BENHA UNIVERSITY
FACULTY OF ENGINEERING (SHOUBRA)
ELECTRONICS AND COMMUNICATIONS ENGINEERING

ECE 444
Industrial Electronics

(2022 - 2023) 1st term

Lecture 6: Controller Principles (part1).

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Outlines:

- Introduction.
- Process Characteristics.
- Control System Parameters.
- Discontinuous Controller Modes.

Introduction

- Using input measurements & setpoint, the controller solves certain equations to calculate the proper output.

- The equations describe the modes or action of controller operation.

- The nature of the process and the variable controlled determine which mode(s) of control to be used.

Process Characteristics

- Process equation:

  TL = f(QA,QB,QS,TS,T0)

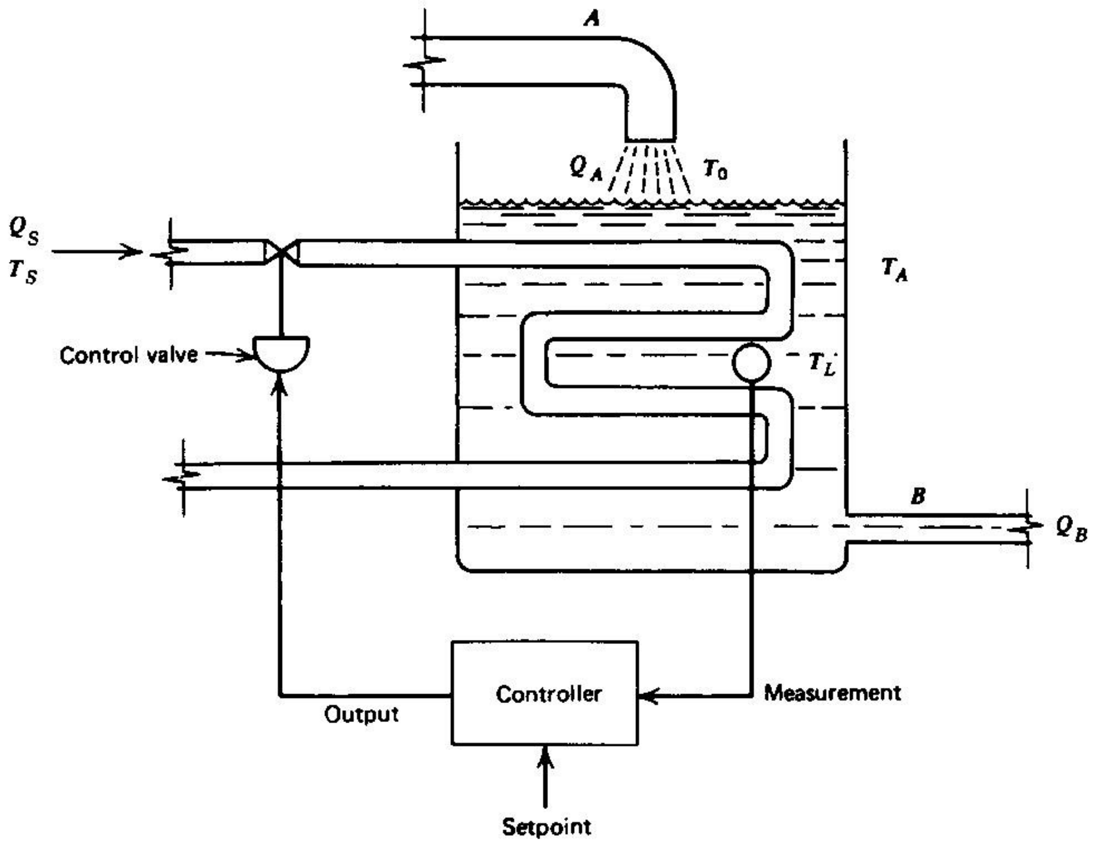
  h=f( )?

- Process load ?

  Set of all parameters excluding controlled variable.

- Process lag, Control lag ?

  There is no advantage in designing control system faster than the process lag.



Control System Parameters

- Inputs to the controller are measured indication of both the controlled variable & the set point expressed in the same fashion.
- Error e = r-b

  expressed as % of span

$$e_p = \frac{r - b}{b_{max} - b_{min}} \times 100$$

  ep = error expressed as percent of span

  why?

- Example

You can see the convenience of using a standard measured indication range like 4 to 20 mA, because the span is always 16 mA. Suppose we have a setpoint of 10.5 mA and a measurement of 13.7 mA. Then, without even knowing what is being measured, we know the error is

$$e_p = \frac{10.5\ \text{mA} - 13.7\ \text{mA}}{20\ \text{mA} - 4\ \text{mA}} \times 100$$

$$e_p = -20\%$$

A positive error indicates a measurement below the setpoint, and a negative error indicates a measurement above the setpoint.

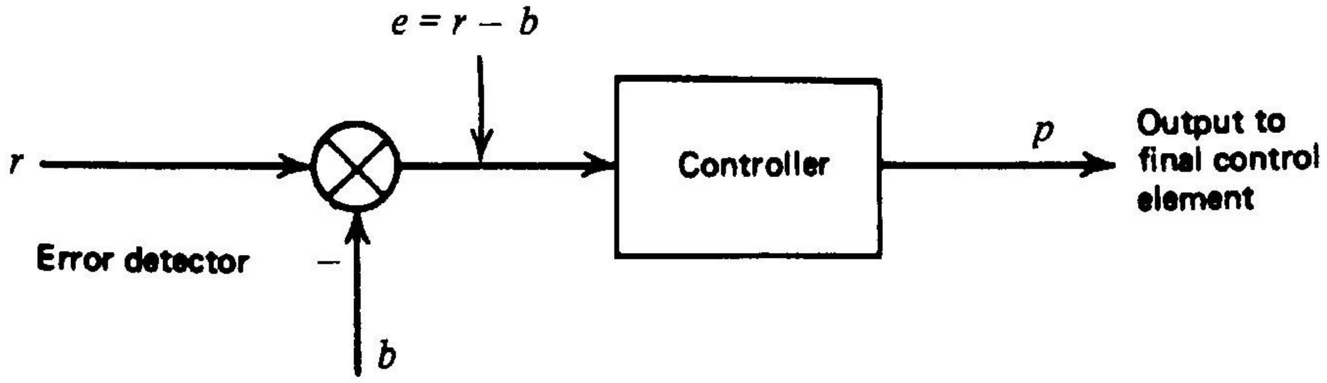
Control System Parameters

- Control parameter range

  P: controller output as % of span scale.

$$p = \frac{u - u_{min}}{u_{max} - u_{min}} \times 100$$

where
p = controller output as percent of full scale
u = value of the output
u_{max} = maximum value of controlling parameter
u_{min} = minimum value of controlling parameter



Control System Parameters

EXAMPLE 2

A controller outputs a 4- to 20-mA signal to control motor speed from 140 to 600 rpm with a linear dependence. Calculate **(a)** current corresponding to 310 rpm, and **(b)** the value of (a) expressed as the percent of control output.

Solution

a. We find the slope m and intersect S_0 of the linear relation between current I and speed S, where

$$S_p = mI + S_0$$

Knowing S_p and I at the two given positions, we write two equations:

$$140 = 4m + S_0$$
$$600 = 20m + S_0$$

Solving these simultaneous equations, we get $m = 28.75$ rpm/mA and $S_0 = 25$ rpm. Thus, at 310 rpm we have $310 = 28.75I + 25$, which gives $I = 9.91$ mA.

b. Expressed as a percentage of the 4- to 20-mA range, this controller output is

$$p = \frac{u - u_{\min}}{u_{\max} - u_{\min}} \times 100$$

$$p = \left[\frac{9.91 - 4}{20 - 4}\right] \times 100$$

$$p = \mathbf{36.9\%}$$

Control System Parameters

Reverse and direct action.

- Direct action: when an increasing value of the controlled variable causes an increasing value of the controller output (Level).

- Reverse action: is the opposite case, where an increase in a controlled variable causes a decrease in controller output (Temp).

Controller modes

- Discontinuous Controller Modes: show discontinuous changes in controller output as controlled variable error occurs.
- Continuous Controller Modes: The output of the controller changes smoothly in response to the error or rate of change of the error.

Discontinuous Controller Modes:
1- Two position Mode

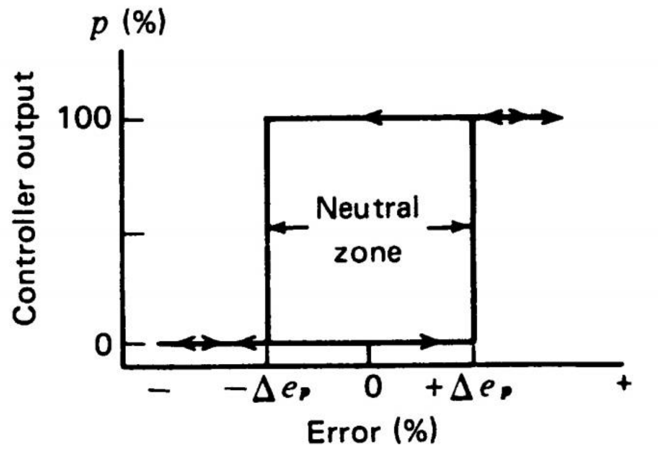
- Other names: ON/OFF ...Bang-Bang
- Simple – Cheap.

$$p = \begin{cases} 0\% & e_p < 0 \\ 100\% & e_p > 0 \end{cases}$$

- Neutral zone = differential gap ?

  A region around zero error at which no change in the output occurs. Why ?
- Application:

  Large-scale systems with relatively slow process rates.



Discontinuous Controller Modes:
1- Two position Mode

EXAMPLE 4 The temperature of water in a tank is controlled by a two-position controller. When the heater is *off* the temperature drops at 2 K per minute. When the heater is *on* the temperature rises at 4 K per minute. The setpoint is 323 K and the neutral zone is ±4% of the setpoint. There is a 0.5-min lag at both the *on* and *off* switch points. Find the period of oscillation and plot the water temperature versus time.

Soln: - assume The temp is setpoint = 323 K So The heater is off
So Temp decrease To ?? (310.1 K)

Neutral zone = ± 4 % of set point = $\frac{4}{100} \times 323 = \pm 12.9$ K

∴ Temp range = (323 − 12.9) → (323 + 12.9)
310.1 → 335.9 K

$T_1 = \frac{323 - 310.1}{2} = \boxed{6.46 \text{ min}}$

- when Temp reach 310.1 The heater will on but after lag 0.5 min This make Temp reach (309.1 K) at time $(T_1 + 0.5\ min)$ heater ON:

Temp increase from 309.1 to 335.9 K

$$T_2 = \frac{335.9 - 309.1}{4} = \boxed{6.71\ min}$$

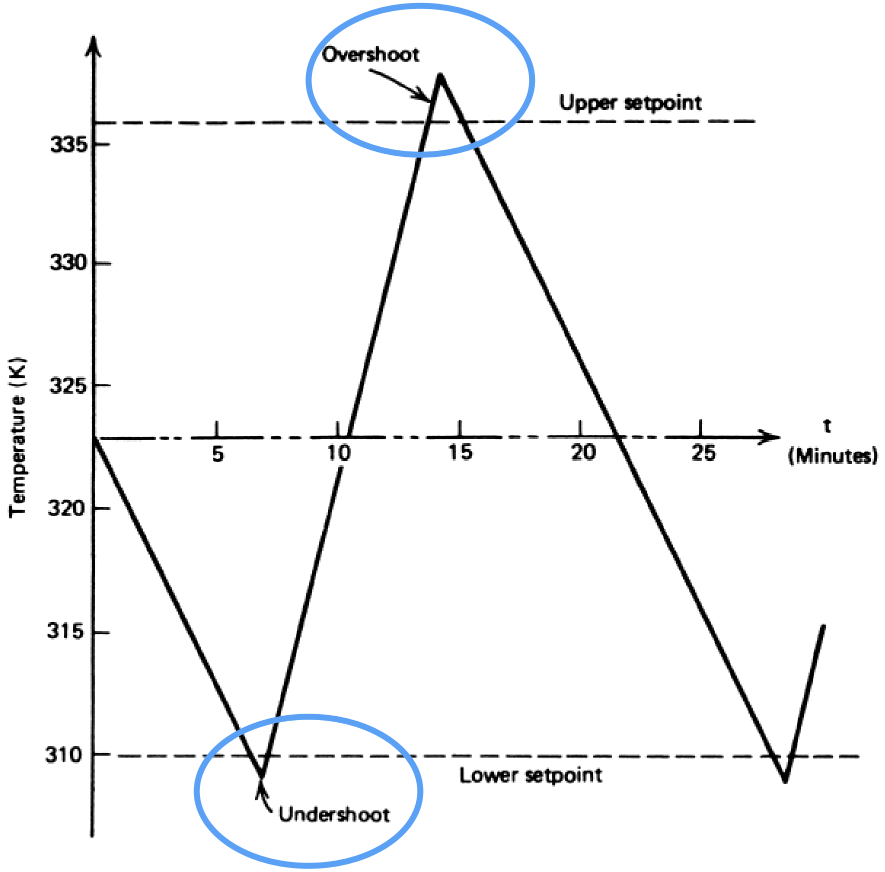
- when Temp reach 335.9 K heater off after 0.5 min lag so Temp reach to 337.9 K

- at Time $(T_1 + 0.5\ min) + (T_2 + 0.5\ min)$ heater off:

Temp decrease from 337.9 → 323.

$$T_3 = \frac{337.9 - 323}{2} = 7.46$$

So The oscillation Time = $T_1 + 0.5 + T_2 + 0.5 + T_3$
= 21.6 min



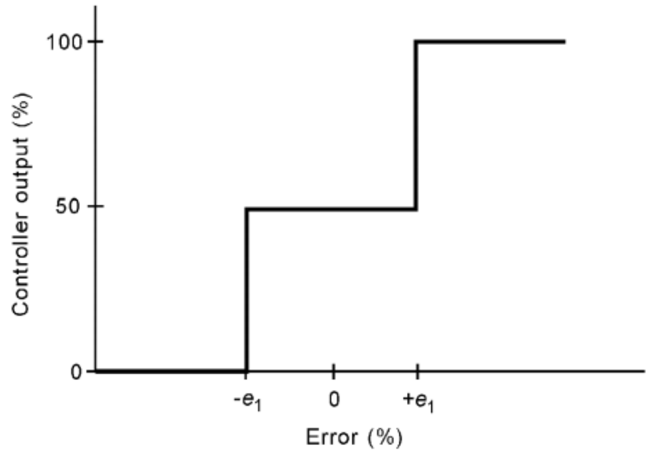
- In general, some overshoot and undershoot of the controlled variable will occur, as in Example 4. This is due to the finite time required for the control element to impress its full effect on the process.
- In some cases, if the final control element lag is large, substantial errors can result, and the neutral zone must be reduced to lower these errors.

Discontinuous Controller Modes: 2- Multiposition Mode

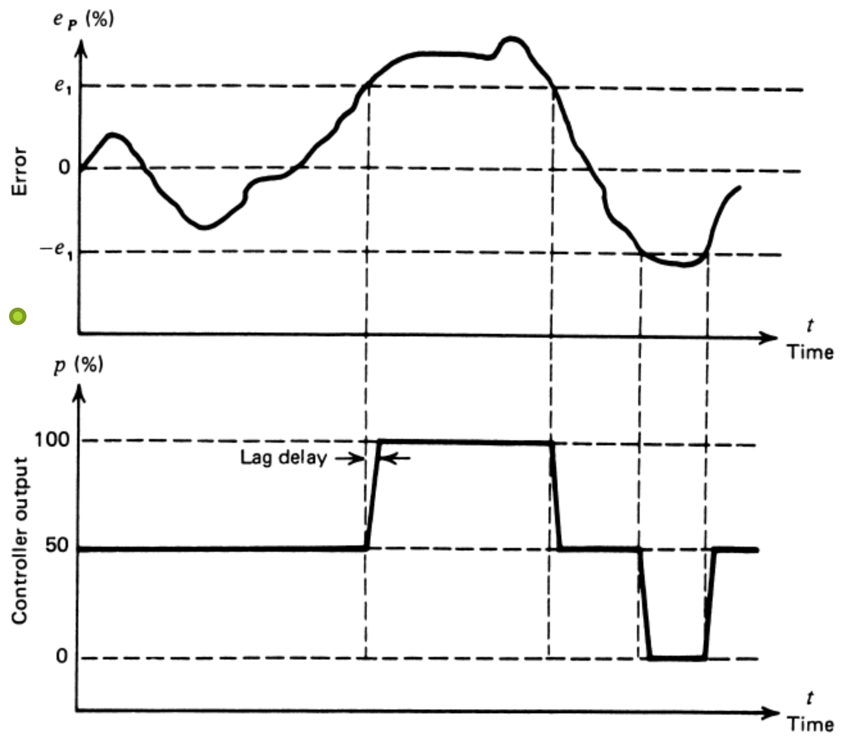
- A logical extension of the previous two-position control mode is to provide several intermediate, rather than only two, settings of the controller output.

- Why?.. To reduce the cycling behavior and overshoot and undershoot inherent in the two-position mode.

$$p = \begin{cases} 100 & e_p > e_2 \\ 50 & -e_1 < e_p < e_2 \\ 0 & e_p < -e_1 \end{cases}$$



What is the action...?



Discontinuous Controller Modes:
3- Floating-Control Mode (Single speed)

- If the error is zero, the output doesn't change but remains (floats) at whatever setting it was when error went to zero.
- There is a neutral zone around zero error where no change in controller output.
- The output of the control element changes at a fixed rate when the error exceeds the neutral zone.

$$\frac{dp}{dt} = \pm K_F \qquad |e_p| > \Delta e_p$$

where

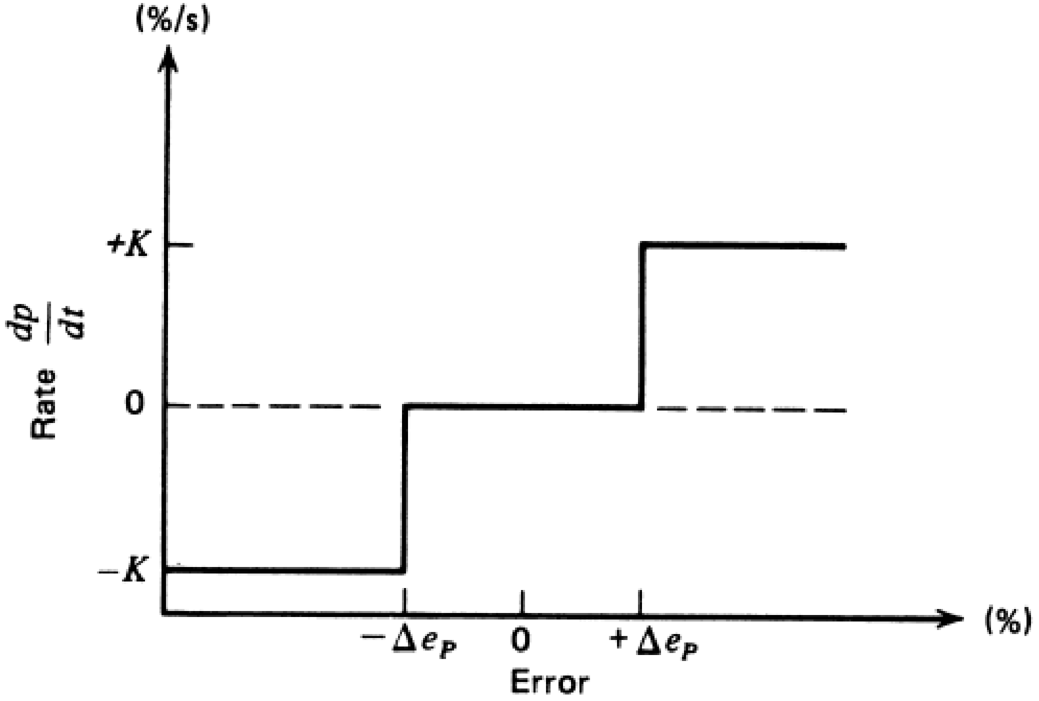
$\frac{dp}{dt}$ = rate of change of controller output with time

K_F = rate constant (%/s)

Δe_p = half the neutral zone

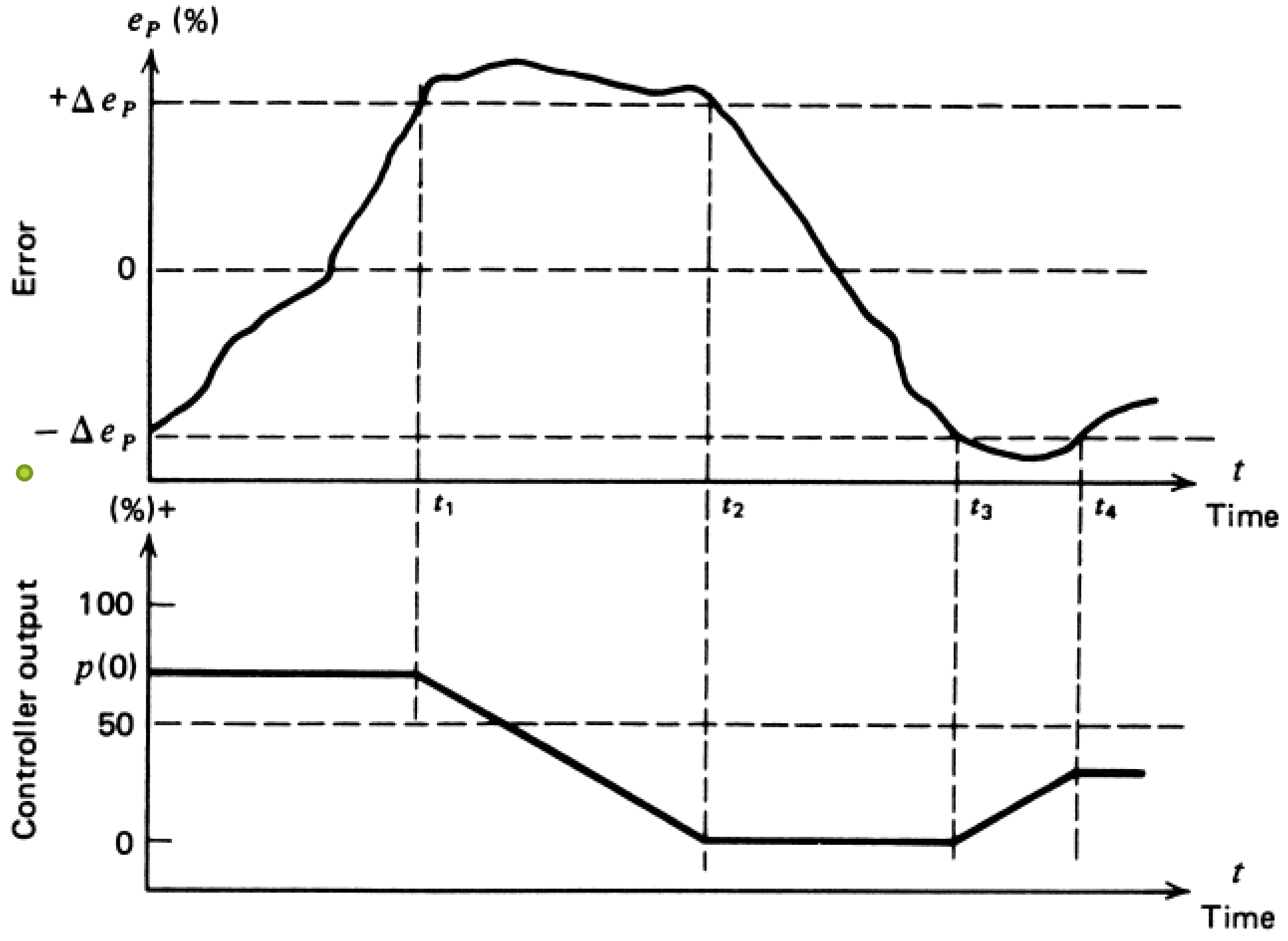
$$p = \pm K_F t + p(0) \qquad |e_p| > \Delta e_p$$

where $p(0)$ = controller output at $t = 0$



Discontinuous Controller Modes:
3- Floating-Control Mode (Single speed)

$$\frac{dP}{dt} = \mp K_f \qquad |e_p| > \Delta e_p$$



Discontinuous Controller Modes: 3- Floating-Control Mode (Single speed)

EXAMPLE 5

Suppose a process error lies within the neutral zone with $p = 25\%$. At $t = 0$, the error falls below the neutral zone. If $K = +2\%$ per second, find the time when the output saturates.

Solution

The relation between controller output and time is

$$p = K_F t + p(0)$$

When $p = 100$

$$100\% = (2\%/\text{s})(t) + 25\%$$

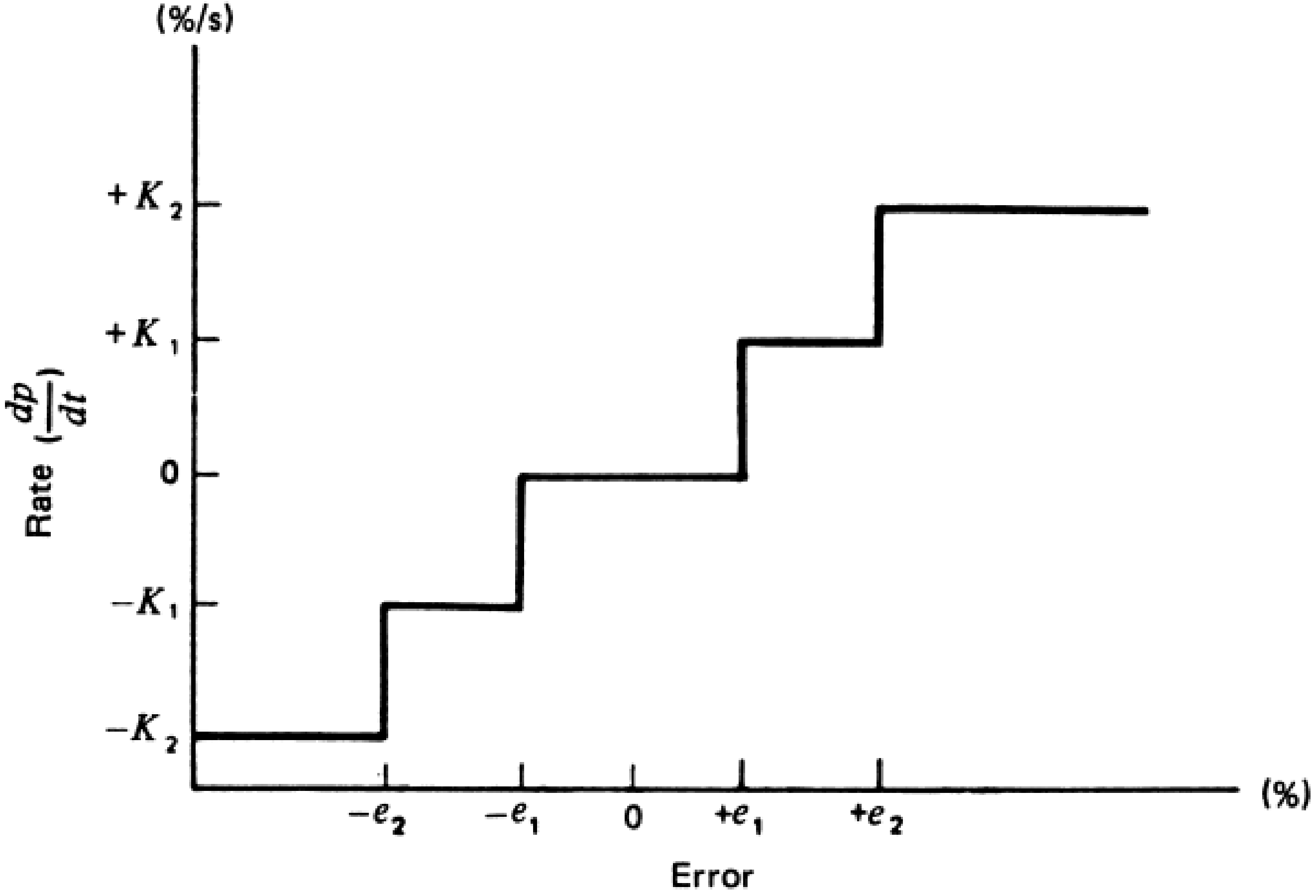
that, when solved for t, yields

$$t = \mathbf{37.5\ s}$$

Discontinuous Controller Modes:
4- Floating-Control Mode (Multiple speed)

- In the floating multiple-speed control mode, not one but several possible speeds (rates) are changed by controller output.
- Usually, the rate increases as the deviation exceeds certain limits.

$$\frac{dp}{dt} = \pm K_{Fi} \qquad |e_p| > e_{pi}$$



END OF LECTURE

BEST WISHES