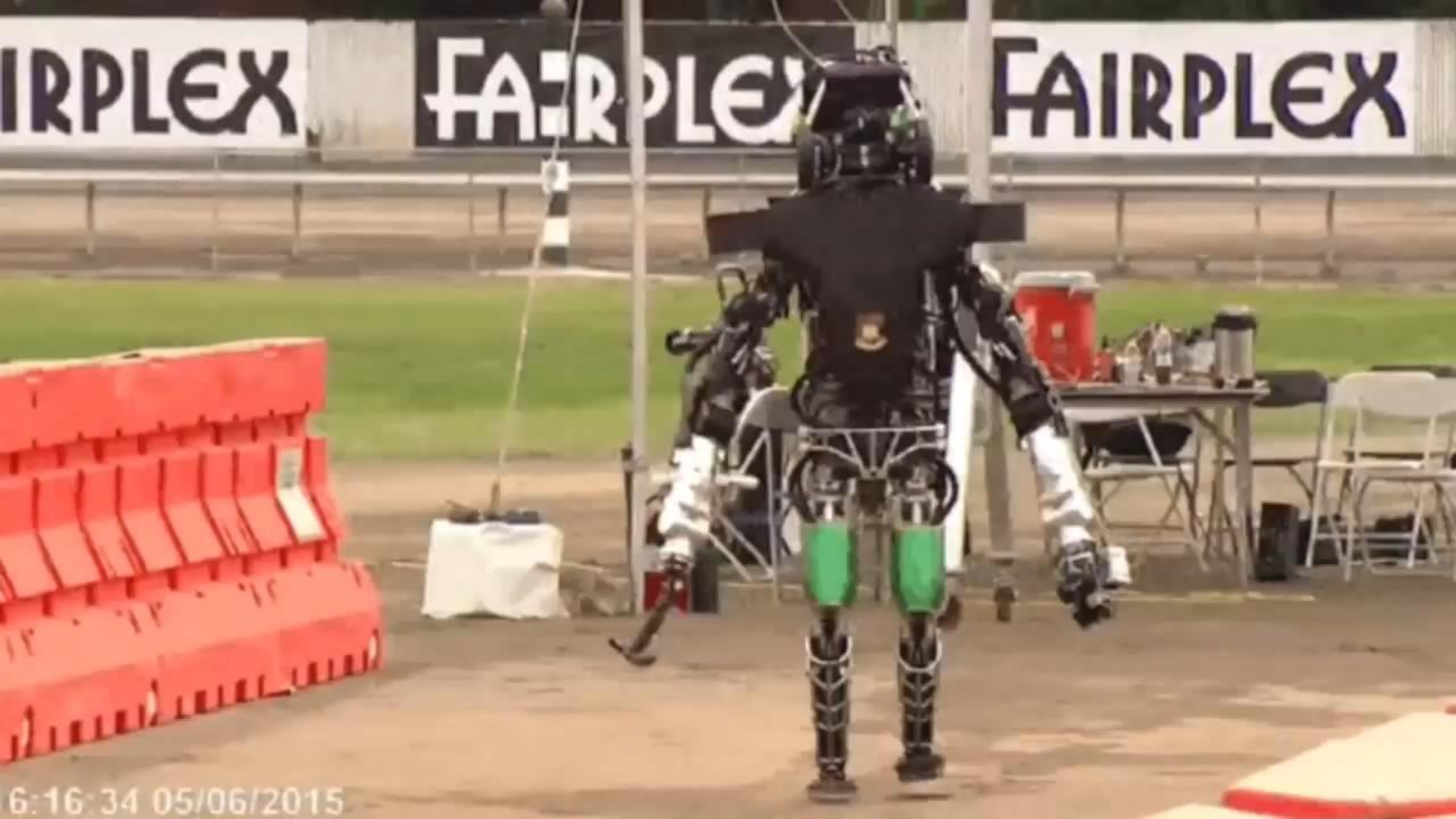
FUNDAMENTALS OF FEEDBACK CONTROL

LAB 3



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FEEDBACK CONTROL

Often the inherent system behavior is unsatisfactory

- Slow response
- Unstable response
- External influences

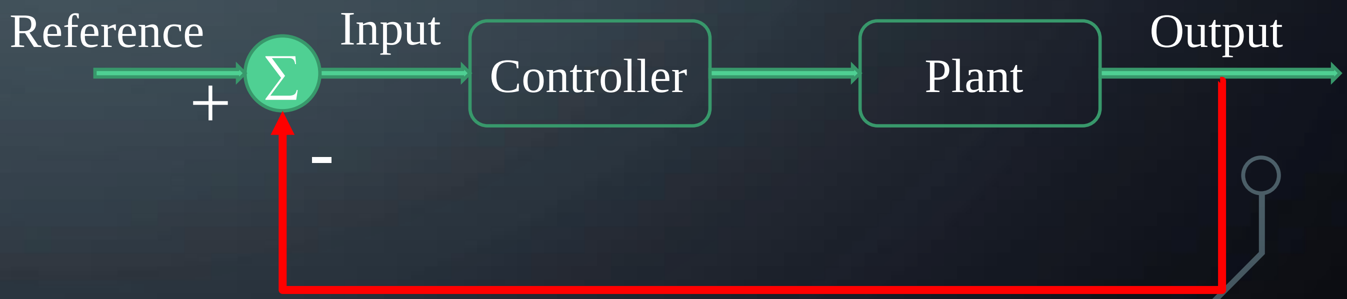
No control:

Output is the natural response of the plant

Open-loop:

Output has no effect on the control action

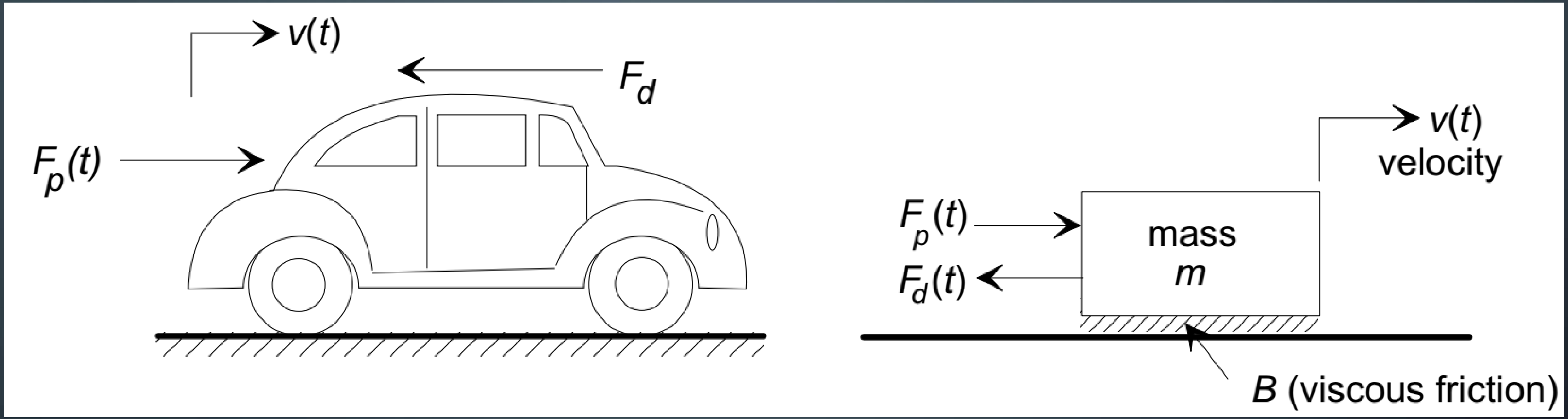
Closed-loop:



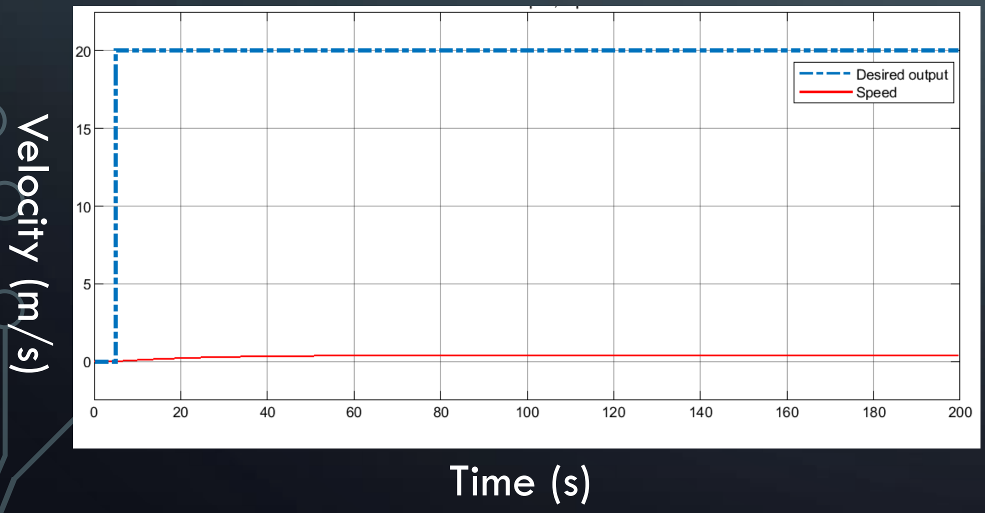
Output has effect on the control action though **feedback**

FEEDBACK CONTROL EXAMPLE

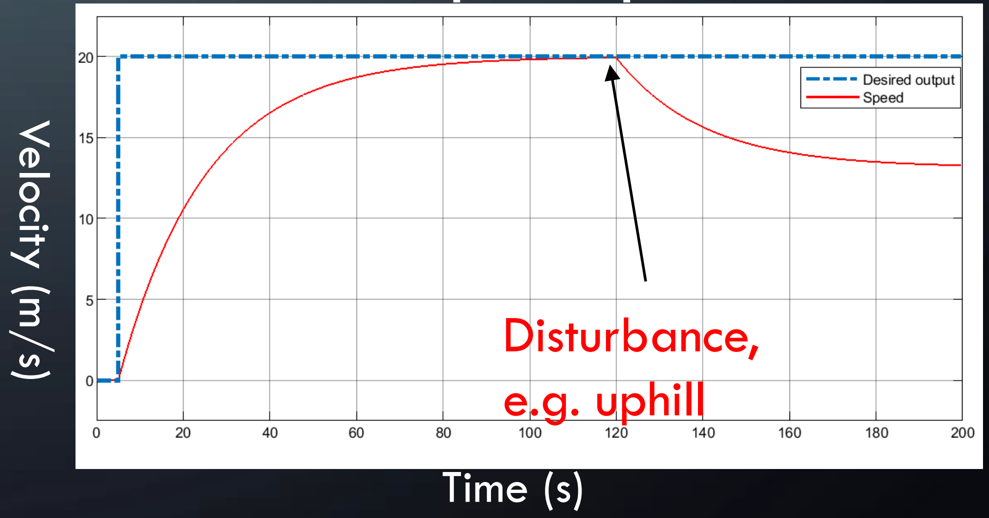
Example: Car cruise control with the desired velocity of 20 m/s



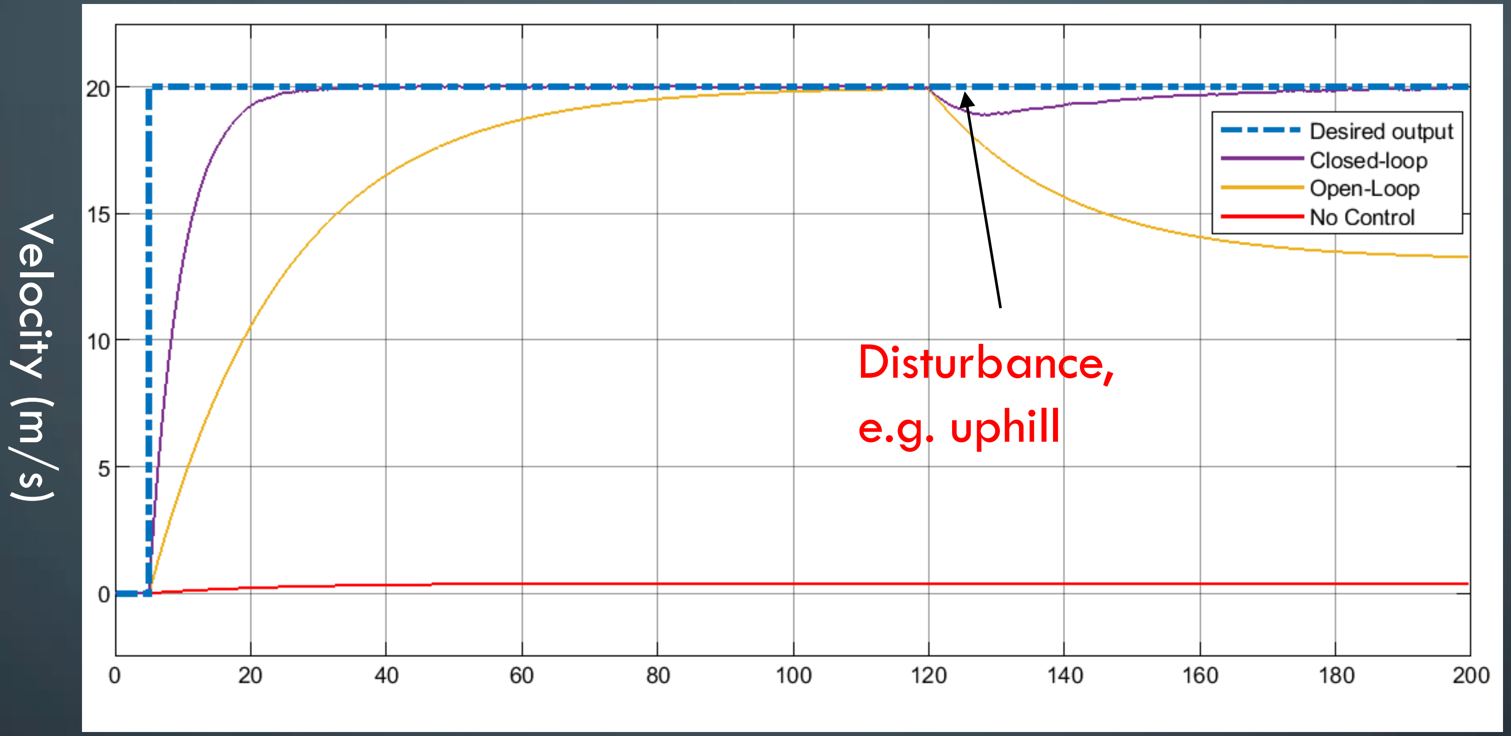
No control



Open-loop



BENEFITS OF FEEDBACK CONTROL

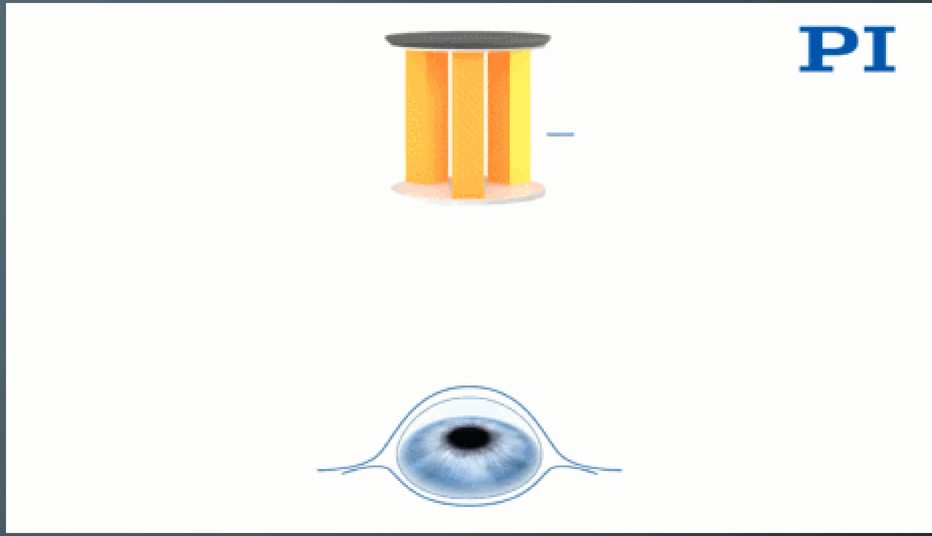


Benefits of feedback control:

- Stabilize the plant (Stabilization)
- Regulate the output to follow the desired reference (Regulation)
- Better transient performance (Tracking)
- Reduce response to disturbances (Disturbance Rejection)

APPLICATIONS

Hard disk



Surgery robot

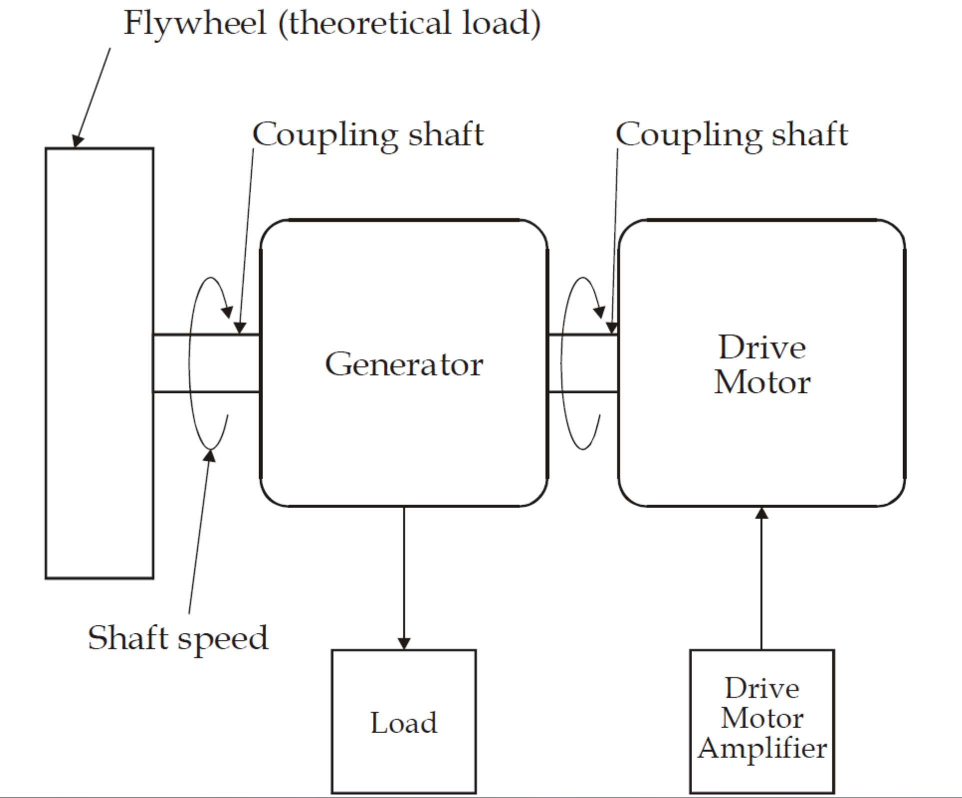
Robot Arm

Segway

FUNDAMENTALS OF FEEDBACK CONTROLS

- Control theory
- Servo trainer modelling
- Velocity control system
- Goal: The objective of this experiment is to study the speed control of a motor with different types of controls. Also, to investigate the effect of proportional controls and PI controls on the steady state error.

CONTROL PRINCIPLES



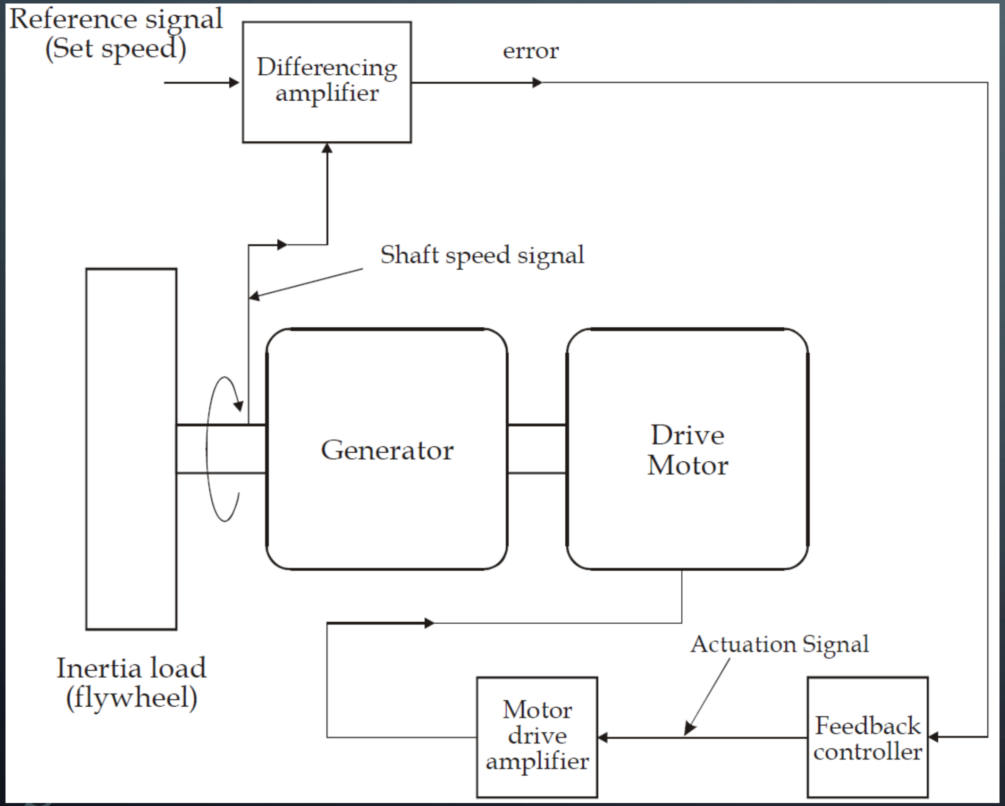
- Manual adjustment
  - Measurement of speed
  - Computation of remedial action
  - Manual effort for load adjustment
- Problems
  - Time consuming and expensive
  - Concentration
  - Response speed

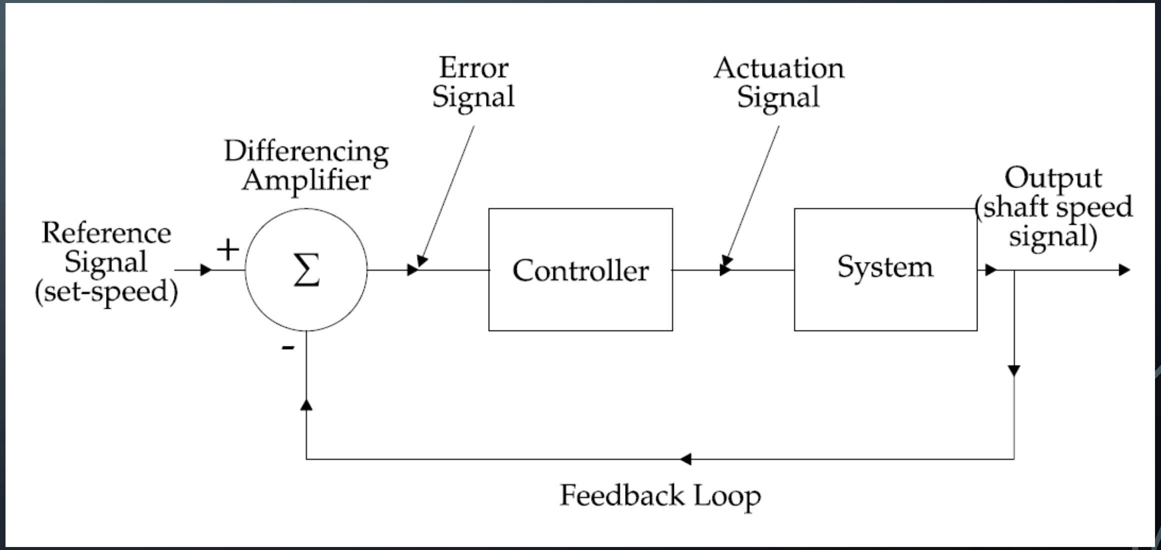
CONTROL PRINCIPLES

- Error signal

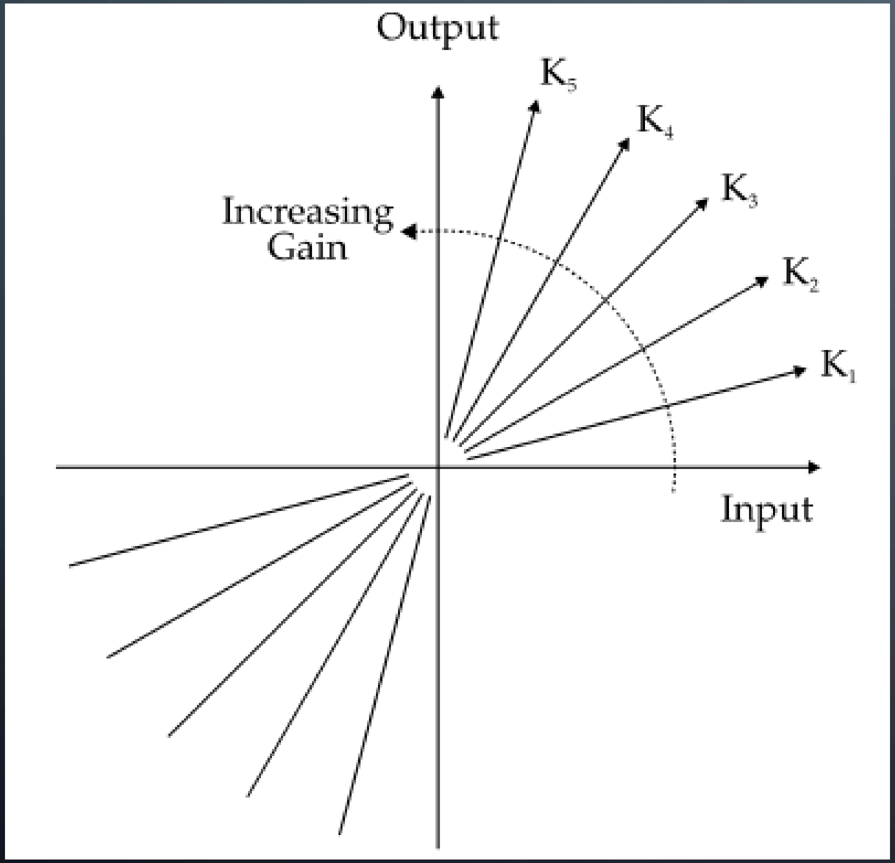
=Measured signal - reference signal (Setpoint)

- Feedback
- Closed-loop control system





PROPORTIONAL CONTROL



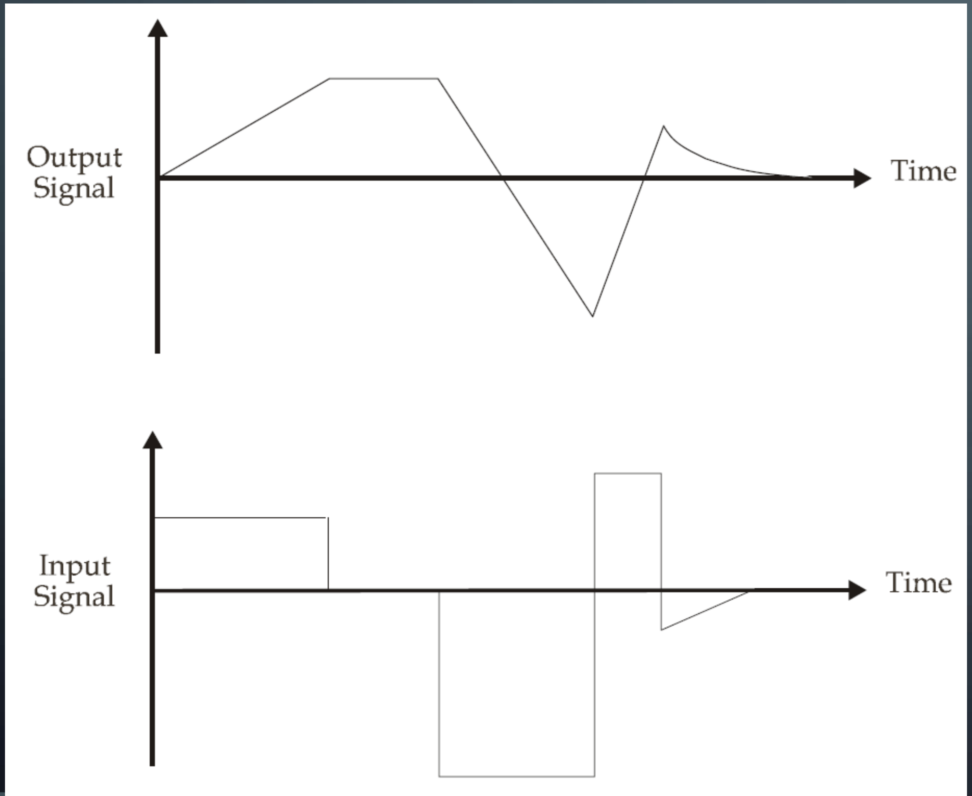
- Steady state error

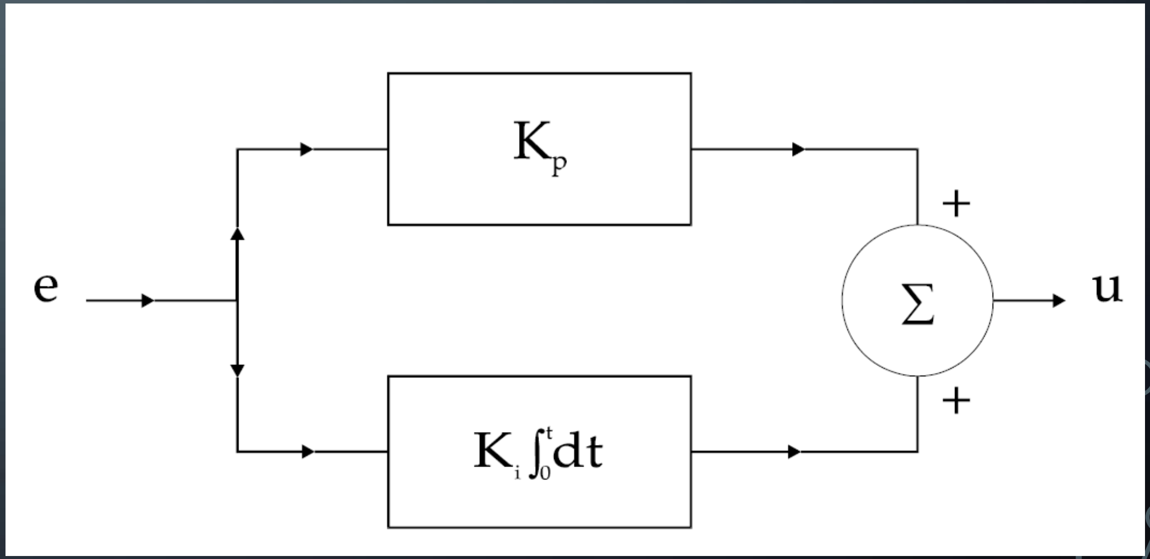
=actual speed - set speed

- Gain
- Instability

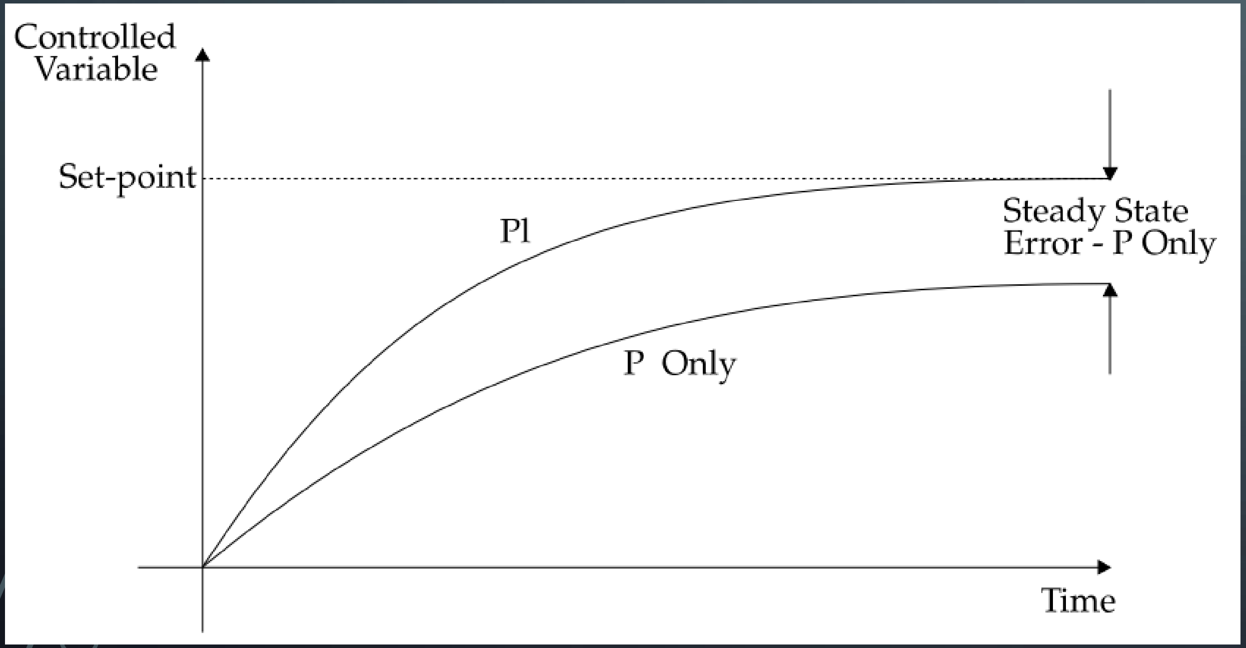
INTEGRAL CONTROL

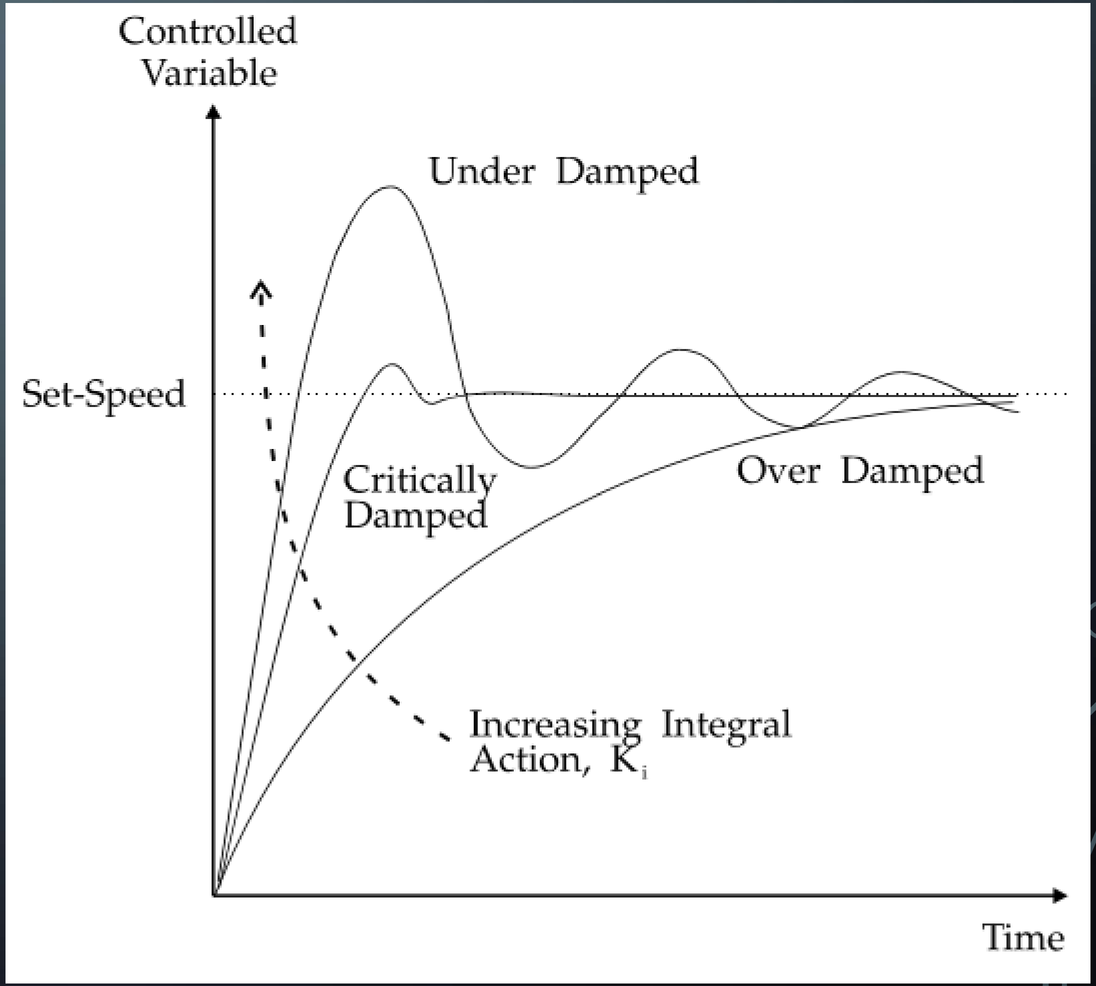
- Input: zero, output: constant
- Input: positive, output: ramp upward
- Input: negative, output: ramp downward
- Integration characteristic





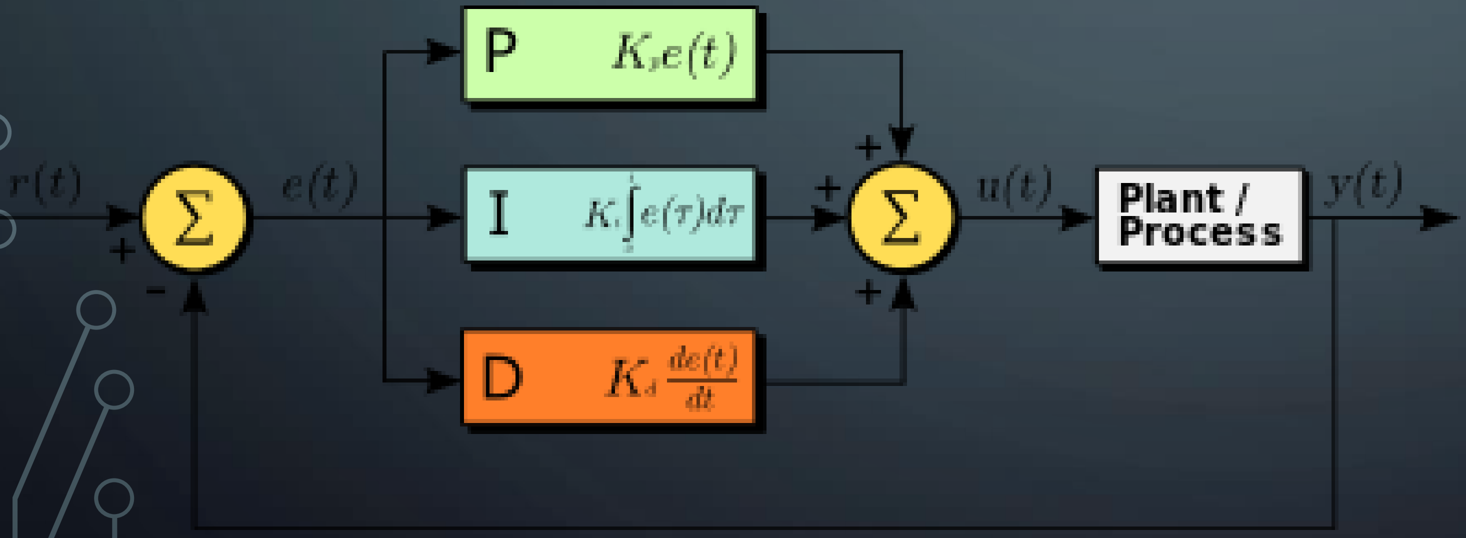
PROPORTIONAL INTEGRAL CONTROL



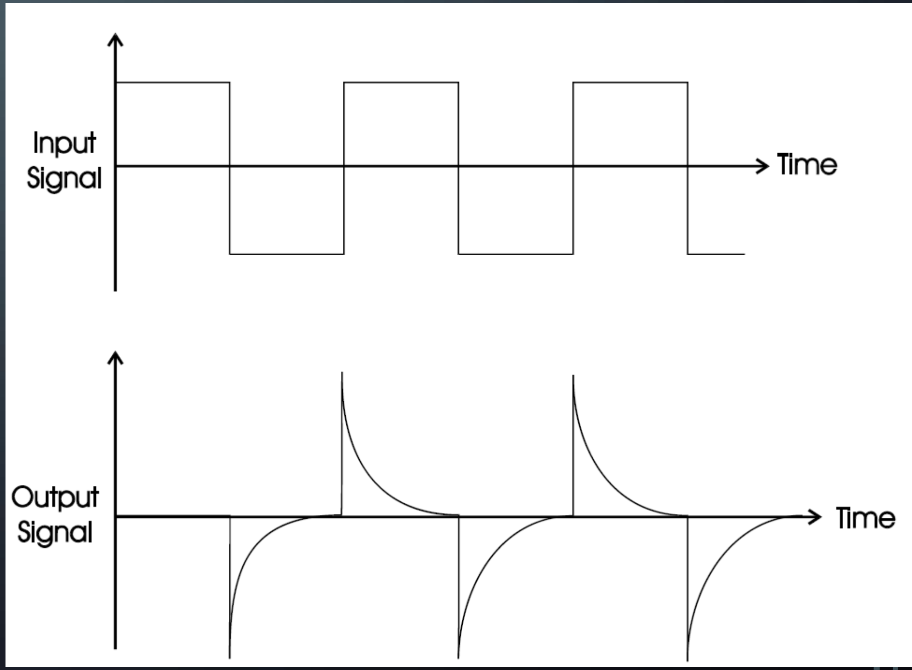


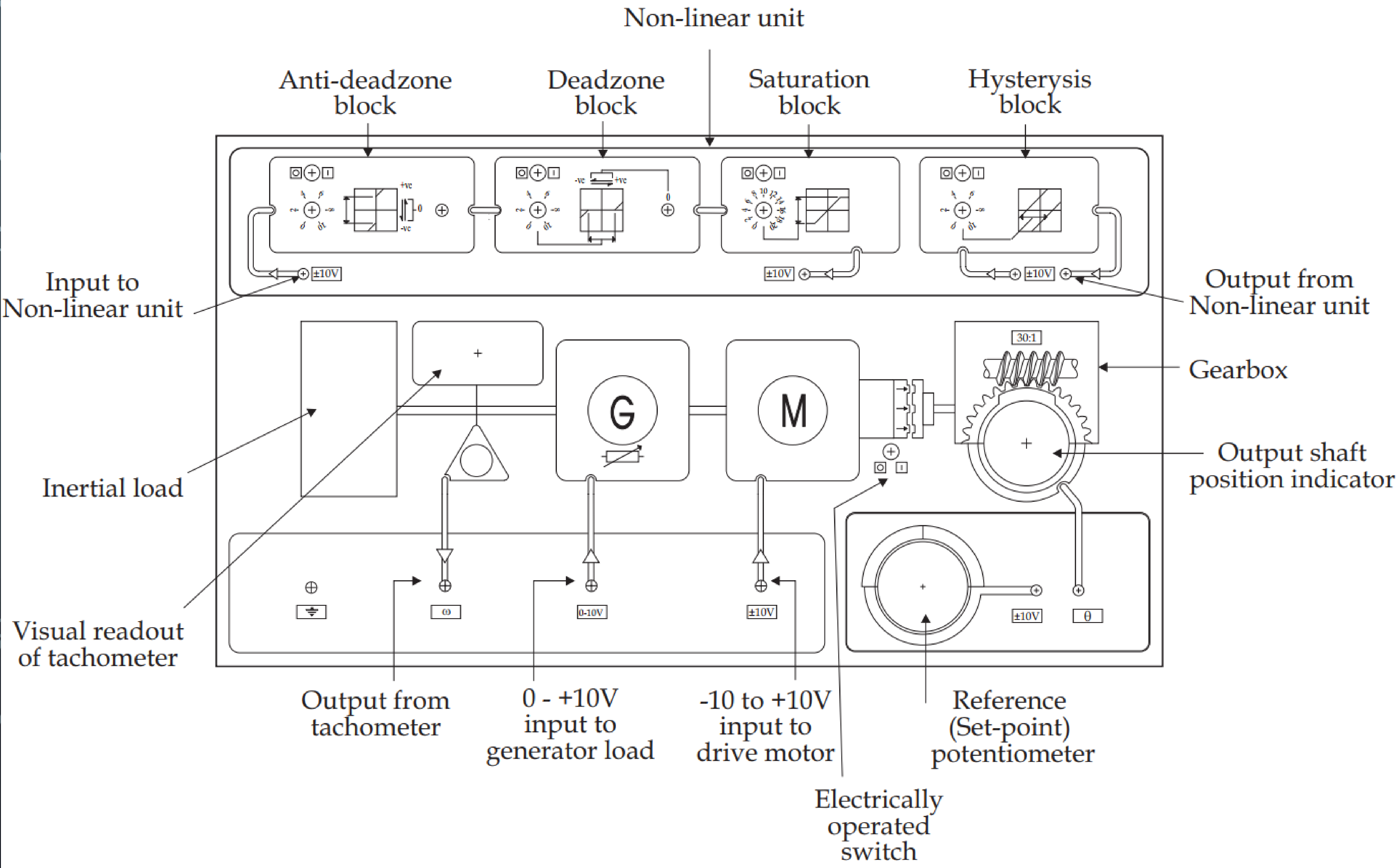
THREE TERM CONTROLLER

- Fast response with minimum overshoot
- Proportional-integral-derivative

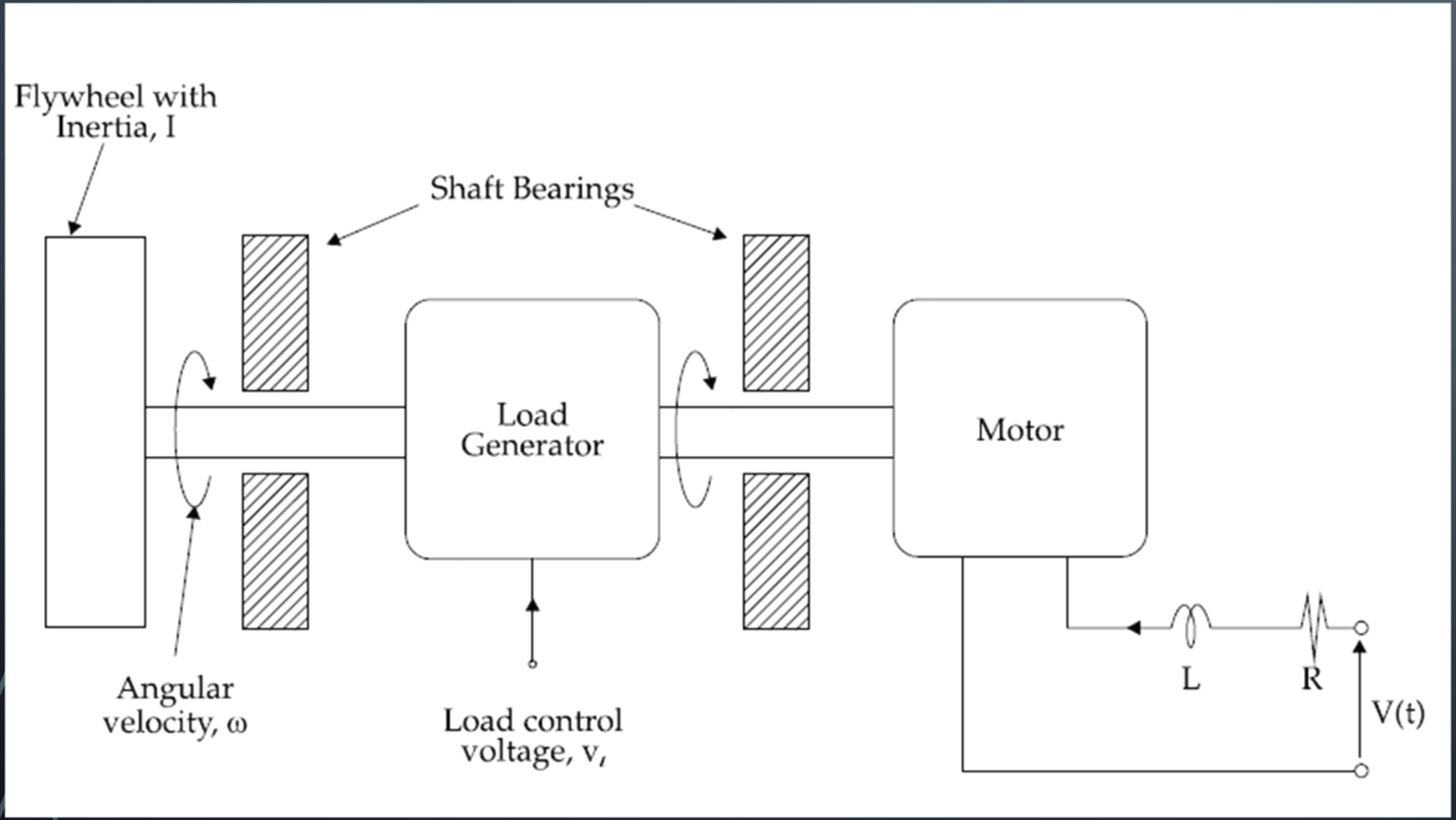


- Differential control
  - Input: reverse polarity
  - Output: large peak then decay




Non-linear unit
Anti-deadzone block
Deadzone block
Saturation block
Hysterysis block
Input to Non-linear unit
Output from Non-linear unit
±10V
±10V
±10V
30:1
Gearbox
G
M
Inertial load
Output shaft position indicator
Visual readout of tachometer
ω
0-10V
±10V
±10V
θ
Output from tachometer
0 - +10V input to generator load
-10 to +10V input to drive motor
Electrically operated switch
Reference (Set-point) potentiometer

SERVO TRAINER ANALYSIS



- Torque is proportional to current

$$\tau_m = k_m i$$

- Back EMF voltage is proportional to rotation speed

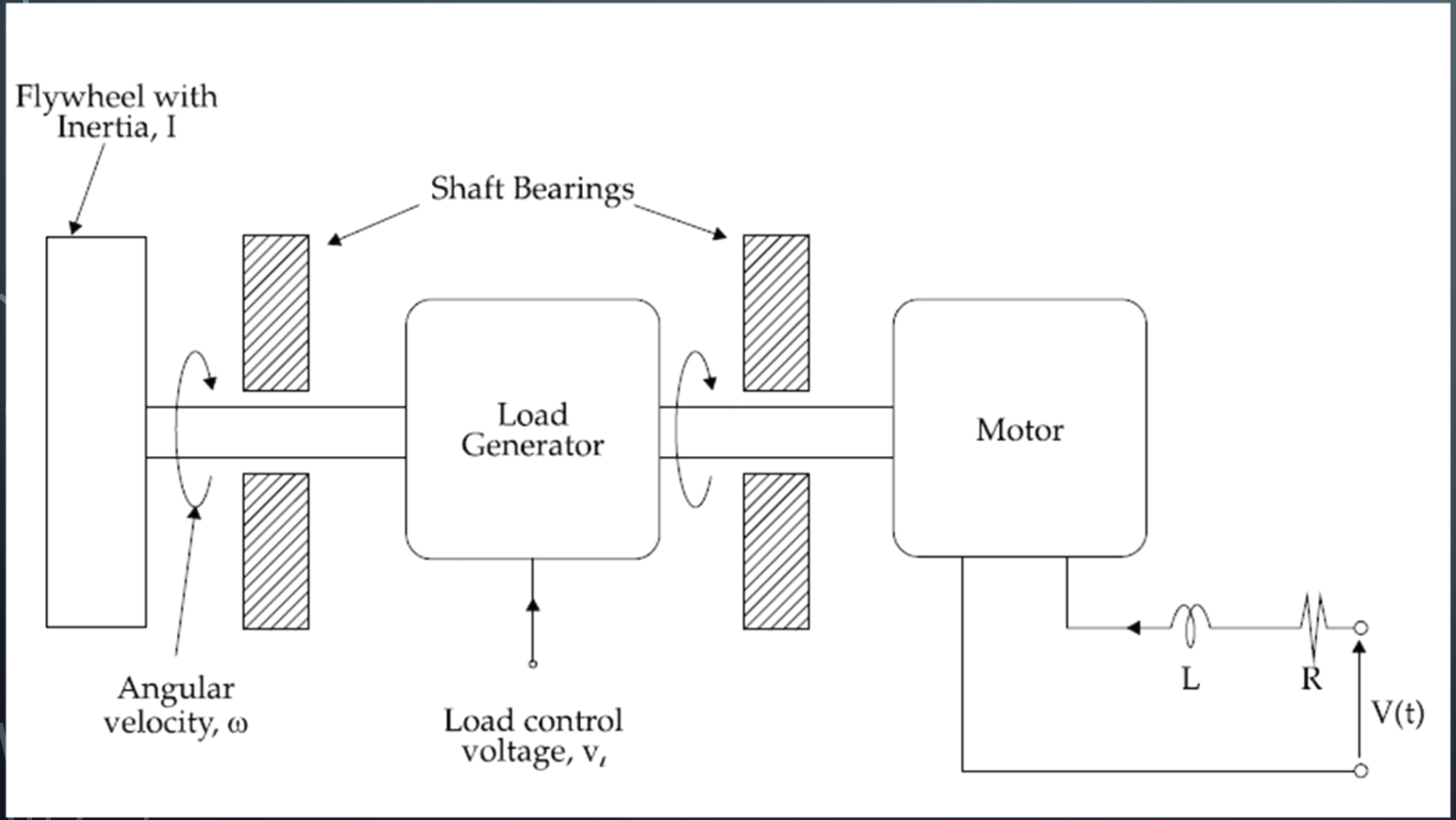
$$v_{bemf} = k_m \omega$$

- System model

$$\tau_m = b\omega + k_l v_l + I\frac{d\omega}{dt}$$

$$V(t) = Ri + L\frac{di}{dt} + v_{bemf}$$

SERVO TRAINER ANALYSIS



- System Transfer function

$$\omega(s) = \frac{k_m v(s)}{(sI+b)(sL+R)+k_m^2} - \frac{k_l(R+sL)v_l(s)}{(sI+b)(sL+R)+k_m^2}$$

- Assume small inductance $L = 0$ and big inertia flywheel

$$\omega(s) = \frac{k'_m v(s)}{Ts+1} - \frac{k'_l v_l(s)}{Ts+1}$$

$$T = \frac{IR}{bR+k_m^2}$$

$$k'_m = \frac{k_m}{bR+k_m^2}$$

$$k'_l = \frac{k_l R}{bR+k_m^2}$$

- Assume only inertia load

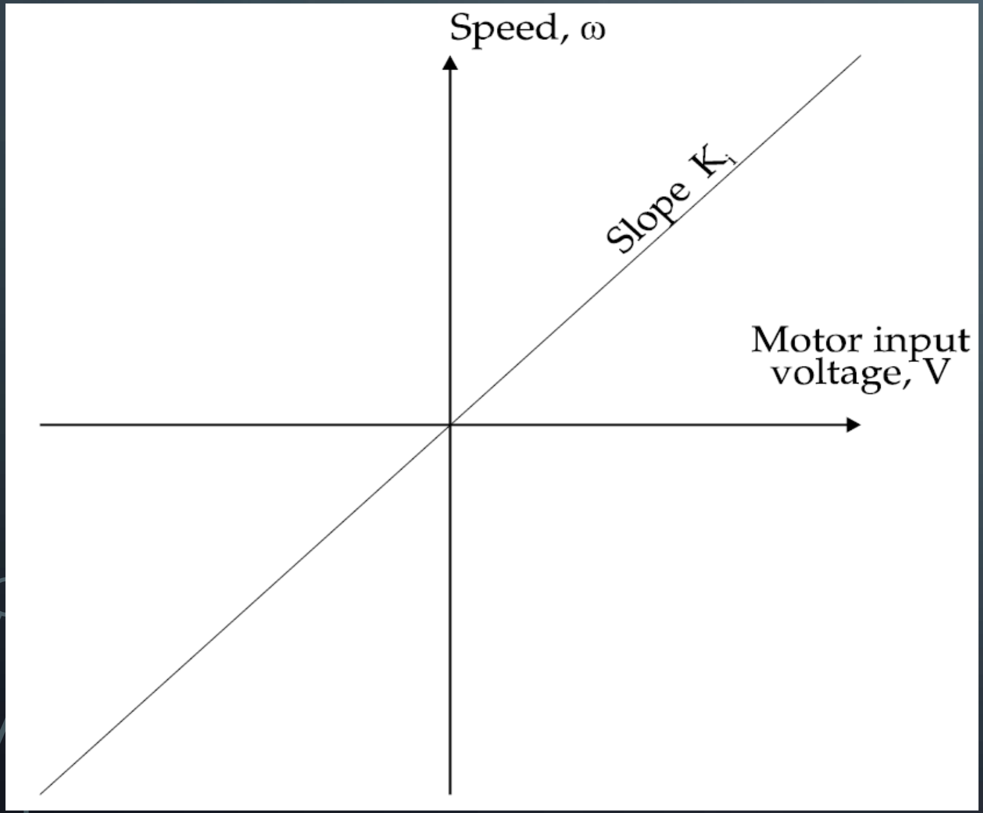
$$\omega(s) = \frac{k'_m}{Ts+1} v(s)$$

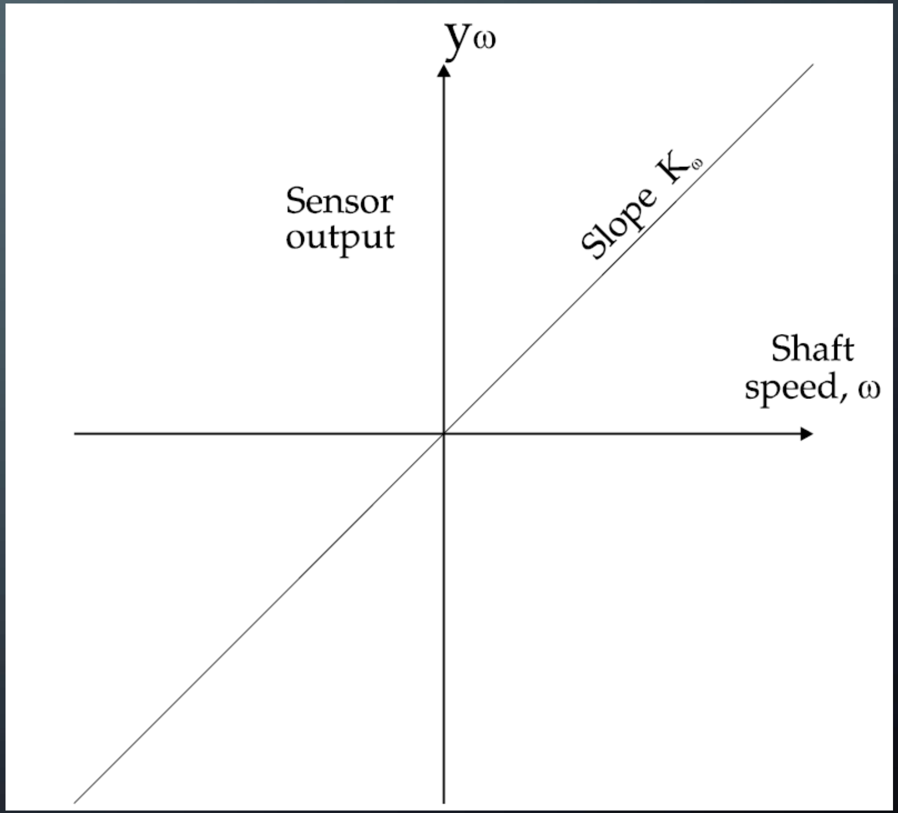
SERVO TRAINER ANALYSIS

$$\omega(s) = \frac{k'_m}{Ts+1} v(s)$$

$$y_\omega = k_\omega \omega$$

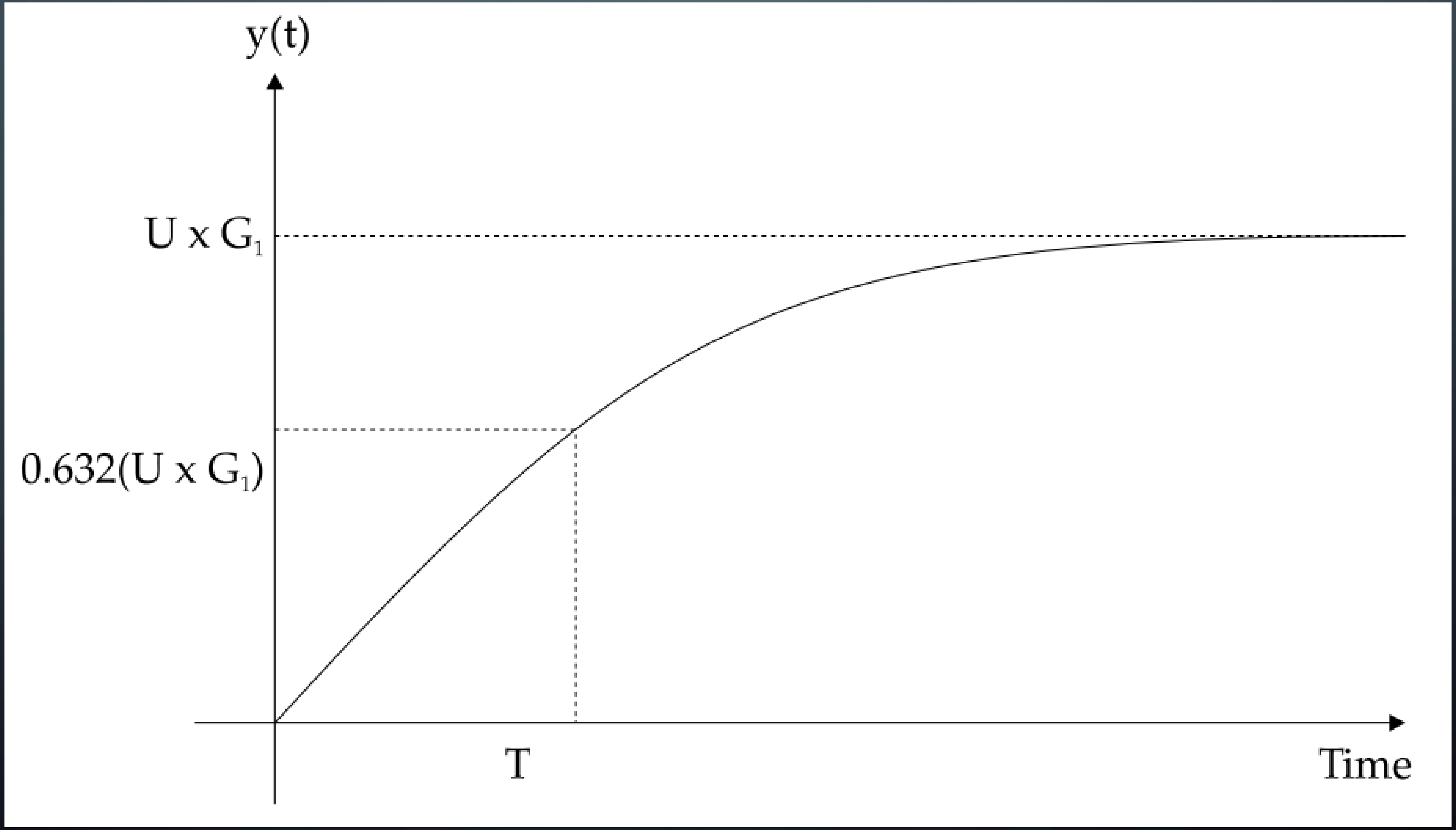
$$\omega = k_i v$$





$$y_\omega(s) = \frac{G_1}{Ts+1} v(s)$$

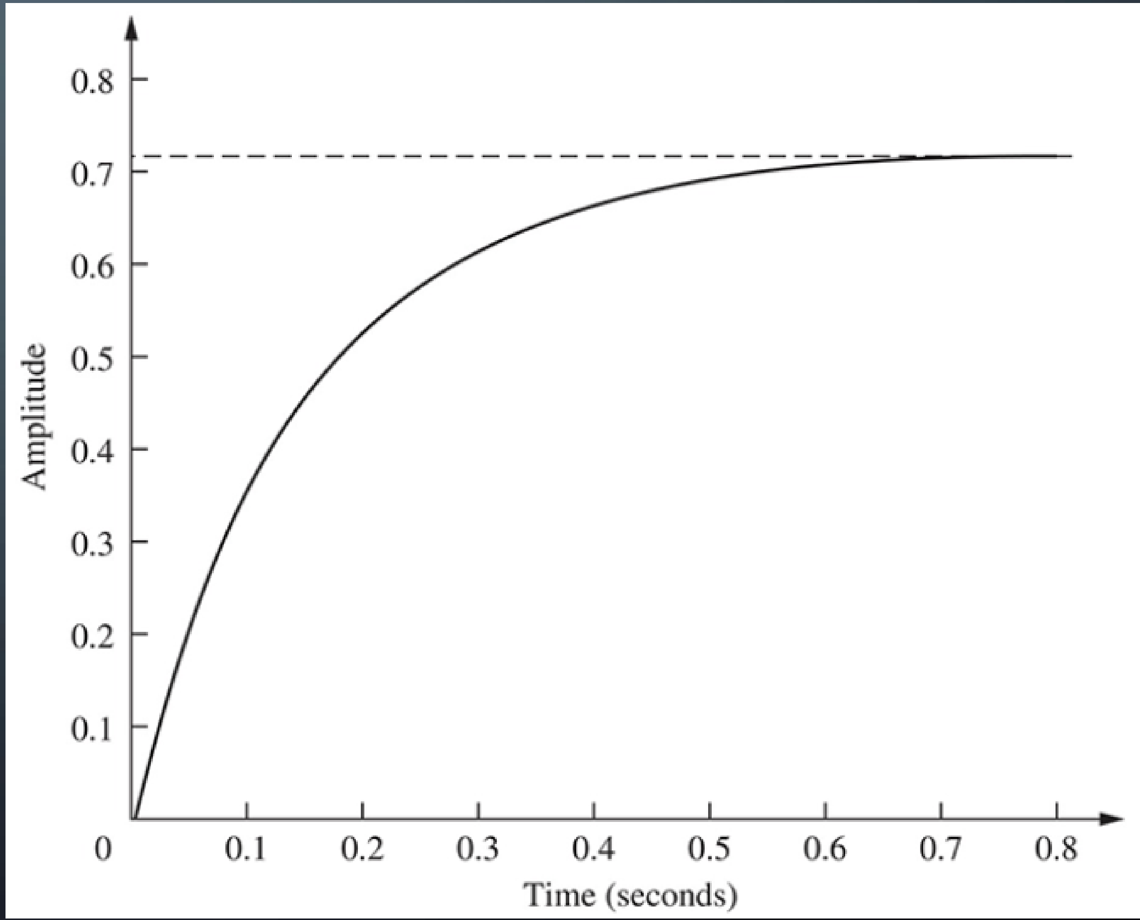
MEASUREMENT OF SYSTEM CHARACTERISTICS



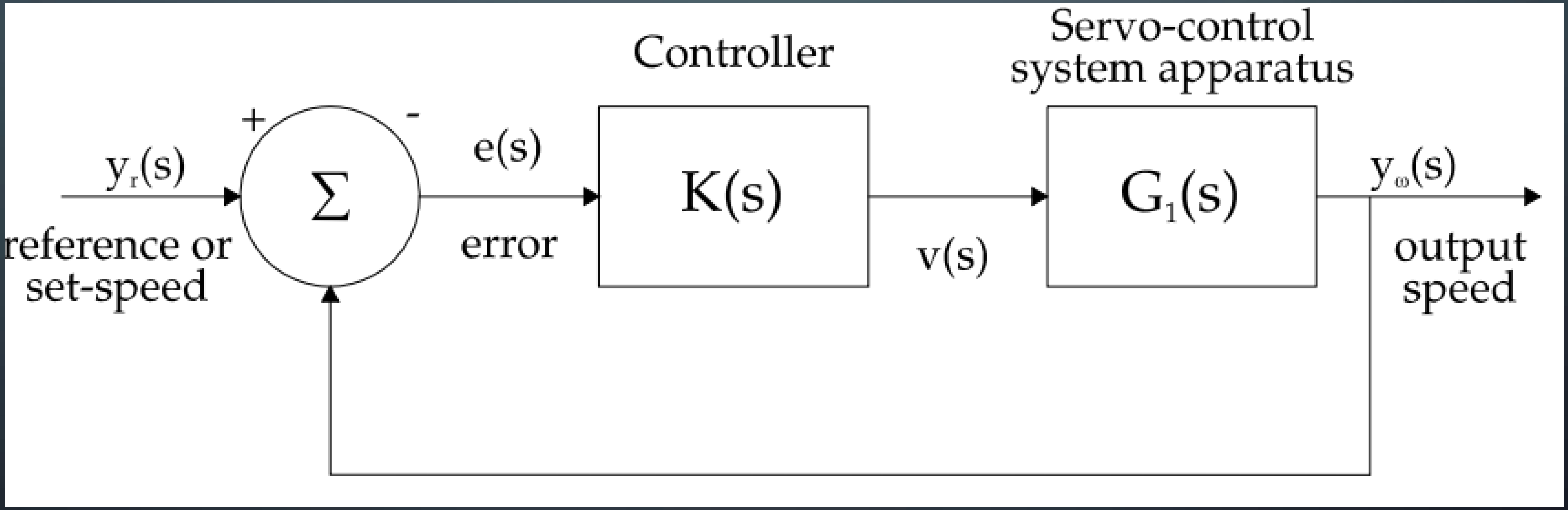
FIRST-ORDER TRANSFER FUNCTIONS VIA TESTING

$$C(s) = \frac{K}{s(s+a)} = \frac{K/a}{s} - \frac{K/a}{(s+a)}$$

- Final value: 0.72
- Time constant
    - 0.63 × 0.72 = 0.45, or
    - 0.13 second
    - a = 1/0.13 = 7.7
    - K/a=0.72
    - K=5.54
- G(s)=5/(s+7)



VELOCITY CONTROL SYSTEM



STEADY STATE ERROR ANALYSIS

- Output and error

$$y_\omega(s) = \frac{K(s)G_1(s)y_r(s)}{1 + K(s)G_1(s)}$$

$$e(s) = \frac{y_r(s)}{1 + K(s)G_1(s)}$$

- Final value theorem

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} se(s)$$

STEADY STATE ERROR ANALYSIS

- Steady state error

$$e_{ss}(s) = \lim_{s \to 0} \frac{y_r(s)}{1 + K(s)G_1(s)}$$

- Proportional control

$$K(s) = K_p$$

$$e_{ss}(s) = \lim_{s \to 0} \frac{sy_r(s)}{1 + K_p G_1(s)}$$

- Proportional integral control

$$K(s) = K_p + \frac{K_i}{s}$$

$$e_{ss}(s) = \lim_{s \to 0} \frac{sy_r(s)}{1 + \left(K_p s + K_i\right) G_1(s)}$$

DYNAMIC RESPONSE ANALYSIS

$$y_\omega(s) = \frac{G_1}{Ts+1} v(s)$$

- Dynamic response

$$y_\omega(s) = \frac{K(s)G_1(s)y_r(s)}{1+K(s)G_1(s)}$$

- Proportional control

$$y_\omega(s) = \frac{k_p G_1}{Ts+1+k_p G_1} y_r(s)$$

- Proportional integral control

$$y_\omega(s) = \frac{(k_p s + k_i)G_1}{Ts^2 + (k_p G_1 + 1)s + k_i G_1} y_r(s)$$