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Setting the Standard for Automation™

CSE PE Exam Review: Control Systems

EN00W4 Version 1.4

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Seminar Logistics

- Seminar materials
  - Downloadable presentation
  - Question and Answer session (audio and email)
  - Survey
  - Earn 1 Professional Development Hour (PDH)
- Seminar length
  - 60 minute presentation
  - Three 10-minute question and answer sessions

Audio Instructions

- As a participant, you are in a “listen-only” mode.
- You may ask questions via the internet, using your keyboard, at any time during the presentation. However, the presenter may decide to wait to answer your question until the next Q&A Session.
- If you have audio difficulties, press *0.

Audio Instructions for Q&A Sessions

- Questions may be asked via your telephone line.
- Press the *1 key on your telephone key-pad.
- If there are no other callers on the line, the operator will announce your name and affiliation to the audience and then ask for your question.
- If other participants are asking questions, you will be placed into a queue until you are first in line.
- While in the queue, you will be in a listen-only mode until the operator indicates that your phone has been activated. The operator will announce your name and affiliation and then ask for your question.

Introduction of Presenter

- **Gerald Wilbanks, P.E.** Vice President of Documentation and Engineering Services in Birmingham, Alabama has over 40 years of experience in engineering, management, consulting, and design in heavy industry. He is a registered professional engineer in 4 states, a member of NSPE, ASQ, and an International Former President (1995) of ISA. Gerald is a graduate of Mississippi State University with a Bachelors Degree in Electrical Engineering and was recognized as the Engineer of the Year in 1991 by the Engineering Council of Birmingham. He is a Distinguished Engineering Fellow of Mississippi State University and is a Life Fellow member of ISA. He has served as an instructor in many courses, seminars, and other educational sessions for ISA and in his own business.

Key Benefits of Seminar

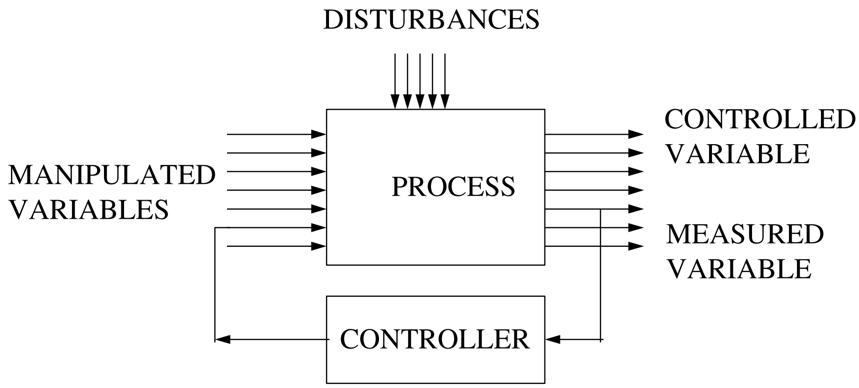
- Identify areas of focus for more effective studying to assist in passing the PE examination
- Explain control system functionality
- List Control System applications
- Discuss system documentation and standards used
- Review Control Loop Tuning
- Control Systems represents 18 problems or 22% of the CSE PE exam

Section 1: Control Loops

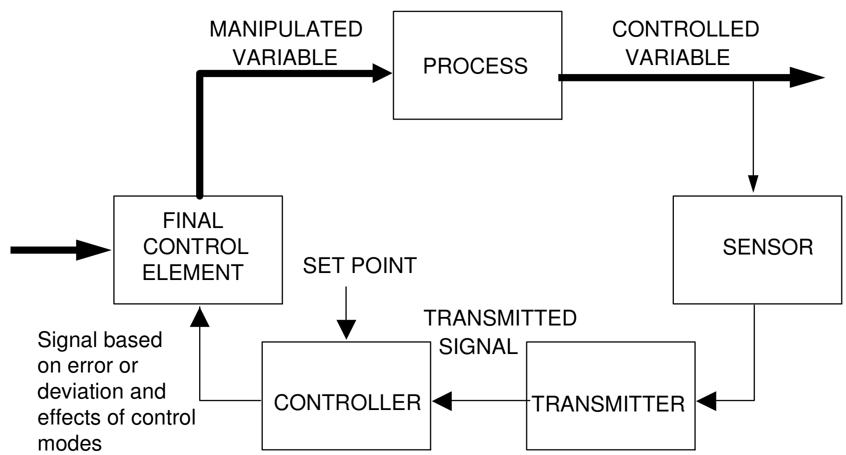
- Loop Definitions
- Controller Actions
- Loop Examples
- Proportional Mode
- Integral Mode
- Derivative Mode
- Controller Characteristics

Process Control

- The regulation or manipulation of variables influencing the conduct of a process in such a way as to obtain a product of desired quality and quantity in an efficient manner



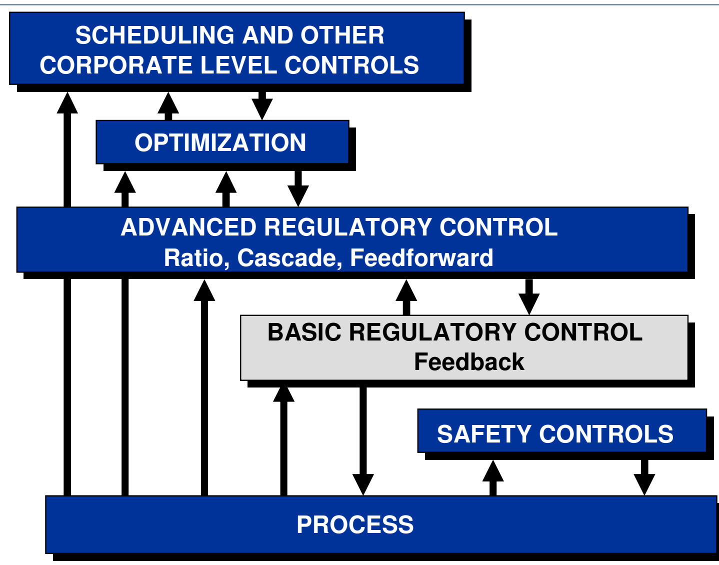
The Process Control System (Loop)



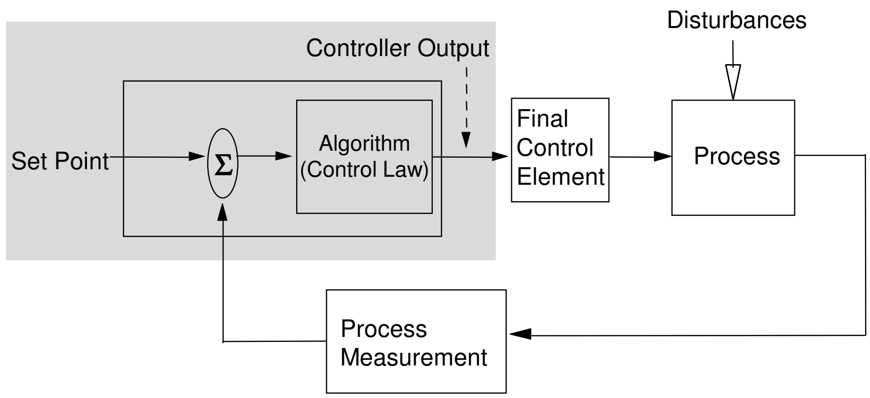
Controller Actions and Modes

- Direct and reverse actions
- On-Off control
- Proportional control
- Integral control
- Derivative control

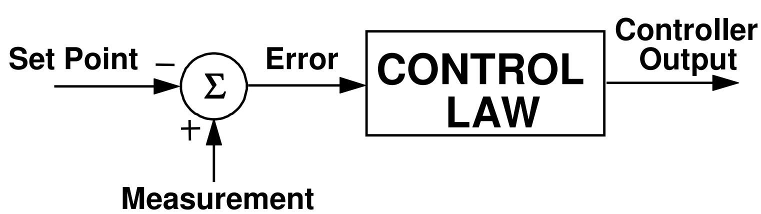
Control Hierarchy



Controllers and Control Strategies

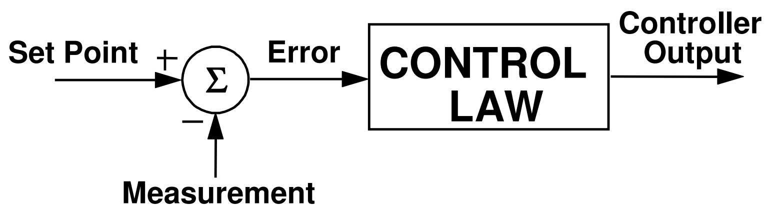


Direct Acting Controller



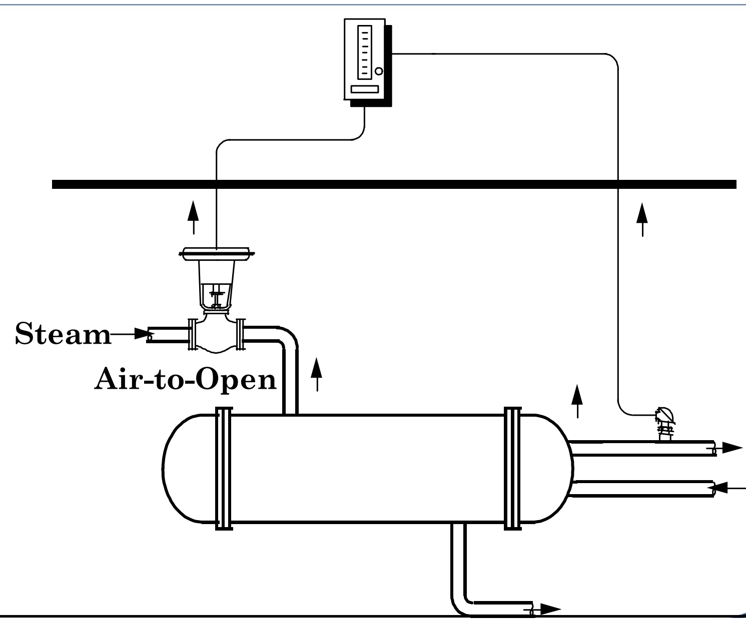
Increase in Measurement
Causes
Increase in Controller Output

Reverse Acting Controller

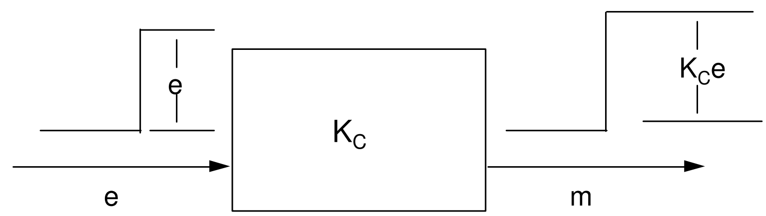


**Increase in Measurement
Causes
Decrease in Controller Output**

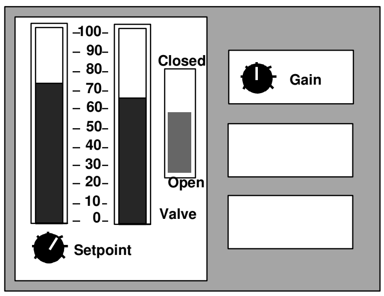
Direct or Reverse Acting - Example



Proportional Control



$$m = K_c e + \text{Bias}$$



Proportional Control Algorithm

Proportional Action

- **Proportional band**
  - The amount of input change that will produce 100% output change.
  - Always expressed as a percentage
- **Gain**
  - A unit-less number that defines the ratio of the change in output, due to proportional control action, to the change in input

$$G = \frac{\Delta out}{\Delta in} \qquad G = \frac{100}{PB}$$

PB	*G*
200%	*.5*
100%	*1*
50%	*2*

Integral Action

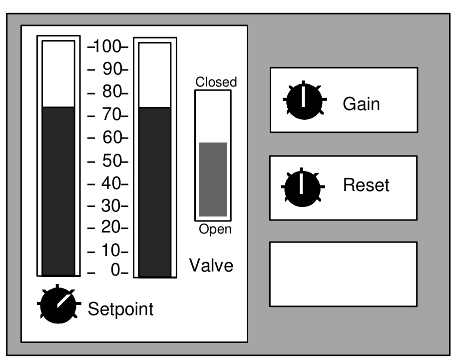
- Integral (reset):
  - Control action in which the output is proportional to the *time integral* of the input
  - Reset action is adjusted in repeats/minutes or minutes/repeat

Minutes/Repeat (T_i)		Repeats/Minute (T_r)
2	-------------------------	.5
1	-------------------------	1
.5	-------------------------	2

Proportional + Integral Control

Integral (Reset) Action: $m = \frac{1}{T_i} \int e\,dt$

Proportional - Plus - Integral (PI): $m = K_c \left[e + \frac{1}{T_i} \int edt \right] + Bias$



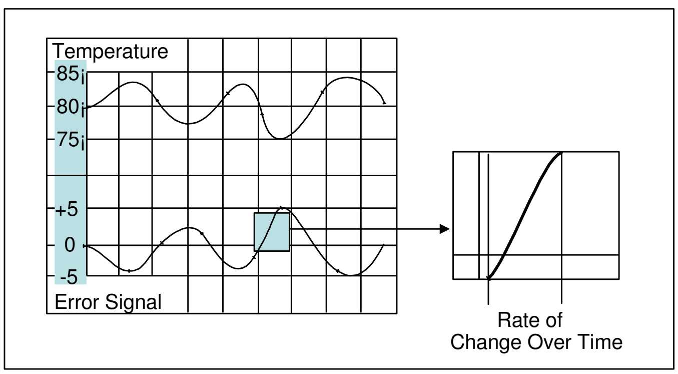
Derivative Action

- Derivative (rate):
  - Control action in which the output is proportional to the rate of change in the input

Derivative (Rate) Control Action

Control action in which the output is proportional to the rate of change in the input

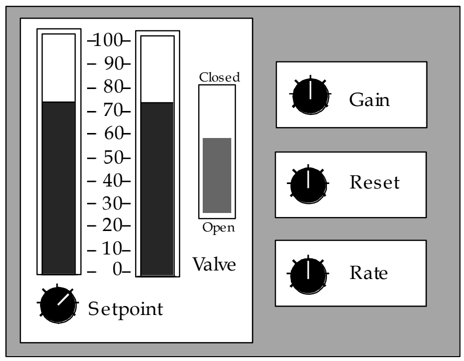
$$m = T_d \frac{d}{dt} e$$



Proportional + Integral + Derivative Control

Derivative (Rate) Action $m = T_D \frac{d}{dt} = e$

P + I + D $m = K_c \left[e + \frac{1}{T_i} \int edt + T_d \frac{d}{dt} e \right]$ + Bias



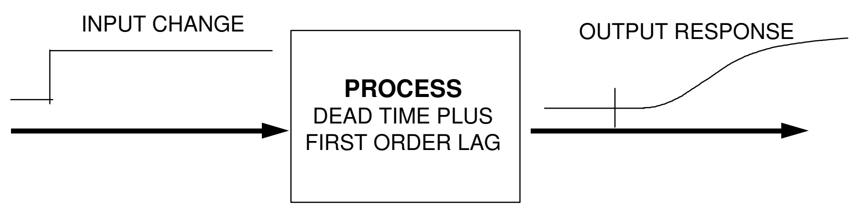
Characteristics of Controller Modes

- Proportional
  - Simple
  - Inherently stable when properly tuned
  - Easy to tune
  - Experiences offset at steady state
- Proportional-plus-reset
  - No offset
  - Better dynamic response than reset alone
  - Possibilities exist for instability due to lag introduced

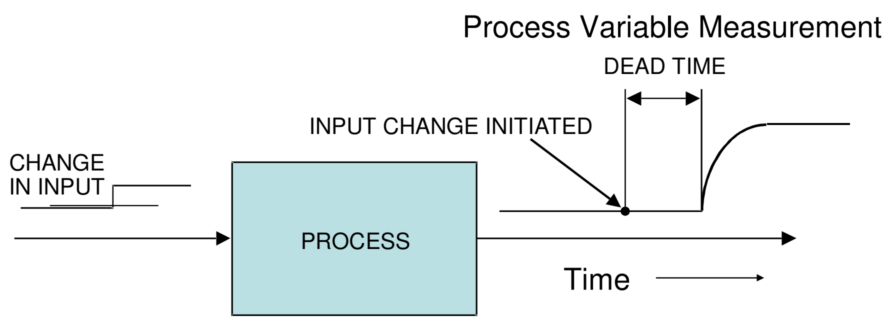
Characteristics of Controller Modes (cont'd)

- Proportional-plus-rate
  - Stable
  - Less offset than proportional alone (use of higher Kc possible)
  - Reduces lags, i.e., more rapid response
- Proportional-plus-reset-plus-rate
  - Most complex
  - Rapid Response
  - No offset
  - Difficult to tune
  - Best control if properly tuned

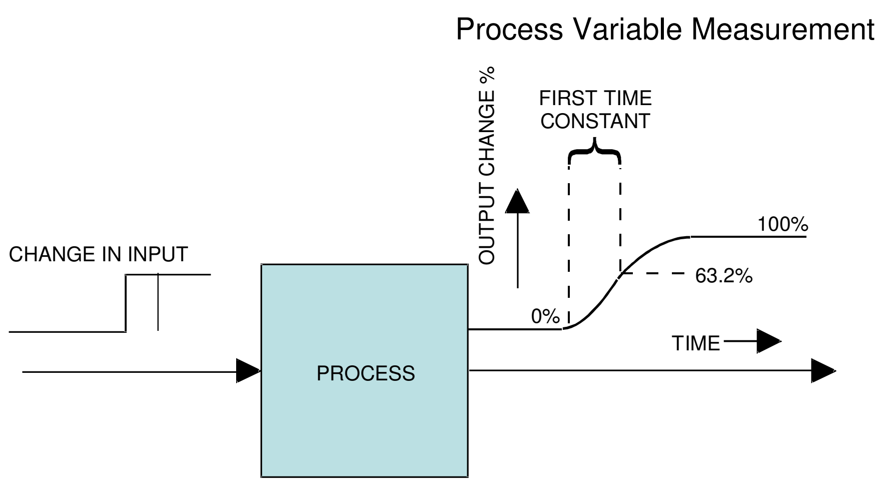
Process Dynamics (Response to Change)



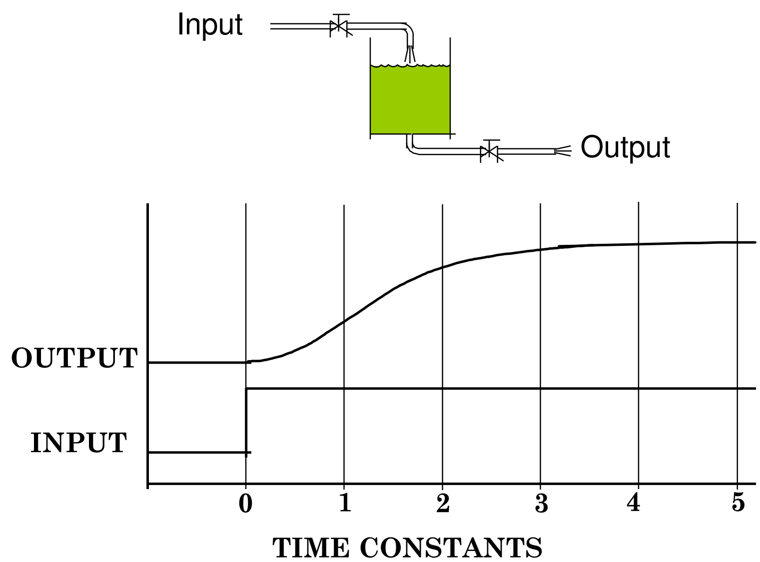
Dead Time



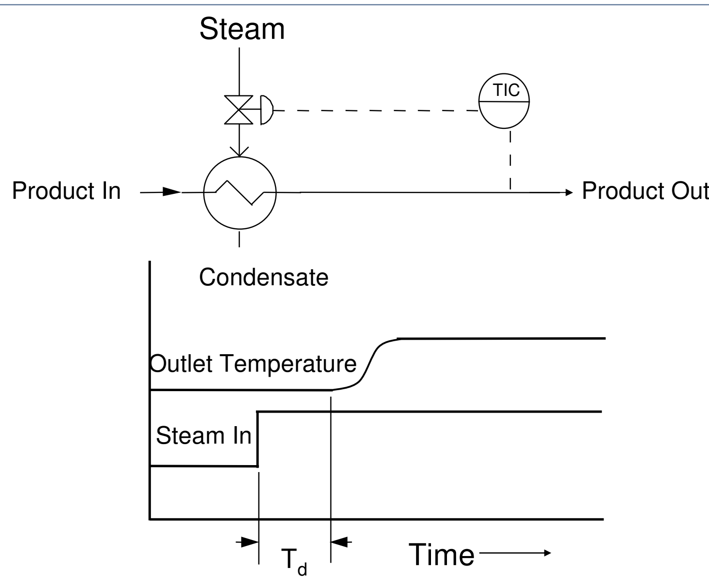
Time Constant



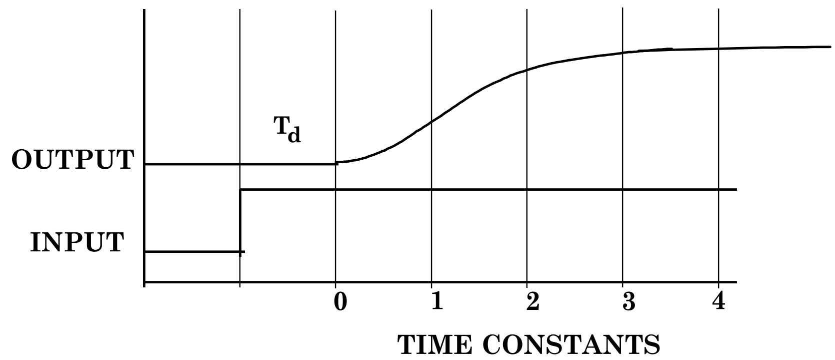
First Order Lag



Dead Time



First Order Lag plus Dead Time

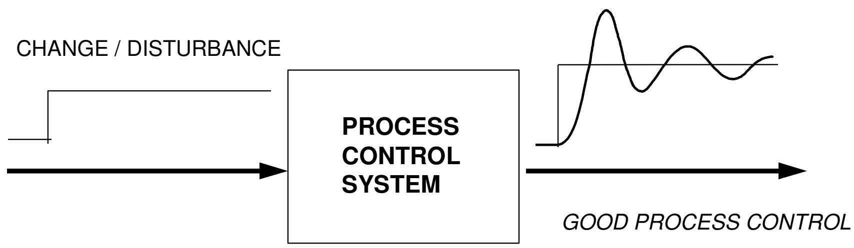


Tuning Methods

- Objectives of Tuning
- Trial & error
- Open-loop test
- Closed-loop test
- Improving “as found” tuning

Objectives of Tuning

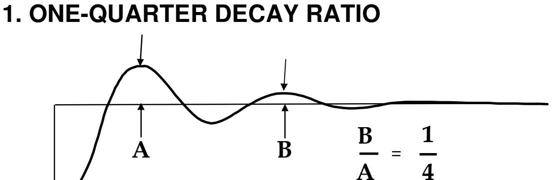
- Adjustment of gain, reset, and rate to achieve *"good" process control*



Objectives of Tuning (cont'd)

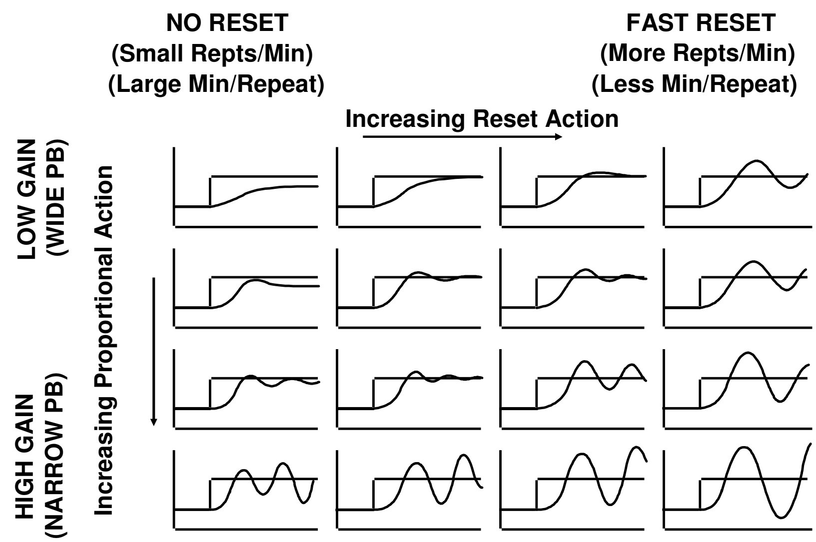
Acceptable response to a set point change

1. ONE-QUARTER DECAY RATIO



2. MINIMIZE OVERSHOOT

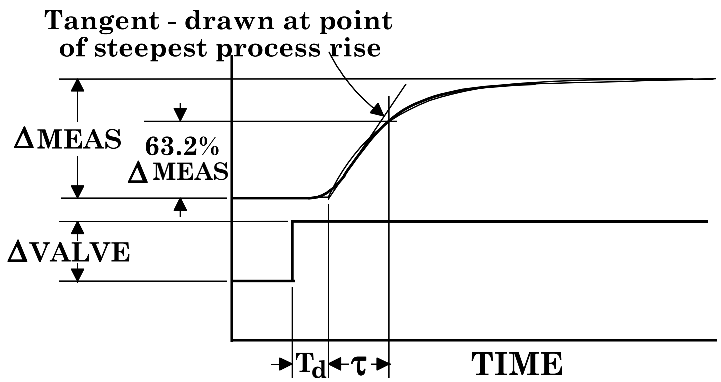
Tuning Map - Gain and Reset



Tuning by Open Loop Testing

- Process near normal operating point
- Controller in MANUAL
- Step change the controller output
- Approximate the observed response by a simplified process model
- From the model parameters, use “somebody’s” correlation to determine controller tuning parameters

Z-N Open Loop Test Method



K_p = PROCESS GAIN = $\frac{\Delta \text{MEAS}}{\Delta \text{VALVE}}$

T_d = DEAD TIME

τ = TIME CONSTANT

Open Loop Method (cont'd)

TUNING PARAMETERS

	P	PI	PID
K_C (Gain)	$\frac{\tau}{K_p T_d}$	$\frac{0.9\,\tau}{K_p T_d}$	$\frac{1.2\,\tau}{K_p T_d}$
T_I (Minutes/Repeat)	—	3.33 T_d	2.0 T_d
T_D (Minutes)	—	—	0.5 T_d

Problems with Open Loop Method

- Sensitive to parameter estimation error (especially dead time)
- Simplified form of process model may not match the actual process
- Controller not in normal operating mode
- Limitations on step size may make it difficult to interpret the response - especially in the presence of noise
- Closed loop response may not be acceptably damped for a set point change

Tuning by Closed Loop Testing

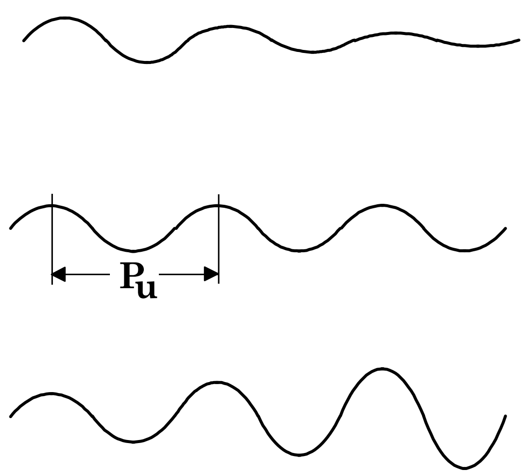
- Process near normal operating point
- Controller in AUTOMATIC
- GAIN only; no RESET nor DERIVATIVE
- Induce sustained oscillation by gradually increasing controller gain
- Note the ultimate period (P_u) and ultimate gain (K_{cu})
- Use correlation to determine controller tuning parameters

Z-N Closed Loop Method

Increase K_c

$K_{cu} = K_c$

Decrease K_c



Closed Loop Method (cont'd)

TUNING PARAMETERS

	P	PI	PID
K_C (Gain)	$0.5\ K_{cu}$	$0.45\ K_{cu}$	$0.6\ K_{cu}$
T_I (Minutes/Repeat)	—	$0.83\ P_u$	$0.5\ P_u$
T_D (Minutes)	—	—	$0.125\ P_u$

Problems with Closed Loop Method

- May not be possible to drive process into oscillating condition
- May require several tests - longer testing time - than open loop method
- Cannot guarantee how much the PV - nor the controller output - will “swing”

Good Points with Closed Loop Test

- Controller is operating in its normal mode (automatic)
- No artificial form of the process model imposed
- Minimal uncertainty in the data

Review of Key Points

- The controller action works together with the control valve operation
- Controller law or algorithm determines the output from the controller in response to loop error
- Control modes must be selected based on the process characteristics and response
- Three mode control is not always the most effective selection
- The control modes are interactive and dynamic

Live Question and Answer Session

- During Q&A, questions may be asked via your telephone line.
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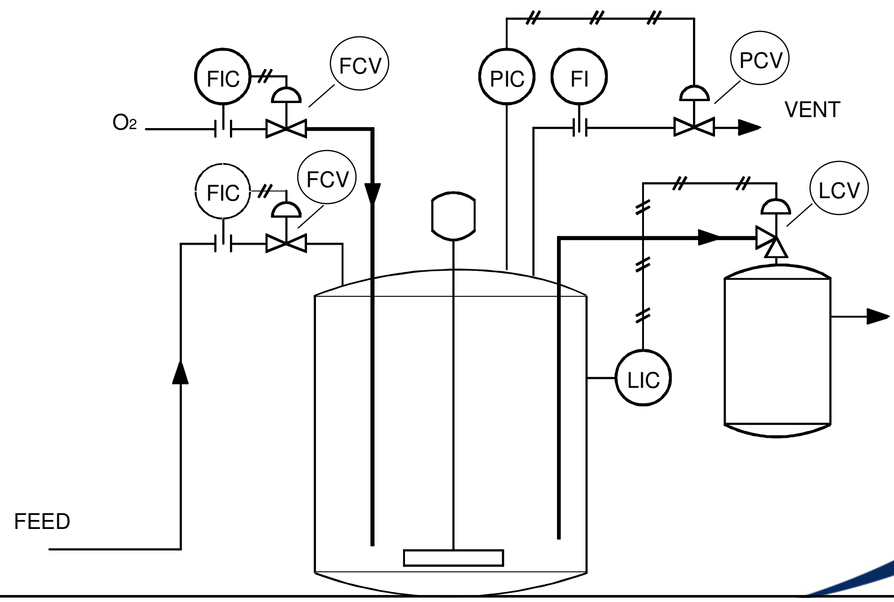
Section 2: System Documentation

- Process and Instrument Diagrams
- ISA Standards for Documentation
- Loop Numbering Conventions
- Loop Diagram Symbology
- Instrument Lists
- Installation Details

Process and Instrumentation Diagram



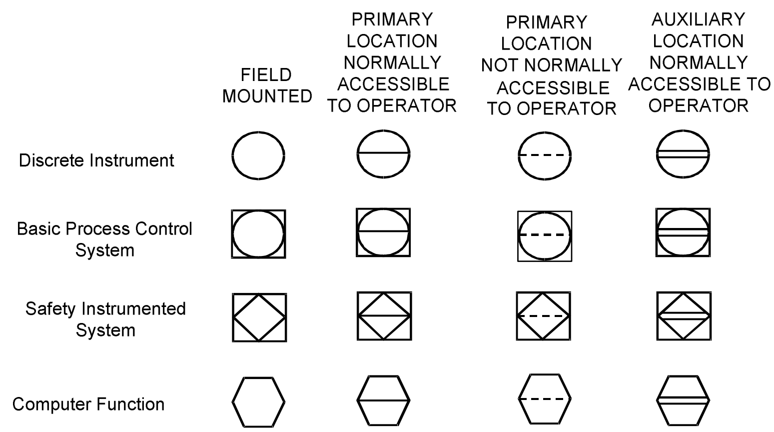
Identification Letters

	FIRST LETTER		SUCCEEDING LETTERS		
	Measured or Initiating Variable	Modifier	Readout or Passive Function	Output Function	Modifier
A	Analysis		Alarm		
B	Burner, Combustion		User's Choice	User's Choice	User's Choice
C	User's Choice			Control	Close
D	User's Choice	Differential			Deviation
E	Voltage		Sensor (Primary) Element		
F	Flow Rate	Ratio (Fraction)			
G	User's Choice		Glass, Gauge Viewing device		
H	Hand				High
I	Current (Electrical)		Indicate		
J	Power	Scan			
K	Time, Time Schedule	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		Open

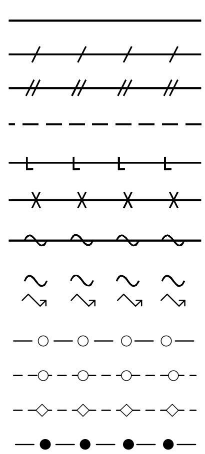
Identification Letters (cont'd)

	FIRST LETTER		SUCCEEDING-LETTERS		
	Measured or Initiating Variable	Modifier	Readout or Passive Function	Output Function	Modifier
P	Pressure, Vacuum		Point Connection		
Q	Quantity	Integrate			
R	Radiation		Record		
S	Speed, Frequency	Safety		Switch	
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	Multifunction
V	Vibration, Mechan. Analysis			Valve, Damper, Louver	
W	Weight, Force		Well		
X	Unclassified	X Axis	Unclassified	Unclassified	Unclassified
Y	Event, State	Y Axis		Relay, Compute	
Z	Position, Dimension	Z Axis		Driver, Actuator, Final Element	

General Instrument or Function Symbols



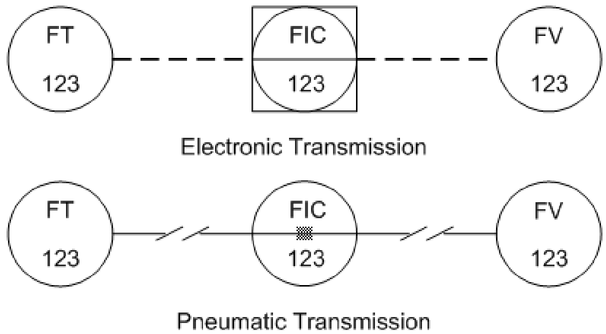
Instrument to Instrument Connection Symbols



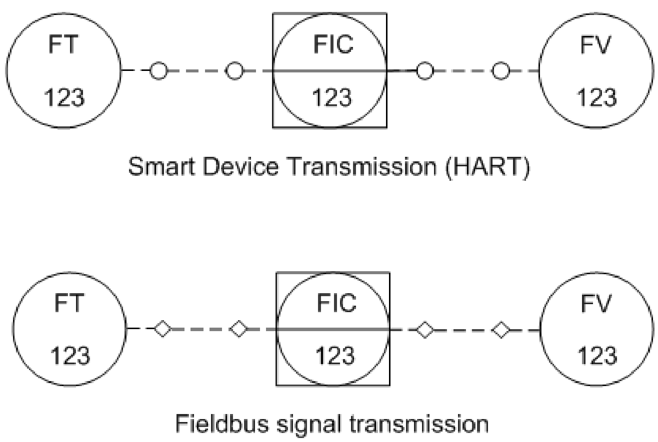
INSTRUMENT SUPPLY OR CONNECTION TO PROCESS
UNDEFINED SIGNAL
PNEUMATIC SIGNAL
ELECTRONIC SIGNAL
HYDRAULIC SIGNAL
CAPILLARY TUBE
ELECTROMAGNETIC SIGNAL (GUIDED)
ELECTROMAGNETIC (WIRELESS) SIGNAL (UNGUIDED)
COMMUNICATIONS LINK – BETWEEN SYSTEM DEVICES
COMMUNICATIONS LINK – TO/FROM SMART (HART) DEVICE
COMMUNICATIONS LINK – TO/FROM INTELLIGENT (FIELDBUS) DEVICE
COMMUNICATIONS LINK – BETWEEN TWO SYSTEMS (e.g. DCS and SIS)

Refer to ISA5.1 Table 5.3.2 for additional symbols

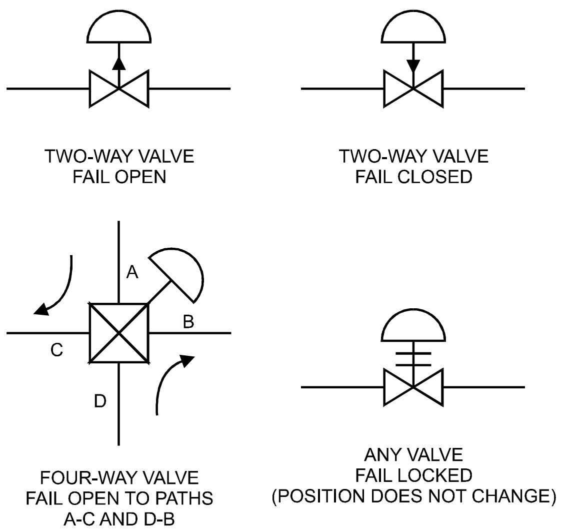
Example #1 – Adding Signal Transmission Lines



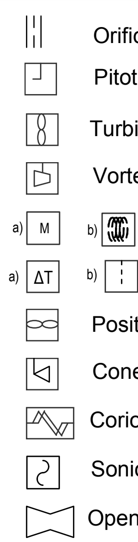
Example #2 – Adding Signal Transmission Lines cont'd



Actuator Action and Power Failure



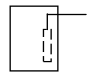
Flow Measuring Element Symbols

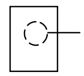


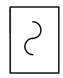
- Orifice plate or restriction orifice
- Pitot tube
- Turbine flowmeter
- Vortex shedding flowmeter
- Magnetic flowmeter
- Thermal mass flowmeter
- Positive displacement flowmeter
- Cone flowmeter
- Coriolis mass flowmeter
- Sonic flowmeter
- Open channel flowmeter

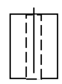
Refer to ISA5.1 Table 5.2.3 for additional symbols

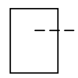
Level Measuring Element Symbols

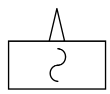

Displacer internally mounted in vessel


Ball float internally mounted in vessel


Sonic or Single point Radiation

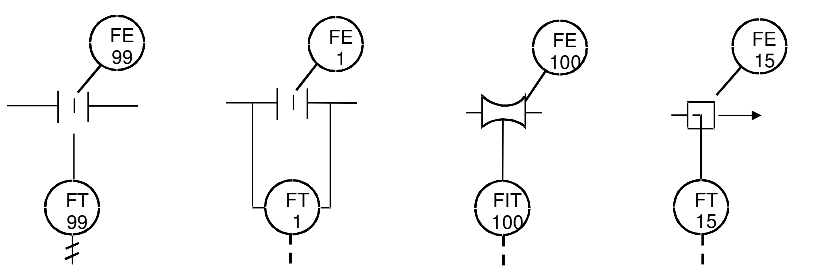

Dip Tube and other primary element


Probe inserted in vessel


Radar

Refer to ISA5.1 Table 5.2.3 for additional symbols

Typical Transmitters – Flow



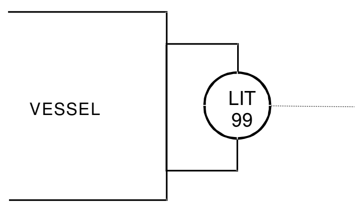
Orifice plate and orifice flanges with flange taps, differential pressure transmitter, pneumatic transmission

Orifice plate and flanges, taps are made in pipe, differential pressure transmitter, electronic transmission

Venturi tube, taps are in tube, differential pressure transmitter with indicator, electronic transmission

Pitot tube, connections are in tube, differential pressure transmitter, electronic transmission

Level using Differential Pressure Transmitter



Differential pressure type transmitter, electronic signal

ISA Standards used for Documentation

- ISA5.1-2009, Instrumentation Symbols and Identification
- ISA5.4-1991, Instrument Loop Diagrams
- ISA5.5-1985, Graphic Symbols for Process Displays

Other Documentation

- Loop diagrams
- Process flow diagrams
- Instrument lists
- Instrument installation
- Piping specifications

Review of Key Points

- Control systems can be documented in a logical and standard manner
- Each drawing has a specific purpose and conveys information to a variety of people
- The P&I Diagram is the central most important document to portray the overall control function
- Calculations and device selection is based on the documents for the system function

Live Question and Answer Session

- During Q&A, questions may be asked via your telephone line.
- Press the *1 key on your telephone key-pad.
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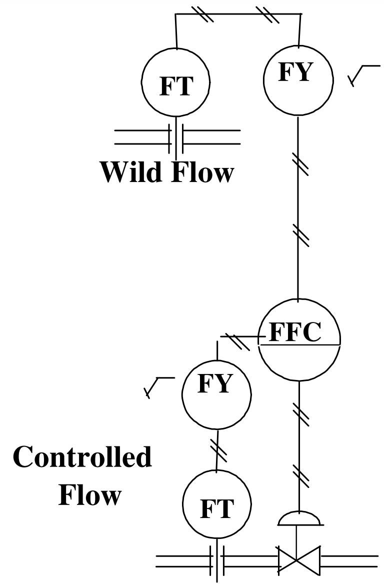
Section 3: Control Types/Characteristics

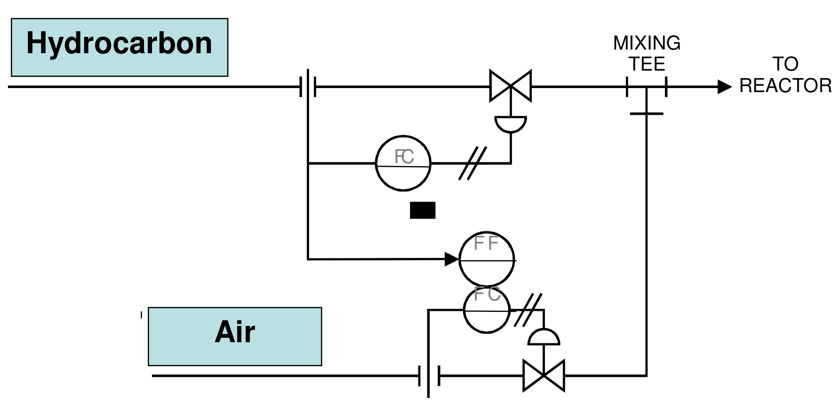
- Ratio control
- Cascade control
- Feedforward control

Ratio Control - Wild Stream

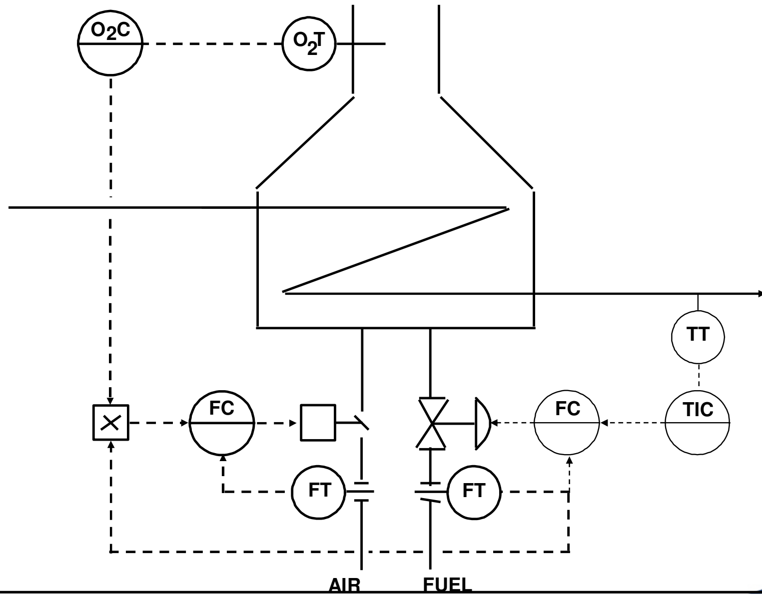
- RATIO CONTROL:
  Flow rate of one stream paces the flow rate of a second stream



Ratio Control - Both Streams Controlled

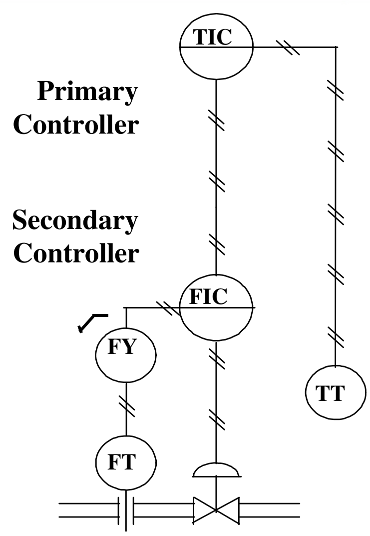


Automatic Ratio Set: Example

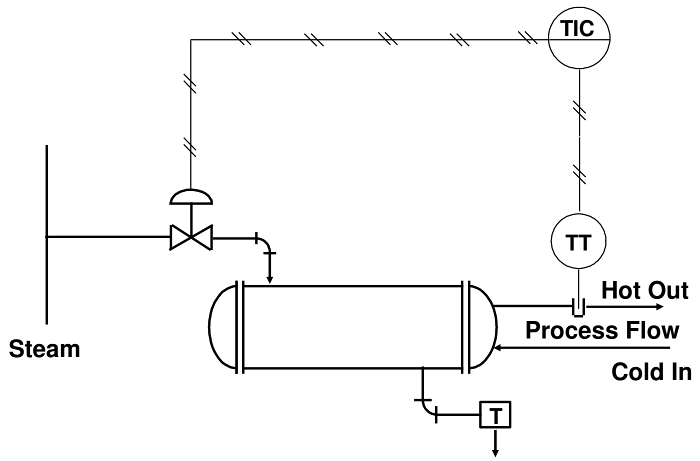


Cascade Control: Diagram

- CASCADE CONTROL:
  When one *feedback controller* sets the set point of another *feedback controller*



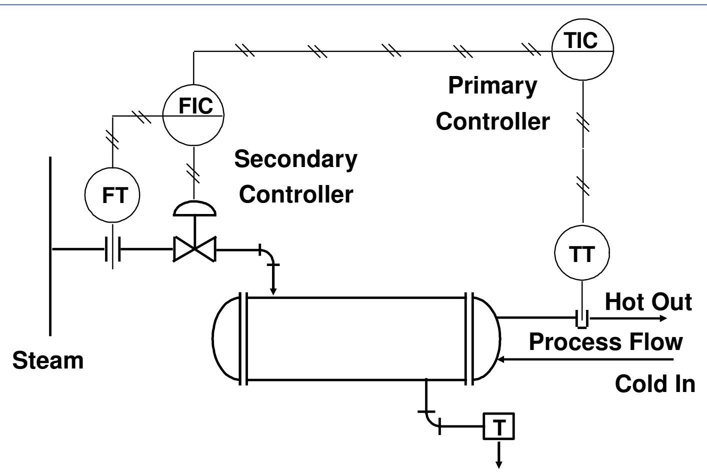
Application: Without Cascade



Disturbance: Drop in Steam Header Pressure

Consequence: Feedback Penalty Paid at Temperature Controller

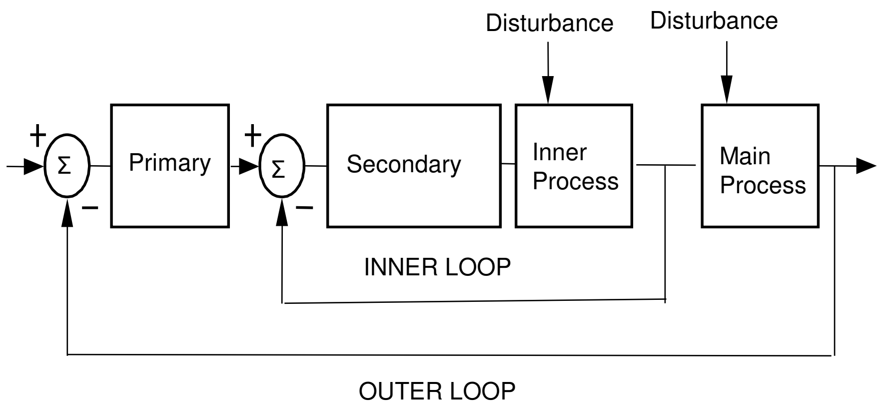
Application: With Cascade



Disturbance: Drop in Steam Header Pressure

Consequence: Feedback Penalty Flow Controller; Minimal Effect at Temperature Controller

Inner and Outer Loops



Feedforward Control: Definition

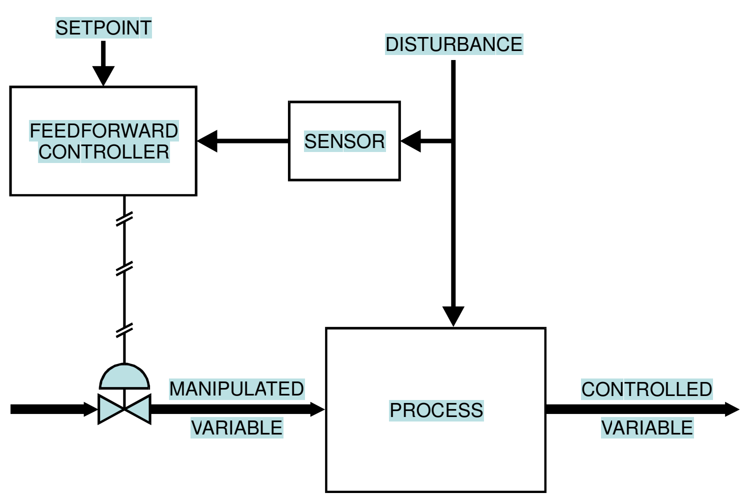
FEEDFORWARD CONTROL:

The final control device (valve or set point of lower level flow controller) is manipulated by a measurement of the process disturbance, rather than by the output of a feedback controller

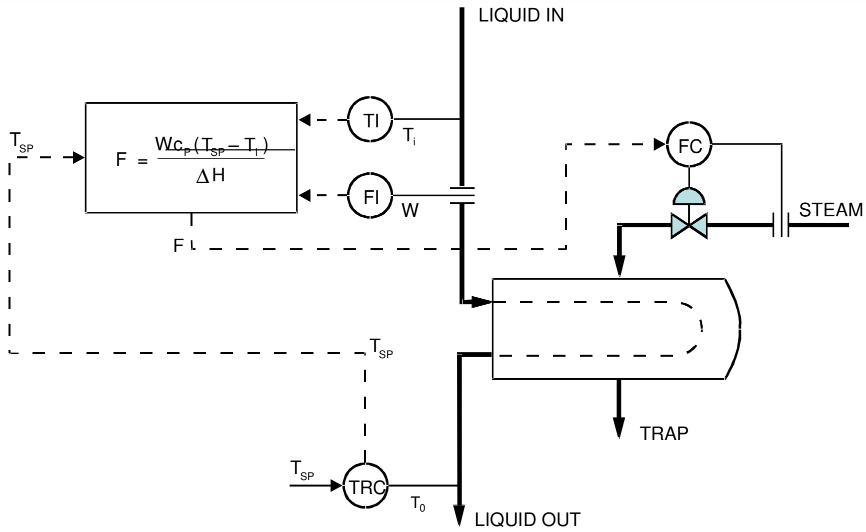
Feedforward Control: Requirements

- The disturbance must be measurable
- We must know what to do to compensate for the disturbance
- We must know when (i.e., on what time schedule) to take the compensating action

Feedforward Control Loop (cont'd)

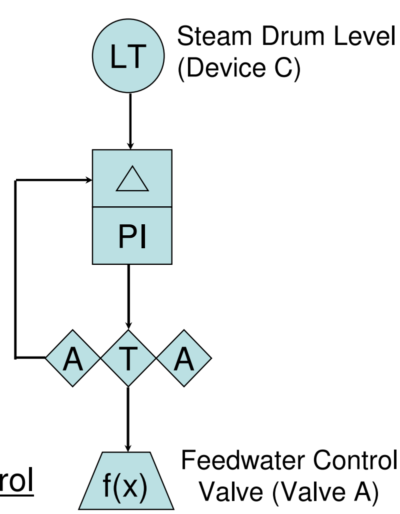


Feedforward Control of Heat Exchanger



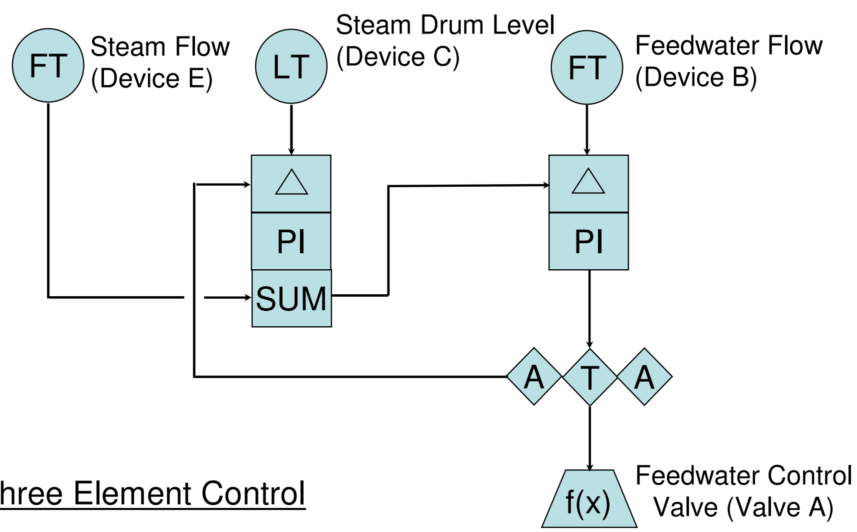
ADJUSTING THE SETPOINT

Level Control Strategy – Functional Diagram



Single Element Control

Level Control Strategy – Functional Diagram



Three Element Control

Review of Key Points

- Blending and mixing can be done with ratio control systems
- Cascade control is when the output of one feedback controller is the set point for another controller
- The inner loop of a cascade system should have a much faster speed of response than the primary control loop
- Feedforward control may be used with feedback control to provide correction in anticipation of a disturbance.

Live Question and Answer Session

- During Q&A, questions may be asked via your telephone line.
- Press the *1 key on your telephone key-pad.
- If there are no other callers on the line, the operator will announce your name and affiliation to the audience and then ask for your question.
- If other participants are asking questions, you will be placed into a queue until you are first in line.
- While in the queue, you will be in a listen-only mode until the operator indicates that your phone has been activated. The operator will announce your name and affiliation and then ask for your question.

How Many People Are at Your Site?

- Poll Slide
- Click on the appropriate number indicating the number of people that are at your site.

Sample Exam Question - #1

- According to ISA Standard 5.1, Instrumentation Symbols and Identification, the terms “record” or “recording” can apply to which of the following:

  I. Graphical data in a strip or circular chart
  II. A table of numerical data in a computer memory
  III. A listing of alarms by a control computer

  A. I and II
  B. II and III
  C. I and III
  D. I, II, and III

Sample Exam Question - #2

- The control algorithm for a flow control loop is under consideration. It is determined that the flow must be maintained near set point with little or no offset and the signal will be rapid response and noisy. The best choice of control modes for this loop will be:

  A. Proportional Mode
  B. Integral plus Derivative
  C. Proportional plus Integral
  D. Proportional plus Integral plus Derivative

Sample Exam Question - #3

- A secondary steam distribution system is being used to control the heat input to a heat exchanger. It has been determined that a control problem will exist since the varying steam header pressure will be a major disturbance. Define the primary controlled variable and what control scheme could be employed to provide the best response with the least amount of measured variable offset.

  A. Product outlet temperature with header pressure feedforward control
  B. Steam header pressure with outlet temperature adjusting set point
  C. Product outlet temperature with temperature cascading steam flow
  D. Product outlet temperature with direct feedback control.

Sample Exam Question - #4

- Compared to a control loop with no dead time (pure time delay), a control loop with an appreciable dead time tends to require:

  A. Less proportional gain and less integral action
  B. More proportional gain and less integral action
  C. More proportional gain and more integral action
  D. Less proportional gain and more integral action

Related Courses from ISA

- Understanding and Applying Standard Instrumentation and Control Documentation (FG15)
- Tuning Advanced Controllers (TC05C2)
- Understanding Industrial Process Measurement and Control (FG05)
- All ISA courses are available any time as on-site training
- For more information: www.isa.org/training or (919) 549-8411

Other Related Resources from ISA

- *Instrument Engineer's Handbook, 3rd Edition* (Bela Liptak) from ISA Press
- *Fundamentals of Process Control Theory* (Paul Murrill) from ISA Press
- *The Condensed Handbook of Measurement and Control, 2nd Edition* (N. Battikha) from ISA Press
- ISA5.1-2009 – Instrumentation Symbols & Identification

Other Related Resources from ISA

- ISA Membership is just $100 per year, which includes free membership in two Technical Divisions (a $20 value) - one from each Department: Automation and Technology and Industries and Sciences.
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