

# Control Systems

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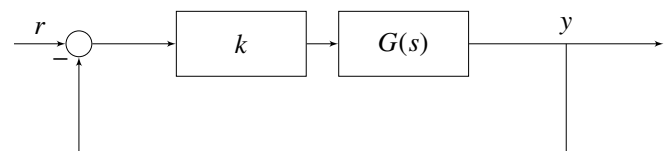


Fig. 3.3.1

$$G(s) = \frac{1}{s^2 + 2s} \quad (3.3.1.1)$$

**Solution:** The closed loop transfer function is

$$H(s) = \frac{kG(s)}{1 + kG(s)} \quad (3.3.1.2)$$

$$= \frac{k}{s^2 + 2s + k} \quad (3.3.1.3)$$

after substituting from (3.3.1.1).

3.3.2. Find the step response of the system.

**Solution:** The characteristics of the poles of transfer function describes the property of the transfer function.

Calculating poles :

$$s^2 + 2s + k = 0 \quad (3.3.2.1)$$

$$s = \frac{-2 \pm \sqrt{(-2)^2 - 4(1)(k)}}{2(1)} \quad (3.3.2.2)$$

$$s = -1 \pm \sqrt{1-k} \quad (3.3.2.3)$$

Calculating step response for a general damping system (3.3.1.3) :

$$X(s) = \frac{1}{s} \quad (3.3.2.4)$$

$$Y(s) = H(s)X(s) \quad (3.3.2.5)$$

$$= \frac{k}{s^2 + 2s + k} \frac{1}{s} \quad (3.3.2.6)$$

$$\begin{aligned} y(t) &= u(t) + \frac{k}{(2\sqrt{1-k})(-1 + \sqrt{1-k})} e^{(-1+\sqrt{1-k})t} u(t) \\ &+ \frac{k}{(2\sqrt{1-k})(1 + \sqrt{1-k})} e^{(-1-\sqrt{1-k})t} u(t) \quad [\text{when } k \neq 1] \end{aligned}$$

$$y(t) = (1 - e^{-t} - te^{-t}) u(t) \quad [\text{when } k = 1]$$

$$(3.3.2.8)$$

Over Damped System:

For the closed loop transfer function (3.3.1.3) to be Over damped system, poles should be Real and Distinct, this happens when  $k$  is less than 1.

Under Damped System:

For the closed loop transfer function (3.3.1.3) to be Under damped system, poles should be

Complex and Conjugate, this happens when  $k$  is greater than 1.

Critical Damped System:

For the closed loop transfer function (3.3.1.3) to be Critical damped system, poles should be Real at same location, this happens when  $k$  is 1.

3.3.3. Find steady state response using the final value theorem.

**Solution:**

$$\lim_{t \rightarrow \infty} y(t) = \lim_{s \rightarrow 0} sY(s) \quad (3.3.3.1)$$

$$= \lim_{s \rightarrow 0} s \frac{k}{s^2 + 2s + k} \frac{1}{s} \quad (3.3.3.2)$$

$$= \lim_{s \rightarrow 0} \frac{k}{s^2 + 2s + k} \quad (3.3.3.3)$$

$$= \frac{k}{k} = 1 \quad (3.3.3.4)$$

3.3.4. Find the settling time in terms of 'k' .

**Solution:**

$$0.98 < y(t) < 1.02 \quad (3.3.4.1)$$

$$\begin{aligned} 0.98 < u(t) + \frac{k}{(2\sqrt{1-k})(-1 + \sqrt{1-k})} e^{(-1+\sqrt{1-k})t} u(t) \\ + \frac{k}{(2\sqrt{1-k})(1 + \sqrt{1-k})} e^{(-1-\sqrt{1-k})t} u(t) < 1.02 \end{aligned} \quad (3.3.4.2)$$

On further simplifying (3.3.4.2)

$$\begin{aligned} -0.02 < \frac{-1}{\sqrt{1-k}} e^{-t} \left[ \sinh(\sqrt{1-k})t + \sqrt{1-k} \cosh(\sqrt{1-k})t \right] < 0.02 \end{aligned} \quad (3.3.4.3)$$

$$(3.3.2.7)$$

## 4 ROUTH HURWITZ CRITERION

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### *4.3 Stability*

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## 9 PHASE MARGIN

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