Fall 2022 (111-1)

控制系統 Control Systems

Unit 6K PID Lead-Lag Compensation

Feng-Li Lian NTU-EE Sep 2022 – Dec 2022

PID Compensation

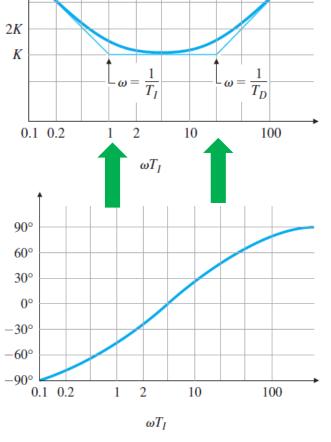
- \triangleright Need PM improvement at ω_c
- ➤ Need low-frequency gain improvement
- A common transfer function:

$$D_c(s) = k_P + \frac{k_I}{s} + k_D s$$

$$D_c(s) = \frac{K}{s} \left[\left(T_D s + 1 \right) \left(s + \frac{1}{T_I} \right) \right]$$

Roughly equivalent to

combining lead and lag compensations referred to as a lead-lag compensator

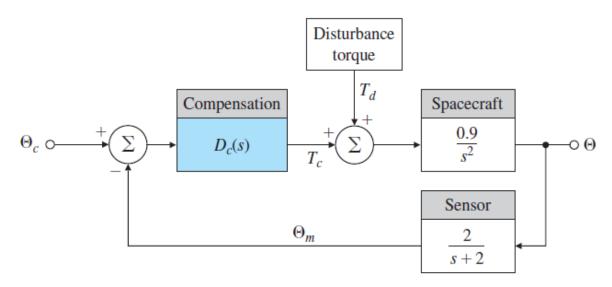


10K

 $|D_c(s)|$

 $\angle D_c(s)$

for Spacecraft Attitude Control



- Design PID controller for:
 - Zero steady-state error
 - $PM = 65^{\circ}$
 - As high a bandwidth as possible
 - Torque disturbance $\omega = 0.001 \text{ rad/sec}$

for Spacecraft Attitude Control

For Final Steady Value

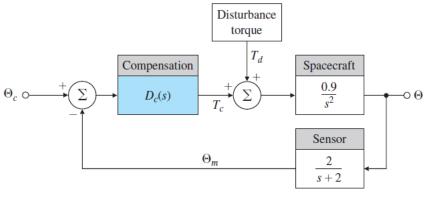
$$\rightarrow T_d + T_c = 0$$

• Therefore, if $T_d = /= 0$

$$\rightarrow$$
 $T_c = - T_d$

• The only way this can be true with no error (e = 0) is: for $D_c(s)$ to contain an integral term.

 $\Theta_{c} \circ \longrightarrow \begin{array}{c} & & & \\$



for Spacecraft Attitude Control 0.9

Compensation for PID design Example 6.20: (a) magnitude.

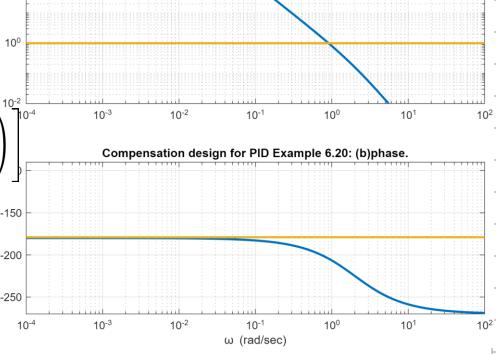
$$G(s) = \frac{1}{s^2}$$

$$H(s) = \frac{2}{s+1}$$

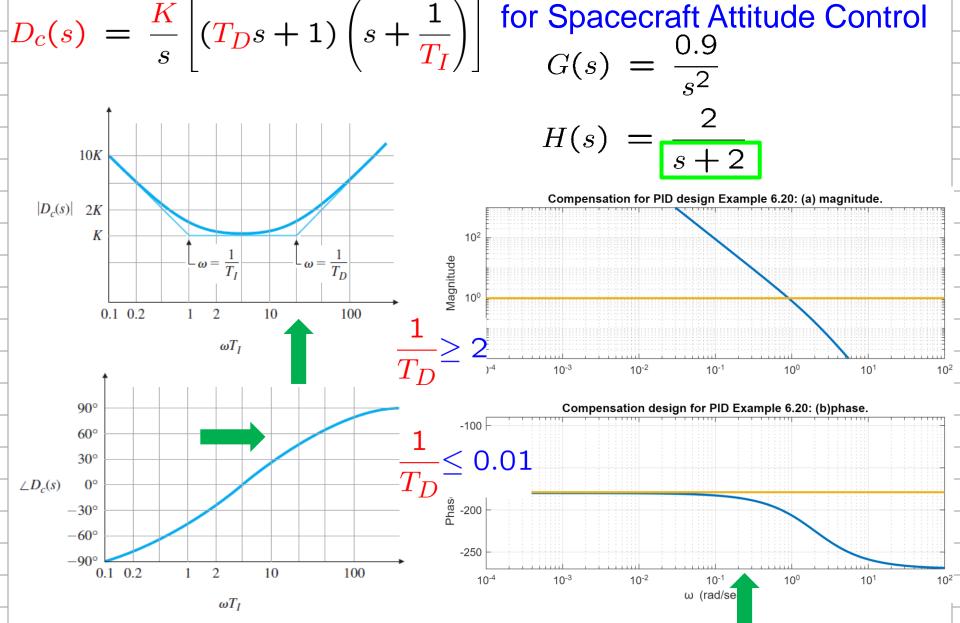
- Frequency Response of GH:
- Unstable

 $D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I}
ight) \right]^{0^{-100}}$ Select: K, T_D , T_I PNA = 650 at high fragraphs r

- PM = 65° at high frequency
 - By adjusting T_D



$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I} \right) \right]$$
 for



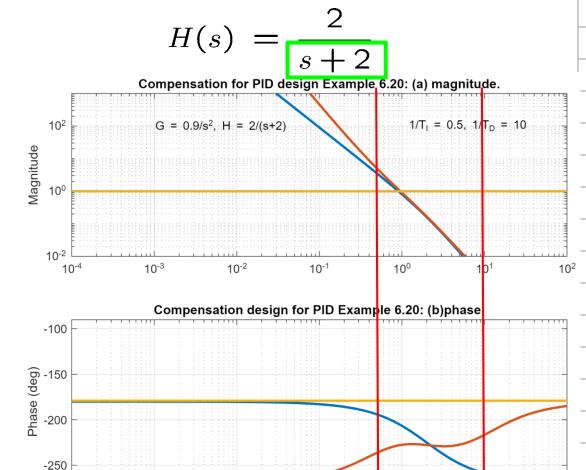
$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I} \right) \right]$$
 for Spacecraft Attitude Control $G(s) = rac{0.9}{s^2}$

$$\frac{1}{T_{I}} = 0.5$$

$$\frac{1}{T_{D}} = 10$$

$$|D_{c}(s)| | |2K| | | |\omega| = \frac{1}{T_{I}} | |\omega| = \frac{1}{T_{D}} | |\omega|$$

 ωT_I



10⁻¹

ω (rad/sec)

10⁰

 10^{2}

10-4

10⁻³

10⁻²

10²

 10^{-2}

-100

-250

10-4

10⁻³

10⁻²

Magnitude

Example 6.20: PID Compensation

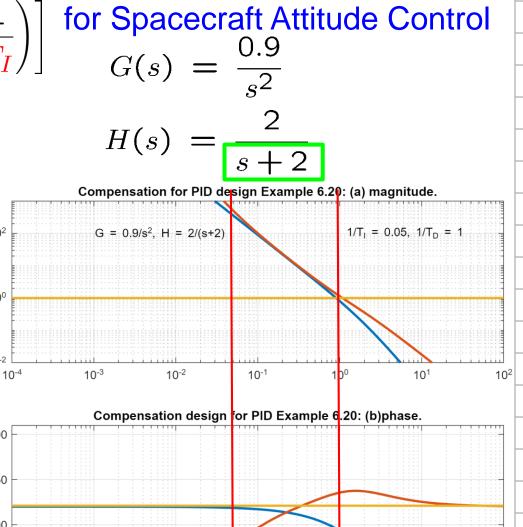
$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I}
ight) \right]$$
 for

$$\frac{1}{T_I} = 0.05$$

$$\frac{1}{T_D} = 1$$

$$\frac{1}{T_D}$$

 ωT_I



10⁻¹

ω (rad/sec)

10⁰

10¹

 10^{2}

Magnitude

Phase (deg)

-200

-250

10-4

10⁻³

10⁻²

Example 6.20: PID Compensation

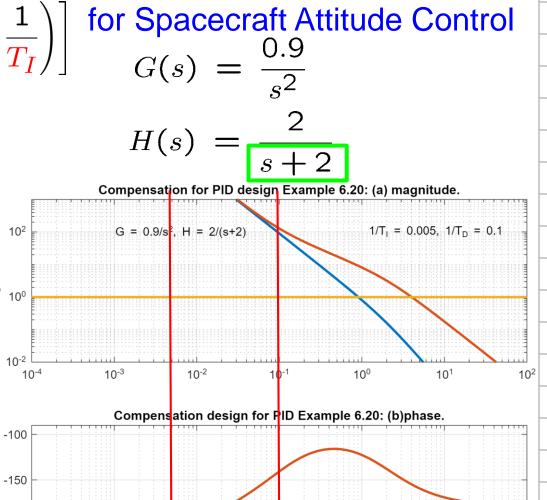
$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I}
ight) \right]$$
 fo

$$\frac{1}{T_{I}} = 0.005$$

$$\frac{1}{T_{D}} = 0.1$$

$$\frac{$$

 ωT_I



10⁻¹

ω (rad/sec)

10⁰

10¹

 10^{2}

CS6K-PIDLeadLag - 10

$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I}
ight) \right]$$
 for Spacecraft Attitude Control $G(s) = rac{0.9}{s^2}$

Aagnitude

10-4

-100

-150

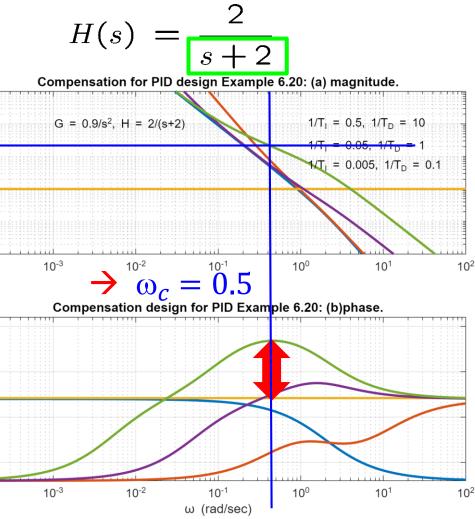
-200

-250

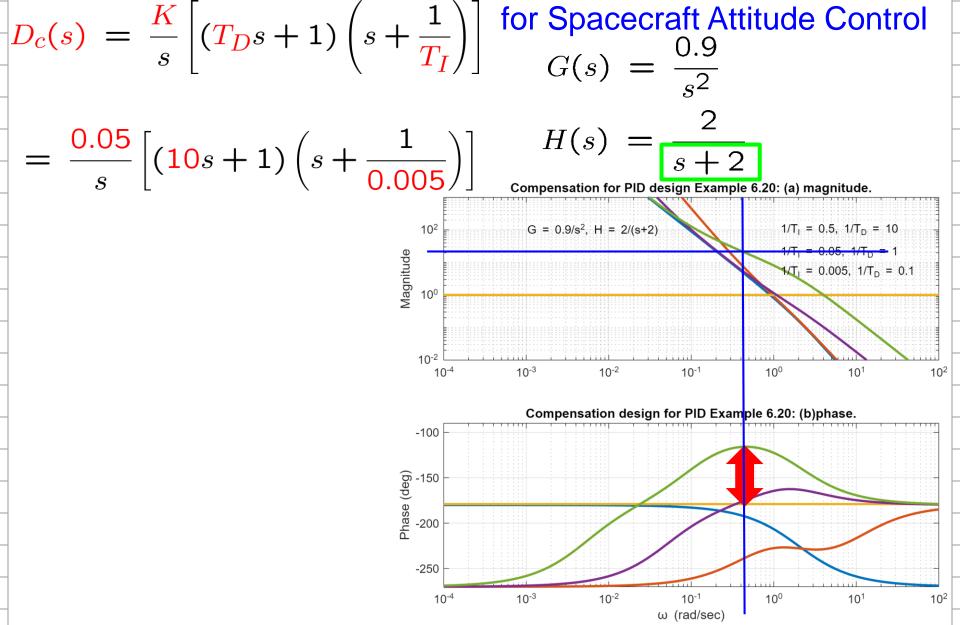
 10^{-4}

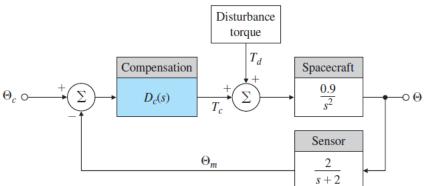
Phase (deg)

$$\frac{1}{T_I} = 0.5$$
 $\frac{1}{T_D} = 10$ $\frac{1}{T_I} = 0.05$ $\frac{1}{T_D} = 1$ $\frac{1}{T_D} = 0.005$ $\frac{1}{T_D} = 0.1$



$$D_c(s) = rac{K}{s} \left[(T_D s + 1) \left(s + rac{1}{T_I}
ight) \right]$$
 for

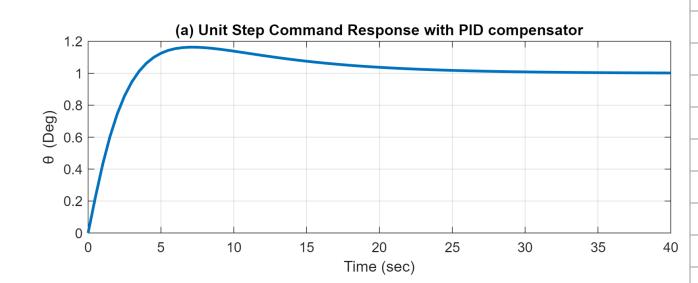




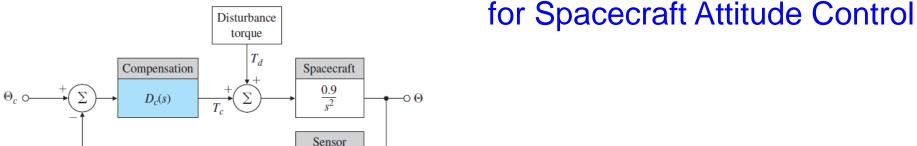
for Spacecraft Attitude Control

Response of the system for a unit step θ_{com} is found from:

$$\mathcal{T}(s) = \frac{\Theta}{\Theta_{com}} = \frac{D_c G}{1 + D_c G H}$$



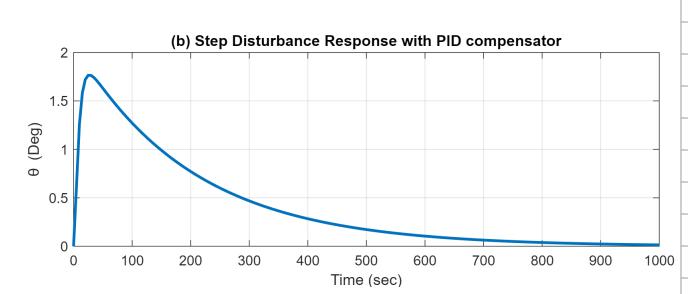
 Θ_m

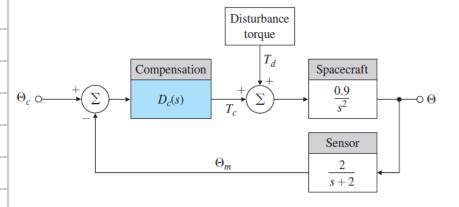


s+2

Response for a step disturbance torque of T_d is found from:

$$\frac{\Theta}{T_d} = \frac{G}{1 + D_c G H}$$





for Spacecraft Attitude Control

Frequency Response of
T(s) and S(s) are shown:

