EXERCISE NO. : 2

MODELLING OF A POSITION CONTROLLED PLANAR MECHANISM

METHOD 1

DATE: 20-8-2020

Reg. No. : RA1711018010101

LAB PREREQUISITES:

Introduction to Physical Modelling

PREREQUISITE KNOWLEDGE:

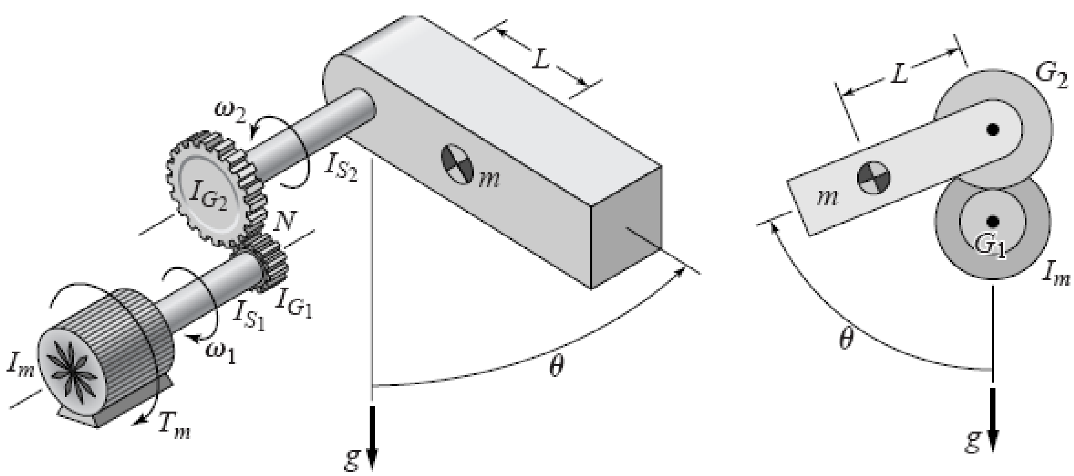
Fundamentals of SIMULINK modelling of physical systems.

OBJECTIVES:

- To model a one degree of freedom joint constituting a planar mechanism using the Foundation Library in Simscape.
- Understand the dynamics of the mechanism for an applied torque by the actuating element.
- To add a controller to the actuator connected to the mechanism and observe the controlled behavior.

THEORY

Dynamics of the Mechanism



Physical Parameter	Specification
Moment of inertia of the drive shaft, I_{s1}	0.085 $kg.m^2$
Moment of inertia of the driven shaft, I_{s2}	0.37 $kg.m^2$
Gear ratio	2
Mass	4 kg
Length of the link	0.25 m
Acceleration due to gravity	9.81 m/s^2

Modelling Gravitational Torque

The torque acting on the link due to gravity may be modelled as

$$- m.g.L.\sin\theta$$

Model of a DC Motor

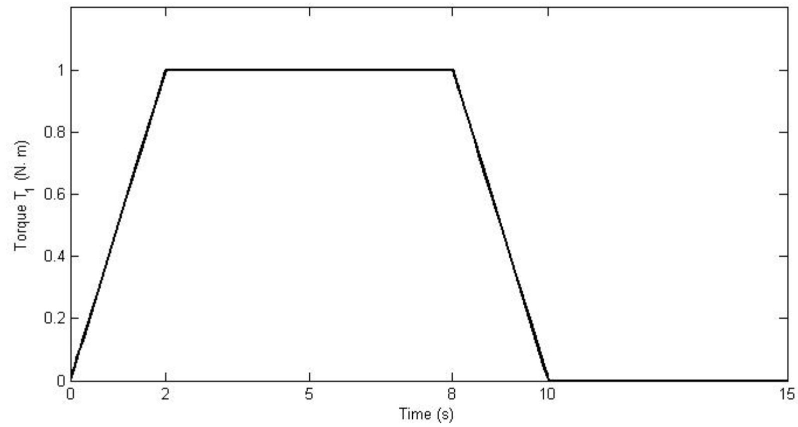
To add actuator to the actuated link model use the following parameters.

Physical Parameter	Specification
Armature resistance	0.5 Ohm
Electrical inductance	0.002 H
Torque Constant	0.05 Nm/A
Motor Inertia	9×10^{-5} $kg\cdot m^2$
Maximum Voltage	10 V

EXERCISE TASKS

Task 1

- Model a one DoF planar mechanism shown in the figure. Use the Ideal Torque Source for the gravitational torque component.
- Model the gearbox with only the gear ratio neglecting the gear friction.
- Use signal builder to generate a torque profile as shown below:



- Use Simscape→Foundation Library→Physical Signals→Functions library →PS Math Function to model the parameters for the gravitational torque component.
- After modelling, simulate the model for 15 seconds. Plot the angular position of the joint.
- Observe the constant amplitude oscillations for time < 10 seconds. Observe the link's oscillations like a pendulum after the applied torque is made to zero after 10 seconds.

Task 2

- The objective of the task is to develop a feedback control in angular position.
- Neglecting the circuit dynamics add a PID controller to the model. Set the values as Proportional, Integral, and Derivative based on tuning. Choose the values by properly selecting the desired response characteristics.
- Observe the control torque (the torque required to achieve the desired performance). *Note the controller gains may be found using tools from Mathworks like pidtool or sisotool or Simulink Control Design. The details of the algorithm used for tuning is not a part of this exercise.*
- Note the maximum torque required and the rate of variation of torque.
- At this point the engineer may want to consider including **the motor circuit model** in order to determine the maximum required current.

Note the benefit of Model-Based Design: It is possible to evaluate alternatives and make informed design decisions well in advance of hardware implementation and testing.

Task 3 (Practice exercise)

- Replace the Ideal Torque Source used for the joint actuation by a DC Motor model with the suitable specifications given in the table.
- Plot the angular velocity and observe the period of oscillation for non-zero value of applied torque.
- Compare the oscillations for the Ideal Torque Source with DC Motor model.
- Plot the armature current.

DELIVERABLES

Task 1

- Plot of Position vs. Time under no load condition for the torque profile.
- Write the reason for the constant amplitude oscillations for t<10 seconds.
- Write the period of oscillations after t = 10 seconds.

Task 2

- Write the values of P, I, D gains after tuning.
- Plot the control torque vs. time.
- From the graph write down the maximum torque required.
- Plot the desired angular position and actual angular position.
- Plot the armature current vs. time.
- Comment on the transients required for the torque and current and what implications do it has on the system design.

Task 3

- Inclusion of dynamics of DC motor to the existing model replacing the ideal torque source
- Plot the Velocity vs. Time
- Compare the oscillations obtained in this case with Ideal torque source used in Task1.

WORKSPACE PARAMETERS

```
% System Parameters
m = 4;
l = 0.25;
g = 9.81;
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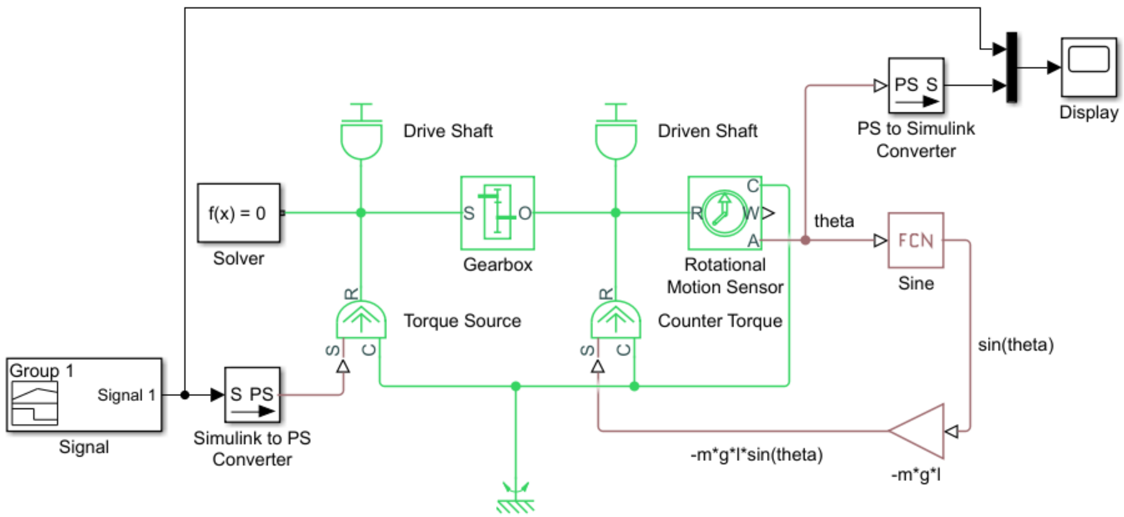
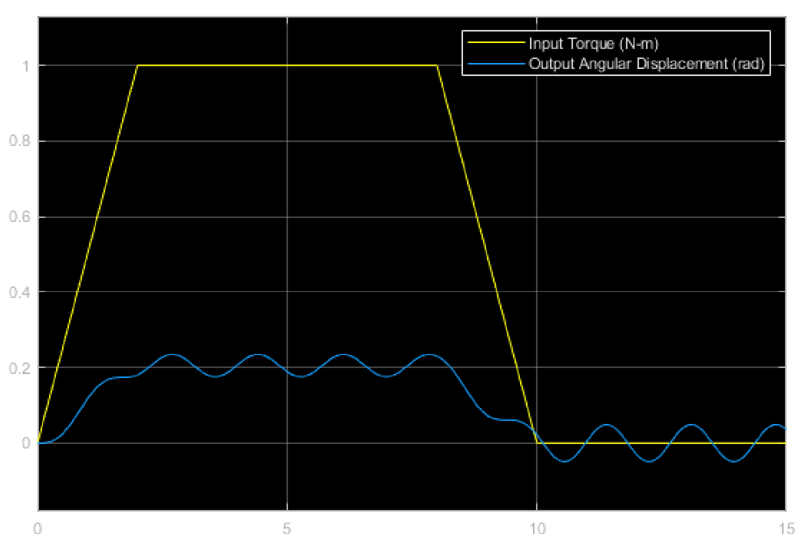
TASK 1: Uncontrolled 1-DOF Mechanism Using Ideal Torque Source

Block Diagram:



Deliverables:

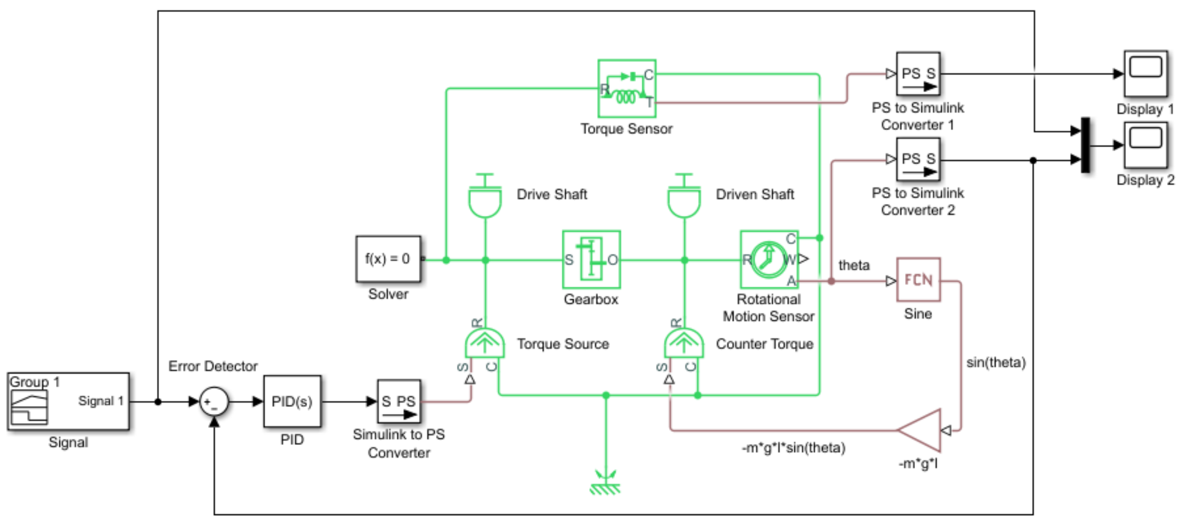
1. Following is the plot of input torque (N-m) and output angular displacement (rad) w.r.t. time (s)



2. There are 3 possible reasons for the constant amplitude oscillations for t<10 seconds:
    - The system is uncontrolled (i.e. no corrective controller is implemented). Hence, the torque produced by the gravitational torque component opposes the driving torque produced by the ideal torque source, thereby fluctuating its value continuously.
    - A more realistic cause would be the requirement of high holding torque requirement for the mechanism (considering its inertial properties). If the driving torque produced by the ideal torque source is not sufficient to hold the mechanism in place at the desired angular position, then the opposing torque produced by the gravitational torque component will tend to dominate.
    - Lastly, the system is modelled very idealistically. There are no damping forces/torques modelled in the entire system which may dampen out these oscillations. Thus, these oscillations are observed to have a constant amplitude throughout the specified time period.
3. The time period of oscillations after t = 10 seconds is approximately <u>1.67 seconds.</u>

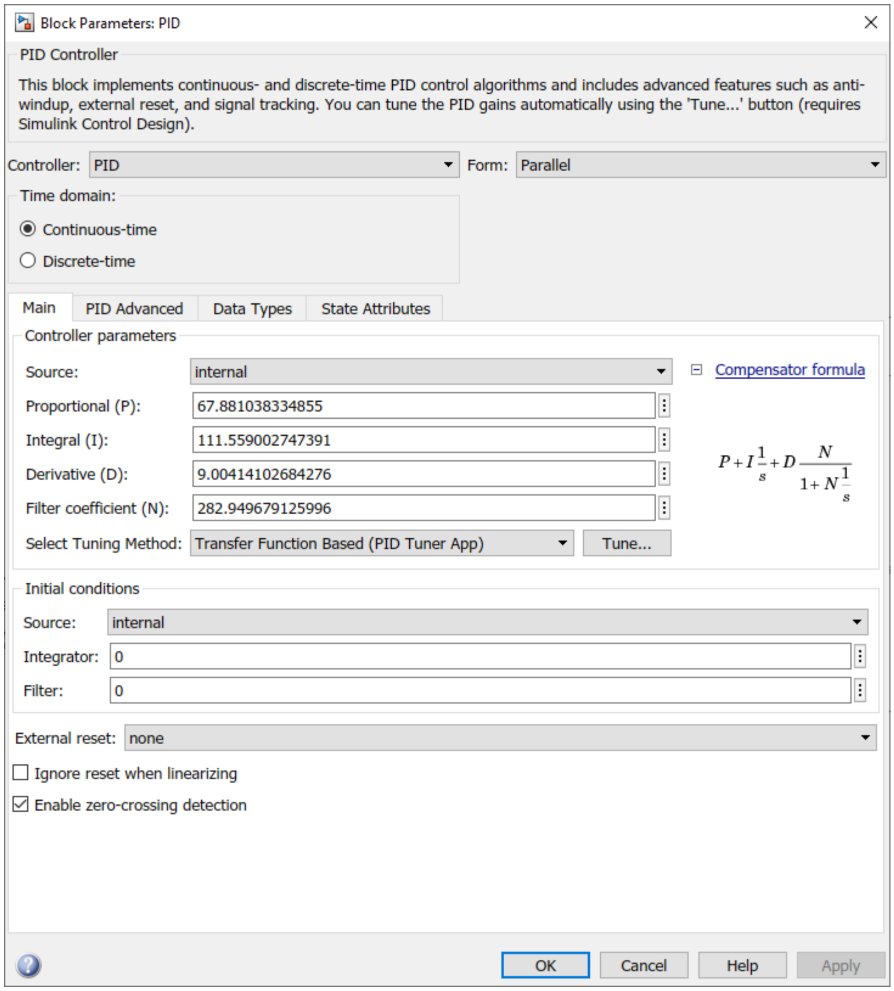
TASK 2: PID Controlled 1-DOF Mechanism Using Ideal Torque Source

Block Diagram:

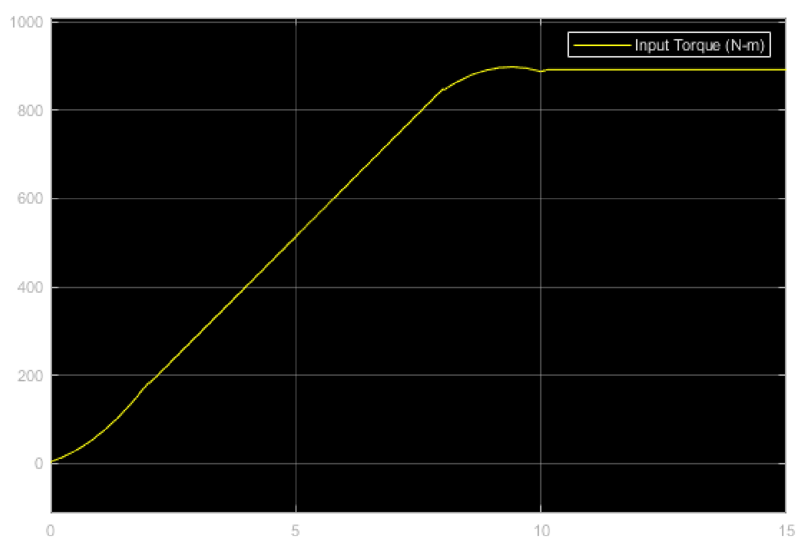


Deliverables:

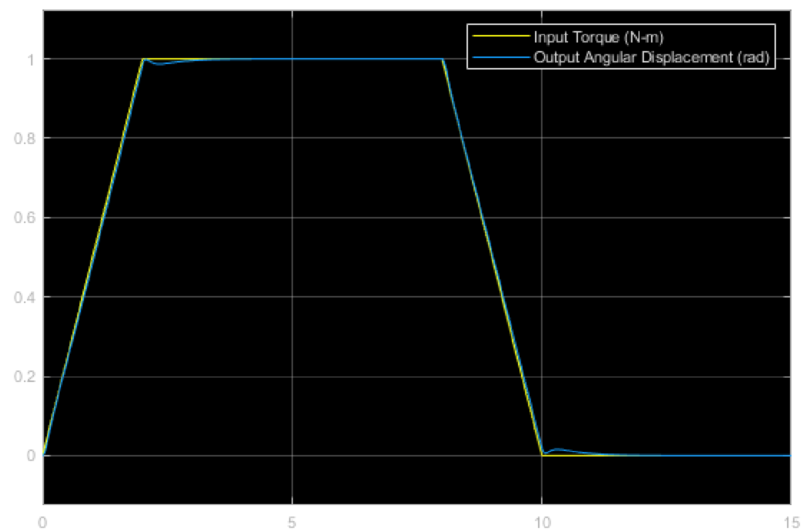
1. Following are the PID gains after tuning:
    - K_P = 67.881038334855
    - K_I = 111.559002747391
    - K_D = 9.00414102684276



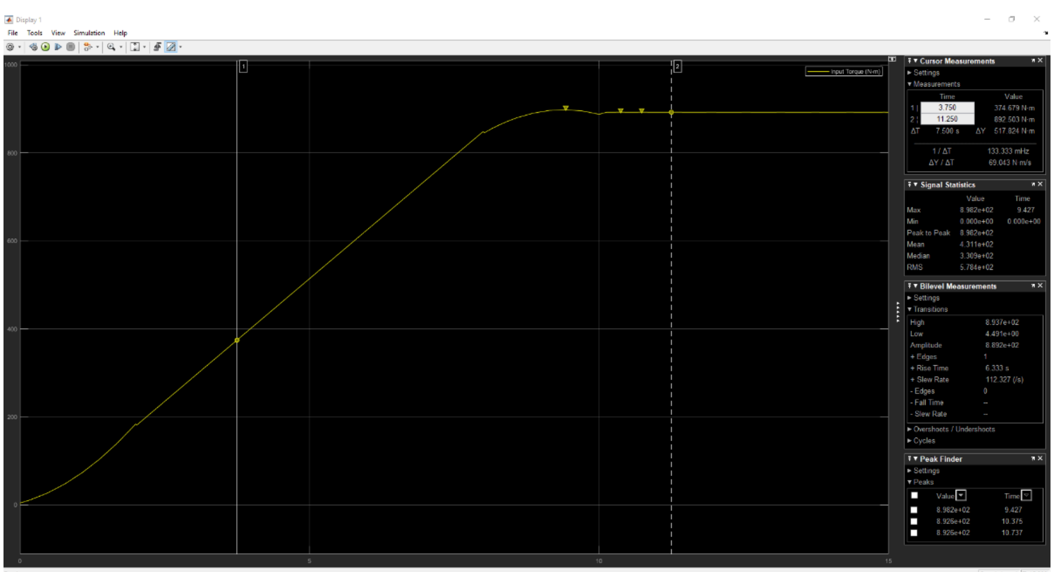
2. Following is the plot of control torque (N-m) w.r.t. time (s)



3. The maximum torque required is 898.185 N-m at t = 9.427 seconds (measured using peak finder).
4. Following is the plot of input torque (N-m) and output angular displacement (rad) w.r.t. time (s). Note that the input torque itself acts as the setpoint for the angular displacement.



5. Following are the characteristic measurement of the control torque:



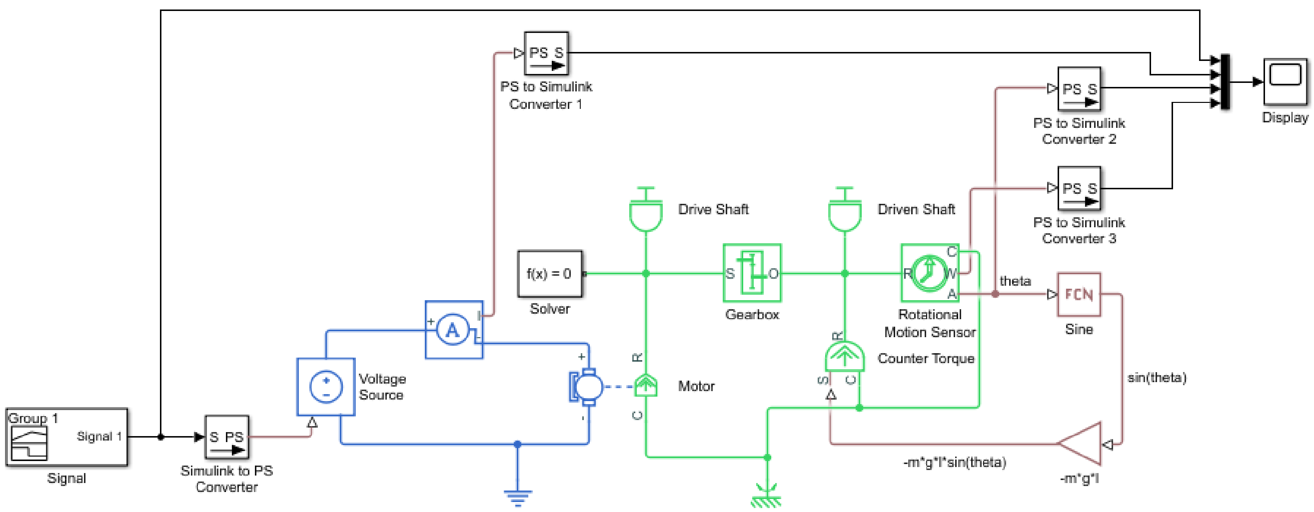
The transient characteristics of torque are:

- Rise Time: 6.333 s
- Peak Overshoot: 898.185 N-m
- Peak Time: 9.427 s
- Settling Time: 11.25 s

The transient characteristics provide us with valuable information so as to choose appropriate actuators for the system.

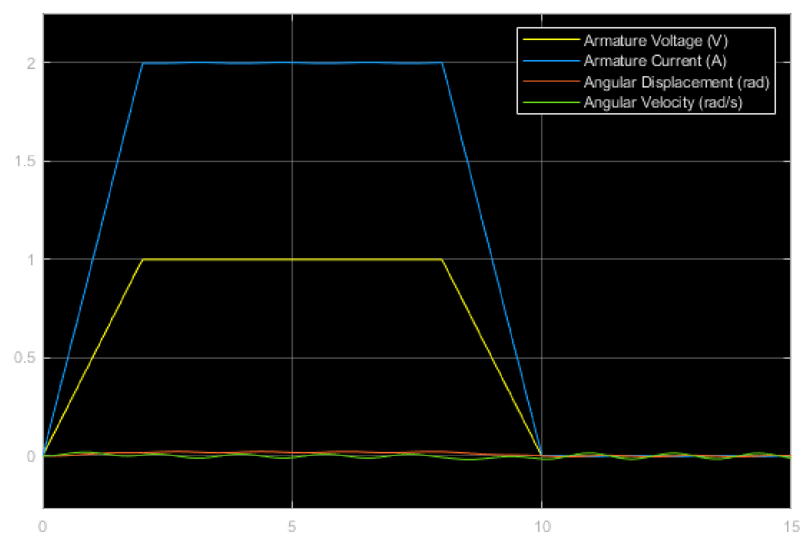
TASK 3: Uncontrolled 1-DOF Mechanism Using DC Motor Model

Block Diagram:



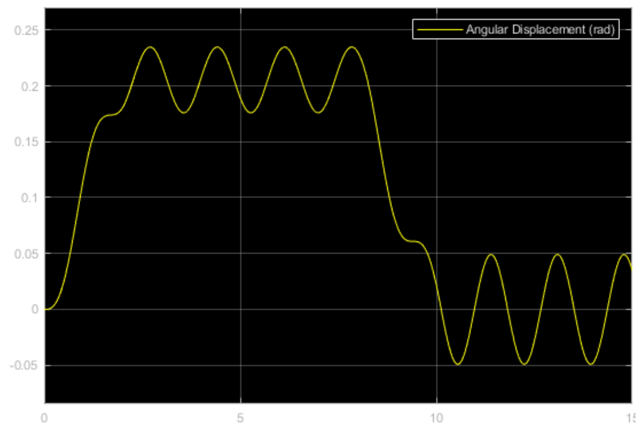
Deliverables:

1. Following is the plot of armature voltage (V), armature current (A), angular displacement (rad) and angular velocity (rad/s) w.r.t. time (s)

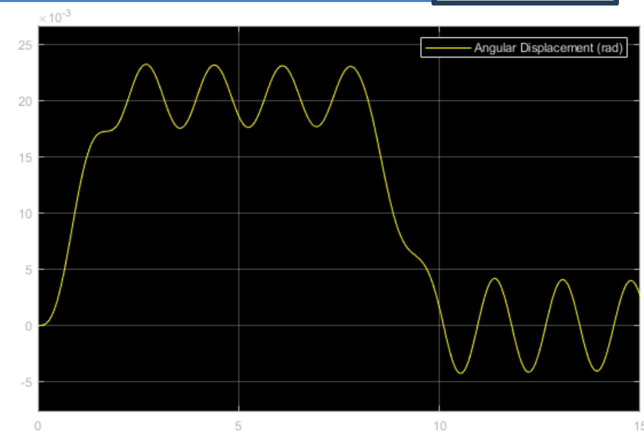


2. It can be seen that the oscillation pattern is identical in both the cases. However, the amplitude of the oscillations is reduced 10 times in case of Task 3. A possible reason for this would be the motor model converting the voltage into torque.

   Following are the two plots represented side-by-side for better comparison. Note the scale of Y-axis carefully!

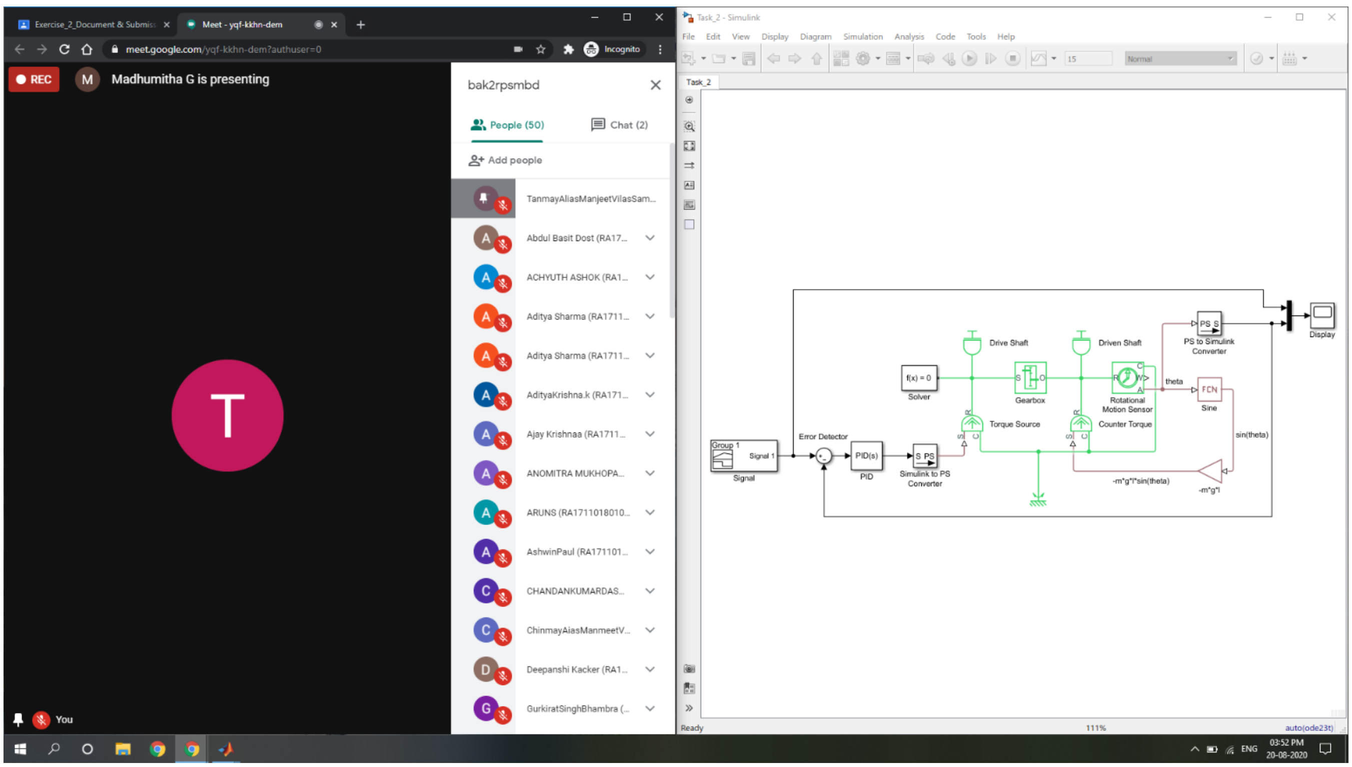


Angular displacement obtained in Task 1



Angular displacement obtained in Task 3

LAB SESSION SCREENSHOT



INFERENCE

This experiment gave a deeper understanding about physical modeling (a simplified yet powerful approach to dynamic system modelling) and simulation of dynamic systems using a case study of a simple 1 DOF (rotational) mechanism, which is a typical mechatronics-based design approach. Moreover, the various tasks in this exercise helped gain a step by step knowledge about physical modeling of the said mechanism starting with minimal required components (ideal sources, inertial components (shafts), gearbox, etc.) and then gradually adding more (PID controller, motor model, etc.) to get a more detailed physical model. That being said, there is still a room for adding physical aspects such as friction, damping, drag, actuator saturation limits, etc. in order to obtain a more realistic physical model of the system.

From this experiment, it is evident that MATLAB - Simulink is a very powerful tool when it comes to modelling and simulation of dynamic systems ranging from simple 1-DOF mechanisms (as modeled and simulated in this exercise) to highly complex multi-disciplinary systems. It provides a range of built-in functions and toolboxes for rapid system analysis across multiple representation types (including Simulink as well as Physical System blocks – it is an important inference that Simulink blocks represent only numerical data whereas Physical System blocks represent a specific physical quantity along with its associated unit/dimension). Furthermore, MATLAB - Simulink is also very powerful software for control system design and offers multiple tools for fast and convenient testing (for example, convenient GUI-based PID controller tuning using Ziegler Nichols heuristic method as used in this exercise).