DID Control on Liquid Transportation System

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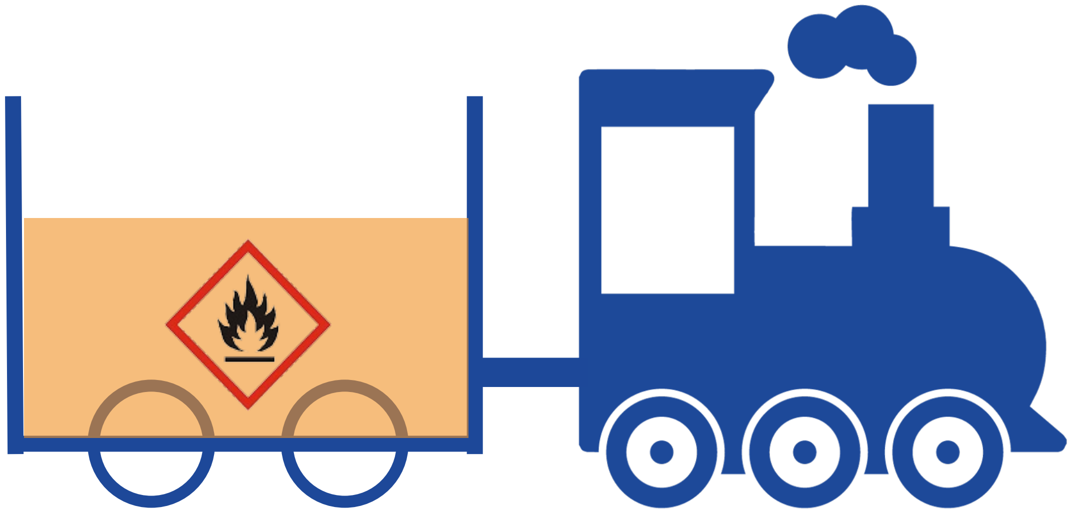
Abstract

- Problem Description
- Disturbance Input Decoupling (DID)
- Model Formulation
- Theoretical Solution
- Simulink Simulation
- Effect of DID
- Conclusion
- Reference

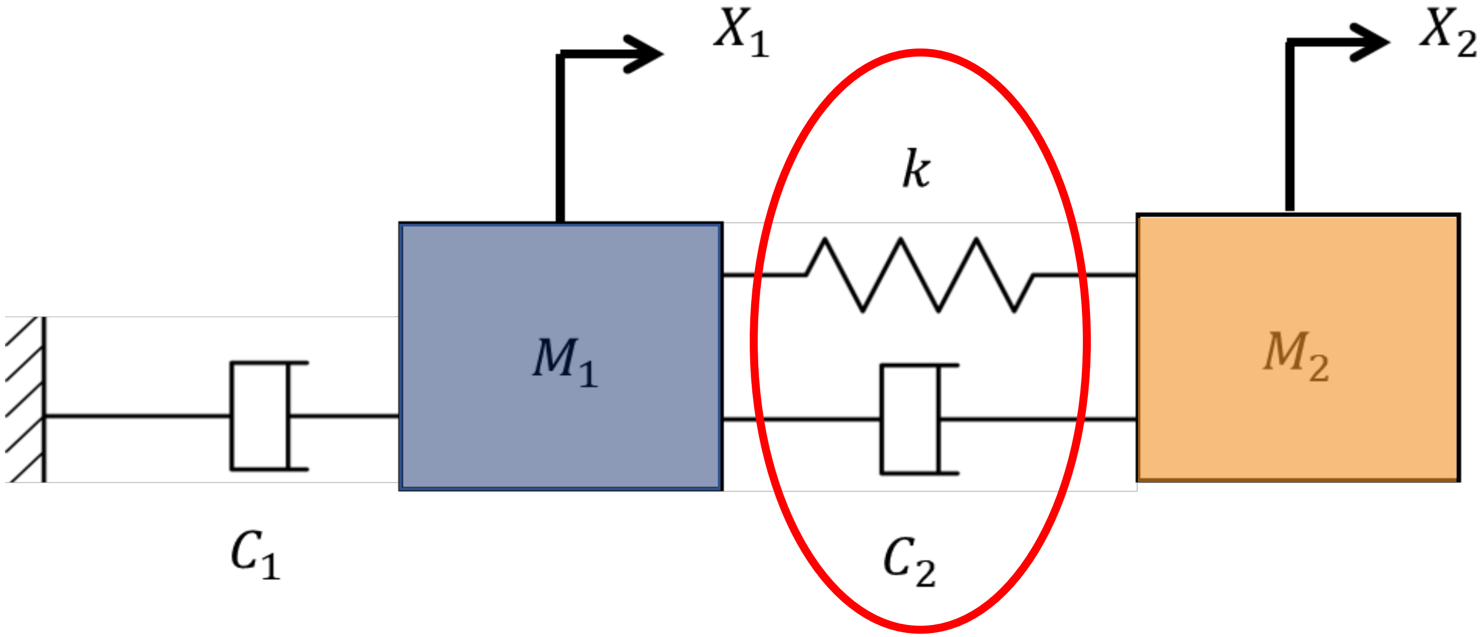
Problem Description

Problem Description

- The train is transferring a dangerous liquid (ex: Nitroglycerin)
- The liquid cannot resist severe wobble and should not spill over
- The train start driving in a constant acceleration of 9.81 m/s^2 and maintain at the velocity 41.667 m/s (150 km/hr)
- The mechanical property of the liquid is unknown
- Assume the road is flat



MCK System



C_2 , k unknown

Disturbance Input Decoupling (DID)

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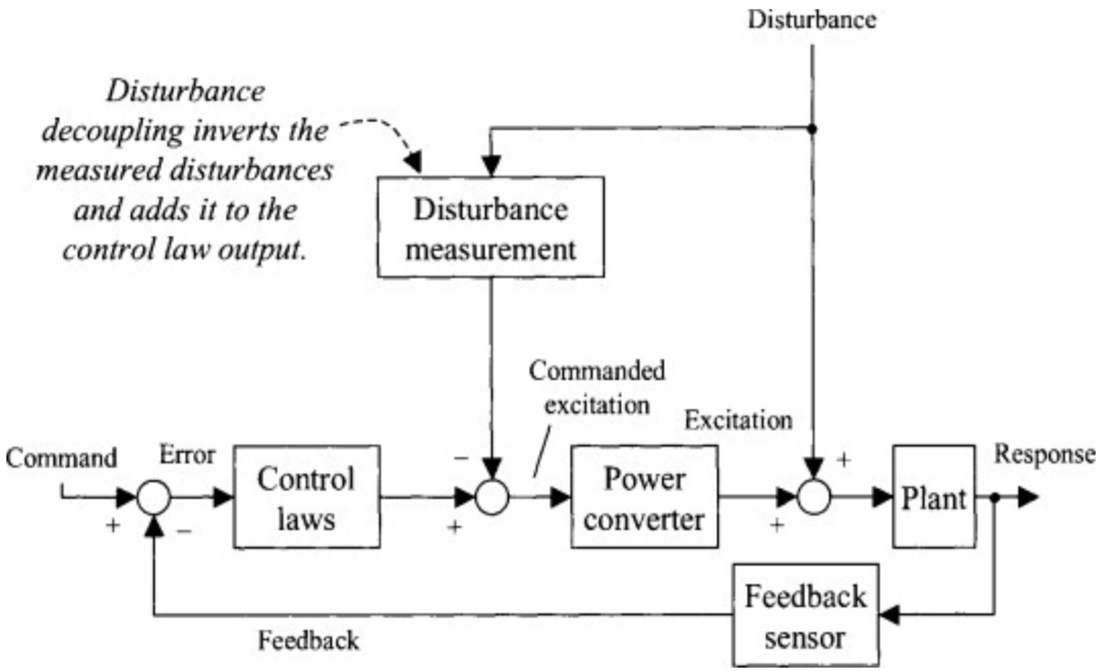
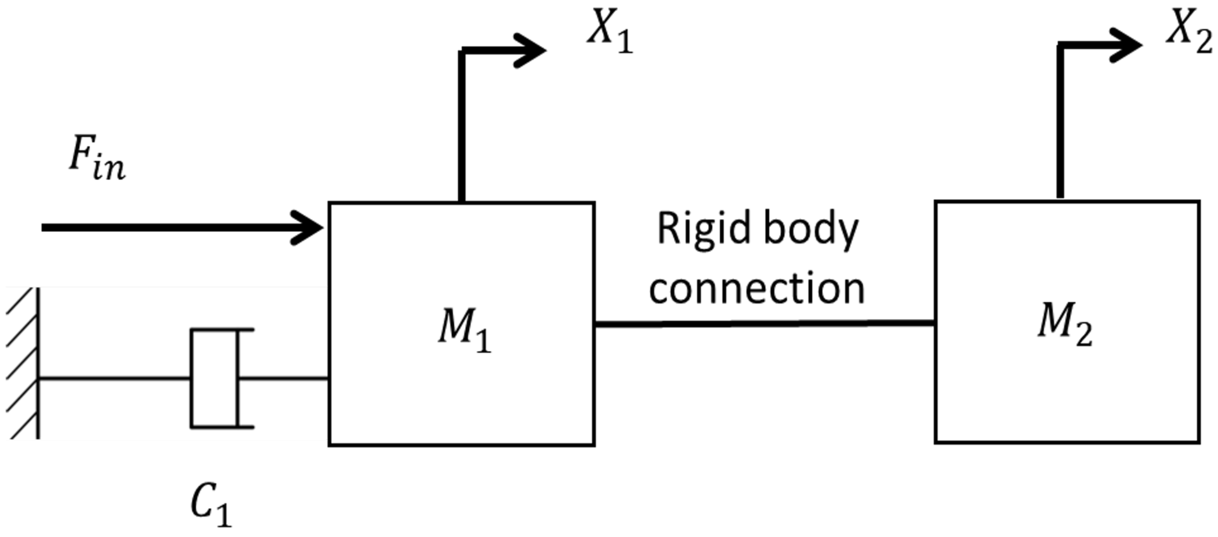
- Disturbance input decoupling is a cancellation technique where the disturbance is fed to the controller output in opposition to the effect of the disturbance.
- The disturbance must be measurable
- Improve, but not eliminate, response to disturbances.



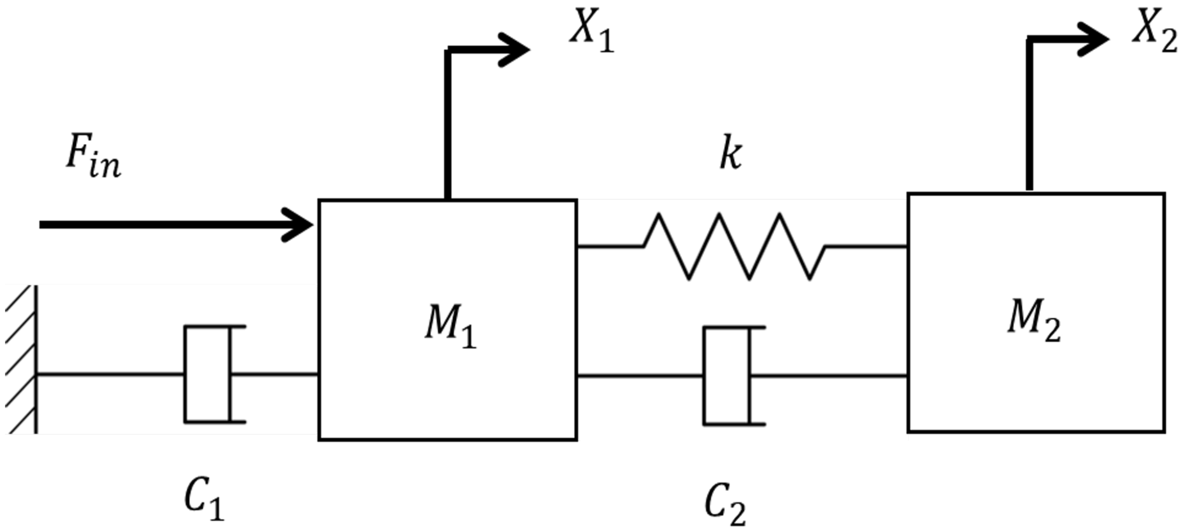
Model Formulation

Decoupling Concept



Traditionnal PI Contorller design

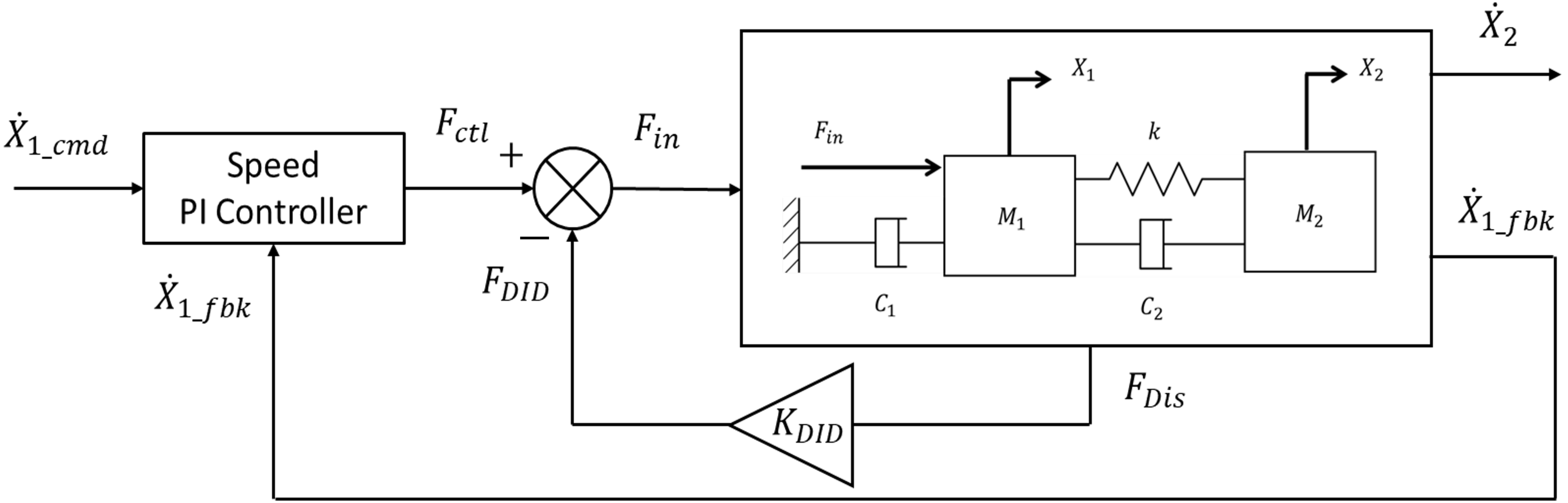
$$K_p = \omega_{BW}(M_1 + M_2)$$
$$K_i = \omega_{BW}\, C_1$$
$$\frac{\dot{X}_2}{\dot{X}_2^*} = \frac{\omega_{BW}}{s + \omega_{BW}}$$



Traditionnal PI Contorller design

$$F_{m_1 - m_2} = \left(\ddot{X}_2 - \ddot{X}_1\right) M_2$$
$$F_{Dis} = \left(\ddot{X}_2 - \ddot{X}_1\right) M_1$$
$$F_{DID} = K_{DID} F_{Dis}$$
$$F_{in} = F_{ctl} + F_{DID}$$

Block Diagram



Parameters & Variables

Parameters

$M_1 = 38000\ kg$ (EMU3000)

$M_2 = \alpha_{mass} M_1\ kg$

$K_p = \omega_{BW}(M_1 + M_2)$

$K_i = \ \omega_{BW}\ C_1$

$C_1 = 0.4\ M_1\ \ N\times s/m$

$C_2 = 0.01\ M_2\ \ N\times s/m$

$k = 10M_1 \frac{N}{m}$

$K_{DID} = 0.9$

Variables

$\alpha_{mass} = 0.01, 0.1, 1, 10$

$\omega_{BW} = 1, 10, 100\ Hz$

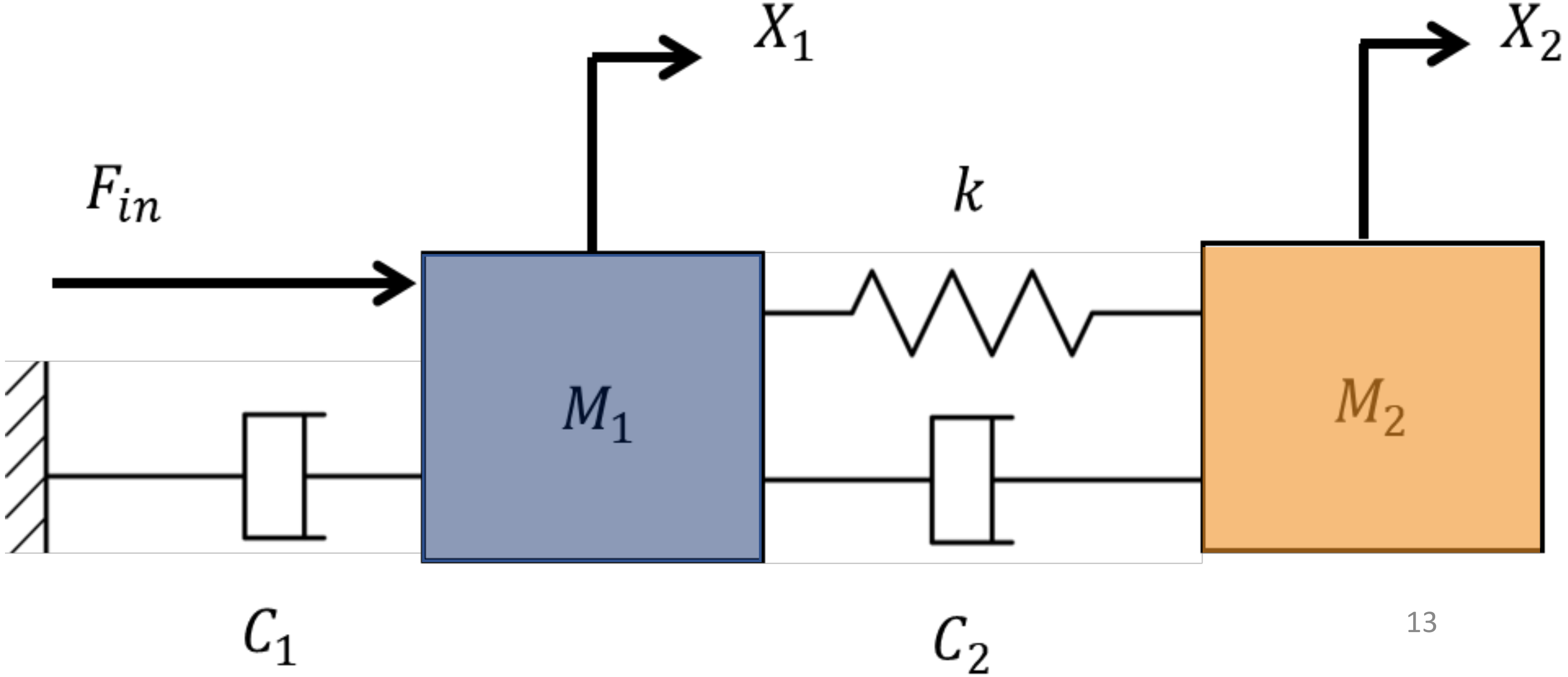
Theoretical Solution

Theoretical Solution

$$M_1\ddot{x}_1(t) = -C_1\dot{x}_1(t) + k\big(x_2(t) - x_1(t)\big) + C_2\big(\dot{x}_2(t) - \dot{x}_1(t)\big) + f_{in}(t)$$

$$M_2\ddot{x}_2(t) = -k(x_2(t) - x_1(t)) - C_2(\dot{x}_2(t) - \dot{x}_1(t))$$

$$f_{in}(t) = K_p\left(\dot{x}_1^{*}(t) - \dot{x}_1(t)\right) + \int K_I\left(\dot{x}_1^{*}(t) - \dot{x}(t)\right)dt + 0.9 * M_1\big(\ddot{x}_1(t) - \ddot{x}_2(t)\big)$$



Theoretical Solution

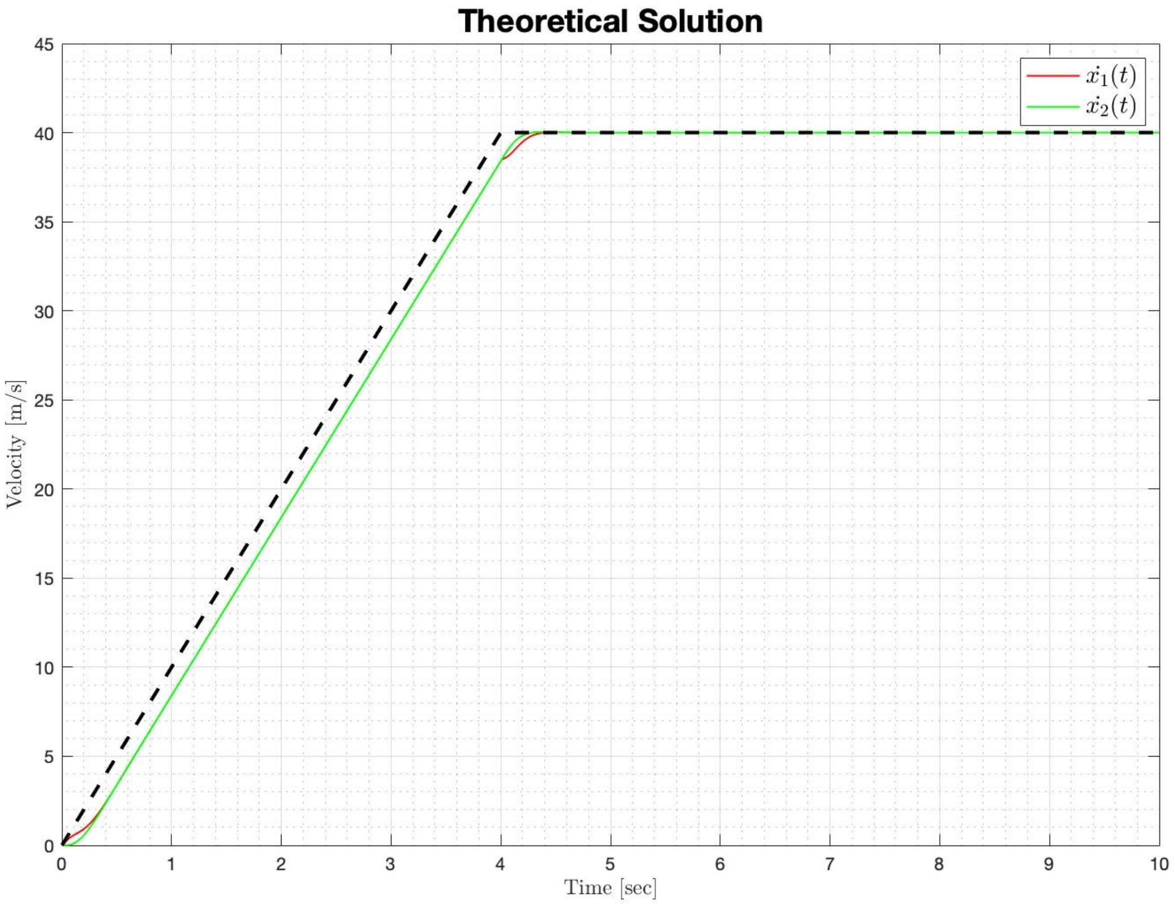
$$\begin{cases} M_1 X_1(S)s^2 = -C_1 X_1(s)s + k\big(X_2(s) - X_1(s)\big) + C_2 s(X_2(s) - X_1(s)) + F_{in}(s) \\ M_2 X_2(s)s^2 = -k(X_2(s) - X_1(s)) - C_2 s(X_2(s) - X_1(s)) \\ F_{in}(s) = \big(K_p s + K_I\big)\big(X_1^*(s) - X_1(s)\big) + 0.9 * M_1 s^2 (X_1(s) - X_2(s)) \end{cases}$$

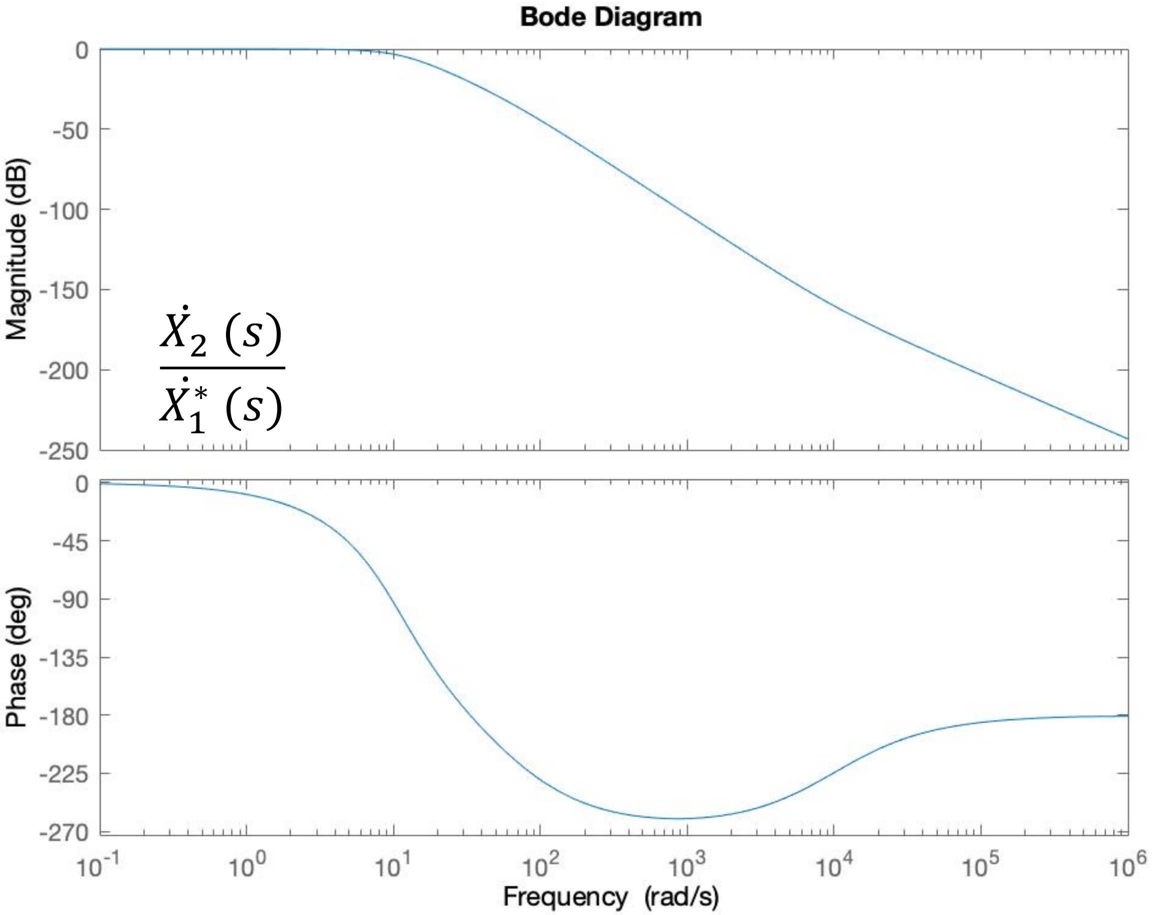
$$\frac{\dot{X}_1\ (s)}{\dot{X}_1^*\ (s)} = \frac{M_2 K_p s^3 + \big(M_2 K_I + C_2 K_p\big)s^2 + \big(C_2 K_I + kK_p\big)s + kK_I}{as^4 + bs^3 + cs^2 + ds + e}$$

$$\frac{\dot{X}_2\ (s)}{\dot{X}_1^*\ (s)} = \frac{K_p C_2 s^2 + \big(K_p k + K_I C_2\big)s + K_I k}{as^4 + bs^3 + cs^2 + ds + e}$$

$a = 0.1M_1 M_2$
$b = M_1 C_2 + M_2 C_1 + M_2 C_2 + M_2 K_p$
$c = M_1 k + C_1 C_2 + M_2 k + C_2 K_p + M_2 K_I$
$d = C_1 k + K_p k + K_I C_2$
$e = kK_i$

Theoretical Result

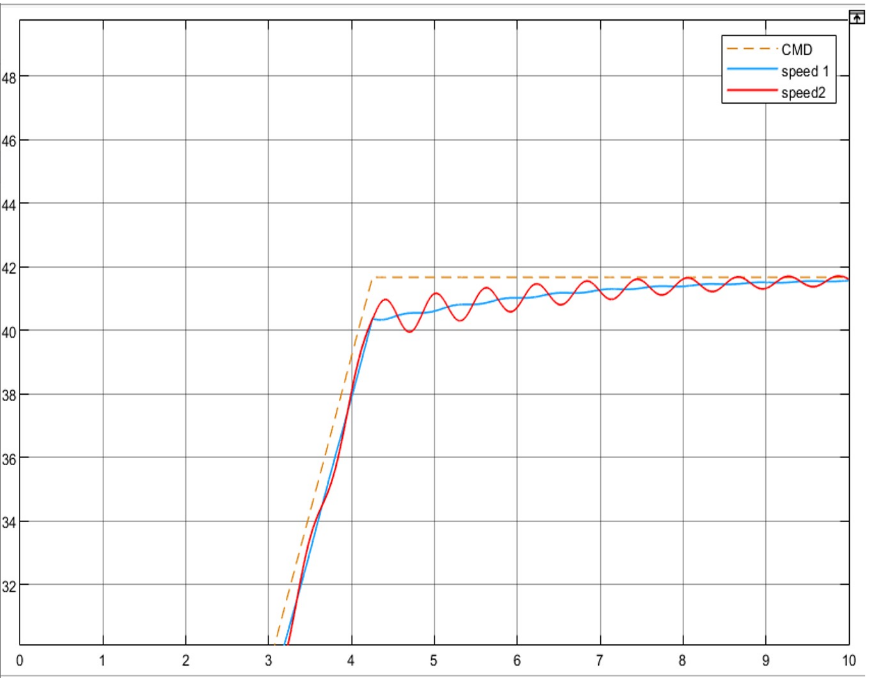


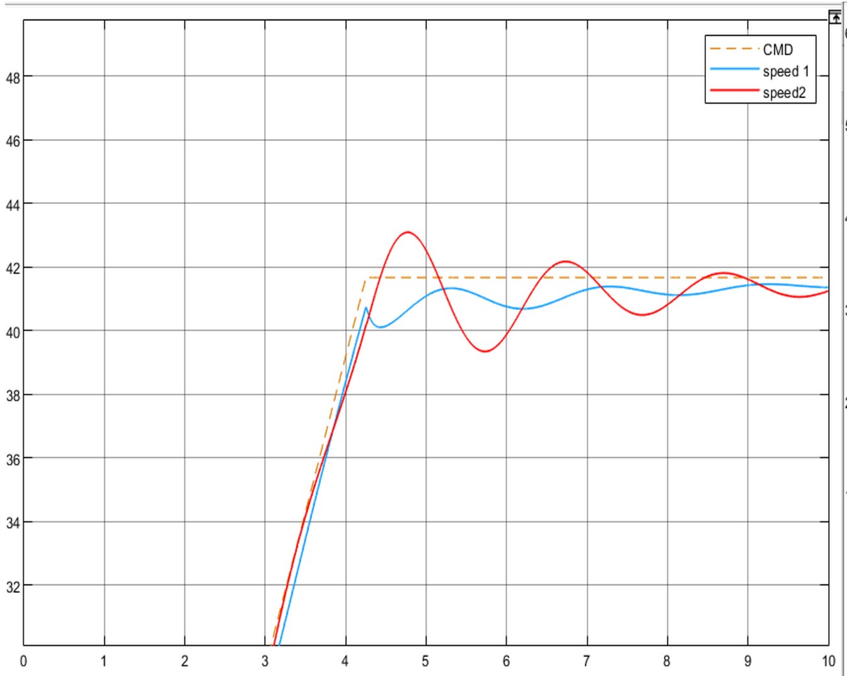


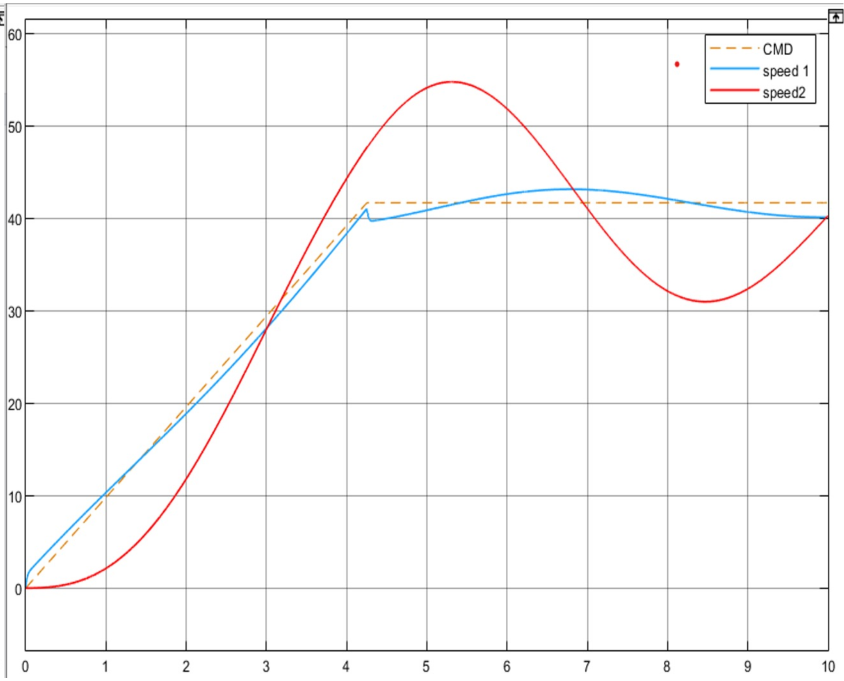
$$pole = -56.4, -8.6413 \pm 6.9056i, -0.4545 \Rightarrow Stable$$

Simulink Simulation

Time domain response with different α_{mass}







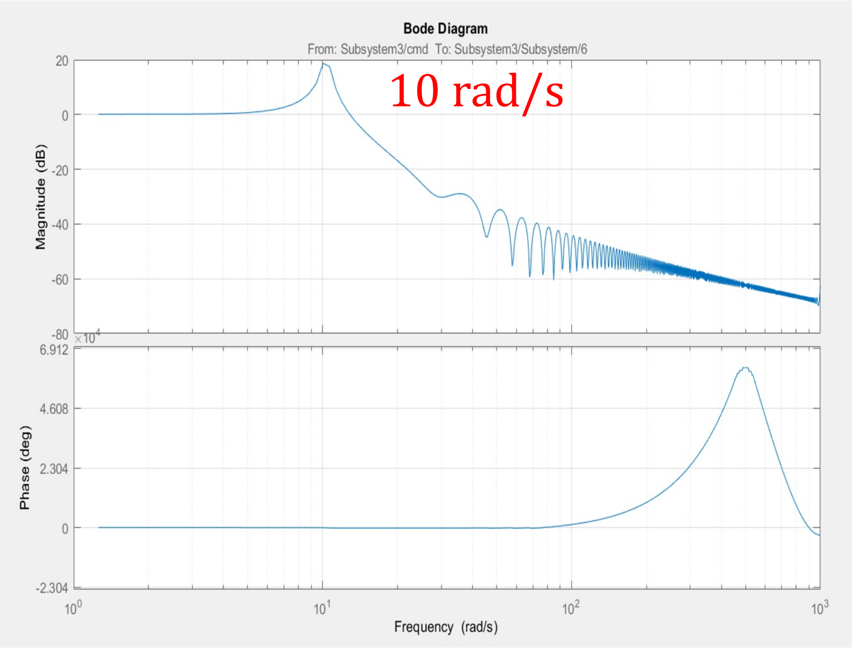
α_{mass} = 0.1
ω_{BW} = 1 Hz

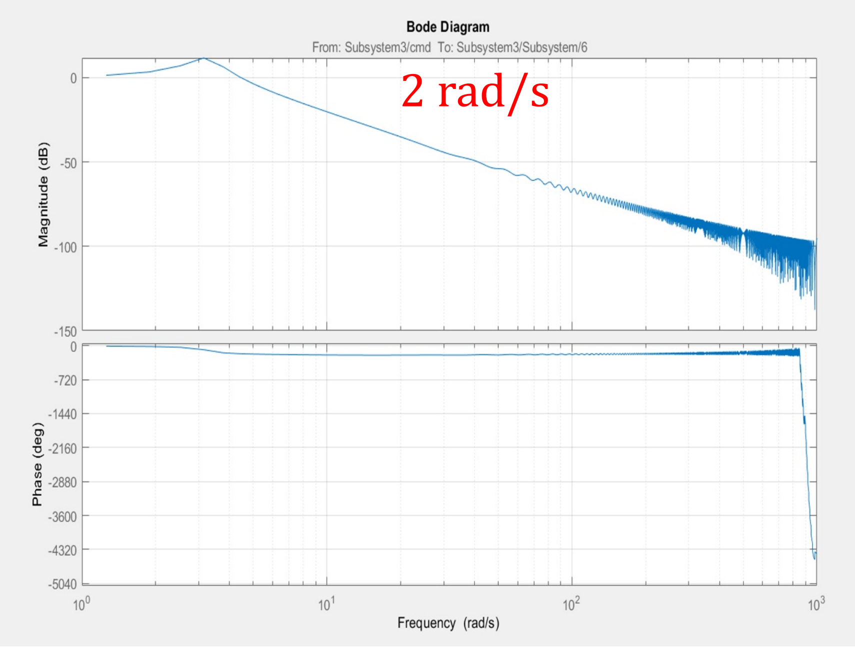
α_{mass} = 1
ω_{BW} = 1 Hz

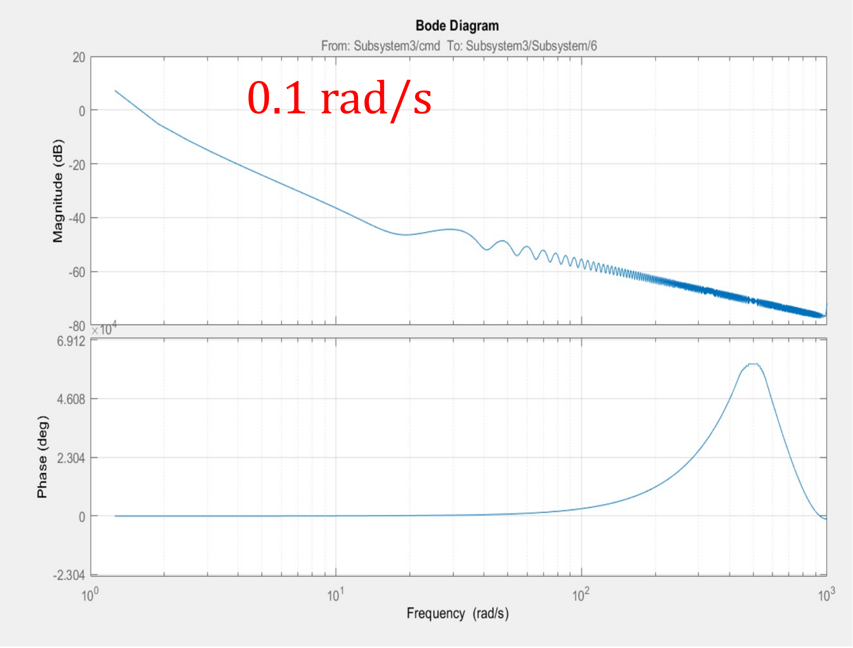
α_{mass} = 10
ω_{BW} = 1 Hz

Mass ratio higher => System resonance frequency gets lower (Since K is fixed)

Frequency response with different α_{mass}







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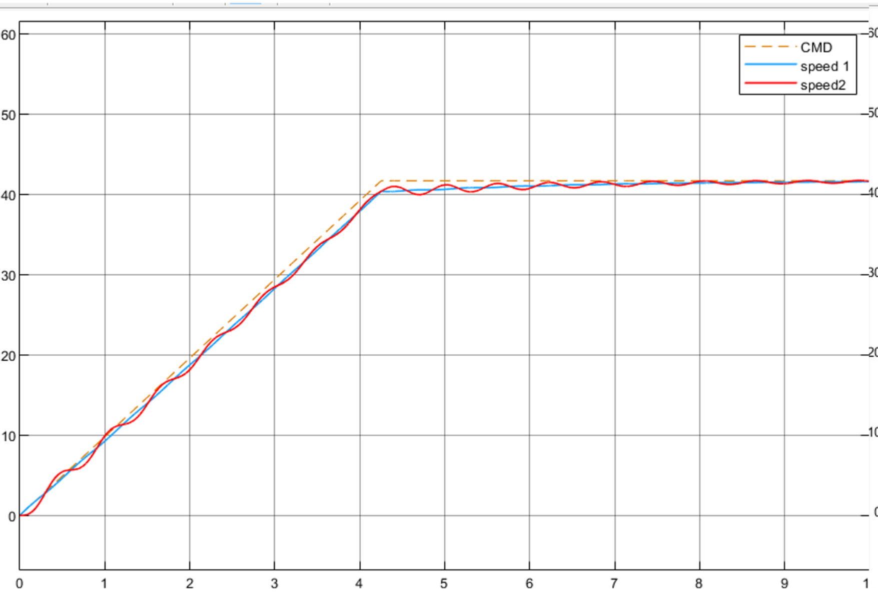
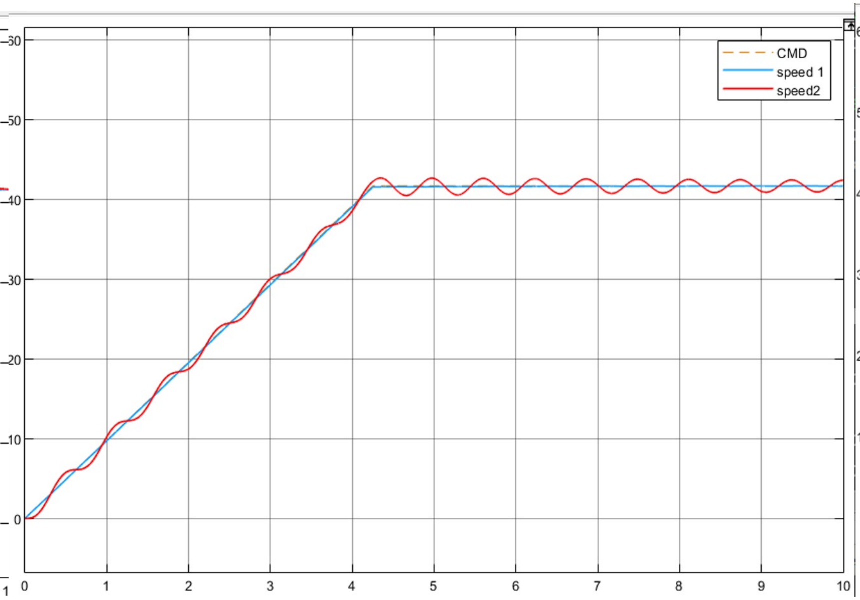
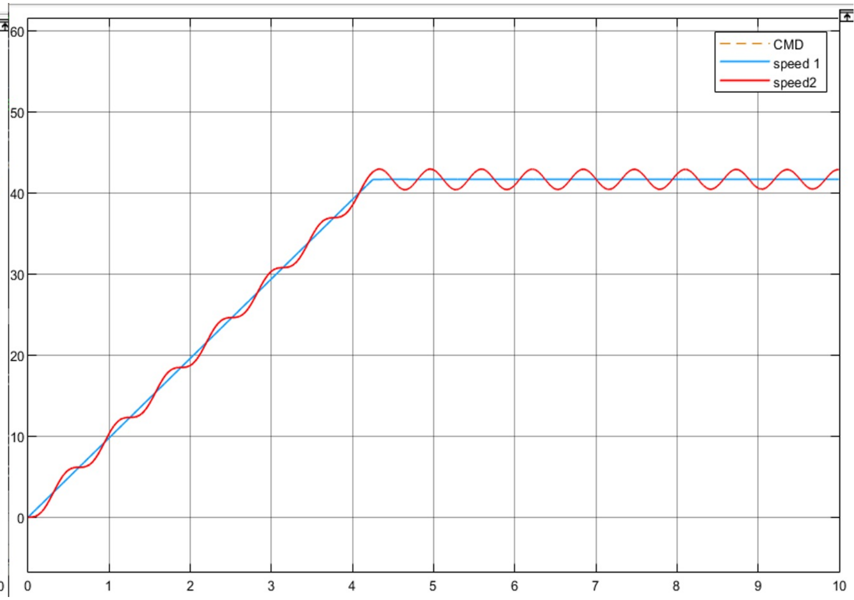
Time domain response with different ω_{BW}







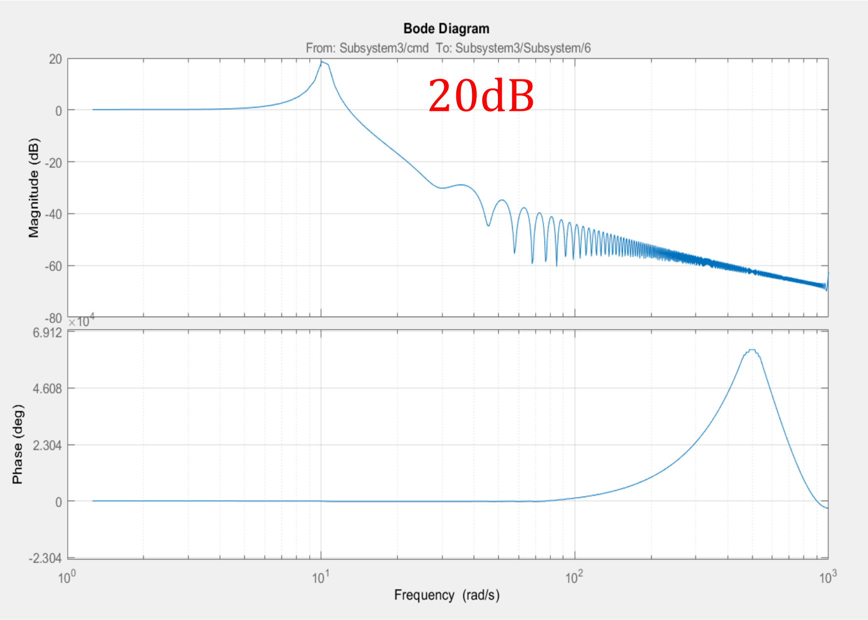
ω_{BW} = 1 Hz
α_{mass} = 0.1

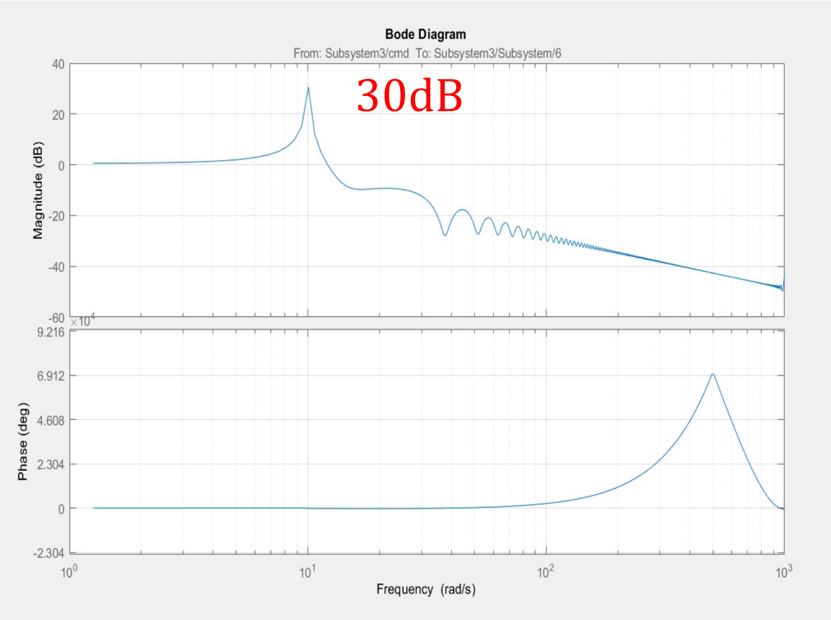
ω_{BW} = 10 Hz
α_{mass} = 0.1

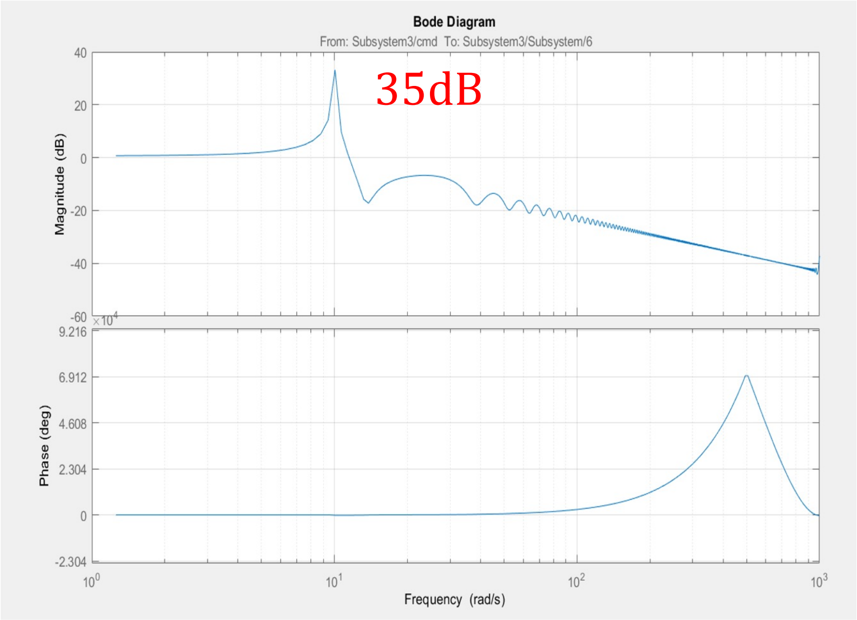
ω_{BW} = 100 Hz
α_{mass} = 0.1

Mass ratio higher => System resonance frequency gets lower (Since K is fixed)

Frequency response with different ω_{BW}







ω_{BW} = 1 Hz
α_{mass} = 0.1

ω_{BW} = 10 Hz
α_{mass} = 0.1

ω_{BW} = 100 Hz
α_{mass} = 0.1

Bandwidth higher => System resonance peak gain higher

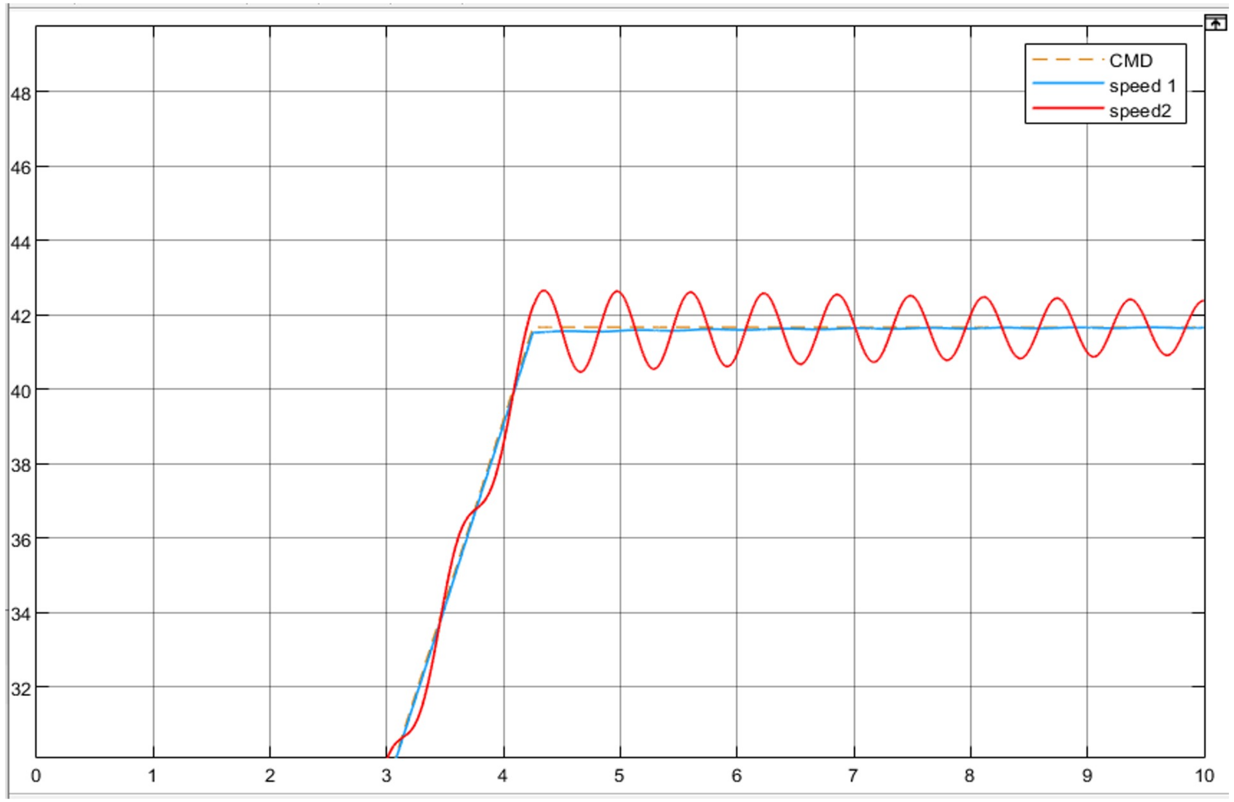
Effect of ω_{BW} & α_{mass} on overshoot (w/o DID)

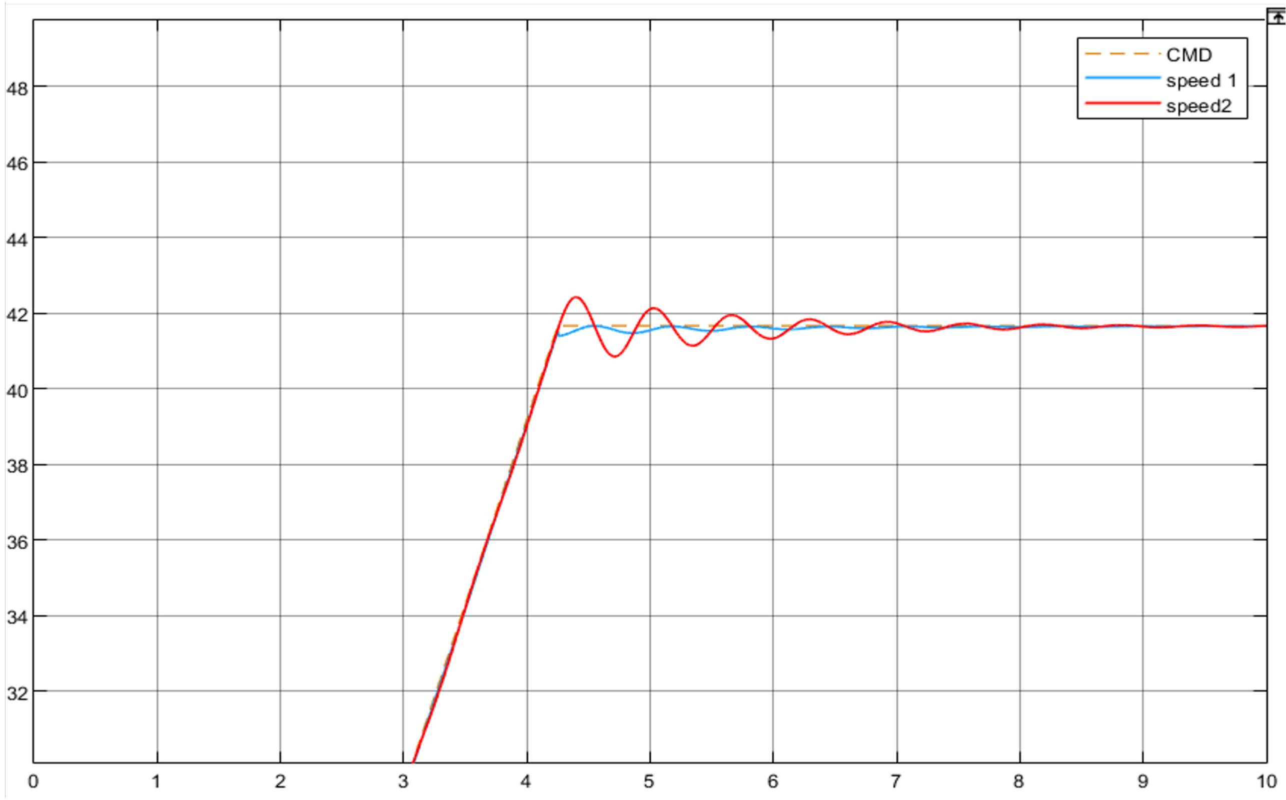
α_{mass} / ω_{BW}	0.01	0.1	1	10
1 Hz	-2%	-1.7%	3.4%	31.3%
10 Hz	0.9%	2.4%	5.4%	38.4%
100 Hz	1.3%	3%	6.1%	39.3%

Mass Ratio larger, Bandwidth larger => Overshoot larger

Effect of DID

Attenuation of oscillation will be faster



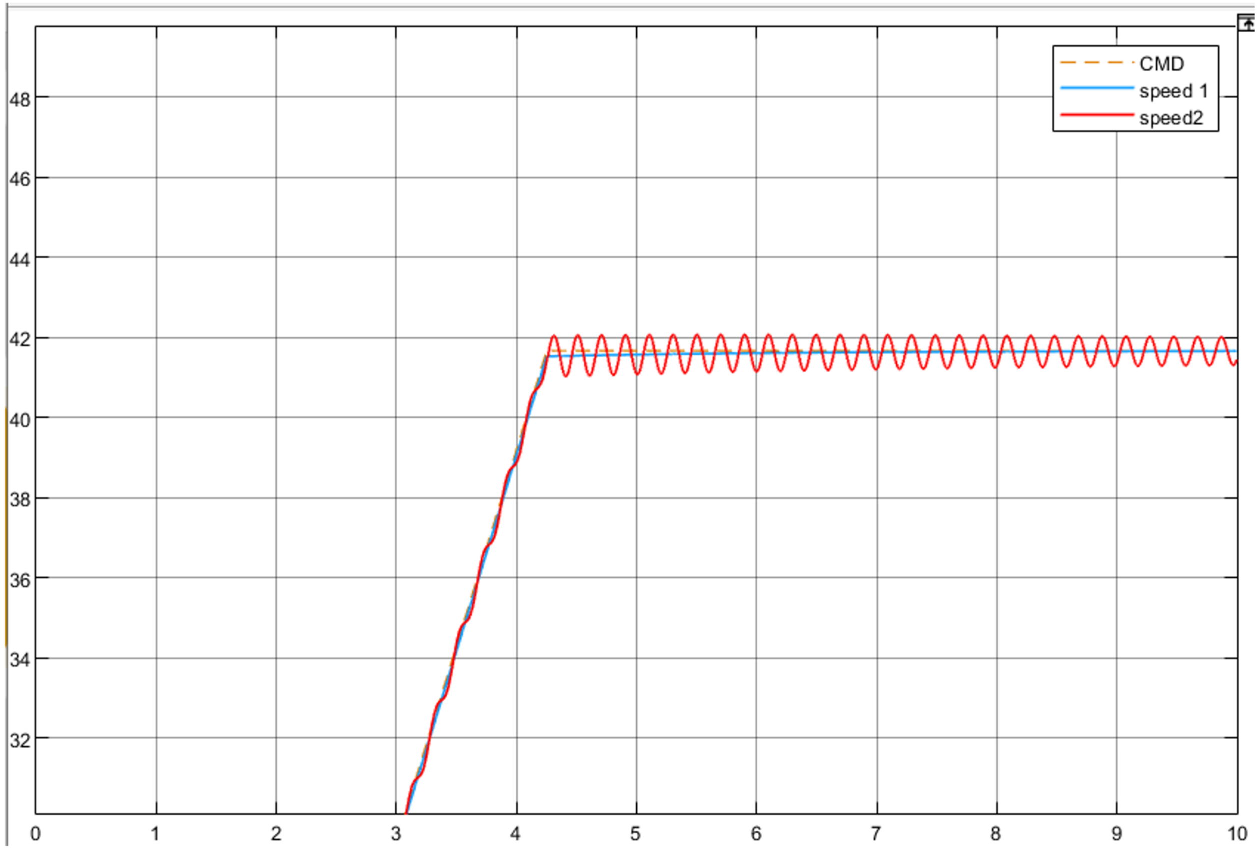


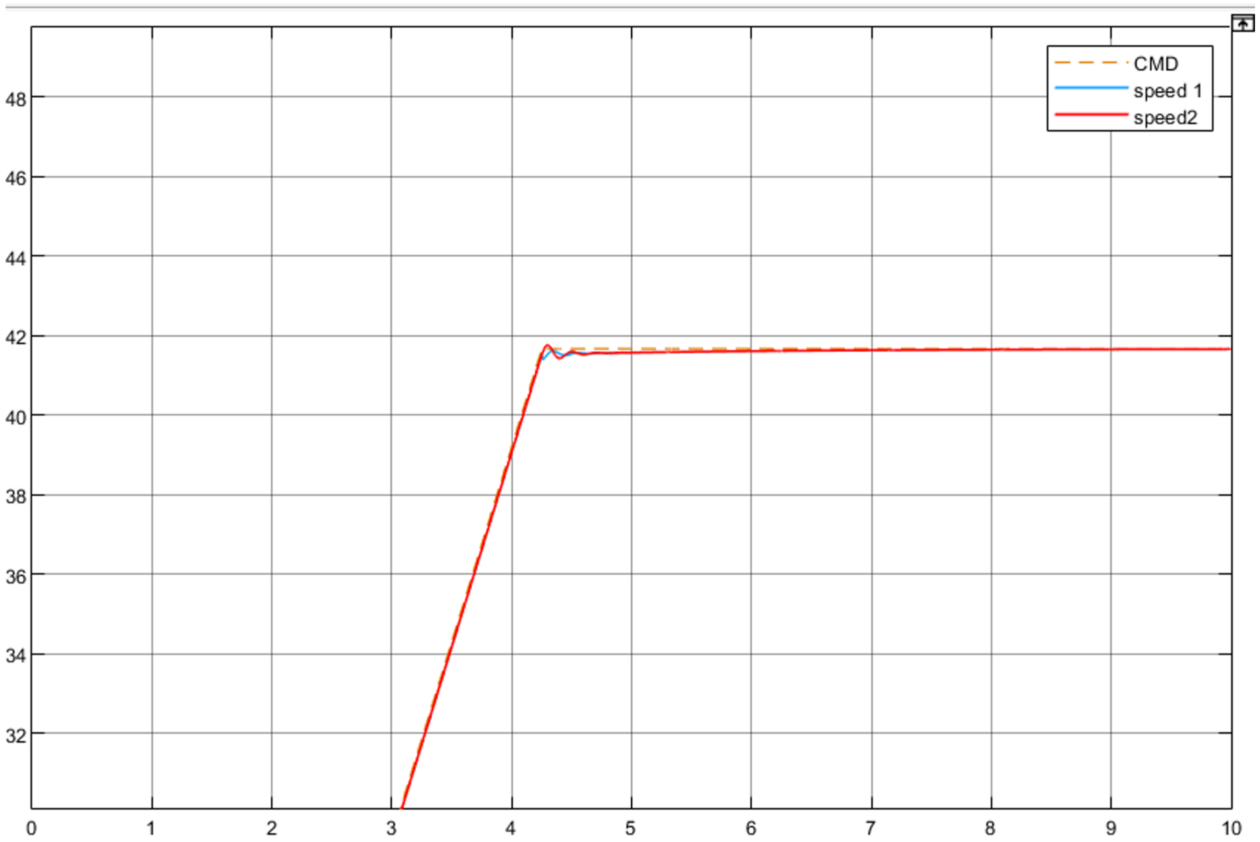
w/o DID

ω_{BW} = 10 Hz
α_{mass} = 0.1

with DID

Attenuation of oscillation will be faster

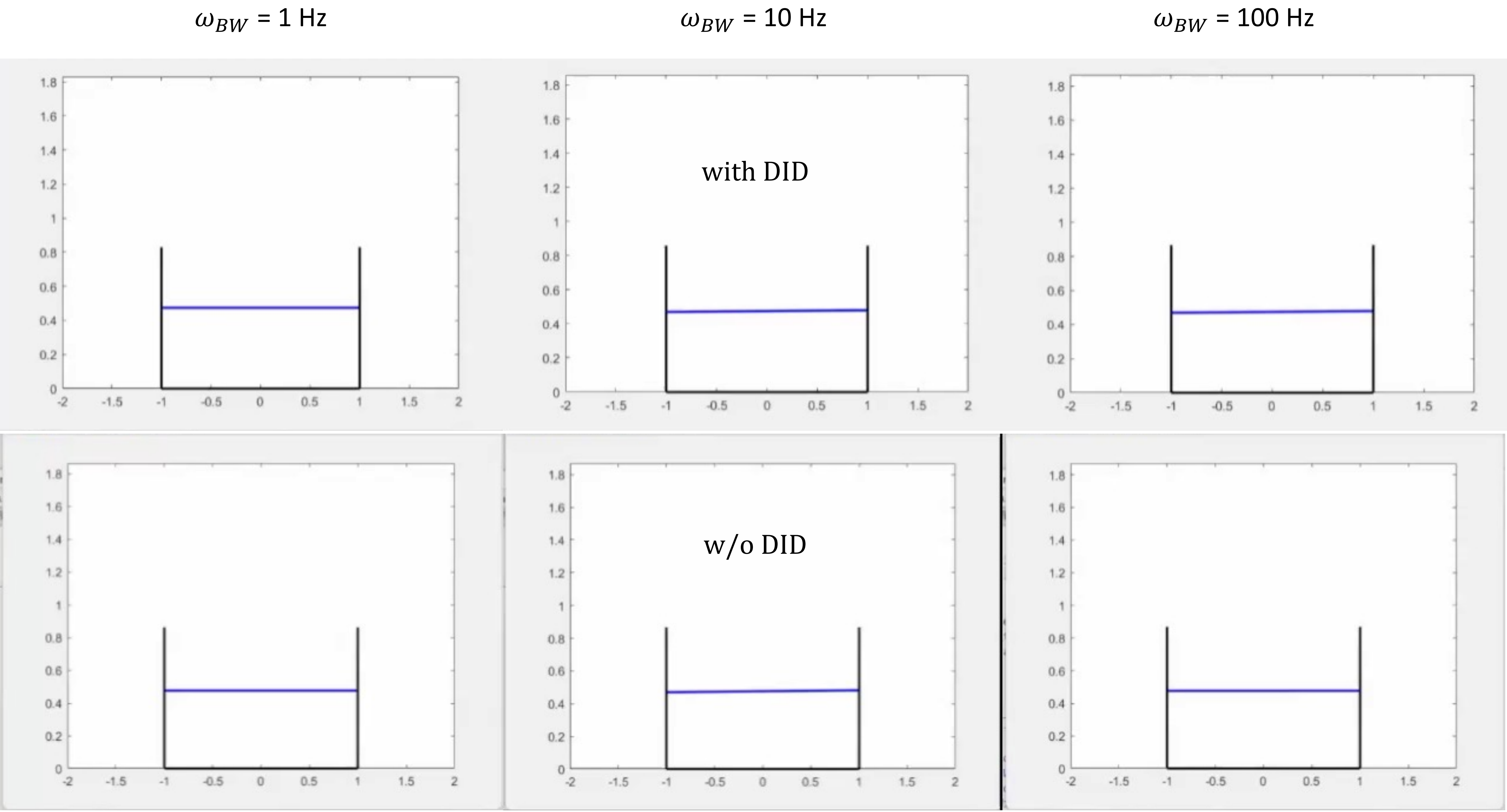




w/o DID

ω_{BW} = 10 Hz
α_{mass} = 0.01

with DID



ω_{BW} = 1 Hz
ω_{BW} = 10 Hz
ω_{BW} = 100 Hz
with DID
w/o DID

Comparison on Overshoot

ω_{BW} \ α_{mass}	0.01	0.1	1	10
1 Hz	-2%	-1.7%	3.4%	31.3%
10 Hz	0.9%	2.4%	5.4%	38.4%
100 Hz	1.3%	3%	6.1%	39.3%

w/o DID

ω_{BW} \ α_{mass}	0.01	0.1	1	10
1 Hz	-4%	-2%	2.7%	30.8%
10 Hz	0.2%	1.8%	2.8%	38.3%
100 Hz	0.7%	2.7%	6%	39.2%

with DID

Mass Ratio larger, Bandwidth larger => Overshoot larger

Conclusion

Conclusion

- ➢ When mass ratio is high, the influence of bandwidth is small, but hard to control
- ➢ Mass Ratio higher, Bandwidth larger

  => Overshoot larger, System resonance frequency lower
- ➢ With DID control, most of the cases can improve the percentages of overshooting and settling time.
- ➢ K_{DID} is an important variable for system design.
  - When $K_{DID} = 1$, M_1 is uncontrollable
  - When $K_{DID} < 1$, larger K_{DID} gives a better performance.

Reference

Ryan, M. J., Brumsickle, W. E., & Lorenz, R. D. (n.d.). Control topology options for single-phase ups inverters. *Proceedings of International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth*. https://doi.org/10.1109/pedes.1996.539673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ATTENTION