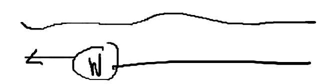
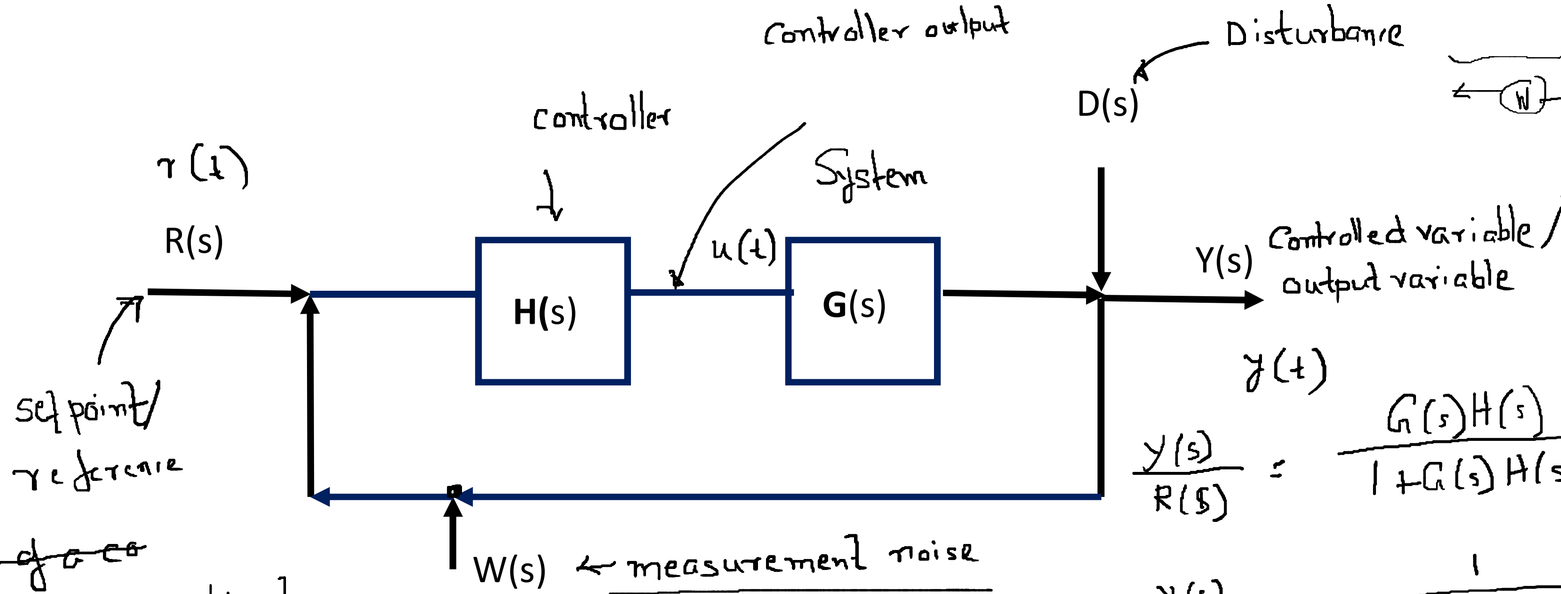
* shaft encoders





$$\frac{Y(s)}{R(s)} = \frac{G(s)H(s)}{1+G(s)H(s)}$$

$$\frac{Y(s)}{D(s)} = \frac{1}{1+G(s)H(s)}$$

$$\left|\frac{Y(s)}{W(s)}\right| = \frac{G(s)H(s)}{1+G(s)H(s)}.$$

~~Characteristics of a co~~

What should a controller achieve?

a. Good Tracking. → y(t) should track r(t)

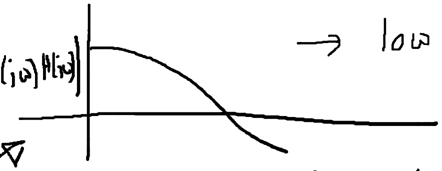
b. Good Disturbance rejection → y(t) should not be affected by D(t).

c. Good Noise rejection → y(t) should not be affected by W(t).

d. Robustness (parametric robustness and stability robustness)

$$\frac{Y(s)}{R(s)} = \frac{G(s)H(s)}{1+G(s)H(s)}.$$

$|G(j\omega)H(j\omega)| \rightarrow$



$\rightarrow$ low pass filter.

As $\omega \uparrow\uparrow$ $|G(j\omega)H(j\omega)| \downarrow\downarrow$

At low frequency.

$$\left|\frac{Y(j\omega)}{R(j\omega)}\right| \approx \frac{|G(j\omega)H(j\omega)|}{|G(j\omega)H(j\omega)|} \approx 1$$

$$\frac{Y(j\omega)}{R(j\omega)} = \frac{G(j\omega)H(j\omega)}{1+G(j\omega)H(j\omega)} \rightarrow \text{input sensitivity}$$

s or complementary sensitivity

At high frequency $\left|\frac{Y(j\omega)}{R(j\omega)}\right| \approx \frac{0}{1+0} \approx 0$

$$\frac{Y(j\omega)}{R(j\omega)} = \frac{1}{1+G(j\omega)H(j\omega)}$$

$\rightarrow$ Output sensitivity or

$\rightarrow$ Now sensitivity

$\Rightarrow$ At high frequency $\frac{1}{1+G(j\omega)H(j\omega)} \rightarrow \frac{1}{1+0} = 1$

But at low frequency $\frac{1}{1+G(j\omega)H(j\omega)} \rightarrow \frac{1}{G(j\omega)H(j\omega)} \rightarrow 0$

Moral of the story.

Design $G(j\omega)H(j\omega)$ as lowpass filter.

Noise rejection $\frac{Y(s)}{W(s)} \rightarrow$ similar to $\frac{Y(s)}{R(s)}$. $\left|\frac{Y(j\omega)}{W(j\omega)}\right|$ is low as $W(j\omega)$ ~~has a~~ is associated with higher frequencies.

this is large

Robustness

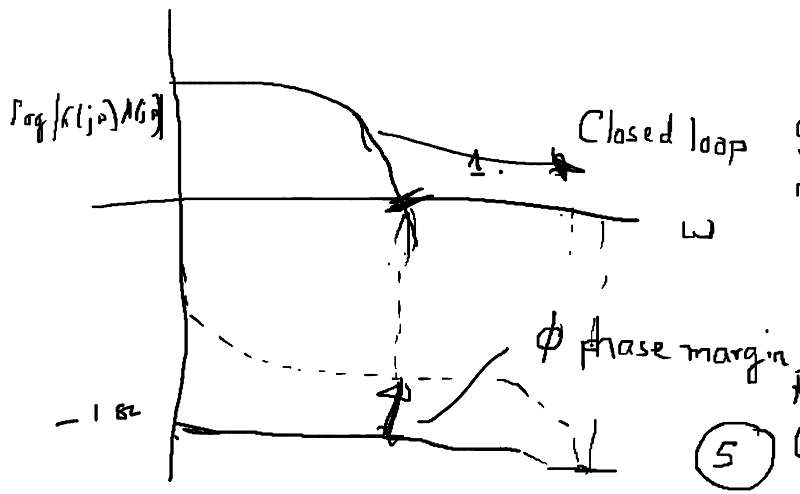
We have designed $G(j\omega)H(j\omega)$ to be a low pass filter.

Thus, as $\omega\uparrow$ $|G(j\omega)H(j\omega)|\downarrow$. What happens to the phase? i.e. $\angle G(j\omega)H(j\omega)$?

$$\frac{\boxed{K}}{1+j\omega T}$$

$$1+G(j\omega)H(j\omega)$$

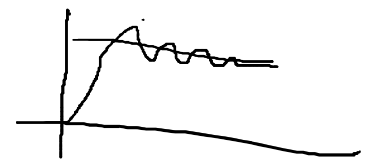
$$1 \quad -1+j0$$



K ~~20~~ $20\log_{10}(K)$ $1\angle -\phi$

System should have good GM and PM

The controller characteristics should remain ~~constant over~~ same over an interval of parameter variations.



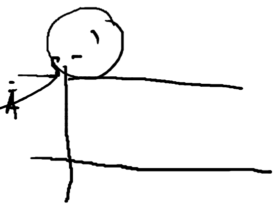
Resilience

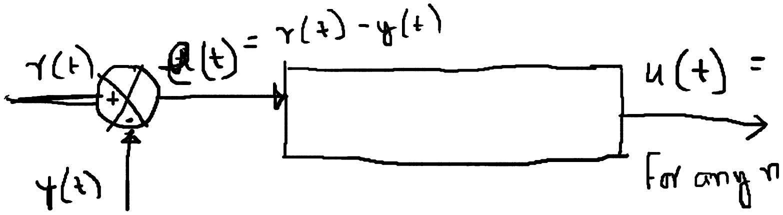
5 Controller

A PID controller. : ~~We re~~ $H(s) = K_p + \frac{K_i}{s} + K_D\, s$

$-1 \to s^{-1}$

$u_{-1}(t) = \frac{1}{s}$





$u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt \;\; K_D \frac{de(t)}{dt}$

For any natural system, let's say $r(t) = A u_{-1}(t)$. $A u_{-1}(t) = A$ for $t \geq 0$

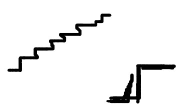
At $t=0$, what is $u(t)$? System has a delay.

So in the worst case $e(t) = r(t)$ and $\frac{de(t)}{dt}$ is very ~~the~~ large at $t=0$. $K_D \frac{de(t)}{dt}$ is called the derivative kick.

$\to$ Integral windup.

A High integral gain ~~=~~ causing actuator saturation

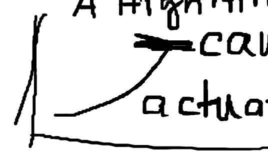
$K_i \int \underline{e(t)}\, dt$



$T_i = \frac{1}{K_i}$ $K_i = \frac{1}{1} \times \frac{1}{K_p T_i}$

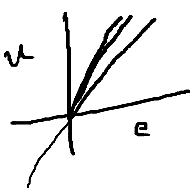
$T_D = K_D$

$e(t)$

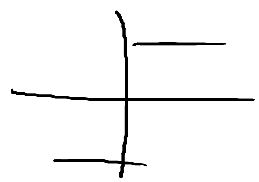


Proportional band.

$\Delta P = \frac{100}{K}\ \%$



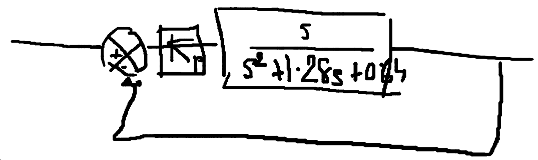
$\Rightarrow$



Bang Bang Control

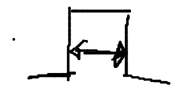
Z-N

$$G_p(s) = \frac{5}{s^2 + 1.28s + 0.64}$$



As k increases, the closed system becomes more and more underdamped.

$$G_c(s) = k_p + \frac{k_i}{s} + k_D s \Rightarrow G_c(s) = \frac{k_p s + k_i + k_D s^2}{s}$$ → High pass filter



$$G_c(s)G_p(s) = \frac{(k_p s + k_i + k_D s^2)}{s} \cdot \frac{5}{s^2 + 1.28s + 0.64}$$