Modelling and simulation of a 4-dof forwarder loader

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Contents

1 Introduction

The main intention of this exercise is to create a simulation model of a 4 DOF actuator and simulate in real time system. In the initial we are creating an offline model and then we are creating real time simulation model. The offline model created is further divided into two parts modelling mechanics and hydraulics. In the mechanics modelling process the model is tested against the gravity, then the model is connected to the hydraulics part.

The simulation is created by MATLAb and SIMULINK, Sim mechanics is used to model the multi body system and Simulink is used to create the hydraulics of the model. The whole model is compiled using the Simulink solver. In the second part of the assignment we will be deploying the system to the real-time simulation platform, the command signals would be given through joystick connected to the PC.

The most important stage in any design process is testing and validating of the design, for this to happen there is a need to create a real prototype. In reality building a real prototype is time consuming, expensive and it cannot be used for destructive testing methods. When we create a simulation of a system, we are depicting the reality virtually. We can analyze the behavior of any non-linear dynamic system. However, complex is the analysis, it could be solved, and different methods involved in the design can be validated. It is easy to study the impact of different parameters for the same external conditions and tune the values for the best responses. The cost for making a prototype would be more, therefore it is better to model, simulate, analyze and then build.

In this document, we will explain the assumptions in the design we have used and how we have planned to build the model and simulation part by part. Also, the problems faced when we were creating the model and simulation, finally the result obtained by modelling and simulation.

2 General Description

This system is used for loading and unloading the logs of wood, it is also called as knuckleboom loaders. Hydraulically operated boom is mounted on to the trailer and it is towed by the truck tractor.

2.1 System Features

Hydraulic log forwarder features:

- It is diesel driven.
- The work and transport functions on the machine are obtained through the supply pressure from the pump
- An articulated steering and forward-reverse is available for the operator while operating the loader and also during the transportation.
- A hydrostatic wheel transmission with variable displacement pump and motor, automatically limits the driving force and thereby preventing the engine to stall. Therefore, it offers a very smooth operation.
- The boom replicates the features of the human arm, the boom is rotated by rack and pinion mechanism. The hydraulic loader consist of 4 cylinders.
- The end of the boom is attached with the hydraulic grapple, which is used to pick and place the log.
- These machines are used to load the huge logs of wood into a truck, the environment in which these machines function are mostly in forest areas.
- The operator or user controls the boom by 2 joysticks installed in front of the chair armrests. This system utilizes remote control system and permits both multi-function speeds and delicate maneuvering.

2.2 High-level architecture

The major components and structure in this system are:

- Diesel Engine: it is the main source of power to the system
- Pumps: Flow and pressure is generated through the pump.
- Cylinder: It acts as an actuator, transmitting the flow energy into mechanical energy.

- Valves: The pressure is controlled with pressure control valves, while modelling the hydraulic circuit we have used 4/3 directional valve.
- Pillar: it is structure which supports lift, tilt and extension. The base of the pillar consists of rack and pinion which gives the rotational movement for the whole system.
- Lift: As the name implies it helps in lifting, it is connected to the tilt with the 4 bar linkage.
- Tilt: this structure comprises of extensions and as well as helps in changing the angle to reach the work part.
- Extensions: it is a structure that has linear motion that is to extend and retract. There are 2 extensions one is driven by the hydraulic force and other one driven by the chain drive.
- Grapple: it is the end part, which helps in grabbing the log and placing it.

2.3 Implementation plan

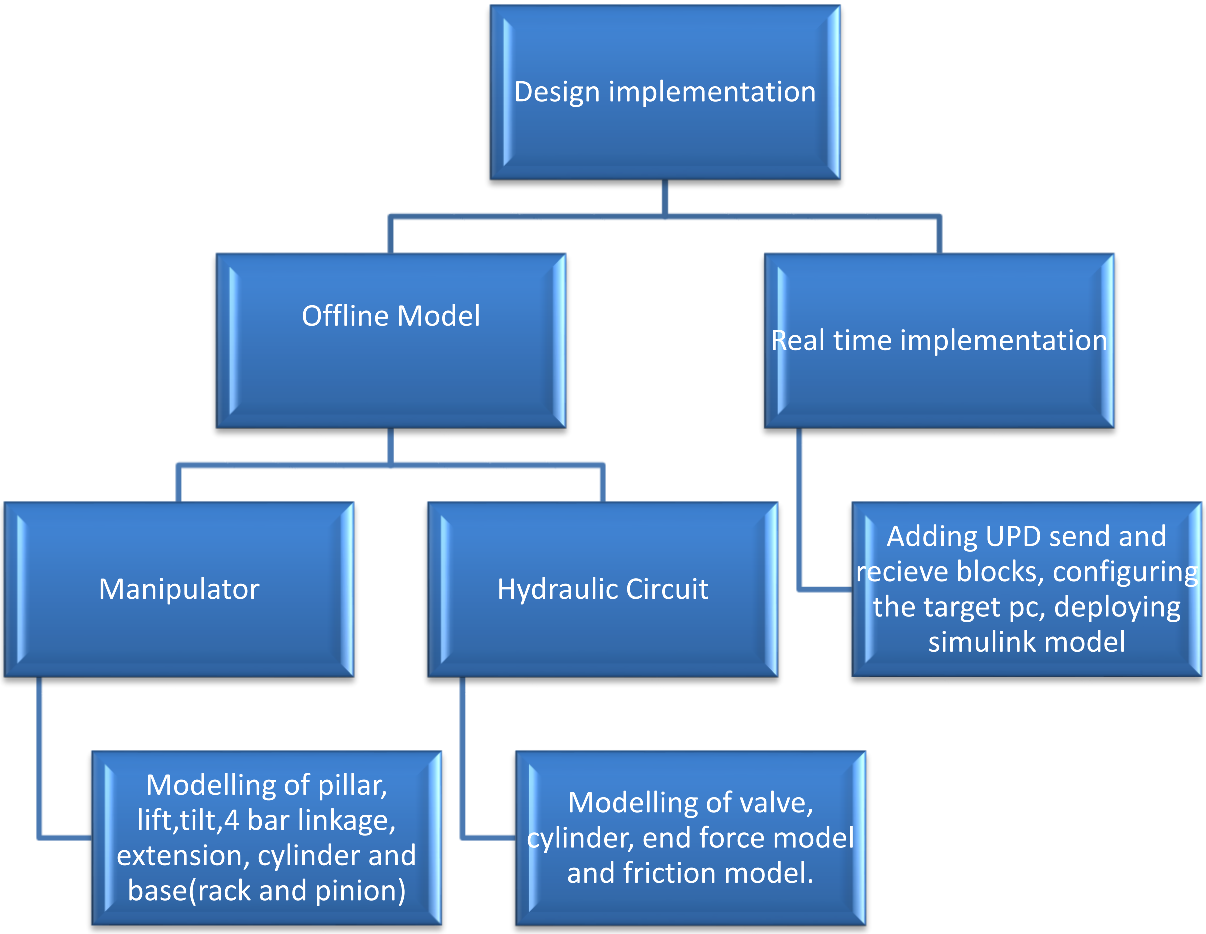

Figure 1: Implementation of the course exercise

3 Modelling

Modelling phase is divided into 2 main sub systems, namely – Hydraulics model and Mechanical model. Further in this document we are discussing about the features of these 2 models in detail.

3.1 Modelling mechanics

Modelling of the manipulator comprises of modelling of several components, modelling of each and every structure and the subsystem is explained below in detail:

Pillar and Lift

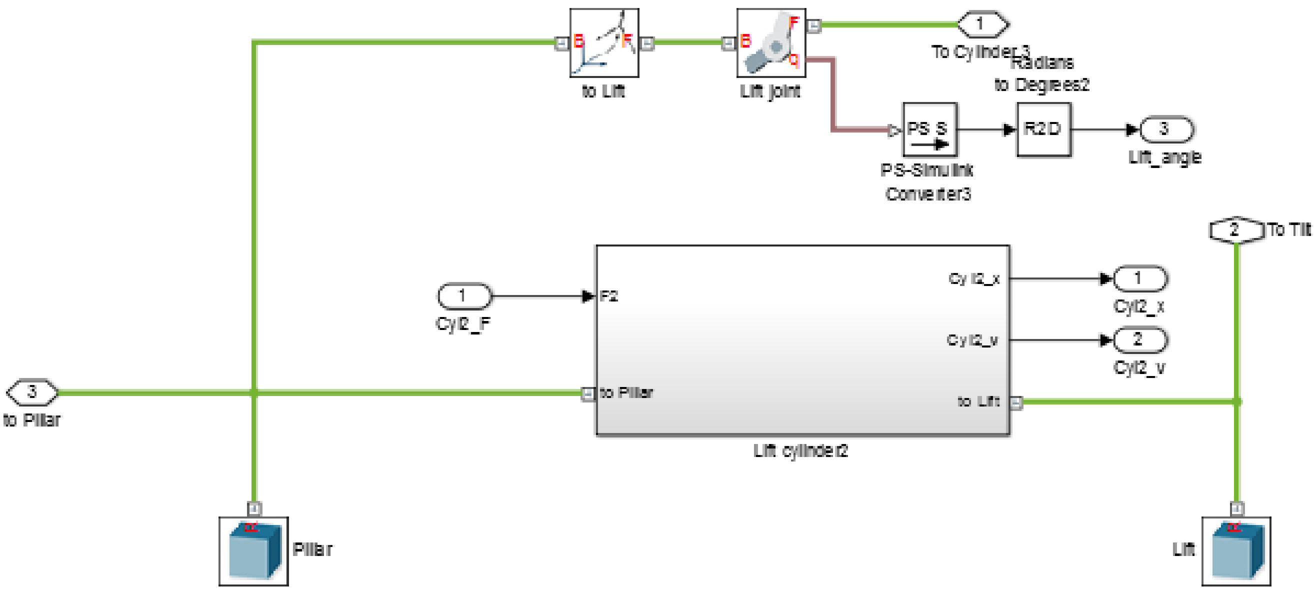

Figure 2: Pillar and lift connection

The model above shows the connection of pillar and lift. With the help of the actuating cylinder 2 the lift can make the up and down movement. The lift and pillar were modelled according to the distance between the joints given in the course exercise pdf.

4 bar linkage

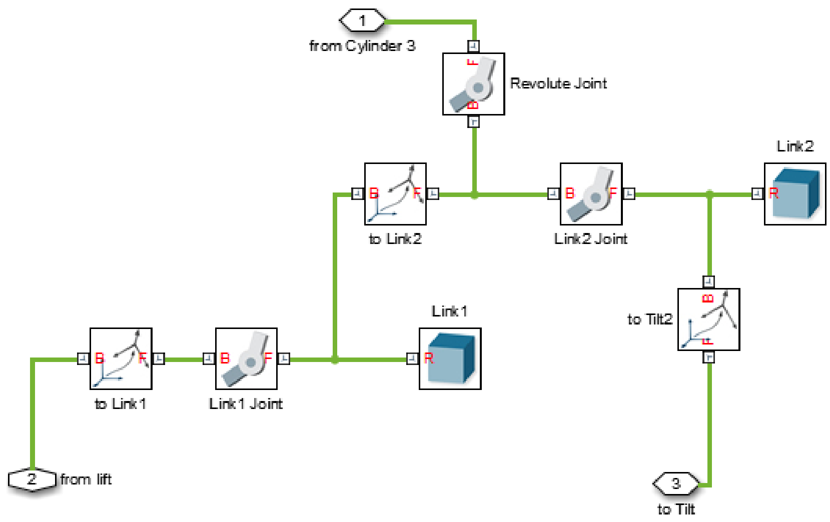

Figure 3: 4 bar linkage model

This linkage is the connection between lift, link1, link 2 and tilt. Here the lift has up and down movement, whereas the tilt has semicircular movement, this is done by the actuating cylinder 3.

Extension 1 and 2

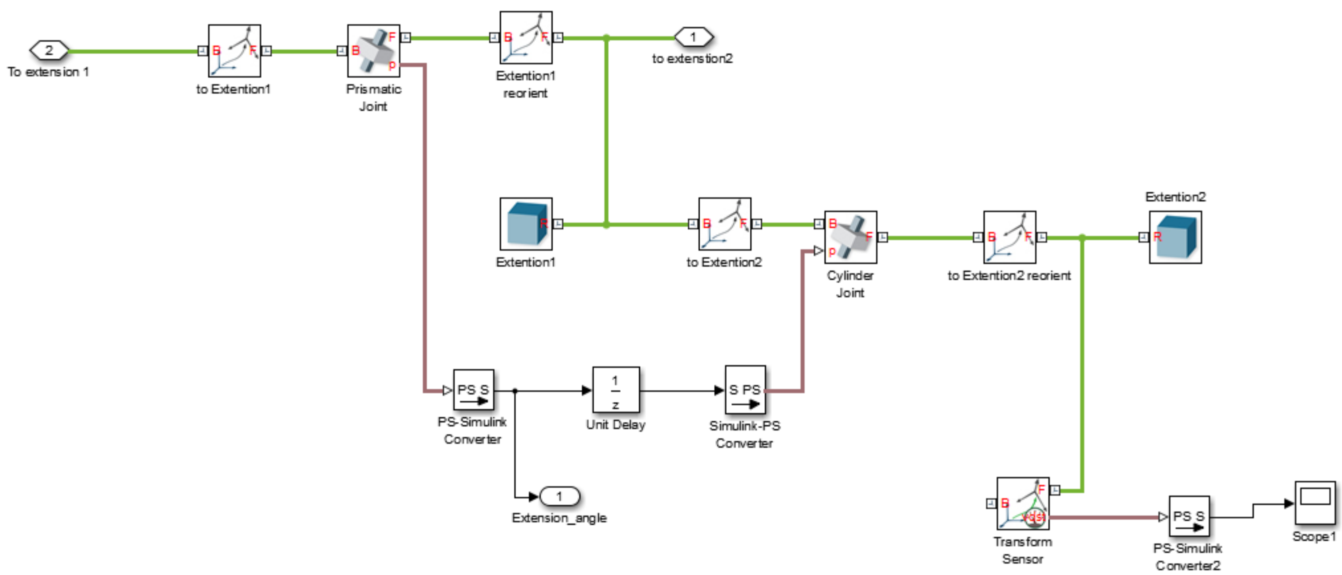

Figure 4: Extension 1 and 2 block diagram

It is housed in the tilt, it has forward extending and retracting movement. One of the extension is driven by cylinder 4 while the other with the unit delay.

Cylinder 2

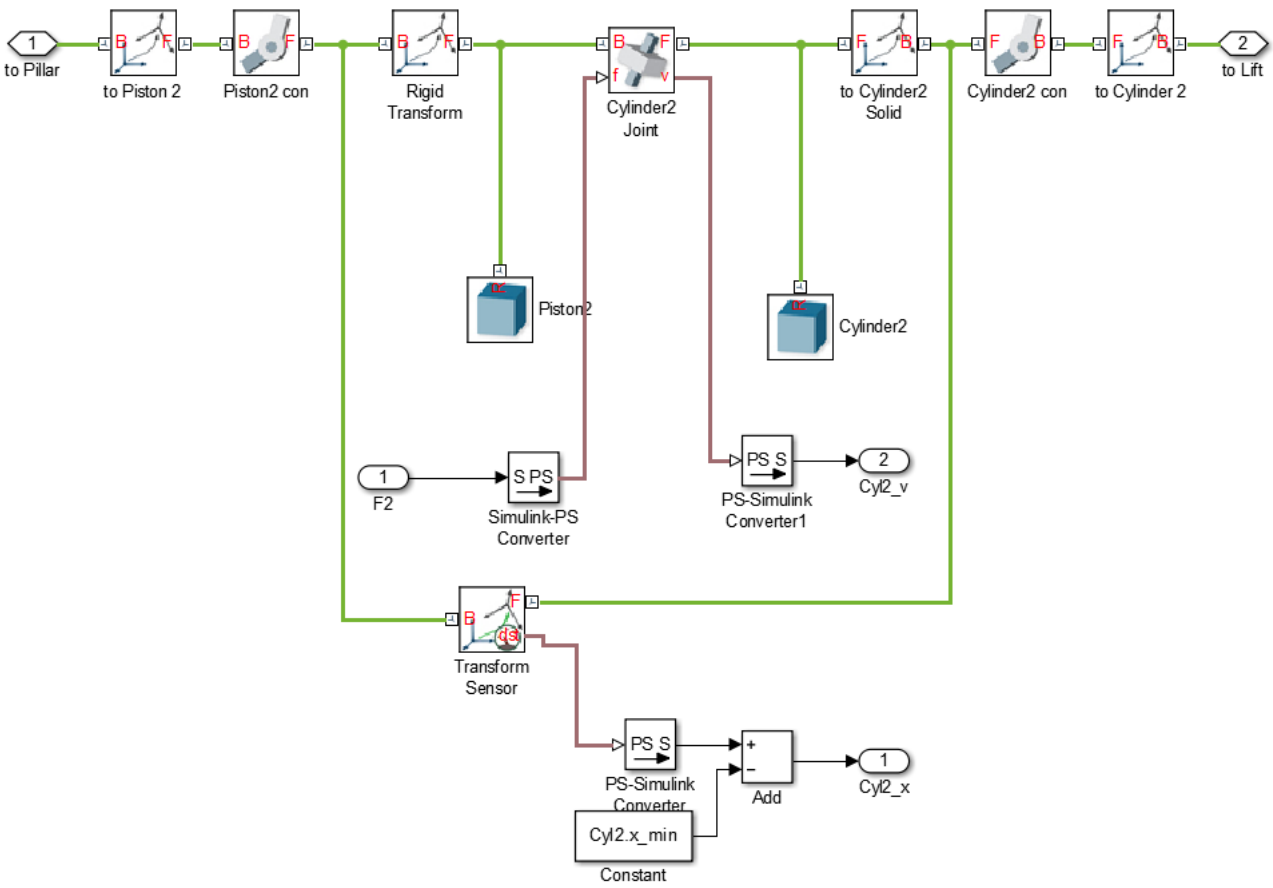

Figure 5: Simulink model of cylinder 2

Cylinder acts as an actuator, this transforms the hydraulic force into mechanical movements. Which for example is seen in movement of lift.

The stroke length is calculated by subtracting the cylinder minimum length from the length between the piston and cylinder joints. In similar way cylinder 1 is used to give linear motion to rack which in turn rotates the pinion. Cylinder 3 helps in movement of tilt through 4 bar linkage. Cylinder 4 helps in extension and retraction.

Rack and pinion

Rack derives the linear motion from cylinder 1 which gives the rotary motion to the pinion. The importance of rack and pinion mechanism is to give rotational movement to the pillar.

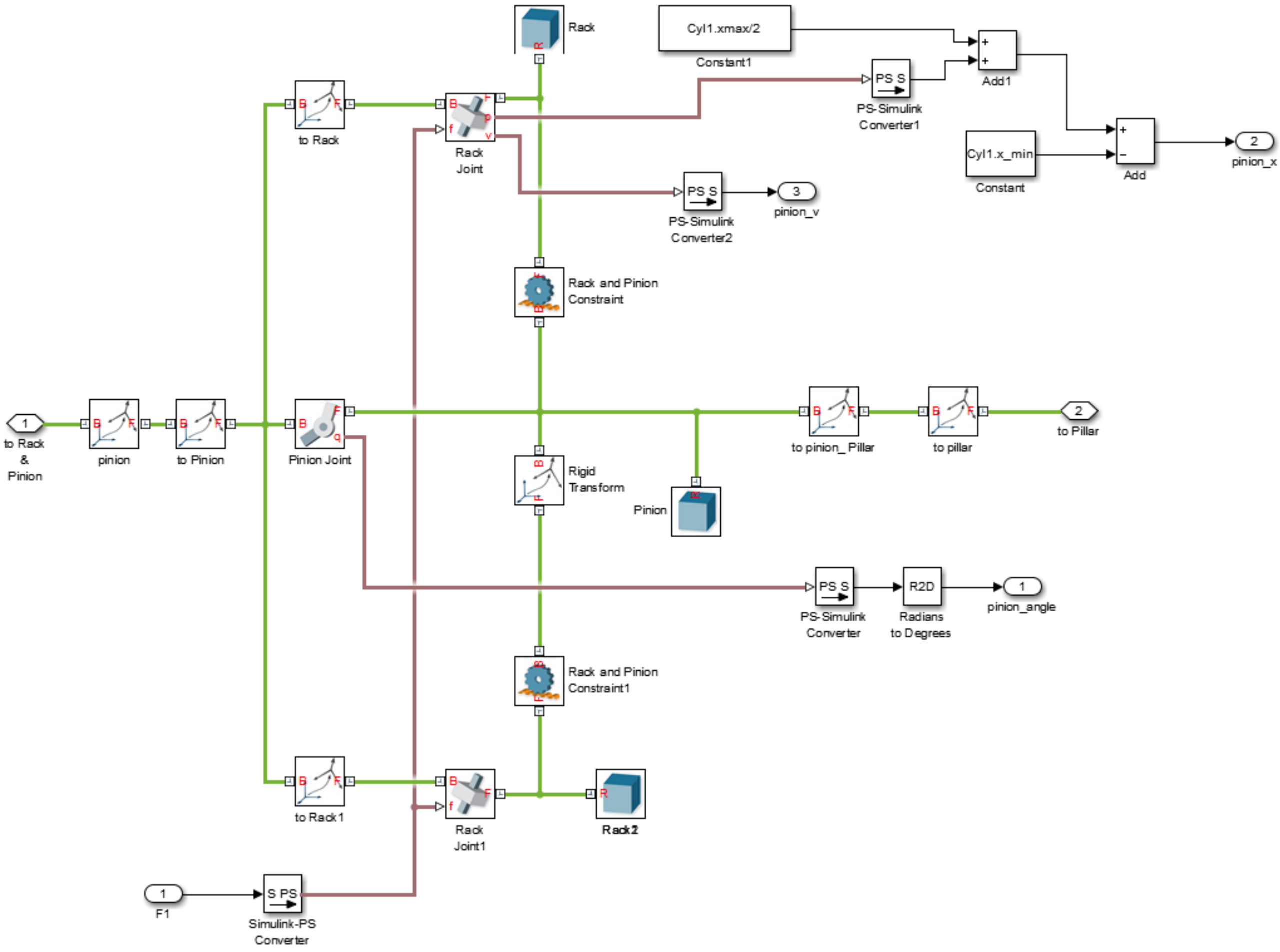

Figure 6: Model of rack and Pinion

3.2 Hydraulics Model

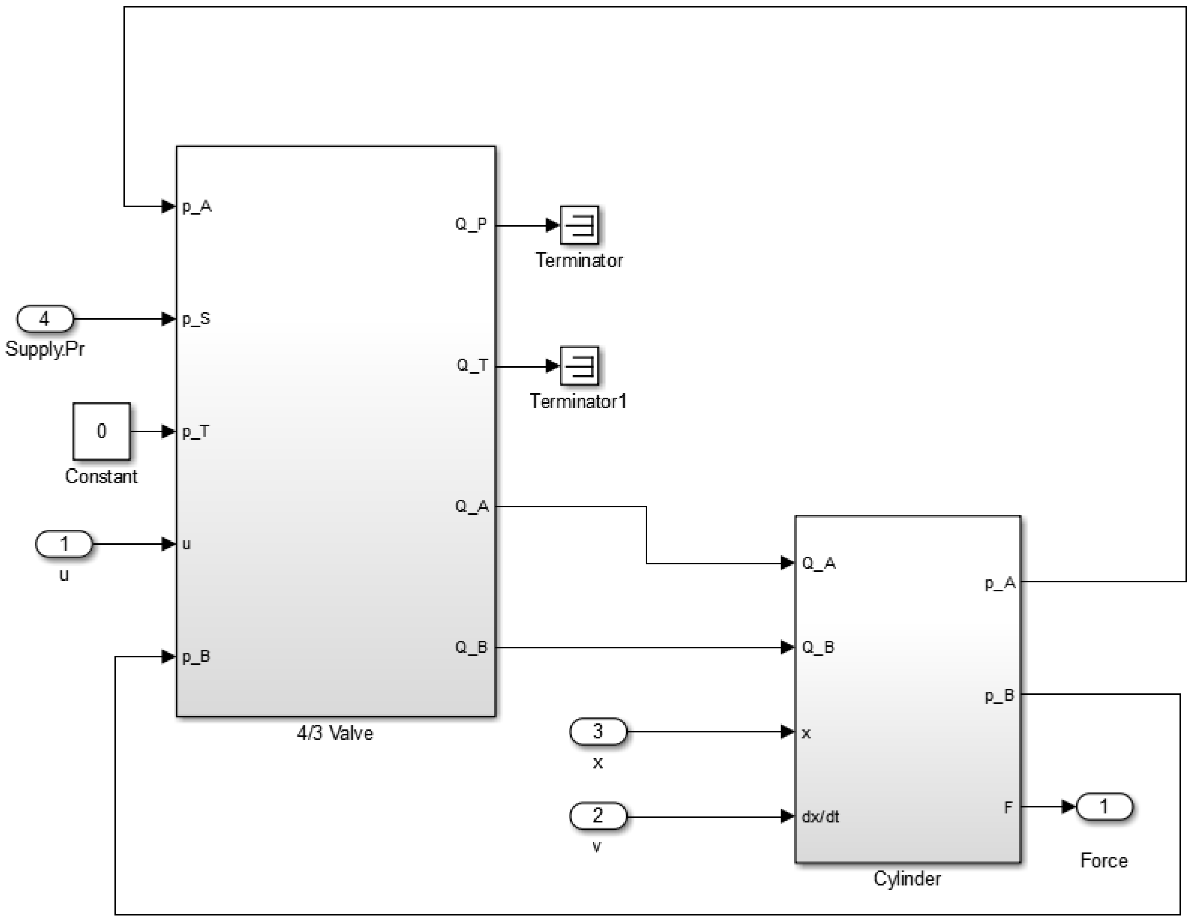

Figure 7: Subsystem of hydraulic circuit

The above model shows the subsystem of hydraulic circuit for the individual cylinder. It consists of 4/3 valve and a cylinder. The valve has 4 inputs namely: supply pressure (constant pressure), tank pressure (constant zero), port A and port B pressure originating from the cylinder block. The output flow from port A and B is the input to the cylinder along with the inputs velocity and displacement from the manipulator. The cylinder provides the force which goes into the manipulator to make movements.

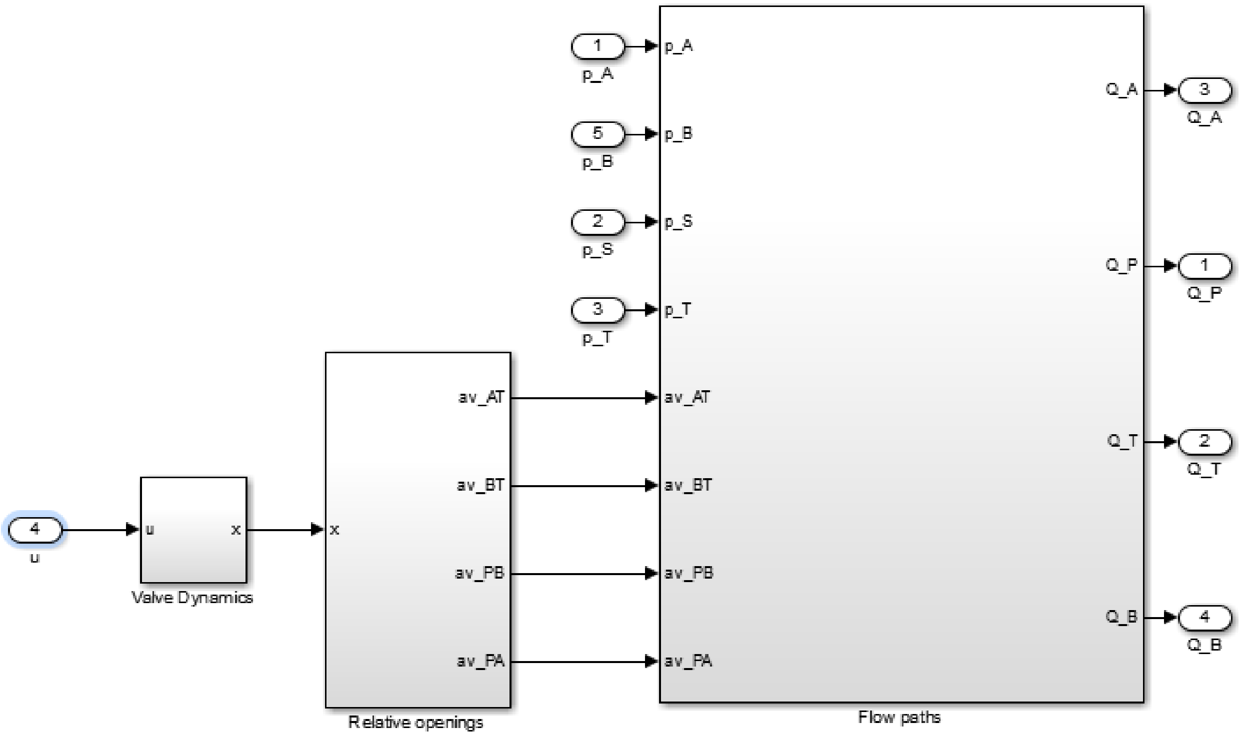

Figure 8: Subsystem of 4/3 valve

The 4/3 valve is modelled with valve dynamics, relative openings (which are modelled using lookup tables) and flow paths which are modelled using 4 orifice blocks which are as shown as below. The orifices takes pressure as input and gives its corresponding flow as the output.

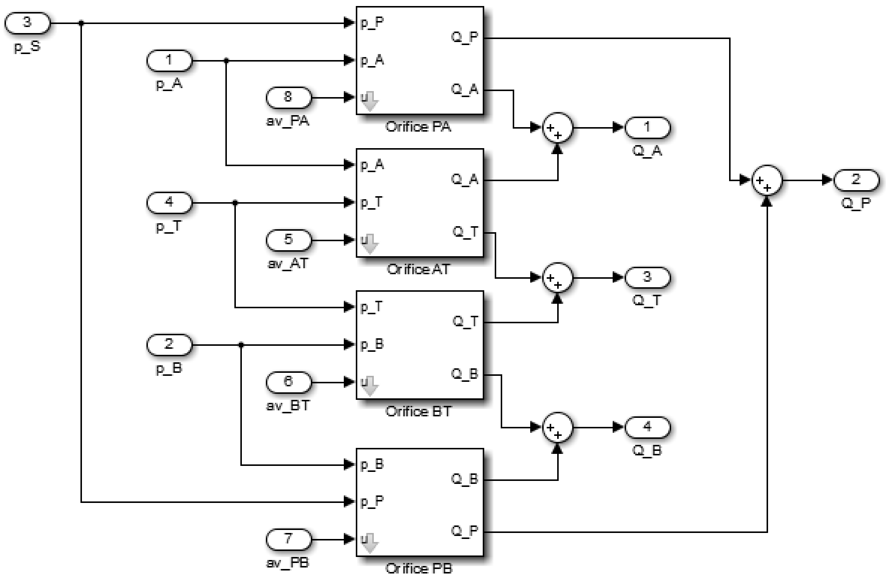

Figure 9: Flow paths

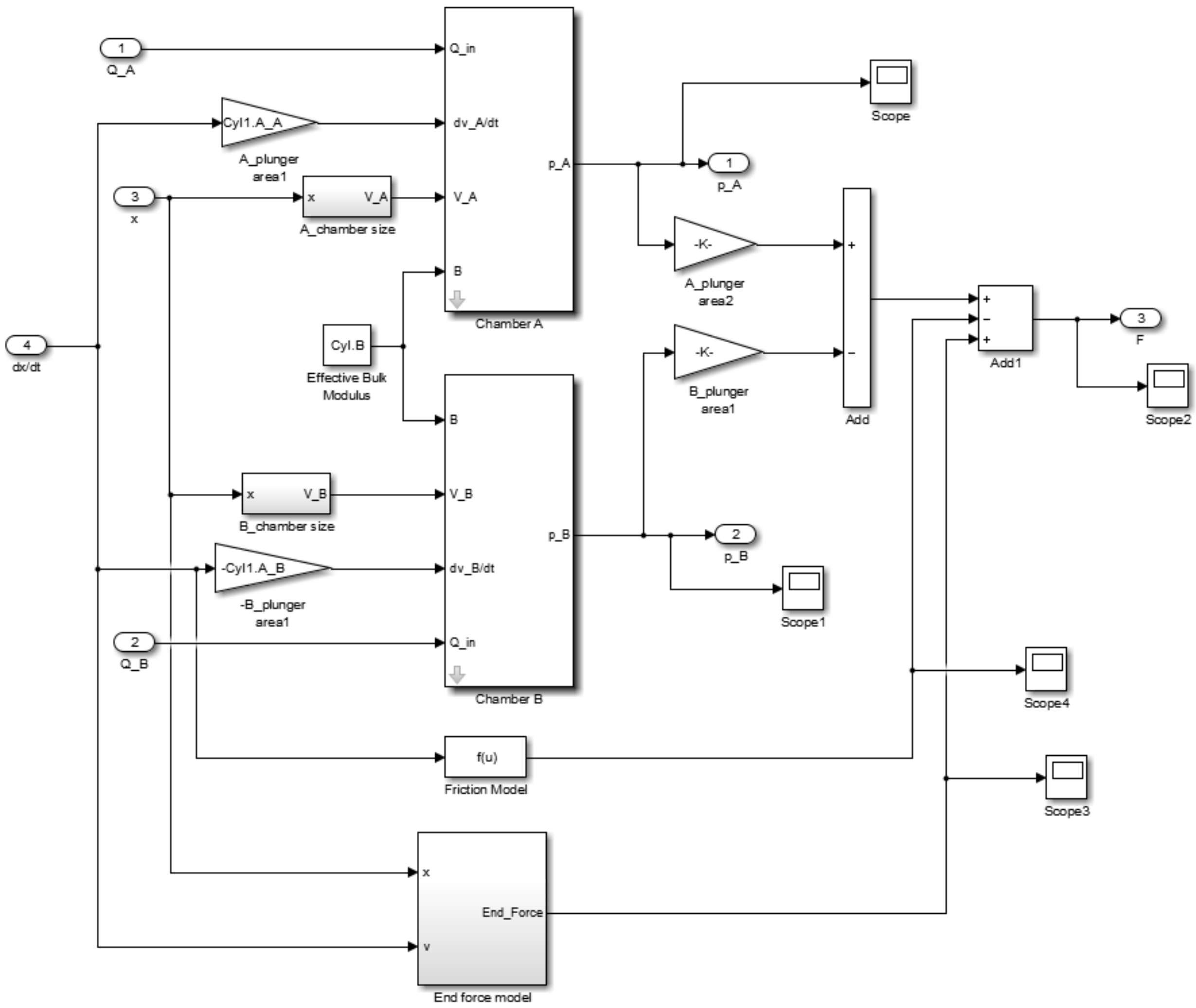

Figure 10: Cylinder model

The cylinder is modelled using two volume blocks where each block presents chamber A and chamber B respectively.

The friction model used here is

$$F_\mu(\dot{x}, p_A, p_B) = \tanh(K\dot{x}) \times \left(F_C + (F_S - F_C) e^{-(\dot{x}/v_S)^2} \right) + b\dot{x}$$

The dynamic friction model is not used here because of the fact that it utilizes small step size which is fine in the offline model but when run in real time model it causes certain problem as the real time system uses slightly a bigger step size.

The cylinder travel is limited using end collision model based on the following equations.

$$F_{end} = \begin{cases} -K_{end}x - b_{end}\dot{x}, & \text{if } x < 0, \dot{x} < 0 \\ -K_{end}x, & \text{if } x < 0, \dot{x} \geq 0 \\ 0, & \text{if } x \leq 0 \leq x_{max} \\ -K_{end}(x - x_{max}) - b_{end}\dot{x}, & \text{if } x > x_{max}, \dot{x} > 0 \\ -K_{end}(x - x_{max}), & \text{if } x > x_{max}, \dot{x} \leq 0, \end{cases}$$

The following figures represent the Simulink model of end force model.

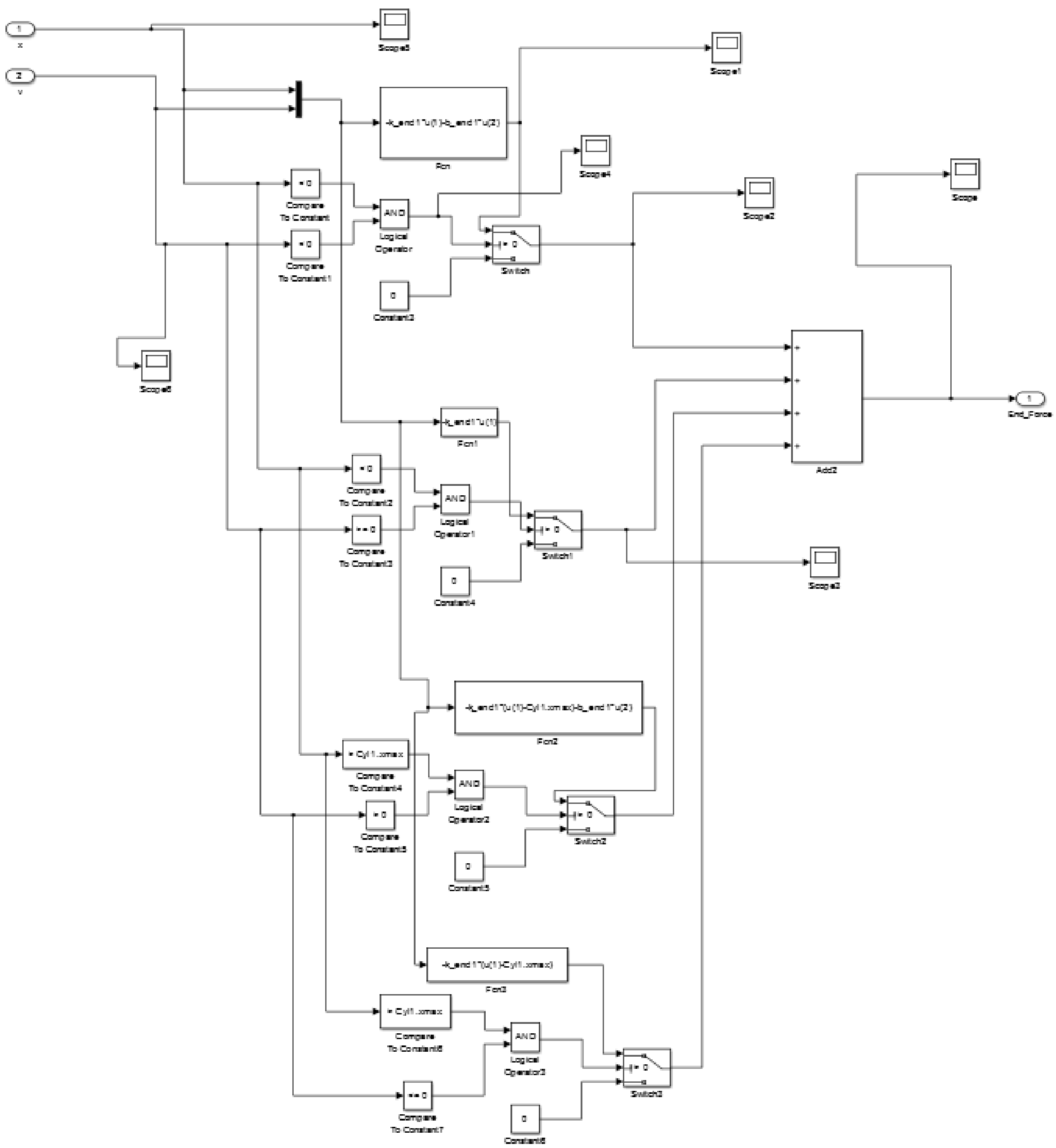

Figure 11: End force model

3.3 Problems

Hydraulic model

Initially the hydraulic model was modelled with the addition of hoses from valve to cylinder. The presence of hose had made the flow go in the reverse direction than the actual required direction. The hoses were modelled with the help of volume block and an orifice block. The reason for reverse flow maybe dude to difference in sign in the orifice block. To resolve this issue we removed the modelled hose and the system was running perfectly fine.

4 Implementation and Testing

The model was tested and verified every time a new subsystem was implemented.

4.1 Off-line implementation

The offline model implementation was tested by providing sinusoidal signals as input to the cylinder. The velocity and displacement behavior of the cylinder was cross verified with the input sine wave. Further the friction parameters were tuned to reduce the vibrations in the system.

Following plots show the behavior of velocity of the system with sine input.

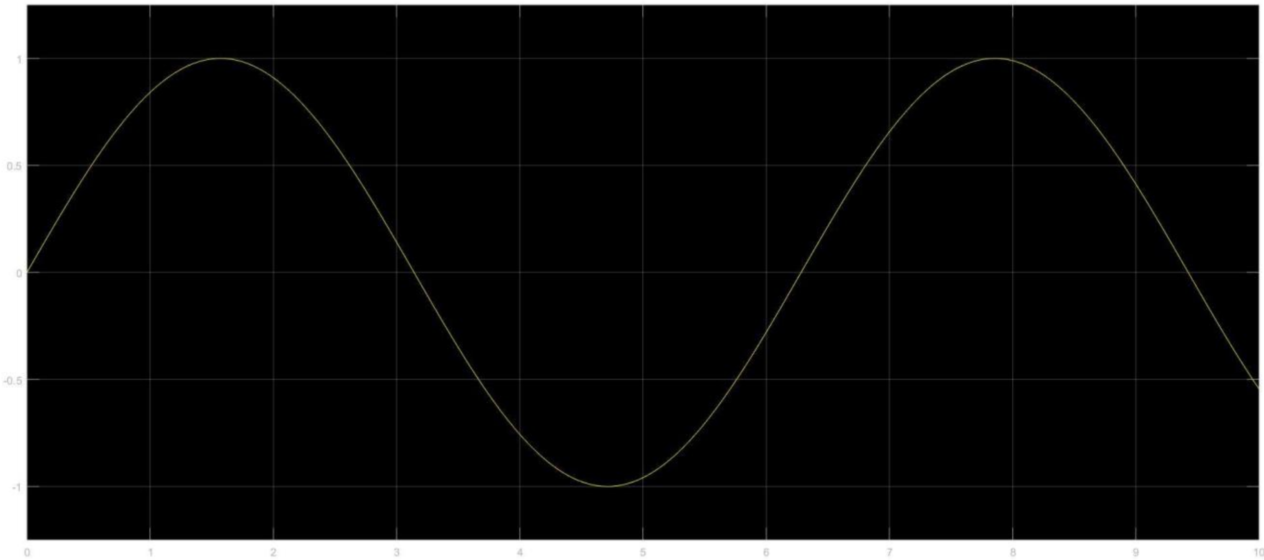

Figure 12: Sinusoidal Input with amplitude 1

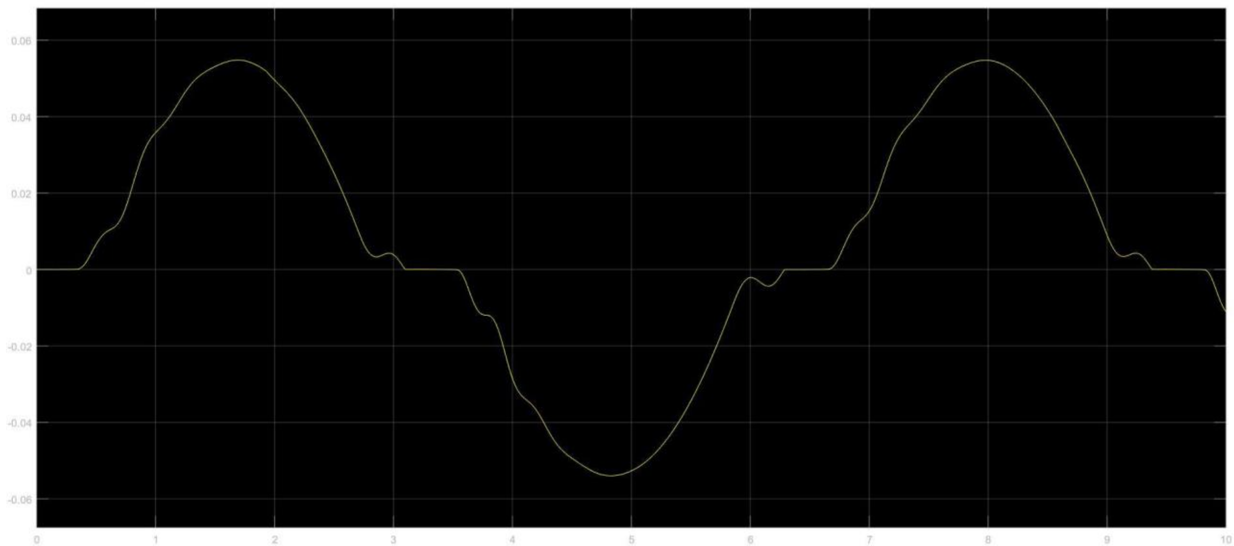

Figure 13: Velocity output of Cylinder1

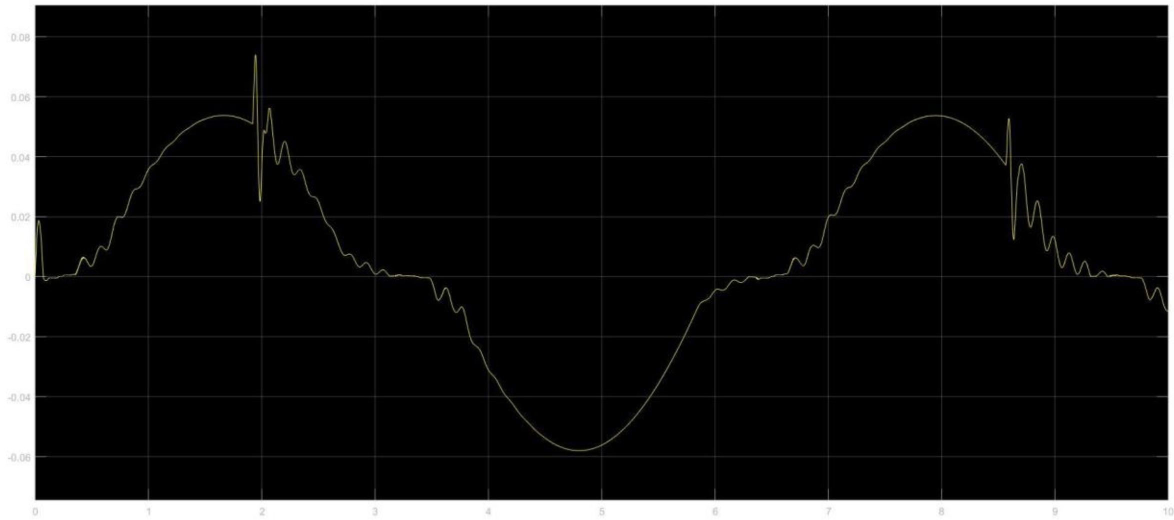

Figure 14 : Velocity output of Cylinder 2

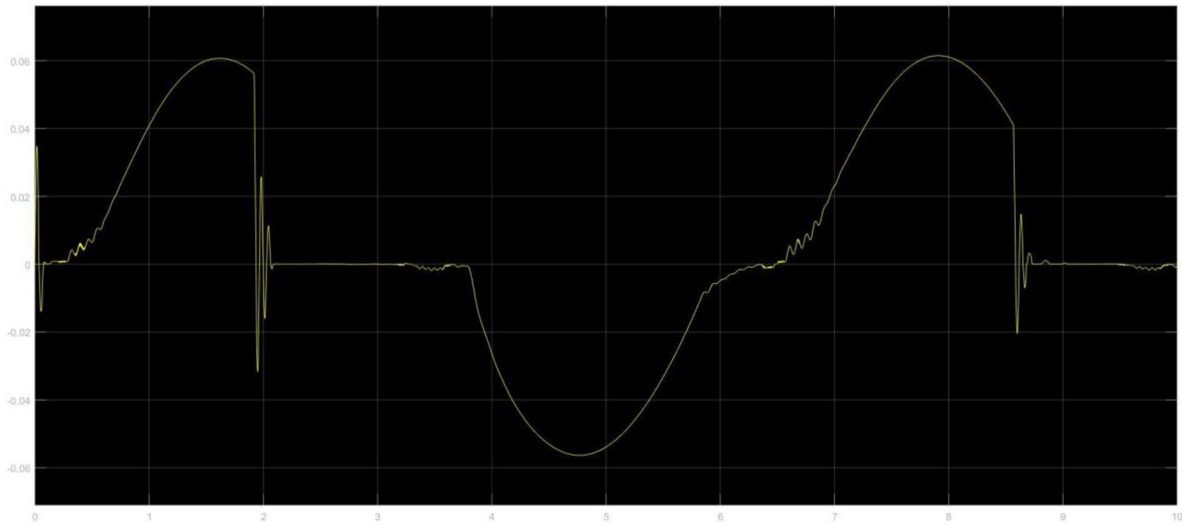

Figure 15: Velocity output of Cylinder3

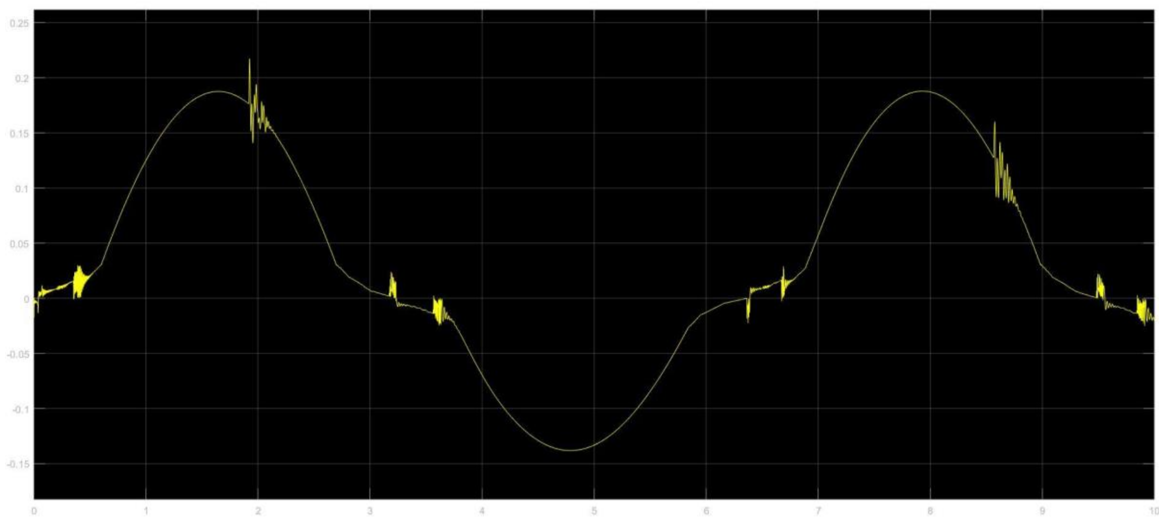

Figure 16: Velocity output of Cylinder 4

From the above plots we could verify that the output follows the sine curve as the input with minimal vibrations. Furthermore the velocity of boom end is maintained to be within 1-2m/s. Hence, the offline model is verified and ready for real time implementation.

4.2 Real-time implementation

For the real time model the input signals received its signals from joysticks through the UDP send blocks and the output joint angles were received by the UDP receive blocks. The Simulink model was deployed into real time system by connecting with the target PC. The real time model was verified by checking if all the parts of the system could perform its movements based on the signals received. Further checking for the vibrations during the simulation and when the cylinders hits its ends.

Initially the sample time was taken to be 0.001 for the real time system but this caused CPU overloading and hence the minimal step time was increased to 0.002.

Any changes in the offline model, the first changes done in the M-script or the simulink model and then the simulink model is built to real time again, furthermore connected to the target pc and the real time simulation is carried out.

The problem experienced in the real time simulation was that sometimes when the model was built it wouldn't get uploaded to the real time explorer as the target PC would get disconnected at times. To resolve this issue the built model is uploaded to real time explorer manually.

4.3 Graphical User Interface

The GUI consists of following instruments:

- Supply pressure knob.

  The supply pressure knob was used from the GUI library, the constant block signal was connected to the supply pressure knob. The knob was given a span of 215 bar. With the help of the supply pressure knob we could adjust the supply pressure to validate the model.

- On and off switch

  A toggle switch was used as on/on switch. When we toggle the button on, the real time simulation works, when it is toggled off it stops. A switch block was introduced after the UDP send block.

- Panels showing the cylinder displacement, velocity and joint angles.

There are panels showing the values of cylinder displacement, velocity and joint angles.

Figure 17: GUI for the system

4.4 Demonstration

During the demonstration, everything went well, but when the tilt was aligned straight to the lift, cylinder 2 was not generating enough force for the lift to come up and it was really slow when it was coming upwards. Also, lift generated some vibrations when it was rotated.

4.5 Post Demonstration changes

To rectify the issue faced during the demonstration, we cross verified all the parameters and then noticed that the link 1 and 2 had taken lift mass has its parameter notation for its mass. We restored it back and everything worked fine. We are not sure how this issue happened but we guess this happened when we were trying to convert to previous MATLAB version to run in the real time system.

But now, the Real time model works fine without any hazels as expected. This was also verified by Tuomo the next day after demonstration and he said it works as expected. This is the reason we have included this subheading, scopes and images of the working of post demonstration is as follows.

Also in this link below, there is complete video of our model working after post demonstration changes.

https://www.youtube.com/watch?v=_cwBJIMx6Ko

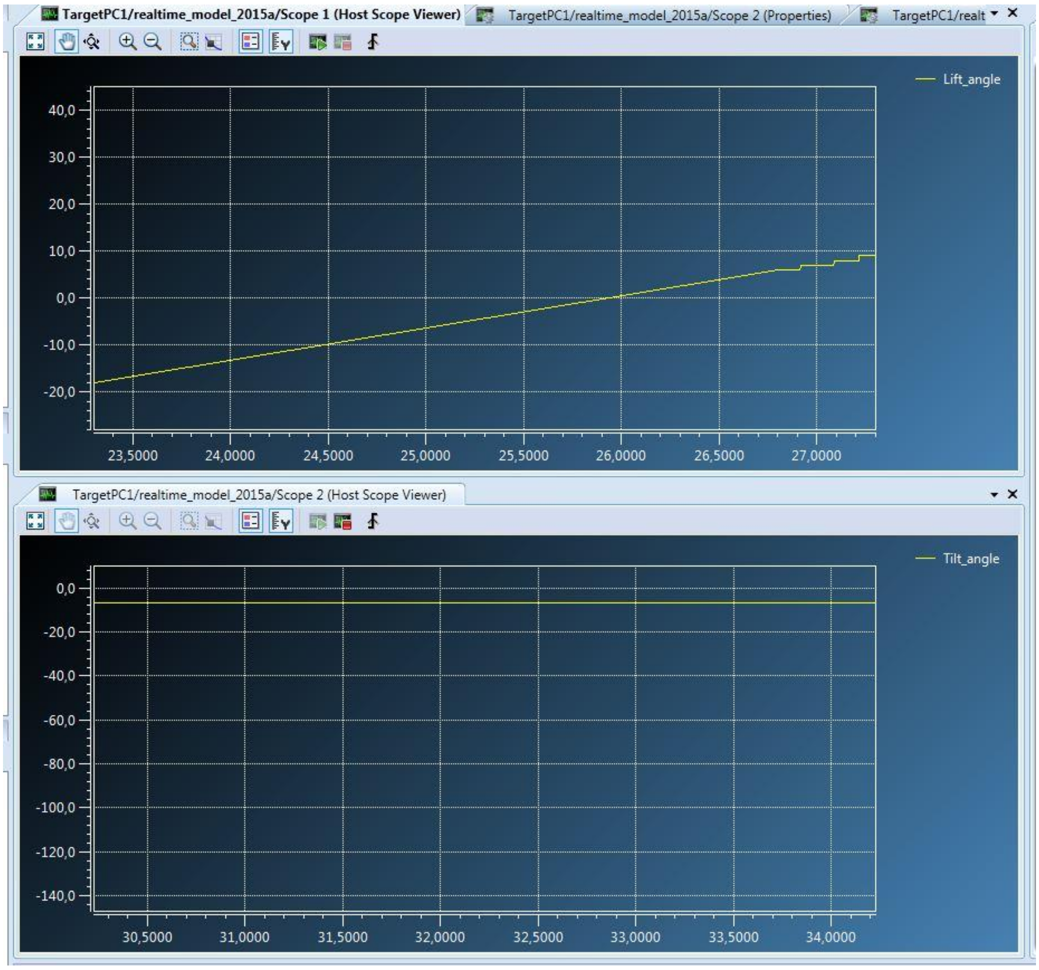

Figure 18: scope showing movement of lift upwards with constant tilt angle

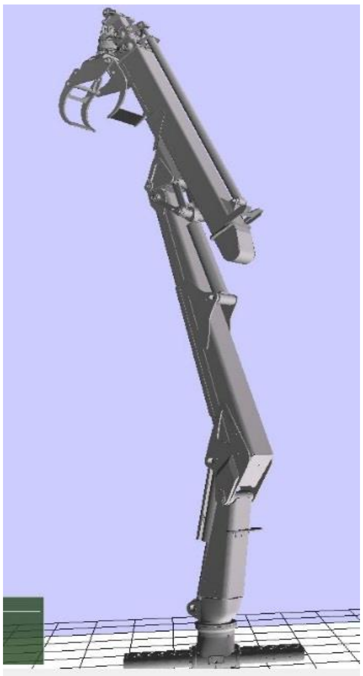

Figure 19: lifting of tilt when it is aligned parallel to the lift

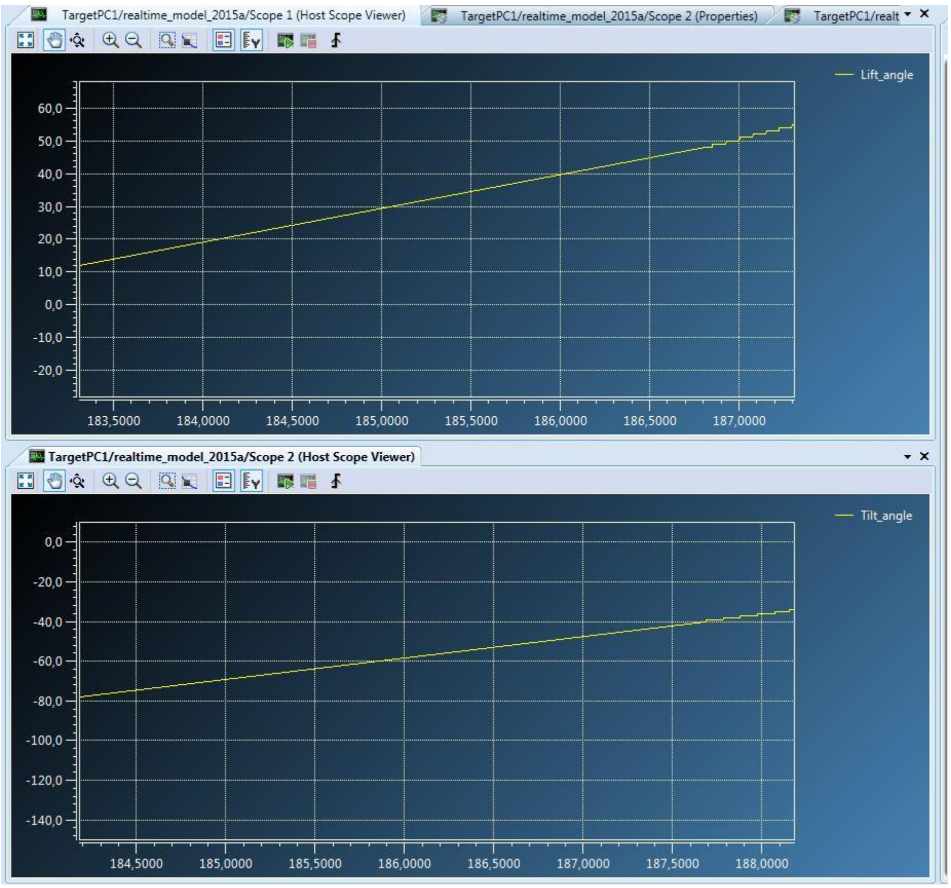

Figure 20: Upper movement of lift with upper movement of tilt

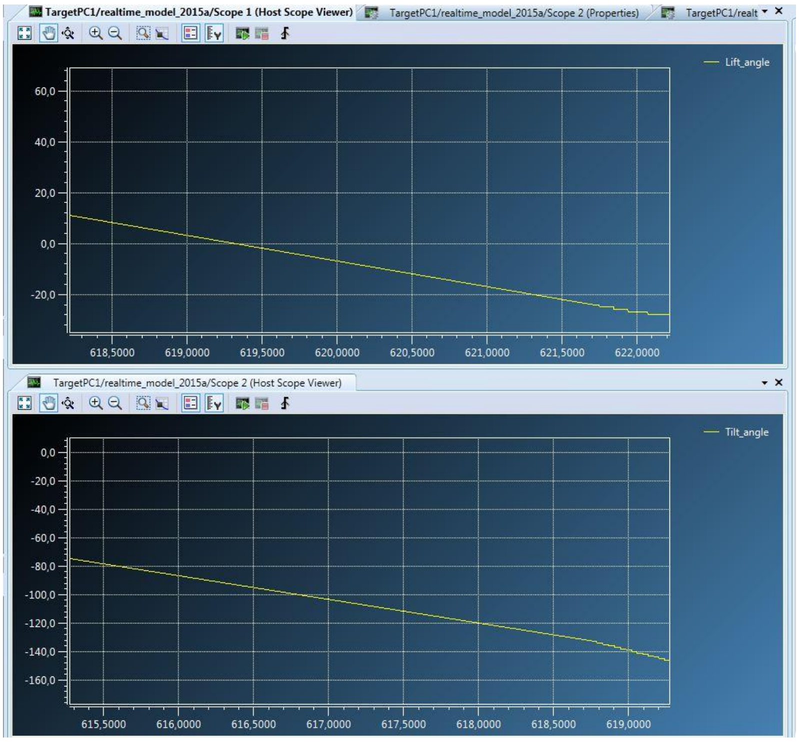

Figure 21:Downward movement of lift with downward movement of tilt

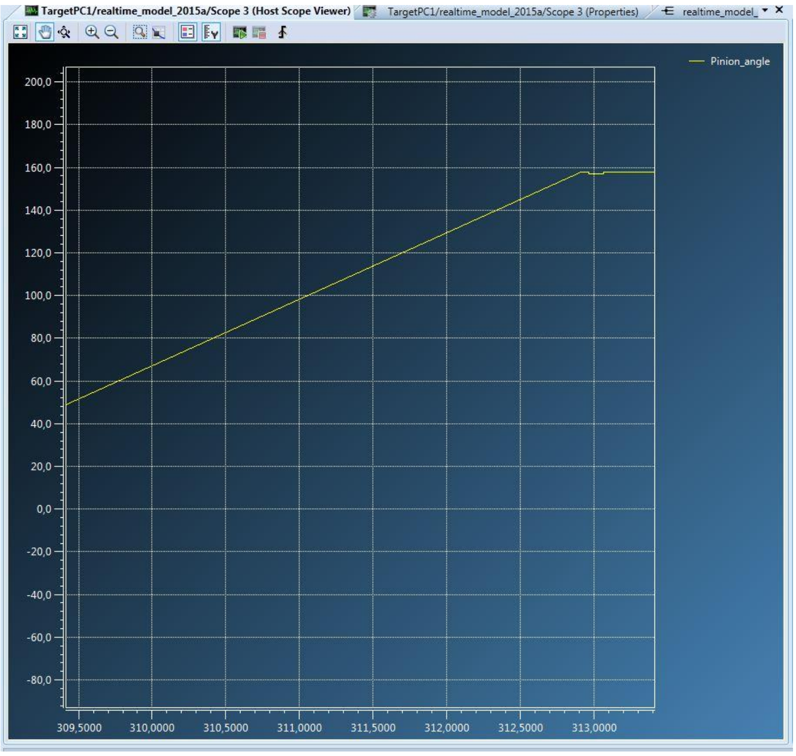

Figure 22: Minimum acceptable vibrations when the rotation of lift is stopped immediately.

5 Future development

For the current simulation, we also have to design the pump, motor, heat exchanger and lot of other components. After all that, make a simulation again with the whole loader itself. When simulation works fine in the real time system then a prototype can be created and tested further.

Further using second generation sim scape it can be tested for vibration analysis and other user related problems that has to be encountered before final product.

The modelling could be more effective if it could be done in some 3D modelling software like CATIA or SolidWorks, if those 3d could be used for co-simulation along with MATLAB and Simulink it would be more effective.

Appendix 1. Self-evaluation

- work divided among group members

Sankeerth	Lakshmi
Report	Report
Modelling pillar, lift and rack and pinion.	Modelling 4 bar linkage, extension and tilt.
Modelling cylinder 3 and 4	Modelling cylinder 1 and 2
Hydraulics model	Hydraulics model
Real time system modelling and tuning	Real time system modelling and tuning

- how successful the group was

  The group was motivated enough to successfully sit and check the errors in model patiently until the end and successfully complete the course exercise.

- problems and failures

  Every time we had some difficulties, the teaching assistants were really kind and helpful.

  Every time we had some issue, we used scopes in the Simulink model to rectify what is happening in the model.

- level of difficulty

  I give a 4, it was quite hard and it was time consuming.

- time used

  4 to 5 hours every day and almost whole day in the weekends.

Appendix 2. Feedback

The exercise classes were really helpful 5/5

Knowledge obtained from the course 5/5

Time consumption over credits earnt 4/5

Help from the teaching assistants 5/5

Lab facility for real time system 3/5 (outdated systems are used and they consumed a lot of time to solve)