CONTROL ENGINEERING 18ME71

Module-1 INTRODUCTION

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OBJECTIVES:

- To **demonstrate** fundamentals of Control engineering and types of Control system.
- To **demonstrate** the concept of feedback control system.
- To **illustrate** different types of Controllers need for controlling action.

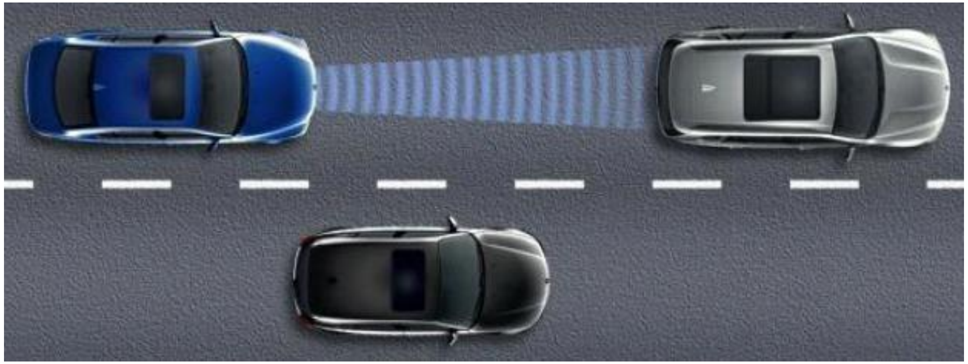
CONTROL SYSTEM

System – An interconnection of elements and devices for a desired purpose.

OR

A group of interdependent items that interact regularly to perform a task.

Control – Control means measuring the value of *controlled variable* of the system and applying the *manipulated variable* to the system to correct or limit the deviation of the measured value from a desired value.

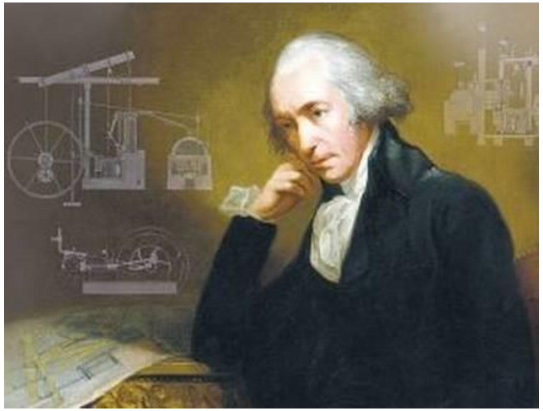


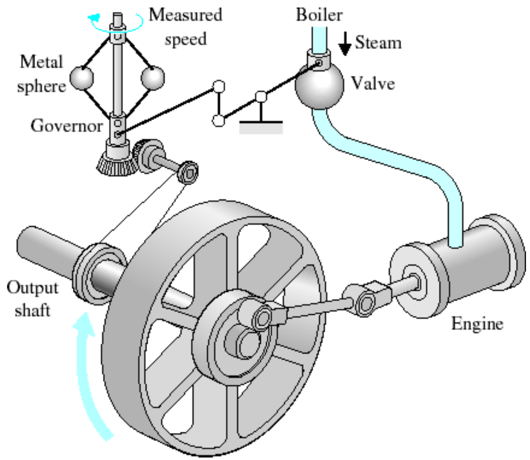
CONTROL SYSTEM

Control System – A control System is a device, or set of devices to manage, command, direct or regulate the behaviour of other device(s) or system(s).

Process – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.

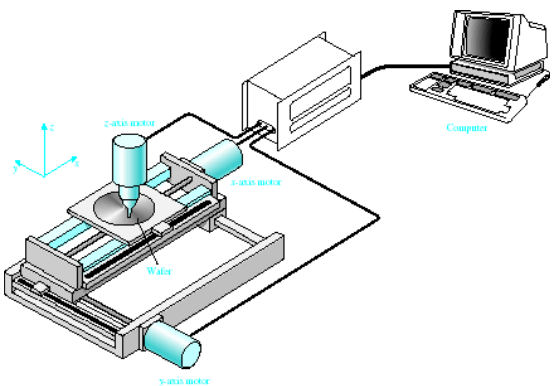
HISTORY

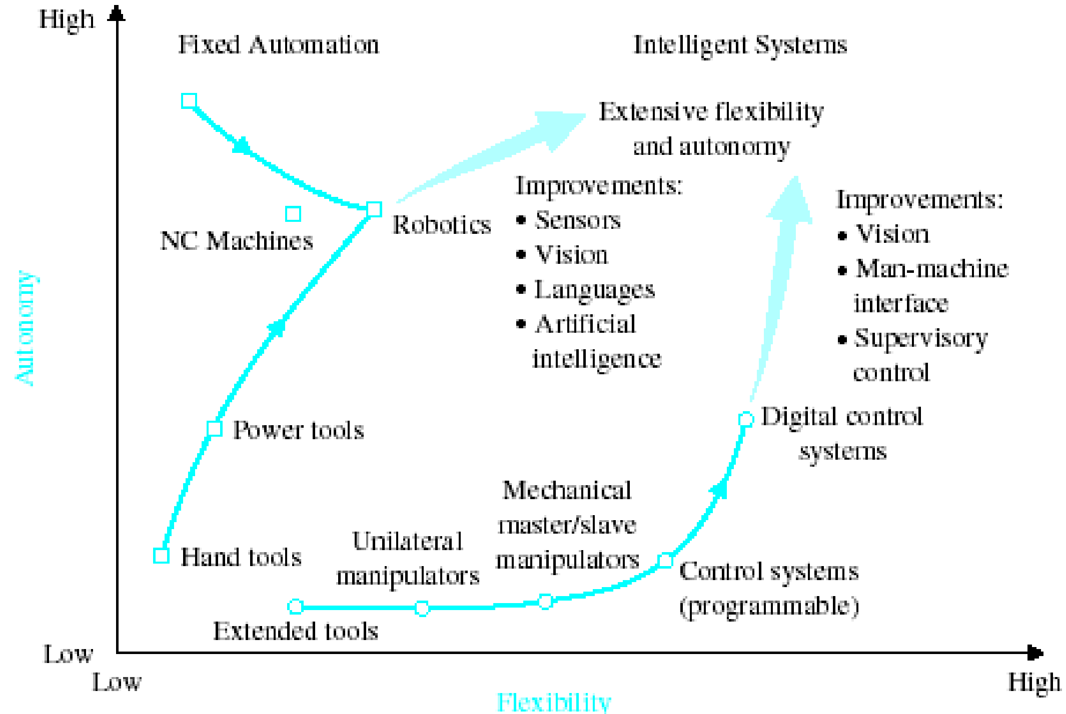




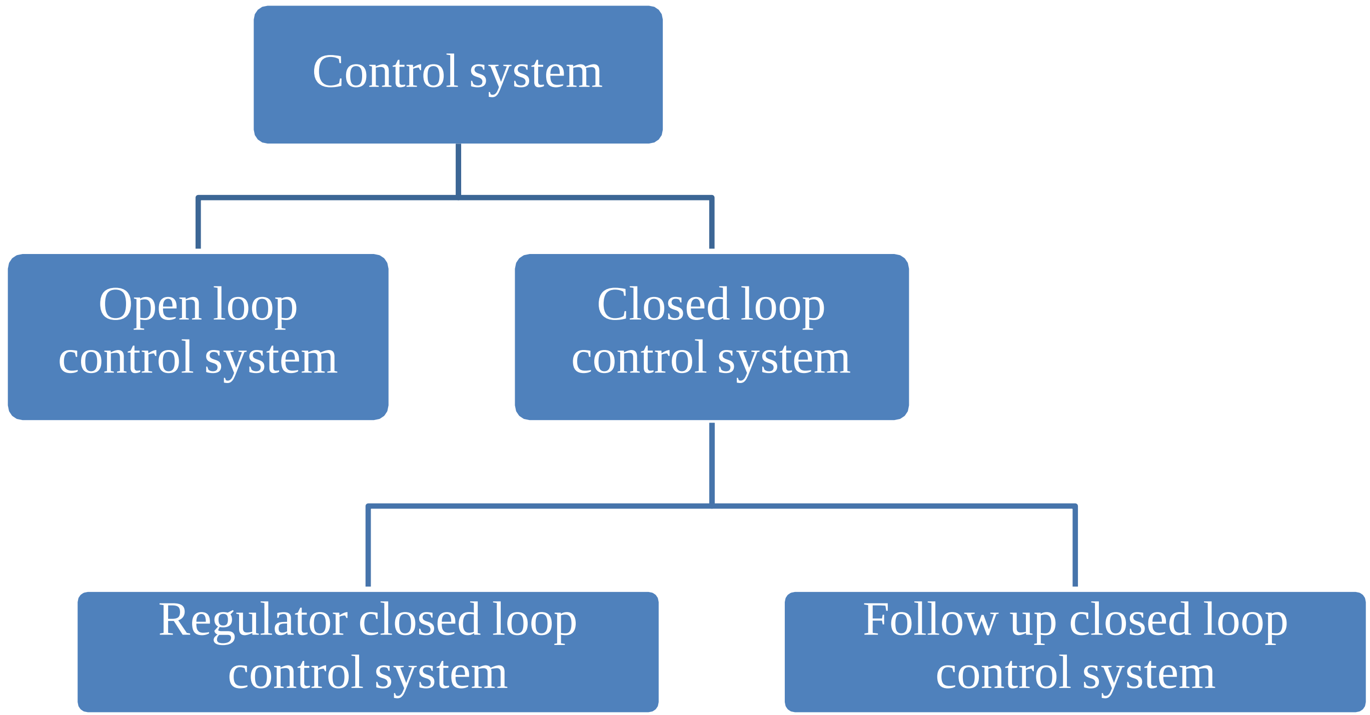
18th Century James Watt's centrifugal governor for the speed control of a steam engine.

Automation



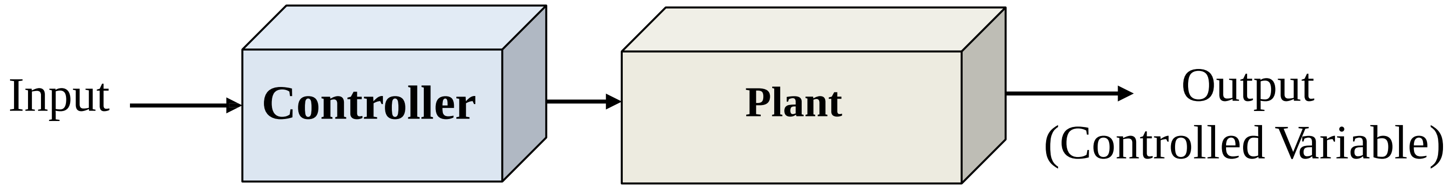

High
Low
Autonomy
Low
High
Flexibility
Fixed Automation
Intelligent Systems
Extensive flexibility and autonomy
NC Machines
Robotics
Improvements:
• Sensors
• Vision
• Languages
• Artificial intelligence
Improvements:
• Vision
• Man-machine interface
• Supervisory control
Power tools
Digital control systems
Mechanical master/slave manipulators
Hand tools
Unilateral manipulators
Control systems (programmable)
Extended tools

Classification of Control Systems:



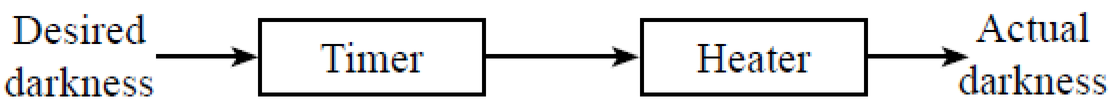
Open Loop Control Systems:

- Open-Loop Control Systems utilize a controller to obtain the desired response.
- Output has no effect on the control action.
- No feedback – no correction of disturbances.



Examples:- Washing Machine, Toaster, Electric Fan

Example : 1. Bread toaster



Advantages :

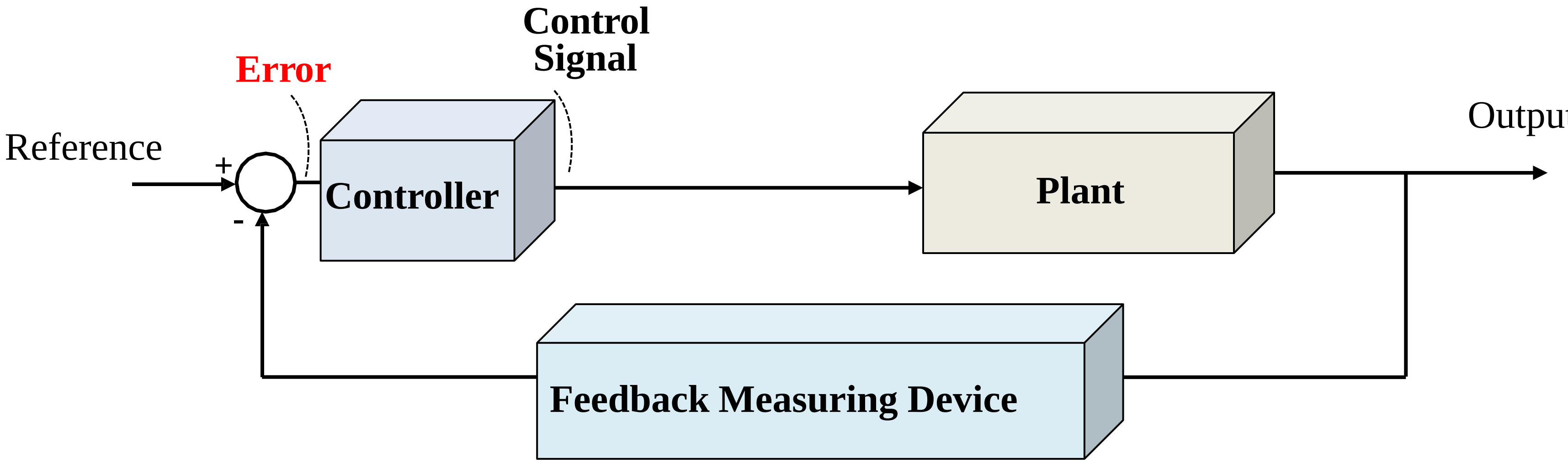
- Relatively simple and economical
- Easy maintainability
- These system are stable
- Have good reliability

Disadvantage :

- In accurate
- Performance are relatively slow
- Time to time calibration is necessary to maintain accuracy.

Closed Loop Control Systems:

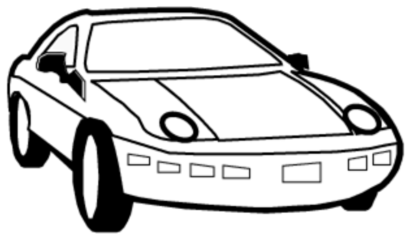
- Closed-Loop Control Systems utilizes feedback to compare the actual output to the desired output response.

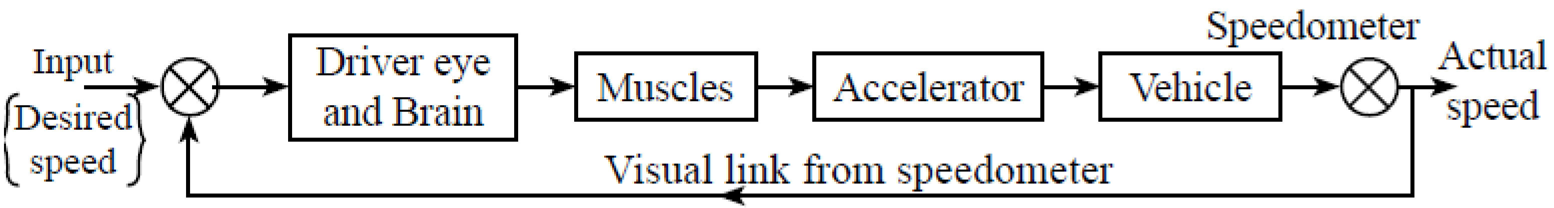


Error signal= Reference – Sensing signal

Examples:- Refrigerator, Robot arm

Example : A human being riding a vehicle





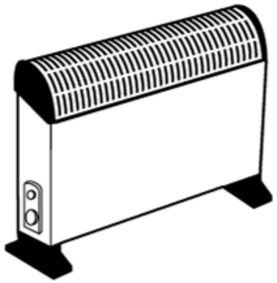
Differences

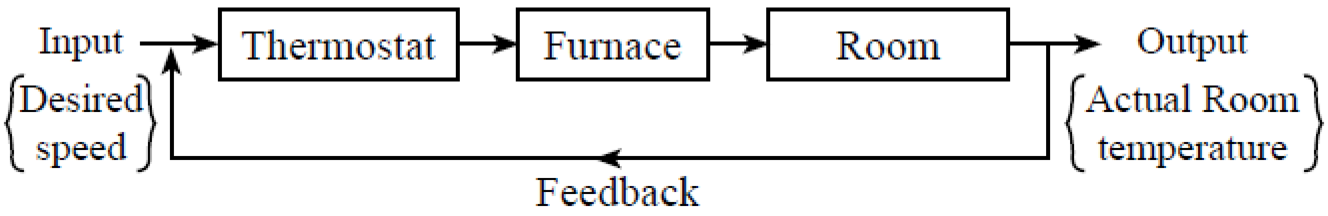
Type of System	Advantages	Disadvantages	Examples
Open Loop Control System	▪ Simple construction and ease of maintenance. ▪ Less expensive than a corresponding closed-loop control system. ▪ There is no stability problem. ▪ Convenient when output is hard to measure or measuring the output precisely is economically not feasible	• The system response very sensitive to external disturbance and internal variations in system parameters. • Recalibration is necessary from time to time in order to maintain the required quality in the output.	• Toaster • Rice cooker • Electric fan
Closed loop control system	• Insensitive to external disturbance. • Possible to use relatively inaccurate and inexpensive components to obtain the accurate control of a given plant. • Better control of transient & steady-state response • Increased accuracy	▪ Instability. ▪ Complexity in analysis and implementation and expensive.	▪ Positioning CS (robot arms) ▪ Temperature CS (Air-conditioner)

Regulator closed loop control system :

The main function of the regulatory system is to maintain the controlled variable as that of the reference variable even though the system is subjected to external disturbances.

Example : Room heating system

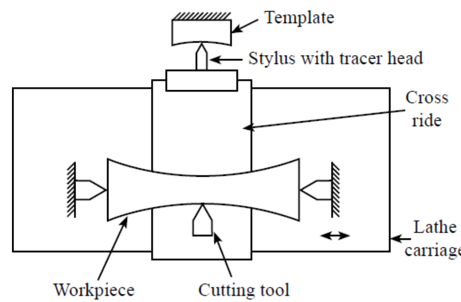


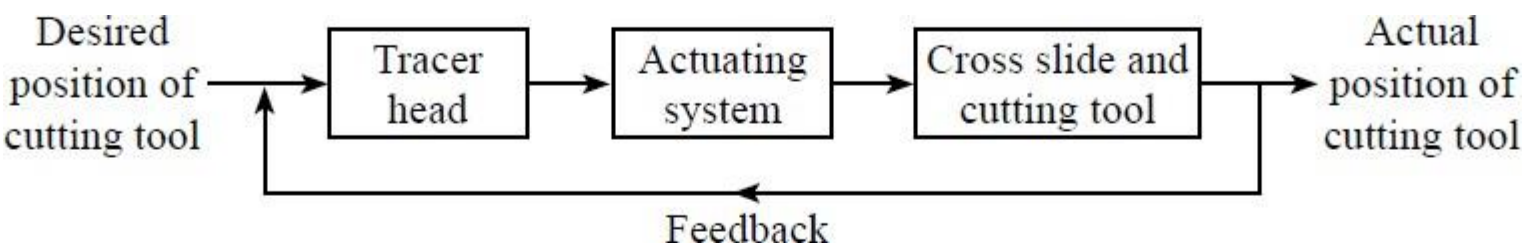


Follow up closed loop control system :

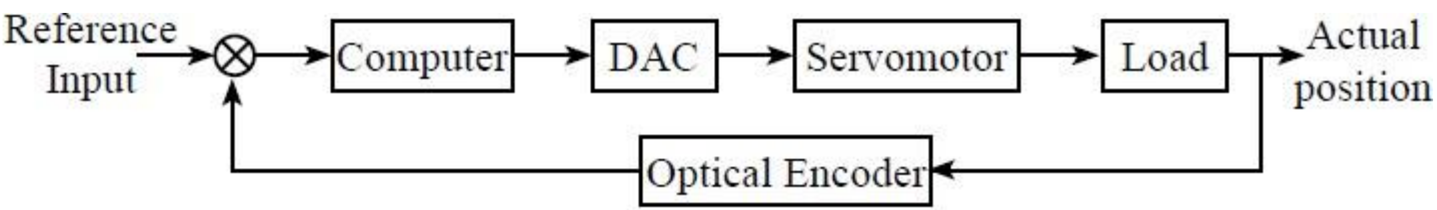
In the follow up closed loop control system, the main function is to keep the controlled variable in close correspondence with the reference variable which is frequently changed.

Example : Lathe tracer mechanism





Servo mechanism :

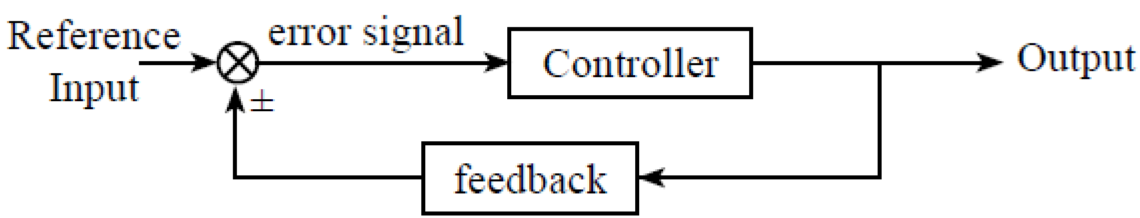


DAC - Digital to Analog convertor

Concepts of Feedback

A 'feedback' is a common and powerful tool for designing a control system, which enables the system to adjust its performance to meet a desired output.

i. System gain and response can be precisely controlled.
ii. Signal distortion due to the non - linear nature of the components can be generally reduced.
iii. Frequency response, gain and bandwidth of a system can be easily controlled

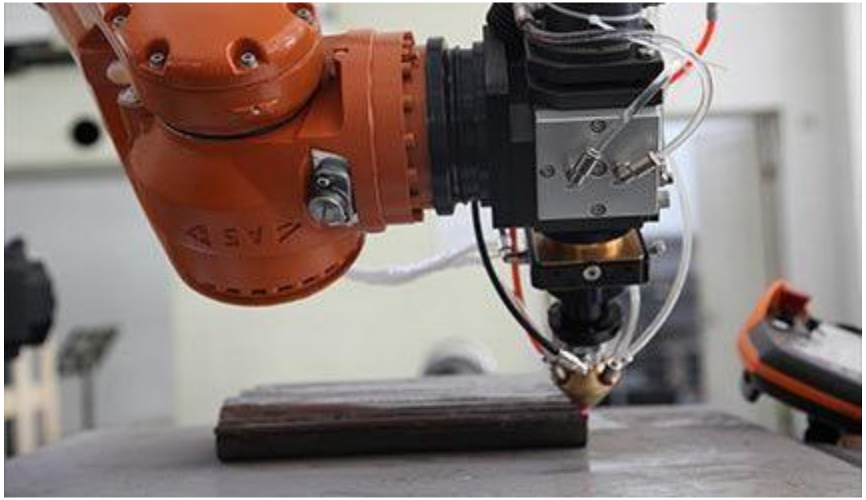


Requirements of an ideal control system

1. Accuracy
2. Stability
3. Speed of response
4. Sensitivity
5. Noise
6. Bandwidth
7. Damping

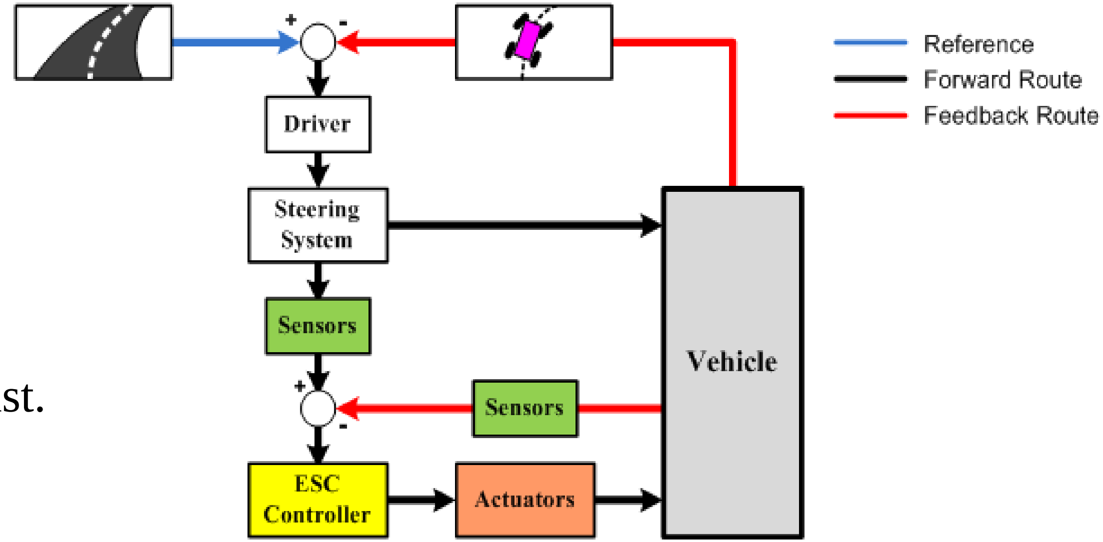
Accuracy :

A system which gives correct output as required is said to be 100% accurate.



Stability :

A controlled system is said to be stable if the response to an input reaches steady state value within a reasonable period of time.



Speed of response :

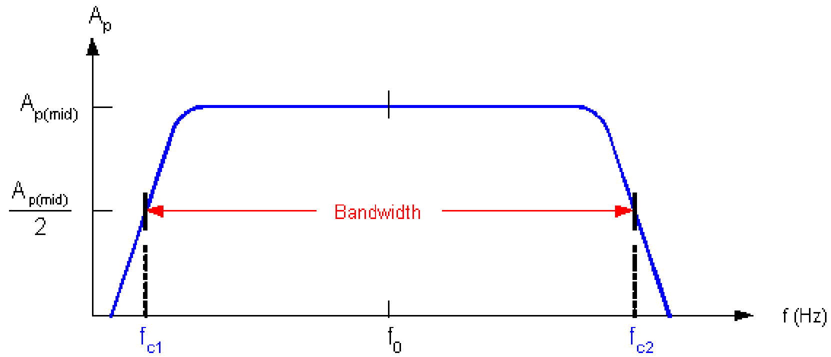
A system is said to have good of response. If the time taken by the system to respond to an input is least.

Sensitivity :

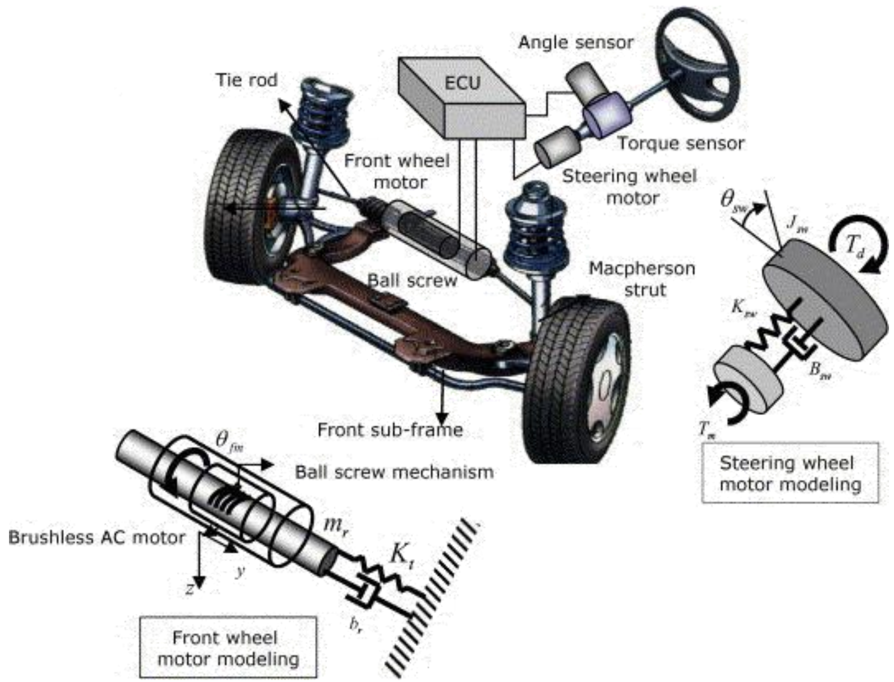
The rate of change of a control system with the change in its surroundings is called "sensitivity".

Noise :

Bandwidth

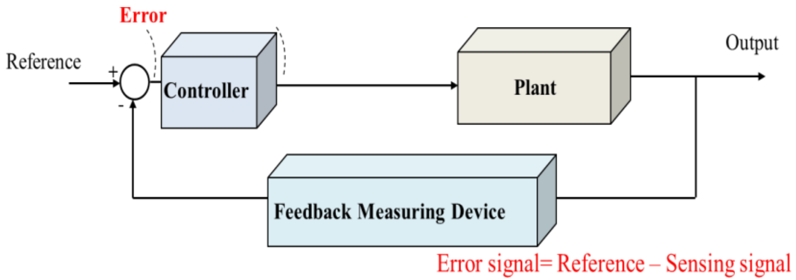


Damping :


Angle sensor
Tie rod
ECU
Torque sensor
Front wheel motor
Steering wheel motor
Macpherson strut
Ball screw
Front sub-frame
Ball screw mechanism
Brushless AC motor
Front wheel motor modeling
Steering wheel motor modeling
θ_{sw}
J_{sw}
T_d
K_{sw}
B_{sw}
T_m
θ_{fm}
m_r
K_t
b_r
y
z

CONTROLLERS:

A ***Controller*** regulates the *error* value as the difference between a measured process variable and a desired value.

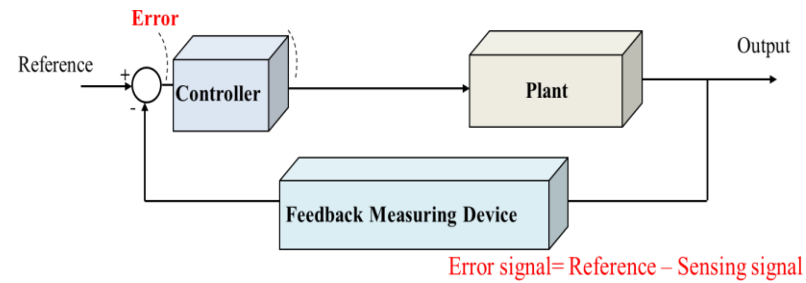


The controller attempts to minimize the *error* by adjusting the process through use of a manipulated variable.

A portion of the signal being fed back is:

- Proportional to the signal (**P**)
- Proportional to integral of the signal (**I**)
- Proportional to the derivative of the signal (**D**)

CONTROLLERS:



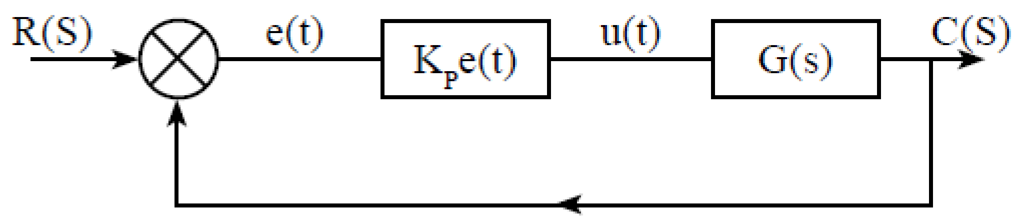
- ***P*** **depends on the *present* error.**
- ***I*** **on the accumulation of *past* errors.**
- ***D*** **is a prediction of *future* errors.**

PID control handles step changes to the Set Point especially well:

- Fast Rise Times
- Little or No Overshoot
- Fast settling Times
- Zero Steady State Error

Proportional controller :

The proportional Controller produces an output value that is proportional to the current ***error value***.



The proportional response can be adjusted by *multiplying* the error by a constant **Kp**.

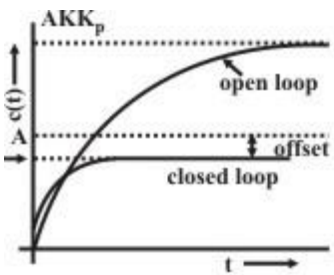
$$u(t) = k_p e(t)$$

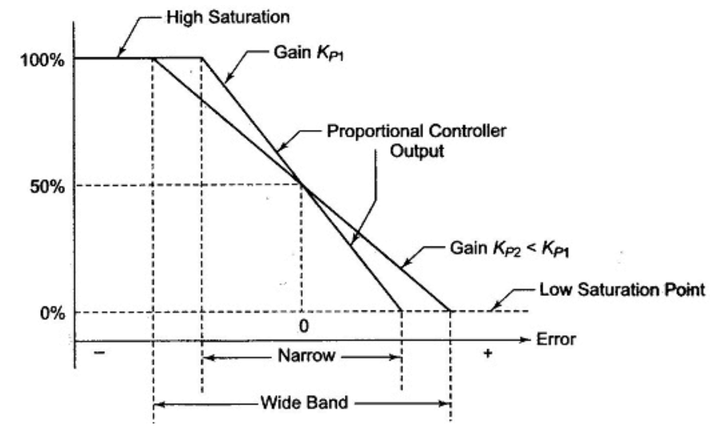
Kp is expressed in terms of "***Proportional Band***".

$$\boxed{\frac{U(s)}{E(s)} = K_P}$$

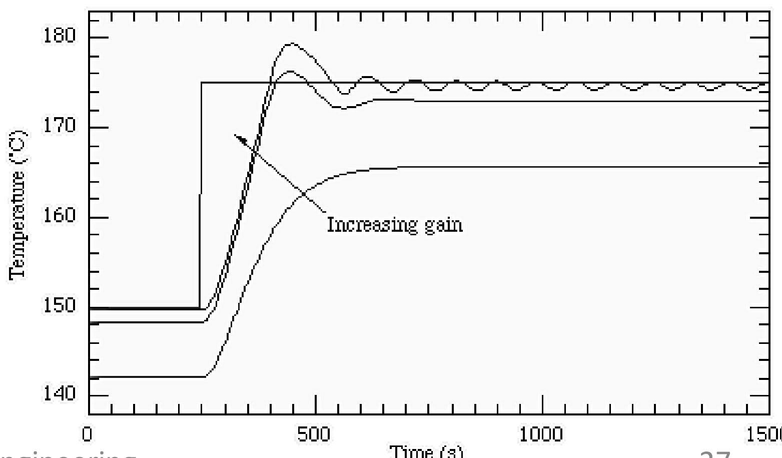
Kp inversely proportional to the gain and expressed in percentage.

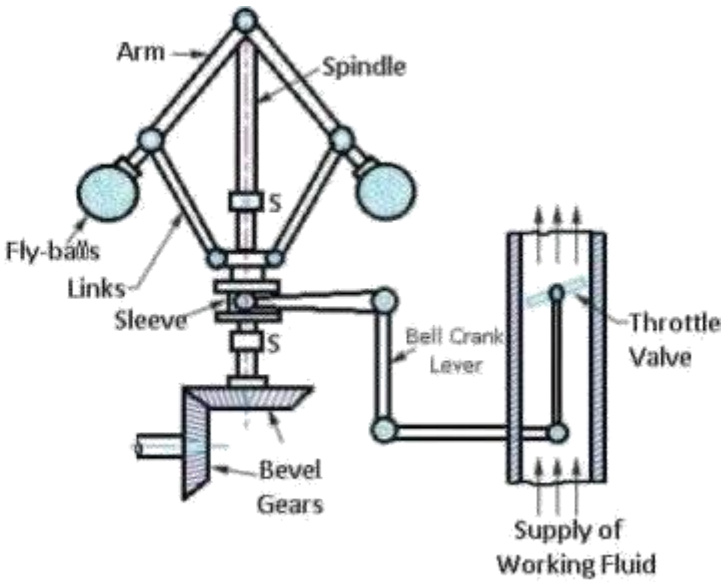
Example: If the gain is 2, the proportional band is 50%.

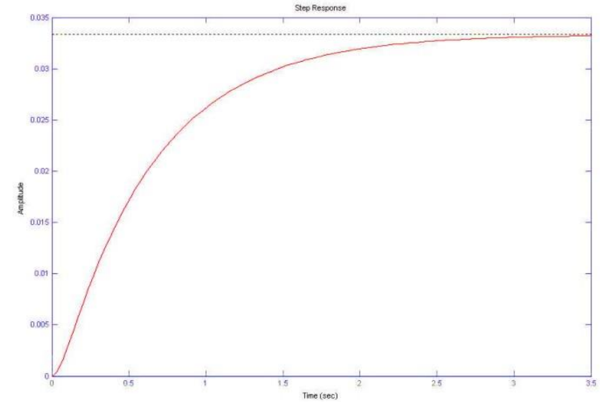


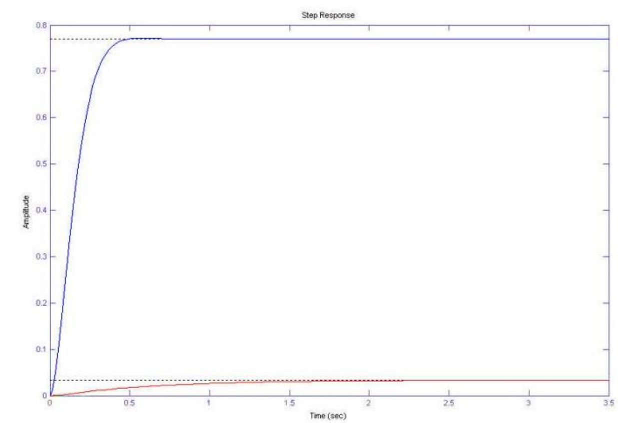


- Increasing gain approaches setpoint faster
- Can leads to overshoot, and even instability
- Steady-state offset

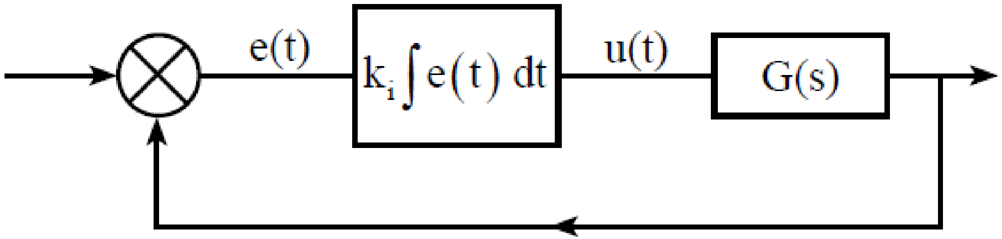



Arm
Spindle
S
Fly-balls
Links
Sleeve
S
Bell Crank Lever
Throttle Valve
Bevel Gears
Supply of Working Fluid


Step Response
Amplitude
Time (sec)


Step Response
Amplitude
Time (sec)

Integral controller :

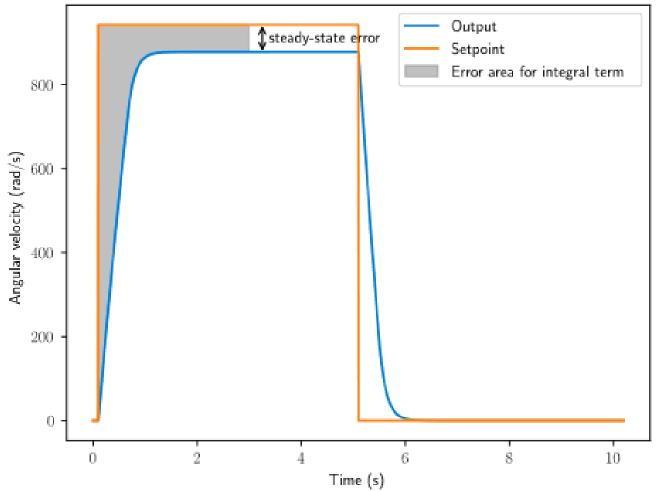


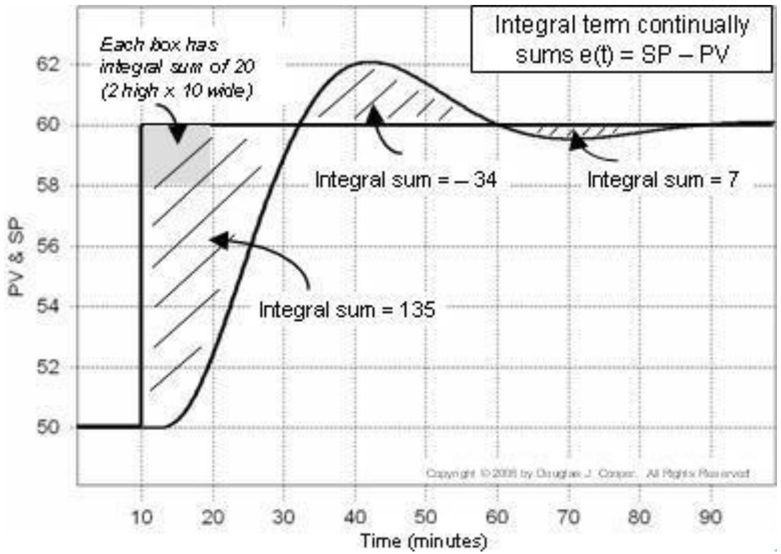
The Integral controller provides output where the integral term is proportional to both the *magnitude of the error* and the *duration of the error*.

$$u(t) = k_i \int e(t)\, dt$$

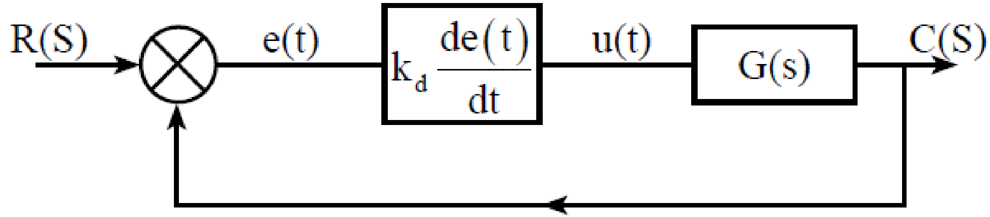
The ***Integral controller*** accelerates the movement of the process towards set-point and eliminates the residual *steady-state error.*

$$\boxed{\frac{U(s)}{E(s)} = \frac{K_i}{S}}$$


steady-state error
Output
Setpoint
Error area for integral term
Angular velocity (rad/s)
Time (s)


Integral term continually sums e(t) = SP – PV
Each box has integral sum of 20 (2 high x 10 wide)
Integral sum = – 34
Integral sum = 7
Integral sum = 135
PV & SP
Time (minutes)

Derivative controller :



In this, controller output is ***proportional*** to first derivative of the error signal.

$$u(t) = k_d \frac{de(t)}{dt}$$

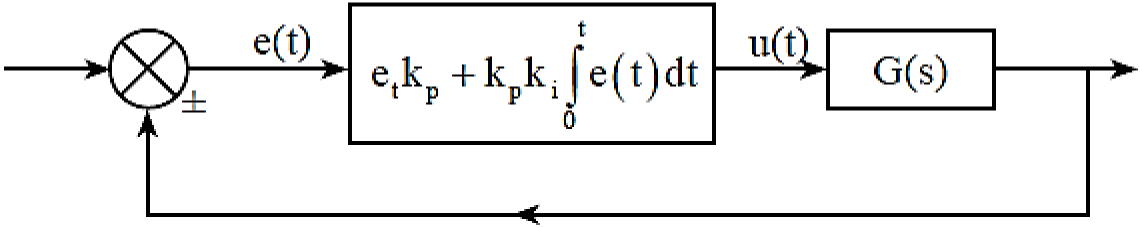
$$\frac{U(s)}{E(s)} = k_d \times s$$

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d.

Effect of increasing parameter

Parameter	Rise Time	Overshoot	Settling Time	Steady-State Error	Stability
K_p	Decrease	Increase	Small Change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor Change	Decrease	Decrease	No Effect	Improve if K_d small

Proportional plus Integral (P-I) Control:



- combination of proportional and integral value of the error signal.

- It is widely used for process industries for controlling variables like level, flow, pressure, etc.

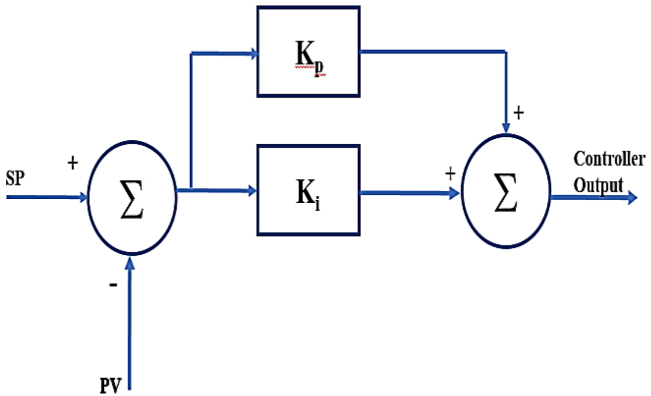
$$u(t) = e_t k_p + k_p k_i \int e(t)\,dt$$

$$u(s) = k_p E(s) + \frac{k_p k_i}{s} E(s)$$

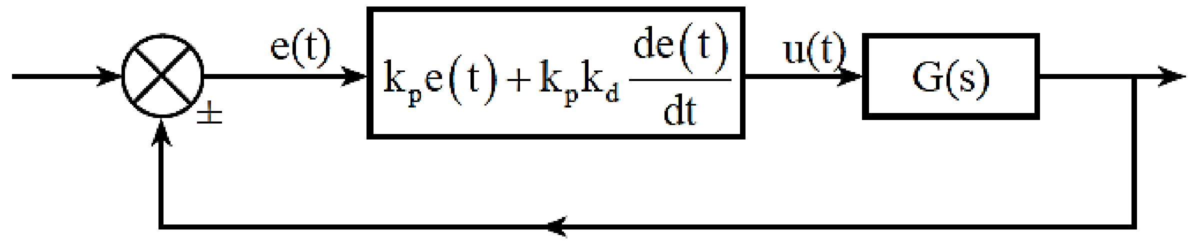
$$\boxed{\therefore \frac{u(s)}{E(s)} = k_p \left[1 + \frac{k_i}{s}\right]}$$

Characteristics of P-I controller

1. It improves steady state accuracy.
2. It decreases the bandwidth of the system.
3. High frequency noise are eliminated.
4. Response of the system decreases.



Proportional - Differential controller (P-D controller) :



It results in a more rapid response and less offset than is possible by pure proportional control.

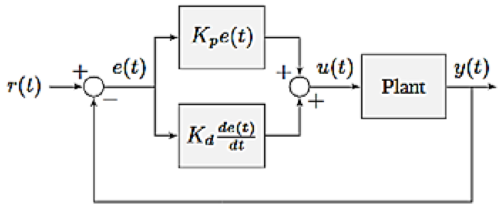
$$u(t) = k_p e(t) + k_p k_d \frac{de(t)}{dt}$$

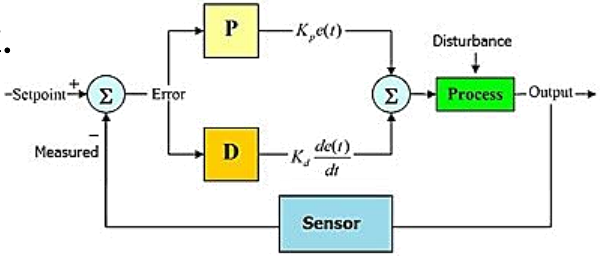
$$u(s) = k_p E(s) + k_p k_d SE(s)$$

$$\boxed{\therefore \frac{u(s)}{E(s)} = k_p + k_p k_d S}$$

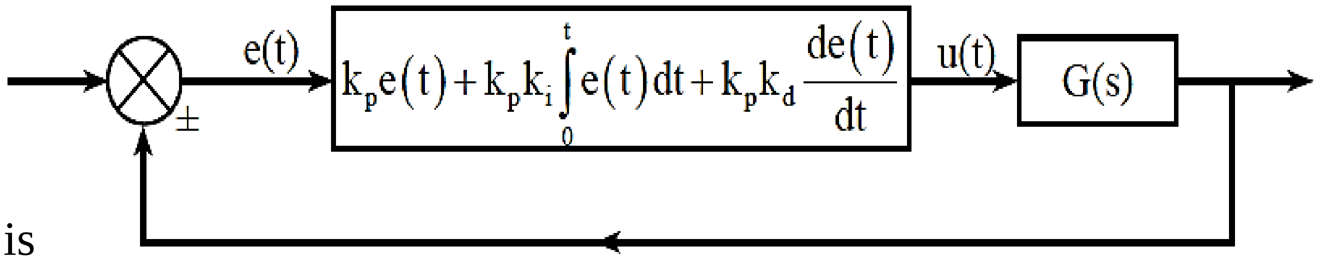
Characteristics of P-D controller:

1. Response of system is increased as rise time is reduced.
2. At higher frequencies the system is noise dominant.
3. Bandwidth of system can be increased.
4. Stability of the system response can be reduced very fast.
5. Damping is improved and reduces Overshoot.





Proportional - integral - differential controller (P-I-D):



- Offset error caused by ***Proportional controller*** is eliminated by ***Integral controller.***
- ***D***elay in rise time is reduced by ***Differential controller.***

$$u(t) = k_p e(t) + k_p k_i \int_0^t e(t)\,dt + k_p k_d \frac{de(t)}{dt}$$

$$u(s) = k_p E(s) + k_p k_i \frac{1}{S} E(s) + k_p k_d S E(s)$$

$$\boxed{\frac{u(s)}{E(s)} = \frac{k_p}{S}\left(S + k_i + S^2 k_d\right)}$$

It is particularly useful for controlling slow variables, like pH, temperature, etc. in process industries.

Characteristics of P-I-D controller:

1. P-I-D controller are its simplicity in structure and the applicable to variety of processes.
2. Response of system is increased as rise time is reduced.
3. High frequency noise are eliminated
4. Bandwidth of system can be increased.
5. It improves steady state accuracy.
6. But proper tuning of the controller is difficult.

Review Questions

1. Define control system
2. Distinguish between open loop and closed loop control system with suitable example.
3. What are the requirements of an ideal control system? Explain in detail.
4. With a suitable example explain regulatory system and follow - up system.
5. Explain the concept of feedback control system.
6. What is control action?
7. Explain proportional-integral-differential (P-I-D) controller with the block diagram.
8. Explain following controller. State its characteristics.
    1. Proportional plus Derivative control action
    2. Proportional plus Integral control action.

VTU Question Paper

Seventh Semester B.E. Degree Examination, Dec.2018/Jan.2019

1 a. Define control system. Explain open and closed loop control systems with examples. (08 Marks)
b. With block diagram, explain:
i) Proportional controller
ii) Integral controller
iii) Proportional plus differential controller. (08 Marks)

OR

2 a. List the advantages and disadvantages of open loop and closed loop control system. (08 Marks)
b. Explain requirements of automatic control system. (08 Marks)

Model Question Paper 1

1 **a.** What are the requirements of Ideal control system? (08 Marks)

b. Differentiate between open loop and closed loop control system with an example for each. (08 Marks)

OR

2 **a.** What is control action? Explain proportional plus integral and proportional plus derivative controller. (08 Marks)

b. With neat block diagram, explain proportional and integral controllers. (08 Marks)

Model Question Paper 1

1 a. With an example for both explain the working of open loop and closed loop control systems. (08 Marks)

b. List the advantages and disadvantages of open loop and closed loop control systems. (08 Marks)

OR

2 a. Explain the requirements of Ideal control system. (08 Marks)

b. With help of block diagram explain proportional plus integral controller. (08 Marks)

thank you