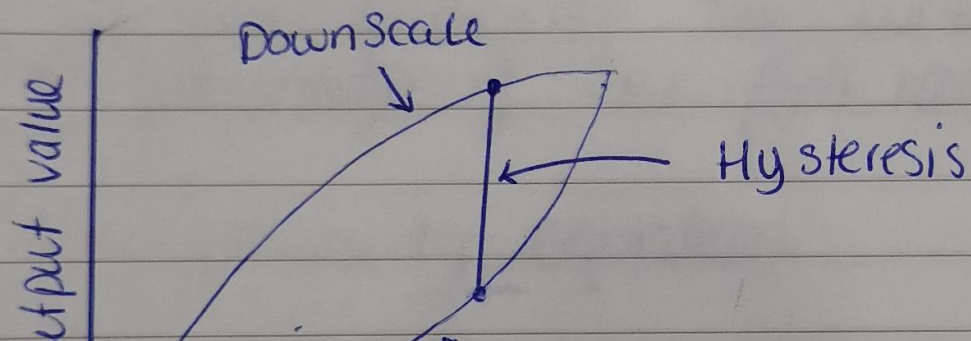


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- Q1 a) The ideal relationship between the measurand x (input) and the transducer output is a linear and proportional.
- b) Hysteresis error is the difference in the output value of a transducer depending on ~~whether~~ whether the instrument is being loaded or unloaded in terms of quantity being measured. Hysteresis error is maximum difference in output for increasing + decreasing values.



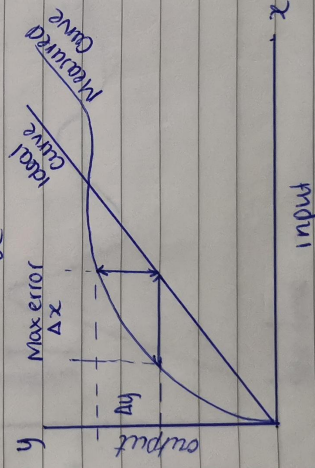
- iii A wheatstone bridge changed the resistance value and turns it into a voltage. This reading will then be output by/on a recorder.

e) Non-linearity is the relationship of output/input being exactly linear is rare. When an output curve is produced a maximum error can then be determined for either input or output quantity. This would be shown as a percentage of the full range. (either input or output)

Non-linearity equation

$$N/L_{in} = \frac{\Delta x}{x} \times 100\%$$

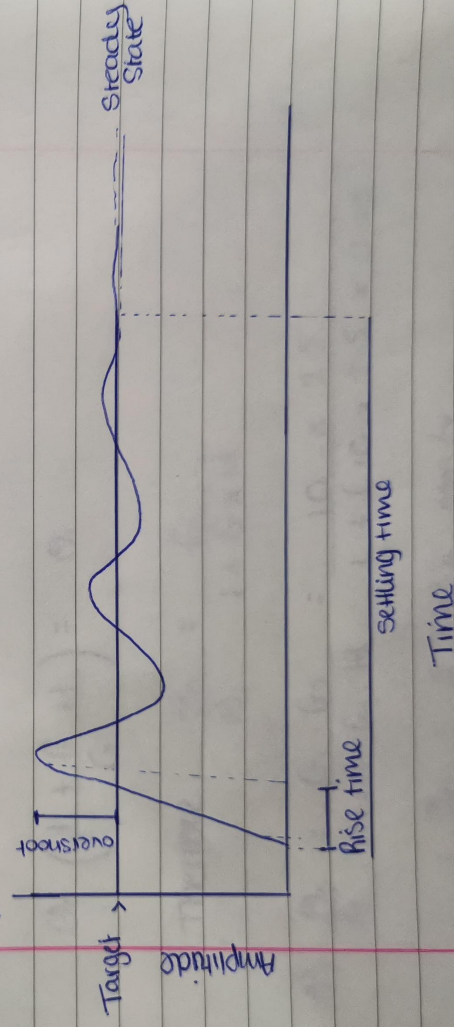
$$NL_{out} = \frac{\Delta y}{y} \times 100\%$$



Q2

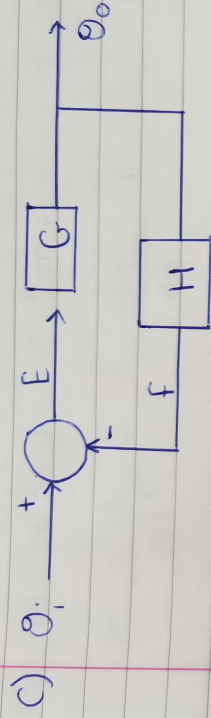
a) A control system is a system which can output the desired response by controlling it. There are two types, an open loop control system and a closed loop control system. By automatically controlling the process it can automatically deal with system disturbance with no human intervention if it is a closed loop control system compared to an open loop control system.

b) A proportional - integral - derivative controller is a control loop device used to send feedback.



A PID continuously calculate an error value as the difference between the desired target or setpoint and corrects using PID terms.

A PID can be used to regulate temperature in a blast furnace.



$$G = \frac{\theta_o}{E} \Rightarrow E = \frac{\theta_o}{G}$$

$$H = \frac{f}{\theta_o} \Rightarrow f = H \cdot \theta_o$$

$$\text{Now, } E = \theta_i - f$$

$$\therefore \frac{\theta_o}{G} = \theta_i - H \theta_o \Rightarrow \frac{\theta_o}{G} + H \theta_o = \theta_i$$

$$\theta_o \left(\frac{1 + G \cdot H}{G} \right) = \theta_i$$

$$\text{Therefore, } \frac{\theta_o}{\theta_i} = \frac{G}{1 + G \cdot H}$$

$$\text{d) } \frac{\theta_o}{\theta_i} = \frac{G_1 \cdot G_2}{1 + G_1 \cdot G_2 \cdot H} = \frac{10 \times 2.5}{1 + (10 \times 2.5 \times 0.15)}$$

$$\therefore \frac{\theta_o}{\theta_i} = 5.2632 \text{ mm/v}$$

- e)
1. Baking process which is temperature controlled
 2. production line conveyor belt which is speed controlled.

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4) a) $m = 14.5 \text{ kg}$ $C = 200 \text{ N s/m}$ $K = 4 \text{ kN/m} = 4000 \text{ N/m}$

$$m \frac{d^2 \theta_o}{dt^2} + C \frac{d\theta_o}{dt} + K\theta_o = f$$

$\therefore$ dividing by m gives

$$\frac{d^2 \theta_o}{dt^2} + \frac{C}{m} \frac{d\theta_o}{dt} + \frac{K}{m} \theta_o = \frac{f}{m}$$

Comparing to $\frac{d^2 \theta_o}{dt^2} + 2\zeta \omega_n \frac{d\theta_o}{dt} + \omega_n^2 \theta_o = b_1 \omega_n \theta_i$

$$\omega_n^2 = \frac{K}{m} = \frac{4000}{14.5} = 275.862$$

$$\omega_n = \sqrt{275.862} = 16.609 \text{ Hz}$$

$$2\zeta \omega_n = \frac{C}{m}$$

$$\therefore \zeta = \frac{C}{2\omega_n m} = \frac{(200)}{2(16.609)(14.5)} = 0.415$$

$\zeta = 0.415$ which is < 1 so system is underdamped.

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$$b) \% \text{ Peak overshoot} = \left[\exp\left(\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}\right) \right] \times 100\%$$

$$\zeta = 0.4152274$$

$$\therefore \% \text{ Peak O.S} = \left[\exp\left(\frac{-(0.415)\pi}{\sqrt{1-(0.415)^2}}\right) \right] \times 100\%$$

$$= 23.837\%$$

$$\omega = \omega_n \sqrt{1-\zeta^2}$$

$$\therefore \omega = (16.609) \sqrt{1-(0.415)^2}$$

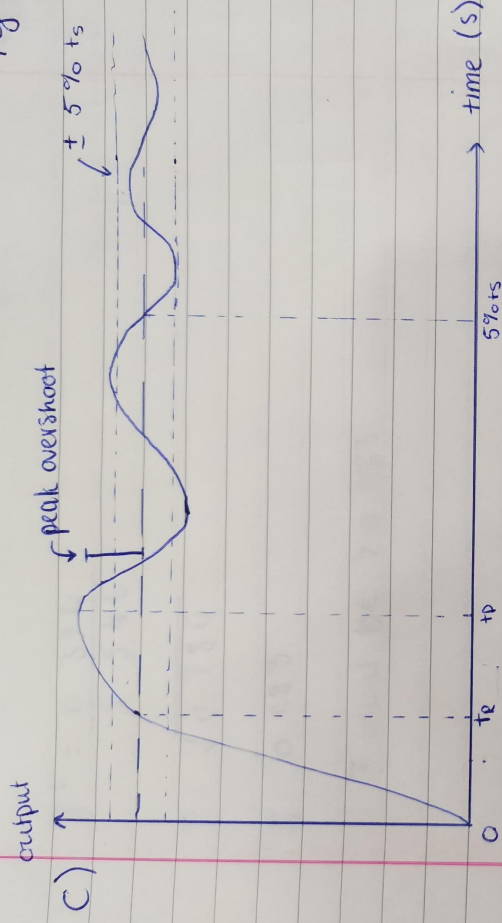
$$\omega = 15.110 \text{ Hz}$$

$$\text{Rise time, } t_r = \frac{\pi}{2\omega} = \frac{\pi}{2(15.11)} = 0.104 \text{ s}$$

$$\text{Peak time } t_p = \frac{\pi}{\omega} = \frac{\pi}{(15.11)} = 0.208 \text{ s}$$

$$5\% \text{ Settling time } 5\% + t_s = \frac{3}{\zeta\omega_n} = \frac{3}{(0.415)(16.609)}$$

$$5\% + t_s = 0.435 \text{ s}$$



d) % Peak overshoot = $\left[\exp\left(\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}\right) \right] \times 100\%$

1f % Peak overshoot = 12.5% =

$$0.125 = \exp\left(\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}\right)$$

Taking natural logs of both sides:

$$\ln(0.125) = \frac{-\zeta\pi}{\sqrt{1-\zeta^2}}$$

$$-2.079 (\sqrt{1-\zeta^2}) = -\zeta\pi$$

Squaring both Sides

$$\begin{aligned} 4.324 (1-\zeta^2) &= 9.870\zeta^2 \\ 4.324 - 4.324\zeta^2 &= 9.870\zeta^2 \\ \therefore 5.546\zeta^2 &= 4.324 \end{aligned}$$

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$$\bar{z}^2 = \frac{4.324}{5.546}$$

$$\bar{z} = \sqrt{0.780}$$

$$\bar{z} = 0.883$$

$\therefore \bar{z}$ must be > 0.883