Design of a control algorithm for a hydraulically driven crane

Reza Sepahi Samian[a], Aki Mikkola[b], Suraj Jaiswal[b]

[a] *Lappeenranta Lahti University of Technology, Mechatronics, Lahti, Finland*
[b] *Lappeenranta Lahti University of Technology, Department of Mechanical Engineering, Lappeenranta, Finland*

Abstract

This project studies a hydraulically driven crane. The crane is modeled using SolidWorks software and imported to MATLAB Simulink. The crane's dynamic performance is investigated. First a simple signal is imposed to the hydraulic valve to change spool position and study performance of mechanical and hydraulic system. After adjustment the model is improved by considering flexibility of lift arm and variable displacement pump. Finally the performance of model is compared with experimental data by adding a PI controller and tuning the location of the piston. Results show that the model was able to follow the input signal properly.

Keywords: Hydraulic, Pressure oscillation, Multibody, Simulation

1. Introduction

Hydraulically driven cranes are an essential portion of machines extensively used in waterfronts, industries, and construction projects that require heavy lifting. Crane structure and the hydraulic system should be reliable, and light [3]. Determination of the dynamic responses of these cranes using simulation can help in the reliable and cost-efficient construction of these cranes. Cranes are driven using a hydraulic system. A control system is needed to improve its performance. It can control the pressure and flow of the hydraulic system to make the crane's performance smooth and reliable. Figure 1. The simulation

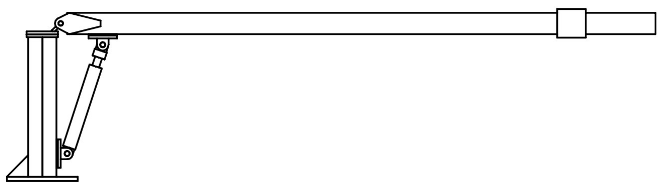


Figure 1: The hydraulic boom lifter geometry.

of a hydraulic boom lifter in MATLAB Simscape models the interaction between hydraulic actuator and mechanical linkages to lift and position point mass load. Hydraulic components like actuator and 3way valve are integrated with mechanical joints to replicate dynamics. This enables performance analysis and design optimization.

1.1. The purpose of the study and the specification of what is studied

Numerically effective models of mechanical systems play a fundamental role in various applications such as hydraulics, control, and robotics [2]. In computer simulations of interconnected mechanical systems, it's common to model both the mechanical components and the subsystems linked by actuators or other connections.

2. Methods

2.1. Introduction of used methods

The hydraulic system is modeled using the lumped fluid theory. In this method, pressure is computed integrating a differential equation where the effective bulk modulus is divided by the volume. This formulation can introduce numerical stiffness, making the time integration of hydraulically actuated systems computationally challenging. The Reduced-Order Model is used for the simulation of flexibility of lift arm. The selection of the friction force model significantly influences the relative joint coordinates and hydraulic pressures. This impact is crucial to consider in modeling, as it can lead to pressure oscillations, particularly in applications demanding high precision or minimal vibration [1].

2.2. Degrees of Freedom

A hydraulic boom lifter structure is studied. Geometry of the model is given in Figure 1.

The model includes 5 bodies, 3 revolut joints, 1 prismatic joint and 2 weld joint. The number of bodies is 5 which means in 2d generalized coordinate is 15. According to the given geometry simulation, number of constraints is

$$4 \times 2 + 2 \times 3 = 14$$

. Degree of freedom can be obtained using following equation without assuming hydraulic actuator:

$$DOF = 5 \times 3 - 4 \times 2 - 2 \times 3 = 1$$

By assuming hydraulic actuator and knowing the DOF=1 the model would be dynamically driven.

2.3. Used software and version numbers

In this project, the parts are drawn in SolidWorks 2024 and assembled. After assembly to be able to import the MATLAB the file is saved as two separate part files for the pillar and lift arm in SolidWorks 2022 format. This format is supported in MATLAB Simulink.

Pressure-Compensated Pump (IL) Parameters

Pressure-compensated pump is used for the simulation of Axial Piston Pump of Parker model PV016 variable displacement. The setting parameters are given in Table 1

Table 1: Pressure-Compensated Pump (IL) Parameters

Parameter	**Value**
Nominal displacement	16 cm^3/rev
Nominal shaft angular velocity	1500 rpm
Nominal pressure gain	14 MPa
Volumetric efficiency at nominal conditions	0.92
No-load torque	0 N.m
Mechanical efficiency at nominal conditions	0.88

3. Results

In the first step a solid lift boom with a signal is modeled. The input signal is shown in Figure 2.

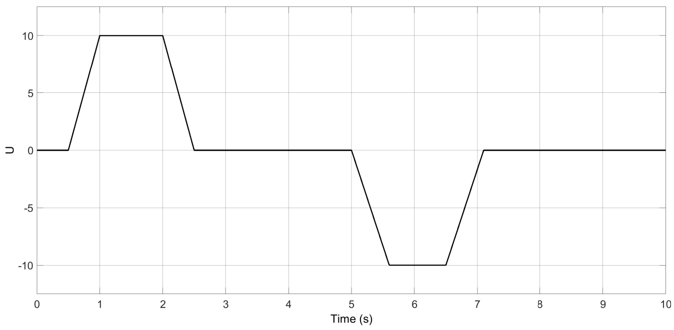


Figure 2: Input signal

The position of piston according to the input signal is shown in Figure 3. The velocity of the piston is shown in Figure 4. The flow of the piston and rod sides are shown in Figure 5. The Pressure of the piston and rod sides are shown in Figure 6. In Figures 7, 8, 9, 10, 11, 12, and 13 mode shapes of Lift boom are given. First six mode shapes were solid movement and aren't given in this report.

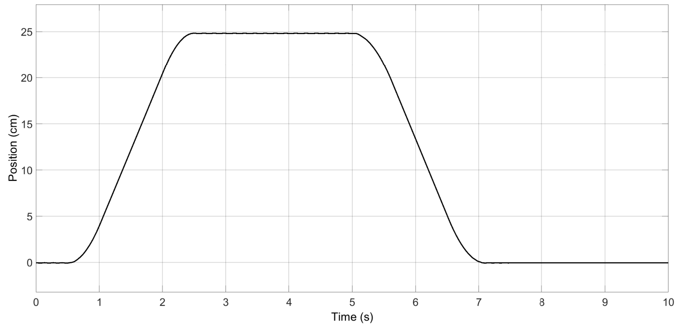


Figure 3: Piston position (cm)

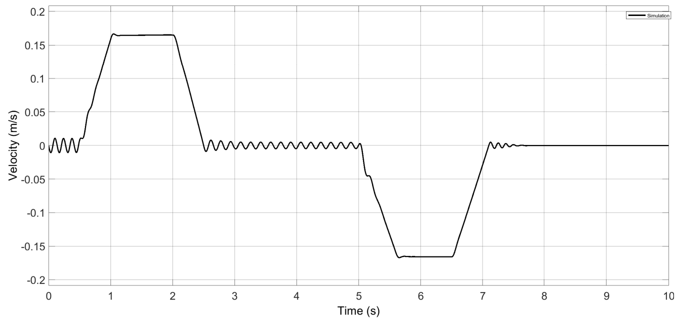


Figure 4: Piston velocity (cm)

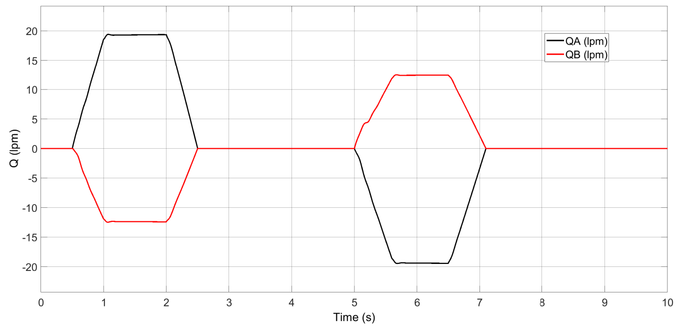


Figure 5: Piston and rod sides flow (lpm)

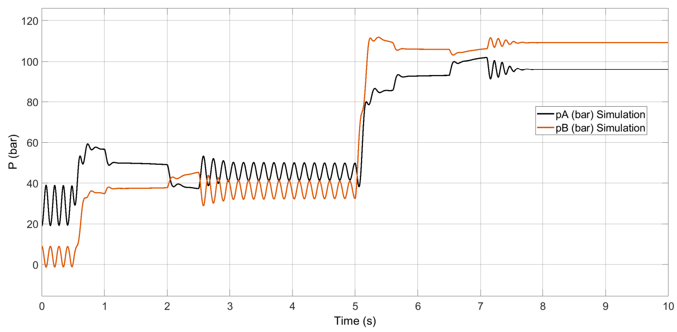


Figure 6: Piston and rod sides pressure (bar)

The stl file contains a triangulation that defines the CAD geometry of the lift arm. The view of the geometry stored in this file is give in Figure 14. In this project we used a multipoint constraint (MPC) to preserve the six degrees of freedom at each boundary node. To recognize the geometric zones (such as faces, edges, or vertices) to relate with every MPC, primarily plot the arm geometry in Figure 15.

The mesh is plotted and the selected faces highlighted

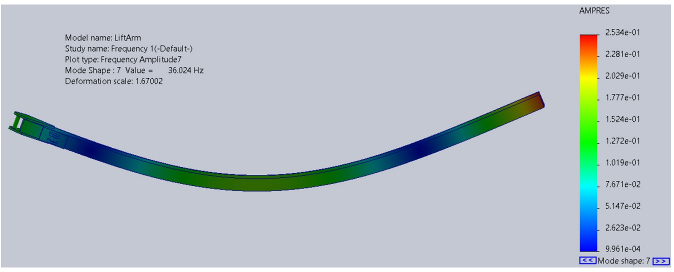


Figure 7: Mode 7, f=36 Hz

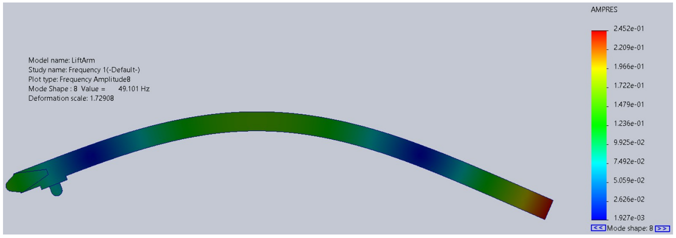


Figure 8: Mode 8, f=49 Hz

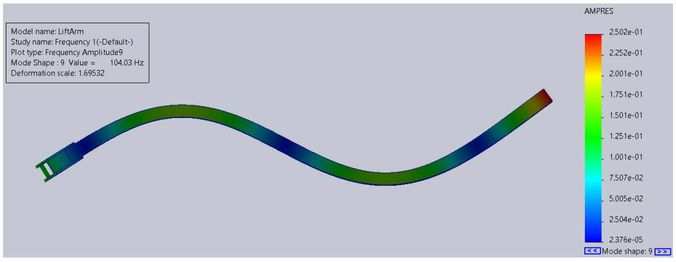


Figure 9: Mode 9, f=104 Hz

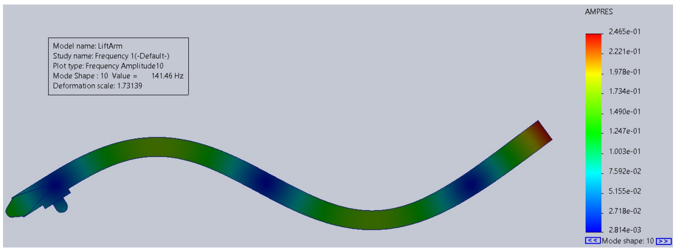


Figure 10: Mode 10, f=141 Hz

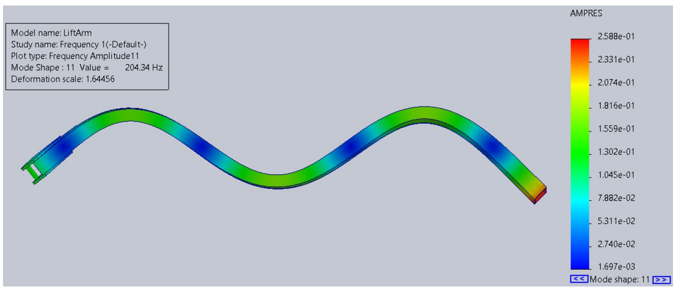


Figure 11: Mode 11, f=204 Hz

in Figure 16 : Simulation results are compared with experimental data. A PI controller is used for tuning of ex-

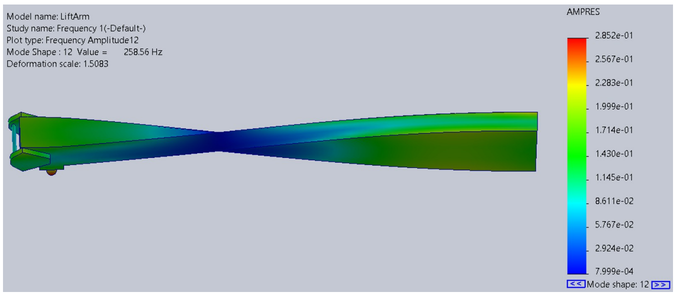


Figure 12: Mode 12, f=258 Hz

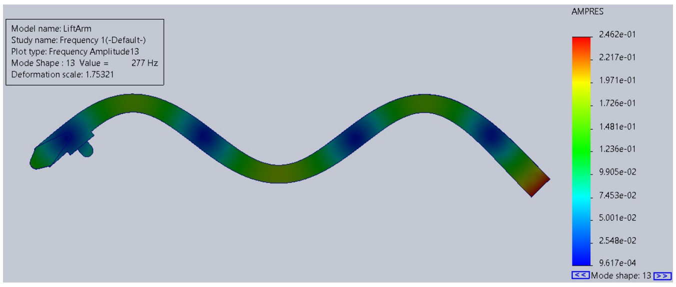


Figure 13: Mode 13, f=277 Hz

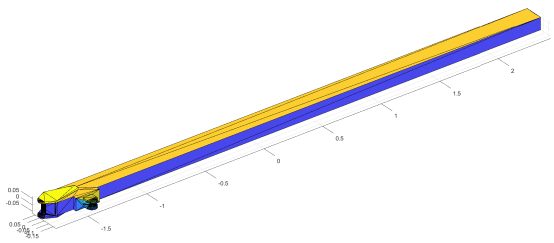


Figure 14: stl file containing a triangulation of the CAD geometry

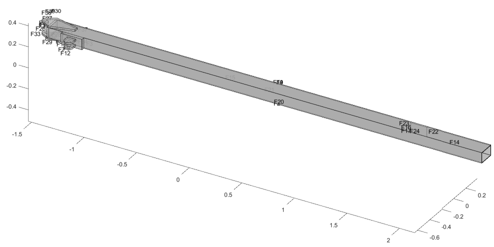


Figure 15: The arm geometry with face numbers

perimental data. Position from experimental data is compared to tuned position values in Figure 17. In addition the velocity of the piston is compared from experiment is compared to the values of the simulation in Figure 18. The value of velocity is obtained by differentiating of position in time. Data are filtered to decrease the velocity fluctuation. Average of 19 values are used for filtering of velocity

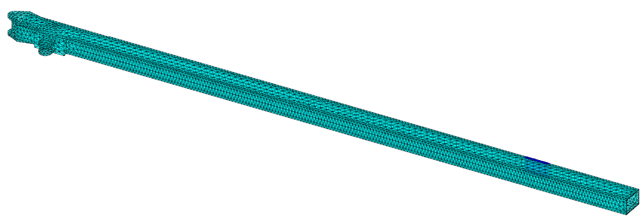


Figure 16: The mesh plot that selected faces are highlighted

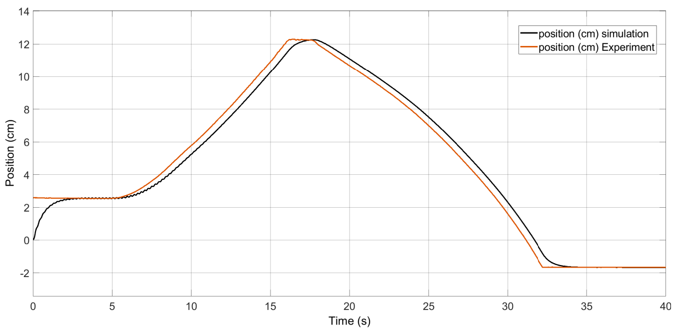


Figure 17: Position of piston in experiment and simulation.

values. Pressure plots of experiment and simulation are

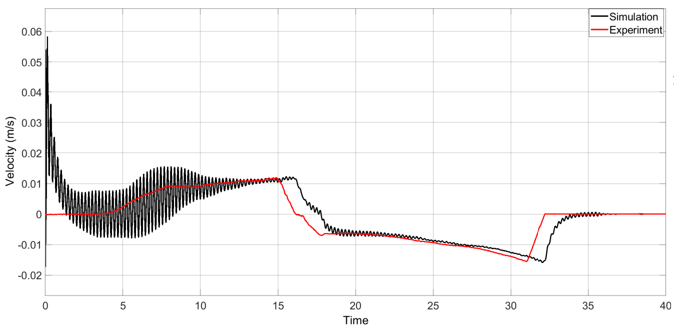


Figure 18: velocity of piston in experiment and simulation.

given in Figure 19. As can be seen pressure plots tune the experimental results till t=32 s. After this time the experimental results show sudden change in pressure which may be results of sudden stop of the boom. This sudden fluctuation isn't obtained in the simulation. This may be results of controlled stop of mass and boom in our simulation that doesn't let high deceleration and high value forces in cylinder.

Flow through ports A and B for simulation are plotted in Figure 20.

4. Conclusion

In this project a hydraulically driven crane is simulated. The effect of arm flexibility is studied. I addition

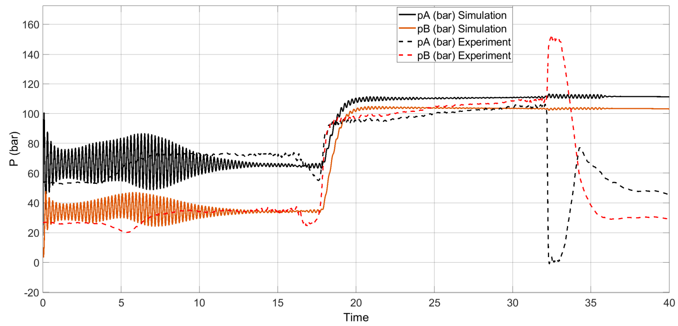


Figure 19: Pressure variation in cylinder in experiment and simulation.

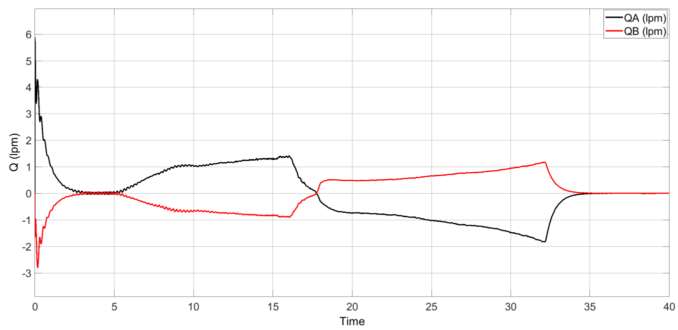


Figure 20: Flow through ports A and B for simulation

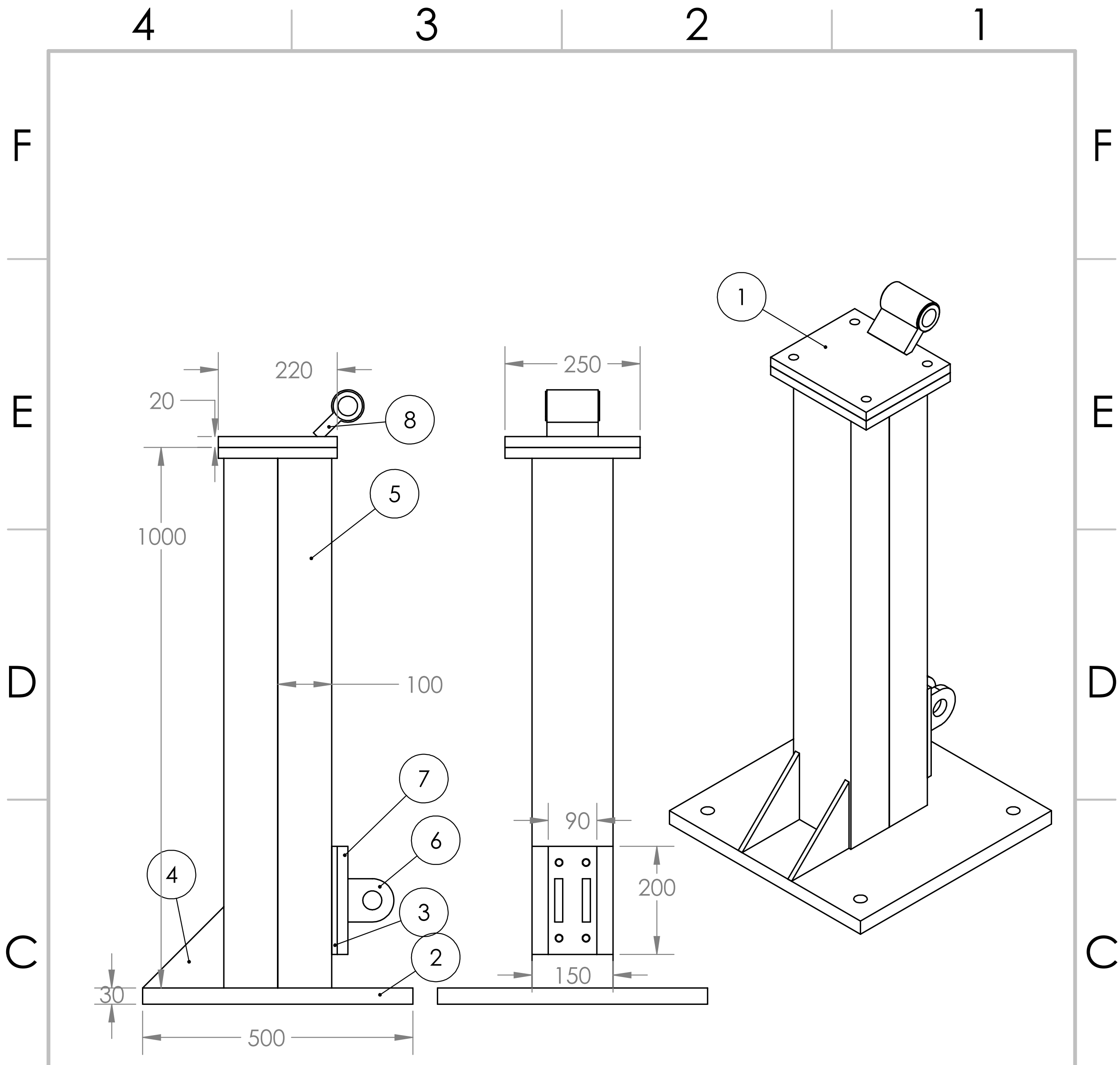
a PI controller is selected for crane to tune experimental data. There are some phenomena present in real system, but not accounted for in the model. For instance, it is assumed that the hydraulic fluid doesn't have any air mixed into it. In addition a simple model for friction is used for the simulation of friction. Hydraulic pressure can be affected by the friction model considered in the simulation.

References

[1] S. Jaiswal, J. Sopanen, and A. Mikkola. Efficiency comparison of various friction models of a hydraulic cylinder in the framework of multibody system dynamics. *Nonlinear Dynamics*, 104(4):3497–3515, 2021.

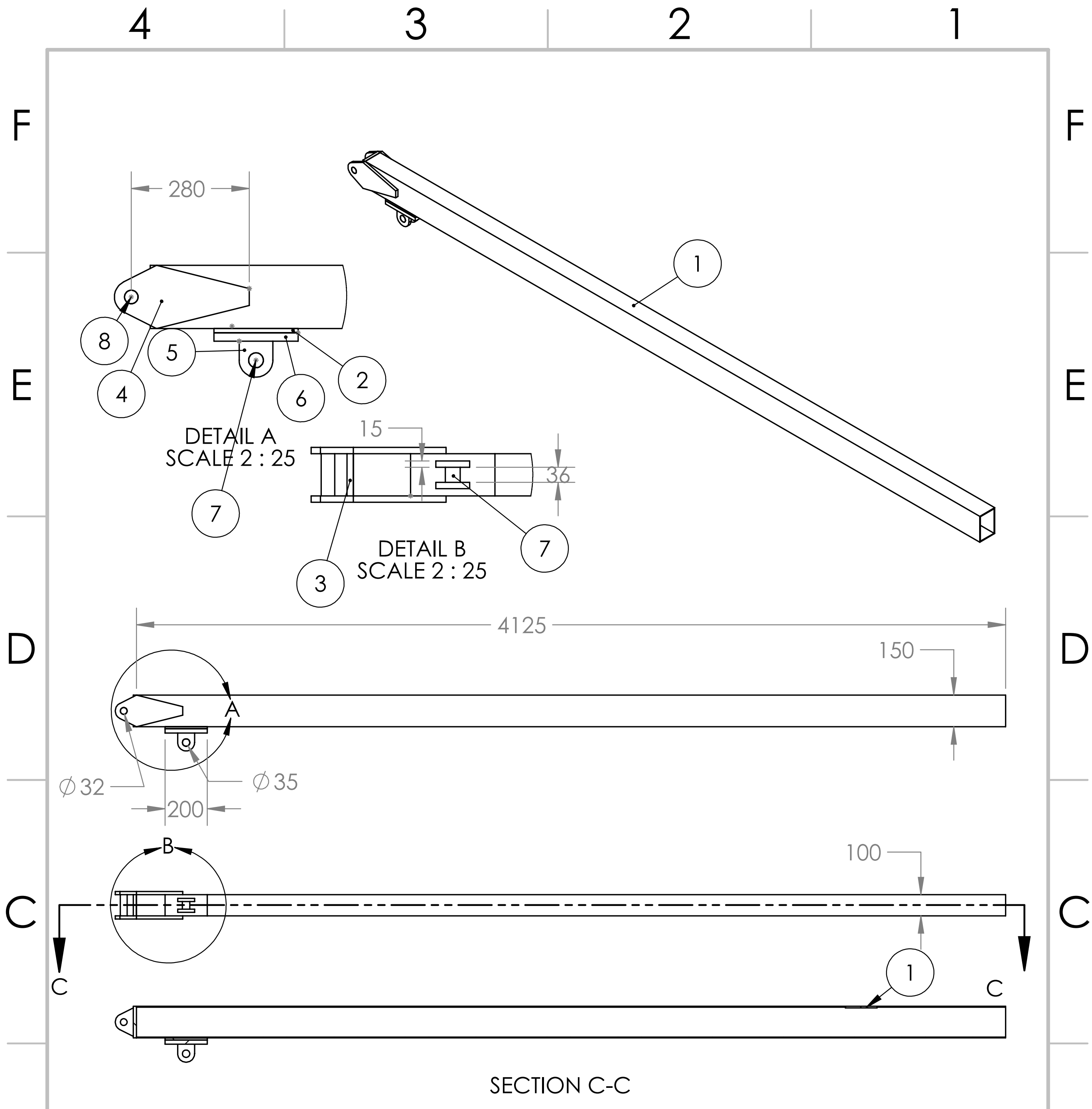
[2] Qasim Khadim, Emil Kurvinen, Aki Mikkola, and Grzegorz Orzechowski. Simulation-driven universal surrogates of coupled mechanical systems: Real-time simulation of a forestry crane. *Journal of Computational and Nonlinear Dynamics*, 19(7), 2024.

[3] Guangfu Sun and Michael Kleeberger. Dynamic responses of hydraulic mobile crane with consideration of the drive system. *Mechanism and machine theory*, 38(12):1489–1508, 2003.



ITEM NO.	PART NUMBER	DIMENSION (mm)	Weight (kg)	QTY.
1	End Plate	250×220×20	8.53	2
2	Plate	500×500×30	58.78	1
3	Reinforcement Plate	200×150×10	2.33	1
4	Support Plate	150×150	0.89	2
5	Vertical Beam	150×100×4×980	11.33	2
6	LugPlate	90×80×15	0.61	2
7	LugPlateBase	200×90×20	2.75	1
8	BearingHousing	Bearing Housing	2.13	1

Figure 21: Pillar and its parts



ITEM NO.	PART NAME	DIMENSION (mm)	Weight (kg)	QTY.
1	Bar	150×100×4×4125	63.53	1
2	ReinforcementPlate	200×100×10	1.58	1
3	EndPlate	160×100×15	1.78	1
4	Mountoing Plate	330×150×15	3.54	2
5	LugPlate	90×80×15	0.61	2
6	LugPlateBase	200×90×20	3.16	1
7	pin	Ø35x66	0.50	1
8	pin2	Ø32x130	0.83	1

SCALE:1:25

Figure 22: Lifting boom modeled in SolidWorks and its parts