# HOMEWORK 2

# INTERACTIVE MEDICAL ROBOTICS
# ROB-GY 6423


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**Question 1**

**Paper 1**

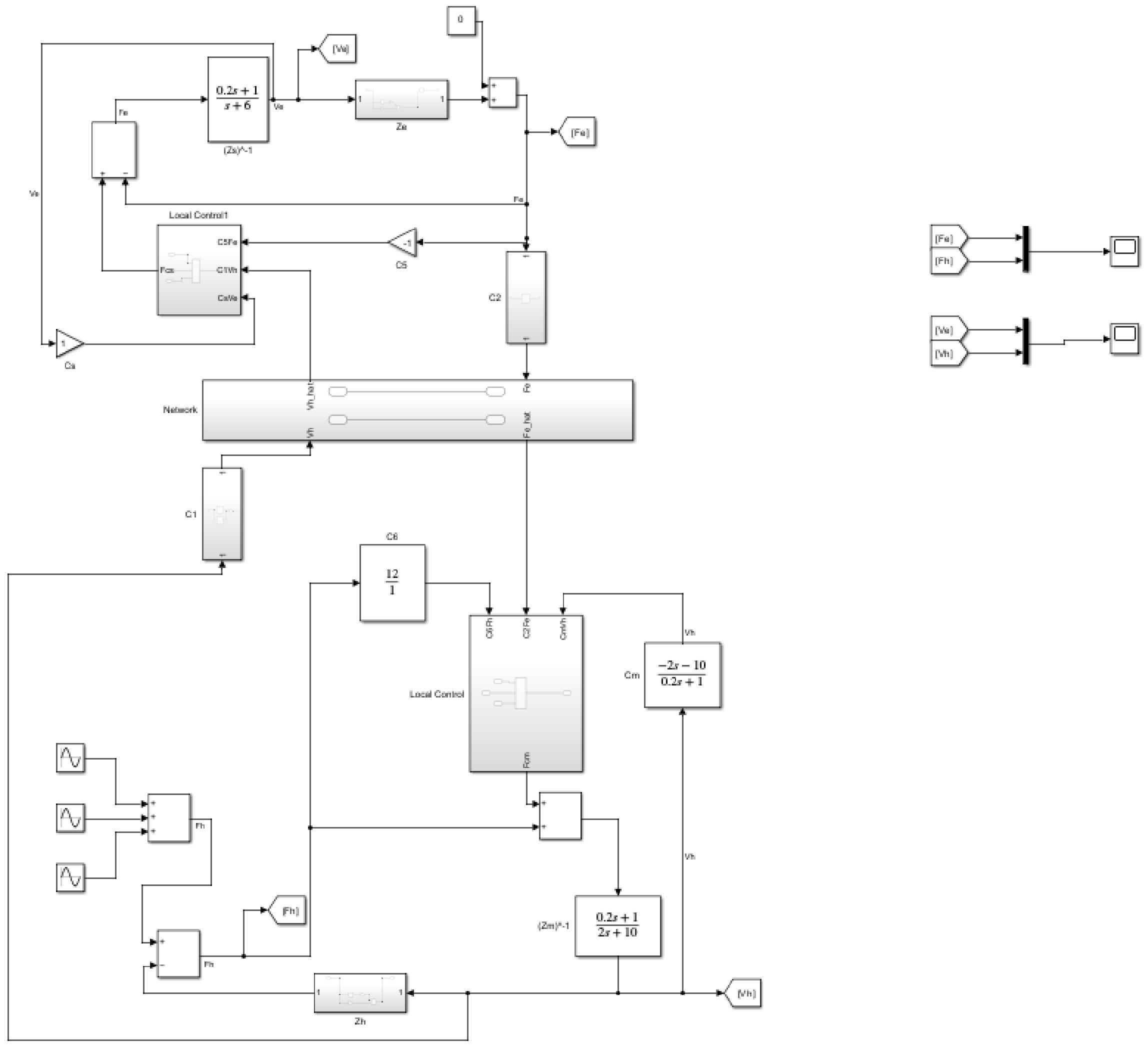
The ankle joint has been viewed as a key contributor to propulsion during activities like walking and running. Muscles surrounding the joint, like the calf muscles, actively contract to push the foot off the ground, generating the necessary force for forward movement.  However, this study challenges this long-held assumption. Researchers employed sophisticated techniques to measure the energy transfer within the ankle joint during movement in healthy young adults. Surprisingly, the results revealed a different story. Even with active muscle engagement, the ankle joint behaved primarily in a passive manner, functioning like a shock absorber to dissipate energy rather than actively generating it for propulsion. This finding has significant implications for our understanding of human movement. It suggests that the human nervous system prioritizes a passive, energy-dissipative interaction between the body and the ground during locomotion. This passive strategy likely optimizes efficiency by minimizing the metabolic cost of movement. Actively generating force with the ankle muscles for propulsion would require additional energy expenditure. Passive approach to the joint capsule and surrounding ligaments possesses a certain stiffness, allowing for energy storage and release during movement. Additionally, the muscles themselves exhibit a characteristic “stretch-shortening cycle” where they can absorb and return energy through rapid stretching and shortening. This passive dissipation likely provides several advantages. It reduces the workload on the muscles, minimizing fatigue and muscle damage. Additionally, by absorbing impact forces, the ankle joint protects the skeleton from excessive stress, particularly in the knees and hips, which are more susceptible to injury. The nervous system appears to leverage these inherent properties to our advantage. By prioritizing a passive strategy, our bodies can move efficiently and safely.  This passive approach might also explain the remarkable adaptability of human locomotion across diverse terrains. Uneven surfaces or changes in grade require adjustments in force production, yet the basic strategy of passive energy dissipation through the ankle joint remains a constant. Exoskeletons and powered prostheses aim to augment or replace human limbs, restoring mobility and function to individuals with disabilities or injuries. By leveraging passive energy dissipation, these devices could reduce the overall energy required for movement, improving battery life and user comfort. Passive designs could potentially decrease the stress placed on healthy joints by absorbing impact forces more effectively. Understanding the role of passive energy dissipation can inform physical therapists in developing rehabilitation protocols that promote natural movement patterns. The principles of passive energy dissipation within the ankle joint could inspire the design of more agile and energy-efficient robots for various applications.

**Paper 2**

This research delves into a critical aspect of ensuring safe interactions between humans and robots: understanding the capacity of the human hip joint to absorb energy during collaborative tasks with robots. This understanding is vital for preventing potential injuries that could arise from excessive energy transfer between the human body and the robot. Researchers monitored the electrical activity in specific leg muscles while participants engaged in various tasks with robots. By analyzing this data, they were able to quantify a parameter called "excess of passivity." This metric essentially represents the amount of energy that the hip joint can absorb under different conditions. The study revealed that the excess of passivity increased significantly when leg muscles were contracted compared to when they were relaxed. This finding suggests that contracted muscles behave akin to springs, efficiently absorbing and releasing energy during movement. Additionally, the researchers observed variations in excess of passivity depending on whether the muscles were flexed or extended, indicating that different muscles might play distinct roles in energy absorption depending on the movement of the leg. Understanding how passivity changes with different hip angles is crucial for predicting joint stability during various postures when interacting with robots. By factoring in passivity, designers can develop robots that limit the transfer of energy to the human joint, thereby reducing the risk of injury, especially during sudden or unexpected movements. This knowledge can improve the design of robots used in physical therapy, enabling them to be tailored to target specific muscle contractions and hip positions to optimize energy absorption. This tailored approach has the potential to improve rehabilitation outcomes by ensuring that therapy sessions are not only effective but also safe for the patient.

This research provides valuable insights for designing safer and more effective robotic interfaces for various purposes. By understanding how muscle activation and hip position influence the human hip's capacity to absorb energy, we can create a future where humans and robots collaborate seamlessly.

**Question 2**



A) The $Z_{to}$ for the system is equal to $Z_e$. The system has ideal transparency. Zto as a function of hybrid parameters are

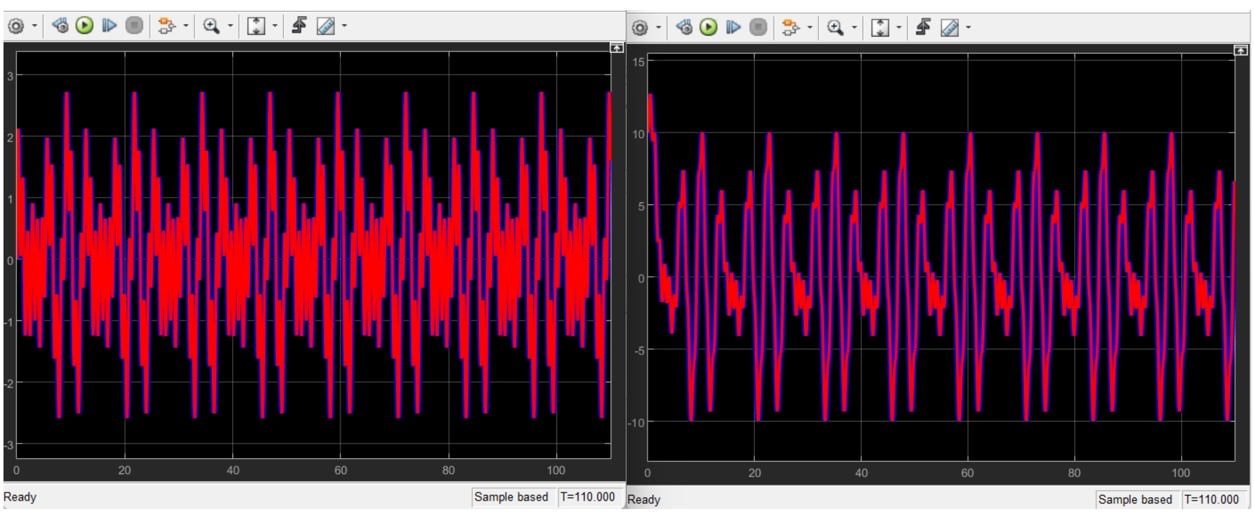
$$Z_{to} = \frac{F_h}{V_h} = h_{11} - h_{12}\frac{h_{21}}{1+h_{22}Z_e}$$

$$Z_e = \frac{h_{11} + \Delta h Z_e}{1 + h_{22} Z_e}$$

The hybrid matrix of the system is

$$H(s) = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

$$V_e \rightarrow V_h$$
$$F_h \rightarrow F_e$$

B) 


C) The system is stable for the above condition. The system has ideal trasparency. The Velocity of the slave follows the velocity of the master and the force of the slave follows the force of the master.

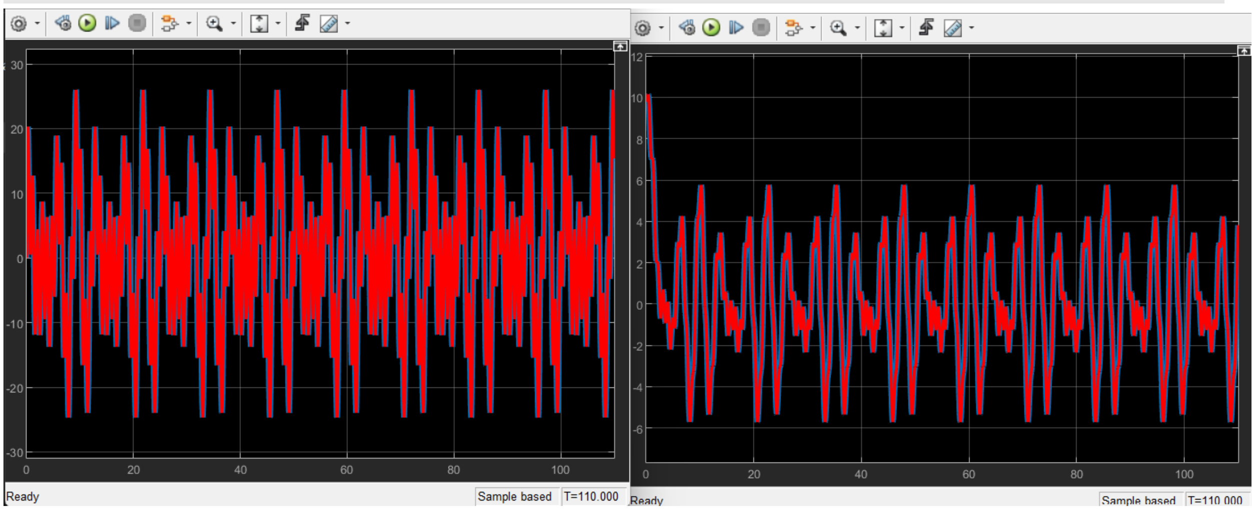
Condition for ideal transparency

$h_{11}(s) = h_{22}(s) = 0$

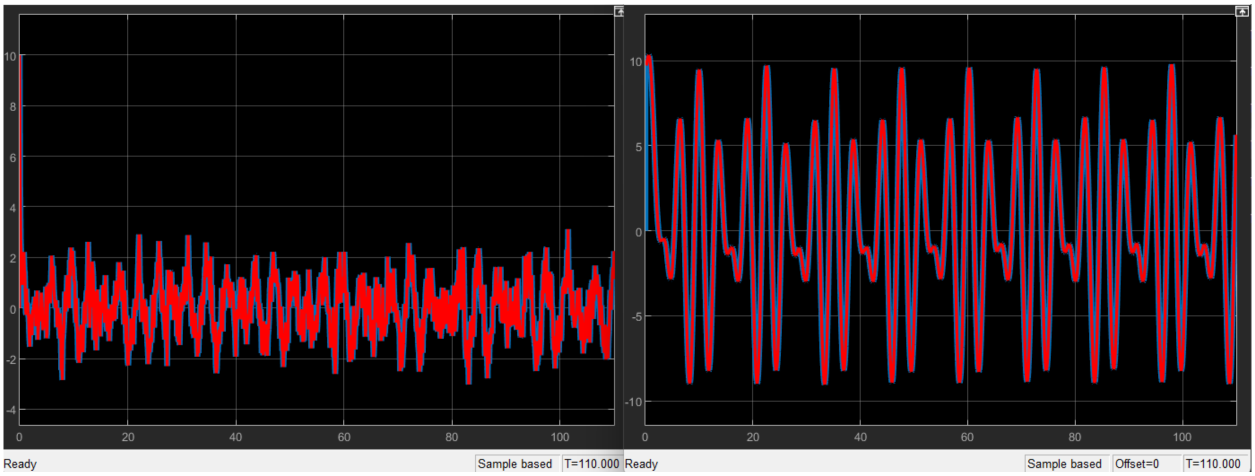
Llewellyn's condition - any unconditionally stable system must satisfy

$Re(h_{11}(s)) \geq 0 \quad Re(h_{22}(s)) \geq 0$

Ideally transparent system borders stability




D)
The system was stable after scaling down the force received from the environment. Scaling down the reflected force can make the system more stable as it reduces positive feedback loop and potentially dampend=s the oscillations.




E) Adding a low pass filter reduces the effect of noise on the filter. The effect can be seen on both the force and velocity graphs.

**Question 3**

(A) $F = B * v(t)$ — ①

Integral passivity

$$\int_0^t y(t) * u(t)\, dt \geq 0$$

$$\Rightarrow \int_0^t F(t) * v(t)\, dt \geq 0$$

Substituting ①

$$\int_0^t B * v(t) * v(t)\, dt \geq 0$$

$$= B \int_0^t v(t)^2\, dt \geq 0$$

B is a positive constant (damping coefficient)
$v^2$ is total kinetic energy which is always non-negative
Product of the two is always non-negative which satisfies integral passivity condition
Relationship is passive when I/P is velocity & O/P is force

(B) $F = -k * x(t)$ - (1)

Integral passivity

$$\int_0^t y(t) * u(t)\,dt \geq 0$$

$$\Rightarrow \int_0^t F(t) * v(t)\,dt \geq 0$$

Substituting (1)

$$\int_0^t -k * x(t) * v(t)\,dt \geq 0$$

$$v(t) = \dot{x}(t)\,dt$$

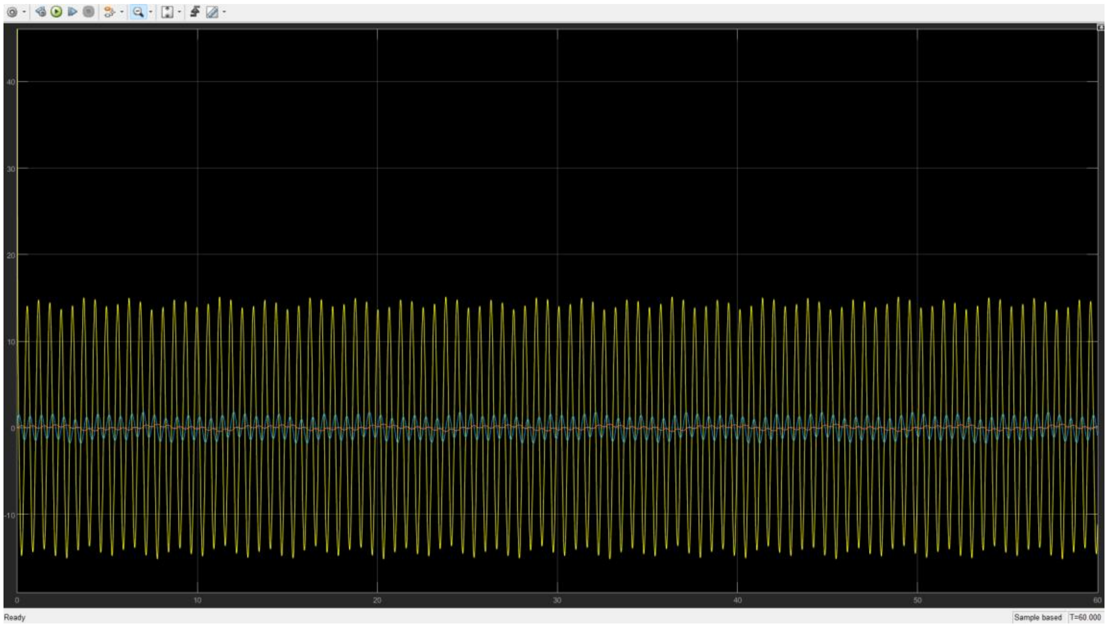
$$\Rightarrow \int_0^t -k * x(t) * \dot{x}(t)\quad dt \geq 0$$

Integrating by parts

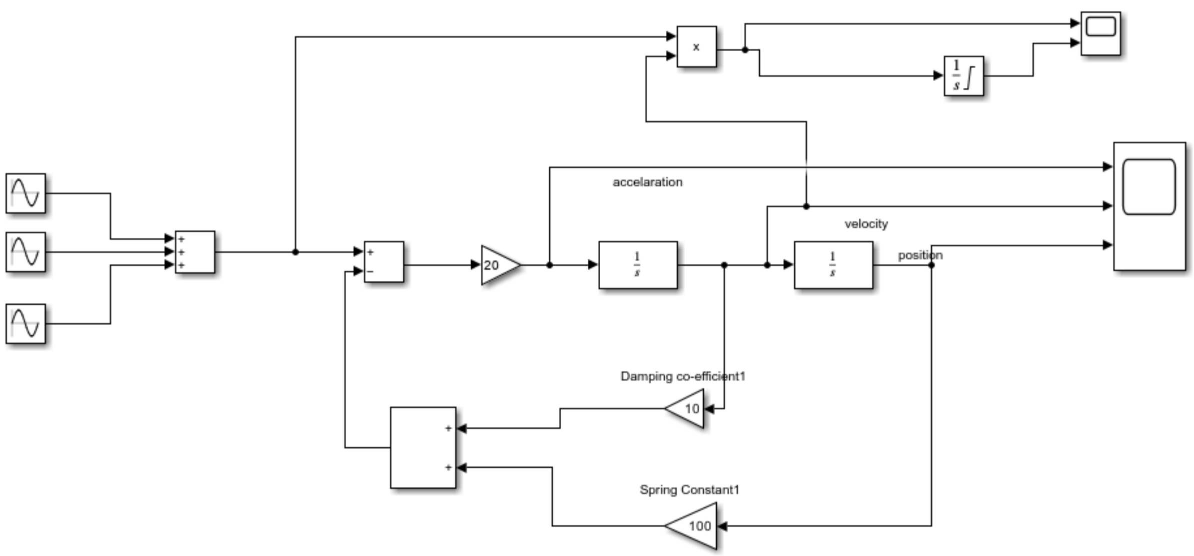
$$= \frac{-k\ x(t)^2}{2}$$

Relationship is not passive when I/P is force and O/P is velocity

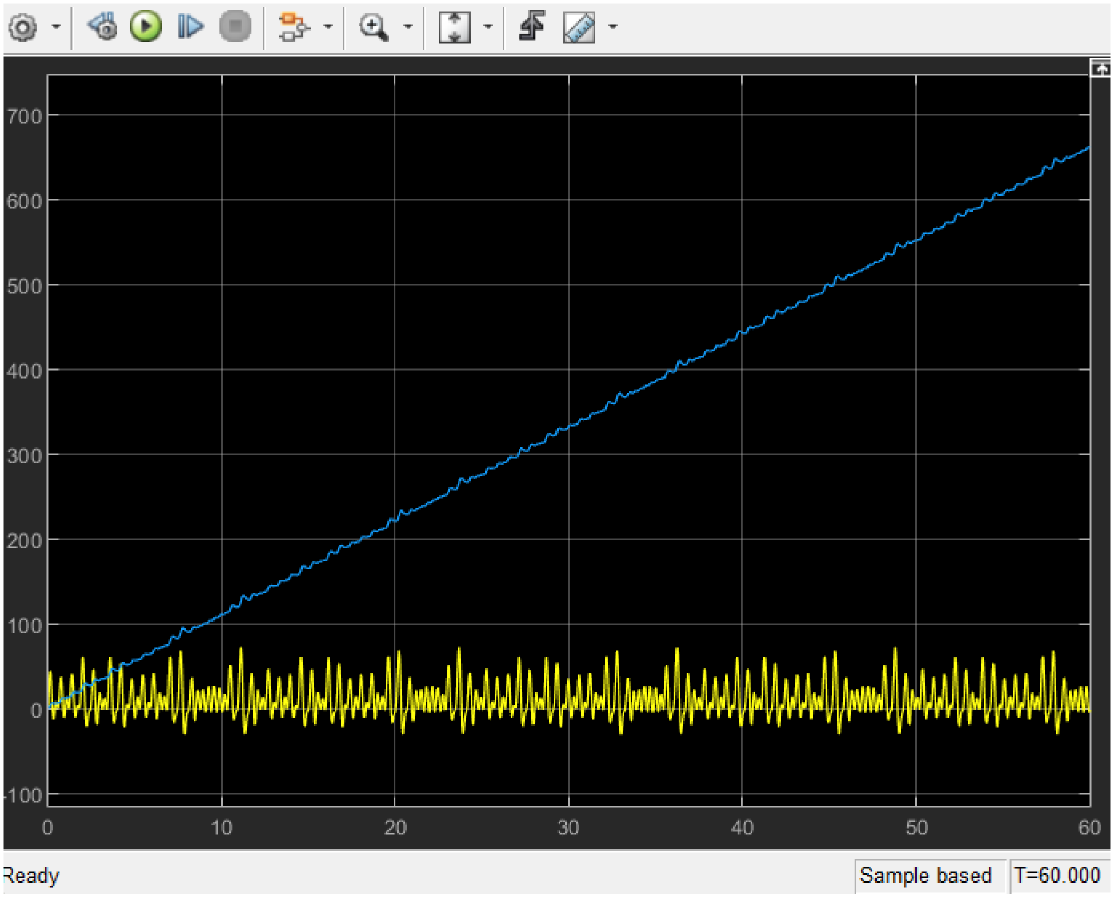
C)



40
30
20
10
0
-10
0
10
20
30
40
50
60
Ready
Sample based
T=60.000

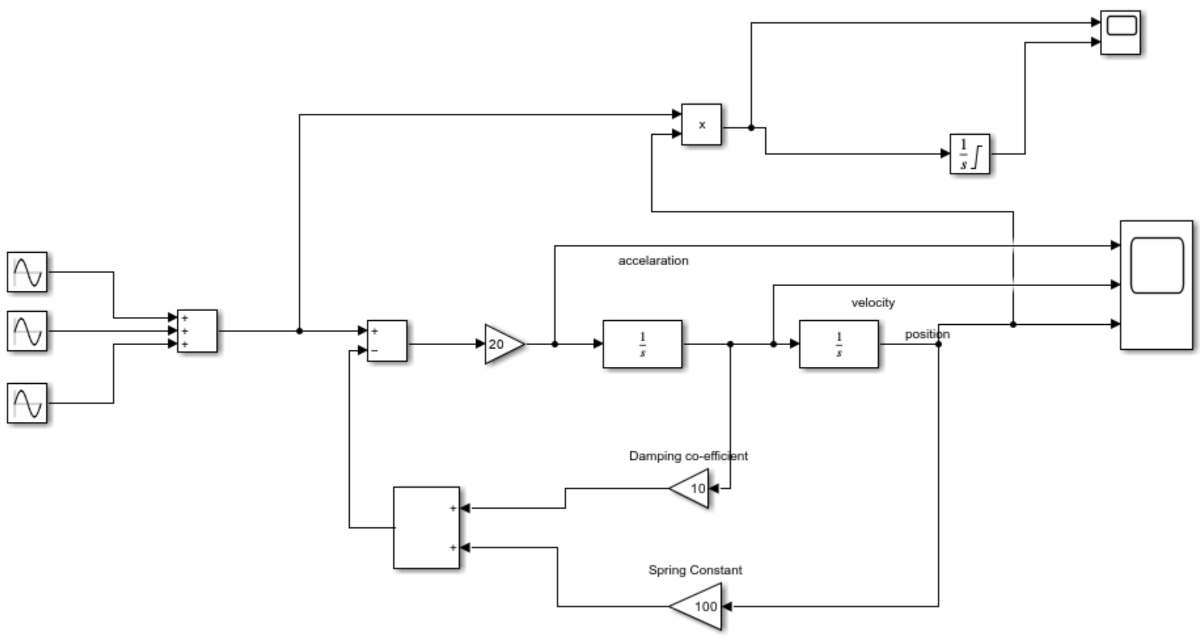



x
accelaration
velocity
position
20
Damping co-efficient1
10
Spring Constant1
100

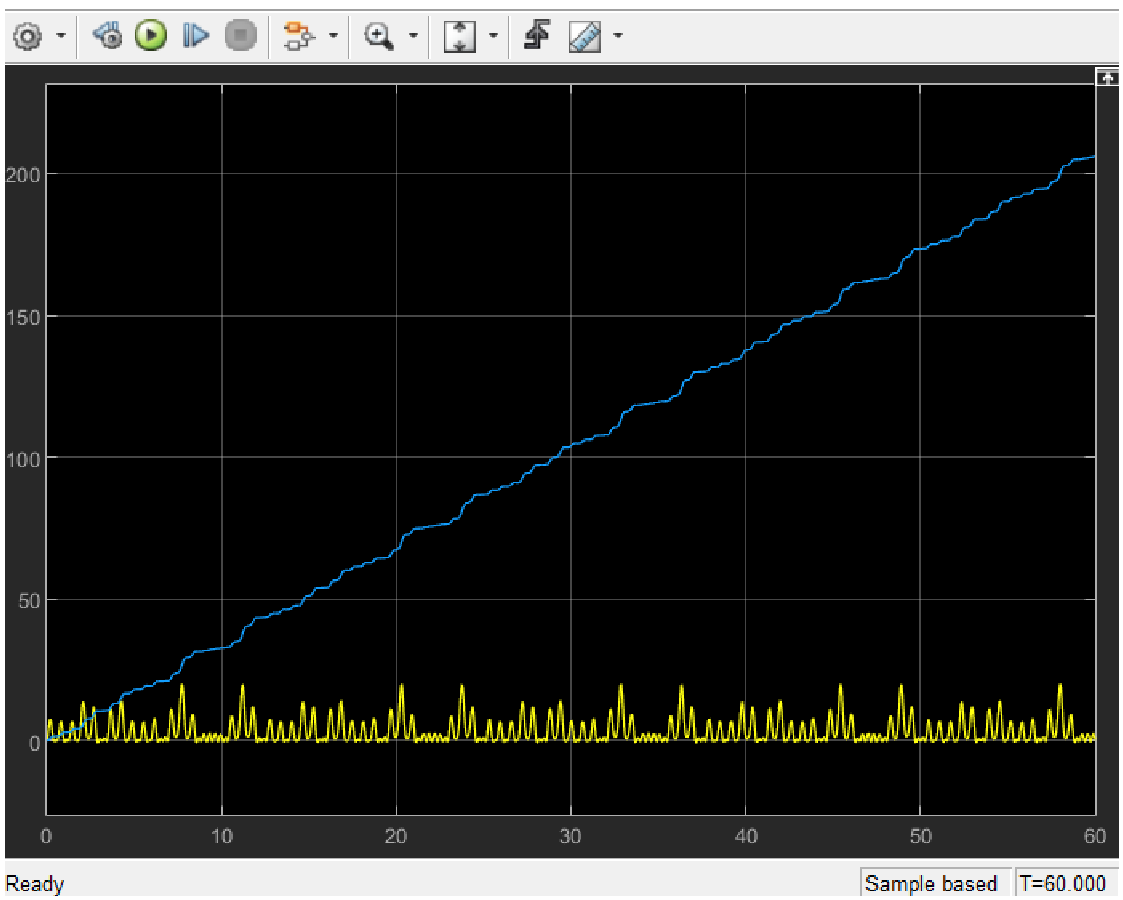



The system is passive as the graph is positive

D)



accelaration
velocity
position
20
10
Damping co-efficient
100
Spring Constant
x

200
150
100
50
0
0
10
20
30
40
50
60
Ready
Sample based
T=60.000

The system is passive as the graph is positive. The result is similar to the previous result, the slight variations in the graphs stem from the fact that the output variables are different hence they dissipate energies differently thus resulting in variations in the graphs

$$X(s) = \frac{1}{ms^2 + bs} F(s)$$

$$\frac{F(s)}{X(s)} = ms^2 + bs$$

$$P(jw) = -mw^2 + Bjw$$
$$P(-jw) = -mw^2 - Bjw$$

$$P(jw) + P(-jw) = -2mw^2 \qquad w = \sqrt{\frac{k}{m}}$$

$$-2mw^2 \leq 0$$

System is not passive

$$X(s) = \frac{V(s)}{s} \qquad \frac{F(s)}{V(s)} = ms + B$$

$$P(jw) + P(-jw) = 2B$$

$$2B \geq 0$$

System is passive

**E)**

**Question 4**

The system may not always remain stable. Stability depends on the interplay between Master-side and Slave-side dynamics, modeled by a mass spring damper system the coefficients play a role in stability. The control used to translate position from master to force at the slave and the effect the environment has on the master impacts stability.

In an ideal two channel teleoperation it has zero communication delay but the system may still not always remain stable. If both the master and the slave systems have passive damping then the system becomes stable as damping helps dissipate energy and prevents oscillations. Considering specific values of mass spring damper, the system can either be stable or unstable.  Since there's no delay in sending position commands, the leader can accurately control the position of the follower in real-time. Assuming the control algorithm is designed properly, the position control loop should be stable. The force feedback loop involves sending force information from the follower back to the leader. This feedback loop is crucial for the operator to perceive the interaction forces between the follower and the environment. In an ideal scenario with zero communication delay, the force feedback loop should also be stable. Considering both loops are stable and there are no inherent instabilities introduced by the mass-spring-damper model, we can conclude that the system is stable under the assumption of zero communication delay.

$F = -k x(t) \qquad v(t) = \dot{x}(t)\,dt$

$$\int_0^t F(t)\,V(t)\,dt \geq 0$$

$$= \int_0^t -k\,x(t)\,\dot{x}(t)\,dt \geq 0$$

Integrating

$$= -k\frac{x(t)^2}{2}$$

System is not passive when I/P is force & O/P is velocity

$F = BV(t)$

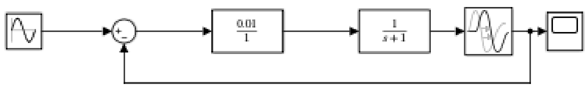
$$= \int_0^t F(t)\,V(t)\,dt \geq 0$$

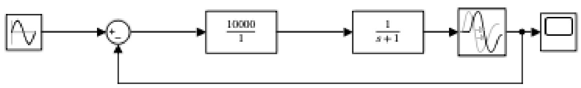
$$= \int_0^t F(t)\,\dot{x}(t)\,dt = B\int_0^t \dot{x}(t)^2\,dt$$

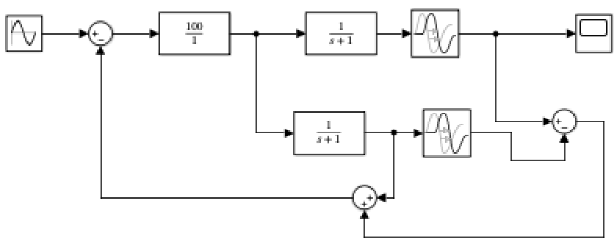
$$= \frac{B}{2}x^2 \geq 0$$ by chain rule

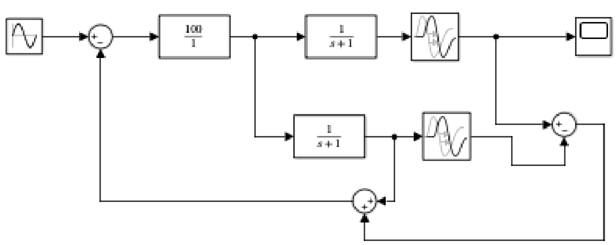
System is passive

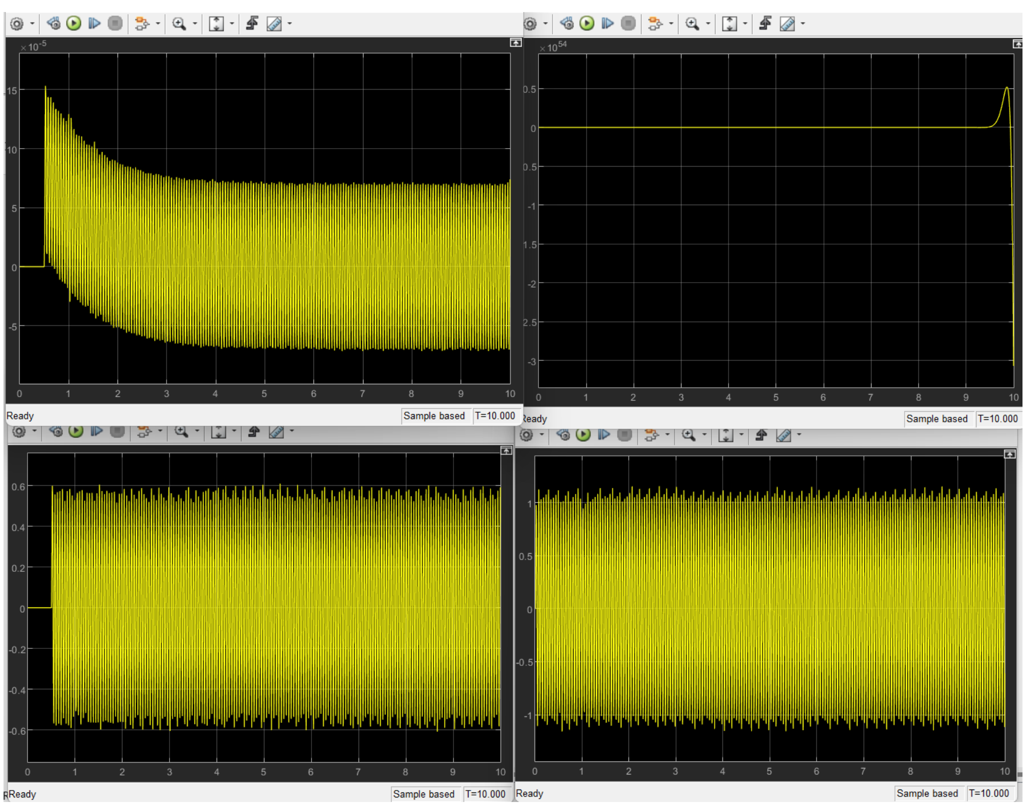
# Question 5


0.01
1
1
s+1


10000
1
1
s+1


100
1
1
s+1
1
s+1


100
1
1
s+1
1
s+1


× 10^-5
× 10^54
Ready
Sample based
T=10.000

C(s) = 0.001due to low gain output has much smaller amplitude compared to the input sine wave. It tracks the input shape bur with a reduced magnitude. C(s) = 10000 due to high gain the output amplitude will be larger than the input. System might become unstable depending on open loop transfer function

With Smith Predictor C(s) = 100 it aims to compensate for the time delay by introducing a model of the plant in the control loop. The delay value provided is very small compared to the system dynamics od 1 second.