LAB 5: Modeling a Hydraulic Piston & Load

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Student Name	Signature*	Total Mark
Michael McCorkell		49 **/ 50**

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LAB 5 Grading Sheet

Student First Name:	Student Last Name:
Michael	McCorkell

Part A1: Modeling of Hydraulic Subsystem	10 **/10**
Part A2: Modeling of Mechanical Subsystem	5 **/5**
Part A3: Setting the Parameters Values	5 **/5**
Part A4: Running the Simulation	10 **/10**
Post Lab Assignment	11 **/15**
General Formatting: Clarity, Writing style, Grammar, Spelling, Layout of the report	5 **/5**
Total Mark	49 **/50**

LAB 5: Modeling a Hydraulic Piston & Load

OBJECTIVES

- To utilize Simscape to construct model of hydraulic systems.
- To explore data-driven modeling methods and derive continuous-time transfer function models from input-output data and using MATLAB System Identification toolbox.

INTRODUCTION

In the first part of this lab, you will learn how to utilize **Simscape** to construct models of ***hydraulic systems***. Figure 1 shows a ***double-acting piston and cylinder***. The device moves the **load mass** m in response to the **pressure sources** p_1 and p_2. Assume the fluid is incompressible, the resistances are linear, and the piston mass is included in m.

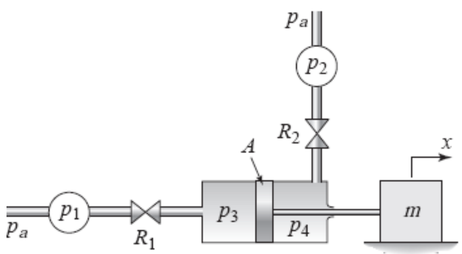


Figure 1: Double-acting piston and cylinder

The system under consideration and the corresponding **Simscape** model are shown in Figure 2. Note that, similar to the physical system, the system model is composed of ***hydraulic*** and ***mechanical*** subsystems coupled by the piston.

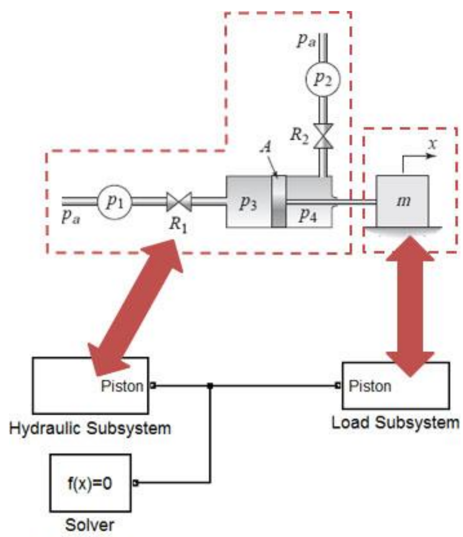


Figure 2: Subsystems of the physical system

In the following steps, we will first build the ***hydraulic subsystem*** followed by the ***mechanical subsystem***. Then, we will assemble these to form the complete system model.

A.1 Modeling of Hydraulic Subsystem

1. **Modeling the Left-Hand Side of the Piston**: Open a new **Simulink** model page. Select and place the following elements and components from the **Simulink Library Browser.**

   - **Simscape > Foundation Library > Hydraulic > Hydraulic Sources > Hydraulic Pressure Source**

     This block represents an ideal source that maintains the pressure difference specified at **input port S** between **physical ports P** and **T**, regardless of the flow. The block has no parameters. Here this block represents the **pressure source** $\boldsymbol{p_1}$ at the left side of the cylinder. This is the pressure above atmospheric pressure.

   - **Simscape > Foundation Library > Hydraulic > Hydraulic Elements > Hydraulic Reference**

     The pressure at **physical port T** of the **Hydraulic Pressure Source** block is set to atmospheric pressure by connecting **Port T** to a **Hydraulic Reference** block. The block has no parameters.

   - **Simscape > Foundation Library > Hydraulic > Hydraulic Elements > Linear Hydraulic Resistance**

     This component represents a hydraulic resistance whose pressure drop p is directly proportional to its volumetric flow rate q_v, such that $p = Rq_v$. The positive direction is from **port A** to **port B**. The block has one parameter, the resistance R, whose units are selectable. Enter the **Resistance** variable name $\boldsymbol{R1}$. Here this block represents the resistance of the inlet on the left side of the cylinder.

   - **Simscape > Foundation Library > Hydraulic > Hydraulic Elements > Hydraulic Piston Chamber**

     This block represents the fluid volume within the cylinder on the left side of the piston. Enter the following variable names and values shown in the **Block Parameters** dialog box.

     Piston area = A m^2, **Piston initial position** = 0 m, **Chamber dead volume** = 1e-4 m^3

     Chamber orientation = Positive displacement increases volume, **Specific heat ratio** = 1.4,

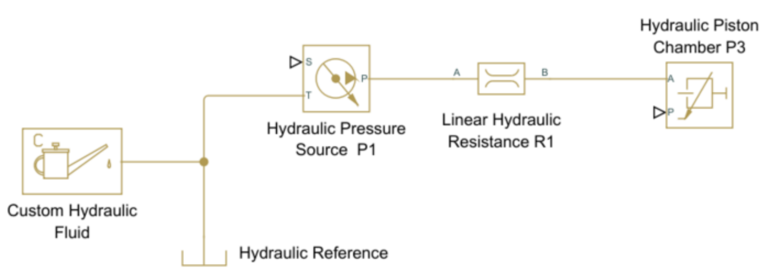
     It is important to note that we have selected "**Increases at positive**" from the **Chamber orientation** drop-down menu, as opposed to "**Decreases at positive**." This indicates that piston motion in a positive direction will increase the volume of the chamber.

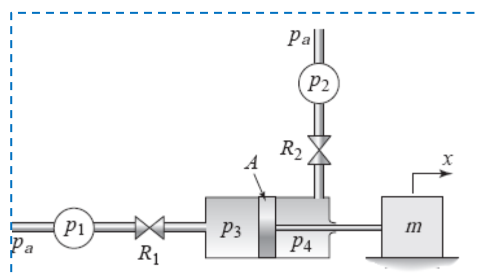
   - **Simscape > Foundation Library > Hydraulic > Hydraulic Utilities > Custom Hydraulic Fluid**

     This component enables the properties of the fluid used to be modeled. Enter the following variable names and values shown in the **Block Parameters** dialog box.

     Fluid density = 850 kg/m^3, **Kinematic viscosity** = 18e-6, **Bulk modulus** = 0.8e+9, **Relative air trapped** = 0

2. Arrange and connect the blocks as shown below. This is the **left-hand hydraulic network** from source p_1 to piston chamber p_3.





3. Now we will add two blocks to the model to define the profile for the **pressure source** $\boldsymbol{p_1}$.

4. Select and place the **Pulse Generator** block from the **Simulink** > **Sources** library. Open the **Block Parameters** dialog box and set the following parameters:

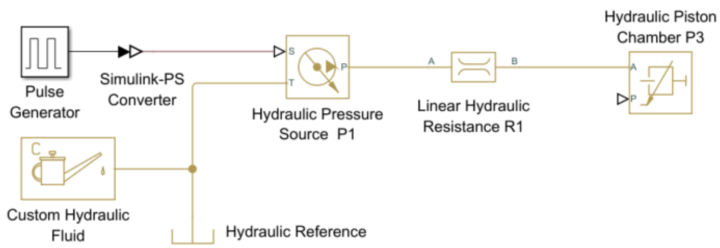
   Amplitude = p1, **Period** = Period, **Pulse Width** = Width, **Phase delay** = 0

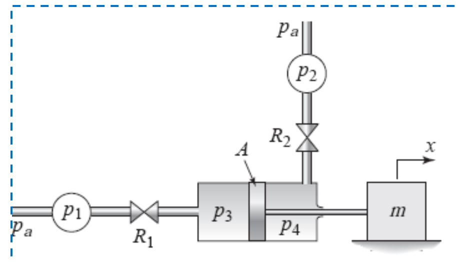
   This parameterization will enable us to easily consider different pressure profiles.

5. Next select and place the **Simulink-PS Converter** block from the **Simscape** > **Utilities** library.

   Open the **Block Parameters** dialog box and set **Input signal unit** = **Pa**.

6. Connect the elements as shown below. This completes the description of the **left-hand** hydraulic network from **source $\boldsymbol{p_1}$** to **piston chamber $\boldsymbol{p_3}$**.





7. **Modeling the Right-Hand Side of the Piston:** Now we must describe the **hydraulic piston chamber** on the **right-hand side** of the piston. Using the same six types of blocks previously discussed, place and connect them as shown below. You can copy and paste the blocks inserted earlier.

8. Set the new **Pulse Generator** block parameters as below,

   Amplitude = p2, **Period** = Period, **Pulse Width** = Width, **Phase delay** = Delay

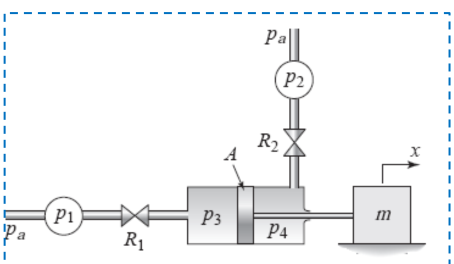
   The **phase delay** between the pressure inputs will enable the hydraulic system to drive the load back and forth.

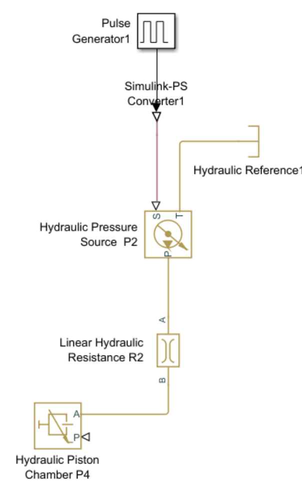
9. In the new **Hydraulic Resistance** block, set the **Resistance** variable from to **R2**.

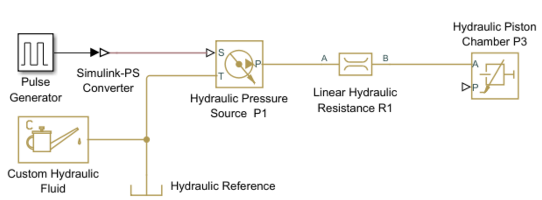
10. In the new **Hydraulic Piston Chamber** block, set the values as below,

    Piston area = A m^2, **Piston initial position** = 0 m, **Chamber dead volume** = 1e-4 m^3

    Chamber orientation = Positive displacement increases volume, **Specific heat ratio** = 1.4,







11. **Converting the Hydraulic Power to Mechanical Power:** The **hydraulic piston chambers** determine the pressure on the **left-hand** and **right-hand** sides of the piston, $\boldsymbol{p_3}$ and $\boldsymbol{p_4}$, respectively. The pressure difference will exert a net force on the piston and drive the load mass.

$$\boldsymbol{F = m\ddot{x} \quad \rightarrow \quad (p_3 - p_4)A = m\ddot{x}}$$

Thus, we must introduce elements to capture this conversion from **hydraulic** to **mechanical** power.

12. Select and insert **two** **Translational Hydro-Mechanical Converter** and **Mechanical Translational Reference** blocks from the following library,
    - **Simscape > Foundation Library > Mechanical > Translational Elements > Mechanical Translational Reference**
    - **Simscape > Foundation Library > Hydraulic > Hydraulic Elements > Translational Hydro-Mechanical Converter**

    This block essentially converts a **fluid volume change** ΔV on one side of the piston into the resulting **displacement of the piston** Δx, and also converts the **pressure** p on one side of the piston into the resulting **force** f on the piston. The **piston area** A appears in both relationships:

$$A\Delta x = \Delta V \qquad f = Ap$$

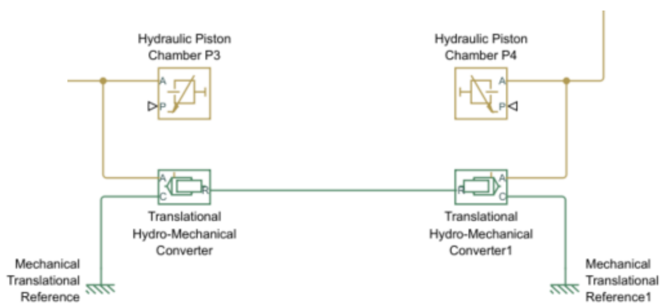
    Set the **Translational Hydro-Mechanical Converter** block parameters of $\boldsymbol{p_3}$ the **left-hand side** as below:

    Piston area = A m^2, **Converter orientation** = Causes positive displacement

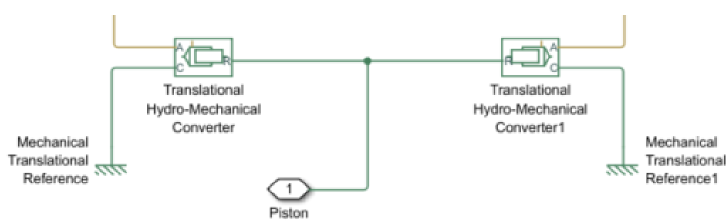
    Set the **Translational Hydro-Mechanical Converter** block parameters of $\boldsymbol{p_4}$ the **right-hand side** as below:

    Piston area = A m^2, **Converter orientation** = Causes negative displacement

13. Connect **port A** on each **Converter** to the **Hydraulic Piston Chamber** blocks from the previous diagram, as shown below,



14. Next insert a **Physical Modeling Connection Port** block (**PMC_Port**) from the **Simscape > Utilities** library.
15. Place and connect it as shown below. Label it as **Piston**. Thus, the power delivered by the hydraulic system to **PMC port 1** represents the net effect of these opposing forces.



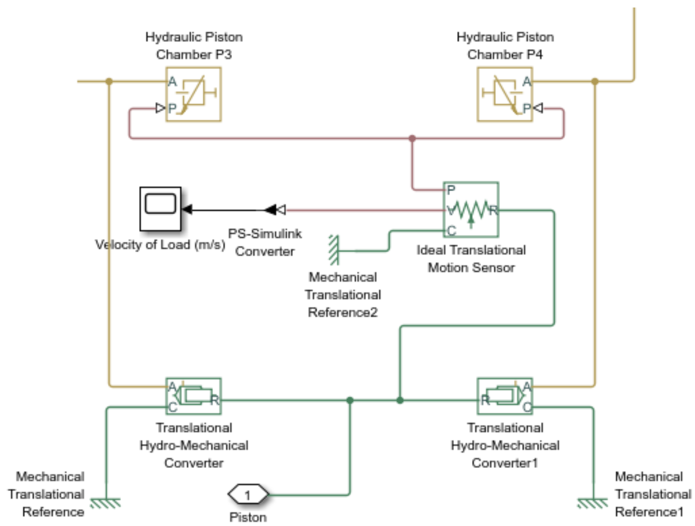
16. Open the **Block Parameters** dialog box of the **PMC_port** block and set the parameters as shown below to identify its connection to another part of the diagram (the load subsystem in our case):

    Port number = 1, **Port location** = Right

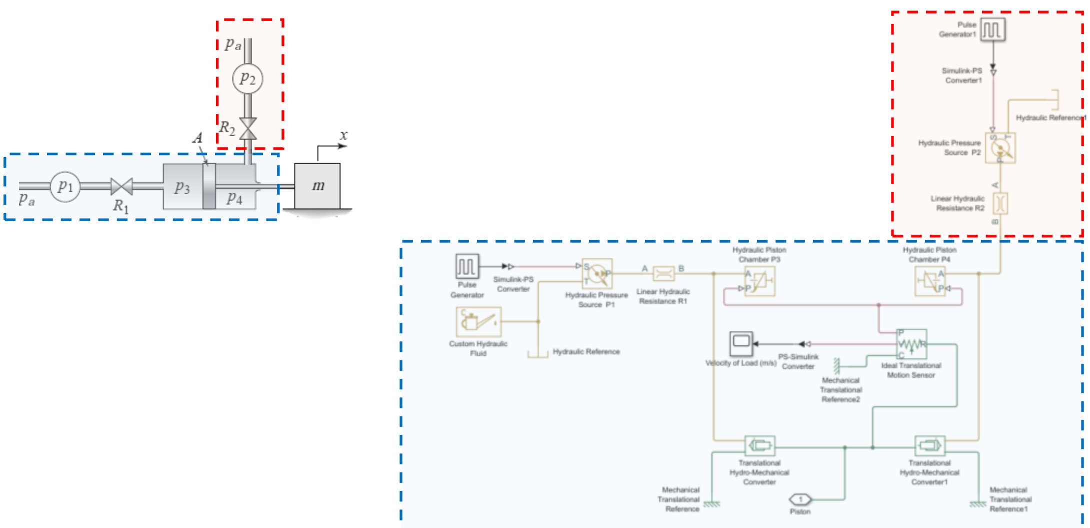
17. The size of the piston chambers is controlled by the **displacement** of the piston. We need to use a ***sensor*** to measure the **displacement** of the piston and provide that information to the **Hydraulic Piston Chambers**.
18. Select and place the **Ideal Translational Motion Sensor** block and a **Mechanical Translational Reference** block from the following library:
    - **Simscape > Foundation Library > Mechanical > Mechanical Sensors > Ideal Translational Motion Sensor**

      In this block, the **C port** provides the **reference frame**. The **V output port** gives the **velocity** signal, and the **P output port** gives the **position** signal. Set the block parameters as below:

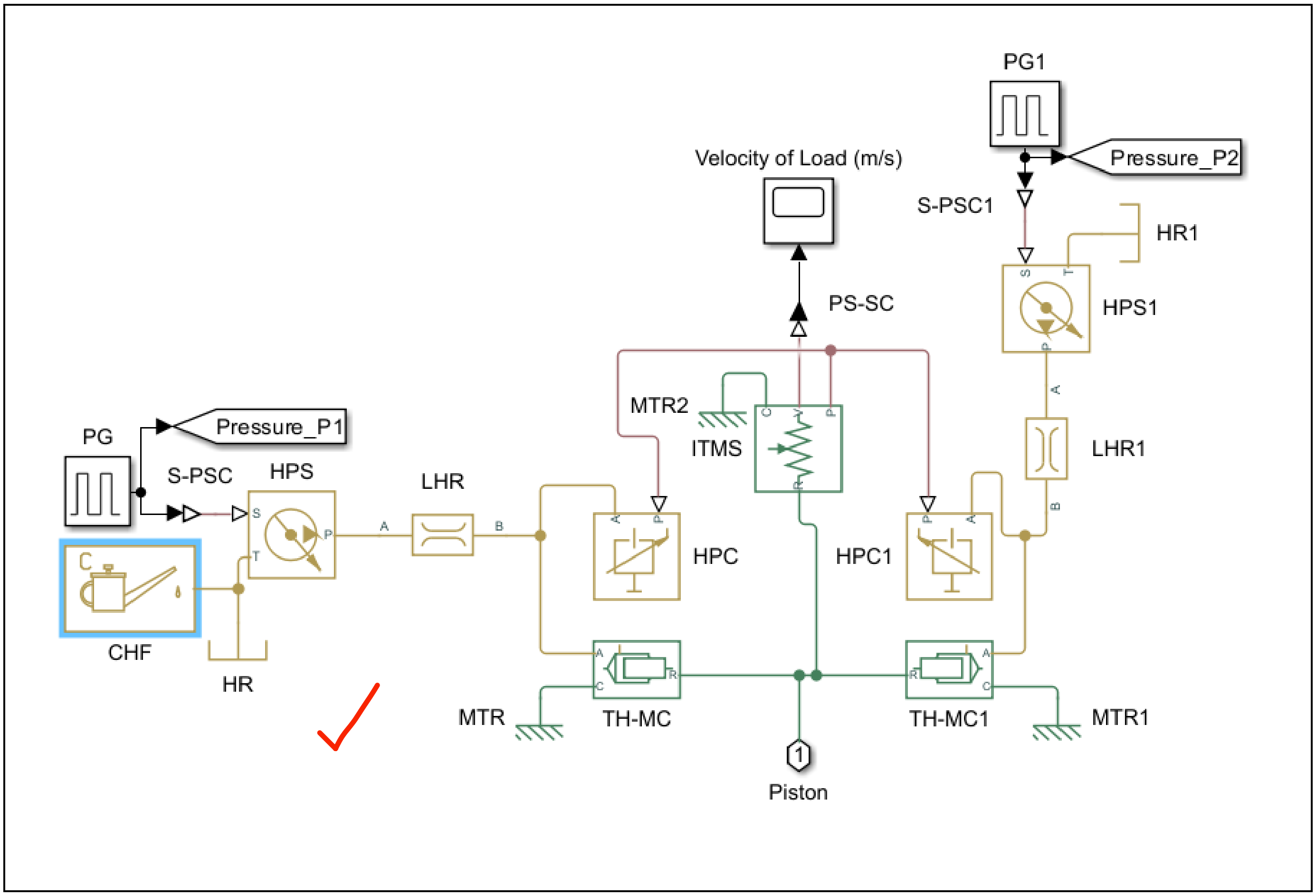
      Initial position = 0 m
    - **Simscape > Foundation Library > Mechanical > Translational Elements > Mechanical Translational Reference**
19. Connect the **P** output of the **sensor** to the **P** input of each **Hydraulic Piston Chamber** as shown below,
20. Insert a **PS-Simulink Converter** block from the **Simscape > Utilities** library and connect it to the **V port** of the **sensor** as shown below. This block converts a physical signal (PS) to a unit-less **Simulink** output signal. Connect the output of this block to a **Scope** block.



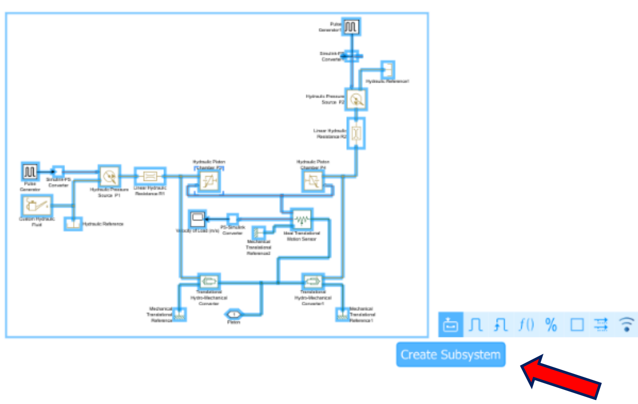
21. At this point the **model of the hydraulic subsystem** should now appear as shown below:



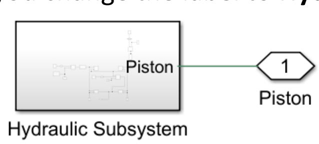
22. Provide your final **Simscape** model diagram of **hydraulic subsystem** for **Part A1** below:



23. **[Creating the Hydraulic Subsystem Block]()**: Because this diagram is getting rather detailed, we will now create a **subsystem** to represent our model thus far. Use a standard **Simulink** method to do this. For example, use the mouse to enclose all the elements in a bounding box and then select **Create Subsystem** from the **Edit** window.



You should see the following model after you change the label to **Hydraulic Subsystem** and reorient the blocks.



A.2 Modeling of Mechanical Subsystem

Now we are ready to model the **purely mechanical** part of the system. This consists of the load **mass** and a **spring**, which we have added to provide a **restoring force** on the piston to center it when the pressures are no longer applied. The model of this subsystem is shown below.

24. Select and place the following elements and components from the **Simulink Library Browser.**

- **Simscape > Foundation Library > Mechanical > Translational Elements > Mass**

  Set the **Mass** block parameters as below:

  Mass = m kg, **Initial velocity** = 0 m/s

- **Simscape > Foundation Library > Mechanical > Translational Elements > Translational Spring**

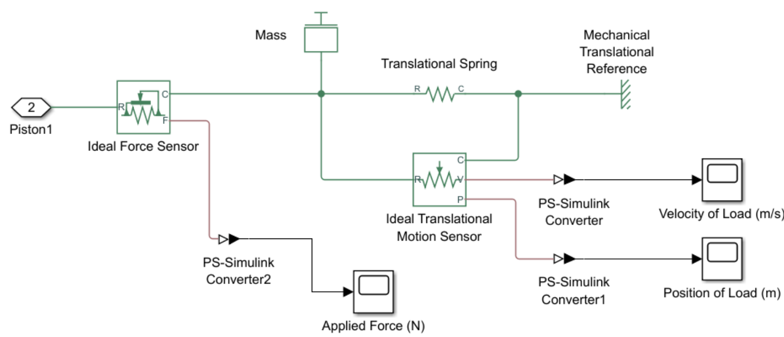
  Set the **Translational Spring** block parameters as below:

  Spring rate = k N/m, **Initial deformation** = 0 m

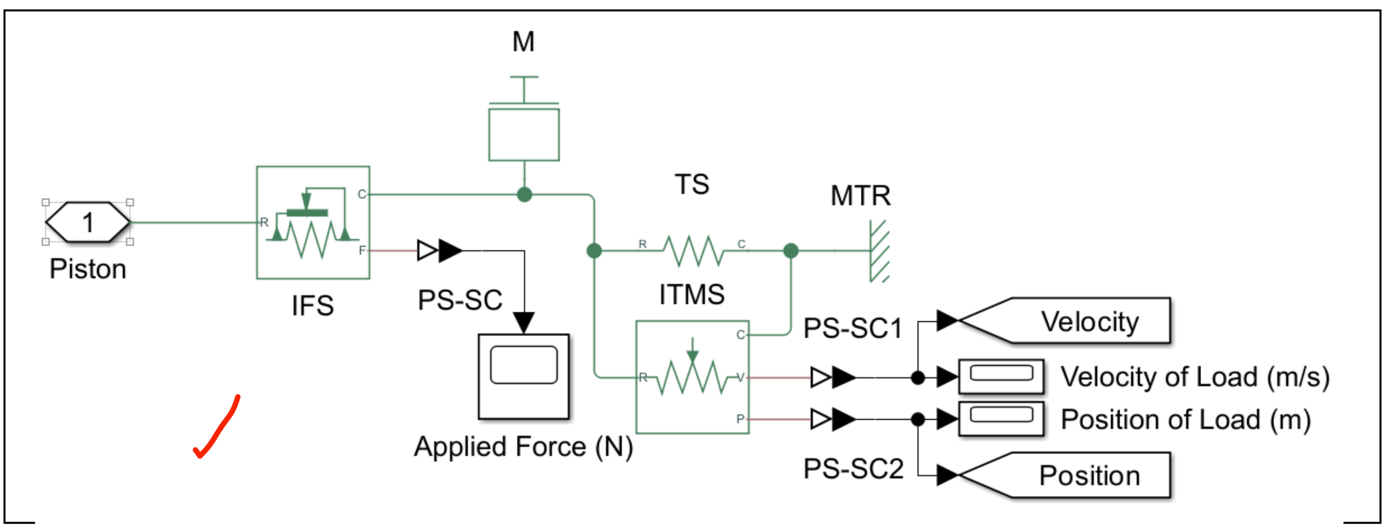
- **Simscape > Foundation Library > Mechanical > Translational Elements > Mechanical Translational Reference**
- **Simscape > Foundation Library > Mechanical > Mechanical Sensors > Translational Motion Sensor**
- **Simscape > Foundation Library > Mechanical > Mechanical Sensors > Ideal Force Sensor**
- **Simscape > Utilities > Physical Modeling Connection Port**

  Locate it as shown and label it as **Piston**.

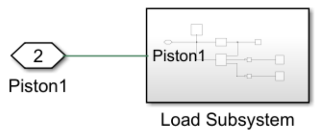
- **Simscape > Utilities > PS-Simulink Converter**
- **Simulink > Sinks > Scope**



25. Provide your final **Simscape** model diagram of **mechanical subsystem** for **Part A2** below:

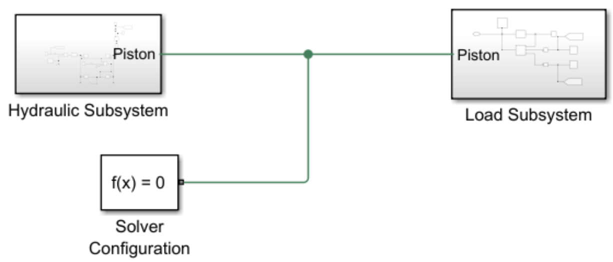


26. **Creating the Mechanical Subsystem Block**: Now create a **subsystem** model as done previously for the **Hydraulic Subsystem**. You should see the following model after you change the subsystem block label to **Load Subsystem**.



27. To assemble the system model, delete the port symbols and connect the input and output ports as shown below. Notice that the **port names match**. If it is required edit the **PMC port** connection names inside one of the subsystems.

28. Now select and insert a **Solver Configuration** block from the **Simscape > Utilities** library and connect it as shown.



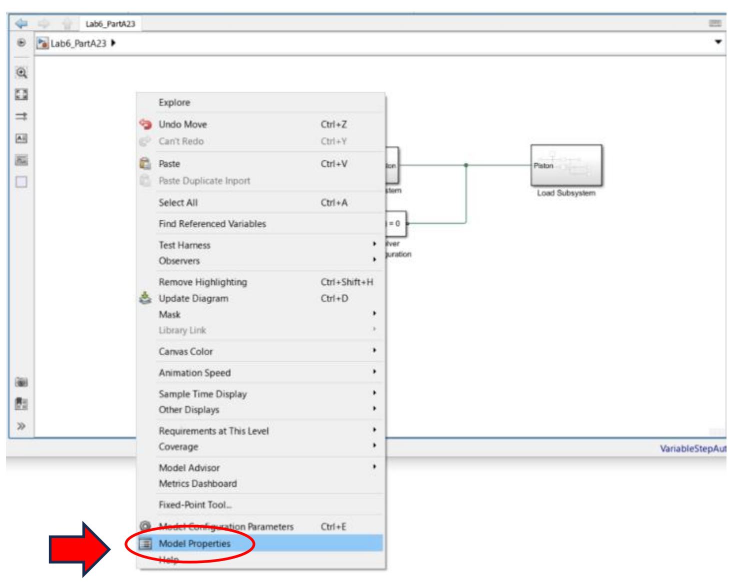
A.3 Setting the Parameters Values

In addition to specifying the **Stop Time,** to **Run** the simulation we must specify the numerical values of the various parameters. One way to do this is to assign values to the variables in the **MATLAB Command** window.

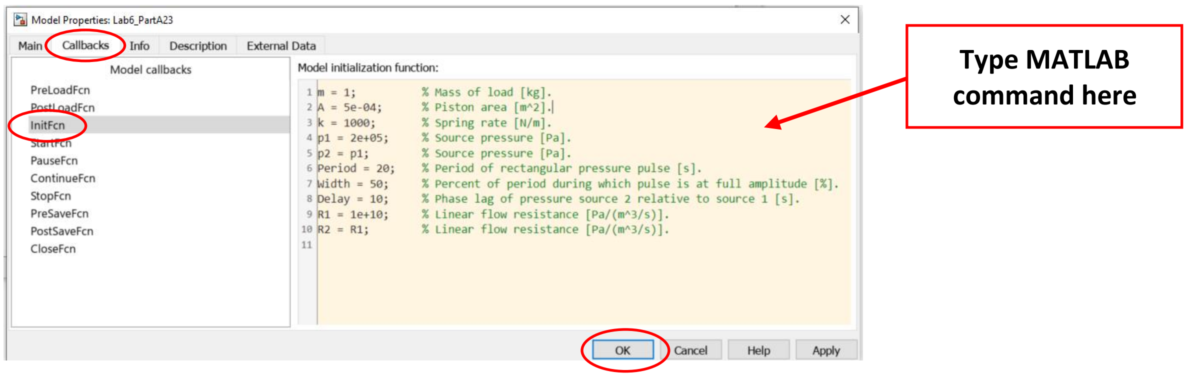
However, if you are going to share the model file, a more convenient way is to store the values in the model file itself. You could do this by typing the values in the **Block Parameter** dialog boxes, but then you would not have the variables available for use in another program.

To store the values in the model file, you can create a **MATLAB script** by following the steps below.

29. ***Right-click*** in the **Simulink** model window, select **Model Properties** from drop down menu. This will bring up the **Model Properties** dialog box.



30. Select the **Callbacks** tab.
31. Select **InitFcn** from the list of **Model callbacks**.
32. Then, type **MATLAB** commands into the pane under **Model initialization function**. Click **Ok**. These commands will be executed at the start of model simulation. Note that an asterisk will appear next to a callback function that has commands written into it.

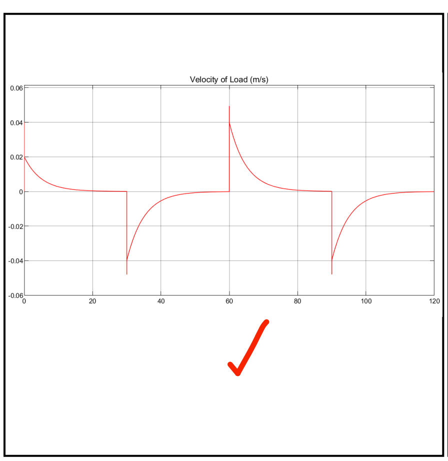
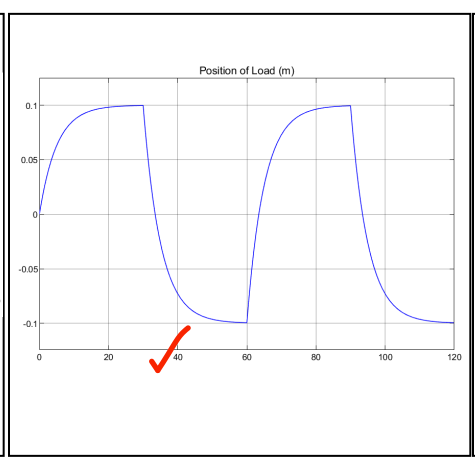
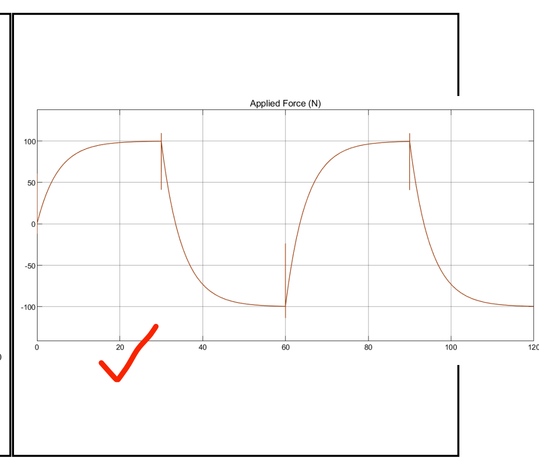


The Model Parameters:

```
m = 5;             % Mass of load [kg].
A = 5e-04;         % Piston area [m^2].
k = 1000;          % Spring rate [N/m].
p1 = 2e+05;        % Source pressure [Pa].
p2 = p1;           % Source pressure [Pa].
Period = 60;       % Period of rectangular pressure pulse [s].
Width = 50;        % Percent of period during which pulse is at full amplitude [%].
Delay = 30;        % Phase lag of pressure source 2 relative to source 1 [s].
R1 = 1e+10;        % Linear flow resistance [Pa/(m^3/s)].
R2 = R1;           % Linear flow resistance [Pa/(m^3/s)].
```

A.4 Running the Simulation

33. Click on the **Model Settings** icon in the **MODELING** tab to open the **Configuration Parameters** window, click on the **Solver** drop down menu and select the **ode23t** solver. Then click **OK**.
34. **Save** the model file as **Lab5_PartA.slx**. Set the **Stop Time** to **120 seconds** and **Run** the simulation.
35. Since we have embedded the **Scope** blocks in the **Load Subsystem**, we must double-click on that subsystem to see the **Scope**. Double click on the **Scopes** to see the load position and load velocity graphs. Provide the graphs below:

Load Velocity (m/s)	Load Position (m)	Applied Force (N)
		

36. Measure the <u>maximum displacement</u> of the mass from the initial center position, the <u>maximum speed</u> of the mass and the <u>maximum applied force</u>. Insert the values in **Table 1**.

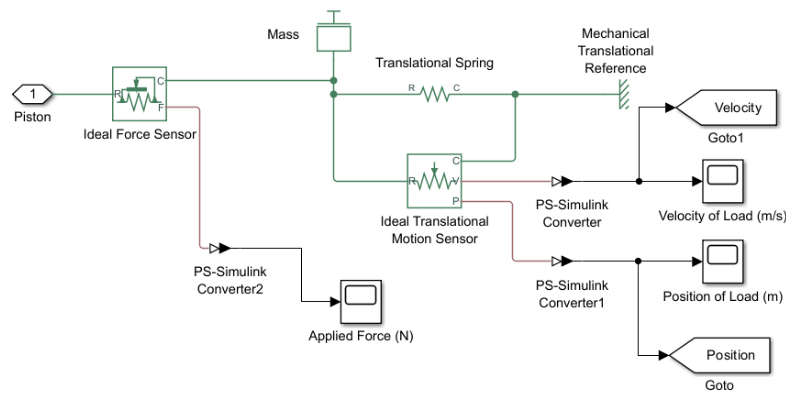
Table 1

Maximum Displacement (cm)	Maximum Speed (cm/s)	Maximum Force (N)
8.648 cm	4.021 cm/s	86.47 N

37. It can sometimes be helpful to use the **signal routing functionalities** to <u>simplify</u> the results view.
38. Double-click on the **Load Subsystem** and add the **Goto** blocks from the **Simulink > Signal Routing** library as shown below. The **Goto** block enables a **Tag** to be placed on a signal and the signal to be received using a **From** block.
39. Set the **Goto** block parameters for **load's velocity** and **load's position** as below:

Goto tag = Velocity, **Tag visibility** = global

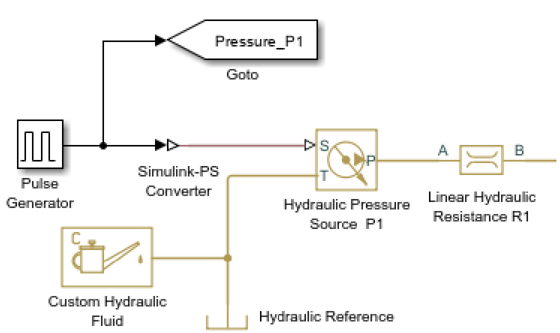
Goto tag = Position, **Tag visibility** = global

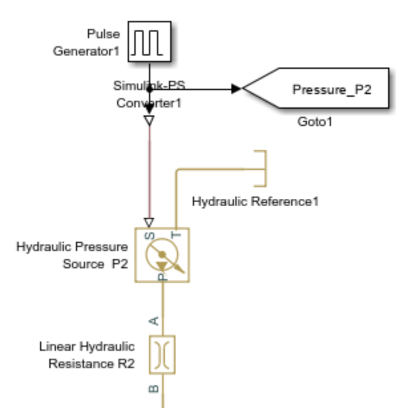


40. Double-click on the **Hydraulic Subsystem** and add the **Goto** blocks from the **Simulink > Signal Routing** library as shown below. Set the **Goto** block parameters for each **Pulse Generator** blocks as below:

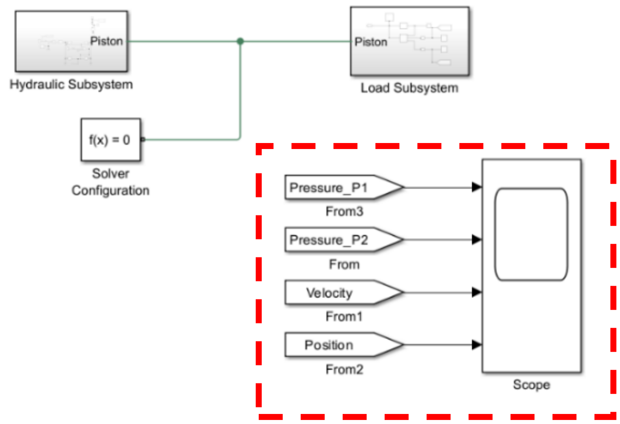
Goto tag = Pressure_P1, **Tag visibility** = global

Goto tag = Pressure_P2, **Tag visibility** = global

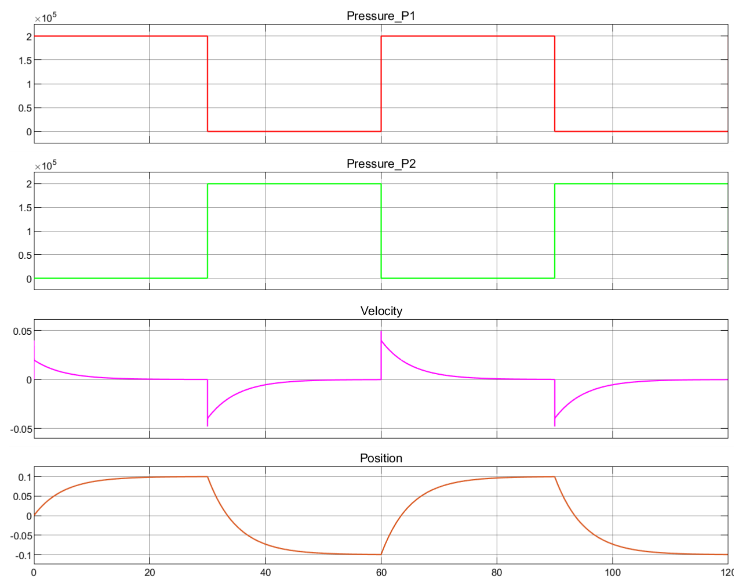




41. Return back to the **Simulink** model main window. Add one **Scope** block from the **Simulink > Sinks** library and four **From** blocks from the **Simulink > Signal Routing** library and connect them as shown below. The **From** block enables the **Tag** from a signal created using a **Goto** block to be received. Set the **From** blocks Tags according to the **Goto** blocks.



42. **Run** the simulation for **120 seconds**. Open the **Scope** block in the main window. Provide the graph below.

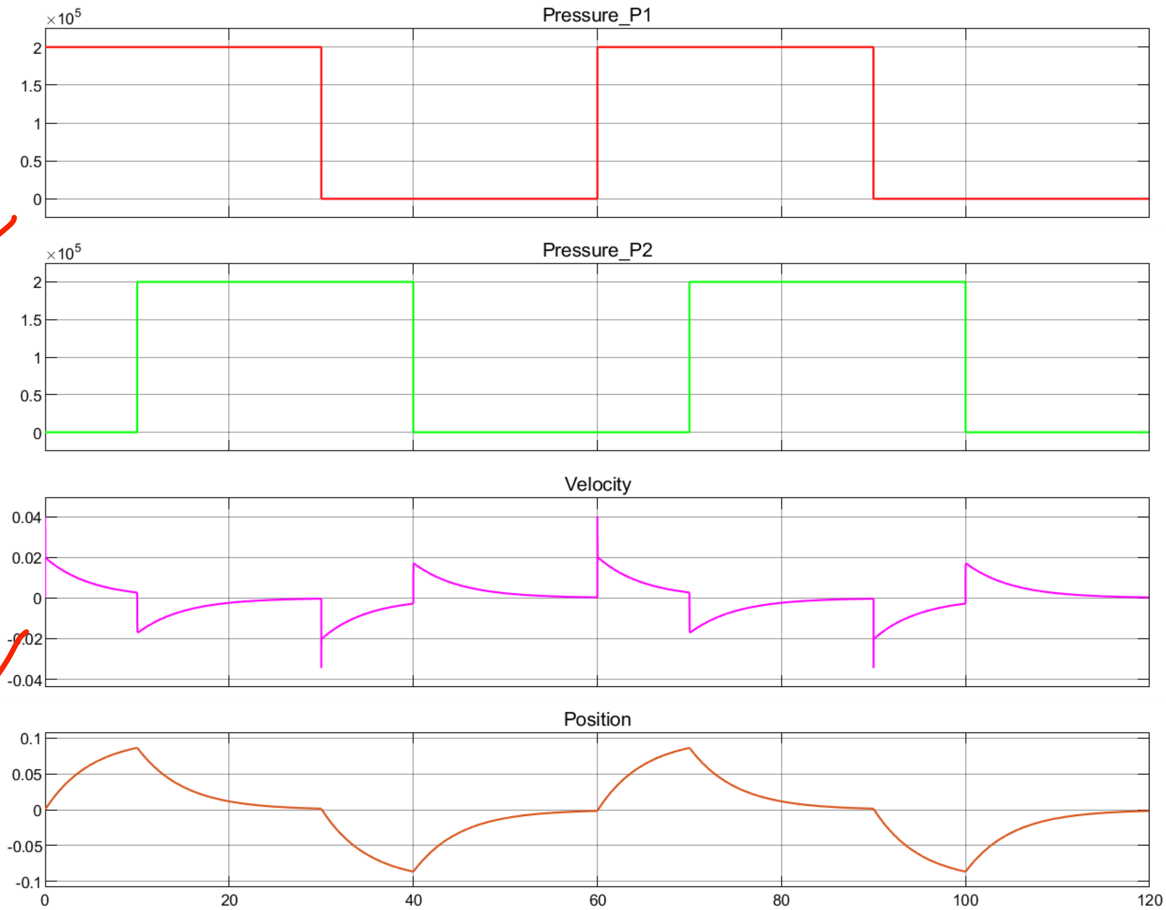


43. Briefly explain the operation of system based on the timing sequence of the applied pressures p_1 and p_2.

p1 & p2 alternate to control phases in the system's operation, triggering transitions and outputs that follow the applied pressure patterns to maintain a cyclic process of 30 seconds because of the delay applied.

44. To see the effect of the restoring spring force we can change the timing sequence of the applied pressures p_1 and p_2. Open the **Model Parameters** dialogue window and change the parameter **Delay** to **10 seconds**. In this case the pressure source p_2 will be activated **10sec** after than the pressure source p_1.

45. **Run** the simulation for **120 seconds**. Open the **Scope** block. Provide the graph below.

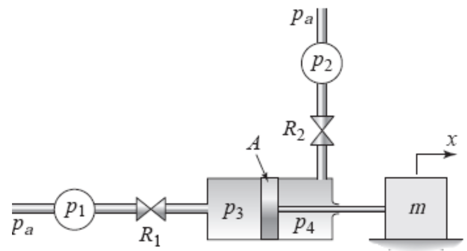


46. Briefly explain effect of changing the **Delay** parameter on the system operation. Discuss the effect of the **spring** and the restoring force to positioning the piston in the center when the pressures are equal or no longer applied.

The Delay parameter determines how quickly the system responds to pressure changes. A longer delay slows the response, causing the piston to move more gradually. A short delay causes the piston to react quickly. The spring and restoring force help to keep the piston in the middle. When the pressures P1 and P2 are equal or not applied, the spring pulls the piston back to the center. This keeps it stable and prevents it from moving off center.

Post Lab Assignment

1. Consider the ***double-acting piston and cylinder*** system. The device moves the **load mass** m in response to the **pressure sources** p_1 and p_2. Assume the fluid is incompressible, the resistances are linear, and the piston mass is included in m. Suppose that there is a friction between the mass m and the surface with the friction coefficient of μ and a **spring**, which we have added to provide a **restoring force** on the piston to center it when the pressures are no longer applied.

   Equation of motion of the load mass can be determined as below:

   $$\boldsymbol{m\ddot{x}(t) + A^2\rho(R_1 + R_2)\dot{x}(t) + Kx(t) + \mu mg = A(p_1 - p_2)}$$

   where,

   Load mass: $m = 5\ kg$

   Gravity acceleration: $g = 9.81\ m/s^2$

   Friction coefficient: $\mu = 0.6$

   Spring coefficient: $K = 1000\ \ N/m$

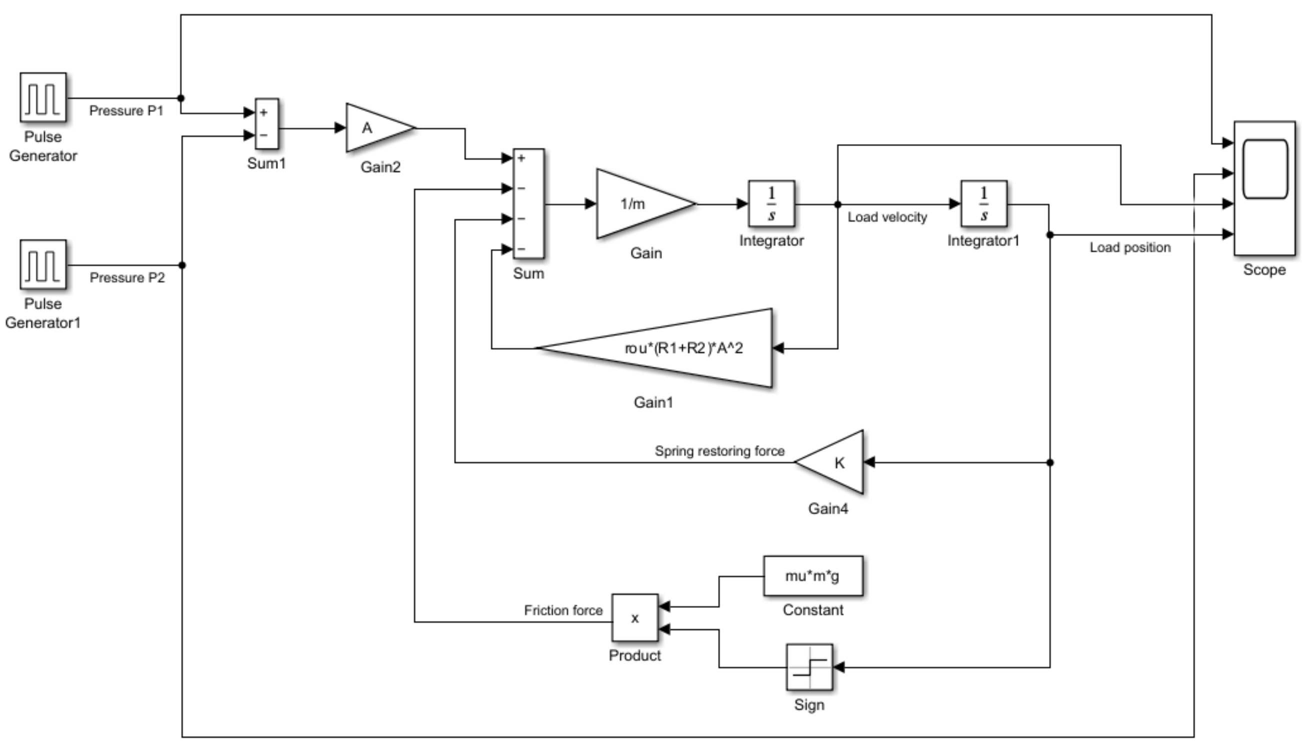
   Piston area: $A = 5 \times 10^{-4}\ m^2$

   Hydraulic resistance: $R_1 = R_2 = 10^{10}\quad Pa.s/m^3$

   Source pressures: $p_1 = p_2 = 2 \times 10^5\quad Pa$

   Fluid density: $\rho = 1\ \ kg/m^3$

   Build the following system using **Simulink** block diagram model of the system. Set the component values as parameters and assign the values in the **Model Properties** as shown in **Part A3** of the lab manual.

Set the Pulse Generator blocks parameters as shown below:

Pressure P1:

Amplitude = $2 \times 10^5\ Pa$, Period = 60 sec, Pulse Width(%) = 50, Phase delay = 0

Pressure P2:

Amplitude = $2 \times 10^5\ Pa$, Period = 60 sec, Pulse Width(%) = 50, Phase delay = 30 sec

Run the simulation for **120 seconds** and provide the following components:

a. The Simulink model of the system and the Simulink .slx file.

b. Explain how the Friction force has been generated and the reason for having the Sign block.

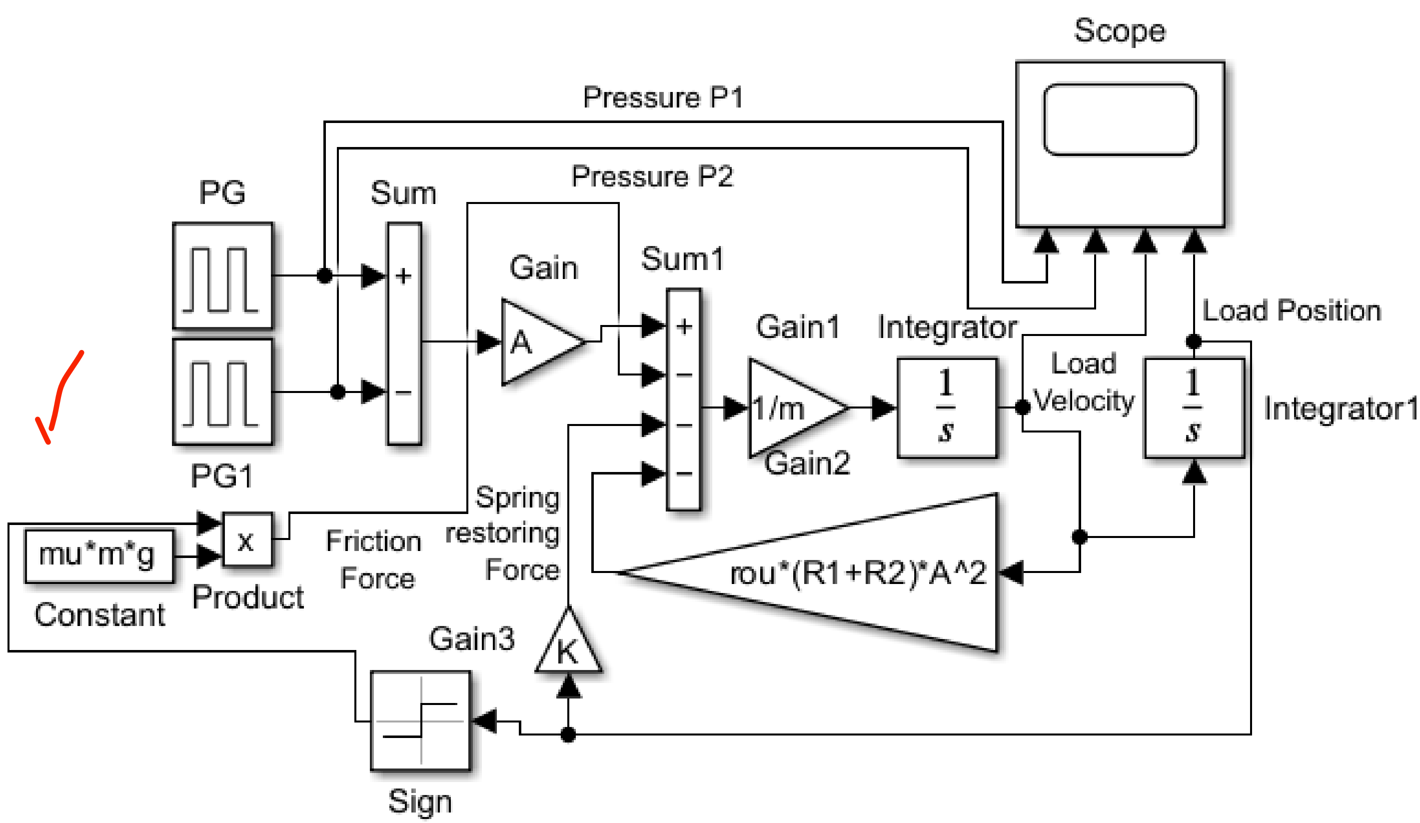
c. Plot the Pressure P1, Pressure P2, Load velocity and Load position as separate graphs in a single Scope with white background and appropriate titles. Provide the graphs.

d. Determine the maximum speed and maximum displacement of the mass from the center point.

e. Decrease the friction coefficient μ to zero which results to have a frictionless surface. Run the simulation and plot the new graphs. Provide the graphs.

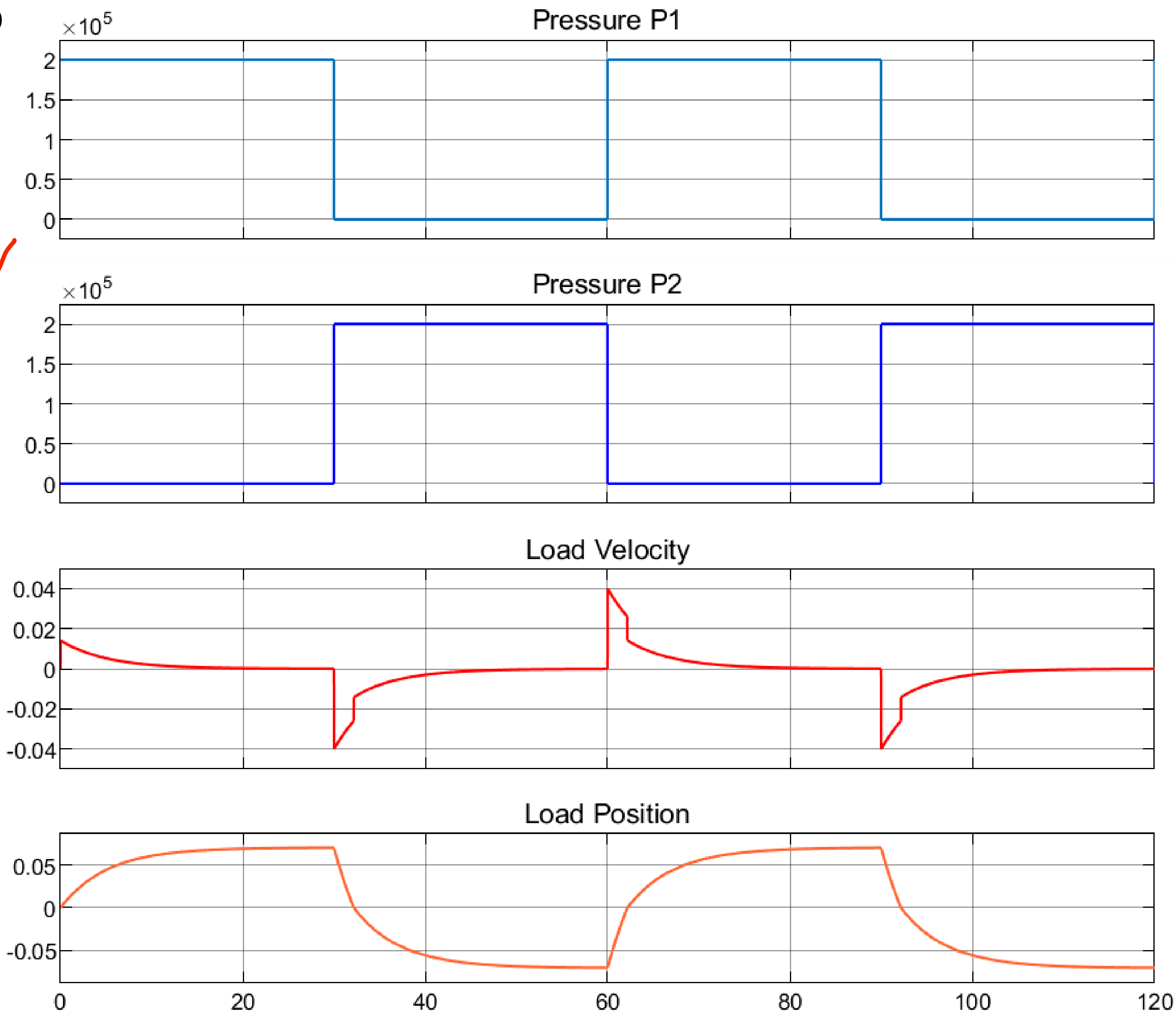
f. Determine the maximum speed and maximum displacement of the mass from the center point in this case and explain the effect of having no friction in the maximum displacement.

A)



B) In Simulink, the friction force is calculated by multiplying the friction coefficient by the gravitational force, which yields a constant number. The Sign block uses velocity to calculate the friction direction, which might be +1, -1, or zero. This indicates that the friction force opposes the motion, acting positively in one direction and negatively in the other. The Sign block is required to accurately simulate kinetic friction, which constantly resists the direction of motion.

C)

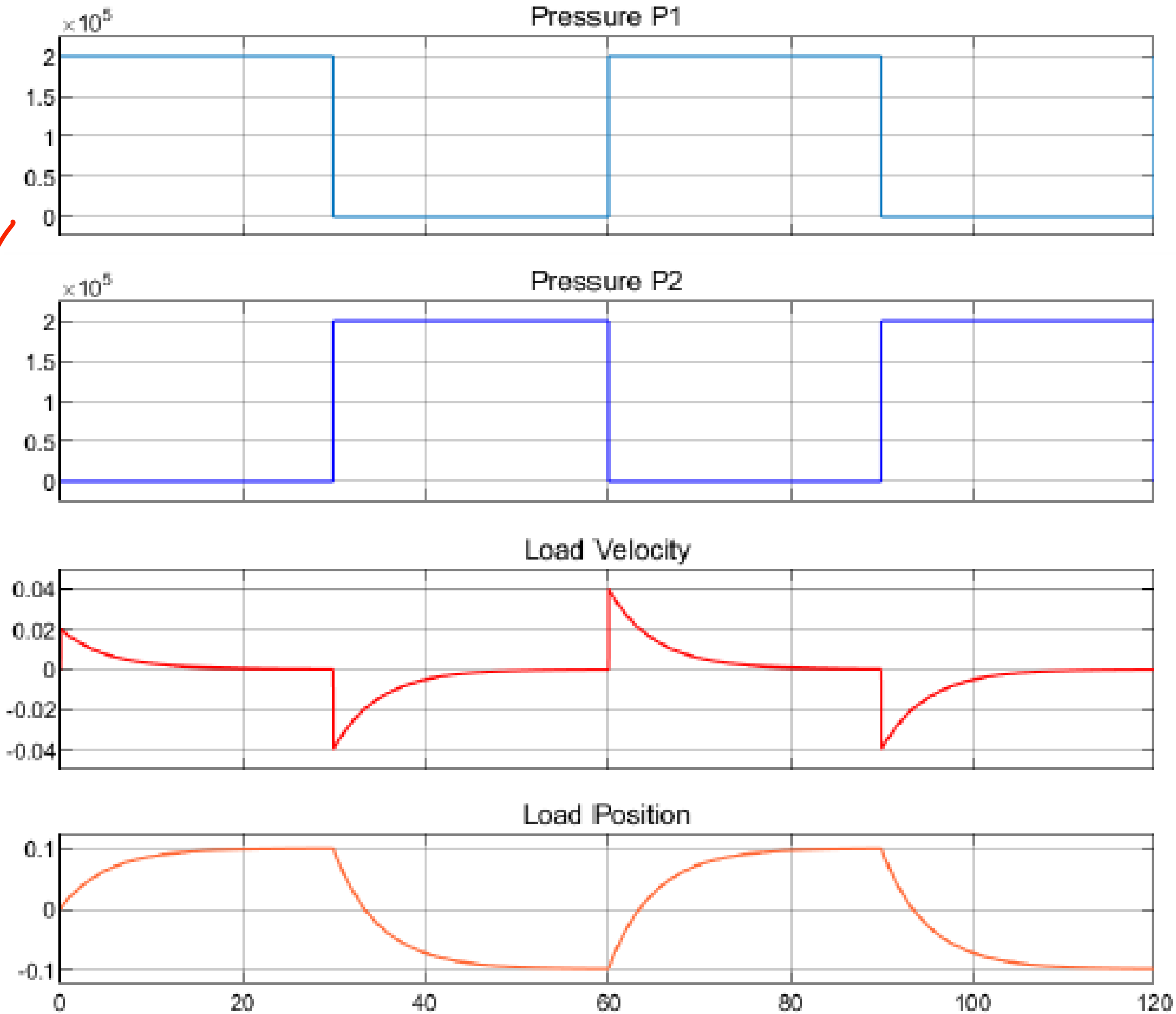


D)

Max Velocity = 4 cm/s

Max Displacement = 7.5 cm

E)



F)
Max Velocity = 4 cm/s
Max Displacement = 10 cm

Explain the effect of having no friction on the maximum displacement. [-1]