Process Control
20EI601
July/August 2023
Scheme of evaluation and Solutions

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EIE Department

Signature of faculty Signature of HOD

20EI601

Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

July/August, 2023 **Electronics & Instrumentation Engineering**

Sixth Semester **Process Control**

Time: Three Hours **Maximum:** 70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**

Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	M
1	a)	Give any two examples of proportional elements.	CO1	BL1	1
	b)	List the applications of Flapper-Nozzle system.	CO1	BL1	1
	c)	Where self-regulation is needed ?	CO1	BL1	1
	d)	What is ITAE criterion?	CO1	BL2	1
	e)	What is the role of Dead Band in ON-OFF control ?	CO2	BL2	1
	f)	Sketch any one type of plug for each of the single-seat and double-seat valves.	CO2	BL1	1
	g)	What are the applications of gate valve?	CO2	BL2	1
	h)	Identify the applications of ratio controller.	CO2	BL3	1
	i)	What are the disadvantages of feed forward control?	CO3	BL1	1
	j)	Sketch the structure of internal model control scheme.	CO3	BL2	1
	k)	Define controller tuning.	CO4	BL1	1
	l)	Write the mathematical model of a single time-constant process.	CO4	BL3	1
	m)	What is the need of mathematical modelling ?	CO4	BL1	1
	n)	Draw a typical first order liquid system.	CO4	BL2	1
		Unit-I			
2	a)	Distinguish between Batch process and Continuous process control with suitable examples.	CO1	BL3	7M
	b)	Describe the mathematical modeling of home heating system	CO4	BL3	7M
		(OR)			
3	a)	Analyze the degree of freedom of a process with an example	CO1	BL3	7M
	b)	Explain the characteristics of a PID controller. What is meant by reset rate?	CO2	BL2	7M
		Unit-II			
4	a)	Discuss about electronic controller with relevant diagram	CO2	BL2	7M
	b)	Explain the operation of a pneumatic actuator with positioner with a neat diagram.	CO2	BL2	7M
		(OR)			
5	a)	With a neat sketch explain the realization of pneumatic Proportional-Derivative control action.	CO2	BL2	7M
	b)	Outline the operation of rotating vane type control valves with neat sketch.	CO2	BL2	7M
		Unit-III			
6	a)	Design a cascade control system choosing an example process and analyze the same.	CO4	BL4	7M
	b)	Explain the concept of split range control with an application .	CO3	BL2	7M
		(OR)			
7	a)	Explain the feed forward control with a suitable example and neat sketch.	CO3	BL2	7M
	b)	Explain how smith predictor control scheme is suitable for dead time processes.	CO3	BL2	7M
		Unit-IV			
8	a)	Explain the procedure to design internal model control for a first order process	CO3	BL2	7M
	b)	What is process identification? Explain frequency testing and pulse testing methods.	CO3	BL2	7M
		(OR)			
9	a)	Explain about Cohen-Coon controller tuning method.	CO4	BL3	7M
	b)	Define the terms and symbols used in P&I diagrams	CO4	BL2	7M

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1(a) Give any two examples of proportional elements
(b) List the applications of Flapper-Nozzle system
(c) Where self-regulation is needed ?
(d) What is ITAE criterion?
(e) What is the role of Dead Band in ON-OFF control ?
(f) Sketch any one type of plug for each of the single-seat and double-seat valves
(g) What are the applications of gate valve?
(h) Identify the applications of ratio controller.
(i) What are the disadvantages of feed forward control?
(j) Sketch the structure of internal model control scheme.
(k) Define controller tuning
(l) Write the mathematical model of a single time-constant process.
(m) What is the need of mathematical modelling ?
(n) Draw a typical first order liquid system.

2(a) Distinguish between Batch process and Continuous process control with suitable examples.
2(b) Describe the mathematical modeling of home heating system

(OR)

3(a) Analyze the degree of freedom of a process with an example.
3(b) Explain the characteristics of a PID controller. What is meant by reset rate?

4(a) Discuss about electronic controller with relevant diagram
4(b) Explain the operation of a pneumatic actuator with positioner with a neat diagram

(OR)

5(a) With a neat sketch explain the realization of pneumatic Proportional-Derivative control action.
5(b) Outline the operation of rotating vane type control valves with neat sketch.

6(a) Design a cascade control system choosing an example process and analyze the same
6(b) Explain the concept of split range control with an application.

(OR)

7(a) Explain the feed forward control with a suitable example and neat sketch.
7(b) Explain how smith predictor control scheme is suitable for dead time processes.

8(a) Explain the procedure to design internal model control for a first order process
8(b) What is process identification? Explain frequency testing and pulse testing methods.

(OR)

9(a) Explain about Cohen-Coon controller tuning method.
9(b) Define the terms and symbols used in P&I diagrams

Scheme of Evaluation

1.	$14 \times 1 = 14M$	
2(a)	Description of any 4 differences	: $(3 \times 2)+ 1= 7M$
2(b)	Sketch of home heating system	: 2M
	Process equation	: 3M
	Mathematical model	: 2M
3(a)	Definition of Process degree of freedom	: 2M
	Schematic of example process	: 3M
	Evaluation of degree of freedom	: 2M
3(b)	PID control law	: 3M
	Definitions of Kp, Ti and Td	: 3M
	Reset rate	: 1M
4(a)	Circuit diagram	: 3M
	Derivation of controller transfer function	: 4M
4(b)	Diagram of pneumatic actuator	: 4M
	Operation	: 3M
5(a)	Diagram of pneumatic PD controller	: 4M
	Derivation of transfer function	: 3M
5(b)	Diagram of the valve	: 4M
	Operation	: 3M
6(a)	Design of cascade control	: 4M
	Analysis	: 3M
6(b)	Principle	: 3M
	Application	: 4M
7(a)	Schematic of the Feedforward control	: 2M
	Description of the need of Feedforward control	: 2M
	Derivation of Feedforward controller transfer function	: 3M
7(b)	Schematic diagram	: 4M
	Description of the control	: 3M
8(a)	Schematic diagram	: 3M
	Design steps	: 4M
8(b)	Definition	: 1M
	Frequency testing	: 3M
	Pulse testing	: 3M
9(a)	Block diagram of requirement	: 2M
	Design steps	: 5M
9(b)	Definitions of any 4 terms	: 4M
	Symbols in P&I diagrams	: 3M

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1(a) Give any two examples of proportional elements
capillary, electrical resistance, gas flow resistance, thermal resistance and mechanical spring.

(b) List the applications of Flapper-Nozzle system.
In I/P converters and in pneumatic actuators

(c) Where self-regulation is needed ?
Self regulation is the characteristic of the process that limits the deviation of the controlled variable when all other process variables are maintained constant. Self regulation is needed when we want to design a control system with proportional only control.

(d) What is ITAE criterion?
Integral of time-weighted absolute error (ITAE):

$$\text{ITAE} = \int_0^{\infty} |e| \; t \, dt$$

(e) What is the role of Dead Band in ON-OFF control ?
The value of the deviation of the controlled variable at which the controller initiates the action.

(f) Sketch any one type of plug for each of the single-seat and double-seat valves.
A few types of plugs for single seat and double seat valves are shown in the following figures.

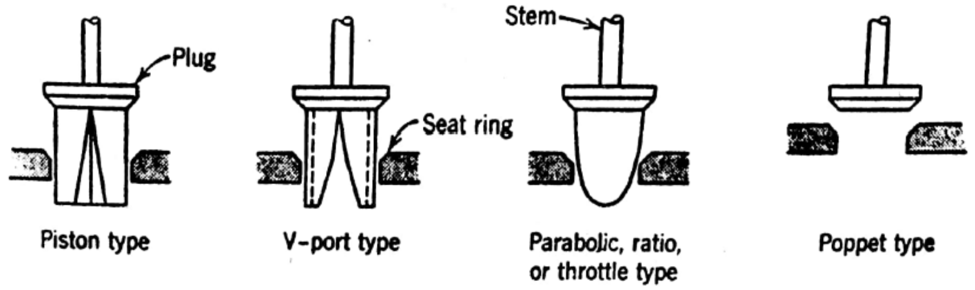


Fig : A few types of single seat valve plugs

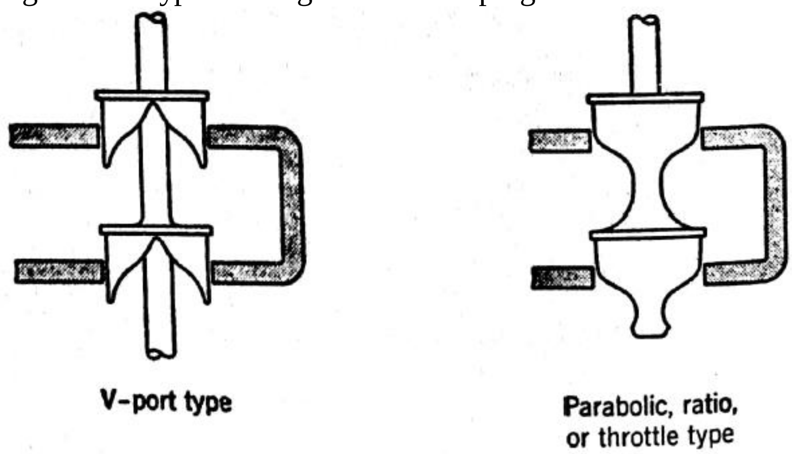


Fig :Two types of double seat valve plugs

(g) What are the applications of gate valve?
Gate valves may be used for all types of fluids, including water and gas. They may be used with potable water, wastewater, and neutral liquids between -20 and 70 degrees Celsius. They can also be used with gases between -20 and 60 degrees Celsius with a maximum of 20 m/s flow velocity.

(h) Identify the applications of ratio controller.

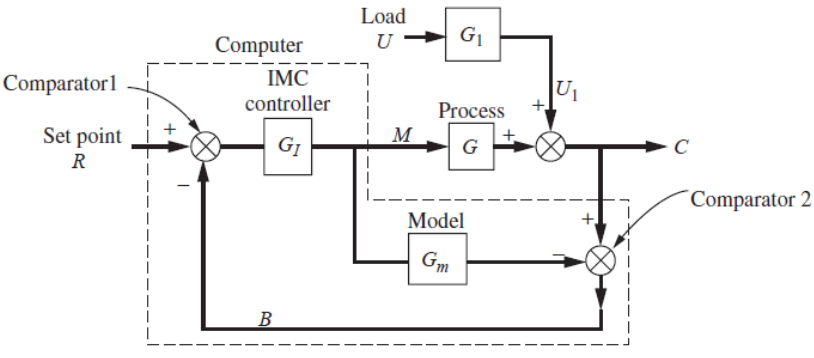
Ratio control loop configuration is widely used for maintaining.

- Composition
- Fuel/air ratio in burners
- Reflux ratio in columns

(i) What are the disadvantages of feed forward control?

The Controller design is based on accuracy of mathematical model of the process and it is of an open loop control.

(j) Sketch the structure of internal model control scheme.



(a)

(k) Define controller tuning

Determination of controller parameters for satisfactory performance of the control system.

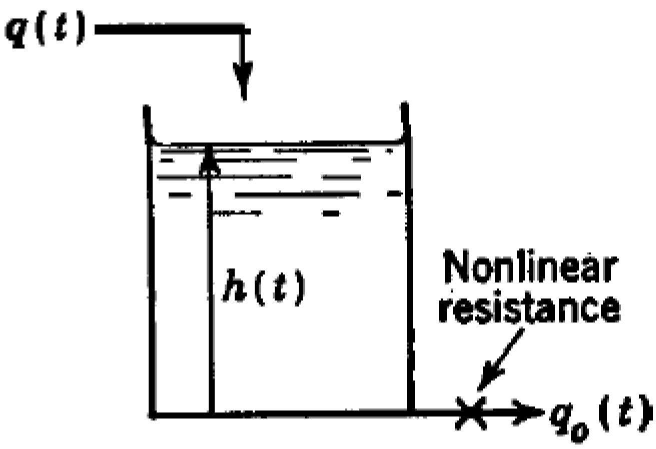
(l) Write the mathematical model of a single time-constant process.

$\frac{k}{ts+1}$ where k = steady state gain and T = time constant.

(m) What is the need of mathematical modelling ?

The need for process models arises in many control applications. Process models are also needed in developing feedforwardcontrol algorithms, self-tuning algorithms, and internal model control algorithms.

(n) Draw a typical first order liquid system.

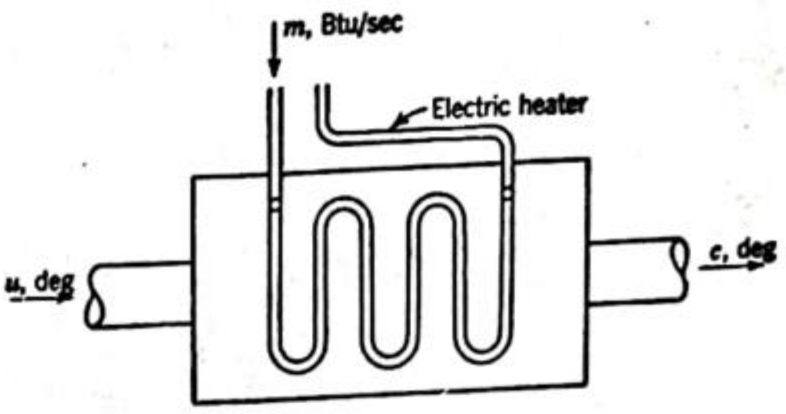


2(a) Distinguish between Batch process and Continuous process control with suitable examples.

Batch process involves processing of bulk material in batches between each step of the desired process. Continuous process involves moving one work unit at a time. between each step of the process with no breaks in time, sequence or extent.

	Batch Process	Continuous Process
Definition	Batch process refers to a process that involves a sequence of steps followed in a specific order.	Continuous process refers to the flow of a single unit of product between every step of the process without any break in time, substance or extend.
Coordination	Scheduling is done to maintain the timing between move to earth.	Each machine performs a certain processing function and they operates in a steady state.
Quantities produced	A whole unit of products are produced.	Large quantities of products are obtained.
Fouling	Batch process is involved if the fouling expectations are high	Continuous process is involved if fouling is not considered
Product life span	Short, 1-2 years	Longer than batch process
Cost of factory equipment	Low cost equipment	High cost equipment
Controlling	Batch process can be controlled very easily	Control batch process requires sophisticated control systems
Shut Down times	Often	Rare
Workforce	Small workforce is needed	Continuous process is generally available in fully automated plants. If not, large workforce will be necessary.

2(b) Describe the mathematical modelling of home heating system



The air heating process of the following figure is an example of a simple thermal process. Heat flow m into the system is provided by an electrical heater. Since all the electrical energy must be transferred to the air,

$$C\dot{c} = m + QPu - QPc$$

where

C = thermal capacitance = WP, Btu/deg
W = weight of air contained in heater, lb
c = heater outlet temperature, deg
m = heat input, Btu/sec
Q = weight flow of air through heater, lb/sec
P = specific heat of air, Btu/lb deg^{-1}
u = inlet air temperature, deg

The heat losses and the capacitance of metal parts in the heater are assumed to be negligible. Rewriting the above equation, the process equation is obtained:

$$c = \left(\frac{1}{QP}\right)\left(\frac{1}{Ts+1}\right)m + \left(\frac{1}{Ts+1}\right)u$$

where T = C/QP = W/Q is the time constant of the process.

3(a) Analyze the degree of freedom of a process with an example.

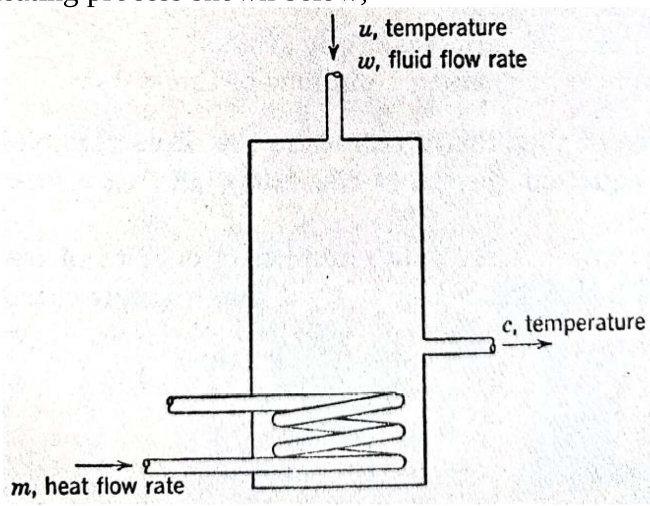
Process degree of freedom :

It is defined by

$$n = n_v - n_e$$

where n = number of degrees of freedom
n_v = number of variables of the system
n_e = number of defining equations of the system

For the water heating process shown below,



there are four variables:

u = inlet temperature
c = outlet temperature
w = water flow rate
m = heat input rate

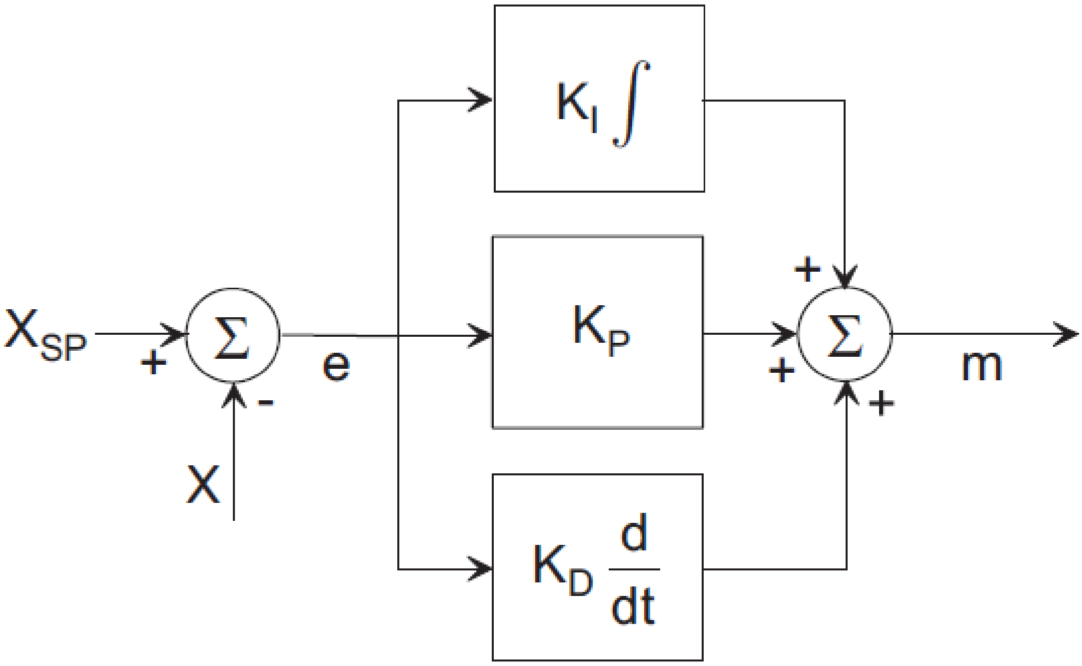
Therefore $n_v = 4$. There is one defining equation obtained from conservation of energy. Therefore $n_e = 1$.

The number of degrees of freedom are

$$n = n_v - n_e = 4 - 1 = 3.$$

System variables and system parameters must be carefully distinguished. For example, the weight of water contained in the heater and specific heat of water are parameters not variables.

3(b) Explain the characteristics of a PID controller. What is meant by reset rate?

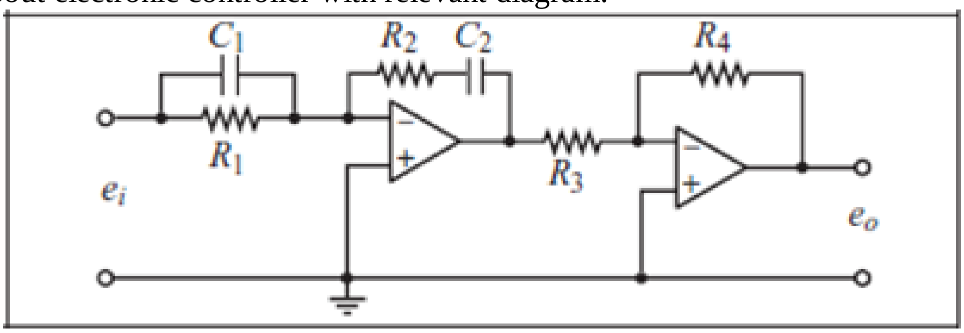


m(t) = $k_p[e(t)+\frac{1}{Ti}\int e(t)dt + Td\frac{de(t)}{dt}]$

Ti is defined as the time taken to repeat proportional control action for step error signal. units are minutes/repeat.

Td is defined as the time for the proportional term to equal the derivative term for a ramp error signal. Unit is minutes.

4(a) Discuss about electronic controller with relevant diagram.

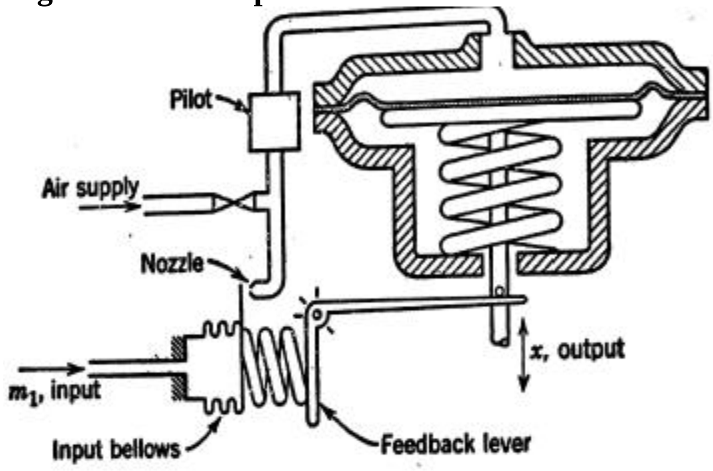


The transfer function of the controller is given by

$$\frac{R_4}{R_3}\frac{R_2}{R_1}\frac{(R_1C_1s+1)(R_2C_2s+1)}{R_2C_2s}$$

4(b) Explain the operation of a pneumatic actuator with positioner with a neat diagram.

Pneumatic Spring actuator with positioner:



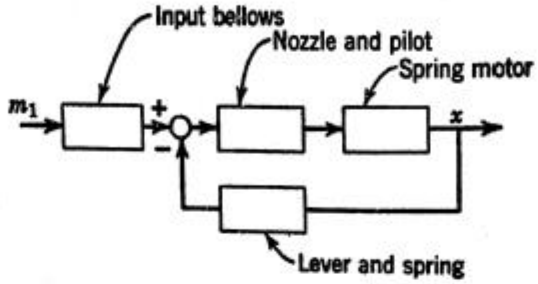


Fig : Spring and diaphragm motor with positioner

The spring actuator often requires a positioner as shown in the above figure when static friction forces are larger or when the response of the motor is too slow.

The positioner consists of an input bellows, a nozzle and amplifying pilot, and the feedback levers and spring.

An air supply of 20 to 100 psig must be provided.

The operation is as follows: When the input air pressure m1 increases, the input bellows move to the right and causes the baffle to cover the nozzle. The nozzle back pressure change is amplified by the pilot and is transmitted to the diaphragm.

The diaphragm moves down and the feedback lever compresses the spring to return the baffle to balanced position.

Thus actuator stem assumes a position dictated by the input air pressure.

The use of positioner results in several improvements in performance.

1.Hysteresis is reduced and linearity is usually improved because the static operation is governed by the feedback spring and input bellows.

2.The actuator can handle much higher static friction forces because of the amplifying pilot.

3.Variable thrust forces on the motor stem do not disturb the stem position to any great extent.

4.Speed of response is generally improved because the pneumatic controller must supply sufficient air to fill the small input bellows rather than the large actuator chamber.

5(a) With a neat sketch explain the realization of pneumatic Proportional-Derivative control action.

Pneumatic PD controller :

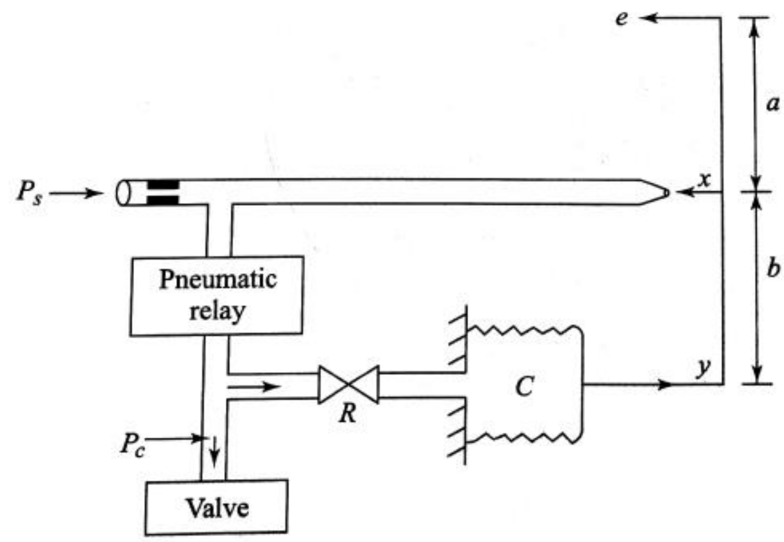


Fig : Pneumatic PD Controller

The addition of a restriction in the negative feedback path will modify the proportional controller to a Proportional Derivative Controller.

The operation of the above PD controller is as follows.

For a step change in e, the change in control pressure Pc will be instantaneous, which will affect control valve position.

The restriction R will momentarily prevent the feedback bellows from sensing the pressure change Pc.

Thus, the feedback bellows will not respond momentarily, and the pneumatic actuating valve will feel the full effect of flapper movement.

As time goes on, the feedback bellows will expand or contract.

At steady state, the feedback bellows acts like an ordinary feedback mechanism.

A block diagram corresponding to this pneumatic controller is shown in the following fig. K is a constant relating P_c (control pressure) and 'x' is distance between nozzle and flapper, A is the area of the bellows, and K_s is the equivalent spring constant of the bellows.

The block diagram representation of the pneumatic PD controller is shown below.

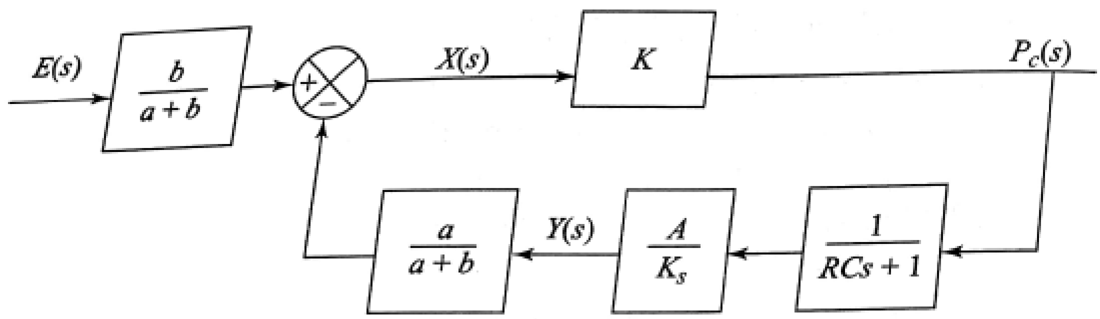


Fig : Block diagram of pneumatic PD controller

The transfer function of this controller is given by

$$\frac{P_c(s)}{E(s)} = \left(\frac{b}{a+b}\right)\frac{K}{1+K\left(\frac{a}{a+b}\right)\left(\frac{A}{K_s}\right)\left(\frac{1}{RCs+1}\right)}$$

Assuming $GH \gg 1$,

$$\frac{P_c(s)}{E(s)} = \frac{b}{a}\cdot\frac{K_s}{A}(RCs+1)$$

5(b) Outline the operation of rotating vane type control valves with neat sketch.

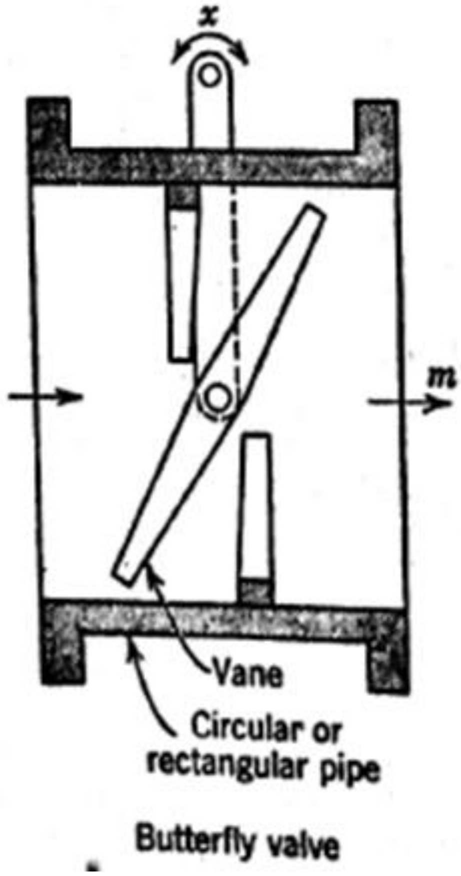


Fig : Rotating Vane type control valve

The rotating plug valve is shown in the above figure. The plug is a cylindrical or conical element with a transverse opening. It is rotated in the valve body by an external lever so that the opening on one side of the plug is gradually covered or uncovered. The shape of the opening or port may be circular, V-shape, rectangular, or any form that is desired to produce a given flow-angle characteristic. The flow angle characteristic is shown in the following fig for a near rectangular port shape.

6(a) Design a cascade control system choosing an example process and analyze the same.
Cascade Control :

To provide motivation for the study of cascade control, consider the single-loop controlof a jacketed kettle as shown in the following Fig. 17–1 *a* .

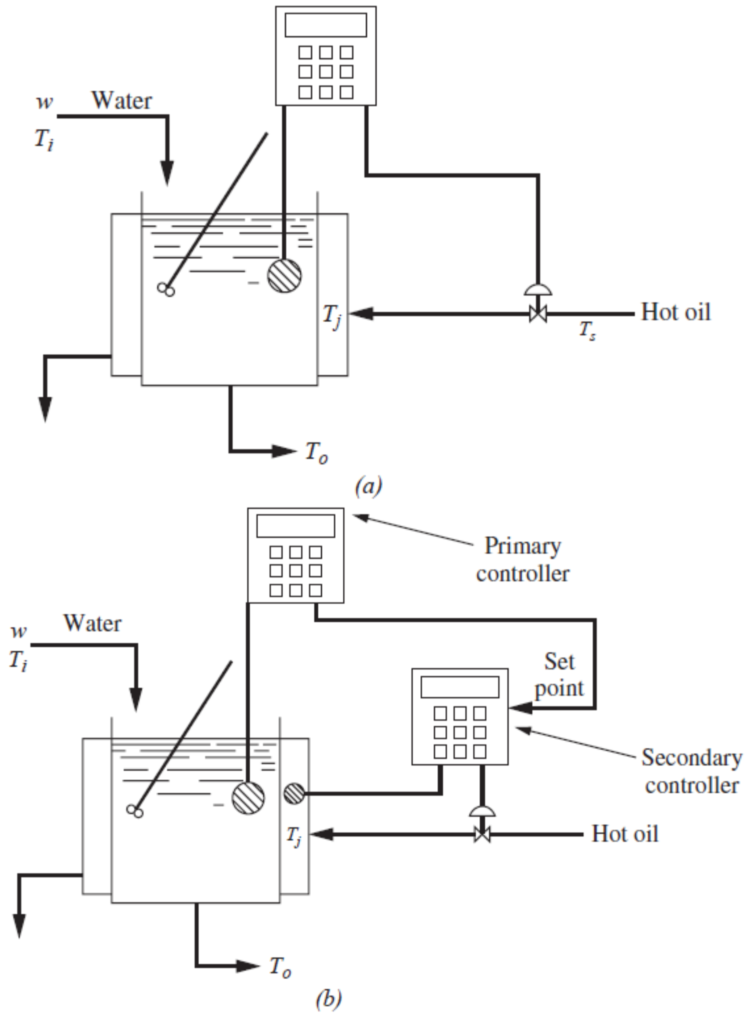


Fig : (*a*) Single-loop control of a jacketed kettle; (*b*) cascade control of a jacketed kettle.

The system consists of a kettle through which water, entering at temperature T_i, is heated to T_0 by the flow of hot oil through a jacket surrounding the kettle.

The temperature of the water in the kettle is measured and transmitted to the controller, which in turn adjusts the flow of hot oil through the jacket.

This control system is satisfactory for controlling the kettle temperature; however, if the temperature of the oil supply should drop, the kettle temperature can undergo a large prolonged excursion from the set point before control is again established.

The reason is that the controller does not take corrective action until the effect of the drop in oil supply temperature has worked itself through the system of several resistances to reach the measuring element.

To prevent the sluggish response of kettle temperature to a disturbance in oil supply temperature, the control system shown in Fig.*b* is proposed.

In this system, which includes two controllers and two measuring elements, the output of the primary controller is used to adjust the set point of a secondary controller, which is used to control the jacket temperature.

Under these conditions, the primary controller indirectly adjusts the jacket temperature.

If the oil temperature should drop, the secondary control loop will act quickly to maintain the jacket temperature close to the value determined by the set point that is adjusted by the primary controller.

This system shown in Fig. *b* is called a *cascade* control system.

The primary controller is also referred to as the master controller, and the secondary controller is referred to as the slave controller.

The block diagrams of the single-loop system and cascade control systems are shown in the following Fig.

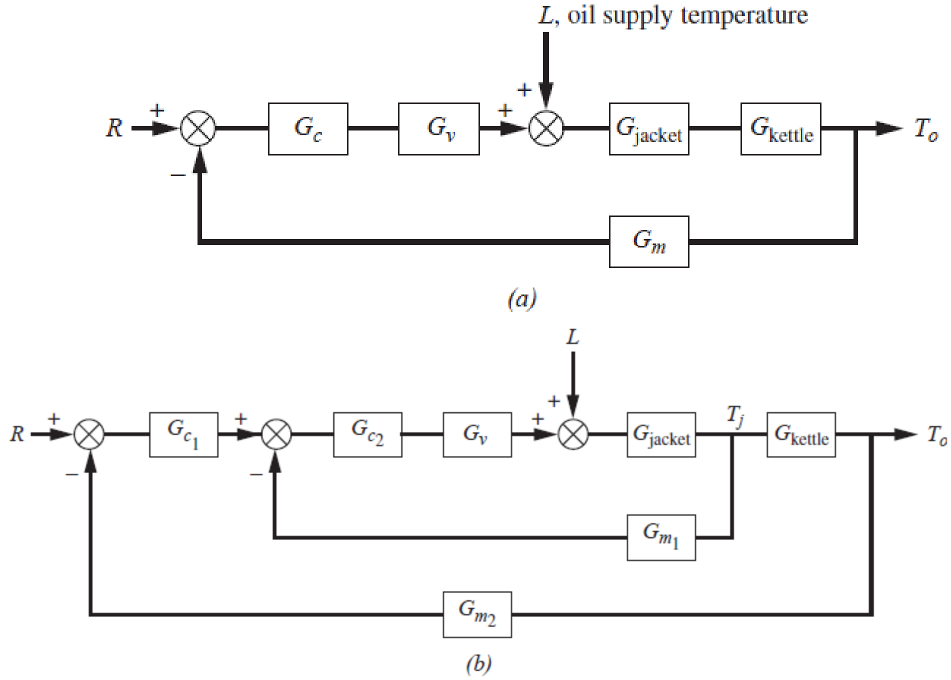


Fig :Block diagram: (*a*) single-loop conventional control; (*b*) cascade control.

Comparison of Conventional control and Cascade Control :

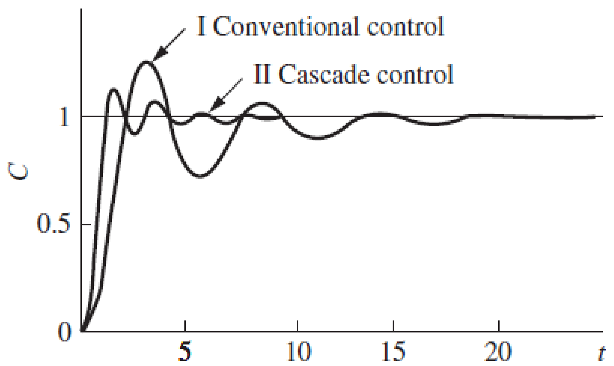


Fig :Responses to step change in set point for single-loop control and cascade control .

Generalizations

Cascade control is especially useful in reducing the *effect of a load disturbance* that moves through the control system slowly.

The inner loop has the effect of reducing the lag in the outer loop, with the result that the cascade system responds more quickly with a higher frequency of oscillation.

The control action for the inner loop is often proportional with the gain set to a high value.

The reason for the use of proportional control is that tuning is simplified and any offset associated with proportional control of the inner loop can be handled by the presence of integral action in the primary controller.

The gain of the secondary controller should be set to a high value to give a tight inner loop that responds quickly to load disturbance; however, the gain should not be so high that the inner loop is unstable.

Although the primary control loop can provide stable control even when the inner loop is unstable, it is considered unwise to have an unstable inner loop because the system will go unstable if the primary controller is placed in manual operation or if there is a break in the outer loop.

The action for the primary controller is generally PI or PID. The integral action is needed to reduce offset when sustained changes in load or set point occur.

6(b) Explain the concept of split range control with an application.

Duplex or Split-Range Control:

A duplex controller has one input and two outputs.

It may have two control mechanisms, each with an output, or a single-control mechanism operating two control valves by means of relays or positioners.

The need for such a system is apparent in a process such as electroplating.

For example, the quality of bright chromium plating depends largely on proper temperature control of the bath.

With a given current density and bath composition, variations in temperature not only affect the final appearance, but also the rate of chromium deposition.

Desired thicknesses and finishes can only be produced on successive jobs if the operating conditions are duplicated exactly (following Figure).

Plating current flowing through the electrolyte generates heat that is normally dissipated by a controlled flow of cooling water through the tank coils.

Frequently, however, when large, cold metal pieces are introduced, the solution becomes too cool for good plating.

Also, on start up, the temperature must be brought up to the operating level or the initial batch will be below specifications.

The problem is solved by a duplex controller that adds cooling water when the temperature is too high, and steam to the heating coils when the temperature is too low.

If the temperature is within acceptable limits, neither cooling water nor steam is admitted.

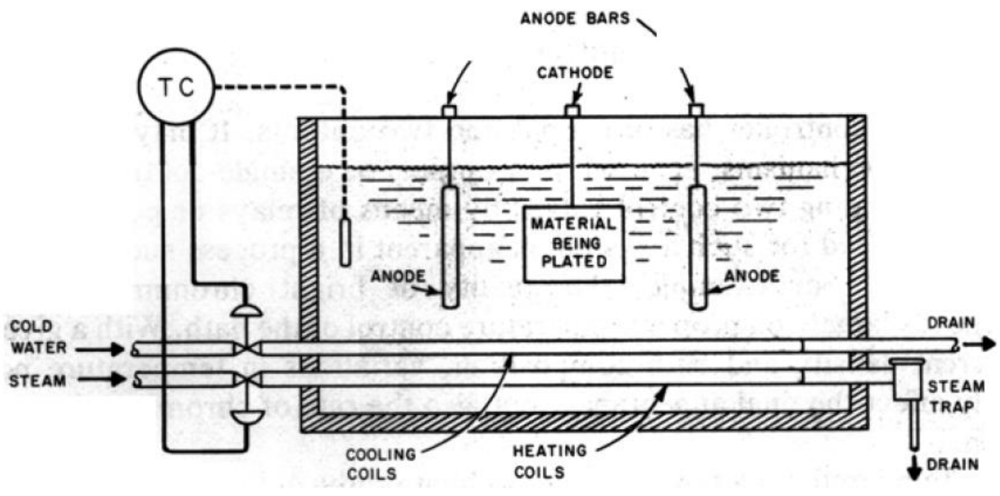


Fig. : Plating process requires a duplex control1er one with one input but two outputs.

The control action is pneumatically produced by a conventional controller with proportional action (left in the above Figure).

Controller output is simultaneously fed to (1) the receiver bellows in a valve positioner, located on the water (cooling) valve, and (2) a similar bellows in a second positioner located on the steam (heating) valve.

7(a) Explain the feed forward control with a suitable example and neat sketch.

If a particular load disturbance occurs frequently in a control process, the quality of control can often be improved by the addition of feedforward control.

Consider the composition control system shown in the following Fig. in which a concentrated stream of control reagent containing water and solute is used to control the concentration of the stream leaving a three-tank system.

The stream to be processed passes through a pre conditioning stirred tank where composition fluctuations are smoothed out before the outlet stream is mixed with control reagent.

A three-tank system has been chosen for ease of computation in a numerical example that follows.

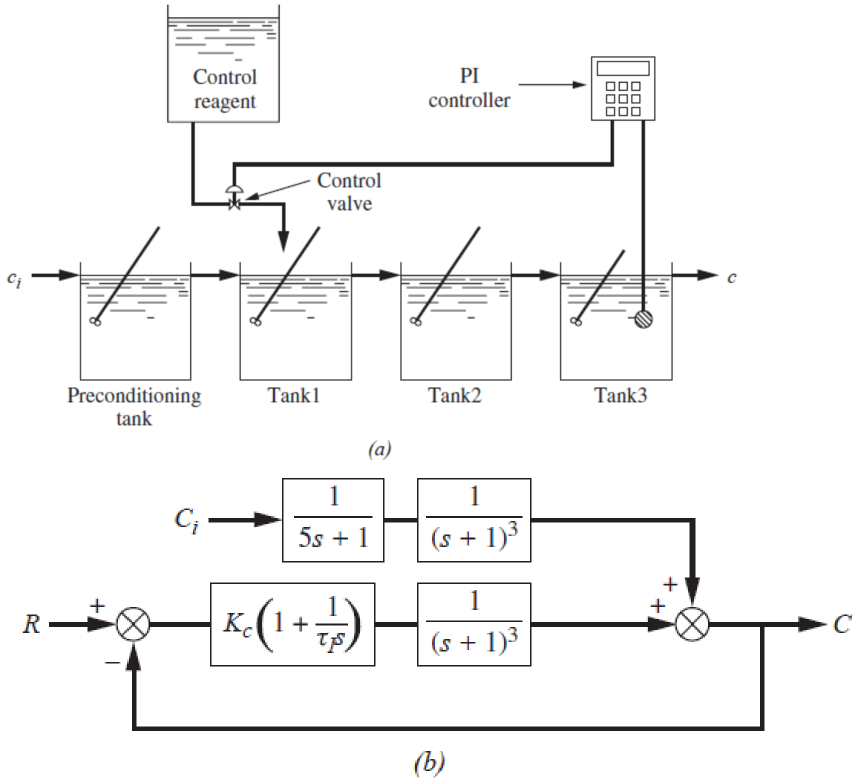


Fig : Composition control system: (*a*) physical process; (*b*) block diagram.

In the conventional feedback control system shown in the above Fig.*a*, the measurement of composition in the third tank is sent to a controller, which generates a signal that opens or closes the control valve, which in turn supplies concentrated reagent to the first tank.

The block diagram corresponding to the control system of Fig. *a* is shown in Fig. *b*. Numerical values of the time constants of the tanks have been chosen as shown in Fig.*b*.

The feedback control system does not begin to respond until the load disturbance has worked its way through the forward loop and reaches the measuring element, with the result that the composition can move far from the set point during the transient.

If the change in load disturbance Ci can be detected as soon as it occurs in the inlet stream, this information can be fed forward to a second controller that adjusts the control valve in such a way as to prevent any change in the outlet composition from the set point.

A controller that uses information fed forward from the source of the load disturbance is called a *feedforward* controller. The block diagram that includes the feedforward controller G_f as well as the feedback controller G_c is shown in the following Fig.

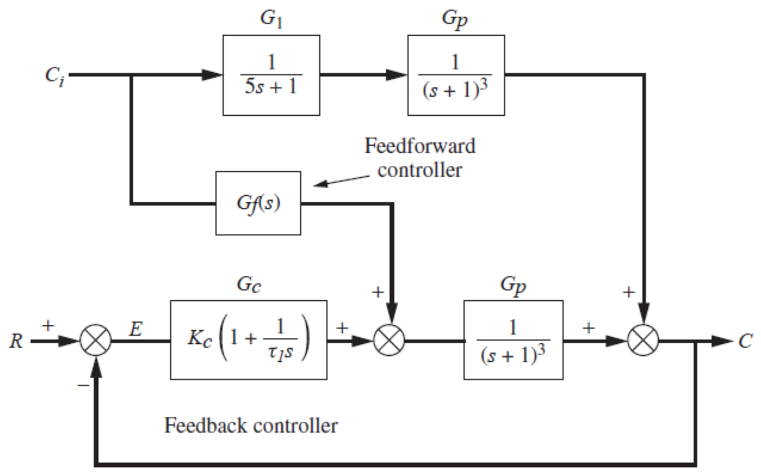


Fig : Control system with feedforward and feedback controllers

Analysis of FeedforwardControl :

The response of C to changes inCi and R can be written from the above Fig. as follows:

$$C(s) = G_1(s)G_p(s)C_i(s) + G_f(s)G_p(s)C_i(s) + G_c(s)G_p(s)E(s)$$

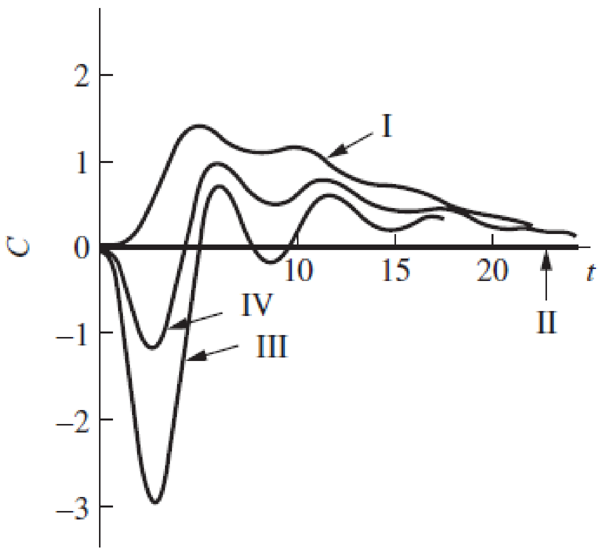
whereE (s) =R (s) -C (s). To determine the transfer function of $G f(s)$ that will prevent any change in the control variable C from its set point R, which is 0, solve the above Eq. for $G f(s)$ with $C =$ 0 and $R =$ 0. The result is

$$G_f(s) = - G_1(s)$$

For the example under consideration in the above fig

$$G_f(s) = \frac{-1}{5s+1}$$

This transfer function can be implemented easily with existing control hardware. The performance of the feedforward control system is shown in the following fig.



Responses to a step change in load for feedforward-feedback control.
Curve I: PI control with $K_c = 2.84$, $\tau_I = 5.0$
Curve II: FF control with $K_c = 2.84$, $\tau_I =$ 5.0, $G_f = -1/(5s + 1)$
Curve III: FF control with $K_c = 2.84$, $\tau_I =$ 5.0, $G_f = -1$
Curve IV: FF control with $K_c = 2.84$, $\tau_I =$ 5.0, $G_f = -0.5$

7(b) Explain how smith predictor control scheme is suitable for dead time processes.

Processes that contain a large transport lag[exp(- τ_Ds)] can be difficult to control because a disturbance in set point or load does not reach the output of the process until$\tau_D$units of time have elapsed.

Dead-time compensation, attempts to reduce the deleterious effect of transport lag. Dead-time compensation, which is also referred to as a Smith predictor, was first described by O. J. M. Smith (1957).

Consider the single-loop control system of the following Fig. 17–26 in which the process transfer function $G_p(s)$ is to be modeled by

$$G_p(s) = G(s)\, e^{-\tau_D s}$$

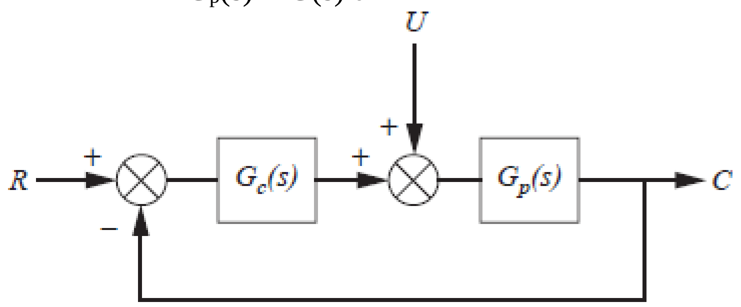


Fig : Control system

The right side of the above Eq. is the product of a transport lag [exp(- τ_Ds)] and a transfer function G(s), which has minimum phase characteristics, such as 1/(τs + 1). For convenience in developing the dead-time compensation method, only a change in set point *R* will be considered. If a step change is made in *R*, the disturbance will not break through and appear at *C* until τ_D units of time elapse. Up to time τ_D, no control action occurs, with the result that the overall closed-loop response will be sluggish and generally unsatisfactory. To overcome this difficulty, Smith suggested that $G_p(s)$ be modeled according to Eq.

$$G_p(s) = G(s)\, e^{-\tau_D s}$$

and that additional feedback paths be inserted into the above Fig. as shown in the following Fig. *a* .

If $G_p(s)$ is modeled exactly by Eq.$G_p(s) = G(s)\, e^{-\tau_D s}$, a close study of the following Fig. *a* shows that the signals entering comparator *A* will be identical; as a result, the signals cancel and cause the output of comparator '*A*'to be zero. The net effect is to completely eliminate the outer feedback path; this simplification is shown in Fig. *b* .

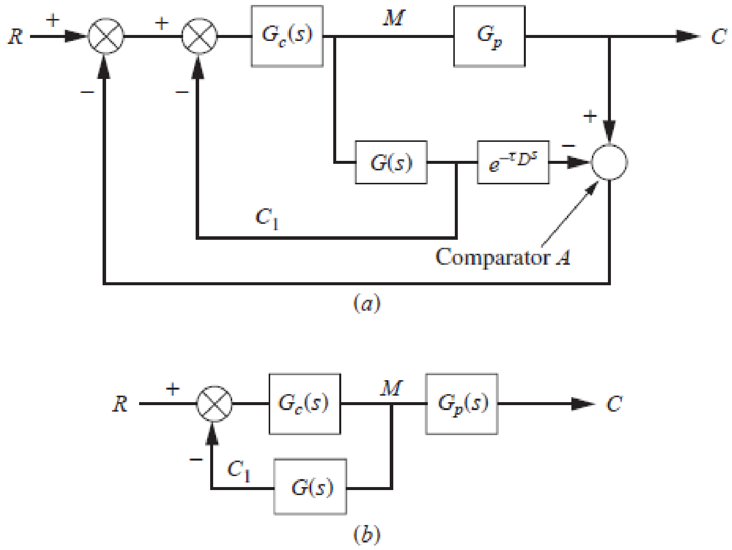
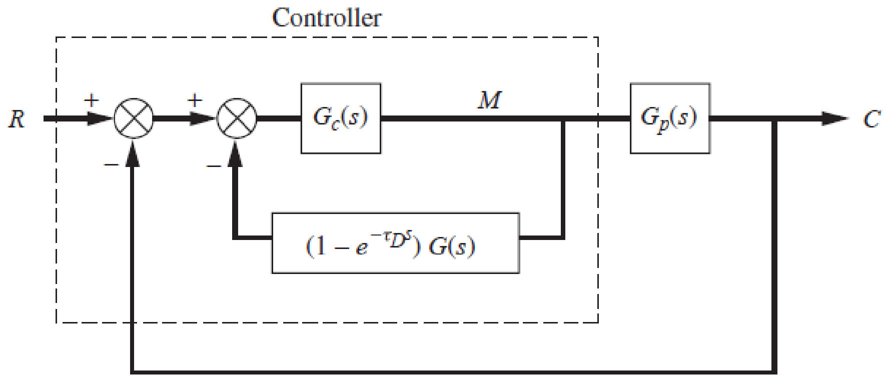
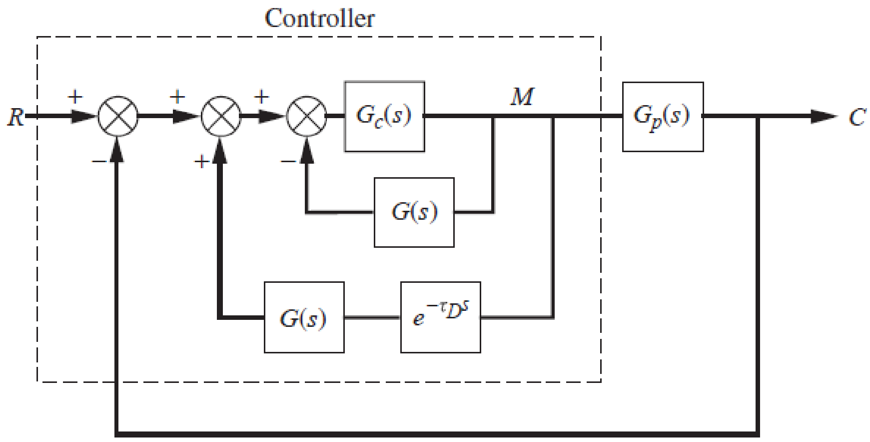


Fig : (*a*) Dead-time compensation (Smith predictor) block diagram; (*b*) equivalent diagram for part (*a*)When $G_p(s) = G(s)\, e^{-\tau_D s}$.

In reality the signal C1 in the above figure is not available to feedback. Only the signal *C* can be measured and fed back to the controller. In terms of controller hardware implementation, the diagram of the above Fig. *a* is redrawn in the following Fig. a and fig bto show which portion of the diagram will be implemented with controller hardware.



(a)



(b)

Fig : Hardware implementation of dead-time compensation.

The recommended procedure for applying dead-time compensation is as follows:

1. Model $G_p(s)$ by using a first-order plus dead-time (FOPDT) model

$$\frac{1}{\tau s+1}e^{-\tau_D s}$$

Many processes in chemical engineering can be modeled by a first-order lag with dead time.

By means of appropriate hardware, implement the controller portion of the above fig a or fig b.

8(a) Explain the procedure to design internal model control for a first order process.

Internal Model Control :

A block diagram of an IMC system is shown in the following Fig.*a* .In this diagram, *G* is the transfer function of the process and *G m* is the model of the process.

Although *G* and *G m* are called the transfer functions of the process, they actually include the valve and the process. The transfer function of the measuring element is taken as 1.0. The portion of the diagram that is implemented by the computer includes the IMC controller and the model; this portion is surrounded by the dotted boundary.

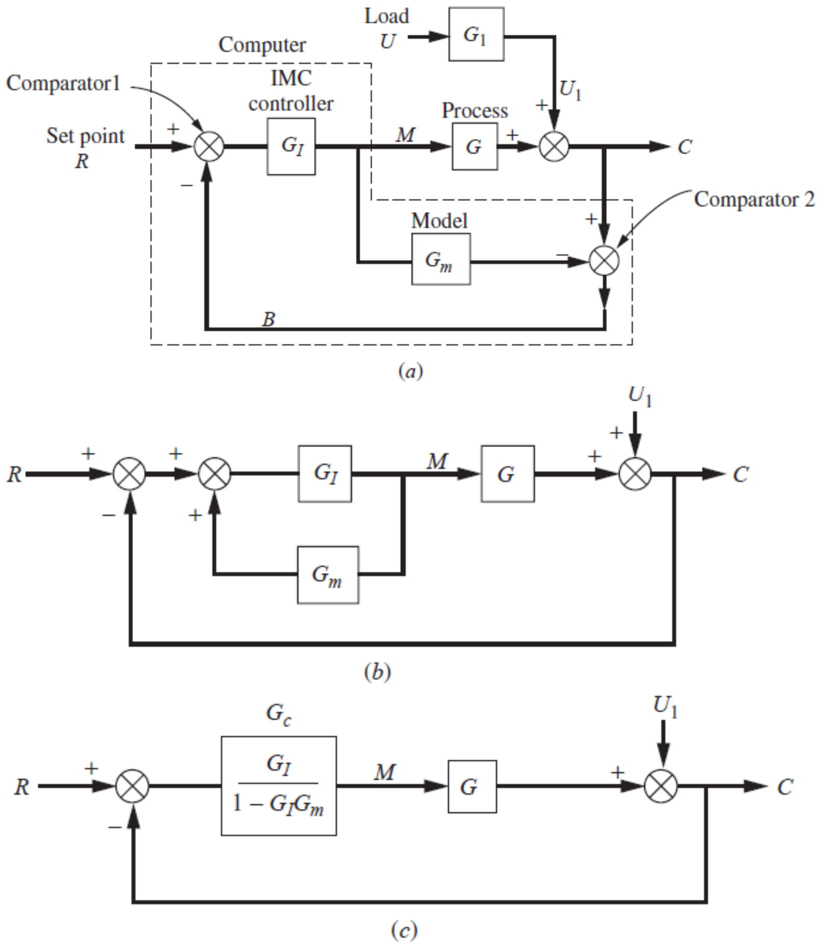


Fig :Internal model control structures: (*a*) basic structure; (*b*) alternate structure; (*c*) structure equivalent.

The structure of Fig. *b* can be used to relate the IMC controller to the conventional controller. Replacing the inner loop of Fig. *b* with a single block gives the structure shown in Fig. *c* . Since this structure is the conventional single-loop control structure, we can identify the single controller block as G_c . After one designs the IMC controller (G_I) by the method to be described, one can determine the equivalent conventional controller G_c by the relation

$$G_c = \frac{G_I}{1 - G_I G_m}$$

For the structure shown in Fig. *a* , one can show that

$$C = U_1 + \frac{G G_I}{1 + G_I (G - G_m)} (R - U_1)$$

If the model exactly matches the process (i.e., Gm = G), the only signal entering comparator1 in Fig. *a* is U_1 . (The signals from G and G_m are equal and cancel each other in going through comparator 2.) Since U_1 is not the result of any processing by the transfer functions in the forward loop, U_1 is not a feedback signal but an independent signal that is equivalent to *R* in its effect on the output *C*. In fact, there is no feedback whenG = Gm, and we have an open-loop system as shown in the following Fig. 17–34 . In this case the stability of the control system depends only on G_I and G_m .If G_I and G_m are stable, the control system is stable.

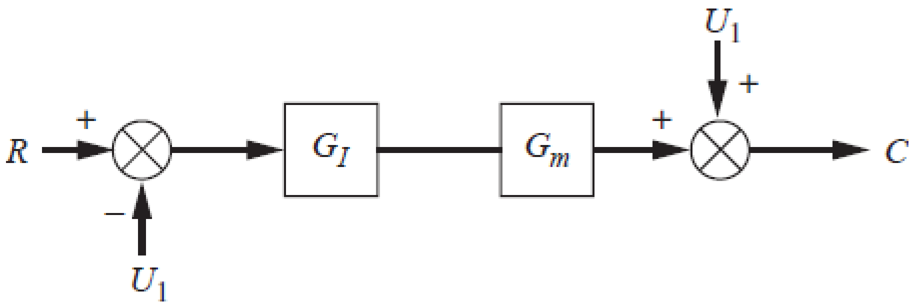


Fig : IMC structure when model matches the process (Gm = G).

Ideally, we should like to have *C* track *R* without lag when only a set point change occurs (i.e., U1 = 0). For this to occur, we see from the above Fig. that GI G = 1, or since G = Gm, we may write GIGm = 1. Solving for *G I* gives

$$G_I = \frac{1}{G_m}$$

The above equation states that the IMC controller should be the inverse of the transfer function of the process model.

Design of IMC Controllers

In using these rules, only a step change in disturbance is considered. The procedure fordisturbances other than a step response is more complicated and beyond the scope of the limited discussion presented here.

1. Separate the process model *G m* into two terms

   $$Gm = G_{m_a} G_{m_m}$$

   where$G_{m_a}$is a transfer function of an all-pass filter.

   The $G_{m_m}$is a transfer function that has minimum phase characteristics. A system has nonminimumphase characteristics if its transfer function contains zeros in the right half-planeor transport lags, or both. Otherwise, a system has minimum phase characteristics.For a step change in disturbance (R = 1/s or U1 = 1/s), GI is determined by

   $$GI = \frac{1}{G_{m_m}}$$

2. To obtain a practical IMC controller, one multiplies *G I* in step 1 by a transfer functionof a filter *f* (*s*). The simplest form recommended by Morari and Zafiriou is given by

   $$f(s) = \frac{1}{(\lambda s+1)^n}$$

   where λ is a filter parameter and n is an integer. The practical IMC controller GI can now be expressed as

   $$GI = \frac{f}{G_{m_m}}$$

   The value of *n* is selected large enough to give a result for GI that does not require pure differentiation.

3. If one wants The conventional controller transfer function Gc can be obtained from the relation

   $$G_c = \frac{G_I}{1 - G_I G_m}$$

8(b) What is process identification? Explain frequency testing and pulse testing methods.

Process Identification :

The experimental determination of the dynamic behaviour of a process is called *process identification.*

The need for process models arises in many control applications. Process models are also needed in developing feedforwardcontrol algorithms, self-tuning algorithms, and internal model control algorithms.

Process identification provides several forms that are useful in process control; some of these forms are

Process reaction curve (obtained by step input)

Frequency response diagram (obtained by sinusoidal input)

Pulse response (obtained by pulse input)

Frequency Testing :

A process having a transferfunction $G(s)$ can be represented by a frequency response diagram (or Bode plot)by taking the magnitude and phase angle of $G(jw)$.

This procedure can be reversed toobtain $G(s)$ from an experimentally determined frequency response diagram.

In frequency testingof an industrial process, a sinusoidal variation in pressure is applied to the top of thecontrol valve so that the manipulated variable can be varied sinusoidally over a range offrequencies.

The block diagram that applies during frequency testing is shown in the following figure with a sinusoidal input signal to the valve.

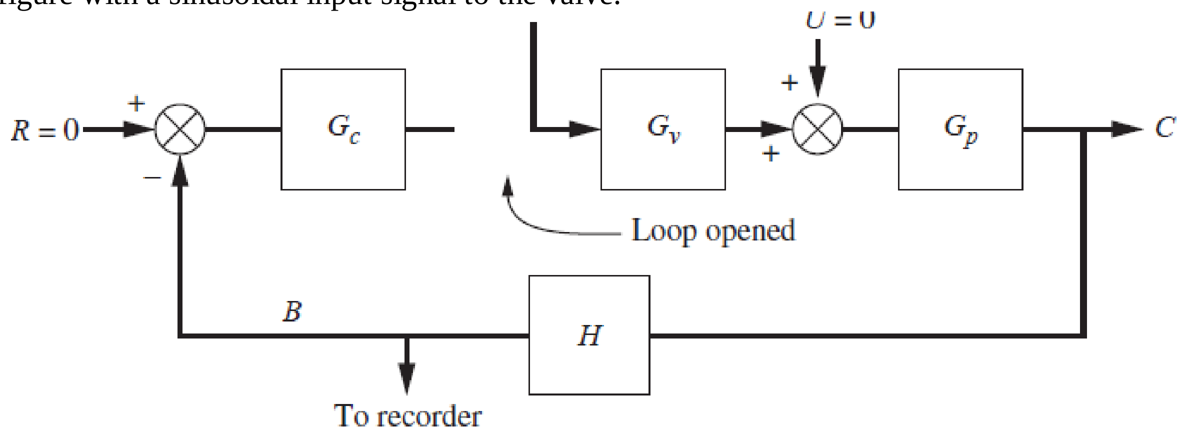


Fig : Experimental Set up for frequency testing

For frequency testing of chemical processes,special low-frequency generators must be built that can produce a sinusoidal variationin pressure to a control valve.

To preserve the sinusoidal signal in the flow of manipulatedvariable through the valve, the valve must be linear.

The great disadvantage of frequency testing is that it takes a long time to collect frequency response data over a range of frequencies that can be used to construct frequency response plots.

The time is especially long for chemical processes, often having long time constants measured in minutes or even hours. The frequency test at a given frequency must last long enough to make sure that the transients have disappeared and only the ultimate periodic response is represented by the data.

Frequency testing usually ties up plant equipment too long to be recommended as a means of process identification.

Pulse testing:

Pulse testing is similar to step testing; the only difference in the experimental procedure is that a pulse disturbance is used in place of a step disturbance.

The pulse is introduced as a variation in valve top pressure as shown in the following fig.

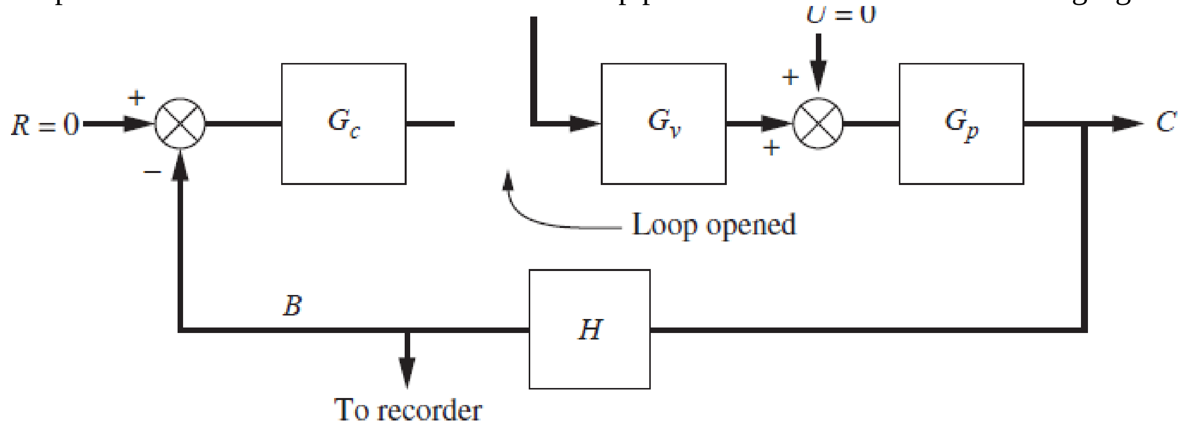


Fig : Experimental Set up for pulse testing

In applying the pulse, the open-loop system is allowed to reach steady state, after which the valve top pressure is displaced from its steady-state value for a short time and then returned to its original value.

The response is recorded at the output of the measuring element (B in the above Fig.) An arbitrary pulse and a typical response are shown in the following Fig.

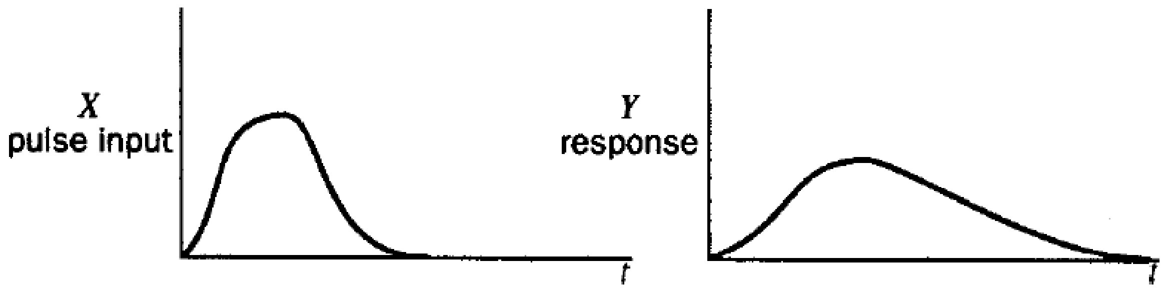


Fig : Typical process response to a pulse input.

Usually the pulse shape is rectangular in experimental work, but other well defined shapes are also used. The input-output data obtained in a pulse test are converted to a frequency response diagram, which can be used to tune a controller. The transfer function of the valve, process, and measuring element (referred to as the process transferfunction, for convenience) is given by:

$$G_p(s) = \frac{Y(s)}{X(s)}$$

Where Y(s) = Laplace transform of the function representing the recorded output response

X(s) = Laplace transform of the function representing the pulse input

Applying the definition of the Laplace transform [Eq. (2. l)] to the numerator and denominator of the above equation and replacing s by jω gives

$$G_p(j\omega) = \frac{\int_0^{\infty} Y(t)e^{-j\omega t}dt}{\int_0^{\infty} X(t)e^{-j\omega t}dt}$$

$$G_p(j\omega) = \frac{\int_0^{\infty} Y(t)cos\omega t\ dt - j\int_0^{\infty} Y(t)sin\omega t\ dt}{\int_0^{\infty} X(t)cos\omega t\ dt - j\int_0^{\infty} X(t)sin\omega t\ dt}$$

The integration is done numerically: the time axis is divided into equal increments and the function *Y(t)*is represented linearly over successive time increments. A computer is necessary to evaluate the integrals.

After the integrals in the above equation are evaluated for several values of ω, $G_p(j\omega)$ for each value of ω can be expressed as

$$G_p(j\omega) = \frac{A+jB}{C+jD} = \alpha + j\beta$$

The magnitude and angle of α + jβ can be found easily and used in plotting a frequency response diagram.

9(a) Explain about Cohen-Coon controller tuning method.

Cohen and Coon (C-C) Rules:

Cohen Coon method of controller tuning *open-loop method,* in which the control action is removed from the controller by placing it in manual mode and an open-loop transient is induced by a step change in the signal to the valve.

The following Fig. 18–5 shows a typical control loop in which the control action is removed and the loop opened for the purpose of introducing a step change (*M/s*) to the valve.

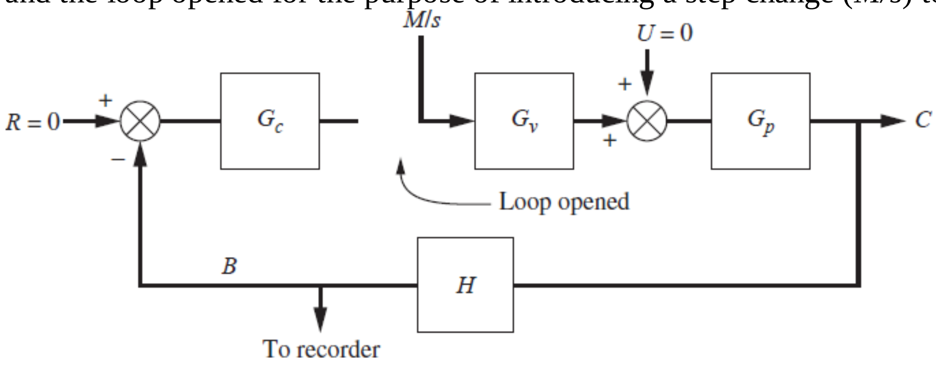


FIGURE : Block diagram of a control loop for measurement of a process reaction curve.

The step response is recorded at the output of the measuring element. The step change to the valve is conveniently provided by the output from the controller, which is in manual mode.

The response of the system (including the valve, process, and measuring element) is called the *process reaction curve;* a typical process reaction curve exhibits an S shape, as shown in the following Fig. 18–6.

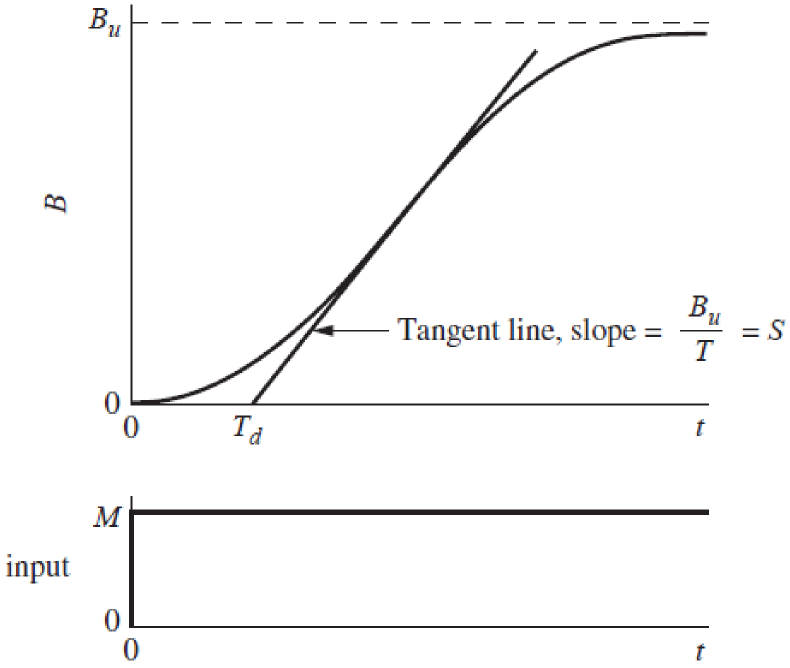


FIGURE
Typical process reaction curve showing graphical constructionto determine first-order with transport lag model.

The C-C method is summarized in the following steps:
1.After the process reaches steady state at the normal level of operation, switch thecontroller to manual.

2.With the controller in manual, introduce a small step change in the controller output that goes to the valve and record the transient, which is the process reaction curve.

3. Draw a straight line tangent to the curve at the point of inflection, as shown in the above Fig. The intersection of the tangent line with the time axis is the apparent transport lag *Td*; the apparent first-order time constant *T* is obtained from

$$T = \frac{B_u}{S}$$

where Bu is the ultimate value of B at large t and S is the slope of the tangent line.The steady-state gain that relates B to M is given by

$$K_p = \frac{B_u}{M}$$

4. Using the values of K_p, T, and $T_d$from step 3, the controller settings are found from the relations given in the following Table.

Cohen-Coon controller settings

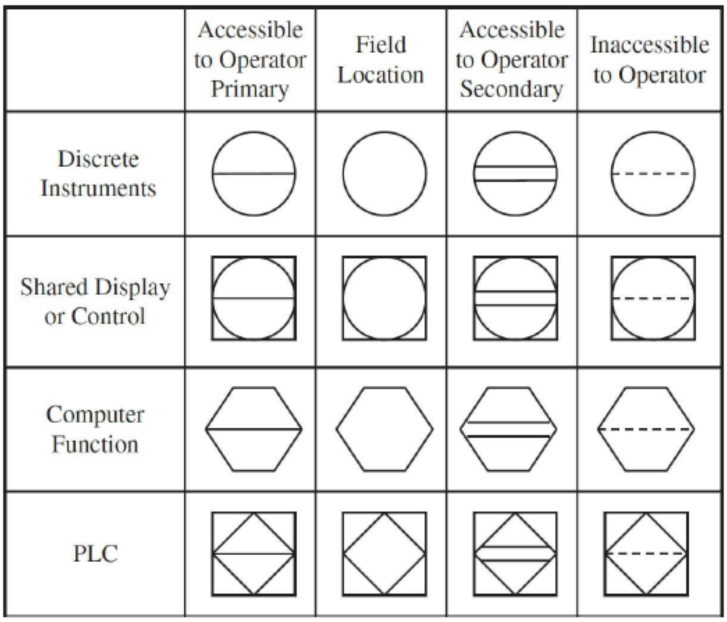
Type of control	Parameter setting
Proportional (P)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(1 + \frac{T_d}{3T}\right)$
Proportional-integral (PI)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(\frac{9}{10} + \frac{T_d}{12T}\right)$
	$\tau_I = T_d \frac{30 + 3T_d/T}{9 + 20T_d/T}$
Proportional-derivative (PD)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(\frac{5}{4} + \frac{T_d}{6T}\right)$
	$\tau_D = T_d \frac{6 - 2T_d/T}{22 + 3T_d/T}$
Proportional-integral-derivative (PID)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(\frac{4}{3} + \frac{T_d}{4T}\right)$
	$\tau_I = T_d \frac{32 + 6T_d/T}{13 + 8T_d/T}$
	$\tau_D = T_d \frac{4}{11 + 2T_d/T}$

9(b) Define the terms and symbols used in P&I diagrams

In an industry, processes can be described and understood by the use of Piping & Instrumentation (P & I) diagrams. The purpose of P & I diagrams is to provide quick, systematic, and reliable information for process analysis, production control, specification of equipment, and preparation of equipment requisitions.

The following table shows the symbols of four graphical elements depending on their physical location.

Table : Four graphical elements and their location (or Standardized instrument symbols.



Definitions of terms used in P & I diagrams :

Alarm : A device that signals the existence of abnormal condition by means of an audible or visible or both discrete change, intended to attract attention.

Balloon : The circular symbol used to denote an instrument.

Board : A structure that has a group of instruments mounted on it and that is chosen to have an individual designation. The board may consist of one or more panels, cubicles, desks or racks.

Board mounted : A term applied to an instrument that is mounted on a board and is accessible to the operator for his normal use.

Computing relay : A relay that performs one or more calculations or logical functions or both and sends out one or more resultant output signals.

Controller : A device having an output that can be varied to maintain a controlled variable at a specified value or within specified limits or to alter the variable in a specified manner.

Control Station : A manual loading station that also provides switching between manual and automatic control modes of a control loop. It is also known as auto-manual station or auto selector station.

Control valve : A device, other than a manual on-off valve that directly manipulates the flow of one or more fluid process streams. In some applications, it is commonly known as a damper or louver.

The designation " hand-control valve" is limited to hand-actuated valves that are used for process throttling.

Converter : A device that receives information in the form of an instrument signal, alters the form of information, and sends out a resultant output signal.

Final control element : The device that directly changes the value of the manipulated variable of a control loop.

Identification : The sequence of letters or digits that are used to uniquely identify an individual instrument or a loop.

Local : The location of an instrument that is neither on nor behind the board. Local instruments are commonly used in the vicinity of a primary element or a final control element.

Local board : A board that is not a central or a main board. Local boards are mainly used in the vicinity of plant subsystems or sub-areas.

Loop:A combination of one or more interconnected instruments arranged to measure and/or control a process variable.

Pilot light : The pilot light is also known as monitor light. This light indicates normal conditions of a system or a device.

Primary element : That part of a loop or an instrument that first senses the value of a process variable, and then assumes a corresponding predetermined and intelligible state or output. The primary element may be separate from or integral with another functional element of a loop. It is also known as a detector or a sensor.

Process : Any operation or sequence of operations involving a change of energy, state, composition, or any other property that may be defined with respect to the given data.

Process Variable : Any variable property of a process

Relay : A device that receives information in the form of one or more instrument signals; modifies the information or its form or both, if required; and sends one or more resultant output signals. It is not designated as a controller or a switch. The term ‘ relay’ is also specifically applied to an electric switch that is remotely actuated by an electric signal.

Scan : To sample each of a number of inputs intermittently is called scanning. A scanning device may provide additional functions such as record or alarm.

Shared Controller : A control device which allows implementation of user defined control strategies or functions. Control of multiple process variables can be implemented by sharing the capabilities of this single device.

Shared display : The operator interface device which is used to selectively display of signals and/or data on a time shared basis.

Shared instruments : An instrument which is permitting shared functions of display, control, signal lines.

Switch : It is adevice that connects, disconnects, or transfers one or more circuits; and is not designated as a controller, arelay, or a control valve.

Transmitter : A device that senses a process variable through the medium of a primary element, and that has an output whose steady state value varies only as a predetermined function of the process variable. The primary element may or may not be integral with the transmitter.