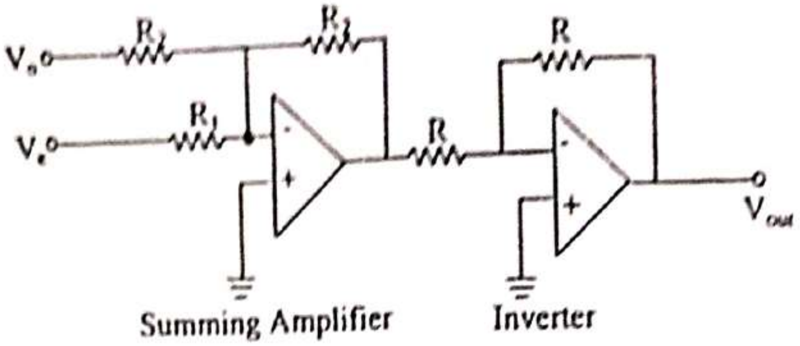
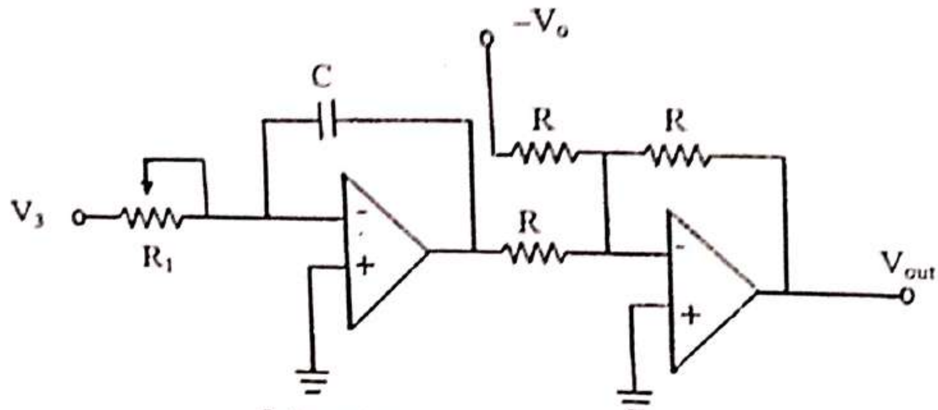
- The amplifier input and output voltages are conveniently scaled such that a 0–$V_{max}$ amplifier output corresponds to a 0-100% or 4-20 mA controller signal. The input error signal is also scaled to match the full range of the error signal. The proportional band is adjusted through the gain $\left(\frac{R_2}{R_1}\right)$




Electronic proportional controller

### *Electronic Integral Controller*




Circuit of electronic Integral controller

- Diagram of an electronic integral controller using . op-amp is shown in the above figure. The output given by

$$V_{out} = K_i \int V_e dt$$

In the above equation $K_i \left(= \frac{1}{R_i C}\right)$ is the RAC integration constant, $V_e$ is the error voltage, and $V_i$ is the initial output voltage. The output of the first stage, due, to the integrator, is $-K_i \int V_e dt$

- The values of R and C are adjusted to obtain the desired integration time. The integration time constant determines the rate at which the controller output increases when the error is constant. If Ki is made too large, the output rises so fast that it overshoots the optimum setting, and cycling/oscillating response produced.

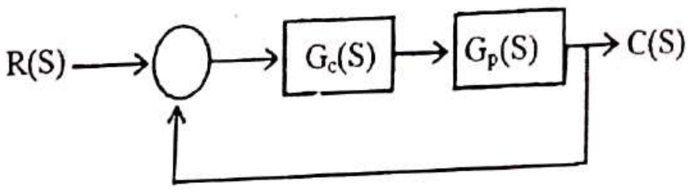
*...to remember*

- The integral control action under steady state condition adjust its output such that its steady state error is brought to zero.
- The integral action tries to eliminate the steady state error
- The integral control action will make the steady state error zero if there was a previous steady state error with out this integral action.

*...mple 2.*

Consider a transport lag process with a transfer function $G_p(S) = e^{-S}$. The process is controlled by a purely integral controller with transfer function $G_c(S) = \frac{K_i}{S}$ in a unity feedback configuration. The value of Ki for which the closed loop plant has a pole at s = -1, is ________

*...tion:*




$G_p(s) = e^{-s}$

$G_{c(s)} = \frac{K_i}{S}$

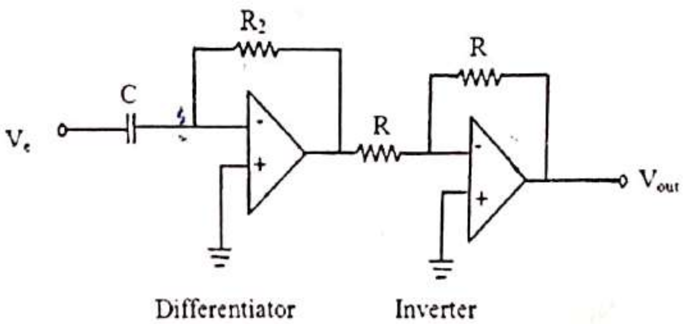
Characteristics equation 1+ G(s) H(s)

$$\Rightarrow 1 + \frac{K_i}{S} \times e^{-s} = 0$$

$$\Rightarrow K_i = \frac{-S}{e^{-s}}$$

$$K\Big|_{s=-1} = \frac{1}{e^1} = 1 \times e^{-1} = 0.34$$

## ...ectronic Derivative Controller




Electronic derivative controller

- The above Figure shows the circuit diagram of an electronic derivative controller.

The control mode equation for the electronics derivative controller is given by:

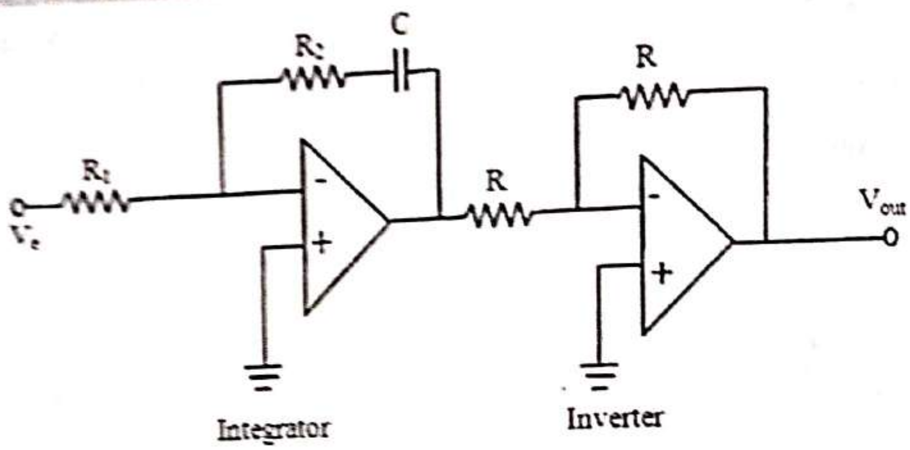
$$V_{out} = K_d \frac{dV_e}{dt}$$

- In the above equation Kai is the derivative time constant in seconds (which is equal to $R_2C$), and $V_e$ the error voltage. If V0 is the required output voltage at zero error, then the second op-amp would configured as an adder.

*Points to remember*

- The derivative control action always influence damping of system and hence influences the overshoot the system.
- Introduction of derivative control action in closed loop increases the damping by decreasing overshoot and improve transient response.

## Electronic PI Controller




A simple combination of the proportional and integral circuits provides proportional-integral mode of cont action. The above figure represents the combination of proportional and integral controller.

The equation for the PI Controller is given as v

$$V_{out} = +\left(\frac{R_2}{R_1}\right)V_e + \frac{1}{R_1C}\int V_e dt$$

We can rewrite the above equation as

$$V_{out} = +\left(\frac{R_2}{R_1}\right)V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_2C}\int V_e dt$$

***Adjustments:***

- The proportional band which through $K_p = R_2/R_1$, and
- The integration gain which through $K_i = 1/R_2C_2$

$$K_P = \frac{R_2}{R_1}$$

$$K_d = T_d = R_1C_1$$

- If $V_o$ is not zero, then add Vo volts to the second op-amp through R in adder mode.

## *Proportional-Integral-Derivative Controller*

- PID Mode is the combinations of proportional, integral and derivative mode.
- A proportional controller ($K_p$) will have the effect of reducing the rise time; and it will reduce, but eliminate, the steady-state error.
- An integral control ($K_i$) will have the effect of eliminate the steady-state error, but it ma ma transient response worse.
- A derivative control ($K_d$) will have the effect of increasing the stability of the system, reduci overshoot, and improving the transient response.

The PID mode provide excellent control performance

The equation for PID controller is:

$$P(t) = K_p E_P + K_p K_d \frac{dE_p}{dt} + K_p K_i \int E_p dt + P_0$$

### *Reset windup:*

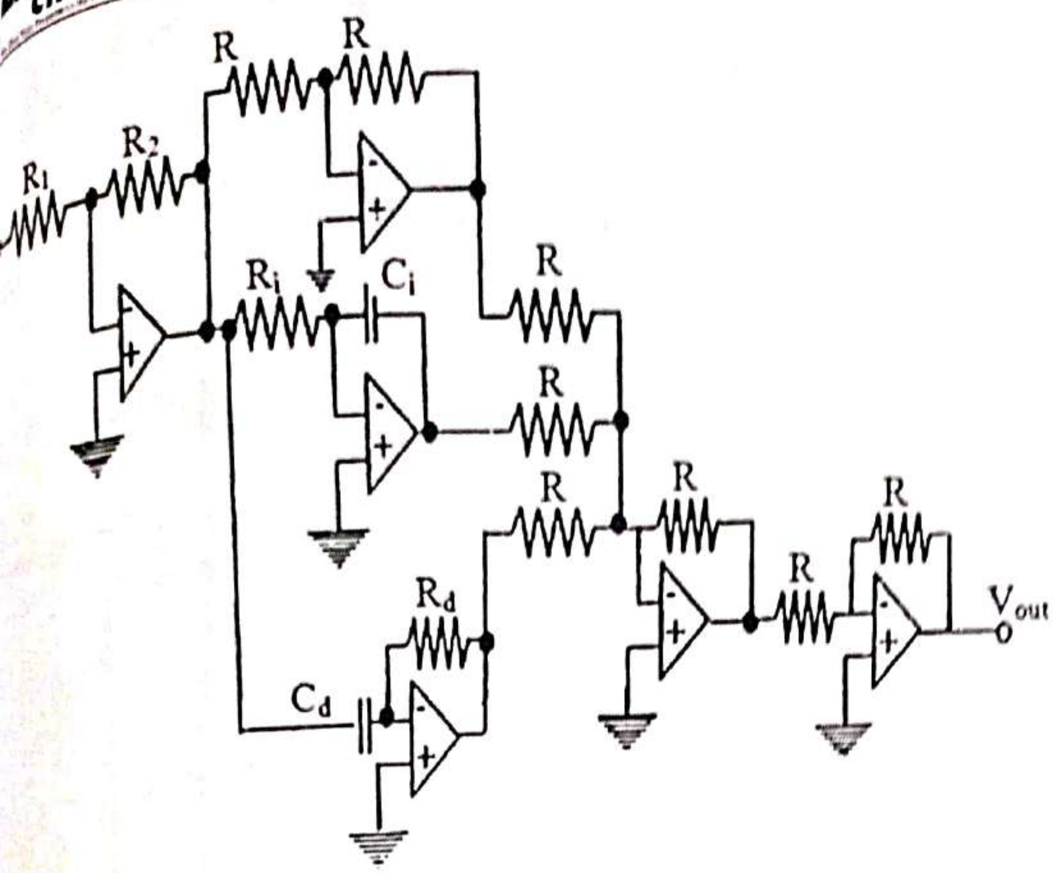
- Reset windup is a basic problem associated with PID controller because of / due to integral c action always trying to eliminate steady state error. in some situation the steady state error con brought to zero. where the integral control action has keep on adding its contribution due to this state error Leads to first the controller saturation and then pushing the controller o/p beyond its ex value this action of controller is called Reset windup. So, to limit the controller o/p going beyond or 4 mA. The close loop controller simply equip with a mechanism called anti Reset windup mecha

### *Role of anti Reset windup mechanism*

This mechanism simply opens the controller from the loop when ever the controller o/p exceeds 20mA or and then put the controller in to the loop when ever the error reduces naturally.

## *Electronic PID Controller*

The circuit for electronic PID controller is given in fig.



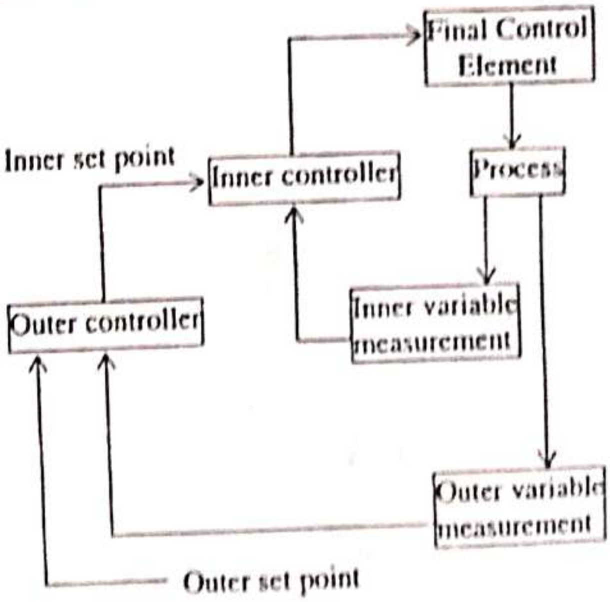

From the above figure

$$V_{out} = \left(\frac{R_2}{R_1}\right)V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_iC_i}\int V_e dt + \left(\frac{R_2}{R_1}\right)R_dC_d\frac{dV_e}{dt} + V_{out}(0)$$

$$K_p = \frac{R_2}{R_1}; K_d = R_dC_d; \text{ and } K_i = \frac{1}{R_iC_i}$$

## cade control

- In this configuration, we have one manipulated variable and more than one measurement. Cascade control uses the output of primary controller to manipulate the set point of secondary controller.



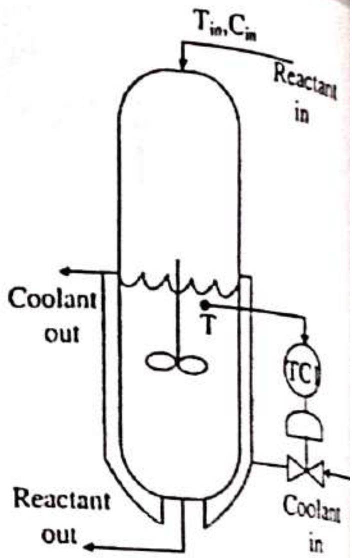

- The basic principle of cascade control is that if the secondary variable responds to distribute sooner than the primary variable, then there -is a possibility to capture and nullify the effect of the disturbance before it propagates into the primary variable. The concept of cascade control is shown in Figure.
- The two measurements are taken from the system and used in their respective control loops. In the outer loop, the controller output is the set point of the inner loop. The outer loop is called primary loop and the inner loop is called secondary loop. Thus, if the outer loop dynamic variable changes, the error signal affects a change in set

point of the inner loop. Even though the measured value of the inner loop has not changed, the loop experiences an error signal and produces a new output by virtue of the set point change.

- The primary objective of cascade control is to divide an otherwise difficult control process into portions; whereby a secondary control loop is formed around major disturbances, leaving only disturbances to be controlled by the primary controller.

## Cascade Control of a Jacketed CSTR

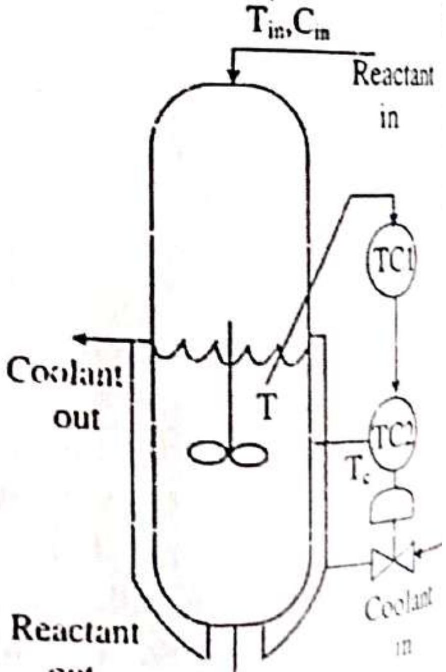
- In the CSTR shown in Figure. The reaction is exothermic and the heat generated is removed by the coolant, which flows in the jacket around the tank. The control objective is to keep the temperature of the reacting mixture, T, Constant at a desired value. Possible disturbances to the reactor include the feed temperature, $T_i$, and the coolant temperature, $T_c$, the only manipulated variable is the coolant flow rate, $F_c$. Let us suppose that the major disturbance is change in collant temperature, $T_c$.



Conventional feedback control scheme on a CSTR

- Consider the simple feedback control of this jacketed CSTR as shown in Fig. where reactor temperature, T, is the measured controlled variable and coolant flow rate, $F_c$, is the manipulated variable. Reactor temperature, T, responds faster to changes in feed temperature, $T_i$, than to changes in coolant temperature $T_c$. Therefore, the simple feedback control is more effective in compensating for changes in and less effective in compensating for changes in $T_c$, since changes are not getting instantly reflected on changes in T.

- The loop that measures T is the dominant, or primary, or master control loop and uses a set point supplied by the operator.
- The loop that measures $T_c$ is the secondary or slave loop. It uses the output of the primary controller as its set point.



Cascaded control scheme on a CSTR

***Advantages:***

- Better control of the primary variable
- Primary variable is less affected by disturbances.
- Faster recovery from disturbances.
- Increases the natural frequency of the system.
- Reduces the effective magnitude of the system.
- Improves dynamic performance
- Provides limits on the secondary variable.