameters (GAIN, Integral time, etc.) are negative

IV Control different kinds of variables (flow, pressure, temperature, etc.) at different frequencies.

V Provide different control algorithms (proportional, squared-error, deadtime, etc.) depending on the control loop

(A) I
(B) II and III
(C) I and IV
(D) I and V
(E) I, IV and V



1. The time required for one conversion is 20 + 30 = 50 microseconds. Hence the conversion rate is most nearly

$$\frac{10^6}{50} = 20{,}000 \text{ conversions/second.}$$

If a few computer instructions are required to address the multiplexer and if they cannot be overlapped with the multiplexer - ADC operation, this rate would be decreased somewhat.

The best answer is (C).

2. Each input requires 4 * 100 + 20 + 30 = 450 microseconds. Each controller has 3 inputs to the multiplexer. Flow controllers are sampled 5 times as often as levels, and the pressure controller twice as often. Therefore, the number of inputs per cycle is 3 * [(1)(1) + (1)(2) + (2)(5)] = 3 * 13 = 39.
(per controller: 1 lea OP, 1 lea PV, 1 lea SP → 3)
level pressure flow

The total time is (39)(450) = 17,550 microseconds.

The correct answer is (E).

3. If all the loops were level control loops, the time required would be (4)(3)(450) = 5,400 microseconds. Out of 30,000 microseconds, the time available for other functions would be 30,000 - 5,400 = 24,600.

The correct answer is (B).

4. The time required for a flow loop is (3)(5)(450) = 6,750 microseconds. In 30,000 microseconds, the system could handle

$$\frac{30{,}000}{6{,}750} = 4.44 \rightarrow 4 \text{ controllers}$$

The correct answer is (A).

5. General-purpose program should provide for all of the listed types of conversion relationships and perhaps others.

The correct answer is (E).

6.

A– Does nothing to inform the operator of the out-of limits condition.

B&C– Informs the operator of the out-of-limits condition, paying no attention to whether it was a pre-existing condition and making no record of any new out-of-limits conditions.

D– Allows different treatment for pre-existing and new out-of-limits conditions, different responses (such as substituting the limit value or some other value) for different variables, etc.

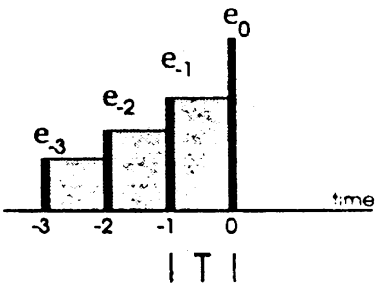
E– Does not take any action to generate or record an alarm; also, executing the control algorithm based on an out-of-limits value may be hazardous.

The correct answer is (D).

7. The control algorithm is derived as follows:

The controller output is m.
The present error is e_0.
Previous errors are
$e_{-1}, e_{-2}, e_{-3},...$

The integral of the error (shaded areas) can be approximated by:



$$\int_{-\infty}^{0} e\ dt = T\,[e_{-1} + e_{-2} + e_{-3} + ...]$$

At time t = 0, the algorithm can be written:

$$m_0 = K\left(e_0 + \frac{1}{TI}\int e\,dt\right)$$

$$= K\left[e_0 + \frac{T}{TI}(e_{-1} + e_{-2} + e_{-3} + ...)\right]$$

At time $t = t_{-1}$, the same algorithm would be:

$$m_{-1} = K\left[e_{-1} + \frac{T}{TI}(e_{-2} + e_{-3} + e_{-4} + \ldots)\right]$$

subtracting:

$$\Delta m = m_0 - m_1 = K\left[e_0 - e_{-1} + \frac{T}{TI} e_{-1}\right]$$

In the notation used in this problem, the algorithm is:

$$XDM = GAINX * (XDE + \left(\frac{T}{TIX}\right)(XEP))$$

where XDE = XE - XEP
and the "X" identifies values or parameters related to a specific variable.

The correct answer is (D).

Answers (A), (B) and (C) do not contain the sampling interval, T, and cannot be correct. Answer (E) uses XSE instead of XEP and is not correct.

8. (A) is incorrect. If XDM is very large but negative, XDM could be less than XDMMAX but ABS (XDM) could be larger than XDMMAX.

(B) is incorrect, because II can only produce positive values of XDM.

(C) is incorrect. It handles the cases where ABS (XDM) is less than the limit, but not the cases where ABS (XDM) exceeds the limit.

(D) is incorrect; it corrects for the deficiency of III, but only produces positive values of XDM (like II).

(E) is the correct answer. III handles the cases where ABS (XDM) is less than the limit, leaving XDM as calculated, while V produces a new XDM with the same sign as the original value and the magnitude of XDMMAX when ABS (XDM) is greater than the limit.

9. The correct answer is (E), because I, II and V are needed to deal with the three possible cases.

   III and IV are attempts to say that XDM, the change in controller output, is acceptable if it is less than the range or maximum possible change in the controller output. This is not correct.

10. The correct answer is (E), because these are all desirable features, whether they are used or not.

    The program should not halt under any circumstances. Where division by zero might be possible, measures should be taken to prevent it. Negative controller parameters should be detected and corrected when they are entered, not during execution of the program.

AREA	DESCRIPTION	PROBLEM
C	Digital Control Systems	A301

Situation:

A digital computer provides closed-loop control for 300 variables as shown in the following table:

Type	Number	Control Interval
Flow	100	1 sec
Pressure	50	2 sec
Level	40	5 sec
Temperature	100	20 sec
Composition	10	60 sec
	300	

The average time required for data input, conversion to engineering units, alarm checking and execution of a PID control algorithm for any one variable (except composition) is 2 milliseconds. The composition variables each require 10 milliseconds.

Requirements:

(a) Determine the fraction of the computer's time used for its input and control functions.

(b) If other scheduled functions (e.g., logging and optimization) take 5 out of every 10 seconds on the average, determine the fraction of the computer's time available for other functions.

AREA	DESCRIPTION	SOLUTION
C	Digital Control Systems	A301

(a) Examine a 60-second interval:

Variable	Number	Repetitions	Time/Rep	Total
Flow	100	60	2 m-s	12,000
Pressure	50	30	2 m-s	3,000
Level	40	12	2 m-s	960
Temperature	100	3	2 m-s	600
Composition	10	1	10 m-s	100
				16,660

$$\text{Time used} = \frac{16{,}660(\text{m–s})}{60(\text{sec}) \times 1000^{(\text{m–s}/\text{sec})}} \cong 0.278 \text{ or } 27.8 \text{ percent}$$

(b) $$\text{Other scheduled functions} = \frac{5}{10} = 0.5 \text{ or } 50 \text{ percent}$$

Total time used = 0.778 or 77.8 percent

$\therefore$ Time available = 1 – [Total time used]

= 0.222 or 22.2 percent

AREA	DESCRIPTION	PROBLEM
C	**Digital Control Systems**	**A302**

Situation:

The data acquisition scanner of a computer control system is required to acquire sensor signals from various data points in a process, as well as the specific variables under closed loop control. A total of 17 signals are to be connected to the scanner. The digital control system must control 9 closed loops consisting of 5 liquid level loops and 4 temperature loops.

For adequate control, the control variable signals must be sampled for each of the loops no less frequently than every ½ second for the liquid level loops (L1, L2, L3, L4, L5), and every 2 seconds for the temperature control loops (T1, T2, T3, and T4).

The process signals that are not associated with control loops must be sampled often enough that frequency components in those process signals can be analyzed as indicated in the following table:

Number of Process Signals		Type	Maximum Frequency Component	Scan Period
Scan only	2	A	2 Hz	—
Scan only	3	B	⅓ Hz	—
Scan only	3	C	1/10 Hz	—
Control	5	L	—	½ sec
Control	4	T	—	2 sec

Requirements:

(a) Given a 28-point data acquisition scanner that cycles through all its input points once each second at the rate of 28 points per second, construct a signal connection list that will permit the system to meet the stated signal input sampling requirements. Discuss the rationale used for determining the signal connections.

(b) Discuss the type of analog signal conditioning that must be used for the Type A signals if frequency components higher than 2 Hz are present, even though it is not desired to analyze the Type A signals beyond 2 Hz.

AREA	DESCRIPTION	SOLUTION
C	Digital Control Systems	A302

(a) To meet the stated requirements, the A1 and A2 signals must each be sampled four times per second. The only way to do this with the scanner characteristics stated is for each signal to appear in the scan list four times. Similarly, the L1, L2, L3, L4 and L5 signals must each be sampled twice per second. Therefore, they must each appear in the scan list twice. For simplest documentation and maintenance, all the other input signals should be ordered in the most direct, simple manner.

1.	A1 *	15.	A1 *
2.	A2 *	16.	A2 *
3.	L1 **	17.	L1 **
4.	L2 **	18.	L2 **
5.	L3 **	19.	L3 **
6.	L4 **	20.	L4 **
7.	L5 **	21.	L5 **
8.	A1 *	22.	A1 *
9.	A2 *	23.	A2 *
10.	B1	24.	C1
11.	B2	25.	C2
12.	B3	26.	C3
13.	T1	27.	T3
14.	T2	28.	T4

* Must appear four times in scan list, equally spaced, but need not appear consecutively.

** Must appear twice in scan list, equally spaced. Need not appear consecutively, nor immediately following A1, A2.

All other signals need only appear once each.

(b) Because of the possibility of frequencies above 2 Hz contaminating the sampled values of the A type signals (aliasing), the A signals must have analog filtering to remove the objectionable frequency components above 2 Hz. Otherwise, the frequency components above 2 Hz will be folded back upon the components below 2 Hz and are indistinguishable from the under 2 Hz components. [Keywords the candidate should use in their explanation are anti-aliasing filter, Shannon (Nyquist) sampling theorem, and analog filtering.]

PRE

PRESENTATION OUTLINE

7. 1. DEFINITIONS
   2. RELIABILITY -- A FUNCTION OF DURATION OF
8. OPERATION
   3. RELIABILITY -- NEGATIVE EXPONENTIAL DISTRIBUTION WITH MTBF AS PARAMETER
9. 4. RELIABILITY CALCULATION FROM MTBF -- AN EXAMPLE
10. 5. TWO COMPONENT SYSTEMS -- CONCEPT OF SERIES AND PARALLEL
11. 6. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES

PRESENTATION OUTLINE (cont.)

7. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES -- EXAMPLE
8. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES -- COMPONENT RELIABILITIES EQUAL
9. RELIABILITY OF SYSTEMS WITH COMPONENTS IN PARALLEL
10. COMPONENTS IN PARALLEL-- SYSTEM REQUIREMENT = 1 OF *n*
11. COMPONENTS IN PARALLEL-- SYSTEM REQUIREMENT = 1 OF *n* --EXAMPLE

PRESENTATION OUTLINE (cont.)

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--
    SYSTEM REQUIREMENT = *m* OF *n*
13. RELIABILITY OF COMBINATION
    PARALLEL/SERIAL COMPONENTS
14. AVAILABILITY
15. PROBLEM EXERCISES
16. REFERENCES

1. DEFINITIONS

AVAILABILITY - the probability that a module or system is in an operating state at time t.

FAILURE - termination of the ability of a module to perform its required function satisfactorily.

FAILURE RATE - the expected number of failures in a given time interval under specified conditions.

1. DEFINITIONS (cont.)

FAIL-SAFE SYSTEM a system that fails its outputs to a pre-determined condition to leave the process in a safe state on the occurrence of a non-recoverable fault.

FAULT TOLERANT SYSTEM - a system with the capability: to detect internal faults, to prevent the propagation of faults, to continue to operate in spite of a single failure, and then to fail to a pre-determined state, in the event of multiple internal failures.

1. DEFINITIONS (cont.)

MODULE - an assembly of interconnected components which constitutes an identifiable item, device, instrument, or piece of equipment.

MTBF - (MEAN TIME BETWEEN FAILURES) the average time interval between failures for repairable modules

MTTR - (MEAN TIME TO REPAIR) the average time to repair a failure under the operating conditions encountered.

1. DEFINITIONS (cont.)

PROBABILITY - the ratio of the number of outcomes in ~~an~~ exhaustive set of equally likely outcomes that produce ~~a~~ given event to the total number of possible outcomes; i.e., the chance that a given event will occur.

REDUNDANCY - a property of a parallel configuration of multiple elements whereby a correct output can still be produced when one or more of the elements is not functioning correctly.

Parallel

1. DEFINITIONS (cont.)

RELIABILITY - the probability that a module or system will (not fail) satisfactorily perform its required function under stated conditions over a given in-service period.

SYSTEM - any composite of hardware or software items that work together to perform a function or a set of related functions. Not just computer system, But entire system!

2. RELIABILITY -- A FUNCTION OF DURATION OF OPERATION

When failure rate is constant and relatively low, the reliability of components or systems follows a negative exponential distribution:

$$R_i(t) = e^{-\lambda t}$$

where: $R_i(t)$ = item reliability as a function of time, and

λ = long term average failures per time unit.

3. RELIABILITY -- NEGATIVE EXPONENTIAL DISTRIBUTION WITH MTBF AS PARAMETER

The negative exponential distribution is appropriate whenever an item fails only by random causes but never experiences deterioration during its life. This implies that the expected future life of an item is independent of the previous duration of operation.

The reciprocal of the failure rate λ is called the mean time between failure (MTBF).

$$MTBF = 1/\lambda$$

4. RELIABILITY CALCULATION FROM MTBF -- AN EXAMPLE

An item exhibits an exponential time to failure distribution with MTBF of 1000 hours. What is the maximum operating time such that the reliability does not drop below 0.99?

Solution: $0.99 = e^{-t/1000}$

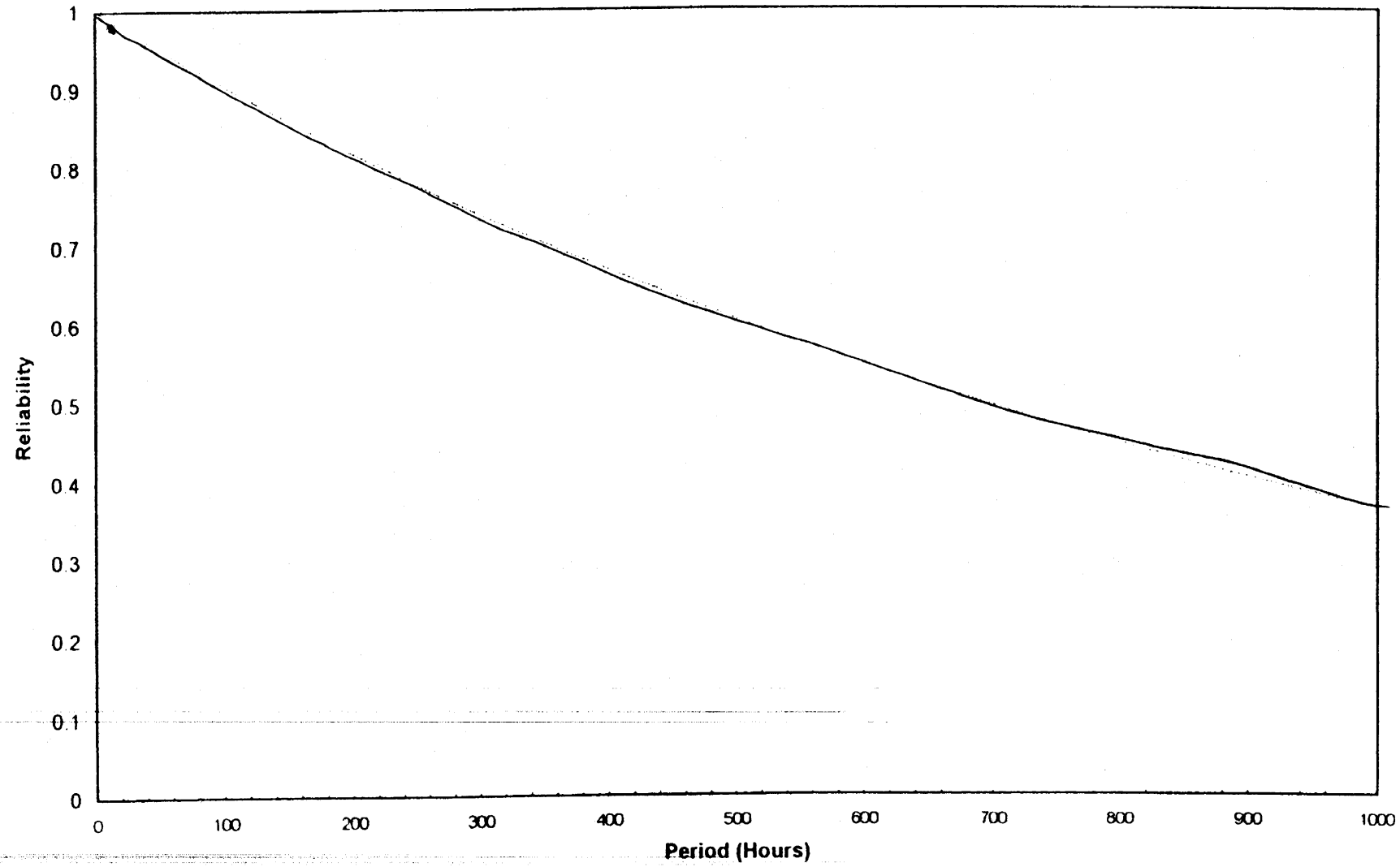
$\ln .99 = -t/1000$

$(-1000)(-0.01005) = (-t/1000)(-1000)$

$10.05 \text{ hrs} = t$

t = 10.05 hours

Reliability vs. Period
Exponential Time to Failure
MTBF = 1000 Hrs



5. TWO COMPONENT SYSTEMS -- CONCEPT OF SERIES & PARALLEL

If the probabilities of failure of two components (i and j), comprising a system, are independent, then, by definition, the probabilities of all combinations of failure events are:

	i FAILS	i DOES NOT FAIL
j FAILS	$(1-R_i)(1-R_j)$	$R_i\ (1-R_j)$
j DOES NOT FAIL	$(1-R_i)R_j$	R_iR_j

If i OR j failing causes system to fail, then (Series Components)

$$R_s=R_iR_j$$

If i AND j must both fail for system to fail, then: (Parallel Components)

$$R_s=1-(1-R_i)(1-R_j)$$

$R_s \equiv$ System Reliability

6. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES

The reliability of a system of "n" parts or components in series is:

$$R_s = R_1 \times R_2 \times R_3 \times \ldots R_n$$

where each reliability is of the form:

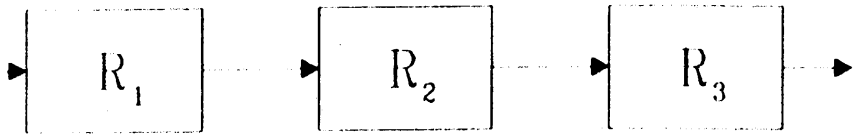
$$R_i(t) = e^{-\lambda t}$$

and R_s = overall system reliability

This implies that the system will fail if any one or more of the individual items fail.

7. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES -- EXAMPLE

A system is built by serially connecting three components as shown below. Suppose that $R_1 = 0.8$, $R_2 = 0.75$, and $R_3 = 0.98$. Determine the overall reliability of this system.



$$R_S = (0.8)(0.75)(0.98) =$$

7. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES -- EXAMPLE (cont.)

Solution:

In this case $R_s = R_1 \times R_2 \times R_3$

$= 0.8 \times 0.75 \times 0.98$

$= 0.59$

8. RELIABILITY OF SYSTEMS WITH COMPONENTS IN SERIES -- COMPONENT RELIABILITIES EQUAL

If there are n components in series, and all n components have identical failure rates, then:

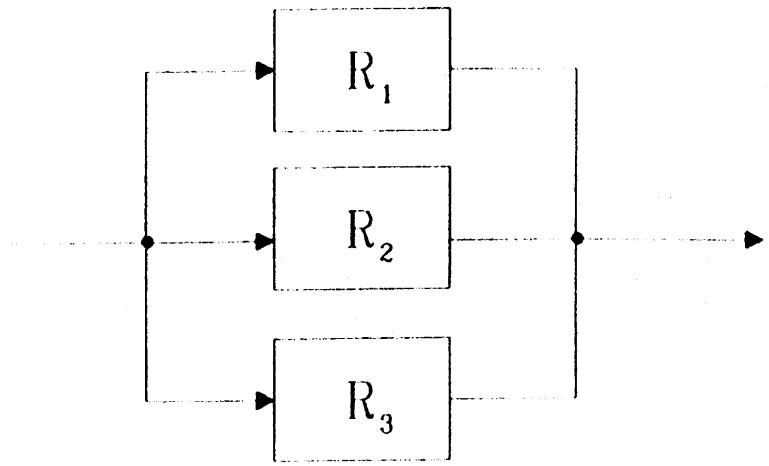
$$R_s = e^{-n\lambda t}$$

or

$$R_s = (R_i)^n$$

9. RELIABILITY OF SYSTEMS WITH COMPONENTS IN PARALLEL

The reliability of systems, with two or more components in parallel (see figure below), depends on the stated requirement. Several cases are possible.



10. COMPONENTS IN PARALLEL-- SYSTEM REQUIREMENT = 1 OF *n*

The system only fails if all *n* components fail. The probability of the i^{th} component failing is:

$$(1- R_i)$$

The probability of all *n* not failing is:

$$R_s = 1-(1-R_1)(1-R_2)(1-R_3)\ldots(1-R_n)$$

If component reliabilities are all equal:

$$R_s = 1-(1-R)^n$$

11. COMPONENTS IN PARALLEL-- SYSTEM REQUIREMENT = 1 OF *n* --EXAMPLE

A system has a 1 of 3 parallel requirement with the same component reliabilities as the series example: $R_1 = 0.8$, $R_2 = 0.75$, and $R_3 = 0.98$. Determine the overall reliability of this system.

$$1 - \left[(1-0.8)(1-0.75)(1-0.98) \right]$$

11. COMPONENTS IN PARALLEL-- SYSTEM REQUIREMENT = 1 OF *n* --EXAMPLE (cont.)

Solution:

$$R_s = 1-(1-R_1)(1-R_2)(1-R_3)$$

$$R_s = 1-(0.2)(0.25)(0.02)$$

$$R_s = 0.999$$

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n*

The system will function properly only if m ($\leq n$) or more components work properly.

The evaluation of the system reliability in this case is quite difficult unless all components have equal reliabilities. Then, the system reliability follows the binomial distribution.

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n* (cont.)

Combinations:

The number of combinations of n components into groups of m (where $m \leq n$) that do not fail and $(n-m)$ that do fail is:

$$\binom{n}{m} = \frac{n!}{m!(n-m)!}$$

"n choose m"

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n* (cont.)

Combinations Example:

How many combinations of the 4 components A,B,C, & D, can be found with 2 not failing and 2 failing?

NOT FAIL	FAIL
A,B	C,D
A,C	B,D
A,D	B,C
B,C	A,D
B,D	A,C
C,D	A,B

$$\frac{4!}{2!2!} = \frac{4 \cdot 3 \cdot 2 \cdot 1}{2 \cdot 1 \cdot 2 \cdot 1} = 6$$

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n* (cont.)

The probability of any one specific combination with exactly m of n not failing and $n-m$ failing is:

$$R^m(1-R)^{n-m}$$

The probability of any combination is:

$$\binom{n}{m} R^m(1-R)^{n-m}$$

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n* (cont.)

System reliability for a parallel system requires m or more components not to fail. Therefore, we sum the probabilities of *m*, *m+1*, *m+2*, ...,*n* not failing:

$$R_S = \sum_{i=m}^{n} \binom{n}{i} R^i (1-R)^{n-i}$$

12. EQUALLY RELIABLE COMPONENTS IN PARALLEL--SYSTEM REQUIREMENT = *m* OF *n* (cont.)

Example:
What is the system reliability of a 2 of 3 parallel system?

1 fail

none fail

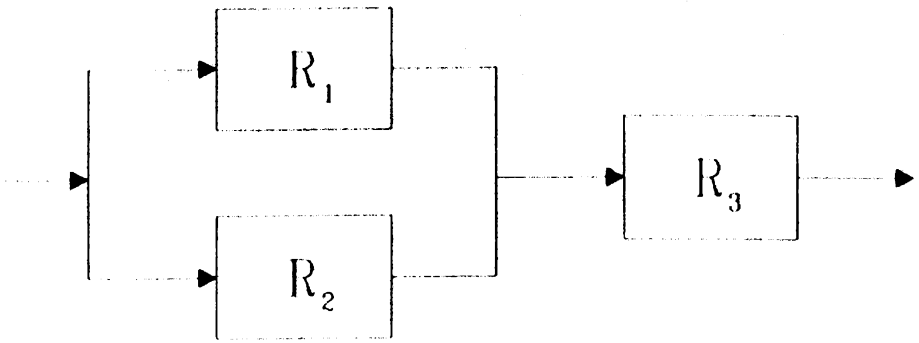
$$R_s = 3R^2(1-R) + R^3$$

(any 2) (all 3)

$$= 3R^2 - 2R^3$$

13. RELIABILITY OF COMBINATION PARALLEL/SERIAL COMPONENTS

Systems composed of a combination of parallel and serial components are frequently encountered in actual practice. Note that in this arrangement, component 3 represents a single point of failure and should therefore have a higher reliability than either of the two redundant components.



13. RELIABILITY OF COMBINATION PARALLEL/SERIAL COMPONENTS (cont.)

Problem:

For the parallel/serial system shown, let the component reliabilities R1 = 0.8, R2 = 0.75, and R3 = 0.98. Assume the survival of either parallel component is sufficient. Determine the overall reliability of this system.

Solution:

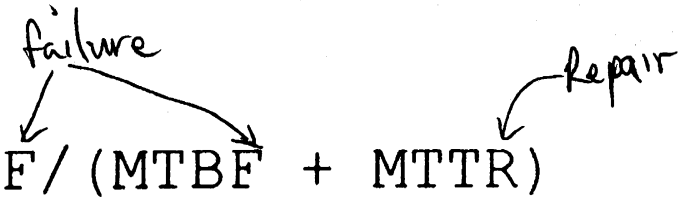
$$R_s = [1 - (1 - R_1)(1 - R_2)] \times R_3$$

$$= 0.95 \times 0.98$$

$$= 0.9310$$

14. AVAILABILITY

Availability is the fraction or percent of time that a component or system is expected to be able to perform its designated functions. A common formula for availability A is:



$$A = MTBF/(MTBF + MTTR)$$

where MTBF AND MTTR are as defined above. When the availability of a control system is known, its unavailability is

$$\overline{A} = 1 - A$$

14. AVAILABILITY (cont.)

The time lost due to system unavailability in, for example, one year can be found by multiplying the total time by the system unavailability:

$$\text{DOWNTIME} = \text{TOTAL TIME} \times \bar{A}$$

The downtime can then be multiplied by the profit value of the product per unit of time to determine the expected dollars lost.

14. AVAILABILITY (cont.)

Example:

A paper mill produces $250,000 worth of paper per hour with a profit margin of 25%. The paper machine control system is non-redundant and has a MTBF of 8758 hours and a MTTR of two hours. Calculate the expected profit loss due to control system failure(s) over two years.

$$\frac{8758 \text{ hrs}}{1} \left| \frac{\text{Day}}{24 \text{ hrs}} \right. = 365 \text{ Days}$$

14. AVAILABILITY (cont.)

Solution: $\overline{A} = 1 - MTBF/(MTBF + MTTR)$

$= 1 - 8758/8760$

$= 0.00023$

DOWNTIME = 2 x 8760 HRS/YR x 0.00023

= 4.0 HRS

LOST PROFIT = $250,000/HR x 0.25 x 4.0 HR

= $250,000

15. PROBLEM EXERCISES

Work problem P501 C.S.E. Study Guide 2nd Edition - (Copy in **Section 16. References**)

What assumption about the repair of a failed console is implicit to the problem? Does this make the answer more or less conservative?

15. PROBLEM EXERCISES(cont.)

Work problem P101 C.S.E. Study Guide 2nd Edition - (Copy in **Section 16. References**).

15. PROBLEM EXERCISES (cont.)

The DCS controller for the OCC plant area (See Page 1-5) is comprised of the following electronic components:

Component	Quantity Required	Description	MTBF (Yrs)
MFP02	1 or 2	Multifunction Processor Module	17.2
PAS02	minimum 3	Modular Power Supply	12
ASO01	5	Analog Output Module (14)	13.8
ASI03	8	Analog Input Module (15)	12.5
DSO04	1	Digital Output Module (16)	38.6
DSI02	1	Digital Input Module	15.6
PEP03	1	Power Entry Panel	137.4
NPM	1 or 2	Network Processing Module	17.2
NIS	1 or 2	Network Interface Module	13.2

MTTR for all electronic components is assumed to be 30 minutes. Full plant capacity of 20 tons/hour can be utilized on the paper machine, and losses of OCC production are made up by substitution of purchased fiber at $300/ton. Plant processing components are essentially in a series arrangement, where any electronics failure will halt production until the repair is completed. Network modules (NPM/NIS) will be redundant to ensure network reliability. Modular Power Supply modules (PAS02) will be supplied at N+1 redundancy (3 of 4). What is the annual production value of redundant Multifunction Controller Modules?

7-36

Assumptions
30 min repa

DCS Redundant Controller
Reliability Comparison

	A	B	C	D	E	F	G	H
					Case 1– Red. MFPs		Case 2 -- Non-red. MFPs	
	Component	MTBF (Yrs)	Reliability (1 Yr)	Reliability (30 Min)	Quantity Required	Effective Reliability (1Yr)	Quantity Required	Effective Reliability (1Yr)
3	MFP02	17.2	0.94351828	0.999996682	1 of 2	0.999999625	1	0.943518285
4	PAS02	12	0.92004441	0.999995244	3 of 4	0.999995436	3 of 4	0.999995436
5	ASO01	13.8	0.93009945		5	0.6960604	5	0.6960604
6	ASI03	12.5	0.92311635		8	0.527292424	8	0.527292424
7	DSO04	38.6	0.97442596		1	0.974425964	1	0.974425964
8	DSI02	15.6	0.9379088		1	0.937908799	1	0.937908799
9	PEP03	137.4	0.9927484		1	0.9927484	1	0.9927484
10	NIS	13.2	0.92704092	0.999995676	1 of 2	0.999999685	1 of 2	0.999999685
11	NPM	17.2	0.94351828	0.999996682	1 of 2	0.999999813	1 of 2	0.999999813
13	System Reliability (1Yr)					0.333000395		0.314192079
14	System MTBF (Yrs)					0.909412012		0.863743763
15	System Availability (fract)					0.999937241		0.999933923
16	System Non-Avail (fract)					6.27593E-05		6.60773E-05
17	Non-Avail Hrs/Year					0.549771296		0.578837131
18	Non-Avail Cost/Yr, @$6,000/hr					$3,299		$3,473

EXP(-30/(B10*365*1440))

EXP(-1/$B3)

1-2*((1-C3)*(1-D3)) EXP(-1/$B3)

1-12*((1-C4)*(1-D4)) ← same

$C5 ^ $E5

6 6

7 7

8 8

$C9 ^ $E9

1-((1-$C10)*(1-$D10))

1-((1-$C11)*(1-$D11))

F3*F4*F5*F6*F7*F8*F9*F10*F11

H3*H4*H5*H6*H7*H8*H9*H10*H11

-1/LN(F13)

-1/LN(H13)

F14*(14+30/(365*1440))

H14/(H14+30/(365*1440))

1-F15

1-H15

F16*8760

H16*8760

F17*6000

H17*6000

(365)(1440) / (2)(30) = 8760 = 365 day/yr | 1440 min/day | repair 30 min | 2

NOTES

1. Failure of any non-redundant DCS component causes loss of production (valued at $6,000/hr -- $300/ton x 20 tons/hr) for the MTTR, which is estimated at 30 min.

2. "System Failure" refers to DCS components only. Failures of other components associated with the DCS, such as a.c. power distribution, motor starters, interposing relays, field instrumentation, field devices, etc. will result in additional non-availability costs.

16. REFERENCES

1. *Guideline for the Reliability of Analysis of Process Control Systems,* Third Edition, International Instrument User's Association, June, 1985.

2. Bloch & Geitner, *An Introduction to Machinery Reliability Assessment,* Van Nostrand & Reinhold, 1990.

3. D. P. Siewwiorek and R. S. Swarz, *The Theory and Practice of Reliable System Design,* Digital Press, Bedford, Mass., 1982.

16. REFERENCES (Cont.)

4. Control Systems Engineering Study Guide 2nd Edition Problems P501 and P101. (Copies, with Solutions Attached)

AREA	DESCRIPTION	PROBLEM
E	**Control Rooms/Interfaces**	**P501**

As a control engineer, you are asked to determine the number of consoles and then to design the CRT displays needed to operate Process Plant A from a central control room. The consoles are the operator's only means for receiving information from the plant and exercising control over its operations.

The system configuration is shown in Figure P501. The system includes 75 single-loop controller and 50 additional controllers in cascade control configurations (two controllers each). The total counts of analog and digital inputs and outputs are shown in the figure.

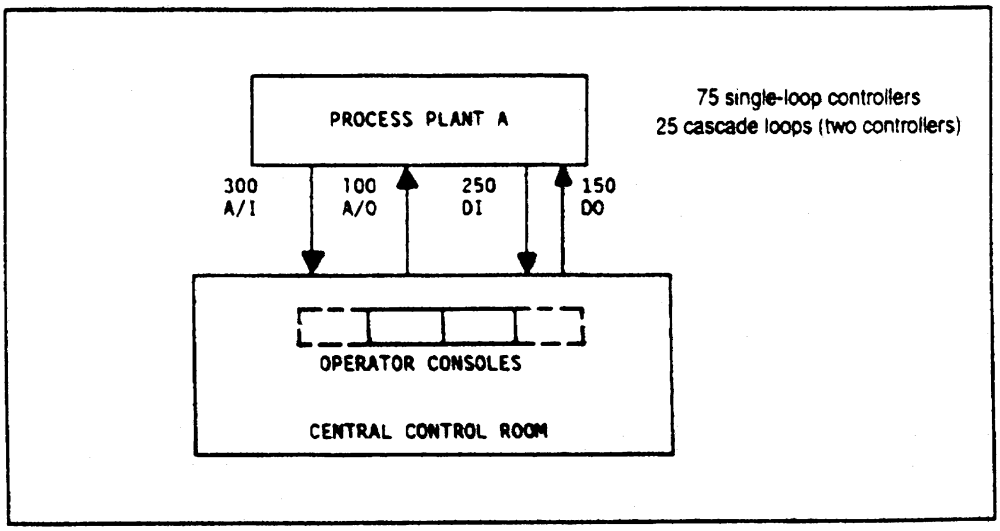


Figure P501

1. Control consoles for this function have a probability of 90 percent of operating for a month without failure. (Failure is defined as any malfunction which prevents full use of the console and takes the console out of operation while it is repaired.) To reduce the probability of losing control of the process, the installation of two consoles is proposed. If this is done, the probability of operation without failure for a month in percent is most nearly

   (A) 80

   (B) 82

   (C) 90

   (D) 98

   (E) 99

2. If three consoles were used, the probability of operation without failure for a month in percent would be most nearly

(A) 72.9
(B) 90.0
(C) 97.0
(D) 97.2
(E) 99.9

3. For operators to control the process, they must have displays of information about each loop. Which of the following sets of variables or parameters should be available for minute-by-minute operation of the process?

(A) Setpoint, process variable, and control mode*
(B) Setpoint, process variable, and controller output
(C) Setpoint, process variable, controller output and control mode*
(D) Process variable, controller output, and control mode*
(E) Process variable and controller output

*Control mode = Manual, Automatic (local), Automatic (remote), Cascade, or Computer

4. Display software for the consoles to be used in Plant A allows information for 10 individual controllers to be displayed simultaneously on a CRT screen. For this system, how many "pages" will be needed for these displays, assuming that the pairs of cascaded controllers are to be displayed on the same screen?

(A) 5
(B) 8
(C) 10
(D) 13
(E) 15

1. For two consoles, the probabilities are:

Two operating	=	$(0.9)^2$	=	0.81
One operating	=	$2(0.1)(0.9)$	=	0.18
None operating	=	$(0.1)^2$	=	0.01
Check:		Total	=	1.00

0.99

The correct answer is (E).

2. For three consoles, the probabilities are:

Three operating	=	$(0.9)^3$	=	0.729
Two operating	=	$3(0.1)(0.9)^2$	=	0.243
One operating	=	$3(0.1)^2(0.9)$	=	0.027
None operating	=	$(0.1)^3$	=	0.001
Check:		Total	=	1.000

0.999

The correct answer is (E).

3. All of the quantities listed are needed, so the correct answer is (C).

4. For cascade control loops: $\frac{25 * 2}{10} = 5$ displays

for single-controller loops: $\frac{75}{10} \cong 8$ displays

Total: 13 displays

The correct answer is (D).

5. Analog inputs not used for control is 175.

$\therefore$ The number of displays = $\frac{175}{20} \cong 9$.

The correct answer is (B).

6. Total digital inputs and outputs is 400.

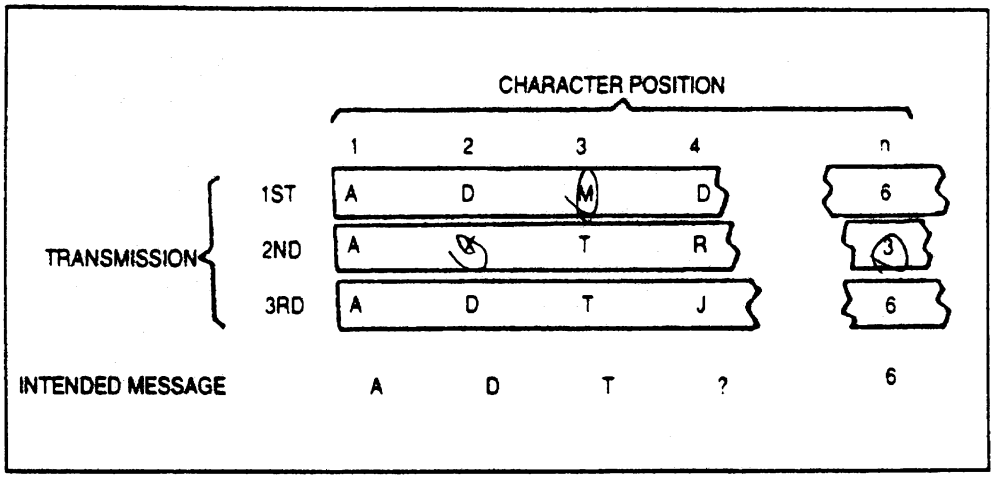
$\therefore$ The number of pages = $\frac{400}{25} = 16$.

The correct answer is (D).

7. Based on the number of P&IDs, the number of displays would be (25)(2) = 50 screens.

Use the following information to answer questions 8 - 10.

The following scheme has been proposed to improve the reliability of data transmission in a computer control system. Each message would be sent three times, and the messages would then be aligned character by character. A two-out-of-three comparison of the corresponding characters in each message would be used to identify the intended message. An example of the scheme is shown in the following figure:



In this figure, the first characters are identical in all three transmissions and are, therefore, assumed to be correct. A single error is apparently made in the second, third and nth position; the intended character in these positions is assumed to be the character that occurs in two out of three of the transmissions. The three characters in the fourth position are all different, so it is not possible to decide what character was intended here.

-3σ
-2σ
-σ
μ
σ
2σ
3σ
68%
95%
99%
±σ
±2σ
±3σ

8. Performance of this data transmission scheme can be analyzed as follows:

   Probability of receiving character incorrectly = 0.02,

   ∴ Probability of receiving character correctly = .98.

   For three characters:

Prob. of no error	$= (0.98)^3$	= 0.941192
Prob. of one error	$= 3(0.02)(0.98)^2$	= 0.057624
Prob. of two errors	$= 3(0.02)^2(0.98)$	= 0.001176
Prob. of three errors	$= (0.02)^3$	= 0.000008
Check: Total		= 1.000000

   ∴ Prob. of identifying intended character
   = 0.941192 + 0.057624 = 0.998816

   The correct answer is (D).

9. The probability of receiving 10 characters correctly using the proposed scheme is $(0.998816)^{10} = 0.9882$

   The correct answer is (C).

10. The probability of receiving 10 characters correctly using only one transmission is $(0.98)^{10} = 0.8171$.

    The correct answer is (B).

PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS

If $Y=f(X_1, X_2, \ldots X_n)$ is a function of n independent variables, the variance of Y is:

$$\sigma_Y^2 = \left(\frac{\partial Y}{\partial X_1}\right)^2 \sigma_{X_1}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 \sigma_{X_2}^2 + \ldots + \left(\frac{\partial Y}{\partial X_n}\right)^2 \sigma_{X_n}^2$$

PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS (cont.)

Two cases are of particular interest:

(1) $Y = aX_1 + bX_2 + \ldots$ LINEAR CASE

(2) $\sigma_Y^{\,2} = a^2\sigma_{X_1}^{\,2} + b^2\sigma_{X_2}^{\,2} + \ldots$

and:

$$Y = a\frac{X_1 X_2 \cdot \ldots}{\ldots \cdot X_{n-1} X_n}$$

$$\left(\frac{\sigma_Y}{Y}\right)^2 = \left(\frac{\sigma_{X_1}}{X_1}\right)^2 + \left(\frac{\sigma_{X_2}}{X_2}\right)^2 + \ldots + \left(\frac{\sigma_{X_{n-1}}}{X_{n-1}}\right)^2 + \left(\frac{\sigma_{X_n}}{X_n}\right)^2$$

PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS (cont.)

Exercise:

Repeatability

"precision"

A pressure transmitter has an "accuracy" of ±0.5% of full span. If two transmitters are each spanned 0-100 psig, what is the accuracy of the computed differential pressure in psi units? (Hint: standard deviation is typically assumed proportional to "accuracy".)

How would this computed variable accuracy compare to that of a differential pressure transmitter, spanned 0-10 psi (same ±0.5%)?

Accuracy of Differential
$= (0.005)(10\ psig)$
$= \pm 0.05$

$Y = X_1 - X_2$

$\sigma_y^2 = \sigma_{x_1}^2 + \sigma_{x_2}^2 = 2\sigma_x^2$

$\sigma_y = \sqrt{2}\,\sigma_x$ 3-3

accuracy of $x = (0.005)(100\ psig)$

accuracy of $y = (\sqrt{2})(\pm 0.5)$ accuracy of $y = \pm 0.05$ psig

± 0.7 psi = accuracy of y

$\frac{0.7}{0.05} = 14\times$ more precise

PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS (cont.)

Exercise:

What percentage improvement in precision would you expect if the signals of two transmitters, of equal precision, were averaged in the controller?

$$\sigma_T^2 = \left(\frac{1}{2}\sigma\right)^2 + \left(\frac{1}{2}\sigma\right)^2 = \frac{1}{4}\sigma^2 + \frac{1}{4}\sigma^2 = \frac{1}{2}\sigma^2 \Rightarrow \sigma_T = \sqrt{\frac{1}{2}}\sigma = 0.7071\,\sigma$$

What further improvement would you expect if a third signal, of equal precision to the first two, is added to the average?

$$\sigma_T^2 = \left(\frac{1}{3}\sigma\right)^2 + \left(\frac{1}{3}\sigma\right)^2 + \left(\frac{1}{3}\sigma\right)^2 = \frac{1}{9}\sigma^2 + \frac{1}{9}\sigma^2 + \frac{1}{9}\sigma^2 = \frac{1}{3}\sigma^2$$

$$\sigma_T = \sqrt{\frac{1}{3}}\,\sigma = 0.5774\,\sigma$$

PRECISION OF A MATHEMATICAL FUNCTION OF MEASUREMENTS (cont.)

Exercise:

Work problem A103 C.S.E. Study Guide 2nd Edition - (Copy end of this section).

Situation:

The "yield" of a chemical process is defined as the ratio of the desired product in a product stream to the amount of the principal raw material in a feed stream:

$$Y = \frac{a\ P}{r\ F}$$

where

P = product stream, units/hour;

F = feed stream, units/hour;

a = concentration of desired product in product stream, fraction;

r = concentration of principal raw material in feed stream, fraction.

Each of the four (4) quantities in the above equation is measured by a suitable sensor. It is desired to compute the yield with an accuracy of 0.5% of the actual value (where "accuracy" is defined by the standard deviation of a large number of determinations under presumably identical conditions).

Requirements:

(a) If the flow rates and concentrations are all measured with equal percentage accuracy, how accurate must the measurements be?

(b) If the concentrations can be measured with twice the percentage accuracy (half the error) of the flow rates, how accurate must the concentration and flow rate measurements be?

(c) Assuming that the measurements must be converted to digital form in an analog-to-digital converter, state the required precision (number of bits) of the A-to-D converter so that it will not degrade significantly the accuracy of the yield calculations for Requirements (b) above, at the maximum values of the variables. Assume the measurements are scaled to use the full span of the A-to-D converter.

$$Y = \frac{aP}{rF}$$

$$\sigma_Y^2 = \left(\frac{\partial Y}{\partial a}\right)^2 \sigma_a^2 + \left(\frac{\partial Y}{\partial P}\right)^2 \sigma_P^2 + \left(\frac{\partial Y}{\partial r}\right)^2 \sigma_r^2 + \left(\frac{\partial Y}{\partial F}\right)^2 \sigma_F^2$$

where σ = standard deviation (σ^2 = variance)

$$\frac{\partial Y}{\partial a} = \frac{P}{rF} \qquad \frac{\partial Y}{\partial P} = \frac{a}{rF}$$

$$\frac{\partial Y}{\partial r} = \frac{-aP}{r^2F} \qquad \frac{\partial Y}{\partial F} = \frac{-aP}{rF^2}$$

$$\sigma_Y^2 = \left(\frac{P}{rF}\right)^2 \sigma_a^2 + \left(\frac{a}{rF}\right)^2 \sigma_P^2 + \left(\frac{aP}{r^2F}\right)^2 \sigma_r^2 + \left(\frac{aP}{rF^2}\right)^2 \sigma_F^2$$

$$= \left(\frac{aP}{rF}\right)^2 \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{aP}{rF}\right)^2 \left(\frac{\sigma_P}{P}\right)^2 + \left(\frac{aP}{rF}\right)^2 \left(\frac{\sigma_r}{r}\right)^2 + \left(\frac{aP}{rF}\right)^2 \left(\frac{\sigma_F}{F}\right)^2$$

$$\downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow$$

$$Y \qquad Y \qquad Y \qquad Y$$

or $$\left(\frac{\sigma_Y}{Y}\right)^2 = \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_P}{P}\right)^2 + \left(\frac{\sigma_r}{r}\right)^2 + \left(\frac{\sigma_F}{F}\right)^2$$

In words, the square of the relative (or percentage) standard deviation of the yield is equal to the sum of the squares of the relative (or percentage) standard deviations of each of the variables involved in the yield.

(a) Let $\sigma_m = \frac{\sigma_a}{a} = \frac{\sigma_P}{P} = \frac{\sigma_r}{r} = \frac{\sigma_F}{F}$ = common percentage standard deviation

Then $$\left(\frac{\sigma_Y}{Y}\right)^2 = \sigma_m^2 + \sigma_m^2 + \sigma_m^2 + \sigma_m^2$$

$$= 4\sigma_m^2 \Rightarrow \frac{\sigma_Y^2}{Y^2} = 4\sigma_m^2 \Rightarrow \sigma_m^2 = \frac{1}{4}\frac{\sigma_Y^2}{Y^2}$$

$$\therefore \sigma_m = \frac{1}{2}\left(\frac{\sigma_Y}{Y}\right) = \frac{1}{2}(0.5) = 0.25 \text{ percent}$$

$$\sigma_m = \frac{1}{2}\left(\frac{\sigma_Y}{Y}\right) = \frac{1}{2}(0.5) = 0.25$$

(b)

$$\text{Let } \sigma_m = \frac{\sigma_P}{P} = \frac{\sigma_F}{F} \text{ and } \frac{\sigma_m}{2} = \frac{\sigma_a}{a} = \frac{\sigma_r}{r}$$

$$\text{Then } \left(\frac{\sigma_Y}{Y}\right)^2 = \left(\frac{\sigma_m}{2}\right)^2 + \sigma_m^2 + \left(\frac{\sigma_m}{2}\right)^2 + \sigma_m^2$$

$$= (\sigma_m)^2\left(\frac{1}{4} + 1 + \frac{1}{4} + 1\right)$$

$$= 2.5\,\sigma_m^2$$

$$\therefore \sigma_m = \frac{1}{\sqrt{2.5}}\left(\frac{\sigma_Y}{Y}\right) = \frac{1}{1.581}(0.5) = 0.316 \text{ percent}$$

Accuracy/std. deviation:

for flows = 0.316 percent

for concentrations = $\frac{0.316}{2}$ = 0.158 percent

Note: Solutions for parts (a) and (b) reflect the probability that errors in the four variables do not assume their maximum values simultaneously; so that a root-mean-square combination of errors better represents the actual behavior of the system. A worst-case analysis, based on simultaneous maximum errors in all variables, leads to specification of greater-than necessary accuracy in the individual measurements.

(c) In (b), concentrations must be measured with a standard deviation of 0.158 percent or less. This is one part in 100/0.158, approximately 633.

Resolution of A-to-D converters:

10-bit	1 part in 1024
11-bit	2048
12-bit	4096

To avoid degrading the accuracy of the yield calculation, use an 11- or 12-bit converter.

(If it is assumed that the average error introduced by the A-to-D converter is one half the least significant bit, the error introduced by a 10-bit converter would be 1 part in 2048, or about one third of the error of the measurement. Somewhat more precision in the converter would be desirable to avoid "significantly degrading" the yield calculation.)

LOW PRESSURE TANK VENTING

Instructor

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Project Leader
Raytheon Engineers and Constructors
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(205) 995-7683 (f)
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DEFINITIONS

Atmospheric Tanks -- A storage tank which has been designed to operate at pressure from atmospheric through 0.5 PSIG.

Flash Point -- The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitable mixture with air near the surface of the liquid.

Low Pressure Tank -- A storage tank designed to withstand an internal pressure above 0.5 PSIG but not more than 15 PSIG measured at the top of the tank.

Pressure Vessel -- Any fired or unfired vessel within the scope of the applicable section of the ASME Boiler and Pressure Vessel Code.

NFPA 30

API 2000

ASME Section only pressured vessels

OSHA 1910

Flammable Liquids Flash Point 100

CLASSIFICATION OF FLAMMABLE AND COMBUSTIBLE LIQUIDS

Flammable Liquids: A liquid having a flash point below 100° F and having a vapor pressure not exceeding 40 PSIA at 100° F shall be known as a Class I liquid.

Class IA shall include those having flash points below 73° F and having a boiling point below 100° F.

Class IB shall include those having flash points below 73° F. and having a boiling point at or above 100° F.

Class IC shall include those having flash points at or above 73° F. and below 100° F.

Combustible Liquids: A liquid having a flash point at or above 100° F.

Class II liquids shall include those having flash points at or above 100° F. and below 140° F.

Class IIIA liquids shall include those having flash points at or above 140° F. and below 200° F.

Class IIIB liquids shall include those having flash points at or above 200°F

PURPOSE OF RELIEF VENTS

I. SAFETY
   a) Pressure/Vacuum Relief (prevent tank damage)

II. CONSERVATION OF VAPORS
   a) Minimize Product Loss
   b) Comply with E.P.A. related ordinances

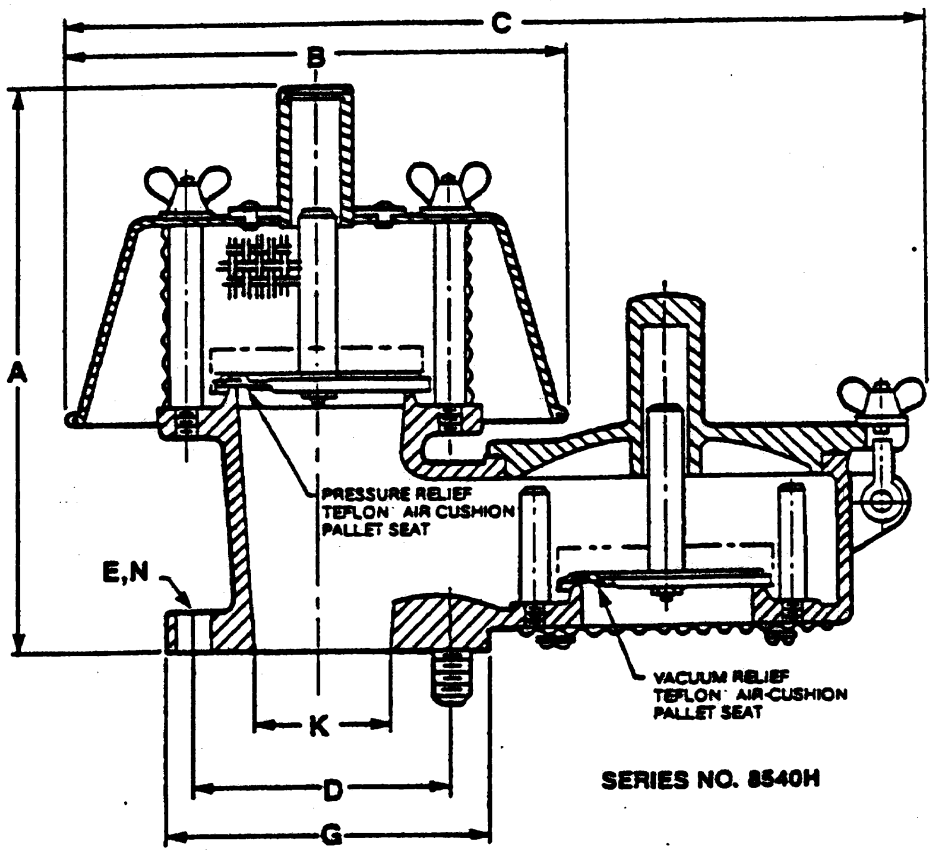
WHY USE VENTING EQUIPMENT?

I. LEGAL REQUIREMENTS
   a) OSHA (1910.106)
   b) State or Local Regulations
      1) E.P.A. compliance

II. ADVISORY ORGANIZATIONS
   a) N.F.P.A.
   b) A.P.I.

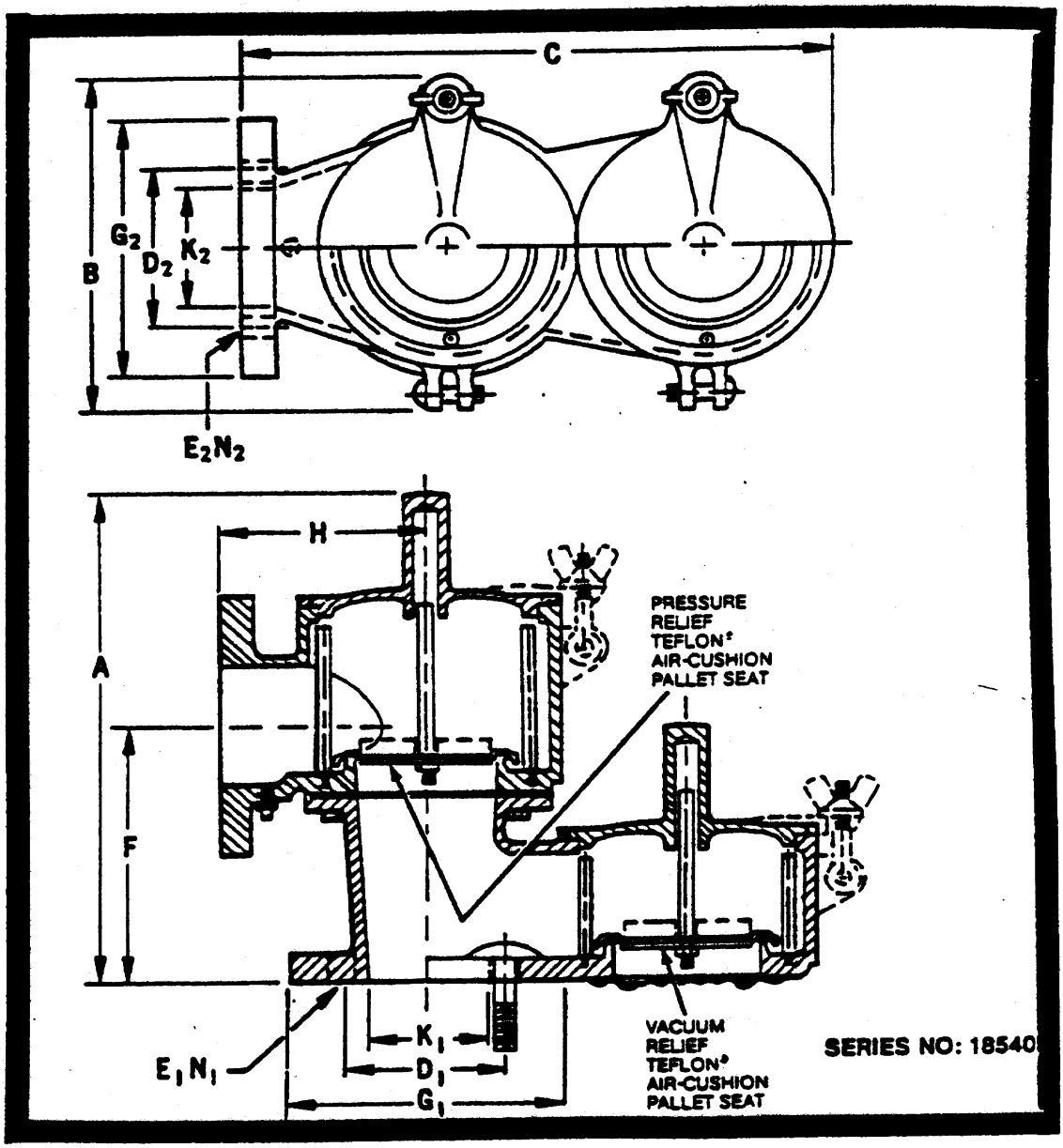
III. CORPORATE SAFETY DIRECTIVES

Series No. 8540H
Conservation Breather Vent

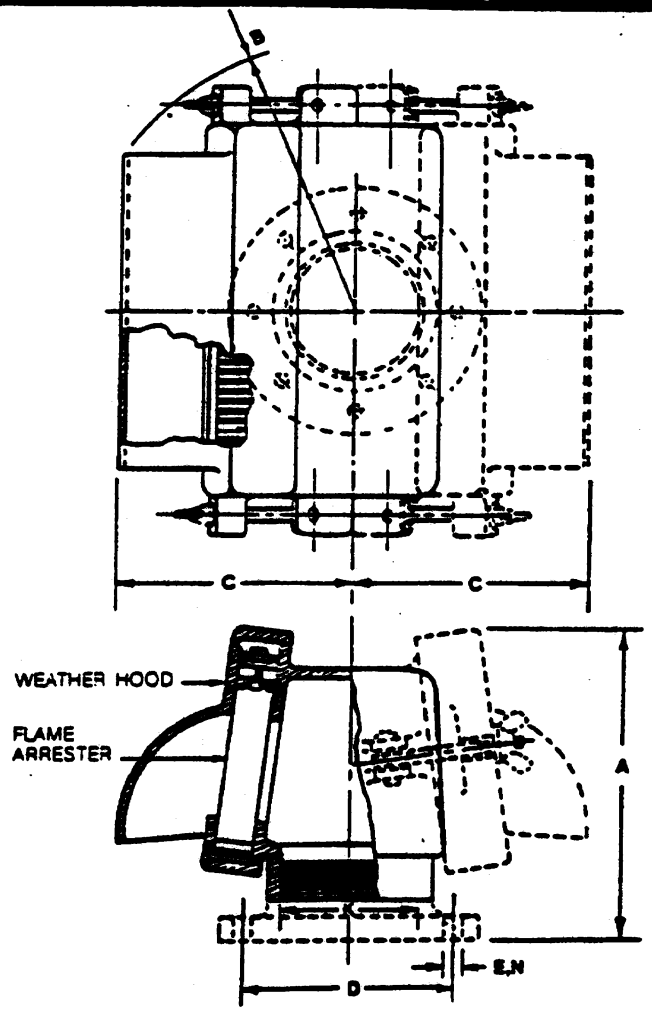


SERIES NO. 8540H

Series No. 18540
Conservation Breather Vent with Pipe-Away

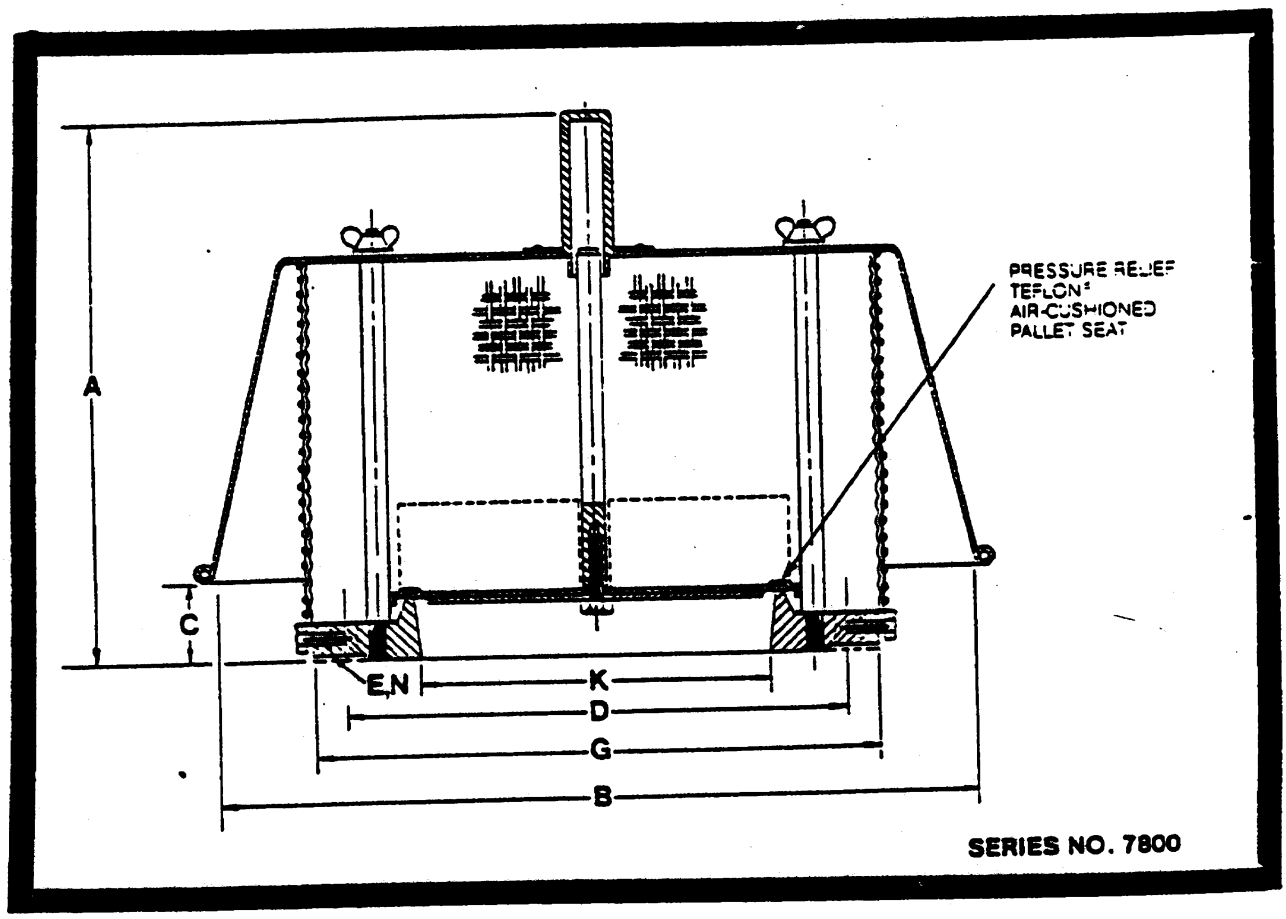


Series No. 860
Flame Arrester

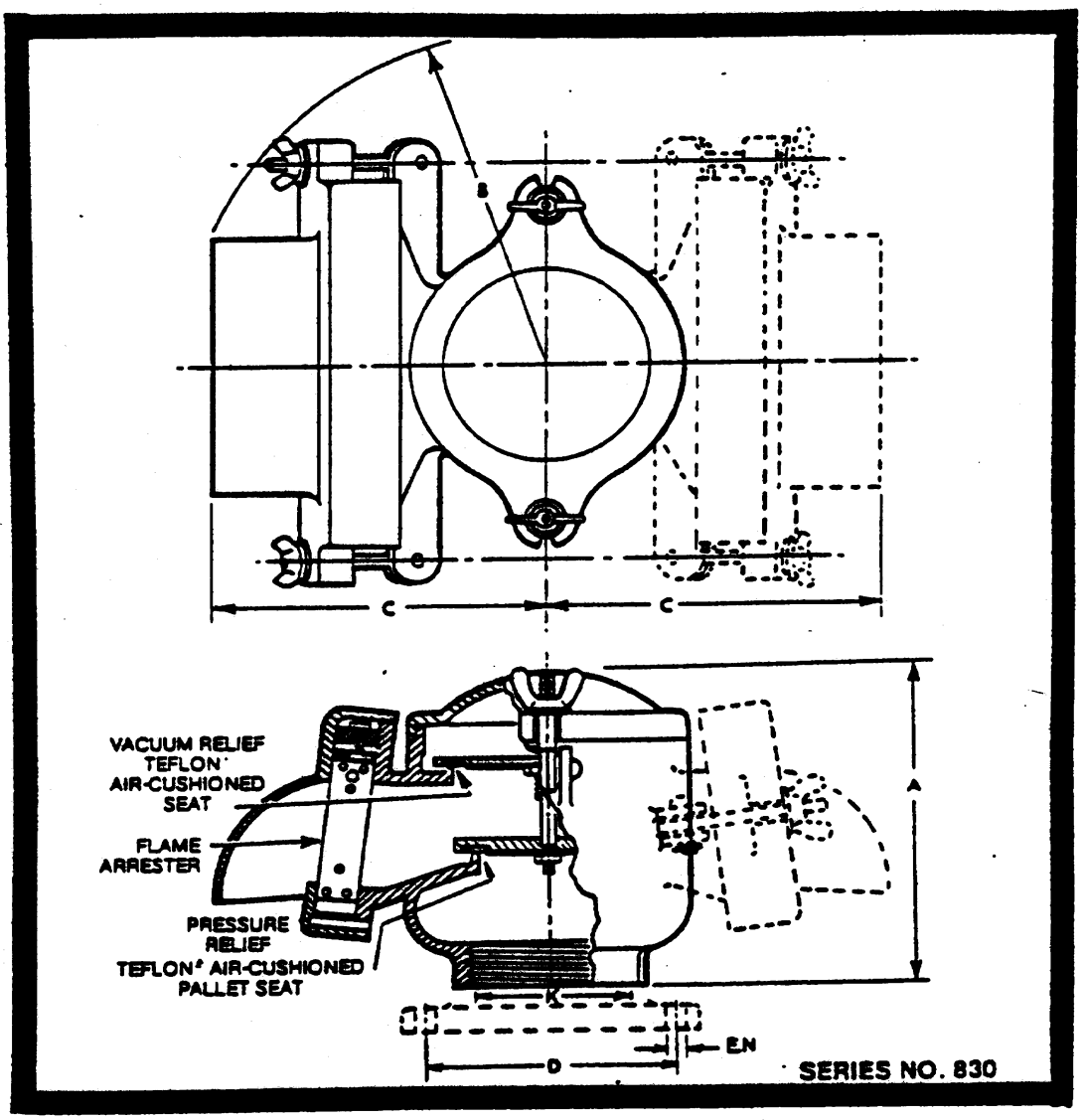


SERIES NO. 860

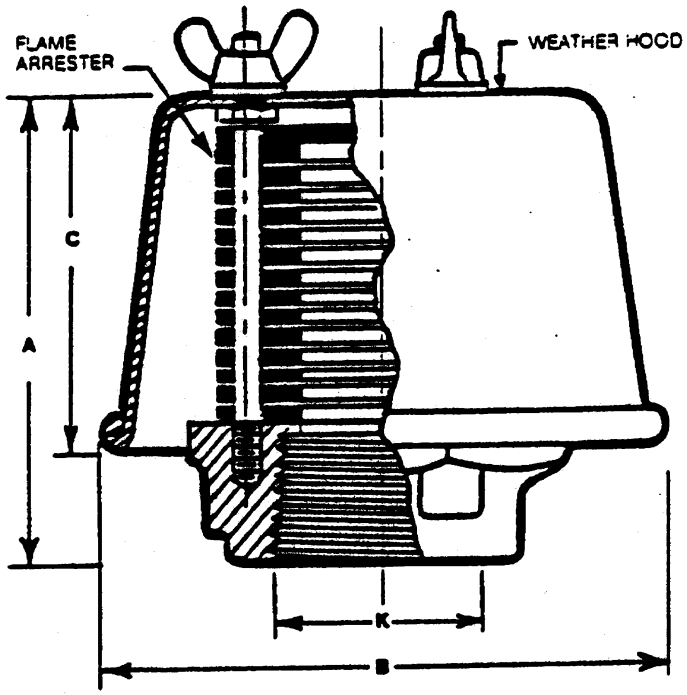
Series No. 7800
Emergency Pressure Vent



Series No. 830
Combination Conservation Vent and Flame Arrester



Series No. 670/6670
Flame Arrester



SERIES NO. 670/6670

CHARACTERISTICS OF WEIGHT LOADED VENTS

1) Set points are determined by total pallet weight.

2) Typical leakage rates are less than 1 SCFH of air at 90% of the set point.

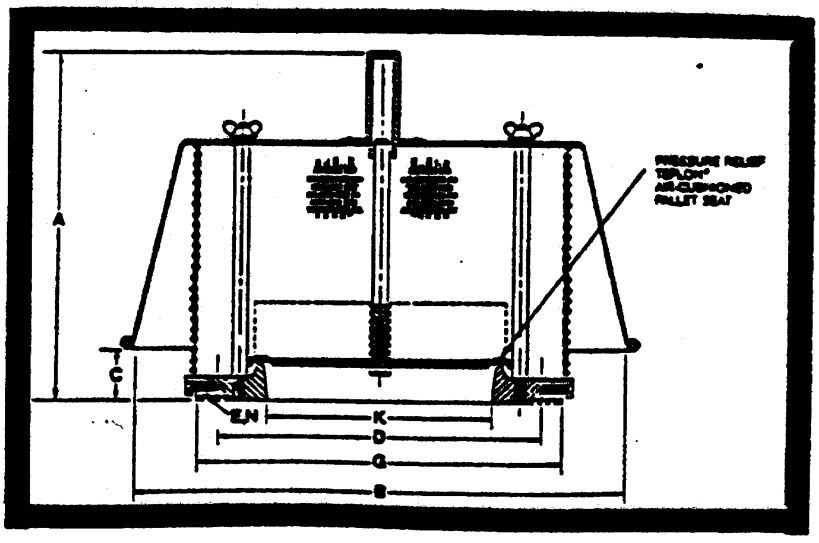
3) Flow at the set point is effectively zero.

4) Substantial overpressures are needed to open vents. (Vents are not necessarily "full open" at 10% above set pressure.)

5) Vents do not "pop" open. They slowly lift as overpressure increases.

6) Vents have specific maximum possible set points. The weights must not excessively restrict lift of the pallet.

7) Curves are used to represent the flow characteristics of a particular size and style vent.



SIZING WEIGHT LOADED VENTS

In order to properly size a venting device, the following information must be evaluated:

1) Total Flow Requirement

2) Set Point of Vent

3) Design Pressure of Tank or Maximum Allowable Overpressure.

NOTE: When dealing with weight loaded venting devices, there are no Codes or Regulations that coordinate the set point of the vent with the design pressure of the tank or vessel.

THE VENT SHOULD NOT NORMALLY BE SET AT THE DESIGN PRESSURE OF THE TANK.

NORMAL VENTING

Normal Venting is comprised of the following:

1. Inbreathing (vacuum) caused by the maximum outflow of liquid from the tank.

2. Inbreathing (vacuum) caused by the contraction of vapors in the tank due to normal atmospheric temperature changes.

3. Outbreathing (pressure) caused by the maximum inflow of liquid to the tank.

4. Outbreathing (pressure) caused by the expansion and evolution of vapors in the tank due to normal atmospheric temperature changes.

EXAMPLE: NORMAL VENTING REQUIREMENTS

84,000 Gallon Vertical Tank
Fluid -- Hexane (Flash Point = -7 F
Pump-in Rate = 150 GPM
Pump-out Rate = 200 GPM

PRESSURE VENTING REQUIREMENT = PUMPING + THERMAL

$$PVR = \frac{GPM\ (Pump\text{-}in) \times 60}{3.5} + THERMAL$$

Pump-In

$$= \frac{150 \times 60}{3.5} + 2000$$

$$= 4571\ SCFH$$

VACUUM VENTING REQUIREMENT = PUMPING + THERMAL

$$VVR = \frac{GPM\ (Pump\text{-}out) \times 60}{7.5} + THERMAL$$

Pump-Out

$$= \frac{200 \times 60}{7.5} + 2000$$

$$= 3600\ SCFH$$

No 854 PRESSUR
Separate
No, 854 Vacuum

CALCULATING NORMAL VENTING REQUIREMENTS

Normal Venting = Pumping + Thermal

Pumping-In (Pressure)

If liquid has flash point less than 100 degrees Farenheit, provide 1 SCFH of air for every 3.5 gallons per hour of maximum filling rate.

If liquid has flash point of 100 degrees Farenheit or hogher, provide 1 SCFH of air for every 7.0 gallons per hour of maximum filling rate.

Pumping-Out (Vacuum)

For all liquids provide 1 SCFH of air for each 7.5 gallons per hour of maximum emptying rate.

Thermal (Pressure & Vacuum)

Provide relief capacity for pressure and vacuum as specified on the chart according to tank capacity.

PROTECTOSEAL

THE PROTECTOSEAL COMPANY
225 Foster Avenue, Bensenville, IL 60106
Phone 1-312-595-0600 Telex 28-2549

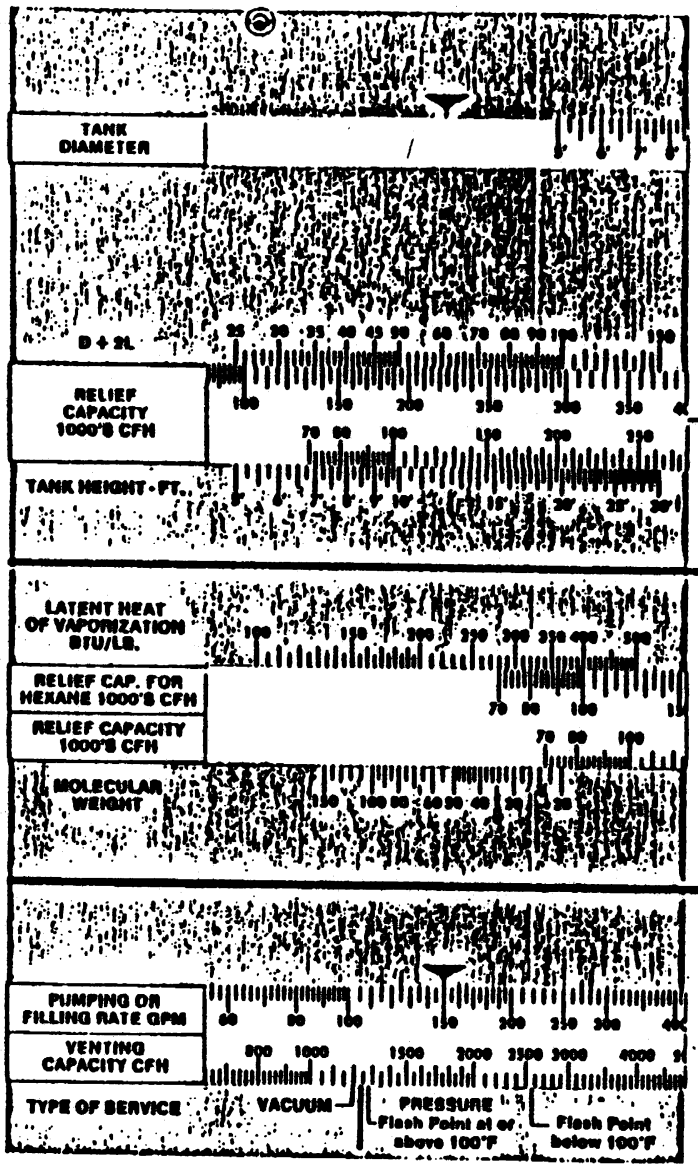
SAFETY WITHOUT COMPROMISE

TANK VENTING GUIDE

THERMAL VENTING CAPACITY REQUIREMENTS—C.F.H.†

TANK CAPACITY*		VACUUM	PRESSURE	
42 Gal. Barrels	Gallons	All Stock	Flash Pt. Below 100°F	Flash Pt. at or above 100°F
50	2,500	50	50	40
100	4,200	100	100	60
500	21,000	500	500	300
1,000	42,000	1,000	1,000	500
2,000	84,000	2,000	2,000	1,200
3,000	126,000	3,000	3,000	1,800
4,000	168,000	4,000	4,000	2,400
5,000	210,000	5,000	5,000	3,000
10,000	420,000	10,000	10,000	6,000
15,000	630,000	15,000	15,000	9,000
20,000	840,000	20,000	20,000	12,000
25,000	1,050,000	24,000	24,000	15,000
30,000		28,000	28,000	17,000
35,000		31,000	31,000	19,000
40,000		34,000	34,000	21,000
45,000		37,000	37,000	23,000
50,000		40,000	40,000	24,000
60,000		44,000	44,000	27,000
70,000		48,000	48,000	29,000
80,000		52,000	52,000	31,000
90,000		56,000	56,000	34,000
100,000		60,000	60,000	36,000
120,000		68,000	68,000	41,000
140,000		75,000	75,000	45,000
160,000		82,000	82,000	50,000
180,000		90,000	90,000	54,000

†Cubic feet of air per hour at 60°F and 14.7 psia.
*Interpolate for intermediate sizes.



EMERGENCY VENTS

Set TANK DIAMETER at arrow.
(Applies to either horizontal or vertical tanks.)

FOR HORIZONTAL TANKS:
Add TANK DIAMETER (D) plus TWICE the LENGTH of the TANK (2L).
Read RELIEF CAPACITY at (D + 2L).

FOR VERTICAL TANKS:
Read RELIEF CAPACITY for vertical tanks at TANK HEIGHT.
†Use 30 ft. maximum height for all higher tanks.

CORRECTION FOR SPECIFIC LIQUID

Relief capacities for Emergency Vents, as calculated above, are based on liquids with the characteristics of HEXANE. For exact answers for any specific liquid, set RELIEF CAPACITY for HEXANE at LATENT HEAT OF VAPORIZATION of liquid.
Read RELIEF CAPACITY at MOLECULAR WEIGHT of liquid.

BREATHER VENTS

Set PUMPING RATE at arrow.
Read VENTING CAPACITY required at index for TYPE OF SERVICE.
Add Thermal Venting Capacity from Table to the left.

SEE OTHER SIDE FOR SIZE OF VENT REQUIRED.

PROTECTOSEAL

THE PROTECTOSEAL COMPANY
225 Foster Avenue, Bensenville, IL 60106
Phone 1-312-595-0800 Telex 28-2549

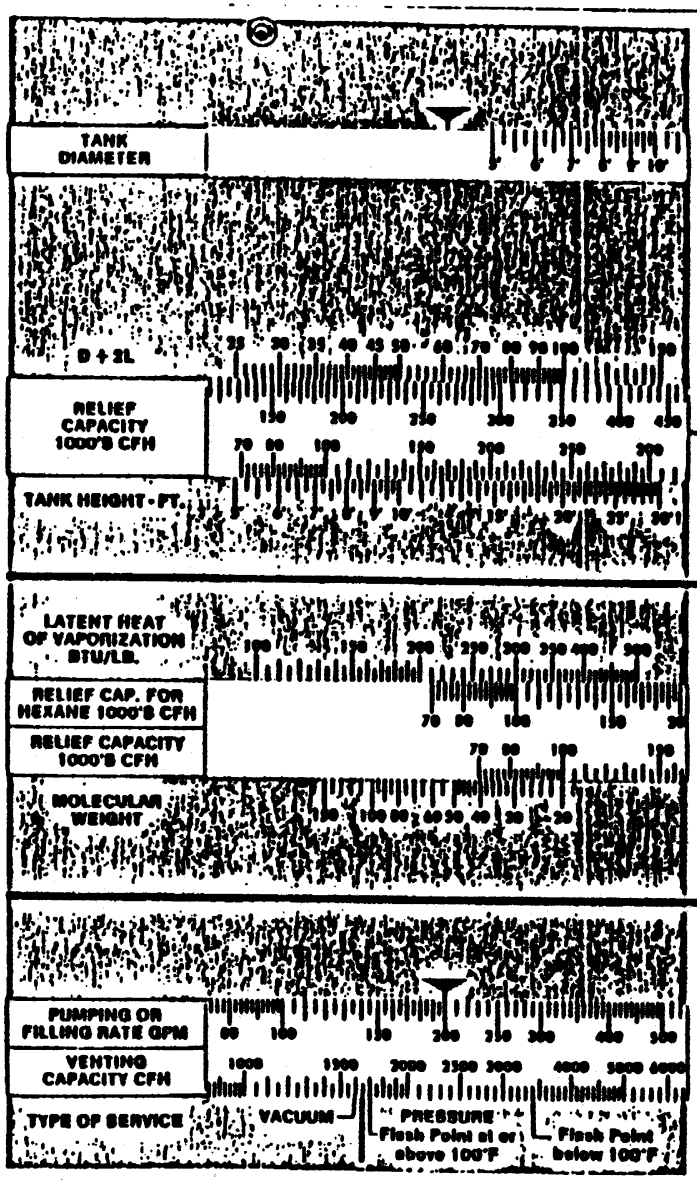
SAFETY WITHOUT COMPROMISE

TANK VENTING GUIDE

THERMAL VENTING CAPACITY REQUIREMENTS—C.F.H.†

TANK CAPACITY*		VACUUM	PRESSURE	
42 Gal. Barrels	Gallons	All Stock	Flash Pt. Below 100°F	Flash Pt. at or above 100°F
50	2,500	90	90	40
100	4,200	100	100	60
500	21,000	500	500	300
1,000	42,000	1,000	1,000	600
2,000	84,000	2,000	2,000	1,200
3,000	126,000	3,000	3,000	1,800
4,000	168,000	4,000	4,000	2,400
5,000	210,000	5,000	5,000	3,000
10,000	420,000	10,000	10,000	6,000
15,000	630,000	15,000	15,000	9,000
20,000	840,000	20,000	20,000	12,000
25,000	1,050,000	24,000	24,000	15,000
30,000		29,000	28,000	17,000
35,000		31,000	31,000	19,000
40,000		34,000	34,000	21,000
45,000		37,000	37,000	23,000
50,000		40,000	40,000	24,000
60,000		44,000	44,000	27,000
70,000		49,000	49,000	29,000
80,000		52,000	52,000	31,000
90,000		56,000	56,000	34,000
100,000		60,000	60,000	36,000
120,000		68,000	68,000	41,000
140,000		75,000	75,000	45,000
160,000		82,000	82,000	50,000
180,000		90,000	90,000	54,000

† Cubic feet of air per hour at 60°F and 14.7 psia.
*Interpolate for intermediate sizes.



EMERGENCY VENTS

Set TANK DIAMETER at arrow.
(Applies to either horizontal or vertical tanks.)

FOR HORIZONTAL TANKS:
Add TANK DIAMETER (D) plus TWICE the LENGTH of the TANK (2L).
Read RELIEF CAPACITY at (D + 2L).

FOR VERTICAL TANKS:
Read RELIEF CAPACITY for vertical tanks at TANK HEIGHT.
‡ Use 30 ft. maximum height for all higher tanks.

CORRECTION FOR SPECIFIC LIQUID

Relief capacities for Emergency Vents, as calculated above, are based on liquids with the characteristics of HEXANE. For exact answers for any specific liquid, set RELIEF CAPACITY for HEXANE at LATENT HEAT OF VAPORIZATION of liquid.
Read RELIEF CAPACITY at MOLECULAR WEIGHT of liquid.

BREATHER VENTS

Set PUMPING RATE at arrow.
Read VENTING CAPACITY required at index for TYPE OF SERVICE.
Add Thermal Venting Capacity from Table to the left.

SEE OTHER SIDE FOR SIZE OF VENT REQUIRED.

EMERGENCY VENTING

When a storage tank is exposed to an external fire, the vent chosen to provide the normal venting may be too small to handle the larger volume of vapors caused by the heat input from the fire.

An Emergency Vent is commonly used.

The calculation used to determine the emergency venting requirements for a tank are based on:

a) The configuration of the tank. (Maximum heat input based on the exposed wetted surface of the tank.)

b) The characteristics of the liquid stored in the tank.

CALCULATING EMERGENCY VENTING REQUIREMENTS

1) Calculate exposed surface area of tank..

2) Determine relief capacity required (based on the hexane model) from the appropriate chart according to exposed area.

3) Make corrections to total required relief capacity based on the specific liquid stored in the tank.

EXAMPLE: EMERGENCY VENTING REQUIREMENTS

Vertical Tank: 30′ dia. x 25′ high
Fluid -- Ethyl Alcohol

---

1) Determine exposed surface area:

Exposed Area = Diameter x 3.14 x Height
= 30 x 3.14 x 25
= 2355 square feet

2) Flow Requirement from Data Chart:
(Table 4 - Page 5 Technical Manual)

2400 square feet = 704,000 SCFH Air
2000 square feet = 662,000 SCFH Air

Interpolate to find:
2355 square feet = 700,000 SCFH Air

3) Correction for Ethyl Alcohol:

$L\sqrt{M}$ For Ethyl Alcohol = 2500
(Table 6 - Page 5 Technical Manual)
L = 368
M = 46.1

$$\text{Corrected Flow} = \text{Flow} \times \frac{1337}{L\sqrt{M}}$$

$$\text{Corrected Flow} = 700{,}000 \times \frac{1337}{2500}$$

Corrected Flow = 375,000 SCFH of Air

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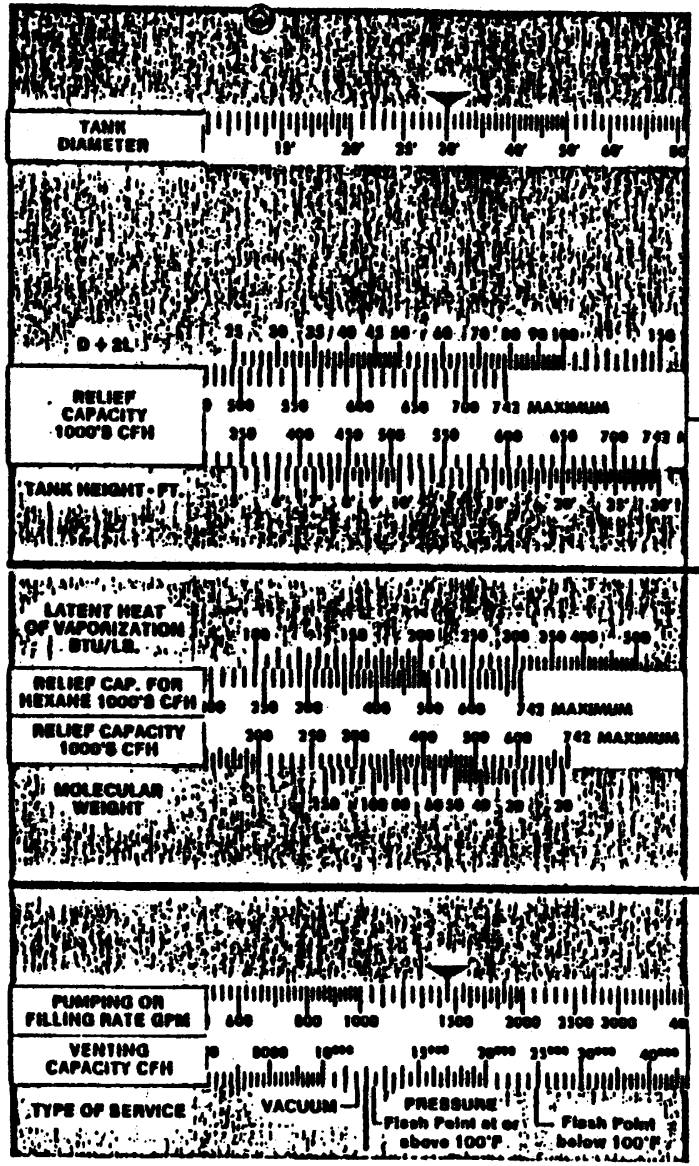
SAFETY WITHOUT COMPROMISE

TANK VENTING GUIDE

THERMAL VENTING CAPACITY REQUIREMENTS—C.F.H.†

TANK CAPACITY*		VACUUM	PRESSURE	
42 Gal. Barrels	Gallons	All Stock	Flash Pt. Below 100°F	Flash Pt. at or above 100°F
50	2,500	50	50	40
100	4,200	100	100	60
500	21,000	500	500	300
1,000	42,000	1,000	1,000	600
2,000	84,000	2,000	2,000	1,200
3,000	126,000	3,000	3,000	1,800
4,000	168,000	4,000	4,000	2,400
5,000	210,000	5,000	5,000	3,000
10,000	420,000	10,000	10,000	6,000
15,000	630,000	15,000	15,000	9,000
20,000	840,000	20,000	20,000	12,000
25,000	1,050,000	24,000	24,000	15,000
30,000		28,000	28,000	17,000
35,000		31,000	31,000	19,000
40,000		34,000	34,000	21,000
45,000		37,000	37,000	23,000
50,000		40,000	40,000	24,000
60,000		44,000	44,000	27,000
70,000		48,000	48,000	29,000
80,000		52,000	52,000	31,000
90,000		56,000	56,000	34,000
100,000		60,000	60,000	36,000
120,000		68,000	68,000	41,000
140,000		76,000	76,000	46,000
160,000		82,000	82,000	50,000
180,000		90,000	90,000	54,000

†Cubic feet of air per hour at 60°F and 14.7 psia.
*Interpolate for intermediate sizes.



EMERGENCY VENTS

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(Applies to either horizontal or vertical tanks.)

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BREATHER VENTS

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Add Thermal Venting Capacity from Table to the left.

SEE OTHER SIDE FOR SIZE OF VENT REQUIRED.

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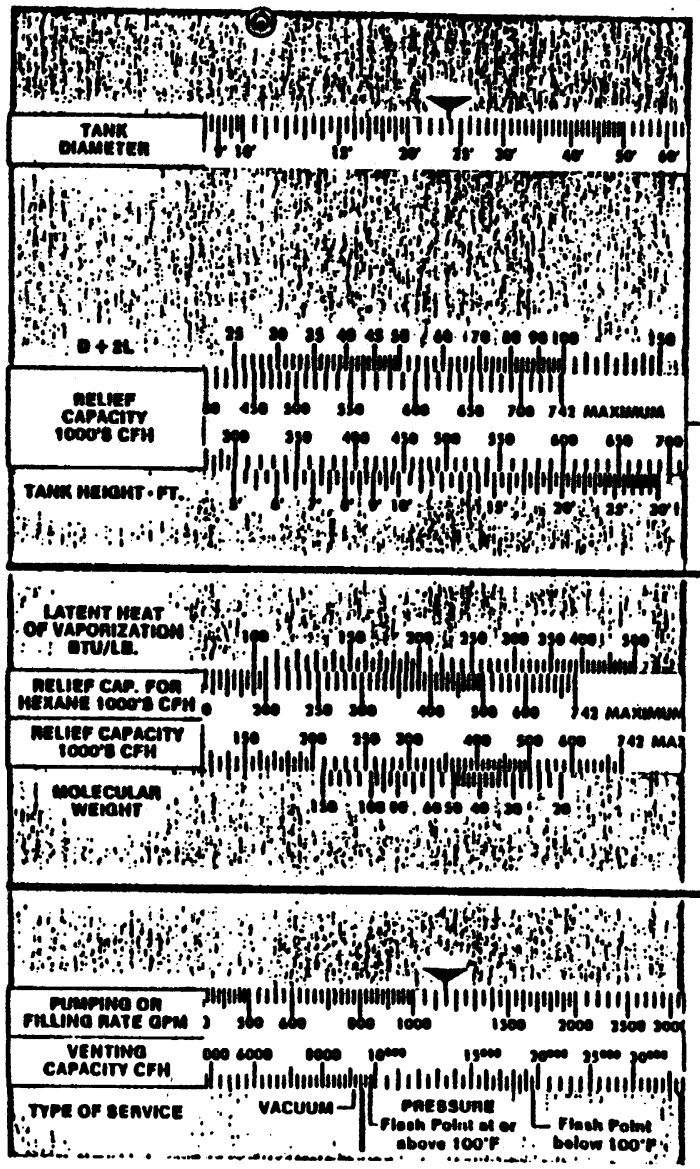
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25,000	1,050,000	24,000	24,000	15,000
30,000	...	28,000	28,000	17,000
35,000	...	31,000	31,000	19,000
40,000	...	34,000	34,000	21,000
45,000	...	37,000	37,000	23,000
50,000	...	40,000	40,000	24,000
60,000	...	44,000	44,000	27,000
70,000	...	48,000	48,000	29,000
80,000	...	52,000	52,000	31,000
90,000	...	56,000	56,000	34,000
100,000	...	60,000	60,000	36,000
120,000	...	68,000	68,000	41,000
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BREATHER VENTS

Set PUMPING RATE at arrow.
Read VENTING CAPACITY required at index for TYPE OF SERVICE.
Add Thermal Venting Capacity from Table to the left.

SEE OTHER SIDE FOR SIZE OF VENT REQUIRED.

PROCEDURE FOR SIZING

1. Determine the venting requirement for the tank system.

2. Choose the style of vent that is best suited for the application.

3. Establish the proper set point and the maximum allowable accumulation.

4. Obtain the flow curves for all sizes of the vent style that has been chosen.

5. For the specific set point, read the pressure drop required to pass the flow necessary for proper venting of the tank.

6. Choose the vent size that allows the required flow to be relieved before the design pressure or the maximum allowable overpressure has been reached.

CHARACTERISTICS OF FLOW CURVES

1) Horizontal Axis -- Flow rate in standard cubic feet per hour(60 F,0 PSIG)

2) Vertical Axis -- Pressure drop in inches of water column.

3) The point on the vertical axis at which the flow is zero corresponds to the set point of the vent.

4) Vent will remain closed (no flow) until the tank pressure increases to the set point.

5) As the pressure in the tank increases, the vent opens gradually and the flow through the vent increases.

For any particular style, size, and set point, the curve completely defines the flow characteristics of the vent.

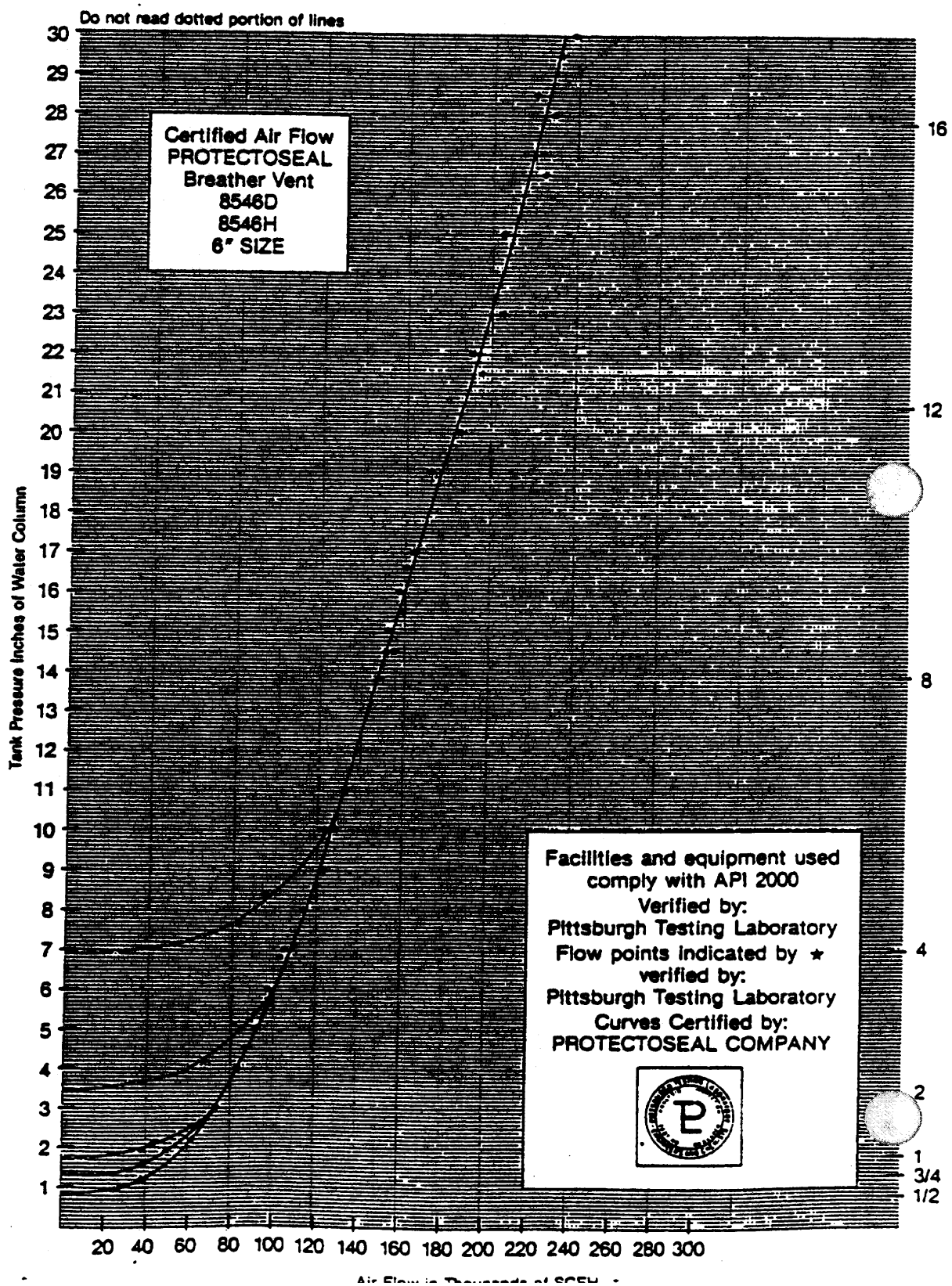
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Series No. 8540

Conservation Breather Vent

Certified Air Flow Curves

PRESSURE



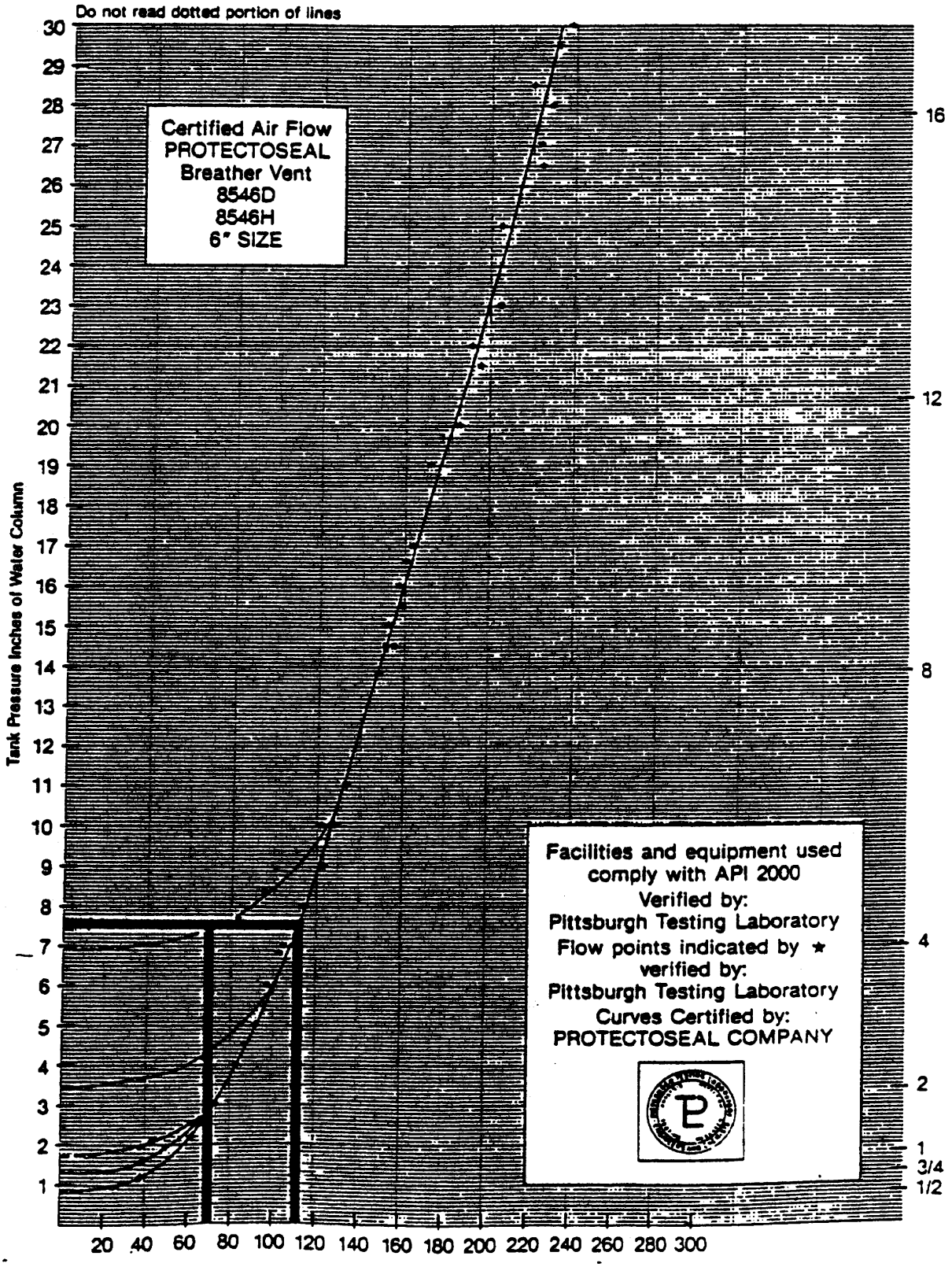
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RELIEF VENTS VS. SAFETY RELIEF VALVES

The proper sizing of weight loaded relief vents used on low pressure or atmospheric pressure tanks seems to cause some degree of confusion among those accustomed to working with safety relief valves and Section VIII pressure vessels. Under the Section VIII requirements, the vessel and the relief valve are considered together in the design specifications. The valve must provide some specific "full-open" relief capacity at 10% overpressure, and the vessel design must accomodate this required accumulation.

When dealing with low pressure relief vents, the following factors must be considered: (1) the required relief capacity; (2) the set point of the vent; (3) the design pressure of the tank; (4) the flow capacity of the specific vent being considered. There are no nationally recognized Codes or Regulations that tie these factors together in a unified design package.

The relief capacity requirement is usually determined by reference to NFPA 30, API 2000, or OSHA 1910.106. These publications set forth methods for determining normal breathing and emergency venting requirements for various tank configurations.

The set point of the vent is established based on the operating characteristics of the system. For example, a 2" water column inert gas blanket would require a vent set in excess of 2" water column.

A weight loaded relief vent does not necessarily reach a "full-open" flow capacity (maximum efficiency) at 10% above its set point. Reference to the attached, independently verified flow curve for Protectoseal's 8546D Conservation Vent reinforces this statement. It can be seen that when this vent is set at 0.86" water column, it will flow 112,000 SCFH of air at 7.6" of water. The same vent set at 6.9 " water will flow approximately 76,000 SCFH of air at 7.6" of water. Even though the 7.6" water represents a 10% overpressure for the 6.9" water setting, the vent has obviously not achieved its maximum flow efficiency. The overpressure at which maximum flow efficiency is achieved varies from one size and style vent to the next.

As a result of these flow characteristics, it is necessary to relate the flow requirement to the set point of the vent and then determine the overpressure required to achieve that flow through the specific vent. The tank system must be capable of withstanding this total overpressure in order for the vent to be properly sized. These various relationships can most easily be analyzed through the use of flow curves or other information supplied by the vendor.

EXAMPLE: READINGS FROM 8546D PRESSURE FLOW CURVE

8546D set @ .86 inches of water flows 80,000 SCFH @ 3.4 inches of water.

8546D set @ 6.9 inches of water flows 160,000 SCFH @ 16 inches of water.

What will an 8546D set @ 1.7 inches of water flow @ 2 inches of water? 40,000 SCFH

What will an 8546D set @ 6.9 inches of water flow @ 10 inches of water? 126,000 SCFH

At what pressure will an 8546D set @ 1.3 inches of water flow 100,000 SCFH? 5.9 inches of water

At what pressure will an 8546D set @ 3.4 inches of water flow 200,000 SCFH? 23.1 inches of water

EXAMPLE: ESTIMATING SHAPE OF CURVE

At what pressure will an 8546D set @ 3 inches of water flow 60,000 SCFH? 3.6 inches of water

UNDERSTANDING AND SPECIFYING FLAME ARRESTERS

OVERVIEW

I. Flame Arresters

A. What Arresters Do
B. How Arresters Function

II. Types of Arresters

III. Critical Variables In Specifying Arresters

A. Location of Arrester
B. Chemical Composition of Vapor or Gas
C. Allowable Pressure Drop
D. Materials of Construction

IV. Summary

A. What questions should be asked?

Speed of Travel

deflagration = speed of travel < speed of sound

detonation = speed of travel > speed of sound

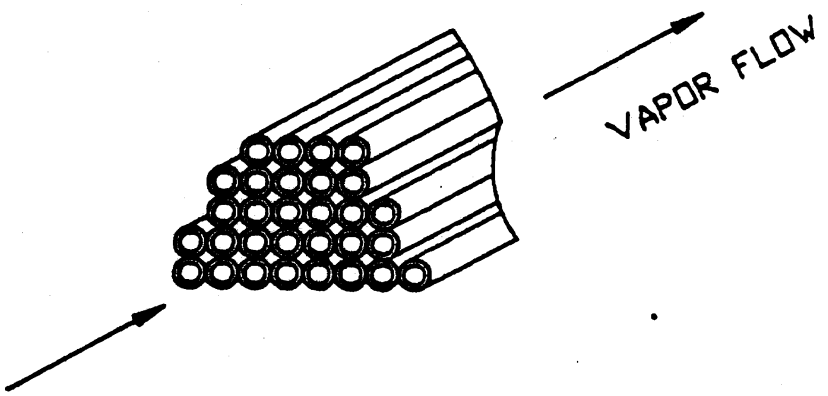
FUNCTION

A Flame Arrester is a device designed to prevent the propagation and transmission of a flame or flame front in locations where flammable gas or vapor mixtures are present.

METHOD

1) Most Arresters are comprised of small passages or apertures which allow vapors to flow, but which are too small for a flame to pass through.

Size of openings based on quenching diameter.



2) In some cases, Arresters must withstand high pressure and velocity flame fronts that can develop in piping systems.

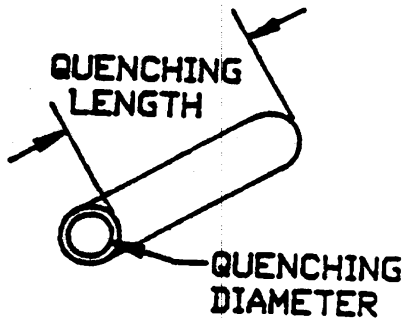
QUENCHING DIAMETER

Definition -- The minimum diameter through which a flame in a stationary gas mixture can propagate indefinitely.

Quenching Diameter indicates the upper limit of aperture diameter in Flame Arresters beyond which flame quenching cannot reliably occur whatever the Arrester thickness.

TYPICAL QUENCHING DIAMETERS

GAS	QUENCHING DIAMETER
Methane	0.145 inches
Propane	0.105 inches
Butane	0.110 inches
Hexane	0.120 inches
Ethylene	0.075 inches
Hydrogen	0.034 inches



The actual aperture size in a Flame Arrester for a particular application is usually not more than 50% of the quenching diameter.

Once the appropriate quenching diameter has been established, testing verifies the proper thickness (length of aperture) for a given set of operating conditions.

Typical Flame Arrester Construction

1) Series of small openings based on the quenching diameter.

2) Length of passage through the openings determined by testing.

3) Strength of housing must be suitable for anticipated service conditions.

TYPES OF FLAME ARRESTERS

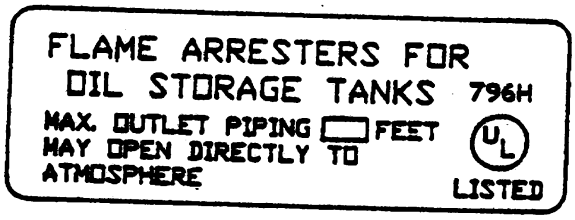
1) Wire Gauze
2) Wire Gauze in Packs
3) Perforated Plates
4) Parallel Plates
5) Packed Tower or Pebble Box.
6) Sintered
7) Wire Pack
8) Metal Foam
9) Hydraulic
10) Crimped Metal

LIMITATIONS ON APPROVED ARRESTERS

Underwriters Laboratories Listing or Factory Mutual Approval does not mean an Arrester is suitable for all applications.

Underwriters Laboratories

Limitations to proper use are specified on a permanent tag affixed to the Arrester.



Factory Mutual

Limitations to use are specified in the Factory Mutual Approval Guide.

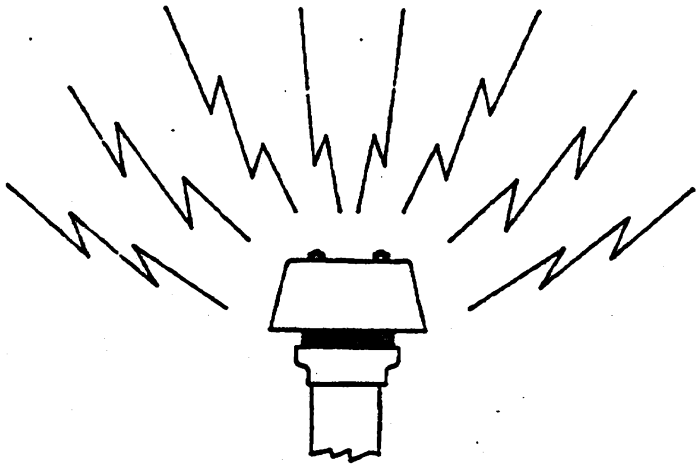
Flame Arresters for Storage Tank Vent Pipes

> Approved flame arresters installed <u>at or within 10 pipe diameters of the end of vent pipes</u> attached to flammable-liquid storage tanks prevent an outside flame from entering the tank.

These limitations are based on several factors that may be encountered in commercial applications.

TYPICAL SCENARIOS FOR ARRESTER USE

END OF LINE APPLICATIONS

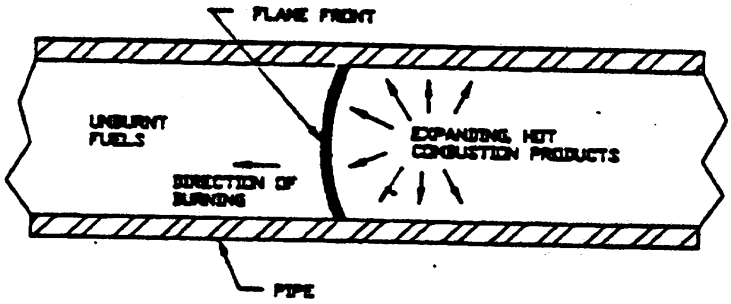


Unconfined Deflagration -- Typified by the combustion of vapor/air mixture at the outlet of an End of Line Arrester.

Deflagration -- Movement of flame through gas or vapor at a speed below the speed of sound.

VENT LINE OR PIPELINE APPLICATIONS

Confined Deflagration



1) Increased pressure caused by hot expanding combustion products causes the flame front velocity and pressure to increase.

   a) The length of the straight pipe run before the Arrester is significant.

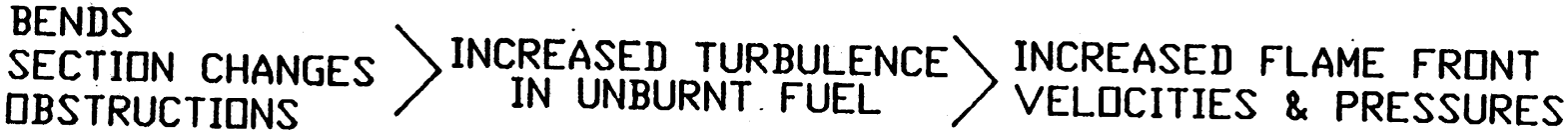
   b) Bends, changes of section or obstructions cause turbulence in the unburnt fuels, dramatically increasing velocities and pressures. Under certain conditions, the flame front can undergo the transition to a detonation.

Detonation

Movement of flame through a gas or vapor at the speed of sound.

Example:

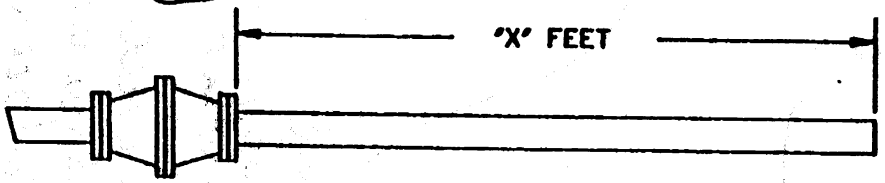
4.3% Propane/Air mixture
   Detonation Pressure --- 500 PSIG
   Detonation Velocity --- 5800 ft./sec.


BENDS
SECTION CHANGES
OBSTRUCTIONS
INCREASED TURBULENCE IN UNBURNT FUEL
INCREASED FLAME FRONT VELOCITIES & PRESSURES

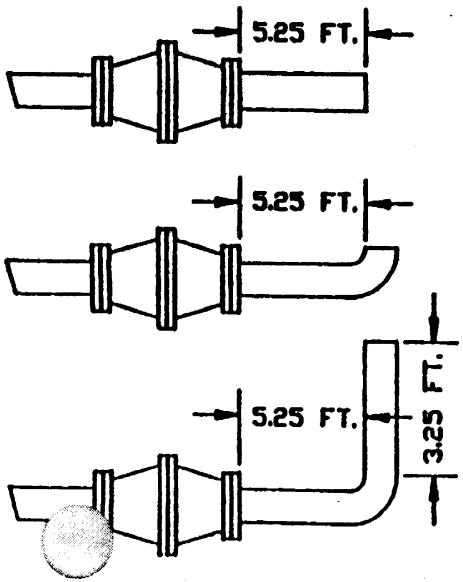
EFFECT OF BENDS & PIPE LENGTH ON VELOCITIES AND PRESSURES

speed of sound ≈ 1000 fps

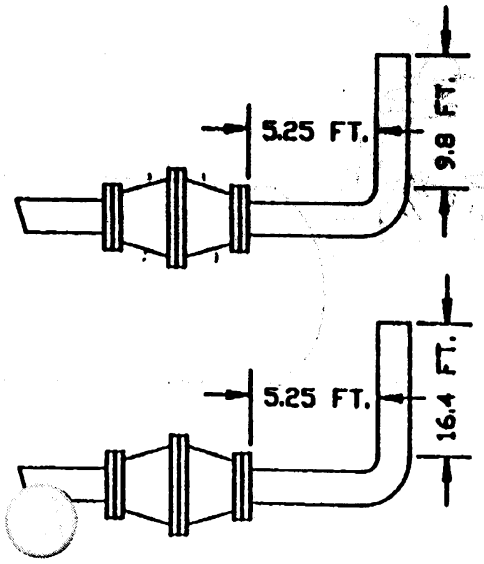
4.3% PROPANE/AIR BY VOLUME
SPARK IGNITION
2 INCH NOMINAL PIPE SIZE



'X' FEET	FLAME SPEED FT./SEC.	PRESSURE PSIG
15	492	5.88
34.7	692	8.23
36.4	741	8.82
38	7350	25.0



FLAME SPEED FT./SEC.	PRESSURE PSIG
269	1.5
469	5.6
1187	5.9



FLAME SPEED FT./SEC.	PRESSURE PSIG
3830	244
6598	252

Pumping into tank

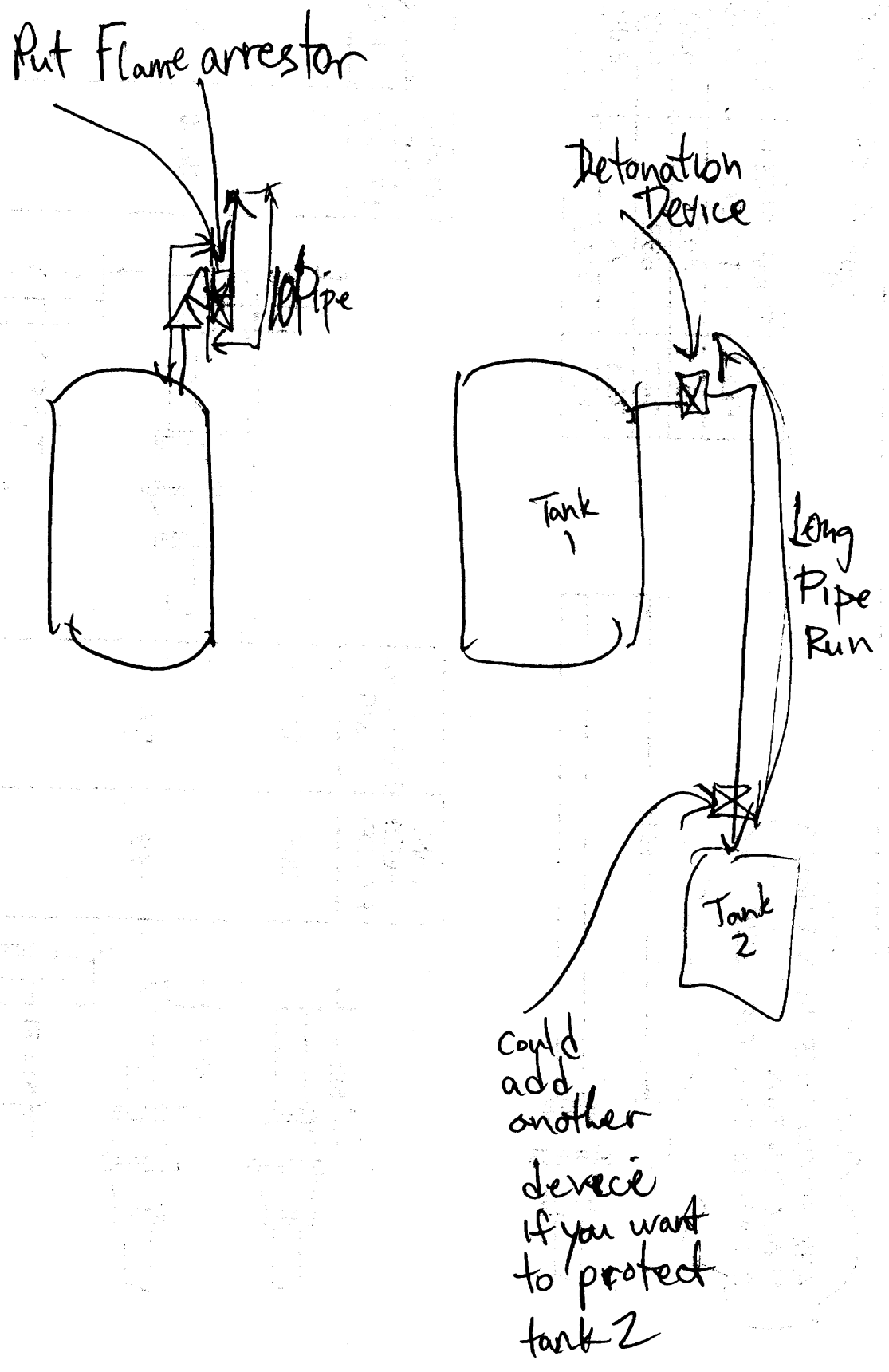
Vapor Compression
OUTBREATHING
(to prevent explosion of the tank)

Pump out of tank

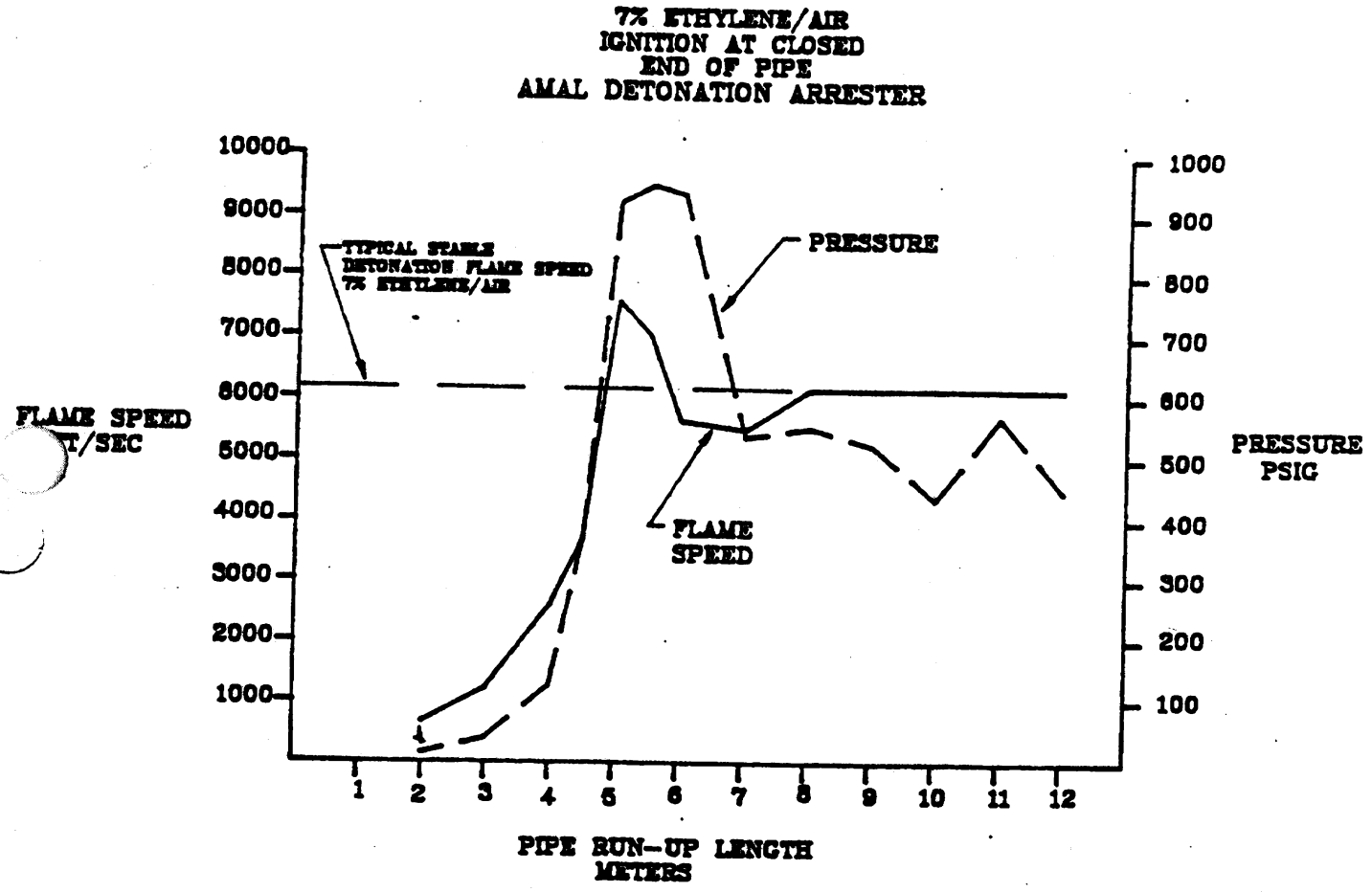
Vapor expansion
INBREATHING
(to prevent collapse of the tank)

Typical Question

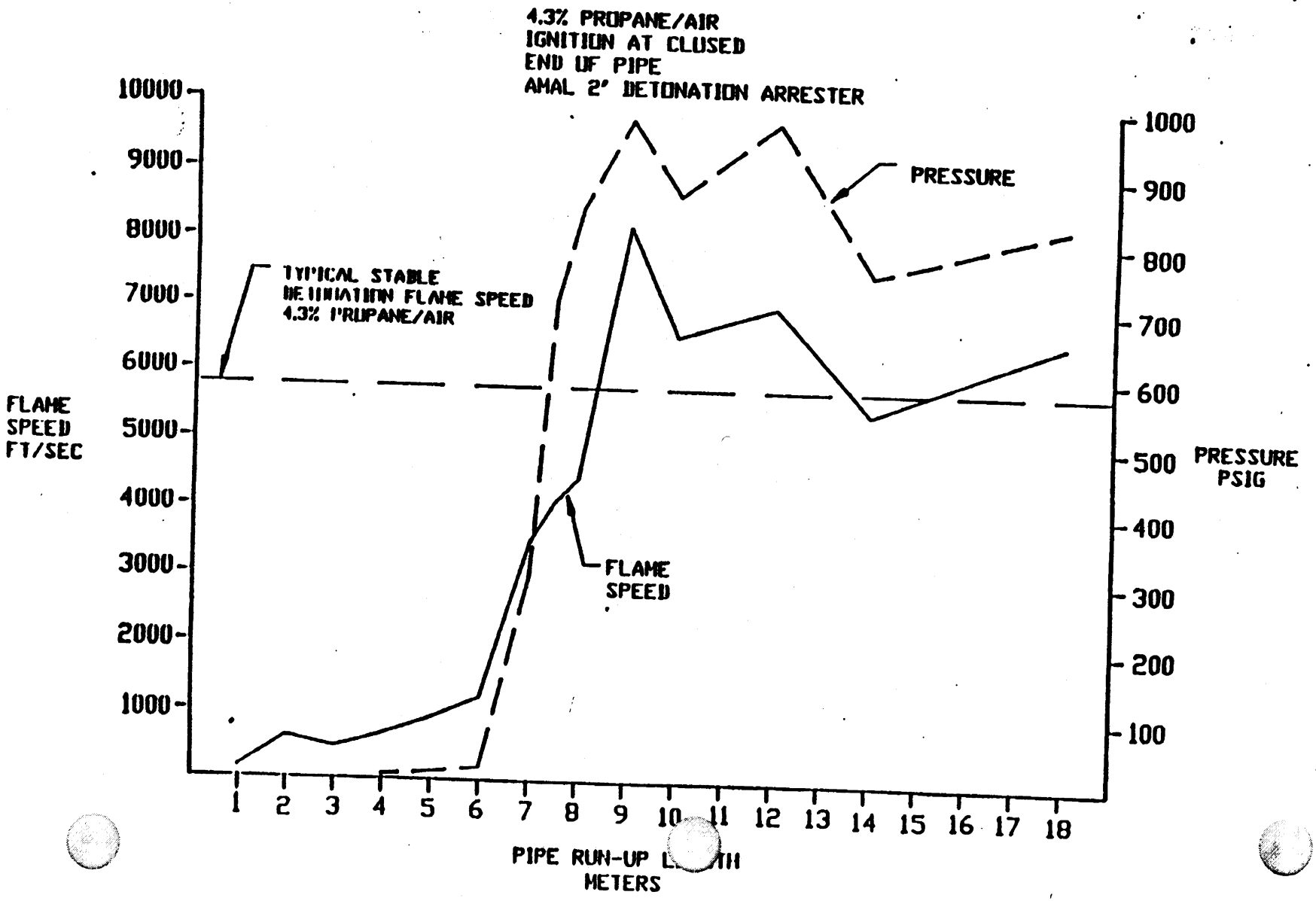
Flame Arrestors placed on end of pipe after vent valve


Put Flame arrestor
10' Pipe
Detonation Device
Tank 1
Long Pipe Run
Tank 2
Could add another devece if you want to protect tank 2

EFFECT OF RUN-UP LENGTH ON PRESSURE & FLAME SPEED



EFFECT OF RUN-UP LENGTH ON PRESSURE & FLAME SPEED



Critical Variables When Specifying Arresters

1) Location of Arrester

2) Chemical Composition of Flammable

3) Allowable Pressure Drop

4) Materials of Construction

Composition of Vapor or Gas

Chemicals are grouped in the National Electric Code based on their burning and explosion characteristics. The chemicals are categorized as Group A, B, C or D.

CHEMICALS BY GROUPS

Group A Atmospheres

acetylene

Group B Atmospheres

butadiene
ethylene oxide
hydrogen
  manufactured gases containing more than 30% hydrogen (by volume)
propylene oxide

Group C Atmospheres

acetaldehyde
cyclopropane
diethyl ether
ethylene
unsymmetrical dimethyl hydrazine

Group D Atmospheres

acetone
acrylonitrile
ammonia
benzene
butane
1-butanol (butyl alcohol)
2-butanol (secondary butyl alcohol)
n-butyl acetate
isobutyl acetate
ethane
ethanol (ethyl alcohol)
ethyl acetate
ethylene dichloride
gasoline
heptanes
hexanes
isoprene
methane (natural gas)
methanol (methyl alcohol)
3-methyl-1-butanol (isoamyl alcohol)
methyl ethyl ketone
methyl isobutyl ketone
2-methyl-1-propanol
  (isobutyl alcohol)
2-methyl-2-propanol
  (tertiary butyl alcohol)
petroleum naptha
octanes
pentanes
1-pentanol (amyl alcohol)
propane
1-propanol (propyl alcohol)
2-propanol (isopropyl alcohol)
propylene
styrene
toluene
vinyl acetate
vinyl chloride
xylenes

CONVENTIONS RELATING TO CHEMICAL GROUPS

1) Arresters tested for one member of a group are generally considered to be suitable for other members of the group under similar conditions.

2) Groups D, C, B and A represent progressively more difficult Flame Arresting situations.

   1) Smaller quenching diameters
   2) Higher detonation pressures and velocities

GAS	GROUP	QUENCHING DIAMETER	DETONATION VELOCITY
Methane	D	0.145 inches	
Propane	D	0.105 inches	5800 FT/SEC
Butane	D	0.110 inches	
Hexane	D	0.120 inches	
Ethylene	C	0.075 inches	
Hydrogen	B	0.034 inches	7000 FT/SEC

NOTE: Underwriters Laboratories and Factory Mutual testing of vent-line Arresters is performed with Group D materials (gasoline, propane).

Critical Variables When Specifying Arresters

1) Location of Arrester

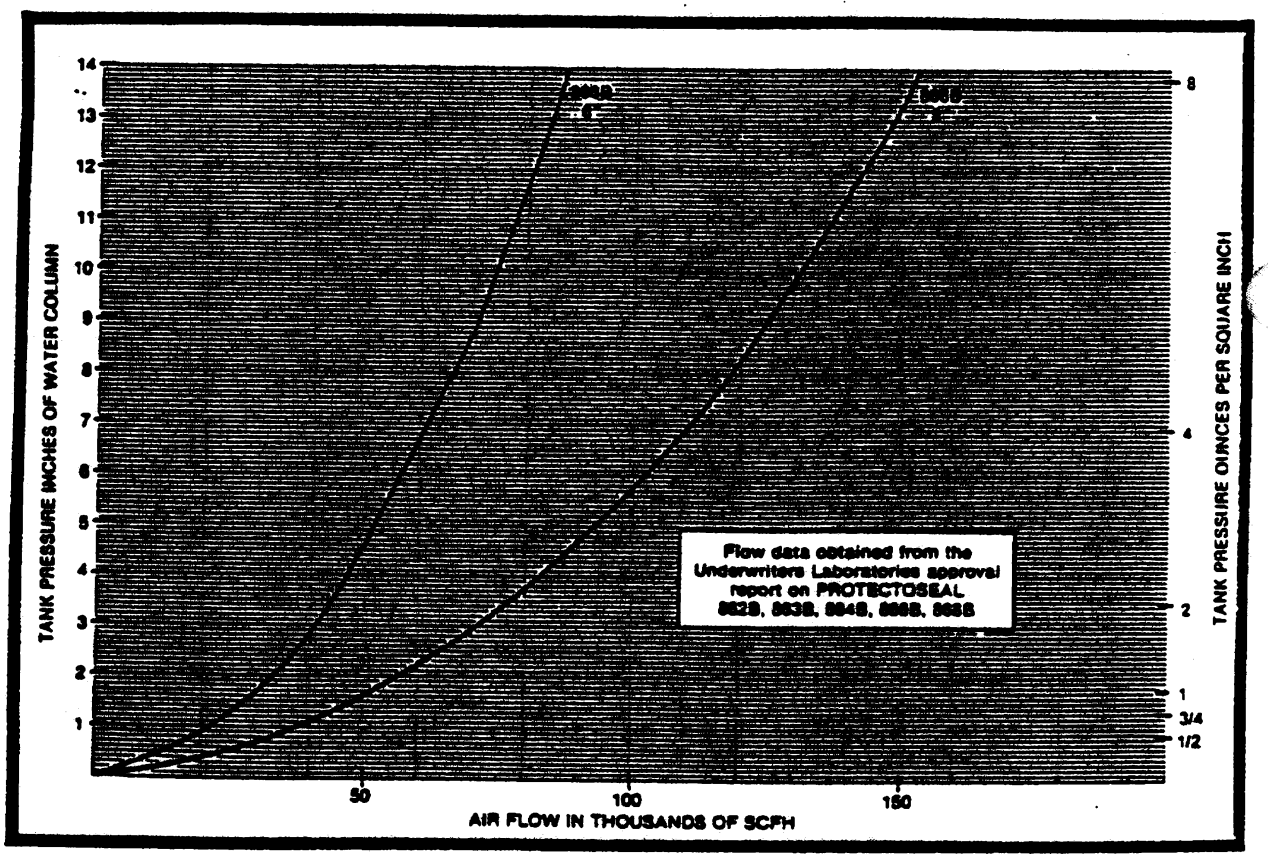
2) Chemical Composition of Flammable

3) Allowable Pressure Drop

4) Materials of Construction

Allowable Pressure Drops

Flow through Flame Arresters is characterized by the Manufacturer's flow curves.



Critical Variables When Specifying Arresters

1) Location of Arrester

2) Chemical Composition of Flammable

3) Allowable Pressure Drop

4) Materials of Construction

Materials of Construction

Arresters (particularly the Arrester element) must be compatible from the standpoint of corrosion with the vapors or gases encountered in the service.

The materials used in construction of the Arrester must be strong enough to withstand the forces that may be encountered in a particular application.

SUMMARY

1) No single Arrester is suitable for all applications.

2) U.L./F.M. approved Flame Arresters are strictly limited in their proper application.

3) Significant Factors

   a) Location of Arrester -- Piping sketch
      1) Bends, pipe lengths, changes of section, obstructions are all significant.
      2) Note the importance of the limitations set by U.L. and F.M.

   b) Composition of Gas or Vapor
      1) Group D, C, B or A

   c) Pressure Drops
      1) Flame Arrester must be properly sized to provide required flow at a specified pressure drop.

   d) Materials of Construction
      1) Corrosion resistance
      2) Strength

QUESTIONS TO ASK

1) Does the application fall within the limitations set for use of the U.L. or F.M. approved Arrester?

2) If application is outside the scope of the applicable approval, does the Manufacturer realize and understand the potential difficulties?

3) On what basis has the manufacturer made a recommendation? Has testing been done to verify suitability of the Arrester under similar conditions?

CODES AND STANDARDS
AND
ECONOMICS OF CONTROL

Instructor

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INSTRUMENTATION SAFETY STANDARDS & CODES

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August 24-26, 1999

Intent

The intent of this presentation is to provide an overview of selected safety standards and codes which are applicable to control systems engineering work and to highlight examples of important topics within them with which CSE exam candidates should be familiar.

SAFETY STANDARDS & CODES PURPOSES

- To provide accepted reference guidelines for the proper specification, design, installation, testing, and/or maintenance of instrumentation and related wiring in hazardous locations and of associated safety systems and equipment.
- To provide accepted reference guidelines for the proper selection and design of safety interlock and permissive functions as implemented in such equipment.

GOALS OF SAFETY STANDARDS & CODES

- To help accomplish the proper selection and safe installation of safety equipment.
- To inhibit an improper process operational sequence or to bring a process or some process equipment to a safe state when it exceeds its normal operational limits.
- To protect process equipment, the environment & surrounding property, & most importantly human lives.

SCOPE OF SELECTED SAFETY STANDARDS & CODES

- Current major safety standards and codes published by recognized American industrial associations , professional societies, and standards institutes.
- Note: international safety standards and codes (such as those by IEC) and safety critical software standards are important also but are not covered in this presentation.

SAFETY STANDARD

- A document which has gone through the sponsoring organization's standards development procedures, has been formally adopted and published as a standard, and can be required to be followed as a recognized compliance guideline by an end user, his industrial insurer, or governmental agency.

SAFETY CODE (Electrical)

- A set of rules and requirements intended to be suitable for mandatory application by governmental bodies exercising legal jurisdiction over electrical installations and for compliance reference by insurance inspectors.

HAZARDOUS (Classified) LOCATION

- A location in which fire or explosion hazards may exist due to the presence of flammable gases or vapors, flammable liquids, combustible dust, or easily ignitible fibers or flyings.

INTRINSICALLY SAFE EQUIPMENT

- Equipment and wiring that, under normal or abnormal conditions, are incapable of releasing sufficient electrical or thermal energy to cause ignition of a specific hazardous atmospheric mixture in its most easily ignitible concentration.

NOTE TO CSE EXAM CANDIDTES

- An asterisk (*) identifies those standards and codes considered important and basic enough that all control systems engineers should be familiar with them and should obtain copies of them for the CSE exam. (Copies of normally encountered standards and codes <u>will not be provided at the exam</u>.)

BLRBAC Instrumentation Checklist & Classification Guide for Instruments & Control Systems Used in the Operation of Black Liquor Recovery Boilers

- Note Section Four, "Installation Checklist and Classification Guide for Instruments and Controls Used in the Operation of Black Liquor Recovery Boilers".

*NFPA 8502 (formerly 85C), Standard for the Prevention of Furnace Explosions/Implosions in Multiple Burner/Boilers

- Know how to calculate the purge time given a particular size boiler.
- Know the major steps in typical purge & light off sequences.
- Know typical boiler trip conditions.
- Be familiar with the typical instrumentation required for fuel trains and igniter systems.

NFPA 497 (formerly 497A), Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installation in Chemical Process Areas

- Be familiar with conditions necessary for ignition.
- Be familiar with behavior of gases, vapors, and liquids.
- Review "Determining the Degree and Extent of Hazardous (Classified) Locations".

Physical Boundaries

ISA-S12.1, Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified Locations

- Read the list of definitions.
- Read the North American methods for area classification. ZONES?
- Read Section 5 on protection techniques.

*ANSI/NEMA 250, Enclosures for Electrical Equipment

- Know the NEMA definitions for & descriptions of types of enclosures for both nonhazardous & hazardous locations.

*NFPA 496, Purged and Pressurized Enclosures for Electrical Equipment

- Know the requirements for Types X, Y, & Z purging.
- Be familiar with the requirements for enclosures in various class locations.

*NFPA 70, National Electrical Code

- Be familiar with Article 250 on grounding.
- Read Articles 500, 501, 502, 503, & 504 on hazardous (classified) locations & intrinsically safe systems.

*ANSI/ISA-RP12.6, Wiring Practices for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety

- Be familiar with intrinsic safety related definitions, especially entity parameters. (4 eq)
- Understand "control drawings".
- Be familiar with proper grounding & bonding techniques.

ANSI/ISA-S12.12, Nonincendive Electrical Equipment for Use in Class I and II, Division 2, and Class III, Divisions 1 and 2, Hazardous (Classified) Locations

- Be familiar with the evaluation of nonincendive circuits and components.

UNDER NORMAL CONDITIONS

ANSI/ISA S84.01, Application of Safety Instrumented Systems for the Process Industries

- Be familiar with the definition of terms & acronyms.
- Be familiar with the "safety life cycle".
- Read Section 7, SIS Detailed Design.

NFPA 85C — Now 8502

NFPA 70 = NEC (HANDBOOK GIVES EXPLAN

OSHA 1910

API 500

ASME Section 8

IES

ISA ~~take exception to IEC standards~~

New IEC Std RTOS In Critical Situations

(all implementing)

NEC

CLASS I
II
III
IV

DIVISION

ZONE Int'l term

KNOW XYZ PURGING

NFPA 496

& Algebraic Equations

ECONOMICS HANDOUT

AUBURN UNIVERSITY
ENGINEERING EXTENSION SERVICE

AND

INSTRUMENT SOCIETY OF AMERICA
BIRMINGHAM SECTION

CONTROL SYSTEMS ENGINEERING EXAMINATION REVIEW

PRESENTATION FOR

INSTRUMENTATION SAFETY STANDARDS & CODES

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INSTRUMENTATION SAFETY STANDARDS & CODES

1.0 INTRODUCTION

1.1 INTENT

The intent of this presentation is to provide an overview of safety standards and codes applicable to control systems engineering work. It is important to the control system engineer to be acquainted with such standards and codes, to be able to determine which ones apply under what circumstances, and to be able to interpret them correctly.

1.2 PURPOSE OF SAFETY STANDARDS & CODES

The purpose of safety standards and codes is severalfold:

- To provide accepted reference guidelines for the proper specification, design, installation, testing, and/or maintenance of instrumentation and related wiring in hazardous locations.
- To provide accepted reference guidelines for the proper specification, design, installation, testing, and/or maintenance of safety equipment and systems themselves.
- To provide accepted reference guidelines for the proper selection and design of safety interlock and permissive functions as implemented in the above equipment.

The ultimate goal of safety equipment/systems/functions is to inhibit an improper process operational sequence or to bring a process or some process equipment to a safe state when it exceeds its normal operational limits and thereby protect the equipment, the environment, surrounding property, and most importantly human lives.

1.3 SCOPE

The scope of the safety standards and codes covered in this presentation is the latest versions of major safety standards and codes published by recognized American industrial associations, professional societies, and standards institutes. Selected frequently encountered standards and codes applicable to control systems and instrumentation engineering work will be reviewed. However the list of standards and codes which will be covered is by no means exhaustive nor is it intended to be.

The focus of the covered safety standards and codes is largely but not exclusively on the electrical aspects of the proper selection and installation of safety components, especially in hazardous (classified) areas. (Mechanical pressure relief and safety venting equipment will not be covered here.) Note:

while the covered safety standards and codes are mainly hardware oriented, new safety standards are coming out for safety-critical operating systems software.

1.4 RELATIVE IMPORTANCE OF STANDARDS & CODES

1.4.1 Safety codes carry the most legal importance and generally apply across multiple industries. Compliance with them is normally mandatory either by governmental bodies or industrial insurers.

1.4.2 Safety standards are reference guidelines which have been formally approved and adopted as a standard, frequently by an industry related organization. However compliance with them, while not mandated by a governmental body, is usually required by most industrial insurers if not the end user himself. Therefore failure to comply with an applicable safety standard can potentially have lawsuit ramifications.

1.4.3 Recommended practices are general consensus best practice recommendations also often put forth by industry related organizations. Their observance is normally voluntary and not necessarily required by an insurer and therefore of a lower legal impact.

1.5 STANDARDS & CODES NOTES TO CANDIDATES

1.5.1 A number of the standards & codes listed in the third edition of the CSE Study Guide on pages 25 thru 36 are out of date, either in terms of the number of the standard or the edition/date of the standard.

1.5.2 Candidates are strongly encouraged to get their own complete copies of the standards and codes marked with an asterisk (*) beside them. Copies of normally encountered standards and codes will not be provided at the exam.

1.5.3 However, if an exam question calls for details of an infrequently-cited standard or code, the needed information will be supplied as part of the question.

2.0 DEFINITIONS

Class (NEC):

The identification of a location based upon the properties of the flammable materials which may be present (gas or vapor, dusts, or easily ignitible fibers or flyings) and in what concentration.

Code (electrical):

A set of rules and requirements intended to be suitable for mandatory application by governmental bodies exercising legal jurisdiction over electrical installations and for use by insurance inspectors.

Division (NEC):

An indication of the probability of the presence of the flammable material in ignitible concentration.

Entity evaluation:

A method used to determine acceptable combinations of intrinsically safe apparatus and connected associated apparatus that have not been investigated in such combination.

Explosion proof enclosure:

An enclosure that is capable of withstanding an explosion of a gas or vapor within it and of preventing the ignition of an explosive gas or vapor that may surround it and that operates at such an external temperature that a surrounding explosive gas or vapor will not be ignited thereby.

Group (NEC):

Specifically listed flammable materials or materials of a particular electrical resistivity.

Hazardous (classified) location:

A location in which fire or explosion hazards may exist due to the presence of flammable gases or vapors, flammable liquids, combustible dust, or easily ignitible fibers or flyings.

Hermetically sealed device:

A device that is sealed against the entrance of an external atmosphere and in which the seal is made by fusion. Continuous soldering, brazing, welding, and the fusion of glass to metal are examples of recognized methods.

Interlock:

A device or group of devices arranged to sense a limit or off-limit condition or improper sequence of events and to shut down the offending or related piece of equipment or to prevent proceeding in an improper sequence in order to avoid a hazardous condition.

Intrinsically safe equipment:

Equipment and wiring that, under normal or abnormal conditions, are incapable of releasing sufficient electrical or thermal energy to cause ignition of a specific hazardous atmospheric mixture in its most easily ignitible concentration.

Nonincendive equipment:

Equipment having electrical/electronic circuitry and components that are incapable, under normal conditions, of causing ignition of a specified flammable gas or vapor-in-air mixture due to arcing or thermal effect.

Permissive:

Condition(s) within a logic sequence that must be satisfied before the sequence is allowed to proceed to the next phase.

Purging:

The process of supplying an enclosure with clean air or inert gas at a specified flow rate and positive pressure to reduce the concentration of any flammable gas or vapor initially present to an acceptably safe level and to maintain this safe level by positive pressure with or without continuous flow.

Recommended practice:

General consensus recommendations applicable to a referenced subject, which are intended to promote understanding, uniformity and general guidance to those concerned with the particular subject. A recommended practice does not establish detailed specifications or set forth specific tests to be performed and passed, and its use may be on a voluntary basis.

Safety instrumented system:

ISA SP 84.01

A system composed of sensors, logic solvers, and final control elements for the purpose of taking a process to a safe state when predetermined conditions are violated. Other terms commonly used include emergency shutdown system, safety shutdown system, and safety interlock system.

Safety integrity level:

One of three possible discrete integrity levels (SIL 1, 2, or 3) of safety instrumented systems. SIL's are defined in terms of probability of failure on demand (PFD).

Seal, conduit, explosionproof:

A sealing fitting, poured with cement-like potting compound, designed to contain an explosion in the enclosure to which it is attached and to minimize passage of flammable gases or vapors from one location to another.

Standard (published):

A document which has gone through the sponsoring organization's standards development procedures, has been formally adopted and published as a standard, and can be required to be followed as a recognized compliance guideline by an end user or his industrial insurer.

Zone:

The international method of specifying the probability that a location is made hazardous by the presence, or potential presence, of flammable concentrations of gases and vapors.

3.0 INSTRUMENTATION SAFETY STANDARDS & CODES

3.1 FOREWORD

This is a representative list of frequently encountered instrumentation safety standards and codes from major **American** professional organizations and standards institutes. It is not an exhaustive list, and it does not cover all organizations sponsoring safety standards and codes. The focus of this list is upon electrical instrumentation and control equipment selection and installation related standards and codes. It is organized by subject rather than by sponsoring organization.

List of American Organizations:

- ANSI = American National Standards Institute
- API = American Petroleum Institute
- ASME = American Society of Mechanical Engineers
- BLRBAC = Black Liquor Recovery Boiler Advisory Committee
- FM = Factory Mutual (Engineering Corp.)
- ISA = Instrument Society of American (AKA - The International Society for Measurement and Control)
- NEMA = National Electrical Manufacturers Association
- NFPA = National Fire Protection Association
- UL = Underwriters Laboratories, Inc.

NOTE: * Identifies those standards or codes considered important and basic enough that all control systems engineers should be familiar with them and should obtain copies of them.

3.2 SAFETY STANDARDS & CODES BY SUBJECT

3.2.1 BOILER SAFETY INSTRUMENTATION

1. ASME CSD-1, Control and Safety Devices for Automatically Fired Boilers, 1998.

The rules of this code cover requirements for the assembly, maintenance, and operation of controls and safety devices installed on automatically operated boilers directly fired with gas, oil, gas-oil, or electricity, subject to certain service limitations and exclusions of CG-120 and CG-130. Use of a gaseous or oil fuel not listed in the definitions has not been evaluated and special considerations may be required. Excluded from this code are: (a) boilers with fuel input ratings of 12.5 million Btu/hr or above, falling within the scope of NFPA 8501, NFPA 8502, NFPA 8503, or NFPA 8504; and (b) water heaters.

2. BLRBAC Instrumentation Checklist and Classification Guide for Instruments & Control Systems Used in the Operation of Black Liquor Recovery Boilers, 1998.

The purpose of this Recommended Good Practice is to provide guidelines for the design, installation, and operation of recovery boiler controls and safety instrumented systems (SIS) to contribute to operating safety. This Recommended Good Practice is intended as a guide and checklist to provide the proper tools for promoting safety and long term unit availability. It is not intended to specify specific hardware but to recommend the functions desired for proper operation of the unit.

3. BLRBAC Recommended Good Practice: Safe Firing of Black Liquor in Black Liquor Recovery Boilers, 1994.

The subjects of this Recommended Good Practice are: (1) failure of a pressure part; (2) unsafe firing conditions; (3) introduction of black liquor into a nonoperating furnace; (4) introduction of water into the furnace through the black liquor firing system; and (5) introduction of water into the furnace through external means. The provision of proper instrumentation and a black liquor safe firing system should go a long way toward reducing black liquor recovery boiler explosions attributed to low solids liquor, low solids balck liquor firing, and water introduced through the liquor firing system.

4. FM 6-4/12-69, Oil and Gas-Fired Single-Burner Boilers, 1994.

This loss prevention data sheet discusses the fuel hazards inherent in gas-fired or oil-fired single-burner boilers. Recommendatins are made for the installation, maintenance, and operation of combustion safeguards and boilers as related to the fuel explosion and fire hazards. Automatic and supervised manual single-burner boilers rated greater than 400,000 Bth/hr input are covered. This data sheet does not apply to natural draft boilers or to boilers rated 2.5 million Btu/hr or less that are listed by a nationally recognized testing laboratory agency.

5. FM 6-5/12-70, Oil or Gas-Fired Multiple Burner Boilers, 1994.

This loss prevention data sheet is concerned primarily with the hazards associated with the firing of natural gas and standard grades of fuel oil in multiple burner boilers. The boilers addressed in this data sheet cover a broad range of sizes. (Generally industrial boilers range from 50,000 lbs/hr to 200,000 lbs/hr of steam.)

6. FM 6-13/12-13, Waste Fuel-Fired Boilers, 1999.

This loss prevention data sheet covers the firing of "waste" type of fuels in boilers. It is divided into three sections: gaseous, liquid, and solid types of fuel. No attempt has been made to cover every type of "waste" fuel. (The information provided in this data sheet may also be used for firing of "waste" fuels in kilns and furnaces.)

7. FM 6-21/12-21, Chemical Recovery Boilers, 1994.

This loss prevention data sheet provides recommendations for the design, operation, and maintenance of chemical recovery boilers utilized in the pulp and paper industry.

8. NFPA 8501 (formerly 85A), Standard for Single Burner Boiler Operation, 1997.

This document is to be used for the design, installation, operation, and maintenance of single burner firetube and watertube boiler-furnaces and their burner management and combustion control systems. This standard applies to boilers with a fuel input rating of 12.5 million Btu/hr or greater. This standard applies only to boiler-furnaces using single burners firing natural gas only, other gas with a Btu value and characteristics similar to natural gas, fuel

oil only, simultaneous firing of gas and oil for fuel transfer, or simultaneous firing of gas and oil continuously.

9. *NFPA 8502 (formerly 85C), Standard for the Prevention of Furnace Explosions/Implosions in Multiple Burner/Boilers, 1999.

This document is to be used for the design, installation, operation, and maintenance of multiple burner boilers and their burner management and combustion control systems. This standard shall apply to boilers with a fuel input rating of 12.5 million Btu/hr or greater. This standard applies only to boilers using multiple burners firing fuel gas only, fuel oil only, or pulverized coal.

10. NFPA 8504, Standard on Atmospheric Fluidized-Bed Boiler Operation, 1996.

This document establishes minimum standards for the design, installation, operation, and maintenance of boilers and their fuel-burning, air supply, and combustion products removal systems. This standard shall apply to boilers with a fuel input rating of 12.5 million Btu/hr or greater. This standard applies only to boilers using atmospheric fluidized-bed combustion. This standard covers firing of individual or blended fuels but not firing of multiple main fuels.

NFPA 8503

3.2.2 CLASSIFICATION OF HAZARDOUS LOCATIONS

1. **API RP 500, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2, 2nd Edition, 1997.**

   The purpose of this recommended practice is to provide guidelines for classifying locations Class I, Division 1 and Class I, Division 2 at petroleum facilities for the selection and installation of electrical equipment. It is intended to serve as a supplement to the National Electrical Code.

   This document applies to the classification of locations for both temporarily and permanently installed electrical equipment. It is intended to be applied where there may be a risk of ignition due to the presence of flammable gas or vapor mixed with air under normal atmospheric conditions.

2. **ANSI/ISA-S12.10, Area Classification in Hazardous (Classified) Dust Locations, 1988.**

   This standard recommends procedures for classifying locations made hazardous by the presence of a cloud or blanket of combustible dust. It conforms with the U.S. *National Electrical Code* (NEC) and the *Canadian Electrical Code* (CEC) and is intended to expand and clarify both.

   This standard refers only to combustible mixtures created by dusts - such as agricultural, carbonaceous, plastic, chemical, and metal dusts.. Such materials are classified in NEC Article 500 as Class II, Groups E, F, and G.

3. **ISA RP12.24.01 (IEC 60079-10 Mod), Recommended Practice for Classification of Locations for Electrical Installations Classified as Class I, Zone 0, Zone 1, or Zone 2, 1998.**

   This recommended practice is concerned with the classification of hazardous areas where flammable gas or vapor risks may arise in order to permit the proper selection and installation of apparatus for use in such hazardous areas. This recommended practice is a modification of IEC 60079-10 (formerly 79-10), *Electrical Apparatus for Explosive Gas Atmospheres, Part 10: Classification of Hazardous Areas*, normalized as an American National Standard.

   It is intended to be applied where there may be a risk of ignition due to the presence of flammable gas or vapor mixed with air under normal atmospheric conditions, but it does not apply to: (a) mines susceptible to firedamp; (b) the processing and manufacture of explosives; (c) areas where a risk may arise due to the presence of ignitable dusts or fibers; (d) catastrophic failures which

are beyond the concept of abnormality dealt with in this recommended practice; (e) rooms used for medical purposes; or (f) areas where the presence of flammable mist may give rise to an unpredictable risk and which require special consideration.

4. **NFPA 497 (formerly 497A), Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 1997.**

This recommended practice provides information on specific flammable gases and vapors, flammable liquids, and combustible liquids, whose relevant combustion properties have been sufficiently identified to allow their classification into the groups established by NFPA 70, *National Electrical Code*, for proper selection of electrical equipment in hazardous (classified) locations. This recommended practice applies to chemical process areas where flammable gases or vapors, flammable liquids liquids, or combustible liquids are processed or handled.

5. NFPA 499 (formerly 497M), Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 1997.

This recommended practice provides information on specific combustible dusts whose relevant combustion properties have been sufficiently identified to allow their classification into the groups established by NFPA 70, *National Electrical Code*, for proper selection of electrical equipment in hazardous (classified) locations. This recommended practice applies to chemical process areas where combustible dusts are produced, processed, or handled but does not apply to agricultural grain-handling facilities.

3.3.3 ELECTRICAL EQUIPMENT INSTALLATIONS IN HAZARDOUS LOCATIONS

1. API RP 540, Electrical Installations in Petroleum Processing Plants, 4th Edition, 1999.

This recommended practice provides information on electrical installations in petroleum processing plants. This recommended practice is limited to electrical systems that provide power, lighting, control, protection, and supervision for petroleum processing plants. It provides a basis for those specifications that industry and engineering contractors develop for inclusion in engineering and construction contracts. The requirements for supplying electric power to instrumentation and process control systems are included.

2. ISA-S12.1, Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified) Locations, 1991.

This standard provides definitions and information pertaining to protection techniques, terminology, and the installation of electrical instruments in hazardous (classified) locations and provides an introduction and basic background to the ISA-SP12, Electrical Safety, series of publications and committee activities.

It provides general guidance for the safe design, installation, and maintenance of electrical instrument systems using appropriate means to prevent ignition of flammable gases and vapors, flammable liquids, combustible dusts, or ignitable fibers or flyings. Not necessarily relevant to hazards posed by pyrophoric materials or propellants containing their own oxidizers, by lightning or static electricity, or by corrosive atmospheres.

3. UL 698 (ANSI/UL 698), Standard for Industrial Control Equipment for Use in Hazardous (Classified) Locations, 1990.

These requirements cover industrial control equipment for installation and use in hazardous locations, Class I, Groups A, B, C, and D, and Class II, Groups E, F, and G, in accordance with the *National Electrical Code*. They do not cover intrinsically safe electrical circuits of industrial control equipment for use in hazardous locations.

3.3.4 ENCLOSURES FOR ELECTRICAL EQUIPMENT

1. ISA-RP12.4, Pressurized Enclosures, 1996.

This recommended practice provides performance and test recommendations for pressurized enclosures and guidance to those who design and install pressurized systems for hazardous (classified) locations. This document should be used in conjunction with ANSI/NFPA 496.

It applies to equipment suitable for use in hazardous (classified) locations by using a pressurizing system and to equipment with and without an internal release of flammable gas or vapor. It does not apply to occupied portions of buildings, such as ventilated or pressurized control rooms.

2. *ANSI/NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum), 1991.

This standard covers enclosures for electrical equipment rated at not more than 1000 volts. It provides descriptions, features, and test criteria for hazardous (classified) and nonhazardous location enclosures. Definitions are given for general terms and specifically for each enclosure type. Descriptions are given of the more common types of enclosures used by the electrical industry to provide protection to personnel against incidental contact with the enclosed equipment and to provide protection to the enclosed equipment against specific environmental conditions.

This standard does not cover: enclosures for rotating apparatus; the protection of devices against conditions such as condensation, icing, corrosion, or contamination which may occur within the enclosure or enters via the conduit or unsealed openings; or means to prevent attempted entry or operation by unauthorized personnel. This standard does not cover requirements for wire and cable.

3. *NFPA 496, Purged and Pressurized Enclosures for Electrical Equipment, 1998.

This standard is intended to provide information on the methods for purging and pressurizing enclosures to prevent ignition of a flammable atmosphere. Such an atmosphere may be introduced into the enclosure by a surrounding external atmosphere or by an internal source. By these means, electrical equipment that is not otherwise acceptable for a flammable atmosphere may be utilized in accordance with Article 500 or Article 505 of NFPA 70, *National Electrical Code*. (This standard does not apply to electrical equipment located in areas classified as Class I, Zone 0 or Class III.)

3.3.5 GENERAL ELECTRICAL & ELECTRONIC EQUIPMENT SAFETY GUIDELINES

1. **ANSI/ISA S82.01, Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment - General Requirements, 1994.**

   This standard is harmonized to IEC Publication 61010-1 (formerly 1010-1), *Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirements.* This standard applies to electrical and electronic test, measuring, controlling, and related equipment. This standard applies to equipment that is rated for connection to supply circuits that exceed extra-low voltage and that do not exceed 480 volts rms, between phases for three-phase supply circuits or 250 volts rms for single-phase or dc.

   This standard does not apply to: (1) medical and laboratory equipment; (2) watt-hour meters and associated equipment installed by electrical utility companies for measuring electrical energy and related quantities; and (3) general use battery chargers, auxiliary supply sources, substitute power supplies, or laboratory-type power supplies not specifically rated for use with measuring or testing equipment.

2. **ANSI/ISA S82.03, Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment, 1988.**

   This standard applies to electrical, electronic (analog/digital), and electromechanical process measurement and control equipment which: (1) measures and controls directly or indirectly an industrial process through a final control element (or elements); (2) is intended to be connected to supply circuits which do not exceed 250 volts rms, single phase or dc; and (3) is rated for use in either indoor, outdoor, or sheltered locations. This standard supplements or amends the requirements of ISA S82.01.

3. ***NFPA 70, National Electrical Code, 1996.**

   This code contains provisions considered necessary for the safeguarding of persons and property from hazards arising from the use of electricity. Compliance therewith and proper maintenance will result in an installation essentially free from hazard but not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use. This code is not intended as a design specification nor as an instruction manual manual for untrained persons.

This code covers: (1) installations of electric conductors and equipment within or on public and private buildings or other structures, including mobile homes, recreational vehicles, and floating dwelling units; and other premises such as yards, carnivals, parking and other lots, and industrial substations; (2) installations of conductors that connect to the supply of electricity; (3) installations of other outside conductors on the premises; and (4) installations of optical fiber cables.

3.3.6 INTRINSICALLY SAFE SYSTEMS

1. *ANSI/ISA-RP12.6, Wiring Practices for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety, 1995.

This recommended practice is intended to promote the uniform installation of intrinsically safe systems for hazardous (classified) locations. Information is provided to clarify and explain the requirements of Article 504 of the *National Electrical Code*. This recommended practice provides guidance to those who design, install, and maintain intrinsically safe systems for hazardous (classified) locations.

2. UL 913 (ANSI/UL 913), Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations, 1988.

The purpose of this standard is to provide requirements for the construction and testing of electrical apparatus, or parts of such apparatus, having circuits that are not capable of causing ignition in Division 1 hazardous locations as defined in Article 500 of the *National Electrical Code*. These requirements shall apply to: apparatus or parts of apparatus in Class I, II, or III, Division 1 locations and those parts of apparatus located outside of the Class I, II, or III, Division 1 locations whose design and construction may influence the intrinsic safety of an electrical circuit within the Class I, II, or III, Division 1 location.

3.3.7 NONINCENDIVE ELECTRICAL EQUIPMENT

- **ANSI/ISA-S12.12, Nonincendive Electrical Equipment for Use in Class I and II, Division 2, and Class III, Divisions 1 and 2, Hazardous (Classified) Locations, 1994.**

  This standard provides requirements for the design, construction, and marking of electrical equipment or parts of such equipment used in Class I, Division 2 locations. This document establishes uniformity in test methods for determining the suitability of the equipment and associated circuits and components as they are related to their ability to ignite a specified flammable gas or vapor-in-air mixture. This standard applies only to equipment, circuits, or components designed and assessed specifically for use in Class I, Division 2, hazardous locations as defined by the *National Electrical Code*, NFPA 70, Articles 500 and 501 or the *Canadian Electric Code* (Part I), C22.1, Section 18.

3.3.8 SAFETY INSTRUMENTED SYSTEMS

1. ANSI/ISA S84.01, Application of Safety Instrumented Systems for the Process Industries, 1996.

Addresses the application of Safety Instrumented Systems (SIS) for the process industries, including electrical, electronic, and programmable electronic technology. This standard follows the Safety Life Cycle activities from initial conception through decommissioning but does not address the method for performing them. This document is intended for those who are involved with design and manufacture of SIS products, installation, commissioning, and pre-startup acceptance testing, and operation, maintenance, documentation, and testing.

2. ANSI/ISA S91.01, Identification of Emergency Shutdown Systems and Control That Are Critical to Maintaining Safety in Process Industries, 1995.

NO TEETH—NO MEAT

Establishes a procedure to identify the emergency shutdown systems and safety critical controls that are key to maintaining safety in the process industries as defined in the Mechanical Integrity and Maintenance sections of Process Safety Management regulations, such as OSHA Federal Regulation 29 CFR 1910.119, and Risk Management Program regulations, such as the (proposed) U.S. Environmental Protection Agency Regulation 40 CFR Part 68. Provides requirements for testing and documenting the results of the tests. This standard does not address requirements that apply only to the nuclear power industry.

CONDUCT HAZOP REVIEW

APPENDICIES

APPENDIX A

NEMA Type Enclosures for Electrical Equipment (1000 Volts Maximum)

NEMA Type Enclosures for Electrical Equipment (1000 Volts Maximum).

The following descriptions are excerpts from NEMA's "Standards Publication/No. 250—1985."

NON-CLASSIFIED LOCATION ENCLOSURES

Type 1 Enclosures
Type 1 enclosures are intended for indoor use primarily to provide a degree of protection against contact with the enclosed equipment in locations where unusual service conditions do not exist. The enclosures shall meet the rod entry and rust-resistance design tests.

Type 2 Enclosures
Type 2 enclosures are intended for indoor use primarily to provide a degree of protection against limited amounts of falling water and dirt. These enclosures shall meet rod entry, drip, and rust-resistance design tests. They are not intended to provide protection against conditions such as dust or internal condensation.

Type 3 Enclosures
Type 3 enclosures are intended for outdoor use primarily to provide a degree of protection against windblown dust, rain, and sleet; and to be undamaged by the formation of ice on the enclosure. They shall meet rain, external icing, dust, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 3R Enclosures
Type 3R enclosures are intended for outdoor use primarily to provide a degree of protection against falling rain; and to be undamaged by the formation of ice on the enclosure. They shall meet rod entry, rain, external icing, and rust-resistance design tests. They are not intended to provide protection against conditions such as dust, internal condensation, or internal icing.

Type 3S Enclosures
Type 3S enclosures are intended for outdoor use primarily to provide a degree of protection against windblown dust, rain, and sleet and to provide for operation of external mechanisms when ice laden. They shall meet rain, dust, external icing, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 4 Enclosures
Type 4 enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, and hose-directed water; and to be undamaged by the formation of ice on the enclosure. They shall meet hosedown, external icing, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 4X Enclosures
Type 4X enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, and hose-directed water; and to be undamaged by the formation of ice on the enclosure. They shall meet the hosedown, external icing, and corrosion-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 5 Enclosures
Type 5 enclosures are intended for indoor use primarily to provide a degree of protection against settling airborne dust, falling dirt, and dripping non-corrosive liquids. They shall meet drip, settling airborne dust, and rust-resistance design tests. They are not intended to provide protection against internal condensation.

Type 6 Enclosures
Type 6 enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against the entry of water during temporary submersion at a limited depth; and to be undamaged by the formation of ice on the enclosure. They shall meet submersion, external icing, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation, internal icing, or corrosive environments.

Type 6P Enclosures
Type 6P enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against the entry of water during prolonged submersion at a limited depth; and to be undamaged by the formation of ice on the enclosure. They shall meet air pressure, external icing, and corrosion-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 11 Enclosures
Type 11 enclosures are intended for indoor use primarily to provide a degree of protection against the corrosive effects of liquids and gases. In addition, they protect the enclosed equipment against the corrosive effects of fumes and gases by providing for immersion of the equipment in oil. They shall meet drip and corrosion-resistance design tests. They are not intended to provide protection against conditions such as internal condensation or internal icing.

Type 12 Enclosures
Type 12 enclosures are intended for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping noncorrosive liquids. They shall meet drip, dust, and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation.

Type 12K Enclosures
Type 12K enclosures with knockouts are intended for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping noncorrosive liquids other than at knockouts. They shall meet drip, dust, and rust-resistance design tests. Knockouts are provided only in the top or bottom walls, or both. After installation of the enclosure, the knockout areas shall meet the environmental characteristics listed above (see NEMA "Standards Publication/No. 250-1985"). They are not intended to provide protection against conditions such as internal condensation.

Type 13 Enclosures
Type 13 enclosures are intended for indoor use primarily to provide a degree of protection against dust, spraying of water, oil, and noncorrosive coolant. They shall meet oil exclusion and rust-resistance design tests. They are not intended to provide protection against conditions such as internal condensation.

CLASSIFIED LOCATION ENCLOSURES

Type 7 Enclosures
Type 7 enclosures are for indoor use in locations classified as Class I, Groups A, B, C, or D, as defined in the *National Electrical Code.*

Type 8 Enclosures
Type 8 enclosures are for indoor or outdoor use in locations classified as Class I, Groups A, B, C, or D, as defined in the *National Electrical Code.*

Type 9 Enclosures
Type 9 enclosures are intended for indoor use in locations classified as Class II, Groups E, or G, as defined in the *National Electrical Code.* (Group F was reinstated in the 1987 NEC).

Type 10 Enclosures (MSHA)
Type 10 enclosures shall be capable of meeting the requirements of the Mine Safety and Health Administration, *30 C.F.R.*, Part 18.

***Descriptions of *NEMA ENCLOSURES* on this page include the May 1988 revision of *NEMA* Type 5.**

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Chicago, Illinois 60657

APPENDIX B

Safety System Design Standards & Guidelines

1. **Application of Safety Instrumented Systems for the Process Industries,** International Society for Measurement and Control, ANSI/ISA S84.01, 1996 Phone (919) 549-8411

2. **Identification of Emergency Shutdown Systems and Control That Are Critical to Maintaining Safety in Process Industries**, International Society for Measurement and Control, ANSI/ISA S91.01, 1995 Phone (919) 549-8411

3. **Guidelines for Safe Automation of Chemical Processes,** American Institute of Chemical Engineers, Center for Chemical Process Safety, ISBN 0-8169-0554-1, 1993, Phone 800-242-4363

   An excellent text on the design of DCS and Safety Interlock Systems.

4. **Functional Safety - Safety Related Systems**, International Electrotechnical Commission, Technical Committee No. 65, Working Groups 9 & 10 draft standard 61508 & 61511, 1998, (Copies may be ordered through ISA - Phone (919) 549-8411.)

   Four out of seven portions to be released in '99.

5. **Programmable Electronic Systems In Safety Related Applications**

   Part 1 - An Introductory Guide,1987, ISBN 011 883913 6

   Part 2 - General Technical Guidelines, 1987, ISBN 011 883906 3

   U.K. Health & Safety Executive, Phone 011-441-787-313-995

   (Has also been available in the U.S. through Unipub at (301) 459-7666)

   An excellent document and the first of it's kind. The starting point for many others like it. Specific for programmable systems, but can easily be applied for other technologies as well.

Reliability Information References

1. **Reliability, Maintainability and Risk (Practical Methods for Engineers)** 4th Edition, David J. Smith, Butterworth-Heinemann, 1993, ISBN 0-7506-0854-4, Phone 800-366-2665

   If you only get one book, this should be it. Outstanding background material plus an excellent listing of failure rates, failure modes, fatality rates, and human error rates.

2. **OREDA-92 (Offshore Reliability Data)** DNV Industry, Veritasveien 1, N-1322 HØVIK, Norway, 1992, (Phone 011 47 67 57 72 50, Fax 011 47 67 57 74 74)

   By far the best listing of failure rate data (even though it is focused for the offshore industry). Unfortunately it's very expensive (about $500). Fax for the latest price.

3. **Guidelines For Process Equipment Reliability Data With Data Tables**, American Institute of Chemical Engineers, Center for Chemical Process Safety, 1989, ISBN 0-8169-0422-7, Phone 800-242-4363

A decent listing of failure rate date in the process industry. Not as complete as OREDA, but less expensive and readily available in the U.S.

4. **IEEE Std 500-1984**, Equipment Reliability Data for Nuclear-Power Generating Stations, IEEE and John Wiley & Sons, 1984, ISBN 471-80785-0, Phone 800-678-4333

   A 2 1/2 inch thick book full of failure rate data.

Other Recommended Reading

1. **Safety Shutdown Systems: Design, Analysis and Justification**, Gruhn & Cheddie, ISA, 1998, ISBN 1-55617-665-1
2. **29 CFR Part 1910.119, Process Safety Management of Highly Hazardous Chemicals**, U.S. Federal Register, Feb. 24, 1992, Contact your local government bookstore, or download the document from OSHA's website at http://www.osha.gov
3. **Out of Control, Why control systems go wrong and how to prevent failure,** Health & Safety Executive (UK), 1995, ISBN 0-7176-0847-6, Phone 011-441-787-881-165, Fax 011-441-787-313-995)
4. **Computer Control and Human Error**, Trevor A. Kletz, ISBN 0-88415-269-3, Gulf Publishing Co., Houston, TX, 1986, Phone 1-800-231-6275
5. **What Went Wrong? Case Histories of Process Plant Disasters**, Trevor A. Kletz, ISBN 0-88415-027-5, Gulf Publishing Co., Houston, TX, 1986, Phone 1-800-231-6275
6. **An Engineer's View Of Human Error**, Trevor A. Kletz, The Institute of Chemical Engineers (Warwickshire, England), 1985, ISBN 0 85295 192 2
7. **Lessons From Disaster - How organizations have no memory and accidents recur,** Trevor A. Kletz, Gulf Publishing Co., Houston, TX, 1993, ISBN 0-88415-154-9
8. **Safeware - System Safety and Computers,** Nancy G. Leveson, Addison-Wesley, 1995, ISBN 0-201-11972-2
9. **Process Safety Management**, Ian Sutton, Southwestern Books, 1997, ISBN 1-57502-528-0, Phone; 281-488-7767, Web; http://www.southwestern-books.com
10. **Safety-Critical Computer Systems**, Neil Storey, Addison-Wesley, 1996, ISBN 0-201-42787-7
11. **Computer Related Risks,** Peter G. Neumann, Addison-Wesley, 1995, ISBN 0-201-55805-X
12. **Evaluating Control System Reliability**, William M. Goble, International Society for Measurement and Control, 1992, ISBN 1-55617-128-5, Phone (919) 549-8411
13. **Guidelines for Hazard Evaluation Procedures,** AIChE CCPS, 1992, ISBN 0-8169-0491-X, Phone 800-242-4363
14. **Guidelines for Chemical Process Quantitative Risk Analysis,** AIChE CCPS, 1989, ISBN 0-8169-0402-2, Phone 800-242-4363
15. **Risk Analysis for Process Plants, Pipelines and Transport**, J.R. Taylor, E&FN Spon, 1994, ISBN 0-419-19090-2
16. **Major Industrial Hazards, Their Appraisal and Control**, John Withers, Halsted Press, 1988, ISBN 0-470-21-67-2

APPENDIX C

PERTINENT ARTICLES

Are Your Instrumented Safety Systems Up to Standard?

A new ANSI/ISA standard sets specific mandates for the integrity of such systems.

Kimberly A. Ford and Angela E. Summers,
Premier Consulting + Engineering, Triconex Corp.

Engineers involved with a process unit that utilizes an instrumented system to prevent or mitigate potentially unsafe conditions need to be aware of the new requirements within ANSI/ISA S84.01-1996. In February 1996, the "Application of Safety Instrumented Systems for the Process Industries" *(1)* was approved by the Instrument Society of America (ISA) and, in 1997, it was adopted by the American National Standards Institute (ANSI). This standard, which is considered by the U.S. Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) as an *accepted industry practice*, has placed many new requirements on the design, selection, installation, operation, and maintenance of instrumented safety systems.

Although neither the EPA nor OSHA rules explicitly state that compliance with this standard is required, both frequently refer to adhering to "...accepted engineering standards and practices" *(2,3)*. OSHA specifically states in 29 CFR 1910.119, Paragraph (d)(3)(ii): "The employer shall document that the equipment complies with recognized and generally accepted good engineering practices." Both OSHA and EPA define good engineering practice as following recognized industrial standards, including those of ANSI.

With over 100 user companies represented on the ANSI/ISA S84.01-1996 Committee, the standard produced clearly represents a consensus of both users and vendors, and the committee membership unanimously endorsed the document as an "accepted industry standard." Its requirements ensure that safety instrumented systems (SISs), including field instrumentation, logic solvers, and final elements, are designed, operated, and maintained to ensure safe operation of the process unit.

This standard now joins the other industry accepted standards, such as the American Soc. of Mechanical Engineers (ASME) codes for vessels, the National Fire Protection Association (NFPA) codes for burner management, and the Institute of Electrical and Electronic Engineers (IEEE) codes for electrical systems.

Most operating companies have strict compliance policies for these standards and would rarely, if ever, violate their requirements. Certainly, the new ANSI/ISA S84.01-1996 standard should be treated similarly.

What does the standard address?

The interpretation and implementation of the requirements contained in ANSI/ISA-S84.01-1996 provide a new challenge for the chemical process industries (CPI). The objective of the standard is "to define [the] requirements for safety instrumented systems." The SIS boundaries include all elements of the system, from the field sensor to the final element connected to the process, including inputs, outputs,

Table 1. SIL performance requirements

SIL	PFD	Availability, %
1	0.01–0.1	90.0–99.0%
2	0.001–0.01	99.0–99.9%
3	0.0001–0.001	99.9–99.99%

system either is provided as an existing safeguard or has been recommended, the team should indicate that a SIS is required.

Once the decision has been made to utilize a SIS for risk reduction, the SIS must be assigned a SIL, which is a relatively new concept for process engineers. ANSI/ISA S84.01-1996 defines three discrete integrity levels — SIL 1, SIL 2, and SIL 3 — based on SIS availability and the probability of failure on demand (PFD), as presented in Table 1. SIL assignment is based upon the PHA findings and on the expected likelihood and consequence of the potential incident. This assignment can be accomplished either as an additional step in the PHA process or in a separate, focused meeting. The assignment of SIL demands the development of a corporate approach that is aligned with management philosophy and risk-acceptance criteria *(4)*.

A number of methods are available for assigning a SIL. Most are qualitative, such as consequence-only, risk matrices, and risk graphs; however, quantitative risk assessment (QRA) techniques also can be employed. Whatever method is selected, the assignment of a SIL must be carefully performed and thoroughly documented.

The conceptual design for the SIS then is developed, based on the assigned target SIL and in accordance with corporate standards, in order to meet the functional and integrity requirements. In developing the SIS architecture to meet these requirements, a number of design aspects may be improved, including:

- separation of process control and SIS functionality;
- redundancy — identical or diverse;
- hardware integrity;
- technology selection;
- SIS architecture;
- power sources;
- testing frequency;
- diagnostics; and
- security of access to SIS functions.

The assigned SIL leads to the selection of architectures and to the commitment to a specific testing frequency. Table 2 presents a sample of typical SIS architectures that

Table 2. Typical SIS architectures

SIL	Reliability	System Architecture	Comment
1	Low	Single input, single logic solver, single output	Inputs may be switches. Logic solver may be relays for small systems (< 25 rungs). Simplex PLCs must include watchdog timer.
	High	Dual (two-out-of-two voting— 2oo2) inputs, redundant logic solver, dual (2oo2) outputs	Voting inputs are analog with comparative diagnostics. Dual outputs may require more frequent testing to achieve SIL
2	Low	Single (1oo1) or dual (1oo2) inputs, redundant logic solver, dual (1002) outputs.	Inputs may be analog or switches.
	High	Dual (2oo2) or triplicated (2oo3) inputs, redundant logic solver, dual (2oo2) outputs	Voting inputs are analog with comparative diagnostics. Dual outputs may require more frequent testing to achieve SIL
3	Low	Dual (1oo2) inputs, redundant logic solver, dual (1oo2) outputs	Inputs may be analog or switches.
	High	Triplicated (2oo3) inputs, redundant logic	Inputs may be analog or switches. Analog devices often utilize comparative diagnostics.

Note: These examples are not to be used as a design tool. The SIL for an actual design must be confirmed by other techniques.

may meet the SIL performance requirements, depending upon the choice of testing frequency, as well as a relative ranking of SIS reliability. The reliability of a SIS is inversely related to its nuisance or spurious trip rate — when the reliability of a SIS is raised, its expected nuisance trip rate is lowered. Nuisance tripping can have a significant economic impact to the operating unit; therefore, the relationship of SIS availability and reliability cannot be ignored.

Whichever architecture is chosen, the commitment to the functional testing frequency should not be taken lightly, because it is as important to long-term system performance as any of the other design choices, including those shown in Table 2. For example, if during the conceptual design stage, annual testing is chosen, this frequency must be maintained throughout the life of the plant. If, later on, a change in the testing frequency is desired, the SIS architecture will likely have to be modified to maintain the SIL. All changes to the SIS will need to be addressed through a formal management of change (MOC) procedure that verifies that the SIL has not been compromised and the SIS revision has been properly documented.

Before detailed design can begin, system performance must be verified against the SIL requirements. Quantitative techniques are utilized to model the system architecture and calculate the expected availability in terms of PFD. Three QRA techniques are applicable to this type of analysis: fault tree analysis, reliability block diagrams, and Markov modeling. If the original design cannot meet the SIL performance requirements, risk-reduction techniques must be employed to improve the design to meet the SIL.

The risk-reduction methods included in the SIL-verification calculations must be clearly documented so that, as the process design is optimized and expanded, these elements are maintained. They also must be maintained throughout the remainder of the SIS life cycle, unless formal MOC procedures are applied.

An important step

The new ANSI/ISA S84.01-1996 standard is the first in the U.S. to establish specific requirements for the design, availability, installation, operation, maintenance, decommissioning, and documentation of SISs. For some firms, this will require a paradigm shift in their policies. Many companies now seem to be struggling with SIL assignments and quantitative assessments. There is no question, however, that the insight and vision of the S84 Committee members to finally link risk assessment and management with good engineering practices will make the CPI safer, and will help protect workers, the community, and the environment. CEP

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1. "Application of Safety Instrumented Systems for the Process Industries," ANSI/ISA-SP 84.01-1996, ISA, Research Triangle Park, NC (1996).
2. "Process Safety Management of Highly Hazardous Chemicals; Explosives and Blasting Agents," 29 CFR Part 1910, OSHA, Washington, DC (1992).
3. "Risk Management Programs for Chemical Accidental Release Prevention," 40 CFR Part 68, EPA, Washington, DC (1996).
4. **Summers, A. E.**, "Techniques for Assigning a Target Safety Integrity Level," *ISA Trans.*, 37, pp. 95–104 (1998).

Further Reading

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Adamski, R. S., "Design Critical Control or Emergency Shut Down Systems for Safety AND Reliability," *Proceedings*, Automatizacion '96, Panamerican Automation Conf., Caracas, Safety Systems Section, Article 2, (May 1996).

"Functional Safety: Safety Related Systems," IEC-1508, Intl. Electrotechnical Com., Geneva, Switz. (June 1995).

"Guidelines for Safe Automation of Chemical Processes," Ctr. for Chem. Proc. Safety, AIChE, New York (1993).

"Programmable Electronic Systems in Safety Related Applications," Health and Safety Executive, Sheffield, U.K. (1987).

Summers, A. E., "How to Assign Target Safety Integrity Levels for your Safety Instrumented Systems," *Proceedings* (CD-ROM), ISA TECH/97, Anaheim, ISA, Research Triangle Park, NC (1997).

Plant safety comes in numbers, assumptions

By Paul Gruhn

Exotic math is a tool in the "incident" probability game. Sound judgment helps too!

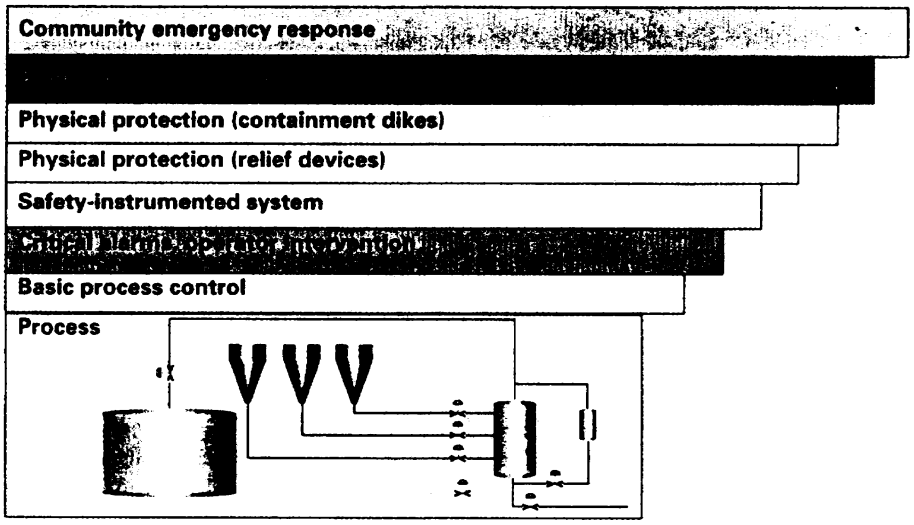


Figure 1. Multiple independent safety layers

Editor's note: Mr. Gruhn talked about the motivation for and means by which present-day process plant safety regimens have come to pass in the January 1999 InTech. *He concludes here with a closer look at safety-instrumented systems (SISs).*

The application of SISs to risk reduction in process plants has been standardized by ANSI/ISA S84.

A safety-instrumented system (SIS) is just one of the many layers protecting the surroundings from the risks inherent in process facilities (see Figure 1).

The process control system should keep the process within normal limits. If that does not work, alarms are typically configured to alert the operator to take action. When the process goes beyond the alarm limits, the SIS takes action.

There are usually additional layers of protection, including mechanical safety devices, relief systems, evacuation procedures, and the like. For an accident to reach the general population, all the layers must fail.

Figure 1 emphasizes the idea that one should not put all of one's eggs in a single basket. The nuclear industry calls this "defense in depth."

SILs served in three flavors

There are three safety integrity levels (SILs) defined for the process industries (see Figure 2). For a SIL 1 system, safety availability between .90 and .99 is required. The typical design uses the best available nonredundant device. This design would incorporate single sensors, single logic solvers, and single actuators.

SIL 2 requires safety availability between .9 and .999. Depending on the types of device employed, this level can sometimes be achieved with a nonredundant system, though there are instances that require a redundant system. Thus a second path is optional. Redundancy should be employed for components with lower self diagnostics levels and higher failure rates.

SIL 3 requires safety availability in the range of .999 to .9999. In order to implement these availability levels, a totally redundant system with high levels of self-diagnostics is typically required.

Buffer the process plant

Figure 3 shows how one can qualitatively evaluate process risk and determine the required SIL. Foremost, risk is a function of an event's frequency/probability (the x-axis) and how severe the damage caused by the event is (the y-axis).

Does the SIS under consideration have any form of additional layers of protection beyond it? In other words, if the system under consideration fails, will anything else be able to prevent the hazard? If not, then you are restricted to the top layer in this figure.

However, if there are additional safety layers (z-axis) in the process, lower requirements are possible. Instead of requiring level 3 performance, perhaps the requirements could be lowered to those for level 2.

The performance numbers required by the standards for the different SILs are shown in Figure 4. Standards do not prescribe technology, level of redundancy, or test intervals.

If the user evaluates their risk and determines the required SIL, then the user must determine and document in some fashion that the proposed system meets the performance requirements.

There are many different terms used to measure system performance, some more confusing than others. Safety availability numbers beyond 99% lose significance with most people.

The complement of safety availability is called the *probability of failure on demand (PFD)*. Many people have difficulty relating to PFDs because they are often expressed using scientific notation.

The term *risk reduction factor (RRF)* was first introduced in the American Institute of Chemical Engineers' guideline textbook in 1993. For many, this range of numbers is easier to relate to and the term itself is more intuitive. The RRF is simply the reciprocal of the PFD (RRF = 1/PFD).

Analyze SIS performance

There are several modeling techniques available to analyze the performance of a SIS.

Fault trees are excellent for modeling an entire system, including the field devices and the process. They do not handle complex redundant systems with time-dependent factors such as test intervals and repair rates very well. Further, they only account for known circumstances.

Reliability block diagrams use simple equations to model the system. They cannot handle the more complex redundant systems or time-dependent variables.

Most reliability practitioners have settled on variations of Markov modeling for these systems (see accompanying sidebar, "Identifying the possible states"). Markov modeling is typically associated with complex transition diagrams and matrix math. There are, however, algebraic simplifications that have been around for decades.

The apparent accuracy offered by the more detailed methods, however, is illusory. The initial assumptions about the system have far more of

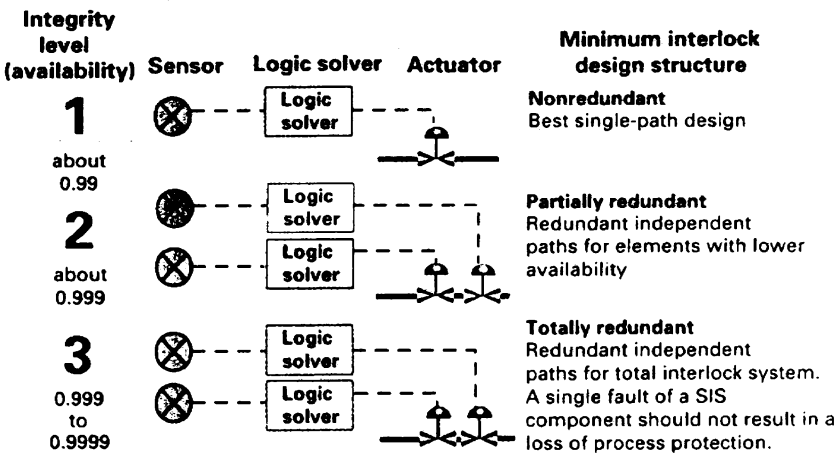


Figure 2. Three SIL configurations

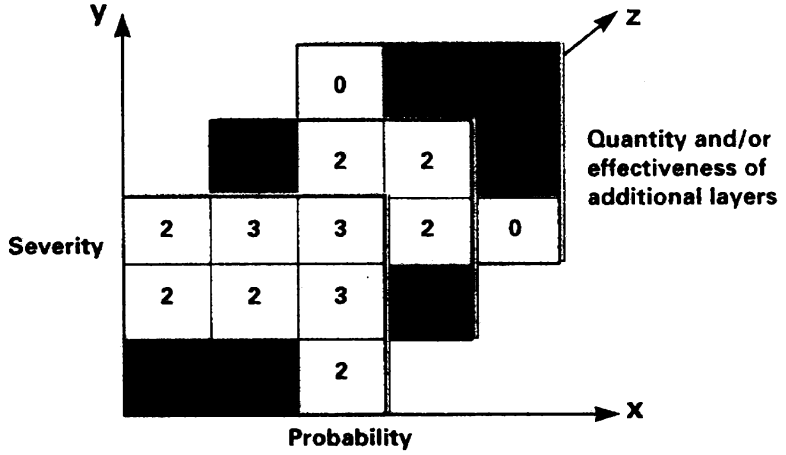
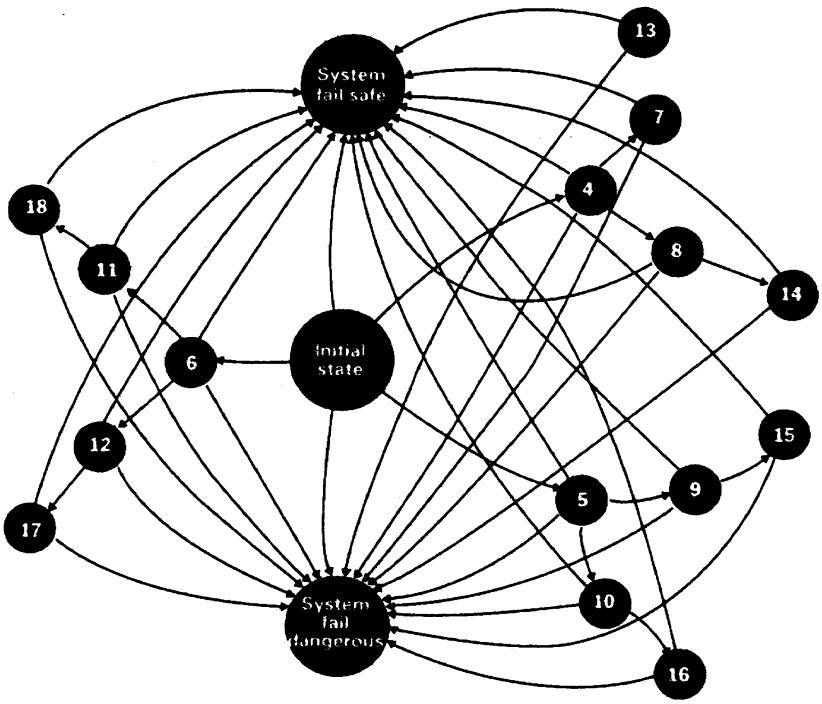


Figure 3. Three-dimensional risk ranking

	Integrity level	Safety availability	PFD	Equivalent RRF
	4	> 99.99%	< .0001	>10,000
ISA and AIChE documents restricted to three levels	3	99.9 - 99.99%	.001 - .0001	1,000 - 10,000
	2	99 - 99.9%	.01 - .001	100 - 1,000
	1	90 - 99%	.1 - .01	10 - 100
	0	(Control - N/A)		

PFD = Probability of failure on demand
RRF = Risk reduction factor (1/PFD)

Figure 4. Performance requirements for each SIL



Identifying the possible states

Markov models are created by identifying all the possible states that the logic solver may enter while transitioning from fully operational, through partially failed (degraded) states, to the failed state.

To accomplish this task, the different logic solver states are identified during the failure modes and effects analysis. The corresponding transition probabilities (the probabilities of components that must fail in order to transition from one state to another) are shown as arcs on the Markov model.

A Markov model

Terminology

HAZOP	**hazard and operability study**
PFD	**probability of failure on demand**
RRF	**risk reduction factor**
SIL	**safety integrity level**
SIS	**safety-instrumented system**

Behind the byline

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an impact on the final results, often by orders of magnitude.

Either way, one can do calculations by hand or by using a computer spreadsheet or specialized program. The intent is to analyze the problem before specifying the solution.

Ignore wisdom at own risk

Engineering responsibility should not require the stimulation that comes in the wake of catastrophe.

—S.C. Florman

As responsible engineers, we should not have to learn the hard way. The plants are too large and the risks are too great to learn by mere trial and error. We cannot recall refineries, so we need to try and get things right the first time. We can learn from the mistakes of others. We do not have to keep reinventing the wheel or operating in isolation.

The result of the increased application of hazard analysis has been a 50% reduction in injuries, increased ease of operations, and decreased production stoppages.

—N. Leveson

Everyone complains about doing safety studies like HAZOPs (hazard and operability studies), but history has shown them to be beneficial. Plants are too complex for any one person to be aware of all the hazards. Complex facilities require a detailed, systematic safety review conducted by an experienced team.

Accidents are not due to lack of knowledge, bu failure to use the knowledge we have.

—T. Kletz

Trevor Kletz is a recognized leader in the field of process safety and is one of the people who developed the HAZOP technique. He has written many excellent textbooks on process safety, inherently safe design, plant disasters, human error, and computer control.

When a man's education is finished, he is finished.

—E.A. Filene

Filene was a businessman who made this statement almost 100 years ago. In a way, times really have not changed. When your knowledge stagnates, no matter what your area of expertise, you are doomed.

The whole key here is that what it takes to be a control systems engineer now is different than what it was 20 years ago. People need to be aware of new standards, new techniques, and new solutions.

Those who cannot remember the past are condemned to repeat it.

—G. Santayana

IT

Is Your SIS "Grandfathered?"

A new standard for safety instrumented systems exempts certain existing installations from some provisions.

Kimberly A. Ford and Angela E. Summers,
Premier Consulting + Engineering,
Triconex Corp.

In 1996, ISA, the International Society for Measurement and Control, formally released a standard on Safety Instrumented Systems (SISs) *(1)*. It was adopted by the American National Standards Institute (ANSI) in 1997 as ANSI/ISA S84.01-1996. Conformance to this standard has become the accepted industry practice for all new SISs in the chemical process industries (CPI). The application of the standard to existing safety systems is not straightforward, however.

The standard includes a clause stating that the owner/operator of a SIS designed and constructed prior to its issue must demonstrate that the system is "designed, maintained, inspected, tested, and operating in a safe manner." Meeting the criteria of this "grandfather" clause, ANSI/ISA S84.01-1996, 2.2.1, releases the owner/operator from some of the requirements of the standard. In this article, we explain how to demonstrate compliance with the clause and at what point modifications to the process or the SIS become significant enough to trigger the full requirements of the standard.

Determining applicability of the grandfather clause

Two methods are being employed within the CPI to demonstrate that a SIS qualifies for the grandfather clause. The first relies on a cyclic Process Hazards Analysis (PHA). The second compares the existing SIS with the key design requirements of the S84 standard, and, by identifying deviations, determines whether further efforts are warranted to analyze the SIS.

One of the principle opportunities to review the safety system associated with a process is during the cyclic PHA. Under the requirements of the OSHA Process Safety Management (PSM) ruling (29 CFR 1910.119) *(2)*, and the EPA Risk Management Plan (40 CFR 68) *(3)*, every covered process must undergo a PHA on a five year cycle. During the PHA, the teams are required to identify potential causes of process hazards, as well as the associated engineering and administrative controls for these hazards. One of the most important types of engineering controls is the SIS provided to prevent or mitigate a potential process event. Following the discussion of each potentially hazardous scenario, the PHA team can subjectively evaluate the existing SIS with regard to the grandfather clause. The team must consider all of the elements of the clause — namely, SIS design, maintenance, inspection, testing, and operation. To assess the adequacy of the design, the PHA team will need to affirm that the SIS functionality is appropriate to fulfill the intended safety function and that the SIS architecture is consistent with the required risk reduction. This judgment also should consider the frequency of process demands on the SIS, as well as the history of incidents and near misses associated with the SIS. In addition, the team must review the maintenance, testing, and inspection records to make sure that their frequency and content are sufficient. If the team is unable to

agree that the SIS meets all of the requirements of the grandfather clause, the SIS cannot be exempted, and should receive full consideration under the standard.

Another approach to SIS evaluation is to develop a checklist that addresses the major philosophical and technology issues defined in the standard. (Some examples of these issues are given in Table 1.) Any significant deviations would prevent exemption under the grandfather clause.

Even if the existing SIS design is accepted under the grandfather clause, however, it is important to understand that the documentation, training, and other such requirements of the standard are not waived. Therefore, effort must be directed at developing documents such as the Safety Requirements Specification (SRS), procedures for SIS operation, testing, and maintenance, and records of periodic functional testing, inspection, and maintenance. The details needed for these documents already should exist as a part of the process safety information required for compliance with OSHA 1910.119. The development of the SRS will involve compiling information from the PHA and other process and SIS documents into statements of the functional and integrity requirements. The operating, maintenance, and testing procedures will need review and expansion to include the SIS-specific information, as described by the S84 standard.

Other important factors to consider when determining the applicability of the grandfather clause are the implications associated with the general duty provisions of both the EPA and OSHA. The Clean Air Act Amendments of 1990 obligate the caretakers of facilities "to design and maintain a safe facility" *(4)*. OSHA requires owners to provide a place of employment that is "free from recognized hazards" *(5)*. These provisions, in effect, mandate adhering to industry standards that provide tools to prevent accidents. By using the shelter of the grandfather clause to avoid bringing existing systems into full compliance with the S84.01 standard, companies may be at risk of penalty for failing to fulfill the responsibilities of the general duty provisions.

Table 1. Typical criteria for evaluating whether an existing SIS can be grandfathered.

Does the SIS function take the process to a safe state without human intervention?
Are the designed failsafe modes of the SIS elements consistent with a safe state?
Is the SIS logic solver separate from the BPCS?
Are sensors for the SIS separate from the sensors for the BPCS?
Is the technology employed in the SIS appropriate for the expected performance?
For a SIS associated with high risk events, are two valves provided for process isolation?
Does each SIS input/output device have independent wiring?
Is periodic functional testing performed for all of the SIS elements, including field sensors, logic solver, and final elements?
Is all equipment to perform testing at the desired test interval provided?
Is sufficiently redundant and available power provided to the SIS?
Is adequate documentation available to describe the desired SIS function and the expected design, operation, maintenance, testing, and inspection?
Historically, has the performance of the SIS met the operating demands?

Note: An answer of "No" to any question indicates the SIS may not qualify under the grandfather clause.

Management of change and the grandfather clause

Even if an existing SIS meets the stipulations of the grandfather clause, modifications of the process unit or the SIS at some point may be significant enough to trigger the full requirements of the standard. Therefore, Management of Change (MOC) procedures must be revised to address the issue of the SIS status with regard to ANSI/ISA S84.01-1996.

The standard requires compliance with the MOC requirements of the OSHA PSM rule following any change to a SIS. OSHA rule 29 CFR 1910.119 Paragraph (l) states that written procedures must be developed and implemented for any change in process chemicals, technology, equipment, and procedures, except for replacement in kind. Two important elements related to SISs are that the MOC procedure must address the "impact of [the] change on safety and health" and that any affected process safety information must be updated to reflect the change.

Within the S84.01 standard, the concept of MOC is introduced at the end of the safety life-cycle model (see Figure 1). The initiation of a change to the SIS or the process should return the SIS to the appropriate phase of the life cycle — that is, the first phase affected by the modification. The elements of all subsequent phases also will need to be addressed. In addition, it must be confirmed that the safety integrity level (a measure of SIS availability) has been maintained.

The standard indicates that a formal MOC procedure may be required as a result of modifications to:

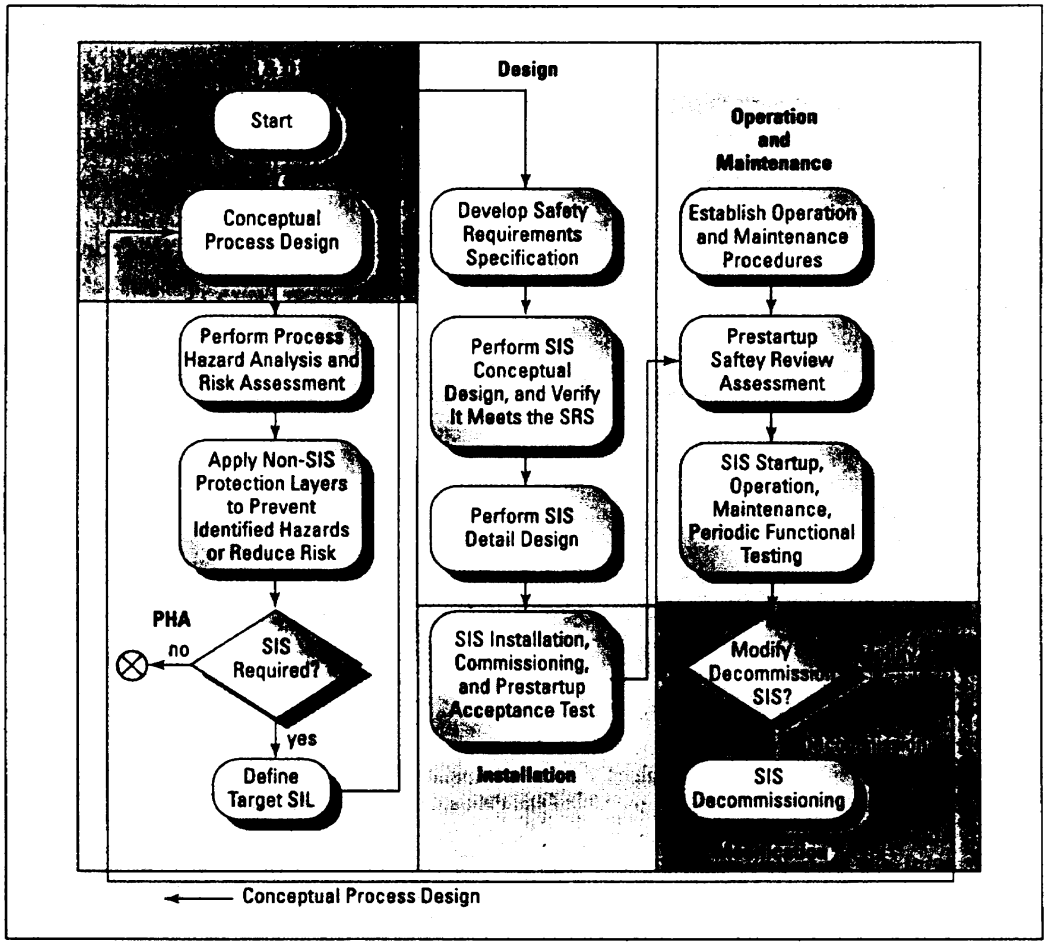
- the process;
- the SRS; or
- software.

In addition, OSHA mandates a MOC procedure for changes in:

- equipment; or
- technology.

So, let's now look at each of the safety life-cycle steps, and the changes that may impact on the applicability of the grandfather clause.

■ *Figure 1.*
Safety life-cycle model.



Conceptual process design. Any change to the conceptual design of the process, as typified by modifications to the Process Flow Diagrams (PFDs) or considerable revision to the Piping and Instrumentation Diagrams (P&IDs), can be expected to have a significant impact on the definition of the safety functions that are to be performed by the associated SISs. New process equipment may necessitate addition of SISs that will be covered by the ISA standard. Existing SISs also may need substantial redesign, because of changes in the potential process hazard, the definition of the safe state of the process, or the performance requirements of the SIS. Conceptual design changes require modification of the SRS — a clear signal to fully apply the requirements of ANSI/ISA S84.01-1996.

Safety Requirements Specification. The SRS serves as the design basis document for the SIS, providing both the functional and integrity requirements.

Among the types of changes that would require a modification to the SRS are those in:

- the definition of the safe state of the process (for instance, modification of the SIS action);
- the functional relationship between process inputs and outputs;
- the tripping action (energize vs. de-energize);
- the expected SIS performance (such as an increase or decrease in the expected number of demands on the SIS or in the consequence of an event, or the addition of independent protection layers that reduce the SIS requirements); and
- the allowable testing frequency.

Treat any changes to an existing SIS that impact the major elements of the SRS as significant, and seriously consider the full application of the S84.01 standard.

SIS conceptual design. Any change that has the potential to alter the availability of the SIS should spur strong questioning of the continued application of the grandfather clause. Such changes include those in:

- the separation between the SIS and the Basic Process Control System (BPCS);
- SIS logic solver technology;
- redundancy and architecture of process sensors, logic solver, or final elements (for instance, switching from 1-out-of-2 to 2-out-of-2 sensors, or from single solenoid valves to 2-out-of-2);

• the power sources (*e.g.*, electrical, hydraulic, or pneumatic) for SIS elements; and

• the field-device type or technology.

SIS detailed design. Changes that only impact the SIS at the detailed design level are unlikely to have a measurable impact on the performance of the system. Therefore, they probably should not jeopardize grandfathered status. Examples of such changes include those in:

• SIS equipment vendor;

• the operator, the maintenance/engineering, and the communications interfaces;

• SIS environmental controls (so long as they remain within vendor specified ranges);

• mechanical or electrical equipment involved in maintenance and testing (presuming no alteration in testing frequency); and

• wiring practices.

SIS operation, maintenance, testing, and inspection. When evaluating the continued applicability of the grandfather clause, it is important to keep in mind that only those changes in operating and maintenance procedures that can have a consequential impact on SIS functionality or performance need be considered.

One possible change with potentially significant impact is a large cut in operations or maintenance staffing. Work force reductions may make it difficult to fulfill requirements related to SIS trips or alarms. SIS performance problems, including an increase in random and common-cause failures, also may result from less maintenance support or maintenance by less experienced staff. These problems include:

• decreased operator diligence in diagnosing failures of SIS equipment;

• inability of maintenance staff to respond to SIS failures in a timely manner;

• increased errors in SIS equipment repair, calibration, inspection, or testing;

• reduced preventive maintenance; and

• less documentation on how problems have been resolved.

Therefore, significant changes in the operations or maintenance philosophy must be taken into account in assessing whether affected SISs can remain grandfathered.

Proceed with care

When considering the use of the grandfather clause provided within ANSI/ISA S84.01-1996, it is important to approach each existing system with a *formal*, *systematic*, and *documented* method. It is the responsibility of the owner/operator to determine that existing SISs meet all of the requirements of the clause and to document the operating, testing, inspection, and maintenance conditions under which this will remain true.

The clause only addresses SIS design and construction. A grandfathered SIS still must meet the other requirements of the standard related to documentation, training, procedures, and testing.

Owner/operators of grandfathered SISs also must realize that this status does not provide an indefinite shield against the full requirements of the standard. After all, the CPI's ongoing quest to optimize operations results in upgrades and expansions. At some point, the modifications of the process unit and the SIS may well be significant enough to trigger the full requirements of ANSI/ISA S84.01-1996. CEP

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3. "Risk Management Programs for Chemical Accidental Release Prevention," 40 CFR Part 68, EPA, Washington, DC (1996).
4. Clean Air Act Amendments of 1990, 42 U.S.C. § 7412 (r)(1) (1990).
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Further Reading

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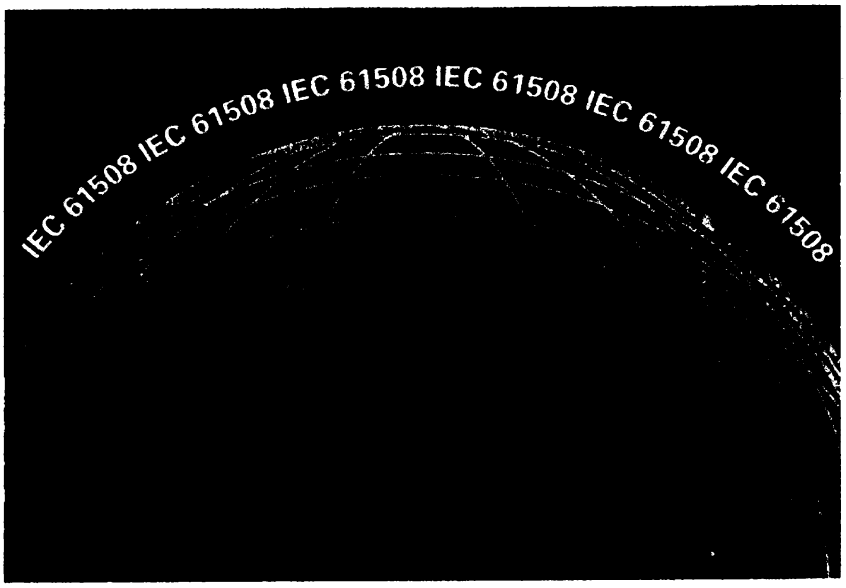
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InTech
SAFETY



Global standards boost safety performance

By Victor J. Maggioli

To promote good engineering practice, international, national, and other standards-setting bodies race to develop process safety standards.

The international safety standard for machine tools, process, railways, avionics, and medical sectors is the International Electrotechnical Commission's (IEC) standard 61508.

Intended to be the sector-specific standard if a standard didn't exist, IEC 61508 initially was rejected by the U.S. and Canada. These countries approved of and accepted IEC's proposed remedy: inserting an exclusionary clause into each of 61508's parts that allows the use of American National Standards Institute (ANSI)/ISA standard S84.01-1996.

IEC 61508, a generic standard with normative standards and informative guidance, has seven parts: parts 1, 3, 4, and 6 are being prepared for final issue, and parts 2, 5, and 7 have committee-draft-voting (CDV) status and will likely be approved by the third quarter of 1999.

National guidance is available

National or professional-society-based standards and guidelines also reflect good engineering practice. Besides ANSI/ISA S84.01-1996, examples include ISA's draft Technical Report 84.0.02 (dTR84.0.02) and the American Institute of Chemical Engineers' (AIChE) Center for Chemical Process Safety (CCPS) *Guidelines for Safe Automation of Chemical Processes.* IEC standards 61511 and 62061, currently being developed, support these standards. (See Table 1 for full titles.)

Global standards and guidelines are based on four elements: safety integrity levels (SILs), safety

Contact us!

Have suggestions for a safety topic you'd like to see in *InTech*? If so, contact Kenna Amos at camos@isa.org or (919) 990-9270.

Standard/guidance	Title
AIChE/CCPS	Guidelines for safe automation of chemical processes
ANSI/ISA S84.01-1996	Application of safety-instrumented systems for the process industries
ANSI/ISA S91.01-1995	Identification of emergency shutdown systems and controls that are critical to maintaining safety in process industries
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
IEC 61511	Functional safety: Safety-instrumented systems (SIS) for the process industry
IEC 62061	Safety machinery: Functional safety of electrical, electronic, and programmable control systems for machinery
ISA dTR84.0.02	Electrical (E)/electronics (E)/programmable electronic systems (PES) for use in safety applications—Safety integrated evaluation techniques

Table 1. International and other process safety standards

Safety integrity level (SIL)	Average probability of failure on demand (PFD)
4	$\geq 10^{-5}$ to $<10^{-4}$
3	$\geq 10^{-4}$ to $<10^{-3}$
2	$\geq 10^{-3}$ to $<10^{-2}$
1	$\geq 10^{-2}$ to $<10^{-1}$

Source: Feltronics Corp.

Table 2. Safety integrity levels: target failure measures at low-demand operation

Terminology

AIChE	**American Institute of Chemical Engineers**
ANSI	**American National Standards Institute**
CCPS	**Center for Chemical Process Safety (AIChE)**
CD	**committee draft (IEC)**
CDV	**committee draft voting (IEC)**
CFR	**U.S. Code of Federal Regulations**
dTR	**draft technical report (ISA)**
IEC	**International Electrotechnical Commission**
ISA	**The international society for measurement and control**
OSHA	**U.S. Occupational Safety and Health Administration**
SIL	**safety integrity level**
SIS	**safety-instrumented system**

life cycle, terminology, and vendor equipment-development guidance.

SILs come from the concept of safety-critical systems. Levels, assigned from low (1) to very high (4), denote the protection capability of the safety-instrumented system (SIS).

Device values for probability of failure on demand (PFD) are given as probabilities for various SILs. Table 2 shows PFD values for SIL 4, at which the safety impact would be very high, as $\geq 10^{-5}$ to $<10^{-4}$. This means that the probability is greater than or equal to 1 in 100,000 but less than 1 in 10,000.

U.S. work parallels 61508

Prior to ANSI/ISA S84.01-1996's actual development, through AIChE's CCPS *Guidelines for Safe Automation of Chemical Processes*, the process user community compared methods used by various companies to handle potential functional (process-related) safety problems.

ANSI and ISA developed S84.01 concurrently with IEC 61508. Even though the U.S. committee followed key guidance provided by IEC 61508, the two standards are not identical. Differences are listed in clause 12 of S84.01.

S84.01 requires quantitative approaches, provided through ISA's dTR84.0.02, to determine SIS and subsystem capabilities. dTR84.0.02 also provides guidance on using simplified equations, fault-free analysis, and Markov modeling techniques, as well as determining the PFD for components, devices, and subsystems.

ANSI and ISA also used guidance from the U.S. Occupational Safety and Health Administration (OSHA), through its 1992 process-sector safety rule, published in Section 1910.119 of Volume 29 of the U.S.'s Code of Federal Regulations (29 CFR 1910.119).

However, initial implementation of OSHA's 1910.119 rule led to confusion about its applicability. This problem surfaced when industrial facilities were audited, particularly with respect to non-safety-related control functions. To settle the ambiguities, ANSI and ISA prepared, reviewed, approved, and then, in 1995, issued ANSI/ISA S91.01-1995.

More global standards coming

Two other global standards currently being developed, IEC 61511 and IEC 62061, also will impact the process sector.

IEC 61511 adheres to key IEC 61508 concepts, but also contains a clause that lists differences between the standards. Presently, IEC 61511 has three parts: part 1, normative; parts 2 and 3, informative. Part 1 is scheduled to be issued as a committee draft (CD) during 1999's second quarter.

As a boost for global commerce, with the intention of assisting vendors in developing products that have worldwide use, IEC 61511 recommends IEC 61508 as the clause to be used by vendors when developing their safety products.

Each country must decide if IEC 61511 is a suitable global process-sector safety standard. To do so, though, users and suppliers first must review and comment on the draft standard's part 1. The U.S. process sector must also decide how to handle ANSI/ISA S84.01, in light of IEC 61511.

Global industry faces new technological approaches: field bus, wireless, fiber optics, self-testing sensors, automatic (online) testing procedures, and safety software. Their use may be directed, or at least suggested, via standards.

However, if improved and safer operations are to be achieved, process-sector participation in standards development is a must. The final applicability of products, standards, and guidelines is and will be directly proportional to industry's involvement.

Go to the Web for more information!

At ISA's Web site, www.isa.org, check Standards and look at Web Resources for links to measurement and control, including links to other standards-setting organizations and standards in general.

For further information on IEC, see IEC's home page, at www.iec.ch, and www.hike.te.chiba-u.ac.jp/ikeda.IEC. Check ANSI at web.ansi.org. AIChE's Center for Chemical Process Safety can be found at www.aiche.org/docs/ccps.

Behind the byline

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APPENDIX D

CLASS PROBLEM

(To Be Handed Out in Class)

CLASS EXERCISE

HAZARDOUS AREA INSTRUMENT WIRING PROBLEM

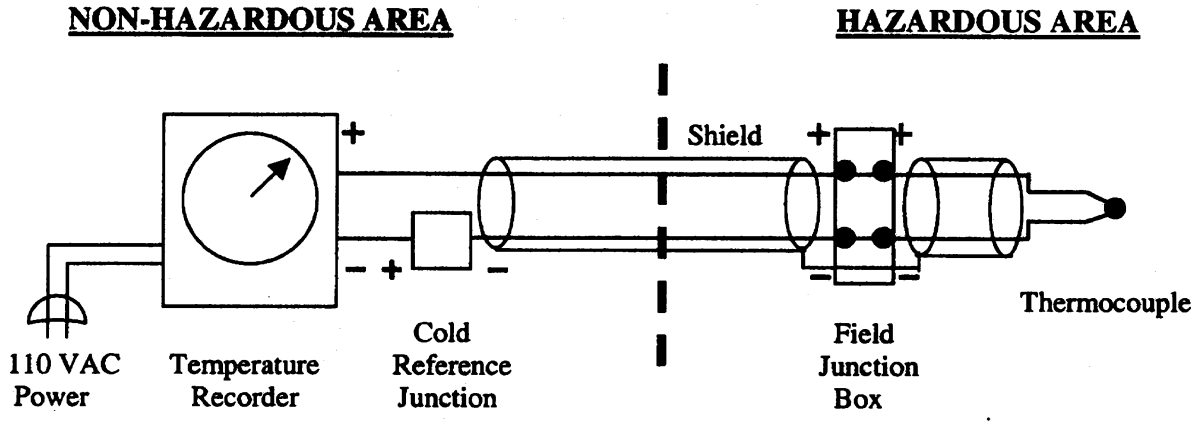


Figure 1

The following information applies to the apparatus shown in Figure 1:

- The thermocouple is type J, ungrounded.
- The maximum voltage produced by the thermocouple is < 0.05V.
- The thermocouple is considered as a "simple device"; i.e., it will not create or store enough energy to ignite any mixture of hazardous gases.
- The hazardous area is classified as Class I, Division 1, Group A (acetylene).

Answer the following questions about the safety of the circuit in Figure 1:

1. Is the thermocouple which is in a Class I, Division 1, Group A hazardous area inherently safe and why or why not?

   A. Yes, because it is a "simple device".

   B. Yes, because the circuit is unpowered.

   C. No because there is no ground connection.

   D. No, because an electrical fault in the temperature recorder could cause excess energy to reach the hazardous area.

2. Assume the thermocouple does not meet safety requirements for the area classification. Select the **best** one of the following techniques to make it meet applicable wiring safety requirements.

   A. Ground the thermocouple at the tip.

HAZARDOUS AREA INSTRUMENT WIRING PROBLEM, Cont.

B. Install a galvanic isolation device(s) in the circuit; e.g., transformer, relays, opto-couplers. not here but can work in the correct area

C. Install an intrinsic safety barrier in the circuit.

3. Based upon your answer to Question 2, select the additional apparatus needed and sketch a diagram of the resulting circuit, including any grounding.

   A. Use a grounded tip thermocouple and ground the shield of the thermocouple extension wire at the control room end.

   B. Install an isolation transformer in the circuit in the field junction box and leave the circuit ungrounded.

   C. Install a double AC intrinsic safety barrier on the non-hazardous side of the circuit and ground the barrier and the recorder supply common to a grounding electrode with not more than 1 ohm path resistance.

CLASS EXERCISE

HAZARDOUS AREA INSTRUMENT WIRING ANSWERS

1. Is the thermocouple which is in a Class I, Division 1, Group A hazardous area inherently safe and why or why not?

   D. No, because even though the thermocouple is a "simple device", an electrical fault in the temperature recorder could cause excess energy to reach the hazardous area.

2. Assume the thermocouple does not meet safety requirements for the area classification. Select the best one of the following techniques to make it meet applicable wiring safety requirements.

   C. Install an intrinsic safety barrier in the circuit. This is better than installing a galvanic isolation device (which could also be made to work) due to the facts that intrinsic safety barriers are more economical, cover a broader spectrum of applications, and introduce virtually no measurement or control signal error.

3. Based upon your answer to Question 2, select the additional apparatus needed and sketch a diagram of the resulting circuit, including any grounding.

   C. Install a double AC intrinsic safety barrier on the non-hazardous side of the circuit and ground the barrier and the recorder supply common to a grounding electrode with not more than 1 ohm path resistance.

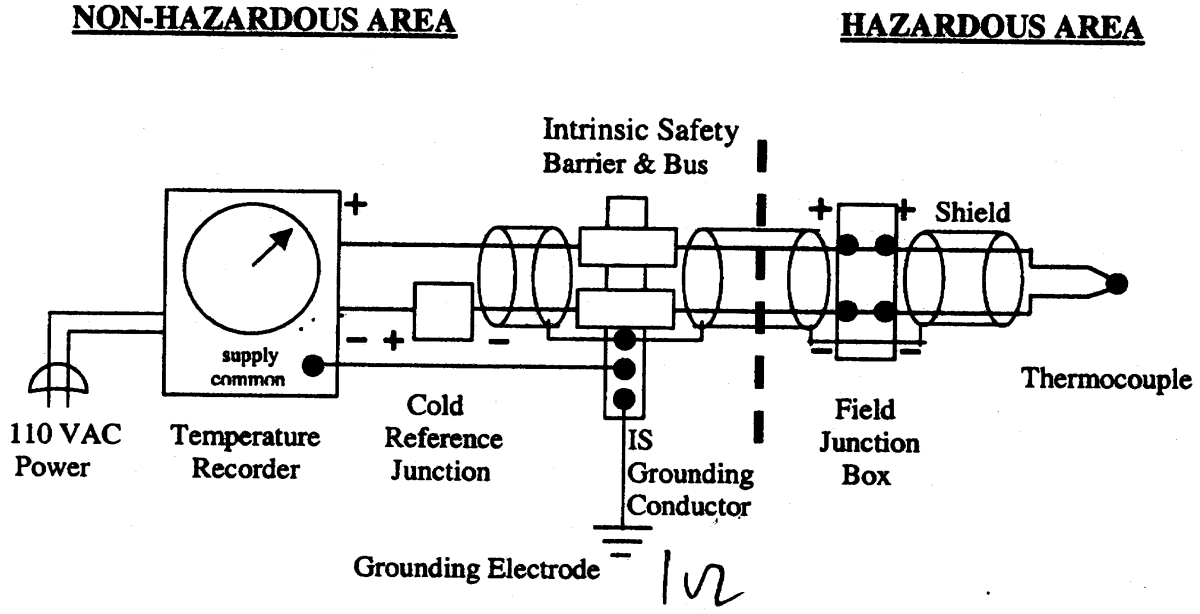


Figure 2

1000(1%, 40

$F = P(1+i)^n$

4% Quarterly
10 yrs

$\frac{4\%}{4} = 1\%$

$\frac{4}{12}\% = 0.333\%$

$n = 40$

1000(1.142)

= 1142

$2000 \frac{i}{(1+i)^n - 1}$

$n = 10$
6%

6.55/YR

2.527

$\frac{i(1+i)^n}{(1+i)^n - 1}$

$n = 20$
8%

8.019

$P = A(P/A, i\%, n)$

$\frac{(1+i)^n - 1}{i(1+i)^n}$

$n = 120$

$i = \frac{12\%}{12} = 1.0\%$

(12)

Purch $500k
Life 25 yrs
Salv 100k

$D = \frac{500000 - 100000}{25}$

$= 16000/YR$

$\frac{100}{25} = 8\%$

500 40000
36,800
33,800

For Yrs 1, 2, 3, Dep
(a) Straight
(b) Do
(c) Sum of

90 25 400000
325

5902.4
325

310 23
325

(25%) = 575
20

Cost: $400,000

(26) life: 10 yr

salvage: $100,000

$\frac{(10)(11)}{2} = 55 \Rightarrow \frac{10}{55}$ 400000

72727 53554 39814

(a) Straight line depreciation

$\frac{400,000 - 100000}{10} = \$30,000$ /yr

(b) Sum of years

$\frac{(10)(11)}{2} = 55 \Rightarrow \frac{10}{55} 300,000 = 54,545$

$\frac{9}{55}$ 300,000 = 49,091

$\frac{8}{55}$ 300,000 = 43,636

(c) Double Rate D

$\left(\frac{2(100)}{10}\right)^{\%} 400,000 = 80,000$

64 000

51,200

Problem 6

(Like example 8 pg 7-12)

$(1+i)^n$

Purchase $12,000

10 yrs	
Salvage	$2000
mtce	1000
	1200
	1400
	1600
	1800
	2000
	2200
	2400
	2600
	2800

Find

10% (a) Present Worth
(b) Annual Cost

$$A/P = \frac{i(1+i)^n}{(1+i)^n - 1} = .1627$$

$1953 + 1000 + 1627$

$$A/G = \frac{1}{i} - \frac{n}{(1+i)^n - 1}$$

(b) 3700 ans 3574

$12000 + 6144 + 4578$

(a) 22722

Ans 21,951

(25) Purchased 12000
life is 6 yr
salvage is 2000

(a) sum of years Depreciation?

$\frac{(6)(7)}{2} = 21$ $\frac{6}{21} 10000$

5
4
3
2

$\frac{2}{21} 10000 = 952$ ←

(b) Double Rate Declining Balance

$\frac{2(100)}{6} = .3333$

4000
2666.7
1777.8
1185.2

ans → 790.1

(c) Straight line $\frac{12000 - 2000}{6} = 1667$

(18) 250,000 $\frac{10\%}{4} = 2.5\%$

40 quarterly payment

$\frac{250000}{(1+i)^n} = 2325$ 9959

$A = F \frac{i(1+i)^n}{(1+i)^n - 1}$

$A = 250{,}000 \frac{(0.025)(1.025)^{40}}{(1.025)^{40} - 1}$

$A =$

(17) 358 $\{10000$ 14A 7 $\}$ 6 mos
$\{9642$ 140+69 $\}$

$\frac{10000}{9642} = \frac{9642(1+i)^n}{9642}$

$1.0761 = 1 + i - 1$

$0.0756 = i$

(a) 31–65 $n = 35$

$i = 5\%$

$A = \$1000$

Gradient Multiplier Pg 7-8

$$F_{100} = \frac{9}{i}\left(\frac{(1+i)^n - 1}{i} - n\right) = 110{,}640$$

$$F_{1000} = A\left[\frac{(1+i)^n - 1}{i}\right] = 90{,}320$$

$$F_{TOTAL} = 200{,}960$$

25 withdrawals

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad 0.07095$$

$14{,}258$

Pg 7-4 Uniform Series Capital Recovery Mult

Eqn 6

$= 1000(F/A, 5\%, 35) + 100(P/G, 5\%, 35)$ F/P 5% 35

$P = A\frac{(1+i)^n - 1}{i(1+i)^n}$		
12	1 yr	11.76
60	5 yrs	44.89
120	10 yrs	69.7
600	50 yrs	99.74
240	20 yrs	80.82



(9) 31 – 65 $n = 35$

$i = 5\%$ 65–90

$A = \$1000^{00}$ 25 withdrawals

$$F = A\frac{(1+i)^n + 1}{i} = 1000\frac{[1+.05]^{35}}{.05}$$

$$F = 110,320$$
$$20,058$$
$$130378$$

~~Ap~~

~~A/6~~

$$F = \frac{a}{i}\left[\frac{(1+i)^n}{i} - n\right] = \frac{100}{.05}\left[\frac{(1+.05)^{34}}{0.05} - 34\right]$$

$F = 102,154$ 150,641

~~1000~~ $1000\left(\frac{P}{A}, 5\%, 35\right) + 100\left(P/6, 5\%, 35\right)$

$$\frac{(1+i)^n - 1}{i(1+i)^n}$$

$$\frac{(1+i)^n - 1}{i(1+i)^n} = (1000)(16.37) = 16,374$$

$$(100)\left[\frac{(1+i)^n - 1}{i(1+i)^n} - \frac{n}{i(1+i)^n}\right] = 20,058$$

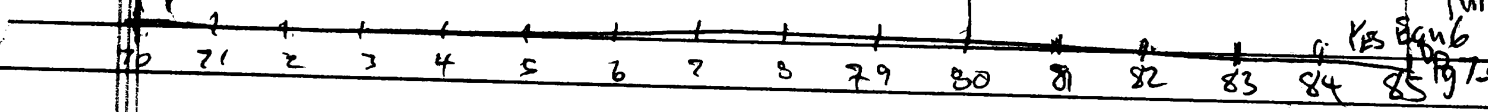
16,374

90320
1064
2096

(15)

$\frac{(1+i)^n - 1}{i}$

$(1+i)^n$



500

$F = 500(1+i)^n$

2523

$2523 = P \frac{i(1+i)^n}{(1+i)^n - 1}$

10,345

$i = 0.07$

$n = 5$

$10345 = x$

$\frac{i}{(1+i)^n - 1}$

$500 \frac{(1+i)^n - 1}{i}$

16

30 payments of $89.30 = 2679

2000(0.04465)

$\frac{i(1+i)^{30}}{(1+i)^{30}-1} = 0.04465(1+i)^{30} - 0.04465$

$i = 0.02$

$-i(1+i)^{30} + 0.04465(1+i)^{30} = 0.04465$

$(0.04465 - i)(1+i)^{30} = 0.04465$

$\ln(0.04465 - i)\ln(1+i)^{30} = \ln(0.04465)$

$= -3.109$

$89.30 = 2000(x)$ $= -.1036$

$\frac{13.588\%}{12}$ 2.09%

0.01132 $\frac{26.8}{12}$ 26

0.04609 2.233

(16) Payment $89.30
$n = 30$ $2000

$$0.04465 = \frac{89.30}{2000} = \frac{2000}{2000}\left[\frac{i(1+i)^{30}}{(1+i)^{30}-1}\right]$$

$$i = 0.02 = 2\%$$

$$i = (1+i)^{12} - 1 = (1+0.02)^{12} - 1$$
$$= 1.26824 - 1$$
$$= 0.26824$$
$$= 26.82\%$$

AUBURN UNIVERSITY
ENGINEERING EXTENSION SERVICE

AND

INSTRUMENT SOCIETY OF AMERICA
BIRMINGHAM SECTION

CONTROL SYSTEMS ENGINEERING EXAMINATION REVIEW

PRESENTATION FOR

ENGINEERING ECONOMY (Economics of Control)

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CHAPTER 7
ENGINEERING ECONOMICS

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PART I. BASIC CONCEPTS

A. INTRODUCTION

Engineering economics is a process of selecting the cheapest alternative. Certain techniques should be used to help us select the right alternative. Actually, we are only interested in the differences in alternatives. If there is no difference in the alternatives, we do not care which one is selected.

The basic question to be answered in engineering economic studies is whether the investment is likely to be recovered plus a return on the investment commensurate with the risk involved. To answer this question, we need to understand the relationship between time and money. This relationship is called the time value of money. To determine the time value of money, an interest rate must be determined. Normally a nominal rate of interest is stated but the "true effective interest rate" is different except when the interest payment period is one year.

To be able to make calculations for specific cases certain general quantitative relationships must be developed.

B. TERMS AND RELATIONSHIPS

The following terms are defined and will be used to develop relationships between the present value of money, interest rate, time, and the value of a sum of money at some future date:

i - Interest rate per interest period.

n - The number of interest periods.

P - The principal, present amount or present worth.

F - The sum of money due in the future that is equivalent to a principal P with interest rate "i" at the end of "n" periods.

A - The repeated payments which are paid at the end of each period.

Using these symbols, formulas that apply to any number of interest periods of any length are developed for any interest rate.

1. Single Payment Formula (compounded)

The single payment formula gives the future value of a principal P invested at an interest rate of "i" per period for "n" periods. The interest at the end of the first period is Pi, and the principal plus interest at the end of one period is P + Pi or P(1+i). At the end of two periods the total amount (F) is $P(1+i)i + P(1+i) = P(1+2i+i^2) = P(1+i)^2$ and for three periods, $F = P(1+i)^2 i + P(1+i)^2 = P(1+i)^2(1+i) = P(1+i)^3$; therefore, for "n" periods

$$F = P(1+i)^n \qquad (1)$$

The expression $(1+i)^n$ is called the single payment compound amount multiplier and is abbreviated, (F/P,i%,n). If, on the other hand, it is desired to find the present worth (P) of some future sum (F) for "n" interest periods and at an interest rate "i", this equation can be rearranged to

$$P = F/(1+i)^n \qquad (2)$$

The term $1/(1+i)^n$ is the single payment present worth multiplier and abbreviated by (P/F,i%,n). This term can be used to determine the compound discount.

2. Formula for Uniform Series of Payments

A regular amount (A) invested at the end of each "n" interest period may be considered as a series of single payments multiplied by their proper single payment compound amount multiplier and will amount to a capital amount or sum (F) after "n" payments. Thus,

$$F = A(1+i)^{n-1} + A(1+i)^{n-2} + \ldots + A(1+i)^1 + A(1+i)^0 \qquad (a)$$

Multiplying by (1+i)

$$F(1+i) = A(1+i)^n + A(1+i)^{n-1} + \ldots + A(1+i)^1 \qquad (b)$$

Subtracting a from b yields

$$Fi = A(1+i)^n - A(1+i)^0 = A(1+i)^n - A \qquad (c)$$

or

$$F = A\left[(1+i)^n-1\right]/i \qquad (3)$$

This equation gives the relationship for A dollars repeatedly deposited at "n" intervals accumulating compound interest and a sum F at the end of the n^{th} period. It should be emphasized that the n^{th} deposit earns no interest. The term $\left[(1+i)^n-1\right]/i$ is called the uniform series compound amount multiplier and abbreviated (F/A,i%,n).

A repeated payment A multiplied by the uniform series compound amount multiplier gives the future sum F after "n" payments and (n-1) interest periods. Solving equation 3 for A in terms of F, "i", and "n" gives

$$A = Fi/\left[(1+i)^n-1\right] \qquad (4)$$

which is the number of A dollars that must be paid periodically for "n" periods to accumulate a sum of F dollars at the end of the "n" periods. The term $i/\left[(1+i)^n-1\right]$ is called the uniform series sinking fund multiplier and abbreviated, (A/F,i%,n).

The last two relationships were concerned with repeated payments A and a future sum F. The relationship between the present worth P and a series of repeated payments A should be of equal interest and can be obtained by equating the expressions for a future sum resulting from a single payment, equation 1, and the future sum resulting from a series of repeated payments, equation 3.

$$F = P(1+i)^n \qquad (1)$$

and

$$F = A\left[(1+i)^n-1\right]/i \qquad (3)$$

Therefore

$$P(1+i)^n = A\left[(1+i)^n-1\right]/i$$

or

$$P = A\left[(1+i)^n-1\right]/\left[i(1+i)^n\right] \qquad (5)$$

The equation gives the present worth of "n" regular payments of A amount at "i" interest rate. The term $\left[(1+i)^n-1\right]/\left[i(1+i)^n\right]$ is the uniform series present worth multiplier and abbreviated, (P/A,i%,n). The present worth multiplier times the amount of the payment repeated "n" times at "i" interest rate gives the present value P of such a series of payments. Solving equation 5 for A gives

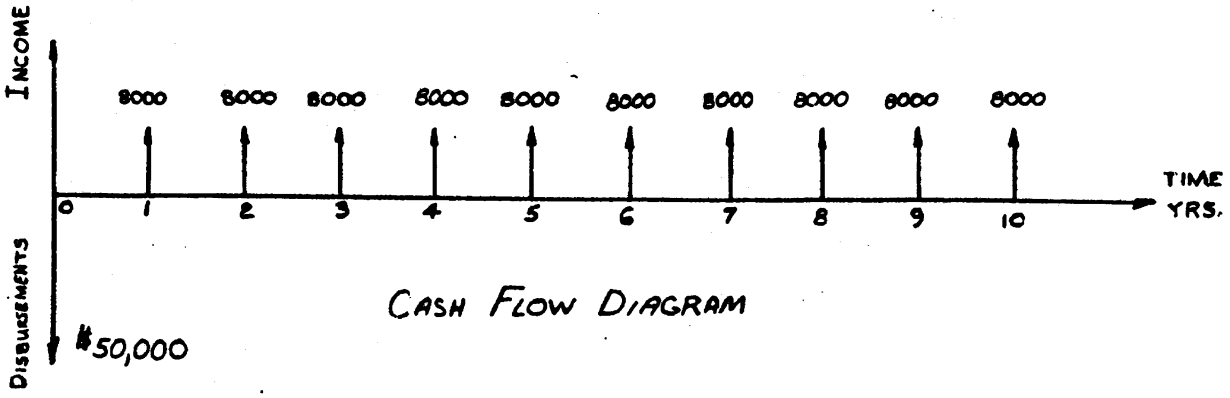
$$A = P\left[i(1+i)^n\right]/\left[(1+i)^n-1\right] \qquad (6)$$

The term $\left[i(1+i)^n\right]/\left[(1+i)^n-1\right]$ is the uniform series capital recovery multiplier and abbreviated, (A/P,i%,n). The present worth (P) multiplied by the uniform series capital recovery multiplier is used to determine the magnitude of each of "n" repeated payments (A), with compound interest "i".

A review of these six equations should make them more meaningful. Two equations for present worth were developed. One is the single payment present worth, and the other is the repeated payment present worth. There are two compound amount equations which are used to calculate the amount of a sum F, accumulated at the end of "n" periods by (1) setting aside a single present worth P or (2) making repeated payments of A, starting at the end of the first period. The remaining two equations give the magnitude of the repeated payments needed to (1) accumulate a future sum F or (2) recover the present sum paid out now through a series of repeated payments and their accumulated compound interest. These six equations are all a function of the compound interest "i" and the period "n". Consequently, tables have been made up showing the relationships of these various factors and can be used with any value of present worth P, repeated payment A, or future sum F. Tables for some of the interest rates are included at the end of this chapter.

3. Cash Flow Diagrams

In financial situations there are many ways that costs are represented. In any case a good method to help give a clear understanding of a problem is to draw a diagram or chart showing the cash disbursements. An example of this type of diagram is shown below.



CASH FLOW DIAGRAM

By drawing a cash flow diagram, the investigator is required to present all of the information in a concise factual manner, and a clearer understanding of the alternatives that are involved may be obtained in a glance. It should be pointed out that the development of a cash flow diagram is not a solution for a complete economic analysis. It is just the starting point of an analysis using the time value of money.

EXAMPLES

(1) A typical credit union charges 1% per month of the unpaid balance on all money borrowed. This is a nominal interest rate of 12%. What is the true effective interest rate?

In one year there are 12 monthly payments, "n" = 12, and the monthly interest "i" is $\frac{12\%}{12}$ or 1% as stated.

Assume $100 is borrowed and no payments are made for 12 months. The amount owed would be

$\frac{1}{(1+i)^n}$

$$F = 100(F/P, 1\%, 12) = 100(1.126825) = \$112.68$$

which is equivalent to a true effective interest rate of 12.68%.

Another way to solve the problem follows:

$$i = (1+i)^{n}-1$$

$$i = (1+0.01)^{12}-1$$

$$= (1.01)^{12}-1$$

$$= 1.1268 - 1$$

$$i_{eff} = 0.1268 \text{ or } 12.68\% \text{ Ans.}$$

(2) Determine the present worth of $10,000 in 10 years at 10% interest.

P.W. = $10,000 (P/F, 10%, 10)

= 10,000 (0.3855)

P.W. = $3,855 Ans.

$$\frac{1}{(1+i)^{n}} = \text{[illegible]}$$

$$n = \frac{1}{(1+0.10)^{10}}$$

(3) How much would you have to deposit annually starting 1 year from now to have $10,000 at the end of 10 years if the interest rate is 8%?

Annual Payments = $10,000 (A/F, 8%, 10)

= 10,000 (0.06903)

Annual Payments = $690.30 Ans.

$$\frac{i}{(1+i)^{n}-1}$$

Eqn 3 Pg 7-3 Uniform Series Sinking Fund

(4) You purchased a new automobile and borrowed $3,000 at 18% annual interest to be repaid in 30 equal installments. What are your monthly payments?

$$i = \frac{18\%}{12} = 1.50\%$$

Monthly Payments = $3000 (A/P, 1.50%, 30)

Monthly Payments = $3000 (0.041639)

Monthly Payments = $124.92 Ans.

$$\frac{i(1+i)^{n}}{(1+i)^{n}-1}$$

Eqn 6 Pg 7-4 Uniform Series Capital Recovery Mult

$i = 0.02$

(5) You won a contest and will receive $100 per month for the next 3 years. If a 6% interest rate is used, what is the present worth of the prize?

$$i = \frac{6\%}{12} = 0.5\%$$

$$P.W. = \$100\ (P/A,\ 0.5\%,\ 36)$$

$$= 100\ (32.8710)$$

$$P.W. = \$3,287.10 \quad \underline{Ans.}$$

$$\frac{(1+i)^n - 1}{i(1+i)^n}$$

4. Uniform Gradient

A uniform gradient occurs when an increase or decrease in an expenditure is the same every period "n".

The formulas for the present worth and the uniform annual cost of a uniform gradient will be developed.

If we have the following payments:

End of Period	Payment
1	0
2	g
3	2g
4	3g
.	.
.	.
.	.
n-1	(n-2)g
n	(n-1)g

These payments can be treated as a series of payments starting each year, and each series will accumulate to an amount F at the end of the n^{th} year. A series of compound amount equations that terminate at the end of period "n" are written.

$$F = g\left[\frac{(1+i)^{n-1}-1}{i} + \frac{(1+i)^{n-2}-1}{i} + \ldots + \frac{(1+i)^{2}-1}{i} + \frac{(1+i)^{1}-1}{i}\right]$$

$$F = \frac{g}{i}\left[(1+i)^{n-1} + (1+i)^{n-2} + \ldots + (1+i)^2 + (1+i) - (n-1)\right]$$

$$F = \frac{g}{i}\left[(1+i)^{n-1} + (1+i)^{n-2} + \ldots + (1+i)^2 + (1+i) + 1\right] - \frac{ng}{i}$$

The term $\left[(1+i)^{n-1} + (1+i)^{n-2} + \ldots (1+i)^2 + (1+i) + 1\right]$ is the compound of a sinking fund of one for "n" periods as shown in equation (a). Substituting the uniform series compound amount multiplier gives

$$F = \frac{g}{i}\left[\frac{(1+i)^n - 1}{i}\right] - \frac{ng}{i} \quad = \quad \frac{g}{i}\left[\frac{(1+i)^n - 1}{i} - n\right]$$

Now convert the future sum, F, to a uniform series, A,

$$A = F(A/F, i\%, n)$$

$$A = \left\{\frac{g}{i}\left[\frac{(1+i)^n - 1}{i}\right] - \frac{ng}{i}\right\}\left\{\frac{i}{(1+i)^n - 1}\right\}$$

$$A = \frac{g}{i} - \frac{ng}{i}\left[\frac{i}{(1+i)^n - 1}\right] = \left[\frac{g}{i} - \frac{ng}{(1+i)^n - 1}\right]$$

$$A = g\left[\frac{1}{i} - \frac{n}{(1+i)^n - 1}\right] \qquad (7)$$

The term in brackets is called the gradient multiplier, (A/G, i%, n).

To get the present worth of this series

$$P = A(P/A, i\%, n) = g\left[\frac{1}{i} - \frac{n}{(1+i)^n - 1}\right]\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

$$P = g\left\{\frac{1}{i}\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] - \frac{n}{(1+i)^n - 1}\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]\right\}$$

$$P = g\left[\frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n}\right] \qquad (8)$$

The term in brackets is called the gradient present worth multiplier, (P/G,i%,n).

EXAMPLE

(6) It is estimated that the maintenance on a piece of machinery will increase $1,000 each year for ten years. The first year all maintenance is covered by the guarantee; the second year it is estimated to be $1,000; the third year, $2,000, etc. Calculate the equivalent uniform annual cost and the present worth of this maintenance expense using an interest rate of 10%.

(a) Annual Cost, A

$$A = \$1000\ (A/G,10\%,10)$$

$$A = \$1000\ (3.72546)$$

$$A = \$3,725 \quad \text{Ans.}$$

$$\left[\frac{1}{i} - \frac{n}{(1+i)^n - 1}\right]$$

(b) Present Worth, P

$$P = \$1000\ (P/G,10\%,10) = 1000\ (22.89134)$$

$$P = \$22,891 \quad \text{Ans.}$$

$$\left[\frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n}\right]$$

PART II. EVALUATION TECHNIQUES

A. METHODS

There are four methods that are commonly used to select the best alternative. These methods are:

a. Annual Cost

b. Present Worth

c. Prospective Rate of Return

d. Benefit-Cost Ratio

The effect of income taxes will not be considered now, but each method will be discussed separately.

1. Annual Cost

For this method the cost of the project is calculated as being an equivalent uniform annual cost. The first step in determining the annual cost is to make a cash flow diagram for the service period, then use the cash flow diagram to calculate the equivalent uniform annual cost.

EXAMPLE

(7) A manufacturer is planning to build a new plant to make do-dads. A consulting engineer has proposed the following two possible methods of manufacture.

(a) Build a completely automated plant, or

(b) Hand manufacture and assemble all do-dads.

The completely automated facility will have the following costs:

Construction and Purchase of Machinery		$100,000
Annual Maintenance -	1st Year . .	5,000
	2nd Year . .	5,500
	3rd Year . .	6,000
	.	.
	.	.
	.	.
	10th Year . .	9,500
Labor Per Year.		24,000

Costs for the manual operation:

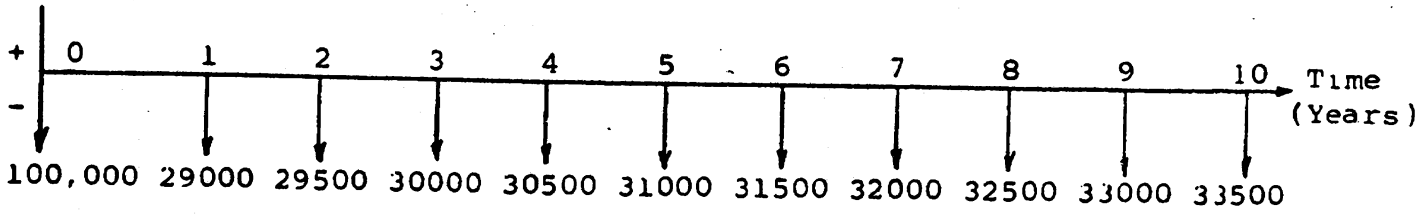
Construction and Purchase of Machinery	$20,000
Annual Maintenance	2,000
Labor Per Year	40,000

Assume all other costs are equal and determine which alternative should be selected on the basis of annual

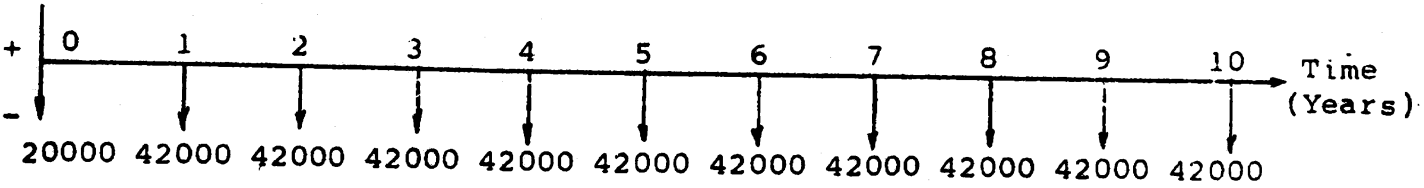
cost if a 10% interest rate is used. Assume that sales are not affected by the method of manufacture and that sales will stop after ten years of manufacturing, and the machinery will have zero salvage value.

Make the cash flow diagrams.

(a) Automated Operation



(b) Manual Operation



Calculate the Annual Cost.

(a) Automated Operation

$$\text{Annual Cost, } A = 100{,}000\ (A/P, 10\%, 10) + 29{,}000 + 500\ (A/G, 10\%, 10)$$

$$= 100{,}000\ (0.16275) + 29{,}000 + 500\ (3.73)$$

$$A = 16{,}275 + 29{,}000 + 1865$$

$$= \underline{\$47{,}140}\ \underline{\text{Ans}}.$$

(b) Manual Operation

$$A = 20,000\ (A/P,10\%,10) + 42,000$$

$$= 20,000\ (0.16275) + 42,000$$

$$A = 3,255.0 + 42,000 = \underline{\$45,255}\ \underline{\text{Ans}}.$$

The manual operation should be selected since its annual cost is less.

The above example assumed that there was no salvage value. There are several ways the salvage value might be considered. The two most common are:

(a) Subtract salvage value from the initial cost and pay interest on the salvage value, or

(b) Treat the salvage value as a positive cash flow at the completion of the project.

EXAMPLE

(8) In the example above, assume the automated operation had a $40,000 salvage value at the end of ten years and that the salvage value of the manual operation was $5,000. Again determine which operation is most economical by calculating the annual costs.

(a) Automated Operation

$$A = (100,000 - 40,000)\ (A/P,10\%,10) + (40,000)(0.10)$$

$$+ 29,000 + 500\ (A/G,10\%,10)$$

$$= 60,000\ (0.16275) + 4,000 + 29,000 + 500\ (3.73)$$

$$A = 9,765 + 33,000 + 1,865 = \underline{\$44,630}\ \underline{\text{Ans}}.$$

(b) Manual Operation

$$A = 20,000\ (A/P,10\%,10) + 42,000 - 5,000\ (A/F,10\%,10)$$

$$= 20,000\ (0.16275) + 42,000 - 5000\ (0.06275)$$

$$A = 3,255 + 42,000 - 314 = \underline{\$44,941}\ \underline{\text{Ans}}.$$

When the salvage value is considered, we see that the automated operation is the more economical.

2. Present Worth

The term present worth is used to mean the present value of all projected cash flow. To use the present worth method, the alternatives to be evaluated must have the same life. When expenditures are considered, the alternative with the smallest present worth should be selected.

EXAMPLE

(9) Calculate the present worth of examples 7 and 8.

Ex. 7a Present Worth,

$$P = 100,000 + 29,000\ (P/A,10\%,10) + 500\ (P/G,10\%,10)$$

$$\frac{(1+i)^n - 1}{i(1+i)^n} \qquad \frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n}$$

$$P = 100,000 + 29,000\ (6.144) + 500\ (22.89)$$

$$P = 100,000 + 178,176 + 11,445$$

$$P = \underline{\$289,621}\ \text{Ans.}$$

Ex. 7b

$$P = 20,000 + 42,000\ (P/A,10\%,10)$$

$$P = 20,000 + 42,000\ (6.144)$$

$$P = 20,000 + 258,048 = \underline{\$278,048}\ \text{Ans.}$$

Notice that the manual operation is still selected on the basis of the present worth.

Ex. 8a

$$P = 100,000 + 29,000\ (P/A,10\%,10) + 500\ (P/G,10\%,10) - 40,000\ (P/F,10\%,10)$$

$$= 100,000 + 178,176 + 11,445 - 40,000\ (0.3855)$$

$$P = 289,621 - 15,420 = \underline{\$274,201} \quad \text{Ans.}$$

Ex. 8b

$$P = 20,000 + 42,000\ (P/A,10\%,10) - 5,000\ (P/F,10\%,10) = 20,000 + 258,048 - 5000\ (0.3855)$$

$$P = 278,048 - 1928 = \underline{\$276,120} \quad \text{Ans.}$$

Again, notice that the proper alternative is not affected by the method of evaluation. It should be pointed out that the most economical alternative is a function of the minimum attractive rate of return, "i".

EXAMPLE

(10) Work examples 7 and 8 using a 20% minimum attractive rate of return.

Ex. 7a Present Worth

$$P = 100,000 + 29,000\ (P/A,20\%,10) + 500\ (P/G,20\%,10)$$

$$P = 100,000 + 29,000\ (4,192) + 500\ (12.89)$$

$$P = 100,000 + 121,568 + 6445$$

$$P = \underline{\$228,013} \quad \text{Ans.}$$

Ex. 7b

$$P = 20,000 + 42,000\ (P/A,20\%,10)$$

$$P = 20,000 + 42,000\ (4.192)$$

$$P = 20,000 + 176,064$$

$$P = \underline{\$196,064} \quad \text{Ans.}$$

Ex. 8a

$$P = 100,000 + 29,000\ (P/A,20\%,10) + 500\ (P/G,20\%,10) - 40,000\ (P/F,20\%,10)$$

$$P = 100,000 + 29,000\ (4.192) + 500\ (12.89) - 40,000\ (0.1615)$$

$$P = 100,000 + 121,568 + 6445 - 6460$$

$$P = \underline{\$221,553}\ \text{Ans.}$$

Ex. 8b

$$P = 20,000 + 42,000\ (P/A,20\%,10) - 5000\ (P/F,20\%,10)$$

$$P = 20,000 + 42,000\ (4.192) - 5000\ (0.1615)$$

$$P = 20,000 + 176,064 - 808$$

$$P = \underline{\$195,256}\ \text{Ans.}$$

Notice that using a 20% interest rate makes the manual operation the more economical choice even when the salvage value is considered.

Present worth calculations are insensitive to changes in distant salvage values. One dollar in 40 years has a present worth of only 4.6¢ today using an 8% interest rate.

The same life period must be used any time present worth calculations are made, otherwise comparison of alternatives is meaningless.

Three common errors that are made when present worths are calculated follow:

(a) Perpetual lives are assumed when the life is short.

(b) Accounting charge dates are substituted for disbursement dates and used to compute present worths.

(c) Too low an interest rate is used.

A term frequently used in present worth calculation is capitalized cost. The annual cost divided by the interest rate is defined as the capitalized cost. For an example, capitalize the annual costs of example 7a. The capitalized cost equals \$47,140 ÷ 0.10 or \$471,400.

3. Prospective Rate of Return

The third method of comparing alternatives is to calculate the rate of return on the investment. This process usually involves a trial and error solution and interpolation to get an approximate answer.

EXAMPLE

(11) A manufacturer has an opportunity to expand his production and increase his gross income by \$500,000 per year for the next 20 years. He estimates the following expenses to be associated with the increased production:

New Machinery (20 year life with no salvage value)..... \$3,000,000

Increased Selling and Overhead Expenses ..... \$ 50,000 per year

Increased Direct Expenses (labor and material)..... \$ 150,000 per year

Calculate the rate of return on this investment.

$$P.W. = 3,000,000 = 300,000\ (P/A, i\%, 20)$$

$$(P/A, i\%, 20) = \frac{3,000,000}{300,000} = 10.000$$

$$(P/A, 7\%, 20) = 10.594 \quad \Delta = 0.594 \quad \Delta = 0.776$$

$$(P/A, i\%, 20) = 10.000$$

$$(P/A, 8\%, 20) = 9.818$$

$$i = 7 + \frac{0.594}{0.776} = \underline{7.766\%} \quad \underline{\text{Ans.}}$$

EXAMPLE

(12) Use the data presented in example 11 and assume that the machinery will have a $1,000,000 salvage value at the end of 20 years. Calculate the rate of return.

$$P.W. = 3,000,000 = 300,000\ (P/A, i\%, 20) + 1,000,000\ (P/F, i\%, 20)$$

or

$$0 = -3,000,000 + 300,000\ (P/A, i\%, 20) + 1,000,000\ (P/F, i\%, 20)$$

$$\frac{(1+i)^n - 1}{i(1+i)^n} \qquad \frac{1}{(1+i)^n}$$

Solve by trial and error.

Try i = 10%

Therefore,

$$-3,000,000 + 300,000\ (P/A, 10\%, 20) + 1,000,000\ (P/F, 10\%, 20)$$

$$= -3,000,000 + 300,000\ (8.514) + 1,000,000\ (0.1486)$$

$$= -3,000,000 + 2,554,200 + 148,600$$

$$= -\$297,200$$

Since the value is negative, the trial interest rate was too high.

Try i = 8%

$$-3,000,000 + 300,000\ (P/A,8\%,20)$$

$$+ 1,000,000\ (P/F,8\%,20)$$

$$= -3,000,000 + 300,000\ (9.818)$$

$$+ 1,000,000\ (0.2145)$$

$$= -3,000,000 + 2,945,400 + 214,500$$

$$= + 159,900$$

Therefore, the correct interest rate is between 8% and 10%.

$$i = 8 + 2\,\frac{159,900}{159,900 + 297,200} = 8 + \frac{319,800}{457,100}$$

$$= \underline{\underline{8.70\%}}\ \underline{\text{Ans}}.$$

4. Benefit-Cost Ratio

The benefit-cost ratio is frequently used to evaluate public projects. In this method the costs associated with the project is divided into the benefits. The benefits and cost may be calculated using present worth or annual cost techniques. A proper interest rate of return should be applied in all calculations involving future benefits and costs. The main difficulty with this method is the determination of benefits and costs. Some items might be considered a benefit to one segment of the public and a "disbenefit" to another segment. The benefit-cost ratio (B/C) will change if an item is subtracted from the benefits or added to the costs.

The actual B/C for a favorable project will be greater than one regardless of whether an item is considered in the numerator or denominator. If the project should be undertaken, the benefits will exceed the costs.

EXAMPLE

(13) A canal is proposed to be built from Ghost Town to Nowhere, U.S.A. The annual cost of capital recovery will be $1,000,000, and the annual cost of maintenance and operation will be $200,000. Annual favorable consequences to the general public of $2,000,000 are offset by $500,000 of adverse consequences to a small segment of the population.

(a) Calculate B/C ratio if all consequences to the government are counted in the denominator and the other consequences are considered in the numerator.

(b) Change the adverse consequence to a cost and recalculate the B/C ratio.

(c) What is the excess of benefits over costs?

(a) B = 2,000,000 - 500,000 = 1,500,000

C = 1,000,000 + 200,000 = 1,200,000

B/C = 1.25

(b) B = 2,000,000

C = 1,000,000 + 200,000 + 500,000 = 1,700,000

B/C = 1.177

(c) B-C = $300,000

B. MULTIPLE ALTERNATIVES

Most examples consider only two alternatives, but most real problems involve more than two alternatives. We will now look at problems where three or more alternatives are proposed, with each alternative having a different level of investment. To solve problems of this nature, arrange the proposals in order

of increasing investment and calculate the overall rate of return on the increment investment for each proposal. The increment calculation must be based on the last acceptable plan. Example 14 illustrates the proper approach.

EXAMPLE

(14) The following proposals for a change in an assembly line have been made.

Proposal	Required Investment	Annual Savings
A	$4,800	$1,100
B	6,000	1,500
C	4,000	850
D	7,200	1,850
E	5,200	1,400
F	8,000	2,000

Management has funds available to finance any proposal that will earn a gross return of 22% before taxes.

Which proposal should be accepted to maximize the investment income?

Proposal	Required Investment	Annual Savings	Gross Return	Increment Return Over Next Lower Alternatives
C	$4,000	$ 850	21.2%	-
~~A~~	~~4,800~~	~~1,100~~	~~22.9%~~	~~31.3%~~
~~E~~	~~5,200~~	~~1,400~~	~~26.9%~~	~~75.0%~~
B	6,000	1,500	25.0%	12.5%
~~D~~	~~7,200~~	~~1,850~~	~~25.7%~~	~~29.2%~~
F	8,000	2,000	25.0%	18.8%

Eliminating Unacceptable Proposals

A	4,800	1,100	22.9%	-
E	5,200	1,400	26.9%	75.0%
D	7,200	1,850	25.7%	22.5%

Proposal (D) should be selected.
? F

PART III. EFFECT OF TAXATION

A. DEPRECIATION

Two important questions related to the study of depreciation in engineering economics are:

a. What is depreciation?

b. How are depreciation charges used in engineering economic studies?

Briefly, the answers to these questions are:

a. Depreciation is the systematic method used to write off a capital expenditure.

b. Depreciation is important in engineering economic studies only because it affects the cash flow for income taxes.

First, we will look at three common methods of calculating depreciation charges.

1. Straight-line rate

$$= \frac{100\% - \text{Estimated Salvage Percentage}}{\text{Estimated Service Life in Years}}$$

2. Declining - balance rate

$$= \frac{100\% \text{ (Rate) (Remaining Book Value)}}{\text{Estimated Service Life in Years}}$$

3. Sum-of-the-years-digits for the y^{th} year

$$= \frac{(n - y)\ (100\% - \text{Estimated Salvage Percentage})}{\sum_{x=1}^{x=n} x}$$

n = Expected life in years

y = Number of years in service before the y^{th} year.

$$\sum_{x=1}^{x=n} x = \frac{(n)\ (n+1)}{2}$$

EXAMPLE

(15) A piece of machinery costs $110,000 and has a salvage value of $10,000. Its estimated life is 20 years. Calculate the first three years depreciation using each of the following methods.

(a) Straight Line

$$\text{Depreciation} = \frac{110,000 - 10,000}{20}$$

$$= \$5,000 \text{ per year} \quad \underline{\text{Ans}}.$$

(b) Double Rate Declining Balance

$$\text{Rate} = \frac{2\ (100)}{20} = 10\%$$

1st year depreciation = 0.10 (110,000)

= $11,000 Ans.

2nd year depreciation = 0.10 (110,000 - 11,000) = $9,900 Ans.

3rd year depreciation = 0.10 (110,000 - 11,000 - 9,900) = $8,910 Ans.

(c) Sum-of-the-Years-Digits

$$= \frac{(20)(21)}{2} = 210$$

1st year depreciation = $\frac{20}{210}$ (110,000 - 10,000) = $9,524 Ans.

$$\text{2nd year depreciation} = \frac{19}{210}(100{,}000)$$

$$= \$9{,}048 \quad \underline{\text{Ans}}.$$

$$\text{3rd year depreciation} = \frac{18}{210}(100{,}000)$$

$$= \$8{,}571 \quad \underline{\text{Ans}}.$$

B. TAX LAWS

Present law allows the use of any systematic method of depreciation, with the restriction that the amount written off at any time during the first 2/3 of life does not exceed the amount which would have been written off using the declining balance method. Besides depreciation, an investment tax credit is presently allowed for certain investments. It will be briefly discussed to illustrate methods of handling various deviation in taxes.

Briefly the investment tax credit law states:

1. Only certain property can qualify. The amount of the tax credit is 7% of the qualified investment.

2. The property had to have an expected life of:

   8 years for full credit
   6-8 years for 2/3 credit
   4-6 years for 1/3 credit

   Public utilities only allowed to use 3/7 of qualified investment.

3. The investment credit cannot exceed tax liability or $25,000 + 25% of tax liability above $25,000.

4. The investment credit can carry back 3 years and forward 5 years.

EXAMPLE

(16) A manufacturing company plans to invest $250,000 in machinery with an estimated life of 25 years and an estimated salvage value of $30,000. This machinery

should reduce the net annual operating expenses $25,000 a year for the next 25 years. The sum-of-the-years-digits depreciation method is used and the overall effective tax rate is 60%.

(a) What is the before tax rate of return?

$$\frac{(1+i)^n - 1}{i(1+i)^n}$$

$$P.W. = \$250,000 = \$25,000\ (P/A,i\%,25) + \$30,000\ (P/F,i\%,25)$$

$$\frac{1}{(1+i)^n}$$

or

$$-250,000 + 25,000\ (P/A,i\%,25) + 30,000\ (P/F,i\%,25) = 0$$

If i = 10%

$$-250,000 + (25,000)\ (9.077) + (30,000)\ (0.0923)$$

$$= -250,000 + 227,425 + 2769 = -19,806$$

Therefore, the rate of return is less than 10%.

If i = 8%

$$-250,000 + (25,000)\ (10.675) + (30,000)\ (0.1460)$$

$$= -250,000 + 266,875 + 4380 = 21,255$$

Therefore, the rate of return is more than 8%.

$$\text{Rate of return} = 8 + 2\ \frac{21,255}{21,255 + 19,806}$$

$$= 8 + 1.036 = 9.04\%$$

(b) What is the after tax rate of return if the investment does not qualify for the 7% investment credit?

The sum of the years is $\frac{(n)\ (n+1)}{2}$

$$= \frac{(25)\ (26)}{2} = 325$$

1st year depreciation = (25/325)

(250,000 - 30,000) = 16,923

2nd year depreciation = (24/325)

(220,000) = 16,246

End of Year	Net Cash Flow Before Income Taxes	Write Off For Tax Purposes	Taxable Income	Cash Flow For Income Taxes	Net Cash Flow After Income Taxes
0	-250,000	-	-	-	-250,000
1	25,000	16,923	8,077	4,846	20,154
2	25,000	16,246	8,754	5,252	19,748
3	25,000	15,569	9,431	5,659	19,341
.	.	.	.	.	.
.	.	.	.	.	.
25	25,000	677	24,323	14,594	10,406
25	30,000	-	-	-	30,000

$$-250,000 + 20,154\ (P/A, i\%, 25) - 406$$

$$(P/G, i\%, 25) + 30,000\ (P/F, i\%, 25) = 0$$

If i = 5% the present worth is equal to - $11,597.

And if i = 4% the present worth is equal to + $12,734.

$$i = 4 + \frac{12,734}{24,331} = 4.52\%$$

(c) What is the after tax rate of return if the investment qualifies for the 7% investment credit?

The investment credit is (0.07) (250,000)

= $17,500.

Therefore, the initial investment is effectively

$250,000 - $17,500 = $232,500

and the present worth (to investor) is $232,500.

$$0 = -232,500 + 20,154\ (P/A,i\%,25) - 406\ (P/G,i\%,25) + 30,000\ (P/F,i\%,25)$$

If i = 5%

Present Worth = $5,903

If i = 6%

Present Worth = -$14,965

Therefore,

$$i = 5 + \frac{5,903}{20,868} = 5.28\%$$

Summary of Example (16)

Rate of return before taxes	9.04%
Rate of return after taxes without investment credit	4.52%
Rate of return after taxes with investment credit	5.28%

C. SUNK COST

A "sunk cost" is a past cost that cannot be recovered. Many people are reluctant to admit that a "sunk cost" exists, because they feel that this is admitting an error in judgement was made. In economic studies, the value of an existing asset is only the

money that would be received on disposal of the asset. The value is not the book value. The "sunk cost" is the difference between the book value and the actual value when the actual value is less than the book value. In economy studies "sunk costs" are irrelevant except for possible influence on future disbursements or receipts for taxes.

CHAPTER 7 - PROBLEMS

(12 months) $(1+0.015)^{12} = 1.196$

After 1 yr, $(1+i)^n - 1 = 1.196 - 1 = 19.6 \Rightarrow 19.6\%$

1. A bank charge plan states that the interest charged is only 1.5% per month of the unpaid balance. What is the true effective interest rate of this bank charge plan?

2. You deposited $1,000 in a bank savings account paying 4% annual interest compounded quarterly. In ten years, how much will you have in your savings account? $F = P(1+i)^n$ $i = \frac{4}{4}\% = 1\%$

$1489 = F = 1000(1.01)^{40}$ $n = 4(10) = 40$

3. You want to start a college savings plan for your new son and estimate that in 18 years you will need $20,000 for his college expenses. How much should you deposit each year, starting on his birth date, so that you will have $20,000 on his 18th birthday? Assume that the last deposit will be made on his 18th birthday, and 5% interest is paid on all deposits. $\frac{i}{(1+i)^n - 1}$ $n = 19$ $i = 5\%$

4. Determine the capital recovery multiplier for a 20 year 8% home mortgage where the payments are made annually. $\frac{i(1+i)^n}{(1+i)^n - 1}$

0.1019

5. Determine the uniform series present worth multiplier using a 12% annual interest rate and 120 monthly payments. $\frac{(1+i)^n - 1}{i(1+i)^n}$

6. A manufacturer purchased a piece of heavy equipment for $12,000. He expects to use the equipment for 10 years and then sell it for $2,000. The estimated maintenance expenses for the first year are $1,000; the second year, $1,200 and are expected to increase by $200 each year. Use an interest rate of 10% and calculate:

   (a) the present worth
   (b) the annual cost

7. Use the data in problem 6 and assume that the equipment results in an increase in income of $4,500 per year. Calculate the rate of return of the investment.

8. Two different methods are being considered to heat and cool a new multi-story office building. It is expected that the building will have a life of 40 years, but that the heating and cooling systems will have to be replaced at the end of 20 years. Cost estimates for the two systems are as follows:

	System A	System B
First Cost	$90,000	$60,000
Salvage Value at 20 Years	10,000	6,000
Annual Energy Cost	3,000	5,000
Annual Maintenance Cost	2,200	3,000
Extra Annual Income Tax	400	

(a) Use the annual cost method and an after tax minimum attractive rate of return of 12% to determine which system should be installed in the building.

(b) Determine which system should be selected using the present worth method and an after-tax minimum attractive rate of return of 10%. Use the life of the heating and cooling system as the study period.

9. A young man in business for himself decides to start an investment plan for his retirement. Starting on his 31st birthday, he deposits $1000 into a savings account. He estimates that he can make a deposit on each birthday up to and including his 65th birthday. He plans to increase the amount of the annual deposit $100 each year, at age 32 the deposit will be $1100, at age 33, $1200, etc. How much money will he have invested on his 65th birthday? He plans to make equal uniform withdrawals for the next 25 years. If interest is paid at a rate of 5% on all deposits, how much can he withdraw starting on his 65th birthday and ending with the last withdrawal which is made on his 90th birthday?

10. It is proposed to build a satellite airport for Busy City, U.S.A. The annual cost of capital recovery for the investment in land, building, runways, etc., will be $75,000, and the annual cost of maintenance and operation will be $100,000 per year.

There will be annual favorable consequences to the general public of $500,000 and adverse consequences to a small segment of the public of $50,000.

(a) What is the excess of benefits over costs?

$B - C = 450000 - 175000 = 275,000$

(b) Consider the adverse consequences as a cost and calculate the B/C ratio.

$$\frac{B}{C} = \frac{500000}{75,000 + 100,000 + 50,000} = 2.22$$

$B/C = \frac{500000 - 50000}{75000 + 109000} = 2.57$

(c) Calculate B/C ratio if all consequences to the government are counted in the denominator and the other consequences are considered in the numerator.

11. An investor is considering six proposals that have been submitted to him concerning a piece of property he owns. The following estimates have been made for the various alternatives:

Plan	Total Cost Of Investment In Buildings And Land	Annual Disbursements (Including Income Taxes, Excluding Initial Investment)	Annual Receipts
A	100,000	15,000	40,000
B	150,000	22,000	60,000
C	250,000	32,000	90,000
D	340,000	38,000	108,000
E	500,000	52,000	140,000
F	600,000	70,000	170,000

Consider each proposal to have an infinite life. The investor is unwilling to make any investment that does not show a prospective rate of return of at least 12%. Which plan should he select?

12. An apartment complex is purchased for $500,000. The expected life of the apartments is 25 years and the estimated salvage value is $100,000. Calculate the first three years depreciation using each of the following methods:

(a) Straight Line $\frac{500000 - 100000}{25} = 16000/YR$

(b) Double Rate Declining Balance $\frac{2(100)}{25}(500000), \frac{2(100)}{25}(500000 - 400000), \frac{2(100)}{25}(500000 - 400000 - 368$

(c) Sum-of-the-Years-Digits $\frac{(25)(26)}{2} = 325 \Rightarrow \frac{25}{325}400000, \frac{24}{325}400000, \frac{23}{325}400000$

13. A corporation is formed to purchase some rental property. The corporation pays a price of $800,000. Half of this money is obtained from the sale of corporation stock and the other half is borrowed at 8% interest. The repayment schedule for the loan calls for the repayment of the principal in 25 equal annual installments plus the interest on the unpaid balance. This investment will produce an annual income of $85,000 a year before expenses. It is estimated that operating expenses will be $10,000 annually and that the whole $800,000 can be

depreciated by straight line accounting in 25 years with zero salvage value. The tax rate of the corporation is 27.5%.

(a) What is the after tax rate of return on this investment assuming 100% equity financing if the investment does not qualify for the investment credit?

(b) Assume that the 7% investment credit was applicable and determine the rate of return. All other facts are the same and assume 100% equity financing.

Make a table and show all of your work clearly.

14. An individual purchased a new El Dorado Cadillac for $9,000 a year ago. He has driven this car for a year and has not been satisfied with its performance and is considering selling the automobile. A used car dealer offered him $5,500 for the car as is. The owner estimates that he will be able to sell the automobile when it is two years old for $4,000. The automobile is driven an average of 1,000 miles per month and the direct operating expenses for gas, oil, and routine maintenance are 6¢ per mile. During the first twelve months of service, all repairs other than normal maintenance were covered by factory warranty. The owner estimates that he will have to spend $240 during the next twelve months for tires and other minor maintenance items not included in the 6¢ per mile.

Discuss what factors this individual should consider in his decision to sell the car or to keep it for another year.

15. Starting January 1, 1970, $500 is deposited in an account, paying 7% interest annually. Each January 1, up to and including January 1, 1980, another $500 will be deposited in this account. Starting January 1, 1985 (date of the first withdrawal) five uniform annual withdrawals are to be made. The last withdrawal will exhaust the fund. How much will be withdrawn each year?

16. An automobile is purchased on the basis of making 30 monthly payments of $89.30 each. A lump sum payment of $2,000 would cancel these monthly payments. What is the effective interest rate for the extended payment plan?

17. An investor purchased $10,000 of short term United States Treasury Bills for $9,642 on October 14, 1969. The Bills were redeemed at the face value of $10,000 on April 14, 1970. The brokerage fee for this transaction was $8. What true effective interest rate did the investor receive?

18. A business borrows $250,000 at 10% interest. The loan is to be repaid in 40 equal quarterly payments. How much is each payment? $A = (F)\frac{i(1+i)^n}{(1+i)^n - 1}$ $i = \frac{10}{4} = 2.5\%$ $n = 40$ $A = \$9,959.00$

19. A piece of automatic machinery is proposed to replace a certain manual operation. Assume that the sales of the item manufactured will not be affected by the method of manufacture. The automatic machinery will have a life of 12 years, a cost of $110,000 and a salvage value of $10,000 in 12 years. Taxes will be $500 a year and labor will cost $15,000 a year. Repairs and maintenance will be zero the first year and will increase $1,000 per year thereafter.

    (a) Calculate the present worth of this proposed automatic machine if the minimum attractive rate of return is 12%.

    (b) Calculate the annual cost if the minimum attractive rate of return is 10%.

20. An investor purchased a piece of property for $14,000 that he expects will appreciate in value in the next ten years. An old house is on the property, and he spends $1,000 repairing the house and then rents it for $75 per month. Assume rent is collected from the time the property is purchased, and that the $1,000 repairs were made at the time of purchase. Taxes are $150 per year and maintenance cost $250 per year. If a 10% rate of return is required, what must the sale price be in 10 years to obtain this stated rate of return? Assume rent is collected at the end of each year.

21. A young engineer is just graduating from college and has the goal to start a business of his own. He feels that he should work 10 years for a consulting engineer before he starts his own firm. He estimates that he will need $5,000 to start his business in 10 years and $8,000 at the end of the first year of business, $5,000 at the end of the second year and $2,000 at the end of the third year to supplement his income. After

three years the business should be self sufficient. How much would he have to save each year at 6% interest in order to have the funds required to start his business? Assume 10 annual payments occur at the end of years 1 through 10.

22. An investor purchased a piece of property for $7,500. He spent $500 repairing an old house that was on the property and then rented the house for $60 per month for three years. He then decided to tear the house down and build a duplex. Tearing the house down and building the duplex cost $50,000 and took the fourth year. The duplex was rented for 16 years resulting in a net income before property taxes of $350 per month. Taxes were $50 per year for the first four years and $800 per year for the next sixteen years. Assume that the rent was collected from the time the property was purchased and that the repairs were made at the time of purchase. Assume all rent was collected at the end of the year and all expenditures were made at the end of the year. If the property was sold for $60,000 at the end of the twentieth year, what was the rate of return on the investment?

23. A road project has initial costs of $1,000,000, benefits of $1,500,000 to the using public and disbenefits of $300,000 to the property owners who live along the right-of-way. Calculate the benefit-cost ratio. What is the excess of benefits over costs?

24. The Whiz Manufacturing Company has initiated a cost reduction drive and stated that any permanent improvement that would yield a gross return of 25% should be made. The 25% return is intended to completely cover all capital recovery costs, taxes, and insurance.

For one operation six proposals have been made as follows:

Proposal	Investment	Annual Saving	Gross Return on Investment	Extra Investment	Extra Annual Savings	Gross Return on Extra Investment
A	1,000	150	15.0%	-	-	-
B	5,000	1,500	30.0%	4,000	1,350	33.8%
C	8,000	2,500	31.3%	3,000	1,000	33.3%
D	10,000	3,000	30.0%	2,000	500	25.0%
E	11,000	3,100	28.2%	1,000	100	10.0%
F	18,000	4,900	27.2%	7,000	1,800	25.8%

Which proposal should be accepted?

25. A piece of equipment is purchased new for $12,000 and has a six year expected life with a $2,000 salvage value. Determine the depreciation charge in the fifth year using:

(a) Sum-of-the-Years-Digits Method
(b) Double Rate Declining Balance Method
(c) Straight Line Method $\frac{12000-2000}{6} = 1667$

26. An eight yard drag line costs $400,000 and has an expected life of 10 years. The salvage value in ten years will be $100,000. Calculate the depreciation for the 1st, 2nd and 3rd year using:

(a) Straight Line Method $\frac{400000-100000}{10} = 30,000$
(b) Sum-of-the-Years-Digits Method
(c) Double Rate Declining Balance Method
$\frac{2(100)}{10} = 20$

27. An investor is considering six proposals that have been submitted to him for the development of a piece of property he owns. The following estimates have been made for the various alternatives:

Plan	Total Cost Of Investment In Buildings	Annual Disbursements (Including Income Taxes, Excluding Initial Investment)	Annual Receipts
A	100,000	15,000	40,000
B	150,000	22,000	60,000
C	250,000	32,000	90,000
D	340,000	38,000	108,000
E	500,000	52,000	140,000
F	600,000	70,000	170,000

The required land is considered to be worth $100,000. In each case, the estimated life of the buildings is 10 years with zero salvage value. In 10 years the land is estimated to have a value of $200,000. The investor is unwilling to make any investment that does not show a prospective rate of return of at least 12%. Which plan should he select?

28. An investor has a chance to purchase a 500 unit apartment complex for 10 million dollars. The average income per apartment is $200 per month. Property taxes are $25,000 a year. Maintenance averages $20 per month per apartment and is expected to increase at the rate of $3 per month per unit each year for the next 25 years (a $36 per year per unit increase). Assume that the average occupancy will be 99% the first year and decreases 1/2% a year. For tax purposes assume that sum-of-the-years-digits depreciation accounting is used with a 25 year life and a two million dollar salvage value. If the investor's combined state and federal income tax rate is estimated to be 40%, what is his after tax rate of return (a) if the investment tax credit does not apply, and (b) if the investment tax credit does occur? Assume year end accounting for income and disbursements.

ANSWERS TO PROBLEMS

1. 19.6%
2. $1,489
3. $655
4. 0.10185
5. 69.90
6. (a) $21,951; (b) $3,574
7. 21.2%
8. (a) System B; (b) System B
9. (a) $201,120; (b) $13,310
10. (a) $275,000; (b) 2.22; (c) 2.57
11. D
12. (a) $16,000; (b) $40,000, $36,800, $33,900; (c) $30,750, $29,550, $28,300
13. (a) 6.11%; (b) 6.88%
14. $3500 is a Sunk Cost
15. $2,523
16. 26.8%
17. 7.4%
18. $9,959
19. (a) $229,285; (b) $35,566
20. $31,000
21. $1,416
22. 6.0%
23. (a) 1.20; (b) $200,000
24. D
25. (a) $952; (b) $790; (c) $1,667
26. (a) $30,000; (b) $54,500, $49,100, $43,600; (c) $80,000, $64,000, $51,200
27. C
28. 5.40%

FORMULAS &
TABLES OF FACTORS

PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT MULTIPLIER $F = P(F/P,i\%,n)$ $(1+i)^n$	SINGLE PAYMENT: PRESENT WORTH MULTIPLIER $P = F(P/F,i\%,n)$ $1/(1+i)^n$	UNIFORM ANNUAL SERIES: SINKING FUND MULTIPLIER $A = F(A/F,i\%,n)$ $i/\left[(1+i)^n-1\right]$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY MULTIPLIER $A = P(A/P,i\%,n)$ $\frac{i(1+i)^n}{(1+i)^n-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT MULTIPLIER $F = A(F/A,i\%,n)$ $\left[(1+i)^n-1\right]/i$	UNIFORM ANNUAL SERIES: PRESENT WORTH MULTIPLIER $P = A(P/A,i\%,n)$ $\frac{(1+i)^n-1}{i(1+i)^n}$	N PERIODS

As $n \to \infty$, becomes $\frac{1}{i}$

0.50 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+I)^{**N}$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+I)^{**N}}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{I}{(1+I)^{**N}-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{I(1+I)^{**N}}{(1+I)^{**N}-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+I)^{**N}-1}{I}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+I)^{**N}-1}{I(1+I)^{**N}}$	N PERIODS
1	1.005000	0.995025	1.000000	1.005000	1.000000	0.995025	1
2	1.010025	0.990075	0.498753	0.503753	2.005000	1.985099	2
3	1.015075	0.985149	0.331672	0.336672	3.015025	2.970248	3
4	1.020151	0.980248	0.248133	0.253133	4.030100	3.950496	4
5	1.025251	0.975371	0.198010	0.203010	5.050251	4.925866	5
6	1.030378	0.970518	0.164595	0.169595	6.075502	5.896384	6
7	1.035529	0.965690	0.140729	0.145729	7.105879	6.862074	7
8	1.040707	0.960885	0.122829	0.127829	8.141409	7.822959	8
9	1.045911	0.956105	0.108907	0.113907	9.182116	8.779064	9
10	1.051140	0.951348	0.097771	0.102771	10.228026	9.730412	10
11	1.056396	0.946615	0.088659	0.093659	11.279167	10.677027	11
12	1.061678	0.941905	0.081066	0.086066	12.335562	11.618932	12
13	1.066986	0.937219	0.074642	0.079642	13.397240	12.556151	13
14	1.072321	0.932556	0.069136	0.074136	14.464226	13.488708	14
15	1.077683	0.927917	0.064364	0.069364	15.536548	14.416625	15
16	1.083071	0.923300	0.060189	0.065189	16.614230	15.339925	16
17	1.088487	0.918707	0.056506	0.061506	17.697301	16.258632	17
18	1.093929	0.914136	0.053232	0.058232	18.785788	17.172768	18
19	1.099399	0.909588	0.050303	0.055303	19.879717	18.082356	19
20	1.104896	0.905063	0.047666	0.052666	20.979115	18.987419	20
21	1.110420	0.900560	0.045282	0.050282	22.084011	19.887979	21
22	1.115972	0.896080	0.043114	0.048114	23.194431	20.784059	22
23	1.121552	0.891622	0.041135	0.046135	24.310403	21.675681	23
24	1.127160	0.887186	0.039321	0.044321	25.431955	22.562866	24
25	1.132796	0.882772	0.037652	0.042652	26.559115	23.445638	25
26	1.138460	0.878380	0.036112	0.041112	27.691911	24.324018	26
27	1.144152	0.874010	0.034686	0.039686	28.830370	25.198028	27
28	1.149873	0.869662	0.033362	0.038362	29.974522	26.067689	28
29	1.155622	0.865335	0.032129	0.037129	31.124395	26.933024	29
30	1.161400	0.861030	0.030979	0.035979	32.280017	27.794054	30
31	1.167207	0.856746	0.029903	0.034903	33.441417	28.650800	31
32	1.173043	0.852484	0.028895	0.033895	34.608624	29.503284	32
33	1.178908	0.848242	0.027947	0.032947	35.781667	30.351526	33
34	1.184803	0.844022	0.027056	0.032056	36.960575	31.195548	34
35	1.190727	0.839823	0.026215	0.031215	38.145378	32.035371	35
40	1.220794	0.819139	0.022646	0.027646	44.158847	36.172228	40
50	1.283226	0.779286	0.017654	0.022654	56.645163	44.142786	50
60	1.348850	0.741372	0.014333	0.019333	69.770031	51.725561	60
70	1.417831	0.705303	0.011967	0.016967	83.566105	58.939418	70
80	1.490339	0.670988	0.010197	0.015197	98.067714	65.802305	80
90	1.566555	0.638344	0.008825	0.013825	113.310936	72.331300	90
100	1.646668	0.607287	0.007732	0.012732	129.333698	78.542645	100

0.75 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+I)^{**}N$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+I)^{**}N}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{1}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+I)^{**}N-1}{I}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	N PERIODS
1	1.007500	0.992556	1.000000	1.007500	1.000000	0.992556	1
2	1.015056	0.985167	0.498132	0.505632	2.007500	1.977723	2
3	1.022669	0.977833	0.330846	0.338346	3.022556	2.955556	3
4	1.030339	0.970554	0.247205	0.254705	4.045225	3.926110	4
5	1.038067	0.963329	0.197022	0.204522	5.075565	4.889440	5
6	1.045852	0.956158	0.163569	0.171069	6.113631	5.845598	6
7	1.053696	0.949040	0.139675	0.147175	7.159484	6.794638	7
8	1.061599	0.941975	0.121756	0.129256	8.213180	7.736613	8
9	1.069561	0.934963	0.107819	0.115319	9.274779	8.671576	9
10	1.077583	0.928003	0.096671	0.104171	10.344339	9.599580	10
11	1.085664	0.921095	0.087551	0.095051	11.421922	10.520675	11
12	1.093807	0.914238	0.079951	0.087451	12.507586	11.434913	12
13	1.102010	0.907432	0.073522	0.081022	13.601393	12.342345	13
14	1.110276	0.900677	0.068011	0.075511	14.703404	13.243022	14
15	1.118603	0.893973	0.063236	0.070736	15.813679	14.136995	15
16	1.126992	0.887318	0.059059	0.066559	16.932282	15.024313	16
17	1.135445	0.880712	0.055373	0.062873	18.059274	15.905025	17
18	1.143960	0.874156	0.052098	0.059598	19.194718	16.779181	18
19	1.152540	0.867649	0.049167	0.056667	20.338679	17.646830	19
20	1.161184	0.861190	0.046531	0.054031	21.491219	18.508020	20
21	1.169893	0.854779	0.044145	0.051645	22.652403	19.362799	21
22	1.178667	0.848416	0.041977	0.049477	23.822296	20.211215	22
23	1.187507	0.842100	0.039998	0.047498	25.000963	21.053315	23
24	1.196414	0.835831	0.038185	0.045685	26.188471	21.889146	24
25	1.205387	0.829609	0.036516	0.044016	27.384884	22.718755	25
26	1.214427	0.823434	0.034977	0.042477	28.590271	23.542189	26
27	1.223535	0.817304	0.033552	0.041052	29.804698	24.359493	27
28	1.232712	0.811220	0.032229	0.039729	31.028233	25.170713	28
29	1.241957	0.805181	0.030997	0.038497	32.260945	25.975893	29
30	1.251272	0.799187	0.029848	0.037348	33.502902	26.775080	30
31	1.260656	0.793238	0.028774	0.036274	34.754174	27.568318	31
32	1.270111	0.787333	0.027766	0.035266	36.014830	28.355650	32
33	1.279637	0.781472	0.026820	0.034320	37.284941	29.137122	33
34	1.289234	0.775654	0.025931	0.033431	38.564578	29.912776	34
35	1.298904	0.769880	0.025092	0.032592	39.853813	30.682656	35
40	1.348349	0.741648	0.021530	0.029030	46.446482	34.446938	40
50	1.452957	0.688252	0.016558	0.024058	60.394257	41.566447	50
60	1.565681	0.638700	0.013258	0.020758	75.424137	48.173374	60
70	1.687151	0.592715	0.010915	0.018415	91.620073	54.304622	70
80	1.818044	0.550042	0.009168	0.016668	109.072531	59.994440	80
90	1.959092	0.510440	0.007820	0.015320	127.878995	65.274609	90
100	2.111084	0.473690	0.006750	0.014250	148.144512	70.174623	100

1.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F (1 + I)**N	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P 1 / (1 + I)**N	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A I / ((1 + I)**N - 1)	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A I((1 + I)**N / ((1 + I)**N - 1)	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F ((1 + I)**N - 1) / I	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P ((1 + I)**N - 1) / I((1 + I)**N)	N PERIODS
1	1.010000	0.990099	1.000000	1.010000	1.000000	0.990099	1
2	1.020100	0.980296	0.497512	0.507512	2.010000	1.970395	2
3	1.030301	0.970590	0.330022	0.340022	3.030100	2.940985	3
4	1.040604	0.960980	0.246281	0.256281	4.060401	3.901966	4
5	1.051010	0.951466	0.196040	0.206040	5.101005	4.853431	5
6	1.061520	0.942045	0.162548	0.172548	6.152015	5.795476	6
7	1.072135	0.932718	0.138628	0.148628	7.213535	6.728195	7
8	1.082857	0.923483	0.120690	0.130690	8.285671	7.651678	8
9	1.093685	0.914340	0.106740	0.116740	9.368527	8.566018	9
10	1.104622	0.905287	0.095582	0.105582	10.462213	9.471305	10
11	1.115668	0.896324	0.086454	0.096454	11.566835	10.367628	11
12	1.126825	0.887449	0.078849	0.088849	12.682503	11.255077	12
13	1.138093	0.878663	0.072415	0.082415	13.809328	12.133740	13
14	1.149474	0.869963	0.066901	0.076901	14.947421	13.003703	14
15	1.160969	0.861349	0.062124	0.072124	16.096896	13.865053	15
16	1.172579	0.852821	0.057945	0.067945	17.257864	14.717874	16
17	1.184304	0.844377	0.054258	0.064258	18.430443	15.562251	17
18	1.196147	0.836017	0.050982	0.060982	19.614748	16.398269	18
19	1.208109	0.827740	0.048052	0.058052	20.810895	17.226008	19
20	1.220190	0.819544	0.045415	0.055415	22.019004	18.045553	20
21	1.232392	0.811430	0.043031	0.053031	23.239194	18.856983	21
22	1.244716	0.803396	0.040864	0.050864	24.471586	19.660379	22
23	1.257163	0.795442	0.038886	0.048886	25.716302	20.455821	23
24	1.269735	0.787566	0.037073	0.047073	26.973465	21.243387	24
25	1.282432	0.779768	0.035407	0.045407	28.243200	22.023156	25
26	1.295256	0.772048	0.033869	0.043869	29.525631	22.795204	26
27	1.308209	0.764404	0.032446	0.042446	30.820888	23.559608	27
28	1.321291	0.756836	0.031124	0.041124	32.129097	24.316443	28
29	1.334504	0.749342	0.029895	0.039895	33.450388	25.065785	29
30	1.347849	0.741923	0.028748	0.038748	34.784892	25.807708	30
31	1.361327	0.734577	0.027676	0.037676	36.132740	26.542285	31
32	1.374941	0.727304	0.026671	0.036671	37.494068	27.269589	32
33	1.388690	0.720103	0.025727	0.035727	38.869009	27.989693	33
34	1.402577	0.712973	0.024840	0.034840	40.257699	28.702666	34
35	1.416603	0.705914	0.024004	0.034004	41.660276	29.408580	35
40	1.488864	0.671653	0.020456	0.030456	48.886373	32.834686	40
50	1.644632	0.608039	0.015513	0.025513	64.463182	39.196118	50
60	1.816697	0.550450	0.012244	0.022244	81.669670	44.955038	60
70	2.006763	0.498315	0.009933	0.019933	100.676337	50.168514	70
80	2.216715	0.451118	0.008219	0.018219	121.671522	54.888206	80
90	2.448633	0.408391	0.006903	0.016903	144.863267	59.160881	90
100	2.704814	0.369711	0.005866	0.015866	170.481383	63.028879	100

1.50 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F (1 + I)**N	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P 1 / (1 + I)**N	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A I / (1 + I)**N - 1	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A I(1 + I)**N / (1 + I)**N - 1	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F (1 + I)**N - 1 / I	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P (1 + I)**N - 1 / I(1 + I)**N	N PERIODS
1	1.015000	0.985222	1.000000	1.015000	1.000000	0.985222	1
2	1.030225	0.970662	0.496278	0.511278	2.015000	1.955883	2
3	1.045678	0.956317	0.328383	0.343383	3.045225	2.912200	3
4	1.061364	0.942184	0.244445	0.259445	4.090903	3.854385	4
5	1.077284	0.928260	0.194089	0.209089	5.152267	4.782645	5
6	1.093443	0.914542	0.160525	0.175525	6.229551	5.697187	6
7	1.109845	0.901027	0.136556	0.151556	7.322994	6.598214	7
8	1.126493	0.887711	0.118584	0.133584	8.432839	7.485925	8
9	1.143390	0.874592	0.104610	0.119610	9.559332	8.360517	9
10	1.160541	0.861667	0.093434	0.108434	10.702722	9.222185	10
11	1.177949	0.848933	0.084294	0.099294	11.863262	10.071118	11
12	1.195618	0.836387	0.076680	0.091680	13.041211	10.907505	12
13	1.213552	0.824027	0.070240	0.085240	14.236830	11.731532	13
14	1.231756	0.811849	0.064723	0.079723	15.450382	12.543382	14
15	1.250232	0.799852	0.059944	0.074944	16.682138	13.343233	15
16	1.268986	0.788031	0.055765	0.070765	17.932370	14.131264	16
17	1.288020	0.776385	0.052080	0.067080	19.201355	14.907649	17
18	1.307341	0.764912	0.048806	0.063806	20.489376	15.672561	18
19	1.326951	0.753607	0.045878	0.060878	21.796716	16.426168	19
20	1.346855	0.742470	0.043246	0.058246	23.123667	17.168639	20
21	1.367058	0.731498	0.040865	0.055865	24.470522	17.900137	21
22	1.387564	0.720688	0.038703	0.053703	25.837580	18.620824	22
23	1.408377	0.710037	0.036731	0.051731	27.225144	19.330861	23
24	1.429503	0.699544	0.034924	0.049924	28.633521	20.030405	24
25	1.450945	0.689206	0.033263	0.048263	30.063024	20.719611	25
26	1.472710	0.679021	0.031732	0.046732	31.513969	21.398632	26
27	1.494800	0.668986	0.030315	0.045315	32.986678	22.067617	27
28	1.517222	0.659099	0.029001	0.044001	34.481479	22.726717	28
29	1.539981	0.649359	0.027779	0.042779	35.998701	23.376076	29
30	1.563080	0.639762	0.026639	0.041639	37.538681	24.015838	30
31	1.586526	0.630308	0.025574	0.040574	39.101762	24.646146	31
32	1.610324	0.620993	0.024577	0.039577	40.688288	25.267139	32
33	1.634479	0.611816	0.023641	0.038641	42.298612	25.878954	33
34	1.658996	0.602774	0.022762	0.037762	43.933092	26.481728	34
35	1.683881	0.593866	0.021934	0.036934	45.592088	27.075595	35
40	1.814018	0.551262	0.018427	0.033427	54.267894	29.915845	40
50	2.105242	0.475005	0.013572	0.028572	73.682828	34.999688	50
60	2.443220	0.409296	0.010393	0.025393	96.214652	39.380269	60
70	2.835456	0.352677	0.007972	0.023172	122.363753	43.154872	70
80	3.290663	0.303840	0.006548	0.021548	152.710852	46.407323	80
90	3.818949	0.261852	0.005321	0.020321	187.929900	49.209855	90
100	4.432046	0.225627	0.004371	0.019371	228.803043	51.624704	100

2.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+I)^{**}N$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+I)^{**}N}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{I}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+I)^{**}N-1}{I}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	N PERIODS
1	1.020000	0.980392	1.000000	1.020000	1.000000	0.980392	1
2	1.040400	0.961169	0.495050	0.515050	2.020000	1.941561	2
3	1.061208	0.942322	0.326755	0.346755	3.060400	2.883883	3
4	1.082432	0.923845	0.242624	0.262624	4.121608	3.807729	4
5	1.104081	0.905731	0.192158	0.212158	5.204040	4.713460	5
6	1.126162	0.887971	0.158526	0.178526	6.308121	5.601431	6
7	1.148686	0.870560	0.134512	0.154512	7.434283	6.471991	7
8	1.171659	0.853490	0.116510	0.136510	8.582969	7.325481	8
9	1.195093	0.836755	0.102515	0.122515	9.754628	8.162237	9
10	1.218994	0.820348	0.091327	0.111327	10.949721	8.982585	10
11	1.243374	0.804263	0.082178	0.102178	12.168715	9.786848	11
12	1.268242	0.788493	0.074560	0.094560	13.412090	10.575341	12
13	1.293607	0.773033	0.068118	0.088118	14.680332	11.348374	13
14	1.319479	0.757875	0.062602	0.082602	15.973938	12.106249	14
15	1.345868	0.743015	0.057825	0.077825	17.293417	12.849264	15
16	1.372786	0.728446	0.053650	0.073650	18.639285	13.577709	16
17	1.400241	0.714163	0.049970	0.069970	20.012071	14.291872	17
18	1.428246	0.700159	0.046702	0.066702	21.412312	14.992031	18
19	1.456811	0.686431	0.043782	0.063782	22.840559	15.678462	19
20	1.485947	0.672971	0.041157	0.061157	24.297370	16.351433	20
21	1.515666	0.659776	0.038785	0.058785	25.783317	17.011209	21
22	1.545980	0.646839	0.036631	0.056631	27.298984	17.658048	22
23	1.576899	0.634156	0.034668	0.054668	28.844963	18.292204	23
24	1.608437	0.621721	0.032871	0.052871	30.421862	18.913926	24
25	1.640606	0.609531	0.031220	0.051220	32.030300	19.523456	25
26	1.673418	0.597579	0.029699	0.049699	33.670906	20.121036	26
27	1.706886	0.585862	0.028293	0.048293	35.344324	20.706898	27
28	1.741024	0.574375	0.026990	0.046990	37.051210	21.281272	28
29	1.775845	0.563112	0.025778	0.045778	38.792235	21.844385	29
30	1.811362	0.552071	0.024650	0.044650	40.568079	22.396456	30
31	1.847589	0.541246	0.023596	0.043596	42.379441	22.937702	31
32	1.884541	0.530633	0.022611	0.042611	44.227030	23.468335	32
33	1.922231	0.520229	0.021687	0.041687	46.111570	23.988564	33
34	1.960676	0.510028	0.020819	0.040819	48.033802	24.498592	34
35	1.999890	0.500028	0.020002	0.040002	49.994478	24.998619	35
40	2.208040	0.452890	0.016556	0.036556	60.401983	27.355479	40
50	2.691588	0.371528	0.011823	0.031823	84.579401	31.423606	50
60	3.281031	0.304782	0.008768	0.028768	114.051539	34.760887	60
70	3.999559	0.250026	0.006668	0.026668	149.977911	37.498619	70
80	4.875439	0.205119	0.005161	0.025161	193.771958	39.744514	80
90	5.943133	0.168261	0.004046	0.024046	247.156656	41.586929	90
100	7.244646	0.138033	0.003203	0.023203	312.232306	43.098352	100

3.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1 + I)^{**}N$	$\frac{1}{(1 + I)^{**}N}$	$\frac{I}{(1 + I)^{**}N - 1}$	$\frac{I(1 + I)^{**}N}{(1 + I)^{**}N - 1}$	$\frac{(1 + I)^{**}N - 1}{I}$	$\frac{(1 + I)^{**}N - 1}{I(1 + I)^{**}N}$	
1	1.030000	0.970874	1.000000	1.030000	1.000000	0.970874	1
2	1.060900	0.942596	0.492611	0.522611	2.030000	1.913470	2
3	1.092727	0.915142	0.323530	0.353530	3.090900	2.828611	3
4	1.125509	0.888487	0.239027	0.269027	4.183627	3.717098	4
5	1.159274	0.862609	0.188355	0.218355	5.309136	4.579707	5
6	1.194052	0.837484	0.154598	0.184598	6.468410	5.417191	6
7	1.229874	0.813092	0.130506	0.160506	7.662462	6.230283	7
8	1.266770	0.789409	0.112456	0.142456	8.892336	7.019692	8
9	1.304773	0.766417	0.098434	0.128434	10.159106	7.786109	9
10	1.343916	0.744094	0.087231	0.117231	11.463879	8.530203	10
11	1.384234	0.722421	0.078077	0.108077	12.807796	9.252624	11
12	1.425761	0.701380	0.070462	0.100462	14.192030	9.954004	12
13	1.468534	0.680951	0.064030	0.094030	15.617790	10.634955	13
14	1.512590	0.661118	0.058526	0.088526	17.086324	11.296073	14
15	1.557967	0.641862	0.053767	0.083767	18.598914	11.937935	15
16	1.604706	0.623167	0.049611	0.079611	20.156881	12.561102	16
17	1.652848	0.605016	0.045953	0.075953	21.761588	13.166118	17
18	1.702433	0.587395	0.042709	0.072709	23.414435	13.753513	18
19	1.753506	0.570286	0.039814	0.069814	25.116868	14.323799	19
20	1.806111	0.553676	0.037216	0.067216	26.870374	14.877475	20
21	1.860295	0.537549	0.034872	0.064872	28.676486	15.415024	21
22	1.916103	0.521893	0.032747	0.062747	30.536780	15.936917	22
23	1.973587	0.506692	0.030814	0.060814	32.452884	16.443608	23
24	2.032794	0.491934	0.029047	0.059047	34.426470	16.935542	24
25	2.093778	0.477606	0.027428	0.057428	36.459264	17.413148	25
26	2.156591	0.463695	0.025938	0.055938	38.553042	17.876842	26
27	2.221289	0.450189	0.024564	0.054564	40.709634	18.327031	27
28	2.287928	0.437077	0.023293	0.053293	42.930923	18.764108	28
29	2.356566	0.424346	0.022115	0.052115	45.218850	19.188455	29
30	2.427262	0.411987	0.021019	0.051019	47.575416	19.600441	30
31	2.500080	0.399987	0.019999	0.049999	50.002678	20.000428	31
32	2.575083	0.388337	0.019047	0.049047	52.502759	20.388766	32
33	2.652335	0.377026	0.018156	0.048156	55.077841	20.765792	33
34	2.731905	0.366045	0.017322	0.047322	57.730177	21.131837	34
35	2.813862	0.355383	0.016539	0.046539	60.462082	21.487220	35
40	3.262038	0.306557	0.013262	0.043262	75.401260	23.114772	40
50	4.383906	0.228107	0.008865	0.038865	112.796867	25.729764	50
60	5.891603	0.169733	0.006133	0.036133	163.053437	27.675564	60
70	7.917822	0.126297	0.004337	0.034337	230.594064	29.123421	70
80	10.640891	0.093977	0.003112	0.033112	321.363019	30.200763	80
90	14.300467	0.069928	0.002256	0.032256	443.348904	31.002407	90
100	19.218632	0.052033	0.001647	0.031647	607.287733	31.598905	100

4.CO PERCENT CCMPCUNC INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1+I)^{**}N$	$\frac{1}{(1+I)^{**}N}$	$\frac{I}{(1+I)^{**}N-1}$	$\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	$\frac{(1+I)^{**}N-1}{I}$	$\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	
1	1.040000	0.961538	1.000000	1.040000	1.000000	0.961538	1
2	1.081600	0.924556	0.490196	0.530196	2.040000	1.886095	2
3	1.124864	0.888596	0.320349	0.360349	3.121600	2.775091	3
4	1.169859	0.854804	0.235490	0.275490	4.246464	3.629895	4
5	1.216653	0.821927	0.184627	0.224627	5.416323	4.451822	5
6	1.265319	0.790315	0.150762	0.190762	6.632975	5.242137	6
7	1.315932	0.759918	0.126610	0.166610	7.898294	6.002055	7
8	1.368569	0.730690	0.108528	0.148528	9.214226	6.732745	8
9	1.423312	0.702587	0.094493	0.134493	10.582795	7.435332	9
10	1.480244	0.675564	0.083291	0.123291	12.006107	8.110896	10
11	1.539454	0.649581	0.074149	0.114149	13.486351	8.760477	11
12	1.601032	0.624597	0.066552	0.106552	15.025805	9.385074	12
13	1.665074	0.600574	0.060144	0.100144	16.626838	9.985648	13
14	1.731676	0.577475	0.054669	0.094669	18.291911	10.563123	14
15	1.800944	0.555265	0.049941	0.089941	20.023588	11.118387	15
16	1.872981	0.533908	0.045820	0.085820	21.824531	11.652296	16
17	1.947900	0.513373	0.042199	0.082199	23.697512	12.165669	17
18	2.025817	0.493628	0.038993	0.078993	25.645413	12.659297	18
19	2.106849	0.474642	0.036139	0.076139	27.671229	13.133939	19
20	2.191123	0.456387	0.033582	0.073582	29.778079	13.590326	20
21	2.278768	0.438834	0.031280	0.071280	31.969202	14.029160	21
22	2.369919	0.421955	0.029199	0.069199	34.247970	14.451115	22
23	2.464716	0.405726	0.027309	0.067309	36.617889	14.856842	23
24	2.563304	0.390121	0.025587	0.065587	39.082604	15.246963	24
25	2.665836	0.375117	0.024012	0.064012	41.645908	15.622080	25
26	2.772470	0.360689	0.022567	0.062567	44.311745	15.982769	26
27	2.883369	0.346817	0.021239	0.061239	47.084214	16.329586	27
28	2.998703	0.333477	0.020013	0.060013	49.967583	16.663063	28
29	3.118651	0.320651	0.018880	0.058880	52.966286	16.983715	29
30	3.243398	0.308319	0.017830	0.057830	56.084938	17.292033	30
31	3.373133	0.296460	0.016855	0.056855	59.328335	17.588494	31
32	3.508059	0.285058	0.015949	0.055949	62.701469	17.873551	32
33	3.648381	0.274094	0.015104	0.055104	66.209527	18.147646	33
34	3.794316	0.263552	0.014315	0.054315	69.857909	18.411198	34
35	3.946089	0.253415	0.013577	0.053577	73.652225	18.664613	35
40	4.801021	0.208289	0.010523	0.050523	95.025516	19.792774	40
50	7.106683	0.140713	0.006550	0.046550	152.667084	21.482185	50
60	10.519627	0.095060	0.004202	0.044202	237.990685	22.623490	60
70	15.571618	0.064219	0.002745	0.042745	364.290459	23.394515	70
80	23.049799	0.043384	0.001814	0.041814	551.244977	23.915392	80
90	34.119333	0.029309	0.001208	0.041208	827.983334	24.267278	90
100	50.504948	0.019800	0.000808	0.040808	1237.623705	24.504599	100

5.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1+I)^{**}N$	$\frac{1}{(1+I)^{**}N}$	$\frac{I}{(1+I)^{**}N-1}$	$\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	$\frac{(1+I)^{**}N-1}{I}$	$\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	
1	1.050000	0.952381	1.000000	1.050000	1.000000	0.952381	1
2	1.102500	0.907029	0.487805	0.537805	2.050000	1.859410	2
3	1.157625	0.863838	0.317209	0.367209	3.152500	2.723248	3
4	1.215506	0.822702	0.232012	0.282012	4.310125	3.545951	4
5	1.276282	0.783526	0.180975	0.230975	5.525631	4.329477	5
6	1.340096	0.746215	0.147017	0.197017	6.801913	5.075692	6
7	1.407100	0.710681	0.122820	0.172820	8.142008	5.786373	7
8	1.477455	0.676839	0.104722	0.154722	9.549109	6.463213	8
9	1.551328	0.644609	0.090690	0.140690	11.026564	7.107822	9
10	1.628895	0.613913	0.079505	0.129505	12.577893	7.721735	10
11	1.710339	0.584679	0.070389	0.120389	14.206787	8.306414	11
12	1.795856	0.556837	0.062825	0.112825	15.917127	8.863252	12
13	1.885649	0.530321	0.056456	0.106456	17.712983	9.393573	13
14	1.979932	0.505068	0.051024	0.101024	19.598632	9.898641	14
15	2.078928	0.481017	0.046342	0.096342	21.578564	10.379658	15
16	2.182875	0.458112	0.042270	0.092270	23.657492	10.837770	16
17	2.292018	0.436297	0.038699	0.088699	25.840366	11.274066	17
18	2.406619	0.415521	0.035546	0.085546	28.132385	11.689587	18
19	2.526950	0.395734	0.032745	0.082745	30.539004	12.085321	19
20	2.653298	0.376889	0.030243	0.080243	33.065954	12.462210	20
21	2.785963	0.358942	0.027996	0.077996	35.719252	12.821153	21
22	2.925261	0.341850	0.025971	0.075971	38.505214	13.163003	22
23	3.071524	0.325571	0.024137	0.074137	41.430475	13.488574	23
24	3.225100	0.310068	0.022471	0.072471	44.501999	13.798642	24
25	3.386355	0.295303	0.020952	0.070952	47.727099	14.093945	25
26	3.555673	0.281241	0.019564	0.069564	51.113454	14.375185	26
27	3.733456	0.267848	0.018292	0.068292	54.669126	14.643034	27
28	3.920129	0.255094	0.017123	0.067123	58.402583	14.898127	28
29	4.116136	0.242946	0.016046	0.066046	62.322712	15.141074	29
30	4.321942	0.231377	0.015051	0.065051	66.438848	15.372451	30
31	4.538039	0.220359	0.014132	0.064132	70.760790	15.592811	31
32	4.764941	0.209866	0.013280	0.063280	75.298829	15.802677	32
33	5.003189	0.199873	0.012490	0.062490	80.063771	16.002549	33
34	5.253348	0.190355	0.011755	0.061755	85.066959	16.192904	34
35	5.516015	0.181290	0.011072	0.061072	90.320307	16.374194	35
40	7.039989	0.142046	0.008278	0.058278	120.799774	17.159086	40
50	11.467400	0.087204	0.004777	0.054777	209.347996	18.255925	50
60	18.679186	0.053536	0.002878	0.052828	353.583718	18.929290	60
70	30.426426	0.032866	0.001699	0.051699	588.528511	19.342677	70
80	49.561441	0.020177	0.001030	0.051030	971.228821	19.596460	80
90	80.730365	0.012387	0.000627	0.050627	1594.607301	19.752262	90
100	131.501258	0.007604	0.000383	0.050383	2610.025157	19.847910	100

6.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1 + I)^{**}N$	$\frac{1}{(1 + I)^{**}N}$	$\frac{I}{(1 + I)^{**}N - 1}$	$\frac{I(1 + I)^{**}N}{(1 + I)^{**}N - 1}$	$\frac{(1 + I)^{**}N - 1}{I}$	$\frac{(1 + I)^{**}N - 1}{I(1 + I)^{**}N}$	
1	1.060000	0.943396	1.000000	1.060000	1.000000	0.943396	1
2	1.123600	0.889996	0.485437	0.545437	2.060000	1.833393	2
3	1.191016	0.839619	0.314110	0.374110	3.183600	2.673012	3
4	1.262477	0.792094	0.228591	0.288591	4.374616	3.465106	4
5	1.338226	0.747258	0.177396	0.237396	5.637093	4.212364	5
6	1.418519	0.704961	0.143363	0.203363	6.975319	4.917324	6
7	1.503630	0.665057	0.119135	0.179135	8.393838	5.582381	7
8	1.593848	0.627412	0.101036	0.161036	9.897468	6.209794	8
9	1.689479	0.591898	0.087022	0.147022	11.491316	6.801692	9
10	1.790848	0.558395	0.075868	0.135868	13.180795	7.360087	10
11	1.898299	0.526788	0.066793	0.126793	14.971643	7.886875	11
12	2.012196	0.496969	0.059277	0.119277	16.869941	8.383844	12
13	2.132928	0.468839	0.052960	0.112960	18.882138	8.852683	13
14	2.260904	0.442301	0.047585	0.107585	21.015066	9.294984	14
15	2.396558	0.417265	0.042963	0.102963	23.275970	9.712249	15
16	2.540352	0.393646	0.038952	0.098952	25.672528	10.105895	16
17	2.692773	0.371364	0.035445	0.095445	28.212880	10.477260	17
18	2.854339	0.350344	0.032357	0.092357	30.905653	10.827603	18
19	3.025600	0.330513	0.029621	0.089621	33.759992	11.158116	19
20	3.207135	0.311805	0.027185	0.087185	36.785591	11.469921	20
21	3.399564	0.294155	0.025005	0.085005	39.992727	11.764077	21
22	3.603537	0.277505	0.023046	0.083046	43.392290	12.041582	22
23	3.819750	0.261797	0.021278	0.081278	46.995828	12.303379	23
24	4.048935	0.246979	0.019679	0.079679	50.815577	12.550358	24
25	4.291871	0.232999	0.018227	0.078227	54.864512	12.783356	25
26	4.549383	0.219810	0.016904	0.076904	59.156383	13.003166	26
27	4.822346	0.207368	0.015697	0.075697	63.705766	13.210534	27
28	5.111687	0.195630	0.014593	0.074593	68.528112	13.406164	28
29	5.418388	0.184557	0.013580	0.073580	73.639798	13.590721	29
30	5.743491	0.174110	0.012649	0.072649	79.058186	13.764831	30
31	6.088101	0.164255	0.011792	0.071792	84.801677	13.929086	31
32	6.453387	0.154957	0.011002	0.071002	90.889778	14.084043	32
33	6.840590	0.146186	0.010273	0.070273	97.343165	14.230230	33
34	7.251025	0.137912	0.009598	0.069598	104.183755	14.368141	34
35	7.686087	0.130105	0.008974	0.068974	111.434780	14.498246	35
40	10.285718	0.097222	0.006462	0.066462	154.761966	15.046297	40
50	18.420154	0.054288	0.003444	0.063444	290.335905	15.761861	50
60	32.987691	0.030314	0.001876	0.061876	533.128181	16.161428	60
70	59.075930	0.016927	0.001033	0.061033	967.932170	16.384544	70
80	105.795993	0.009452	0.000573	0.060573	1746.599891	16.509131	80
90	189.464511	0.005278	0.000318	0.060318	3141.075187	16.578659	90
100	339.302084	0.002947	0.000177	0.060177	5638.368059	16.617546	100

8.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+i)^N$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+i)^N}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{i}{(1+i)^N-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{i(1+i)^N}{(1+i)^N-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+i)^N-1}{i}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+i)^N-1}{i(1+i)^N}$	N PERIODS
1	1.080000	0.925926	1.000000	1.080000	1.000000	0.925926	1
2	1.166400	0.857339	0.480769	0.560769	2.080000	1.783265	2
3	1.259712	0.793832	0.308034	0.388034	3.246400	2.577097	3
4	1.360489	0.735030	0.221921	0.301921	4.506112	3.312127	4
5	1.469328	0.680583	0.170456	0.250456	5.866601	3.992710	5
6	1.586874	0.630170	0.136315	0.216315	7.335929	4.622880	6
7	1.713824	0.583490	0.112072	0.192072	8.922803	5.206370	7
8	1.850930	0.540269	0.094015	0.174015	10.636628	5.746639	8
9	1.999005	0.500249	0.080080	0.160080	12.487558	6.246888	9
10	2.158925	0.463193	0.069029	0.149029	14.486562	6.710081	10
11	2.331639	0.428883	0.060076	0.140076	16.645487	7.138964	11
12	2.518170	0.397114	0.052695	0.132695	18.977126	7.536078	12
13	2.719624	0.367698	0.046522	0.126522	21.495297	7.903776	13
14	2.937194	0.340461	0.041297	0.121297	24.214920	8.244237	14
15	3.172169	0.315242	0.036830	0.116830	27.152114	8.559479	15
16	3.425943	0.291890	0.032977	0.112977	30.324283	8.851369	16
17	3.700018	0.270269	0.029629	0.109629	33.750226	9.121638	17
18	3.996019	0.250249	0.026702	0.106702	37.450244	9.371887	18
19	4.315701	0.231712	0.024128	0.104128	41.446263	9.603599	19
20	4.660957	0.214548	0.021852	0.101852	45.761964	9.818147	20
21	5.033834	0.198656	0.019832	0.099832	50.422921	10.016803	21
22	5.436540	0.183941	0.018032	0.098032	55.456755	10.200744	22
23	5.871464	0.170315	0.016422	0.096422	60.893296	10.371059	23
24	6.341181	0.157699	0.014978	0.094978	66.764759	10.528758	24
25	6.848475	0.146018	0.013679	0.093679	73.105940	10.674776	25
26	7.396353	0.135202	0.012507	0.092507	79.954415	10.809978	26
27	7.988061	0.125187	0.011448	0.091448	87.350768	10.935165	27
28	8.627106	0.115914	0.010489	0.090489	95.338830	11.051078	28
29	9.317275	0.107328	0.009619	0.089619	103.965936	11.158406	29
30	10.062657	0.099377	0.008827	0.088827	113.283211	11.257783	30
31	10.867669	0.092016	0.008107	0.088107	123.345868	11.349799	31
32	11.737083	0.085200	0.007451	0.087451	134.213537	11.434999	32
33	12.676050	0.078889	0.006852	0.086852	145.950620	11.513888	33
34	13.690134	0.073045	0.006304	0.086304	158.626670	11.586934	34
35	14.785344	0.067635	0.005803	0.085803	172.316804	11.654568	35
40	21.724521	0.046031	0.003860	0.083860	259.056519	11.924613	40
50	46.901613	0.021321	0.001743	0.081743	573.770156	12.233485	50
60	101.257064	0.009876	0.000798	0.080798	1253.213296	12.376552	60
70	218.606406	0.004574	0.000368	0.080368	2720.080074	12.442820	70
80	471.954834	0.002119	0.000170	0.080170	5886.935428	12.473514	80
90	1018.915089	0.000981	0.000079	0.080079	12723.938616	12.487732	90
100	2199.761256	0.000455	0.000036	0.080036	27484.515704	12.494318	100

10.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1 + I)^{**}N$	$\frac{1}{(1 + I)^{**}N}$	$\frac{I}{(1 + I)^{**}N - 1}$	$\frac{I(1 + I)^{**}N}{(1 + I)^{**}N - 1}$	$\frac{(1 + I)^{**}N - 1}{I}$	$\frac{(1 + I)^{**}N - 1}{I(1 + I)^{**}N}$	
1	1.100000	0.909091	1.000000	1.100000	1.000000	0.909091	1
2	1.210000	0.826446	0.476190	0.576190	2.100000	1.735537	2
3	1.331000	0.751315	0.302115	0.402115	3.310000	2.486852	3
4	1.464100	0.683013	0.215471	0.315471	4.641000	3.169865	4
5	1.610510	0.620921	0.163797	0.263797	6.105100	3.790787	5
6	1.771561	0.564474	0.129607	0.229607	7.715610	4.355261	6
7	1.948717	0.513158	0.105405	0.205405	9.487171	4.868419	7
8	2.143589	0.466507	0.087444	0.187444	11.435888	5.334926	8
9	2.357948	0.424098	0.073641	0.173641	13.579477	5.759024	9
10	2.593742	0.385543	0.062745	0.162745	15.937425	6.144567	10
11	2.853117	0.350494	0.053963	0.153963	18.531167	6.495061	11
12	3.138428	0.318631	0.046763	0.146763	21.384284	6.813692	12
13	3.452271	0.289664	0.040779	0.140779	24.522712	7.103356	13
14	3.797498	0.263331	0.035746	0.135746	27.974983	7.366687	14
15	4.177248	0.239392	0.031474	0.131474	31.772482	7.606080	15
16	4.594973	0.217629	0.027817	0.127817	35.949730	7.823709	16
17	5.054470	0.197845	0.024664	0.124664	40.544703	8.021553	17
18	5.559917	0.179859	0.021930	0.121930	45.599173	8.201412	18
19	6.115909	0.163508	0.019547	0.119547	51.159090	8.364920	19
20	6.727500	0.148644	0.017460	0.117460	57.274999	8.513564	20
21	7.400250	0.135131	0.015624	0.115624	64.002499	8.648694	21
22	8.140275	0.122846	0.014005	0.114005	71.402749	8.771540	22
23	8.954302	0.111678	0.012572	0.112572	79.543024	8.883218	23
24	9.849733	0.101526	0.011300	0.111300	88.497327	8.984744	24
25	10.834706	0.092296	0.010168	0.110168	98.347059	9.077040	25
26	11.918177	0.083905	0.009159	0.109159	109.181765	9.160945	26
27	13.109994	0.076278	0.008258	0.108258	121.099942	9.237223	27
28	14.420994	0.069343	0.007451	0.107451	134.209936	9.306567	28
29	15.863093	0.063039	0.006728	0.106728	148.630930	9.369606	29
30	17.449402	0.057309	0.006079	0.106079	164.494023	9.426914	30
31	19.194342	0.052099	0.005496	0.105496	181.943425	9.479013	31
32	21.113777	0.047362	0.004972	0.104972	201.137767	9.526376	32
33	23.225154	0.043057	0.004499	0.104499	222.251544	9.569432	33
34	25.547670	0.039143	0.004074	0.104074	245.476699	9.608575	34
35	28.102437	0.035584	0.003690	0.103690	271.024368	9.644159	35
40	45.259256	0.022095	0.002259	0.102259	442.592556	9.779051	40
50	117.390853	0.008519	0.000859	0.100859	1163.908529	9.914814	50
60	304.481640	0.003284	0.000330	0.100330	3034.816395	9.967157	60
70	789.746957	0.001266	0.000127	0.100127	7887.469568	9.987338	70
80	2048.400215	0.000488	0.000049	0.100049	20474.002146	9.995118	80
90	5313.022612	0.000188	0.000019	0.100019	53120.226118	9.998118	90

12.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+I)^{**}N$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+I)^{**}N}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{I}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+I)^{**}N-1}{I}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	N PERIODS
1	1.120000	0.892857	1.000000	1.120000	1.000000	0.892857	1
2	1.254400	0.797194	0.471698	0.591698	2.120000	1.690051	2
3	1.404928	0.711780	0.296349	0.416349	3.374400	2.401831	3
4	1.573519	0.635518	0.209234	0.329234	4.779328	3.037349	4
5	1.762342	0.567427	0.157410	0.277410	6.352847	3.604776	5
6	1.973823	0.506631	0.123226	0.243226	8.115189	4.111407	6
7	2.210681	0.452349	0.099118	0.219118	10.089012	4.563757	7
8	2.475963	0.403883	0.081303	0.201303	12.299693	4.967640	8
9	2.773079	0.360610	0.067679	0.187679	14.775656	5.328250	9
10	3.105848	0.321973	0.056984	0.176984	17.548735	5.650223	10
11	3.478550	0.287476	0.048415	0.168415	20.654583	5.937699	11
12	3.895976	0.256675	0.041437	0.161437	24.133133	6.194374	12
13	4.363493	0.229174	0.035677	0.155677	28.029109	6.423548	13
14	4.887112	0.204620	0.030871	0.150871	32.392602	6.628168	14
15	5.473566	0.182696	0.026824	0.146824	37.279715	6.810864	15
16	6.130394	0.163122	0.023390	0.143390	42.753280	6.973986	16
17	6.866041	0.145644	0.020457	0.140457	48.883674	7.119630	17
18	7.689966	0.130040	0.017937	0.137937	55.749715	7.249670	18
19	8.612762	0.116107	0.015763	0.135763	63.439681	7.365777	19
20	9.646293	0.103667	0.013879	0.133879	72.052442	7.469444	20
21	10.803848	0.092560	0.012240	0.132240	81.698736	7.562003	21
22	12.100310	0.082643	0.010811	0.130811	92.502584	7.644646	22
23	13.552347	0.073788	0.009560	0.129560	104.602894	7.718434	23
24	15.178629	0.065882	0.008463	0.128463	118.155241	7.784316	24
25	17.000064	0.058823	0.007500	0.127500	133.333870	7.843139	25
26	19.040072	0.052521	0.006652	0.126652	150.333934	7.895660	26
27	21.324881	0.046894	0.005904	0.125904	169.374007	7.942554	27
28	23.883866	0.041869	0.005244	0.125244	190.698887	7.984423	28
29	26.749930	0.037383	0.004660	0.124660	214.582754	8.021806	29
30	29.959922	0.033378	0.004144	0.124144	241.332684	8.055184	30
31	33.555113	0.029802	0.003686	0.123686	271.292606	8.084986	31
32	37.581726	0.026609	0.003280	0.123280	304.847719	8.111594	32
33	42.091533	0.023758	0.002920	0.122920	342.429446	8.135352	33
34	47.142517	0.021212	0.002601	0.122601	384.520979	8.156564	34
35	52.799620	0.018940	0.002317	0.122317	431.663496	8.175504	35
40	93.050970	0.010747	0.001304	0.121304	767.091420	8.243777	40
50	289.002190	0.003460	0.000417	0.120417	2400.018249	8.304498	50
60	897.596933	0.001114	0.000134	0.120134	7471.641112	8.324049	60
70	2787.799828	0.000359	0.000043	0.120043	23223.331697	8.330344	70
80	8658.483100	0.000115	0.000014	0.120014	72145.692501	8.332371	80

15.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1 + I)^{**}N$	$\frac{1}{(1 + I)^{**}N}$	$\frac{I}{(1 + I)^{**}N - 1}$	$\frac{I(1 + I)^{**}N}{(1 + I)^{**}N - 1}$	$\frac{(1 + I)^{**}N - 1}{I}$	$\frac{(1 + I)^{**}N - 1}{I(1 + I)^{**}N}$	
1	1.150000	0.869565	1.000000	1.150000	1.000000	0.869565	1
2	1.322500	0.756144	0.465116	0.615116	2.150000	1.625709	2
3	1.520875	0.657516	0.287977	0.437977	3.472500	2.283225	3
4	1.749006	0.571753	0.200265	0.350265	4.993375	2.854978	4
5	2.011357	0.497177	0.148316	0.298316	6.742381	3.352155	5
6	2.313061	0.432328	0.114237	0.264237	8.753738	3.784483	6
7	2.660020	0.375937	0.090360	0.240360	11.066799	4.160420	7
8	3.059023	0.326902	0.072850	0.222850	13.726819	4.487322	8
9	3.517876	0.284262	0.059574	0.209574	16.785842	4.771584	9
10	4.045558	0.247185	0.049252	0.199252	20.303718	5.018769	10
11	4.652391	0.214943	0.041069	0.191069	24.349276	5.233712	11
12	5.350250	0.186907	0.034481	0.184481	29.001667	5.420619	12
13	6.152788	0.162528	0.029110	0.179110	34.351917	5.583147	13
14	7.075706	0.141329	0.024688	0.174688	40.504705	5.724476	14
15	8.137062	0.122894	0.021017	0.171017	47.580411	5.847370	15
16	9.357621	0.106865	0.017948	0.167948	55.717472	5.954235	16
17	10.761264	0.092926	0.015367	0.165367	65.075093	6.047161	17
18	12.375454	0.080805	0.013186	0.163186	75.836357	6.127966	18
19	14.231772	0.070265	0.011336	0.161336	88.211811	6.198231	19
20	16.366537	0.061100	0.009761	0.159761	102.443583	6.259331	20
21	18.821518	0.053131	0.008417	0.158417	118.810120	6.312462	21
22	21.644746	0.046201	0.007266	0.157266	137.631638	6.358663	22
23	24.891458	0.040174	0.006278	0.156278	159.276384	6.398837	23
24	28.625176	0.034934	0.005430	0.155430	184.167841	6.433771	24
25	32.918953	0.030378	0.004699	0.154699	212.793017	6.464149	25
26	37.856796	0.026415	0.004070	0.154070	245.711970	6.490564	26
27	43.535315	0.022970	0.003526	0.153526	283.568766	6.513534	27
28	50.065612	0.019974	0.003057	0.153057	327.104080	6.533508	28
29	57.575454	0.017369	0.002651	0.152651	377.169693	6.550877	29
30	66.211772	0.015103	0.002300	0.152300	434.745146	6.565980	30
31	76.143538	0.013133	0.001996	0.151996	500.956918	6.579113	31
32	87.565068	0.011420	0.001733	0.151733	577.100456	6.590533	32
33	100.699829	0.009931	0.001505	0.151505	664.665524	6.600463	33
34	115.804803	0.008635	0.001307	0.151307	765.365353	6.609099	34
35	133.175523	0.007509	0.001135	0.151135	881.170156	6.616607	35
40	267.863546	0.003733	0.000562	0.150562	1779.090308	6.641778	40
50	1083.657442	0.000923	0.000139	0.150139	7217.716277	6.660515	50
60	4383.998746	0.000228	0.000034	0.150034	29219.991638	6.665146	60

20.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F (1 + I)**N	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P 1 / (1 + I)**N	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A I / (1 + I)**N - 1	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A I(1 + I)**N / (1 + I)**N - 1	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F (1 + I)**N - 1 / I	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P (1 + I)**N - 1 / I(1 + I)**N	N PERIODS
1	1.200000	0.833333	1.000000	1.200000	1.000000	0.833333	1
2	1.440000	0.694444	0.454545	0.654545	2.200000	1.527778	2
3	1.728000	0.578704	0.274725	0.474725	3.640000	2.106481	3
4	2.073600	0.482253	0.186289	0.386289	5.368000	2.588735	4
5	2.488320	0.401878	0.134380	0.334380	7.441600	2.990612	5
6	2.985984	0.334898	0.100706	0.300706	9.929920	3.325510	6
7	3.583181	0.279082	0.077424	0.277424	12.915904	3.604592	7
8	4.299817	0.232568	0.060609	0.260609	16.499085	3.837160	8
9	5.159780	0.193807	0.048079	0.248079	20.798902	4.030967	9
10	6.191736	0.161506	0.038523	0.238523	25.958682	4.192472	10
11	7.430084	0.134588	0.031104	0.231104	32.150419	4.327060	11
12	8.916100	0.112157	0.025265	0.225265	39.580502	4.439217	12
13	10.699321	0.093464	0.020620	0.220620	48.496603	4.532681	13
14	12.839185	0.077887	0.016893	0.216893	59.195923	4.610567	14
15	15.407022	0.064905	0.013882	0.213882	72.035108	4.675473	15
16	18.488426	0.054088	0.011436	0.211436	87.442129	4.729561	16
17	22.186111	0.045073	0.009440	0.209440	105.930555	4.774634	17
18	26.623333	0.037561	0.007805	0.207805	128.116666	4.812195	18
19	31.948000	0.031301	0.006462	0.206462	154.740000	4.843496	19
20	38.337600	0.026084	0.005357	0.205357	186.688000	4.869580	20
21	46.005120	0.021737	0.004444	0.204444	225.025600	4.891316	21
22	55.206144	0.018114	0.003690	0.203690	271.030719	4.909430	22
23	66.247373	0.015095	0.003065	0.203065	326.236863	4.924525	23
24	79.496847	0.012579	0.002548	0.202548	392.484236	4.937104	24
25	95.396217	0.010483	0.002119	0.202119	471.981083	4.947587	25
26	114.475460	0.008735	0.001762	0.201762	567.377300	4.956323	26
27	137.370552	0.007280	0.001467	0.201467	681.852760	4.963602	27
28	164.844662	0.006066	0.001221	0.201221	819.223312	4.969668	28
29	197.813595	0.005055	0.001016	0.201016	984.067974	4.974724	29
30	237.376314	0.004213	0.000846	0.200846	1181.881569	4.978936	30
31	284.851577	0.003511	0.000705	0.200705	1419.257883	4.982447	31
32	341.821892	0.002926	0.000587	0.200587	1704.109459	4.985372	32
33	410.186270	0.002438	0.000489	0.200489	2045.931351	4.987810	33
34	492.223524	0.002032	0.000407	0.200407	2456.117621	4.989842	34
35	590.668229	0.001693	0.000339	0.200339	2948.341146	4.991535	35
40	1469.771568	0.000680	0.000136	0.200136	7343.857840	4.996598	40
50	9100.438150	0.000110	0.000022	0.200022	45497.190750	4.999451	50

25.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1+I)^{**}N$	$\frac{1}{(1+I)^{**}N}$	$\frac{I}{(1+I)^{**}N-1}$	$\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	$\frac{(1+I)^{**}N-1}{I}$	$\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	
1	1.250000	0.800000	1.000000	1.250000	1.000000	0.800000	1
2	1.562500	0.640000	0.444444	0.694444	2.250000	1.440000	2
3	1.953125	0.512000	0.262295	0.512295	3.812500	1.952000	3
4	2.441406	0.409600	0.173442	0.423442	5.765625	2.361600	4
5	3.051758	0.327680	0.121847	0.371847	8.207031	2.689280	5
6	3.814697	0.262144	0.088819	0.338819	11.258789	2.951424	6
7	4.768372	0.209715	0.066342	0.316342	15.073486	3.161139	7
8	5.960464	0.167772	0.050399	0.300399	19.841858	3.328911	8
9	7.450581	0.134218	0.038756	0.288756	25.802322	3.463129	9
10	9.313226	0.107374	0.030073	0.280073	33.252903	3.570503	10
11	11.641532	0.085859	0.023493	0.273493	42.566129	3.656403	11
12	14.551915	0.068719	0.018448	0.268448	54.207661	3.725122	12
13	18.189894	0.054976	0.014543	0.264543	68.759576	3.780098	13
14	22.737368	0.043980	0.011501	0.261501	86.949470	3.824078	14
15	28.421709	0.035184	0.009117	0.259117	109.686838	3.859263	15
16	35.527137	0.028147	0.007241	0.257241	138.108547	3.887410	16
17	44.408921	0.022518	0.005759	0.255759	173.635684	3.909928	17
18	55.511151	0.018014	0.004586	0.254586	218.044605	3.927942	18
19	69.388939	0.014412	0.003656	0.253656	273.555756	3.942354	19
20	86.736174	0.011529	0.002916	0.252916	342.944695	3.953883	20
21	108.420217	0.009223	0.002327	0.252327	429.680869	3.963107	21
22	135.525272	0.007379	0.001858	0.251858	538.101086	3.970485	22
23	169.406589	0.005903	0.001485	0.251485	673.626358	3.976388	23
24	211.758237	0.004722	0.001186	0.251186	843.032947	3.981111	24
25	264.697796	0.003778	0.000948	0.250948	1054.791184	3.984888	25
26	330.872245	0.003022	0.000758	0.250758	1319.488980	3.987911	26
27	413.590306	0.002418	0.000606	0.250606	1650.361225	3.990329	27
28	516.987883	0.001934	0.000485	0.250485	2063.951531	3.992263	28
29	646.234854	0.001547	0.000387	0.250387	2580.939414	3.993810	29
30	807.793567	0.001238	0.000310	0.250310	3227.174268	3.995048	30
31	1009.741959	0.000990	0.000248	0.250248	4034.967835	3.996039	31
32	1262.177448	0.000792	0.000198	0.250198	5044.709793	3.996831	32
33	1577.721810	0.000634	0.000159	0.250159	6306.887242	3.997465	33
34	1972.152263	0.000507	0.000127	0.250127	7884.609052	3.997972	34
35	2465.190329	0.000406	0.000101	0.250101	9856.761315	3.998377	35
40	7523.163845	0.000133	0.000033	0.250033	30088.655381	3.999468	40

30.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P	N PERIODS
	$(1+I)^{**}N$	$\frac{1}{(1+I)^{**}N}$	$\frac{I}{(1+I)^{**}N-1}$	$\frac{I(1+I)^{**}N}{(1+I)^{**}N-1}$	$\frac{(1+I)^{**}N-1}{I}$	$\frac{(1+I)^{**}N-1}{I(1+I)^{**}N}$	
1	1.300000	0.769231	1.000000	1.300000	1.000000	0.769231	1
2	1.690000	0.591716	0.434783	0.734783	2.300000	1.360947	2
3	2.197000	0.455166	0.250627	0.550627	3.990000	1.816113	3
4	2.856100	0.350128	0.161629	0.461629	6.187000	2.166241	4
5	3.712930	0.269329	0.110582	0.410582	9.043100	2.435570	5
6	4.826809	0.207176	0.078394	0.378394	12.756030	2.642746	6
7	6.274852	0.159366	0.056874	0.356874	17.582839	2.802112	7
8	8.157307	0.122589	0.041915	0.341915	23.857691	2.924702	8
9	10.604499	0.094300	0.031235	0.331235	32.014998	3.019001	9
10	13.785849	0.072538	0.023463	0.323463	42.619497	3.091539	10
11	17.921604	0.055799	0.017729	0.317729	56.405346	3.147338	11
12	23.298085	0.042922	0.013454	0.313454	74.326950	3.190260	12
13	30.287511	0.033017	0.010243	0.310243	97.625036	3.223277	13
14	39.373764	0.025398	0.007818	0.307818	127.912546	3.248675	14
15	51.185893	0.019537	0.005978	0.305978	167.286310	3.268211	15
16	66.541661	0.015028	0.004577	0.304577	218.472203	3.283239	16
17	86.504159	0.011560	0.003509	0.303509	285.013864	3.294800	17
18	112.455407	0.008892	0.002692	0.302692	371.518023	3.303692	18
19	146.192029	0.006840	0.002066	0.302066	483.973430	3.310532	19
20	190.049638	0.005262	0.001587	0.301587	630.165459	3.315794	20
21	247.064529	0.004048	0.001219	0.301219	820.215097	3.319842	21
22	321.183888	0.003113	0.000937	0.300937	1067.279626	3.322955	22
23	417.539054	0.002395	0.000720	0.300720	1388.463514	3.325350	23
24	542.800770	0.001842	0.000554	0.300554	1806.002568	3.327192	24
25	705.641001	0.001417	0.000426	0.300426	2348.803338	3.328609	25
26	917.333302	0.001090	0.000327	0.300327	3054.444340	3.329700	26
27	1192.533293	0.000839	0.000252	0.300252	3971.777642	3.330538	27
28	1550.293280	0.000645	0.000194	0.300194	5164.310934	3.331183	28
29	2015.381264	0.000496	0.000149	0.300149	6714.604214	3.331679	29
30	2619.995644	0.000382	0.000115	0.300115	8729.985479	3.332061	30
31	3405.994337	0.000294	0.000088	0.300088	11349.981122	3.332355	31
32	4427.792638	0.000226	0.000068	0.300068	14755.975459	3.332581	32
33	5756.130429	0.000174	0.000052	0.300052	19183.768097	3.332754	33
34	7482.969558	0.000134	0.000040	0.300040	24939.898526	3.332888	34
35	9727.860425	0.000103	0.000031	0.300031	32422.868084	3.332991	35

40.00 PERCENT COMPOUND INTEREST FACTORS

N PERIODS	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR GIVEN P TO FIND F $(1+i)^{**}N$	SINGLE PAYMENT: PRESENT WORTH FACTOR GIVEN F TO FIND P $\frac{1}{(1+i)^{**}N}$	UNIFORM ANNUAL SERIES: SINKING FUND FACTOR GIVEN F TO FIND A $\frac{i}{(1+i)^{**}N-1}$	UNIFORM ANNUAL SERIES: CAPITAL RECOVERY FACTOR GIVEN P TO FIND A $\frac{i(1+i)^{**}N}{(1+i)^{**}N-1}$	UNIFORM ANNUAL SERIES: COMPOUND AMOUNT FACTOR GIVEN A TO FIND F $\frac{(1+i)^{**}N-1}{i}$	UNIFORM ANNUAL SERIES: PRESENT WORTH FACTOR GIVEN A TO FIND P $\frac{(1+i)^{**}N-1}{i(1+i)^{**}N}$	N PERIODS
1	1.400000	0.714286	1.000000	1.400000	1.000000	0.714286	1
2	1.960000	0.510204	0.416667	0.816667	2.400000	1.224490	2
3	2.744000	0.364431	0.229358	0.629358	4.360000	1.588921	3
4	3.841600	0.260308	0.140766	0.540766	7.104000	1.849229	4
5	5.378240	0.185934	0.091361	0.491361	10.945600	2.035164	5
6	7.529536	0.132810	0.061260	0.461260	16.323840	2.167974	6
7	10.541350	0.094865	0.041923	0.441923	23.853376	2.262839	7
8	14.757891	0.067760	0.029074	0.429074	34.394726	2.330599	8
9	20.661047	0.048400	0.020345	0.420345	49.152617	2.378999	9
10	28.925465	0.034572	0.014324	0.414324	69.813664	2.413571	10
11	40.495652	0.024694	0.010128	0.410128	98.739129	2.438265	11
12	56.693912	0.017639	0.007182	0.407182	139.234781	2.455904	12
13	79.371477	0.012599	0.005104	0.405104	195.928693	2.468503	13
14	111.120068	0.008999	0.003632	0.403632	275.300171	2.477502	14
15	155.568096	0.006428	0.002588	0.402588	386.420239	2.483930	15
16	217.795334	0.004591	0.001845	0.401845	541.988334	2.488521	16
17	304.913467	0.003280	0.001316	0.401316	759.783668	2.491801	17
18	426.878854	0.002343	0.000939	0.400939	1064.697136	2.494144	18
19	597.630396	0.001673	0.000670	0.400670	1491.575990	2.495817	19
20	836.682554	0.001195	0.000479	0.400479	2089.206386	2.497012	20
21	1171.355576	0.000854	0.000342	0.400342	2925.888940	2.497866	21
22	1639.897806	0.000610	0.000244	0.400244	4097.244516	2.498476	22
23	2295.856929	0.000436	0.000174	0.400174	5737.142322	2.498911	23
24	3214.199700	0.000311	0.000124	0.400124	8032.999251	2.499222	24
25	4499.879581	0.000222	0.000089	0.400089	11247.198951	2.499444	25
26	6299.831413	0.000159	0.000064	0.400064	15747.078532	2.499603	26
27	8819.763978	0.000113	0.000045	0.400045	22046.909945	2.499717	27

GRADIENT MULTIPLIER

$$\frac{1}{I} - \frac{N}{(1+I)^{**}N - 1}$$

N PERIODS	INTEREST RATE (PERCENT) 1.0	2.0	3.0	4.0	5.0	6.0	8.0
2	0.497512	0.495050	0.492611	0.490196	0.487805	0.485437	0.480769
3	0.993367	0.986799	0.980297	0.973860	0.967486	0.961176	0.948743
4	1.487562	1.475249	1.463061	1.450995	1.439053	1.427234	1.403960
5	1.980100	1.960401	1.940905	1.921611	1.902520	1.883633	1.846472
6	2.470980	2.442256	2.413833	2.385715	2.357904	2.330404	2.276346
7	2.960202	2.920815	2.881851	2.843318	2.805225	2.767581	2.693665
8	3.447766	3.396080	3.344963	3.294434	3.244510	3.195208	3.098524
9	3.933673	3.868053	3.803176	3.739077	3.675786	3.613331	3.491033
10	4.417923	4.336736	4.256498	4.177264	4.099085	4.022007	3.871314
11	4.900517	4.802131	4.704936	4.609014	4.514444	4.421295	4.239503
12	5.381454	5.264242	5.148499	5.034348	4.921902	4.811261	4.595747
13	5.860734	5.723071	5.587198	5.453288	5.321501	5.191977	4.940207
14	6.338360	6.178621	6.021042	5.865859	5.713289	5.563521	5.273051
15	6.814330	6.630896	6.450043	6.272087	6.097314	5.925976	5.594460
16	7.288645	7.079899	6.874214	6.672000	6.473629	6.279428	5.904626
17	7.761306	7.525635	7.293567	7.065628	6.842292	6.623972	6.203746
18	8.232314	7.968108	7.708116	7.453002	7.203360	6.959705	6.492028
19	8.701668	8.407322	8.117876	7.834156	7.556896	7.286728	6.769688
20	9.169370	8.843282	8.522862	8.209125	7.902965	7.605148	7.036948
21	9.635420	9.275993	8.923090	8.577945	8.241635	7.915075	7.294034
22	10.099819	9.705459	9.318577	8.940654	8.572976	8.216625	7.541181
23	10.562568	10.131688	9.709341	9.297292	8.897062	8.509914	7.778626
24	11.023667	10.554683	10.095401	9.647901	9.213968	8.795065	8.006612
25	11.483116	10.974452	10.476774	9.992523	9.523771	9.072201	8.225382
26	11.940918	11.391000	10.853482	10.331203	9.826553	9.341450	8.435184
27	12.397073	11.804334	11.225544	10.663985	10.122396	9.602942	8.636268
28	12.851580	12.214460	11.592982	10.990917	10.411383	9.856809	8.828883
29	13.304443	12.621385	11.955818	11.312048	10.693601	10.103187	9.013281
30	13.755660	13.025117	12.314074	11.627426	10.969139	10.342211	9.189712
31	14.205234	13.425662	12.667774	11.937102	11.238085	10.574020	9.358427
32	14.653166	13.823028	13.016941	12.241128	11.500532	10.798753	9.519675
33	15.099455	14.217224	13.361599	12.539558	11.756571	11.016552	9.673702
34	15.544104	14.608256	13.701775	12.832444	12.006297	11.227559	9.820753
35	15.987114	14.996134	14.037493	13.119843	12.249805	11.431916	9.961072
40	18.177608	16.888504	15.650163	14.476511	13.377471	12.358976	10.569919
50	22.436345	20.441976	18.557509	16.812249	15.223265	13.796428	11.410714
60	26.533314	23.696103	21.067416	18.697232	16.606179	14.790945	11.901538
70	30.470255	26.663230	23.214541	20.196141	17.621186	15.461348	12.178318
80	34.249199	29.357178	25.035345	21.371849	18.352602	15.903279	12.330132
90	37.872449	31.792924	26.566654	22.282554	18.871195	16.189123	12.411584
100	41.342569	33.986282	27.844447	22.980000	19.233724	16.371073	12.454520

GRADIENT MULTIPLIER

$$\frac{1}{I} - \frac{N}{(1 + I)^{**}N - 1}$$

N PERIODS	INTEREST RATE (PERCENT) 10.0	12.0	15.0	20.0	25.0	30.0	40.0
2	0.476190	0.471698	0.465116	0.454545	0.444444	0.434783	0.416667
3	0.936556	0.924609	0.907127	0.879121	0.852459	0.827068	0.779817
4	1.381168	1.358852	1.326257	1.274218	1.224932	1.178277	1.092342
5	1.810126	1.774595	1.722815	1.640507	1.563065	1.490308	1.357989
6	2.223557	2.172047	2.097190	1.978828	1.868332	1.765447	1.581099
7	2.621615	2.551465	2.449850	2.290163	2.142434	2.006282	1.766351
8	3.004479	2.913144	2.781329	2.575623	2.387248	2.215595	1.918516
9	3.372351	3.257417	3.092226	2.836424	2.604777	2.396273	2.042242
10	3.725461	3.584653	3.383196	3.073862	2.797098	2.551219	2.141904
11	4.064054	3.895255	3.654941	3.289291	2.966314	2.683277	2.221488
12	4.388402	4.189653	3.908205	3.484102	3.114516	2.795171	2.284537
13	4.698792	4.468304	4.143760	3.659700	3.243742	2.889458	2.334123
14	4.995529	4.731688	4.362408	3.817486	3.355948	2.968501	2.372866
15	5.278933	4.980303	4.564961	3.958841	3.452988	3.034445	2.402955
16	5.549341	5.214664	4.752246	4.085109	3.536596	3.089214	2.426198
17	5.807097	5.435297	4.925089	4.197588	3.608375	3.134513	2.444063
18	6.052560	5.642737	5.084312	4.297515	3.669792	3.171834	2.457734
19	6.286095	5.837524	5.230729	4.386067	3.722177	3.202472	2.468154
20	6.508075	6.020203	5.365137	4.464347	3.766726	3.227541	2.476067
21	6.718878	6.191317	5.488316	4.533386	3.804506	3.247990	2.482057
22	6.918886	6.351407	5.601020	4.594142	3.836462	3.264623	2.486576
23	7.108483	6.501007	5.703979	4.647495	3.863426	3.278116	2.489978
24	7.288054	6.640645	5.797894	4.694255	3.886125	3.289037	2.492531
25	7.457982	6.770840	5.883433	4.735159	3.905195	3.297854	2.494443
26	7.618650	6.892097	5.961234	4.770876	3.921182	3.304959	2.495872
27	7.770437	7.004912	6.031900	4.802010	3.934560	3.310673	2.496938
28	7.913716	7.109764	6.096002	4.829106	3.945735	3.315261	2.497732
29	8.048858	7.207117	6.154077	4.852652	3.955055	3.318937	2.498322
30	8.176226	7.297419	6.206627	4.873084	3.962816	3.321879	2.498760
31	8.296174	7.381102	6.254123	4.890788	3.969269	3.324229	2.499085
32	8.409051	7.458580	6.297003	4.906109	3.974627	3.326105	2.499325
33	8.515196	7.530248	6.335673	4.919352	3.979070	3.327599	2.499503
34	8.614940	7.596486	6.370512	4.930785	3.982751	3.328789	2.499634
35	8.708603	7.657653	6.401867	4.940645	3.985797	3.329735	2.499731
40	9.096234	7.898791	6.516777	4.972766	3.994682	3.332226	2.499943
50	9.570413	8.159724	6.620484	4.994505	3.999286	3.333233	2.499998
60	9.802294	8.266414	6.652977	4.998935	3.999908	3.333325	2.500000
70	9.911252	8.308215	6.662720	4.999799	3.999988	3.333333	2.500000
80	9.960926	8.324093	6.665552	4.999963	3.999999	3.333333	2.500000
90	9.983057	8.329986	6.666357	4.999993	4.000000	3.333333	2.500000
100	9.992743	8.332136	6.666582	4.999999	4.000000	3.333333	2.500000

GRADIENT PRESENT WORTH MULTIPLIER

$$\frac{(1+I)^{**}N-1}{(I^{**}2)(1+I)^{**}N}-\frac{N}{I(1+I)^{**}N}$$

N PERIODS	INTEREST RATE (PERCENT) 1.0	2.0	3.0	4.0	5.0	6.0	8.0
2	0.980296	0.961169	0.942596	0.924556	0.907029	0.889996	0.857339
3	2.921476	2.845813	2.772879	2.702549	2.634705	2.569235	2.445003
4	5.804417	5.617350	5.438340	5.266962	5.102812	4.945516	4.650093
5	9.610280	9.240273	8.888776	8.554670	8.236917	7.934549	7.372426
6	14.320506	13.680130	13.076197	12.506243	11.967994	11.459351	10.523274
7	19.916815	18.903491	17.954746	17.065749	16.232082	15.449694	14.024216
8	26.381197	24.877924	23.480611	22.180581	20.969957	19.841581	17.806098
9	33.695916	31.571966	29.611944	27.801275	26.126829	24.576768	21.808090
10	41.843498	38.955100	36.308790	33.881352	31.652048	29.602321	25.976831
11	50.806736	46.997731	43.533002	40.377162	37.498841	34.870197	30.265660
12	60.568677	55.671156	51.248181	47.247729	43.624052	40.336860	34.633911
13	71.112628	64.947546	59.419597	54.454618	49.987909	45.962928	39.046287
14	82.422147	74.799921	68.014129	61.961794	56.553792	51.712840	43.472280
15	94.481039	85.202128	77.000196	69.735497	63.288031	57.554551	47.885664
16	107.273358	96.128815	86.347700	77.744120	70.159704	63.459246	52.264021
17	120.783398	107.555416	96.027963	85.958092	77.140451	69.401076	56.588324
18	134.995693	119.458125	106.013671	94.349770	84.204302	75.356921	60.842558
19	149.895011	131.813879	116.278820	102.893334	91.327514	81.306155	65.013375
20	165.466356	144.600334	126.798659	111.564686	98.488414	87.230445	69.089791
21	181.694959	157.795850	137.549645	120.341358	105.667261	93.113553	73.062906
22	198.566280	171.379470	148.509387	129.202421	112.846108	98.941160	76.925656
23	216.065999	185.330900	159.656606	138.128400	120.008677	104.700700	80.672593
24	234.180020	199.630495	170.971082	147.101194	127.140239	110.381206	84.299677
25	252.894463	214.259236	182.433615	156.103997	134.227505	115.973173	87.804107
26	272.195662	229.198718	194.025984	165.121228	141.258524	121.468424	91.184151
27	292.070164	244.431131	205.730899	174.138459	148.222580	126.859991	94.439008
28	312.504724	259.939244	217.531971	183.142351	155.110108	132.142005	97.568679
29	333.486304	275.706388	229.413669	192.120590	161.912605	137.309593	100.573849
30	355.002069	291.716444	241.361285	201.061832	168.622551	142.358787	103.455792
31	377.039383	307.953823	253.360900	209.955639	175.233336	147.286432	106.216274
32	399.585810	324.403456	265.399348	218.792435	181.739187	152.090112	108.857475
33	422.629109	341.050775	277.464188	227.563449	188.135108	156.768071	111.381921
34	446.157229	357.881704	289.543669	236.260668	194.416816	161.319151	113.792416
35	470.158312	374.882643	301.626705	244.876794	200.580686	165.742729	116.091990
40	596.856056	461.993132	361.749945	286.530302	229.545181	185.956823	126.042200
50	879.417630	642.360589	477.480334	361.163846	277.914782	217.457376	139.592790
60	1192.806145	823.697534	583.052609	422.996648	314.343162	239.042791	147.300007
70	1528.647439	999.834315	676.086873	472.478923	340.840898	253.327135	151.532618
80	1879.877099	1166.786767	756.086524	511.116144	359.646048	262.549308	153.800083
90	2240.567482	1322.170082	823.630214	540.736923	372.748792	268.394607	154.992535
100	2605.775753	1464.752746	879.854045	563.124875	381.749224	272.047060	155.610726

GRADIENT PRESENT WORTH MULTIPLIER

$$\frac{(1 + I)^{**}N - 1}{(I^{**}2)(1 + I)^{**}N} - \frac{N}{I(1 + I)^{**}N}$$

N PERIODS	INTEREST RATE (PERCENT) 10.0	12.0	15.0	20.0	25.0	30.0	40.0
2	0.826446	0.797194	0.756144	0.694444	0.640000	0.591716	0.510204
3	2.329076	2.220754	2.071176	1.851852	1.664000	1.502048	1.239067
4	4.378116	4.127309	3.786436	3.298611	2.892800	2.552432	2.019992
5	6.861802	6.397016	5.775143	4.906121	4.203520	3.629748	2.763729
6	9.684171	8.930172	7.936781	6.580611	5.514240	4.665629	3.427781
7	12.763120	11.644267	10.192403	8.255101	6.772531	5.621827	3.996968
8	16.028672	14.471450	12.480715	9.883077	7.946936	6.479953	4.471291
9	19.421453	17.356330	14.754815	11.433531	9.020678	7.234350	4.858493
10	22.891342	20.254089	16.979477	12.887081	9.987046	7.887193	5.169637
11	26.396281	23.128850	19.128909	14.232961	10.846039	8.445179	5.416577
12	29.901220	25.952276	21.184888	15.466684	11.601953	8.917321	5.610602
13	33.377193	28.702366	23.135223	16.588251	12.261660	9.313524	5.761789
14	36.800499	31.362424	24.972496	17.600776	12.833407	9.643693	5.878780
15	40.151988	33.920171	26.693019	18.509453	13.325988	9.917206	5.968773
16	43.416425	36.366996	28.295990	19.320771	13.748200	10.142628	6.037645
17	46.581939	38.697306	29.782805	20.041943	14.108488	10.327591	6.090119
18	49.639539	40.907979	31.156492	20.680481	14.414733	10.478762	6.129943
19	52.582683	42.997901	32.421267	21.243896	14.674140	10.601887	6.160061
20	55.406912	44.967569	33.582173	21.739493	14.893195	10.701861	6.182770
21	58.109523	46.818762	34.644786	22.174228	15.077663	10.782812	6.199844
22	60.689288	48.554254	35.614999	22.554620	15.232615	10.848195	6.212650
23	63.146208	50.177589	36.498836	22.886709	15.362481	10.900885	6.222233
24	65.481297	51.692878	37.302324	23.176028	15.471095	10.943257	6.229388
25	67.696401	53.104637	38.031388	23.427611	15.561764	10.977269	6.234722
26	69.794037	54.417657	38.691771	23.645998	15.637322	11.004522	6.238690
27	71.777257	55.636890	39.288987	23.835267	15.700186	11.026324	6.241638
28	73.649527	56.767361	39.828280	23.999058	15.752412	11.043740	6.243825
29	75.414631	57.814092	40.314598	24.140605	15.795740	11.057633	6.245444
30	77.076579	58.782052	40.752587	24.262774	15.831640	11.068702	6.246643
31	78.639539	59.676104	41.146579	24.368092	15.861351	11.077510	6.247528
32	80.107775	60.500973	41.500602	24.458782	15.885911	11.084511	6.248182
33	81.485591	61.261221	41.818378	24.536796	15.906194	11.090071	6.248664
34	82.777294	61.961226	42.103340	24.603839	15.922927	11.094481	6.249019
35	83.987154	62.605170	42.358642	24.661400	15.936719	11.097976	6.249280
40	88.952536	65.115873	43.282991	24.846915	15.976606	11.107112	6.249848
50	94.888869	67.762412	44.095831	24.969782	15.996917	11.110754	6.249994
60	97.701011	68.810034	44.343066	24.994232	15.999608	11.111080	6.250000
70	98.987017	69.210289	44.415626	24.998925	15.999951	11.111109	6.250000
80	99.560633	69.359428	44.436392	24.999803	15.999994	11.111111	6.250000
90	99.811783	69.413973	44.442224	24.999964	15.999999	11.111111	6.250000
100	99.920178	69.433636	44.443839	24.999994	16.000000	11.111111	6.250000