

# GATE: CH - 45.2023

EE22BTECH11219 - Rada Sai Sujan

## QUESTION

Level ( $h$ ) in a steam boiler is controlled by manipulating the flow rate ( $F$ ) of the break-up(fresh) water using a proportional ( $P$ ) controller. The transfer function between the output and the manipulated input is

$$\frac{h(s)}{F(s)} = \frac{0.25(1-s)}{s(2s+1)}$$

The measurement and the valve transfer functions are both equal to 1. A process engineer wants to tune the controller so that the closed loop response gives the decaying oscillations under the servo mode. Which one of the following is the CORRECT value of the controller gain to be used by the engineer?

- (a) 0.25
- (b) 2
- (c) 4
- (d) 6

**Solution:**

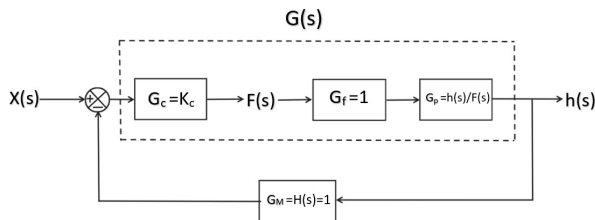


Fig. 1. Closed loop Block diagram

Closed loop signal transfer function of the above block diagram can be given by,

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \quad (1)$$

PARAMETER	DESCRIPTION
$G_c$	Proportional controller's transfer function
$G_f$	Valve transfer function
$G_p$	Process transfer function
$G_M$	Measurement transfer function
$G(s)$	Open loop transfer function
$T(s)$	Transfer function of system

TABLE I  
PARAMETER TABLE 1

From Fig. 1 and Table I for a unit impulse,  $X(s) = 1$

$$h(s) = T(s) \times X(s) \quad (2)$$

$$h(s) = \frac{(1-s)K_c}{8s^2 + (4-K_c)s + K_c} \quad (3)$$

$$\Rightarrow h(s) = \frac{(1-s)K_c}{8(s-s_1)(s-s_2)} \quad (4)$$

Where,

$$s_1 = \frac{(K_c - 4)}{16} + \sqrt{\left(\frac{K_c - 4}{16}\right)^2 - \frac{K_c}{8}} \quad (5)$$

$$s_2 = \frac{(K_c - 4)}{16} - \sqrt{\left(\frac{K_c - 4}{16}\right)^2 - \frac{K_c}{8}} \quad (6)$$

From (4) we get,

$$h(s) = \frac{K_c}{8(s_1 - s_2)} \left( \frac{1-s_1}{s-s_1} - \frac{1-s_2}{s-s_2} \right) \quad (7)$$

Now taking the inverse laplace transform we have,

$$h(t) = \frac{K_c}{8(s_1 - s_2)} [(1 - s_1)e^{s_1 t} - (1 - s_2)e^{s_2 t}] u(t) \quad (8)$$

$$\Rightarrow h(t) = e^{\frac{K_c - 4}{16}t} \left( A_1 e^{\sqrt{\left(\frac{K_c - 4}{16}\right)^2 - \frac{K_c}{8}}t} - A_2 e^{-\sqrt{\left(\frac{K_c - 4}{16}\right)^2 - \frac{K_c}{8}}t} \right) u(t) \quad (9)$$

Where,

$$A_1 = \frac{K_c}{8} \left( \frac{1 - s_1}{s_1 - s_2} \right) \quad (10)$$

$$A_2 = \frac{K_c}{8} \left( \frac{1 - s_2}{s_1 - s_2} \right) \quad (11)$$

Now applying the condition for underdamped oscillations,

$$\left( \frac{K_c - 4}{16} \right)^2 - \frac{K_c}{8} < 0 \quad (12)$$

$$\Rightarrow K_c \in (20 - \sqrt{384}, 20 + \sqrt{384}) \quad (13)$$

For the system to be stable,

$$\frac{K_c - 4}{8} < 0 \quad (14)$$

$$\Rightarrow K_c < 4 \quad (15)$$

From (13) and (15)

$$K_c \in (0.4, 4) \quad (16)$$

(16) represents the  $ROC, (Re\{s\} < 0)$

$$\Rightarrow K_c = 2 \quad (17)$$

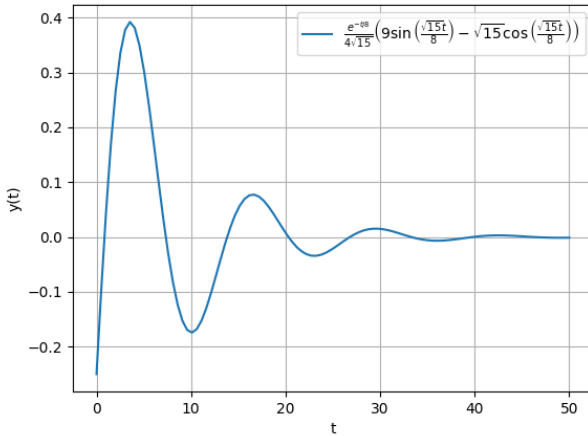


Fig. 2.  $y(t)$  vs  $t$  graph