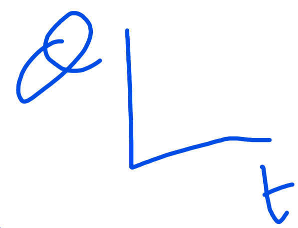
$$\frac{d\theta}{dt} \propto T$$

heat

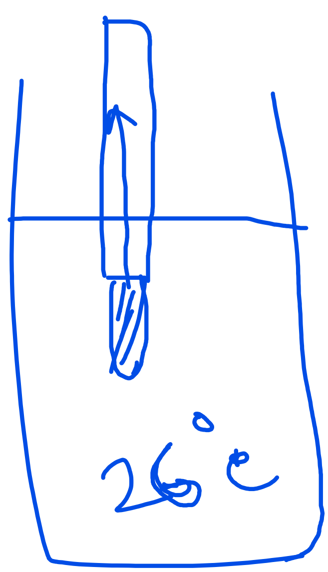
Hg ↑

$$\frac{d\theta}{dt} \propto t_0$$



$$\frac{1}{1+sT}$$

26°C



$$\frac{d\theta}{dt} \propto T$$

2nd order sys

$$c(t) = 1 - \frac{e^{(-\xi \omega_n t)}}{\sqrt{1-\xi^2}} \sin(\omega_d t + \theta)\, u(t)$$

$$\xi = \cos\theta$$

ξ | ω_d

ω_n

$$\sqrt{1-\xi^2} = \sin\theta$$

$$\theta = \tan^{-1}\left(\frac{\sqrt{1-\xi^2}}{\xi}\right)$$

$\boxed{0 < \xi < 1}$ $\rightarrow$ under damped.

1) $\xi = 0$, $\rightarrow$ undamped.

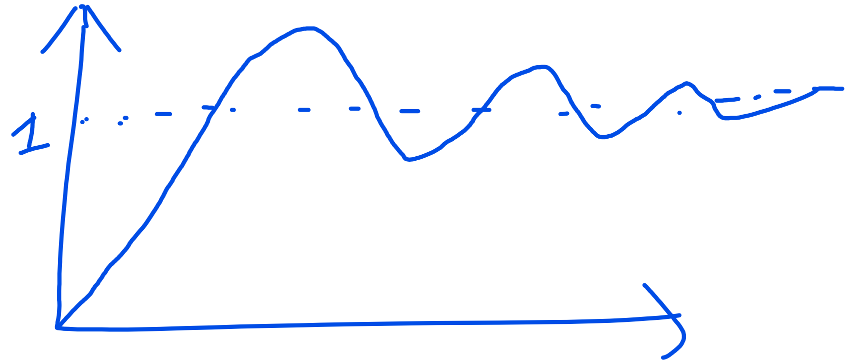
$$c(t) = (1 - \cos \omega_d t), \quad t > 0$$

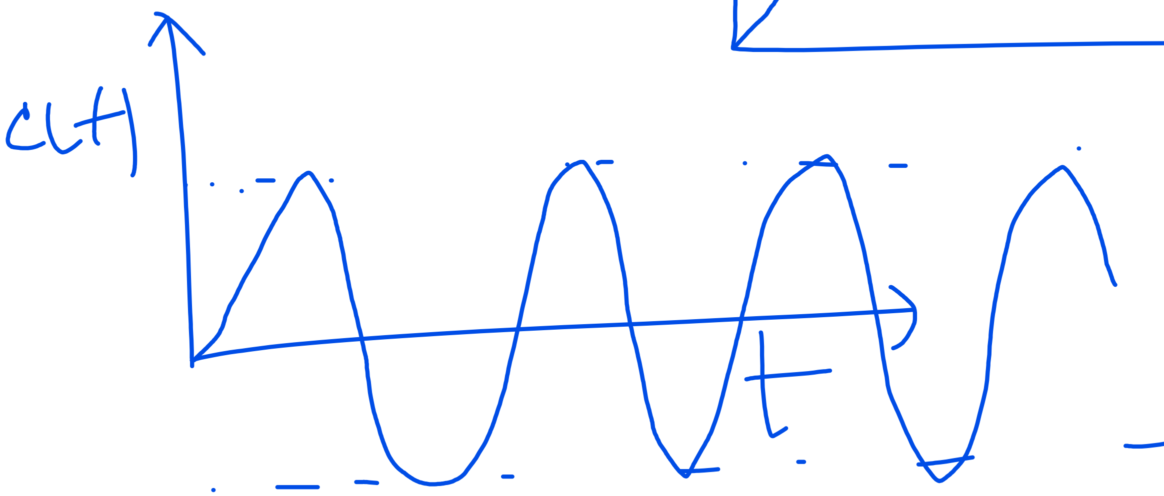
$$1 - e^{-\xi\omega_n t} \cos \omega_d t - \frac{\xi}{\sqrt{1-\xi^2}} e^{-\xi \omega_n t} \sin \omega_d t$$

// $c(t)$

$c(t) = 1 - \text{exp} \times \sin$

$1 - \cos \omega_d t$





* $\xi = 1$, critically damped

$$C(s) = \frac{\omega_n^2}{(s+\omega_n)^2} \times \frac{1}{s}$$

$$c(t) = 1 - e^{-\omega_n t}(1 + \omega_n t)$$

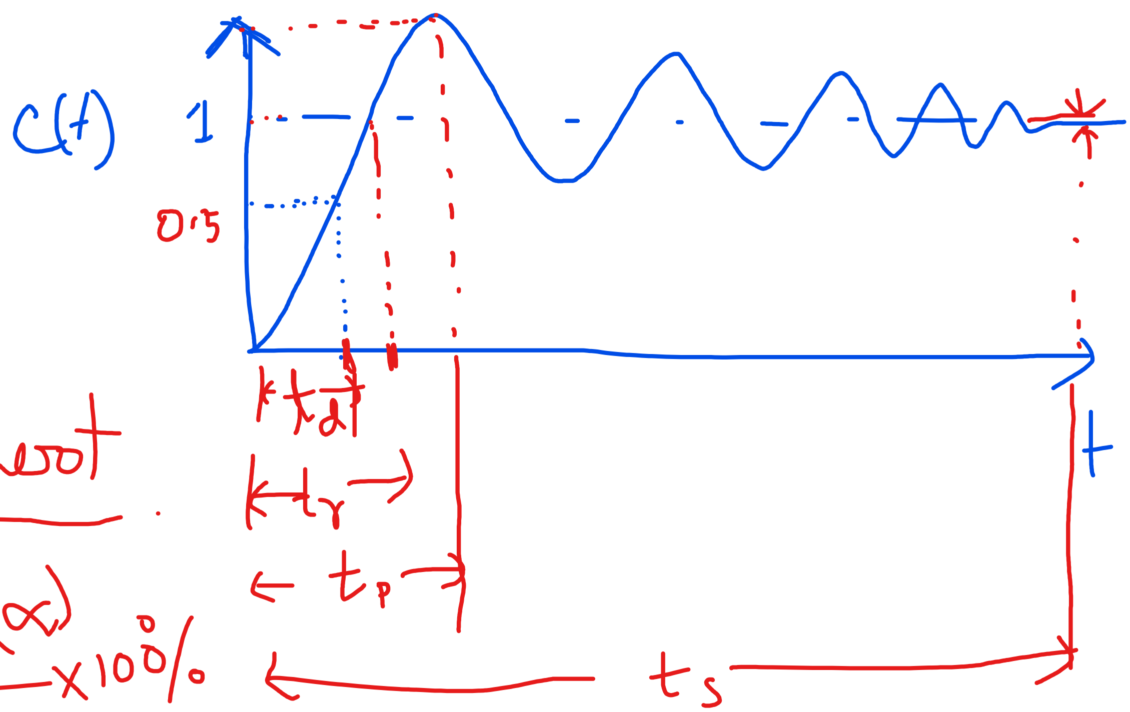
* $\xi > 1$ overdamped

$$c(t) = 1 + \frac{\omega_n}{2\sqrt{\xi^2 - 1}} \left(\frac{e^{-s_1 t}}{s_1} - \frac{e^{-s_2 t}}{s_2} \right)$$

$$S_1 = (\xi + \sqrt{\xi^2 - 1})\omega_n$$

$$S_2 = (\xi - \sqrt{\xi^2 - 1})\omega_n$$

(*)



$(0.02 - 0.01)\%$

Max. Overshoot

$$\frac{c(P) - c(\infty)}{c(\infty)} \times 100\%$$

Rise time:-

$$c(t) = \cancel{1} - e^{-\xi\omega_n t_r}\left(\cos\omega_d t_r + \frac{\xi}{\sqrt{1-\xi^2}}\sin\omega_d t_r\right) = \cancel{1}$$

$t = t_r, \quad c(t) = 1$

$1 = (\quad)$

$$\underbrace{(\exp)}_{\neq 0}\left(\cos \omega_d t_r + \frac{\xi}{\sqrt{1-\xi}} \sin \omega_d t_r\right) = 0$$

$$\cos \omega_d t_r + \frac{\xi}{\sqrt{1-\xi}} \sin \omega_d t_r = 0.$$

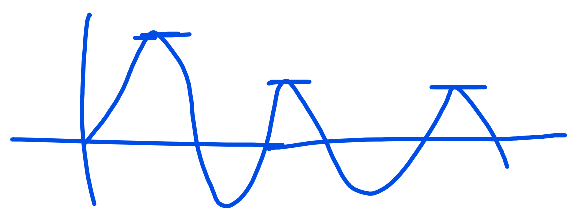
$$\tan \omega_d t_r = -\frac{\sqrt{1-\xi^2}}{\xi}$$

$$t_r = \frac{1}{\omega_d} \tan^{-1}\left(\frac{-\omega_n \sqrt{1-\xi^2}}{\omega_n \xi}\right)$$

$$\omega_d = \omega_n \sqrt{1-\xi^2}$$

$$\boxed{t_r = \frac{1}{\omega_d} \tan^{-1}\left(\frac{-\omega_d}{\sigma}\right)}$$

2) Peak time :=



$$\boxed{\frac{dc}{dt} = 0} \quad t = t_p.$$

$$\sin \omega_d t_p = 0 = \sin(n\pi)$$

$n = 1, 2, 3 \ldots$

$$\omega_d t_p = n\pi$$

$$\Rightarrow \boxed{t_p = \frac{n\pi}{\omega_d}}$$

3) Max Ov. :-

$$\frac{c(t_p) - c(\infty)}{c(\infty)} \times 100\%$$

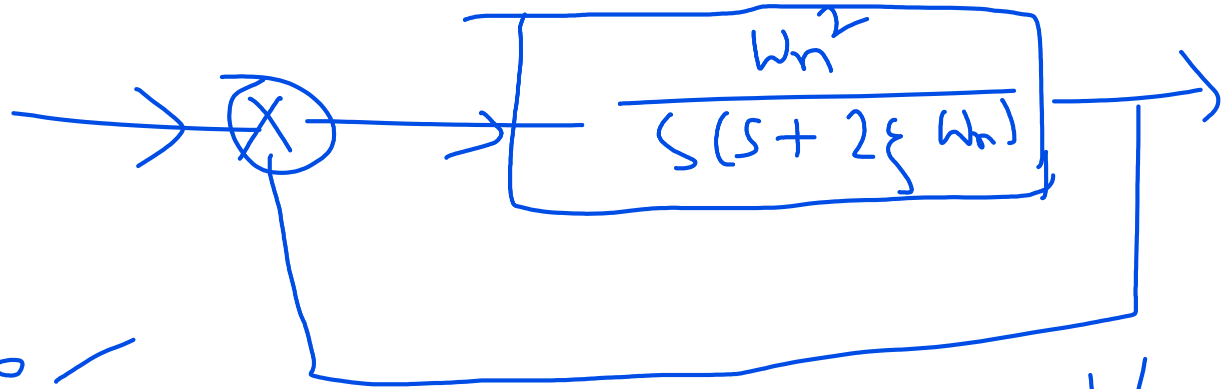
$$\Rightarrow \left[c(t_p) - 1\right] \times 100\%$$

$$M_p\% = e^{-(\xi/\sqrt{1-\xi^2})\pi} \times 100\%$$

4) settling time (2%)

$$t_s = 4T = \frac{4}{\xi\omega_n}$$

Q)



$\xi = 0.6$

$\omega_n = 5$ rad/s $\qquad R(s) = 1/s.$

$$t_r = \frac{1}{\omega_d}\tan^{-1}\left(\frac{\sqrt{1-\xi^2}}{\xi}\right) = \quad s.$$

$$t_p = \frac{\pi}{\omega_d} \text{ s.}$$

$$M_p = e^{-\left(\xi/\sqrt{1-\xi^2}\right)\pi} \times 100\,\%$$

$$t_s = 4T = \frac{4}{\xi\omega_n}$$

2nd. $T(s) \times \frac{1}{s^2}$ ✓

$$\boxed{T(s) \times \frac{1}{s}} \times \frac{1}{s}$$