



**IPE 301**  
**Instrumentation and Control**

**Chapter 5**  
***Process Controllers***

# Introduction

- ***Process Controllers*** are control system components which basically have an input of the error signal and an output of a signal to modify the system output.
- The simplest form of controller is an on-off device which switches on some correcting device when there is an error and switches it off when the error ceases.
- While there are many ways a controller could be designed to react to an error signal, a form of controller which can give satisfactory control in a wide number of situations is the three-term or PID controller.
- The three basic control modes are proportional (P), integral (I) and derivative (D); the three term controller is a combination of all three modes.

# Direct and Reverse Actions

## Direct Action:

If an increase in input gives an increase in output for an element of a control system, it is defined as direct action.

Example: A domestic central heating furnace where an increase in the energy input to the system results in an increase in temperature.

## Reverse Action:

If an increase in input gives an decrease in output for an element of a control system is defined as reverse action.

Example: An air conditioner where an increase in the energy input to it results in a decrease in temperature.

# Dead Time or Lags

In any control system with feedback the system cannot respond instantly to any change and thus there are delays while the system takes time to accommodate the change. Such delays are referred to as dead time or lags.

Example: In the control of the temperature in a room by means of a central heating system, if a window is suddenly opened and the temperature drops **a lag will occur before the control system responds**, switches on the heater and gets the temperature back to its set value.

❖ A source of dead time in a control system is the response time of the measurement sensor. Thus, for a system using a temperature sensor, a resistance temperature detector (RTD) has a slower response time than a thermocouple.

# Dead Time or Lags

Transfer delays are a common event with control systems where flow is concerned.

Example: Water flowing along a pipe from point A where the control valve is to point B where the rate of flow is required and monitored. Any change made at some point A will take some time before its affects are apparent at a point B, the time delay depending on the distance between A and B and the rate of flow between them.

❖ Dead time effectively hides a disturbance from the control system until its well into the system and needs to be made as small as possible.

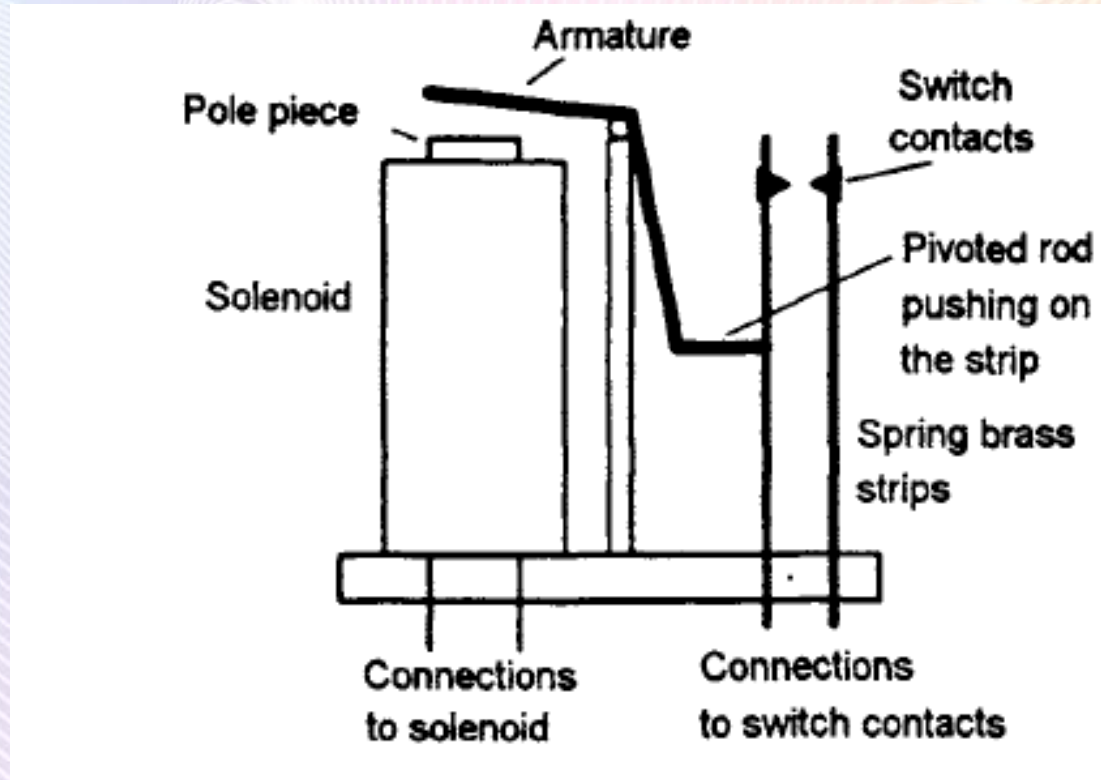
# Capacitance

Capacitance has the tendency to dampen out disturbances.

Example: (i) Consider a domestic heating system controlled by a thermostat. The larger the space being heated the longer it will take the controller to respond and restore a drop in temperature.

(ii) Consider the water tank system. If we have water leaving the tank and the control signal used to determine the rate of flow of water into the tank, then the greater the surface area of the water in the tank the longer it will take the controlled inflow of water to respond and restore a drop in level.

# Relays



**Works as a correction element**

# On-off Control

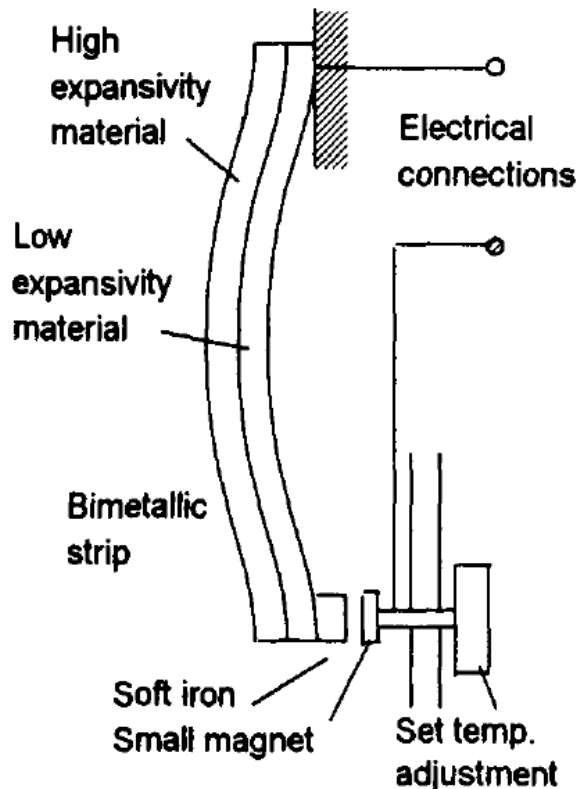


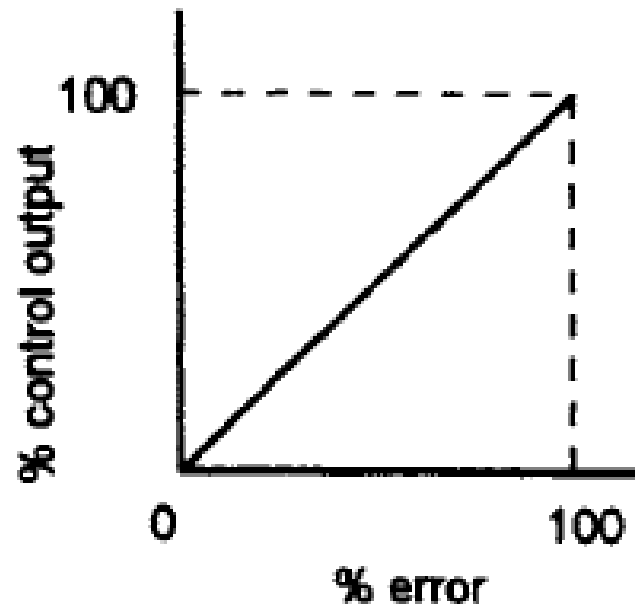
Fig: Bimetallic Thermostat

- The controller is a switch which is activated by the error signal and supplies just an on-off correcting signal.
- The controller output has just two possible values, equivalent to on and off.
- For this reason the controller is sometimes termed a two-step controller.
- With the on-off method of control, the controller output is either an on or an off signal and so the output is not related to the size of the error.

# Proportional Control

- With proportional control the size of the controller output is proportional to the size of the error, i.e. the controller input.
- Thus we have: controller output  $\propto$  controller input.
- Controller output =  $K_p \times$  controller input
- This means the correction element of the control system will have an input of a signal which is proportional to the size of the correction required.

# Proportional Control



# Example of Proportional Control

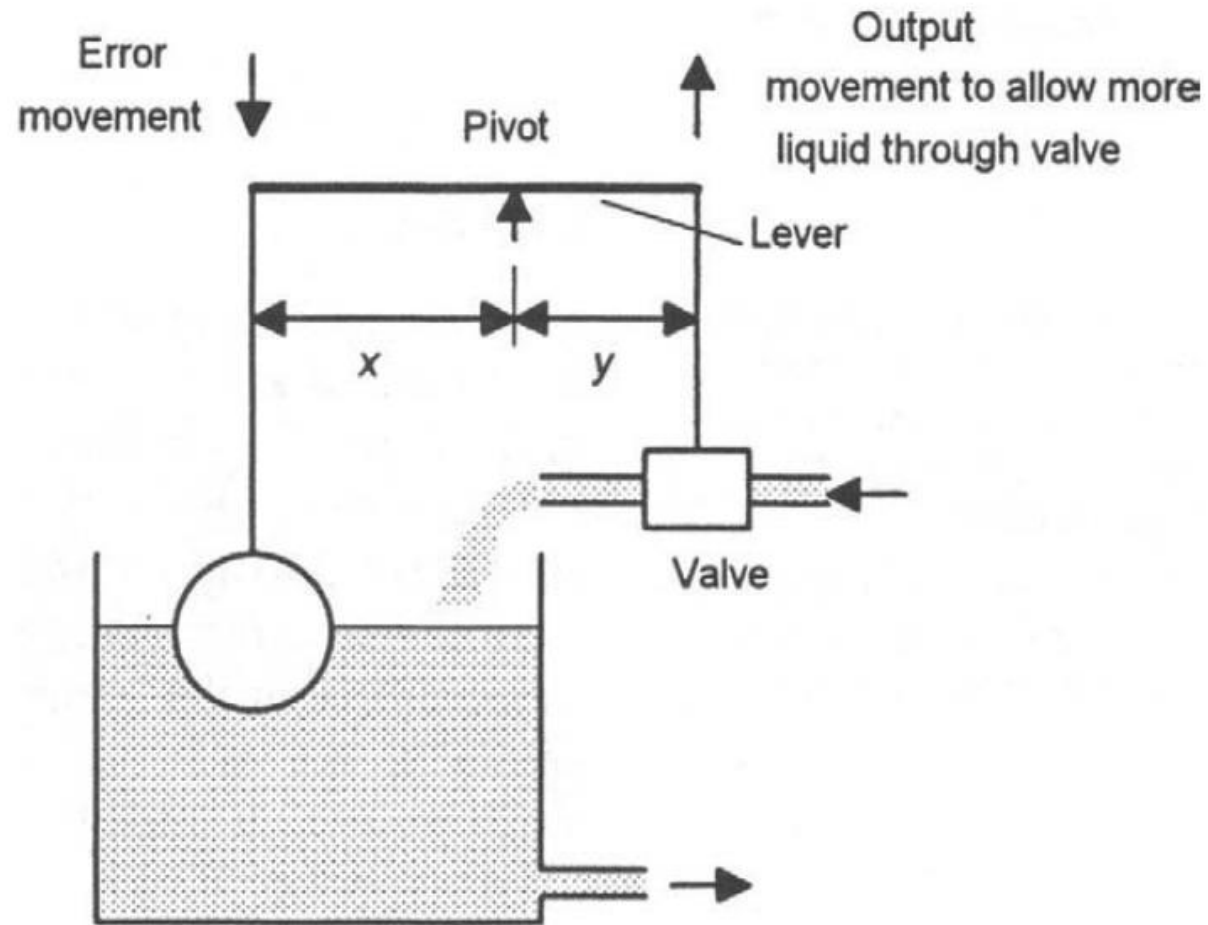


Figure *The float-lever proportional controller*

# Example of Proportional Control

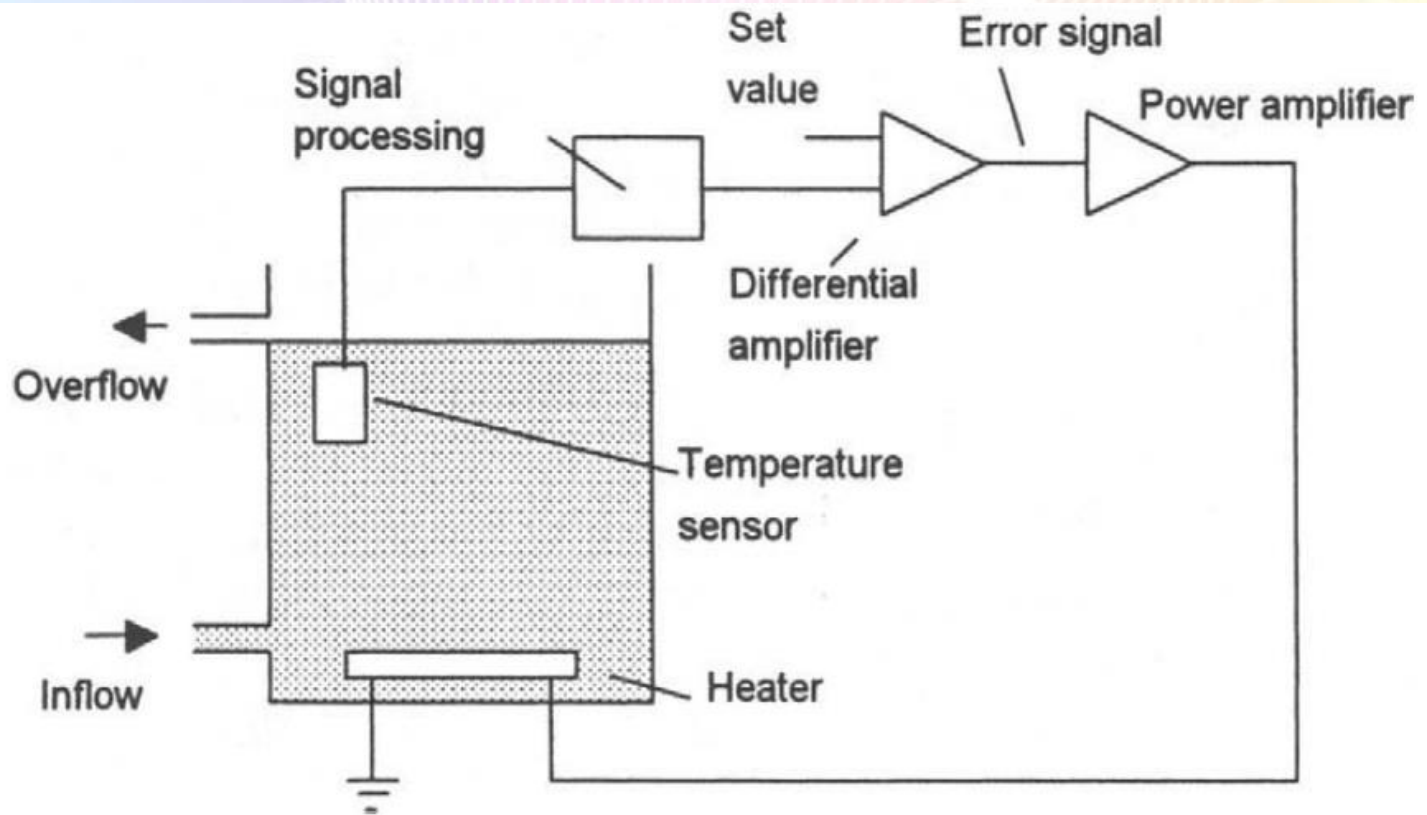


Figure *Proportional controller for the control of temperature*

# Deviation

**Deviation or error:** The set-point is compared to the measured value to give the error signal, this being generally termed the deviation. The term absolute deviation is used when the deviation is just quoted as the difference between the measured value and the set value.

$$e = r - b$$

where  $e = \text{error}$

$b = \text{measured value}$

$r = \text{set value}$

# Deviation

*Problem: If the setpoint in a 4-20 mA range corresponds to 9.9 mA and the measured value is 10.7 mA, what is the error?*

*Solution: Given,*

$$r = 9.9 \text{ mA}$$

$$b = 10.7 \text{ mA}$$

$$e = (9.9 - 10.7) \text{ mA} = -0.8 \text{ mA}$$

# Deviation

## Percent Deviation or fractional deviation:

The deviation is expressed as a fraction or percentage of the span.

$$e_p = \frac{r - b}{b_{\max} - b_{\min}}$$

$b_{\max}$  = maximum measurable value

$b_{\min}$  = minimum measurable value

$b_{\max} - b_{\min}$  = span

**Problem:** A heating element has a range of 300 to 440 K and a setpoint 384 K. Find the percent deviation.

# Proportional Band

The range of error to cover the 0% to 100% controller output is called the proportional band. One-to-one correspondence exists only for errors in this range.

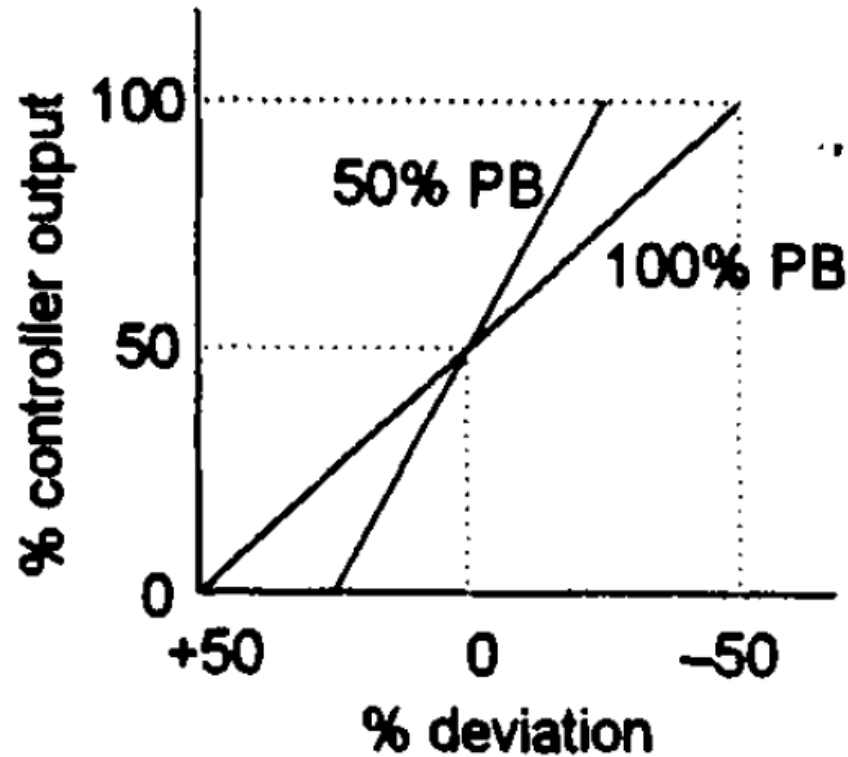


Figure *Proportional band*

# Proportional Band

$$\%PB = \frac{\% \text{ deviation}}{\% \text{ change in controller output}} \times 100$$

$$\%PB = \frac{e}{\text{measurement span}} \times \frac{\text{controller output span}}{y_c} \times 100$$

$$\%PB = \frac{1}{K_p} \frac{\text{controller output span}}{\text{measurement span}} \times 100$$

$$k_p = \frac{y_c}{e}$$

# Proportional Band

Problem: What is the controller gain of a temperature controller with a 60% PB if its input range is 0 - 50°C and its output is 4 mA to 20 mA?

Solution:

$$\%PB = \frac{1}{K_p} \frac{\text{controller output span}}{\text{measurement span}} \times 100$$

$$60 = \frac{1}{K_p} \frac{20 - 4}{50 - 0} \times 100$$

$$K_p = 0.53 \text{ mA/}^\circ\text{C}$$

# Limitation of Proportional Control

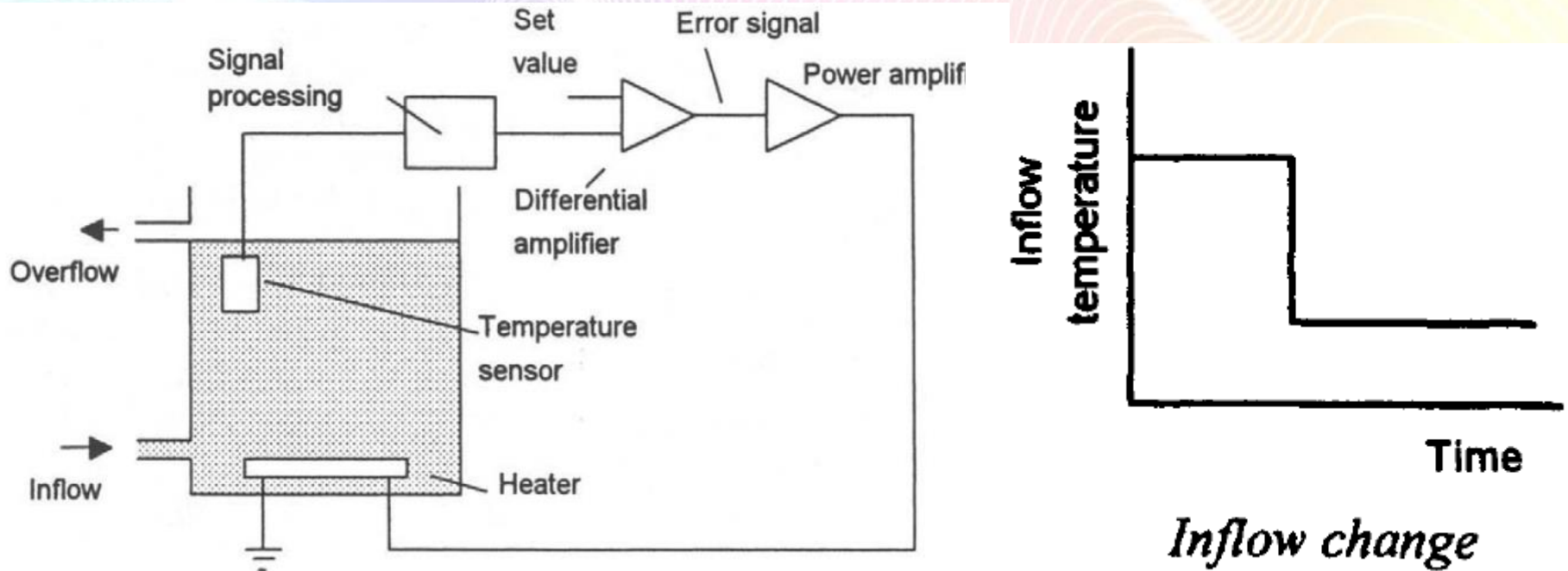
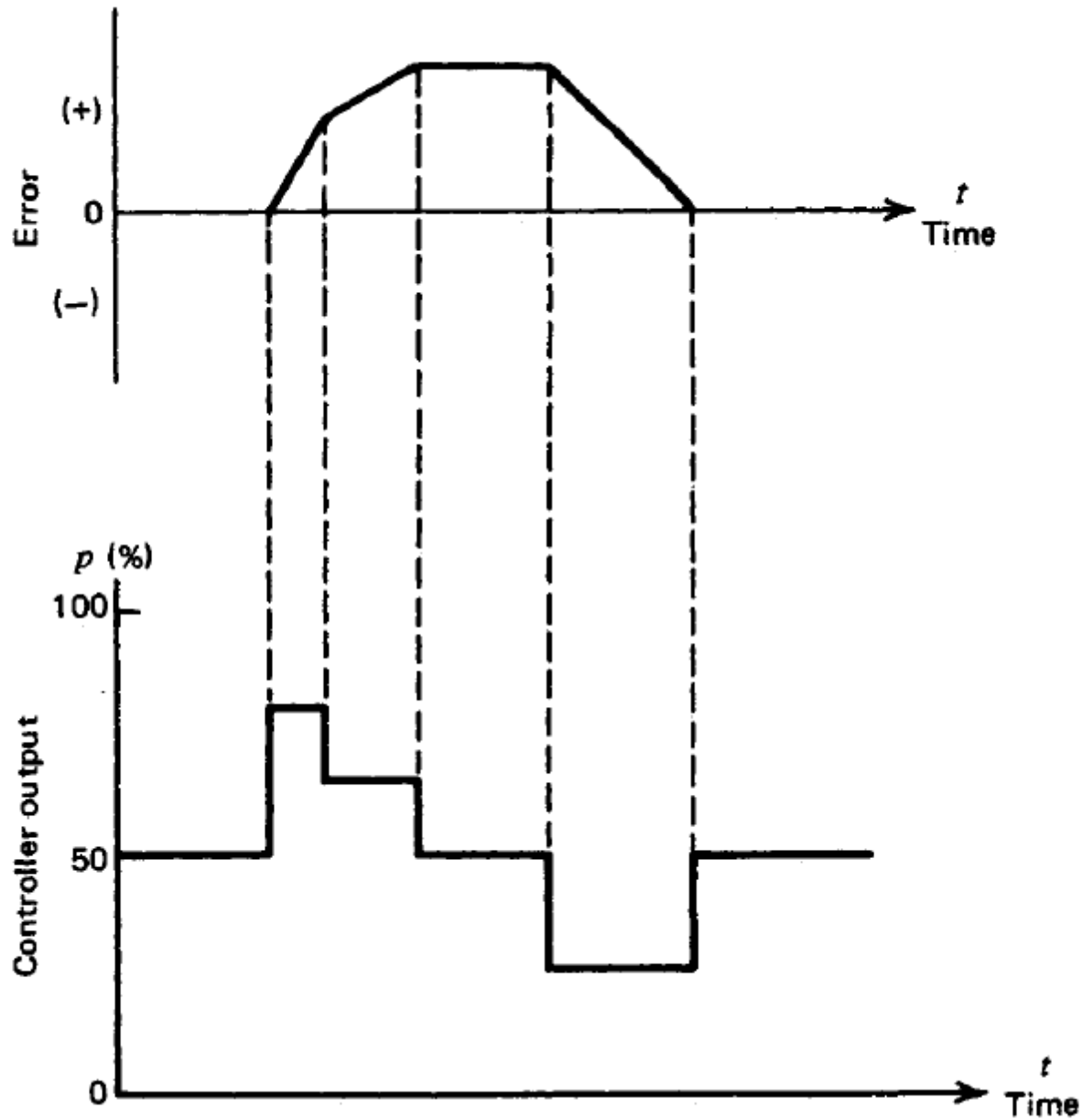


Figure *Proportional controller for the control of temperature*

- ❖ Solve example problems from the book.

# Derivative Control

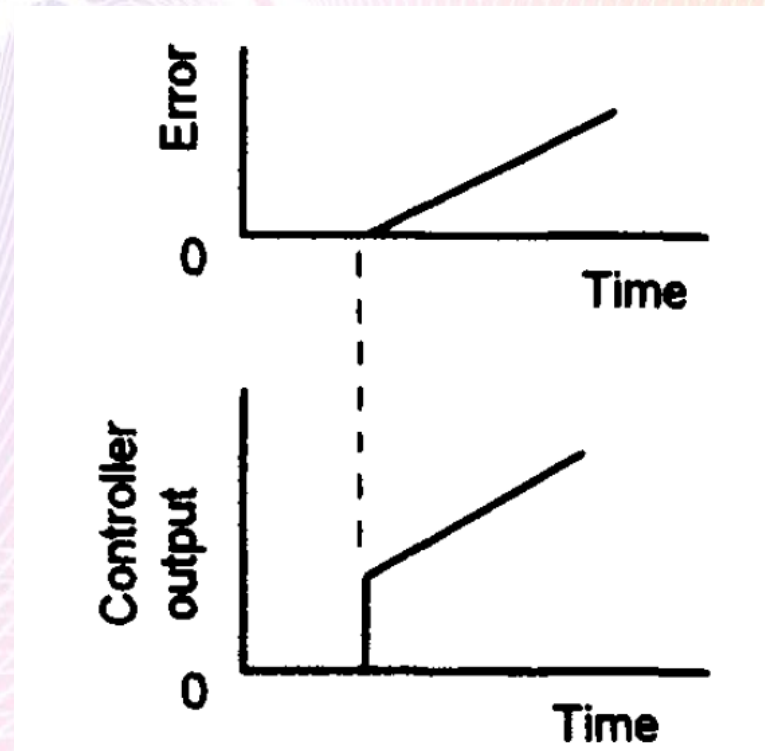


# Derivative Control

- With derivative control the change in controller output from the set point value is proportional to the rate of change with time of the error signal.
- Controller output  $\propto$  rate of change of error.
- D controller output =  $K_d \times$  rate of change of error
- With derivative control, as soon as the error signal begins to change there can be quite a large controller output since it is proportional to the rate of change of the error signal and not its value. Thus with this form of control there can be rapid corrective responses to error signals that occur.

# PD Control

- Derivative controllers give responses to changing error signals but do not, however, respond to constant error signals, since with a constant error the rate of change of error with time is zero.
- Because of this, derivative control D is combined with proportional control P.



# PD Control

PD controller output =  $K_P \times \text{error} + K_D \times \text{rate of change of error with time}$

$$\text{PD controller output} = K_P \left( \text{error} + \frac{K_D}{K_P} \text{rate of change of error} \right)$$

$K_D/K_P$  is called the *derivative action time*  $T_D$  and so:

$$\text{PD controller output} = K_P(\text{error} + T_D \times \text{rate of change of error})$$

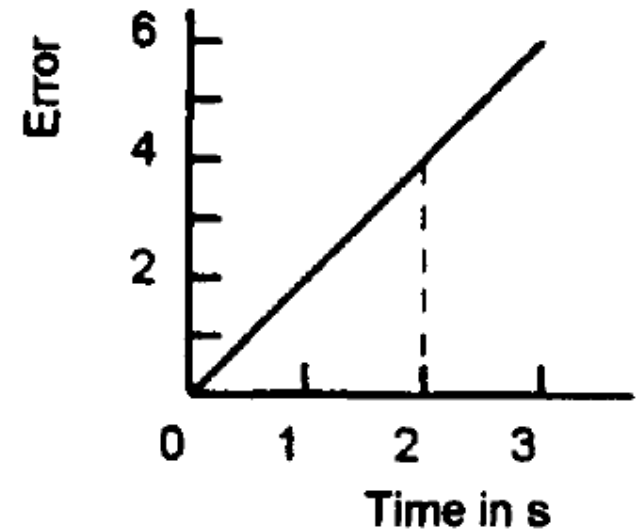
❖ PD control can deal with fast process changes better than just proportional control alone.

# PD Control

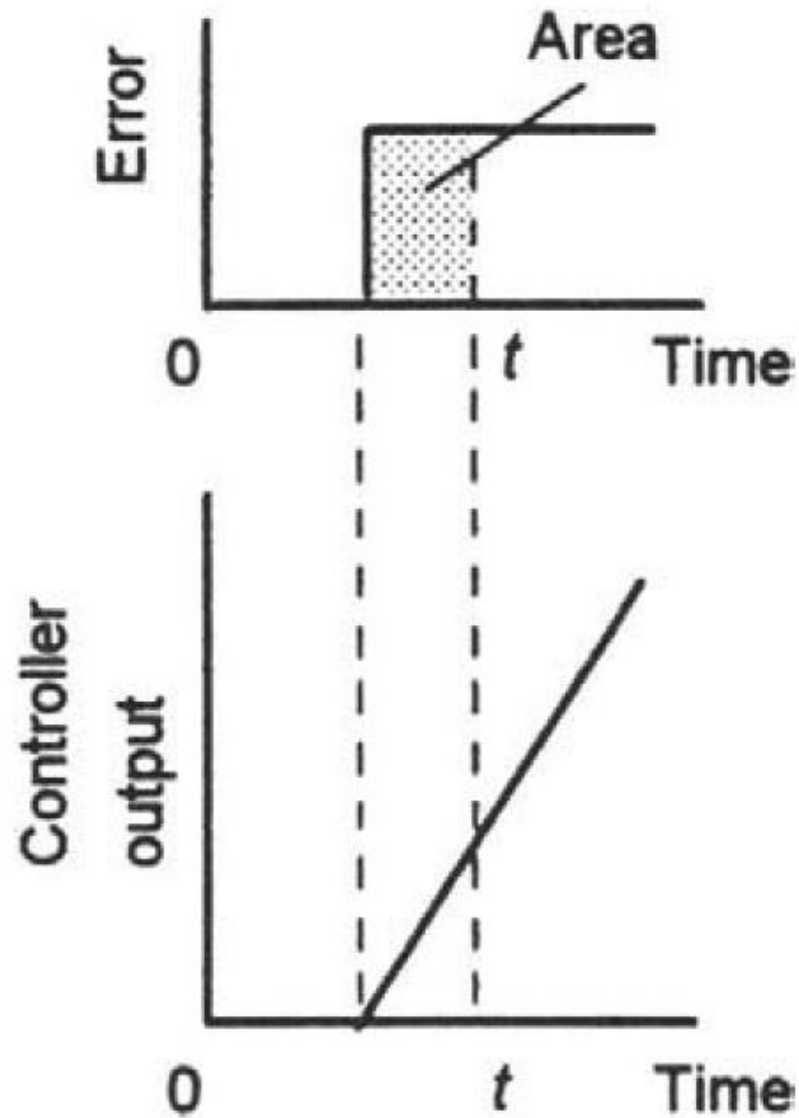
**Problem:** A derivative controller has a derivative constant  $K_D$  of  $0.4s$ . What will be the controller output when the error (a) changes at  $2\%/s$ , (b) is constant at  $4\%$ ?

# PD Control

Problem: What will the controller output be for a proportional plus derivative controller (a) initially and (b) 2s after the error begins to change from the zero error at the rate of 2%/s. The controller has  $K_p = 4$  and  $T_D = 0.4$ .



# Integral Control

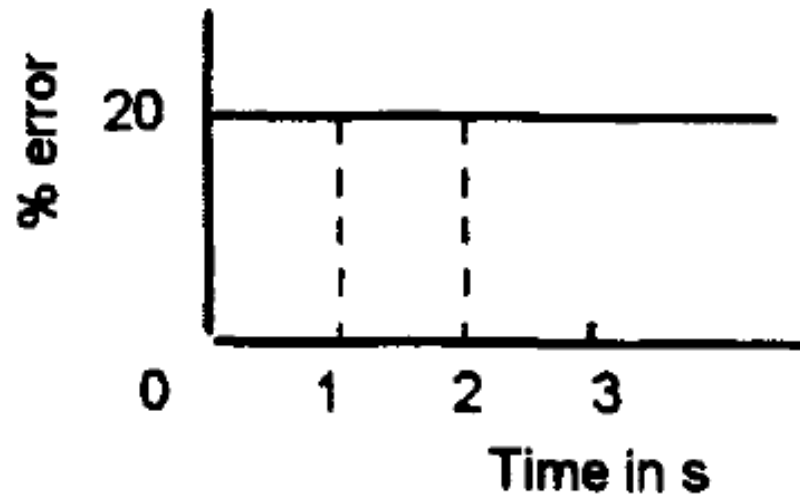


# Integral Control

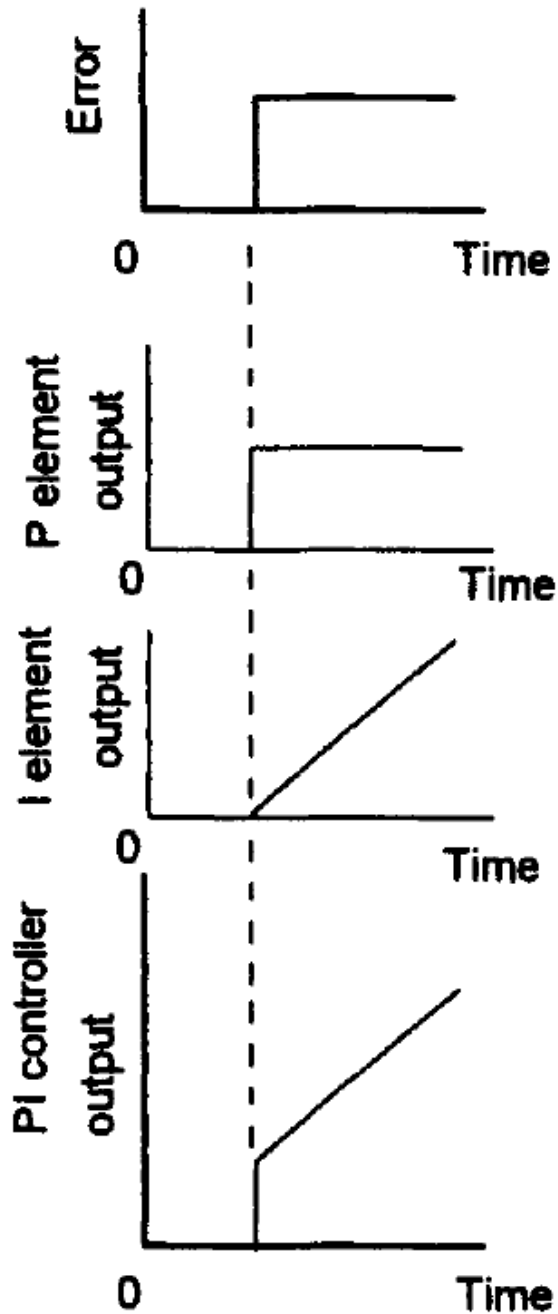
- *Integral control* is the control mode where the controller output is proportional to the integral of the error with respect to time.
- Controller output  $\propto$  integral of error with time
- I controller output =  $K_I \times$  integral of error with time
- Rate of change of controller output  $\propto$  error

# Integral Control

**Problem:** An integral controller has a value of  $K_I$  of  $0.10/s$ . What will be the output after times of (a) 1 s, (b) 2 s, if there is a sudden change to a constant error of 20%, as illustrated in Figure?



# PI Control



PI controller output =  $K_p \times \text{error} + K_I \times \text{integral of error with time}$

# PI Control

❖ The combination of integral mode with proportional mode has one great advantage over the proportional mode alone: the steady state error can be eliminated.

$$\text{PI controller output} = K_P \left( \text{error} + \frac{K_I}{K_P} \text{integral of error} \right)$$

$K_P/K_I$  is called the *integral action time*  $T_I$  and so:

$$\text{PI controller output} = K_P \left( \text{error} + \frac{1}{T_I} \text{integral of error} \right)$$

# PID Control

❖ A PID controller can be considered to be a **proportional controller** which has **integral control** to eliminate the offset error and **derivative control** to reduce time lags.

$$\text{controller output} = K_P \times \text{error} + K_I \times \text{integral of error} \\ + K_D \times \text{rate of change of error}$$

where  $K_P$  is the proportionality constant,  $K_I$  the integral constant and  $K_D$  the derivative constant. The above equation can be written as:

$$\text{PID controller output} = \\ K_P \left( \text{error} + \frac{1}{T_I} \text{integral of error} + T_D \text{rate of change of error} \right)$$

# PID Control

Determine the controller output of a three-mode controller having  $K_p$  as 4,  $T_I$  as 0.2 s,  $T_D$  as 0.5 s at time (a)  $t = 0$  and (b)  $t = 2$  s when there is an error input which starts at 0 at time  $t = 0$  and increases at 1%/s.

