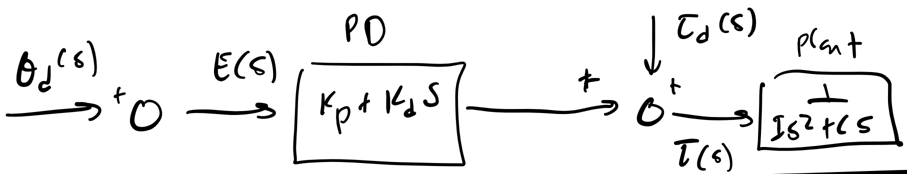
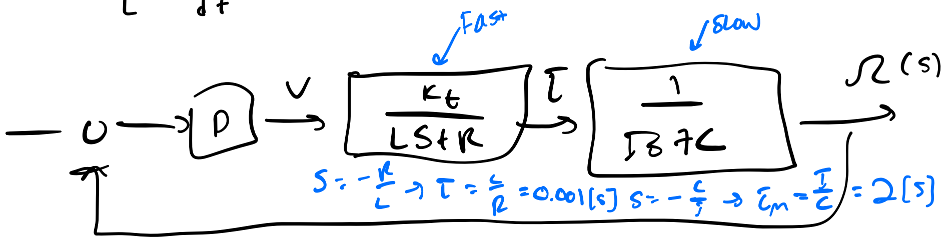
2^{nd} order system: PD control



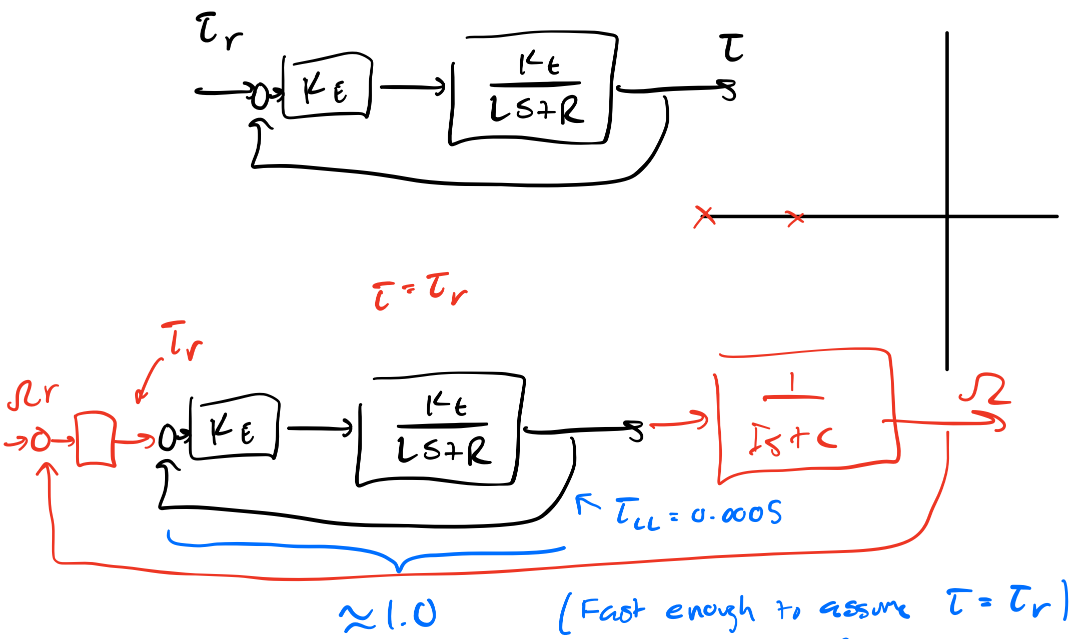
HW

$$I\dot{\omega} + C\omega = \tau$$

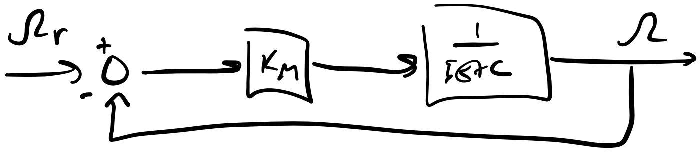
$$\begin{cases} \tau = K_t i \\ L\frac{di}{dt} + Ri = V \end{cases}$$



SUCCESSIVE LOOP CLOSURE



(Fast enough to assume $\tau = \tau_r$)
$\rightarrow$ allows simplifying outer loop



- Factor of 10 or more allows this to be useful
- very common to do experimentally

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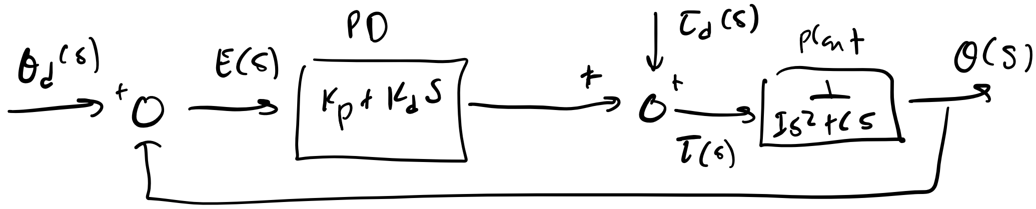

$$\Delta_{cl}(s) = s^2 + \left(\frac{c+K_d}{I}\right)s + \left(\frac{K_p}{I}\right) = 0$$

$$\Delta_{cl}(s) = s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$$

→ Prop. moves poles together & up/down
→ derivative term adds a zero

→ Prop: speeds up
→ Deriv: increases damping

Steady state error due to $\theta_d(t)$: $\dfrac{E(s)}{\Theta_d(s)} = \dfrac{Is^2+cs}{Is^2+(c+K_d)s+K_p}$

Unit step $\theta_d(t) = 1(t)$	unit ramp, $\theta_d(t) = t$	unit accel, $\theta_d(t) = \frac{1}{2}t^2$
$e_{ss} = 0$	$e_{ss} = \frac{c}{K_p} = 0.005$	$e_{ss} = \infty$

SS error due to dist. $\tau_d(t)$ $\rightarrow \frac{E(s)}{\tau_d(s)} = \frac{1}{Js^2 + (C+K_d)s + K_p}$

unit step	unit ramp
$e_{ss} = 0.13$	

→ Adding integral term: increases order of char. eqn.

$$\rightarrow \frac{E(s)}{\tau_d(s)} = \frac{s}{Js^3 + (C+K_d)s^2 + K_p s + K_I}$$

unit step: