



## Modeling and Simulation of Telescopic Hydraulic for Elevating Purposes

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### HIGHLIGHTS

- The simulation and modeling present a good design of the hydraulic telescope cylinder.
- The 3rd stage rod is subjected to the maximum stress.
- The extraordinary vibration is happening to the 3rd piston.

### ARTICLE INFO

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### ABSTRACT

The hydraulic cylinder is widely used in industry as the load lifting structures. A telescopic hydraulic cylinder is a special design of a cylinder with a series of gradually smaller diameter tubes overlapping each other. Three-stage telescopic cylinder performance analysis is performed with the help of the Finite Element Method. Also, MATLAB Simulink is used to create a complete design of the dynamic model of the telescopic cylinder. The analysis results of characteristic curves for telescopic cylinder position, velocity, and acceleration show the simulation model's accuracy and plausibility. This package will provide a basic reference for analyzing and designing the hydraulic cylinders with any number of stages. Simulation results show that a sudden change of pressure upon phase change will lead to multi-phase vibration.

## 1. Introduction

For most city populations, elevators have become an integral part of their everyday lives. Simply put, an elevator is a device for hoisting or lowering, designed to hold passengers who usually travel and serve two or more landings in fixed guides [1,2]. The need for elevators is being increased because of the rapid population growth in cities and multi-stored buildings; with the increasing quality of life and human attention, and with technological advances [3].

Nowadays there are three commonly used elevators which are, Traction elevators, Hydraulic elevators, Pneumatic elevators, etc. The Hydraulic elevators are used in buildings for both freight and passenger services, ranging in height from two to six floors with speeds ranging from (0.125-1.0) m/s. The geared and gearless traction elevators are working similarly, where the cabin is pulled up and down with a rope connected to a motor with a counter-weight. The only difference is in the geared elevator, in which a gearbox is built in between the sheave and the motor [4,5]. The simplest hydraulic elevator usually uses a hydraulic of a single-stage under the cab. An electric motor powers a hydraulic pump, which forces the fluid into the cylinder below the piston leading to raising the piston. The hydraulic cylinder is housed in a well bored in the ground. A hole should fundamentally be made as long as the elevator's height.

Avoiding the drilling by using a telescoping hydraulic cylinder, a telescopic hydraulic cylinder employs a liquid to drive a piston depending on the theory of Pascal [6]. The theory states that the pressure at all points in a closed container is equal. Providing the smaller cylinder with a force would lead the same pressure amount in the larger cylinder, if two cylinders are related. Whereas, the resultant force for the larger cylinder with the larger area will be greater, and more space leads to more strength. Thus, the applied force will increase as the size difference between the two cylinders' increases [7].

Telescopic hydraulic cylinder [8] is a special hydraulic cylinder design, which can give an exceptionally long flight output from a highly compact retraction length. The fallen length of the telescopic cylinder is usually (20-40) % of the entire extended length which depends on the stages' level number. The heavy-duty telescopic cylinder is typically driven by hydraulic oil. Telescopic cylinders are also usually known as multi-stage telescopic cylinders and telescoping cylinders. Employing telescopic cylinders is usually seen as using the dump body on the dump truck utilized at the construction site. To unload the gravel load, the body of dump must be lifted with 60°. This long travel is extremely difficult to achieve with a conventional hydraulic cylinder since the falling length of a cylinder with a single-stage rod is about 110% of the output stroke. Therefore, it is very difficult for the designer to fit the single-stage cylinder into the tipper truck chassis with the dump body in the horizontal position of rest. This task can be easily implemented via utilizing a multi-stage cylinder. The double-acting cylinder

is extending and retracting employing the hydraulic pressure in the two directions. Therefore, the design of the double-acting multi-stage cylinder is more complex than that of the single-acting one. The complexity requires adding the faces of the retracting piston to all stages of the cylinder as well as the difficulty of providing the retraction pistons of the in-between stages with compressed fluids. Ke Li et al. [9] reported the design of an electro-hydraulic system which consists of three flow-control proportional valves. For the speed regulation of the cab, a controller is applied to obtain a velocity pattern of the cab. A solenoid-actuated non-return valve, i.e. a hydraulic lock, is also developed to prevent cab sinking and allow easy inverse. Li et al. [9] proposed a control system of an electro-hydraulic elevator with three control proportional flow valves for controlling the piston velocity and the non-synchronous error of twin cylinders in the hydraulic elevator. Park and Chang [10] analyzed vibration problems in telescopic handler applications that result in lost productivity while waiting for vibration to subside due to suspending operations. Hua and Jun [11] presented a three-stage hydraulic model. The cylinder supporting stability has been studied numerically using ANSYS software. The findings show that the forward-pushing configuration approved would significantly meet the requirements for power lifting, increase overall strokes, shorten stroke per cylinder, and ensure the support stability of the hydraulic cylinder. Hao Liu and Qin He Gao [12] experimentally enhanced accurate control of the hydraulic cylinder position via the rapid on-off hydraulic valve to achieve precise position control. Jamal et al. [13] implemented a new elevator system for learning objectives. The elevator system consisted of pneumatic and electrical components and it was controlled by the PLC. It was stated that the controlled model of the PLC with the elevator system enables students to apply PLC operating skills in the real world. Liu et al. [14] simulated a system by the computer, which led to improve the operation stability, reduce the installed power and energy consumption. The results showed that: the hydraulic driving control system valve of the hydraulic elevator has the advantage of smooth starting, high control precision and small impact in the case of emergency stop, and this system can realize smooth starting of the hydraulic elevator and prevent a sudden-stop shock.

## 2. Geometrical Modeling and Simulation

In hydraulic systems, at least 30% must always be added which corresponds to system friction, pressure loss, and calculation errors. The force output of the hydraulic cylinder is estimated as:

$$F = P \times A \quad (1)$$

Where,  $F$  = Force in N,  $P$  = Pressure in N/mm<sup>2</sup> and  $A$  = Piston Area in mm<sup>2</sup>. The cylinder oil volume can be estimated as:

$$V_c = A \times S \quad \text{and} \quad V_r = A_r \times S \quad (2)$$

Where,  $V_c$  = the total cylinder volume in the rear or cap end,  $V_r$  = the volume of the piston rod,  $A$  = the area of the piston,  $A_r$  = the piston rod area, and  $S$  = the stroke of the cylinder. The cylinder extension rod speed is:

$$R_{se} = Q_x / A_e \quad (3)$$

Where,  $R_{se}$  = the speed of the cylinder with extension,  $Q$  = the flow of the hydraulic pump entering the cylinder, and  $A_e$  = the area of the cap end piston. The return of hydraulic flow to the system tank is often much higher than the hydraulic pump output flow. The rod cylinder will be retracted faster than it will extend, and this will cause a large flow from the cap end as it retracts. The larger the piston rod, the greater the return flow from the cap end of the cylinder. This flow will evaluate the required line size going to the cylinder, the cylinder port size, and the return line filter volumetric capacity in the hydraulic system. The maximum hydraulic flow going to the reservoir is:

$$Q_{max} = R_{se} \times A_{ere} \quad (4)$$

Where,  $Q_{max}$  = the aximum flow of the hydraulic flowing into to the tank,  $R_{sr}$  = the speed of the cylinder rod at retraction, and  $A_{ere}$  = the effective area of the rod end piston.

### 2.1 ANSYS Modeling and Simulation

The hydraulic telescope used consists of three stages as shown in Fig.1. Steel tubing is used with successively smaller diameters nested inside each other. The smaller-diameter sections that move are called stages. The dimensions of the telescope parts were selected according to many trial solutions using the Finite Element Method (FEM).

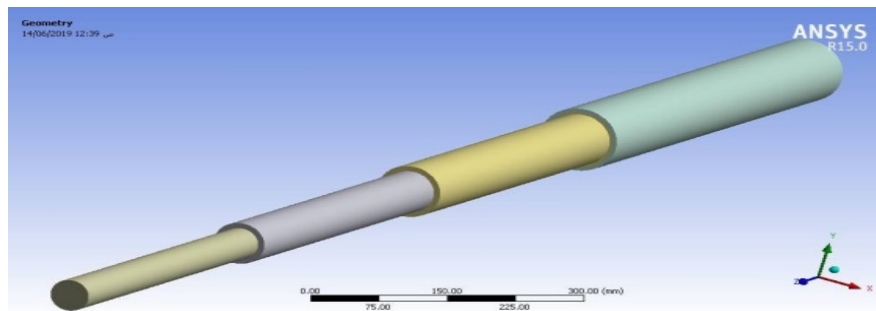


Figure 1: Three stages telescope

### 2.1.1 Main or the Barrel of Cylinder

The largest diameter section is known as the main or barrel. The main function of the barrel cylinder is to hold the cylinder pressure. The barrel of the double-acting telescopic hydraulic cylinder was modeled with 48mm outer diameter and 38mm inside diameter with 800 mm length.

### 2.1.2 Hollow Piston Rod

Telescopic cylinders normally extend from the largest stage, which was modeled with 37mm outer diameter and 34mm inside diameter with 600 mm length. The smallest stage was modeled with 33mm outer diameter and 30mm inside diameter with 500 mm length.

### 2.1.3 Solid Rod (3rd stage)

The smallest (solid rod) stage is also called the plunger. The solid rod is modeled to a diameter of 29 mm and 400 mm in length. The selected material is steel, specifically Ck55 steel material. The mechanical properties of the CK55 steel are shown in Table 1. To estimate the effect of force and pressure on the telescope using FEM and determine the stress and strain on each part, first of all, the meshing steps are required. Therefore, the geometry is divided into small size volume elements. Meshing has been accomplished with 14878 elements and 331340 nodes of 4 active bodies, as shown in Fig. 2. The double-acting hydraulic telescopic cylinder was fixed supported at the end port edge and a load of (491N) was applied at the top end port. This will apply pressure on the cross-section of the piston rod, so the load will be converted to a pressure formula.

Table 1: Mechanical properties of the CK55 steel

Tensile strength Mpa	Yield stress Mpa	Elongation	Reduction in cross-section on fracture
335	327	32	14

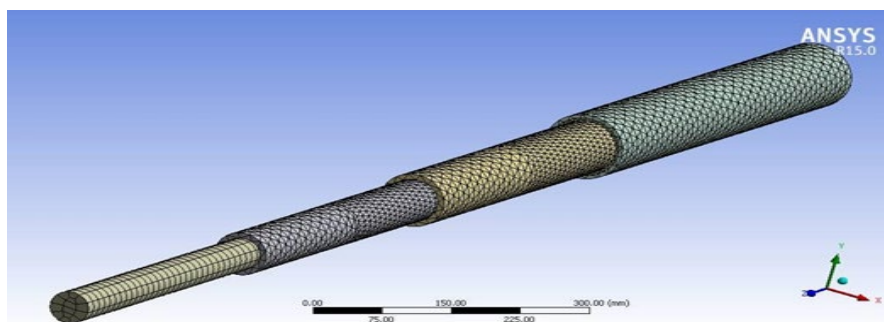


Figure 2: Meshing step

## 2.2 MATLAB Simulation

The simulation in this work focuses on how to simulate fluid power systems by a hydraulic actuator with a double-acting telescopic cylinder. The models can be customized by creating reusable assemblies, adjusting parameterization, and defining custom components. Taking advantage of MATLAB and Simulink, we first take the example application and tasks, build a model: Hydraulic Actuation System, and refine the model, which consists of (adding fidelity, customizing with Sims cape language optimizing the system level design). The basic components of the hydraulic system are shown in Fig. 7 and they are as follows: the fixed displacement pump, the hydraulic tank, 4-way directional valve for controlling the fluid flowing from the hydraulic pump to the hydraulic actuator with specifying the size of the valve, the pressure relief valve to reduce the pressure coming from the hydraulic pump, the telescopic hydraulic cylinder, the piston which connects to the mechanical load, the velocity valve, and the hydraulic fluid.

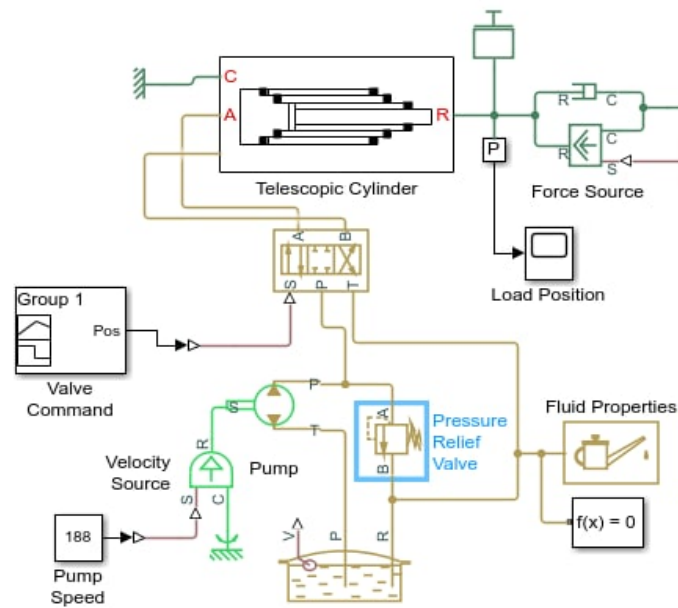


Figure 3: Basic components of the telescopic hydraulic 3-stage cylinder system

### 3. Implementations and Discussions

The numerical analysis using FEM was done on the hydraulic telescope structure with the help of ANSYS software, to ensure the stress and strain due to the pressure on a double-action telescopic hydraulic cylinder, in which we estimate the adequate hydraulic telescope dimensions for the specified load, choosing the steady-state analysis option to simulate the ability to carry the double-action telescopic hydraulic cylinder of different loads.

The result of the solution was achieved using the post-processing or result option. The double-acting telescopic hydraulic cylinder external structure was subjected to different forces. The maximum and minimum stress, strain, shear strain, and total deformation will be presented. The results have been presented in different colors and spectrums. Each color spectrum represents different values.

Figures 4 and 5 represent the equivalent and principal elastic strain distributed over the telescope parts under the load effect. Figure 6 represents the equivalent stress effect on the telescope parts, which show that the maximum effective stresses appear at the 2<sup>nd</sup> stage rod and then decreasing at the 3<sup>rd</sup> stage rod and barrel gradually. The maximum stress present shows that the material selection and the dimensions for the design are safe.

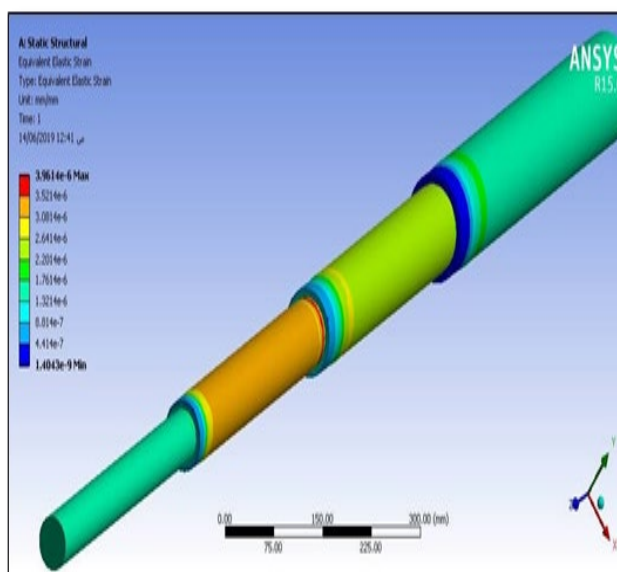


Figure 4: Equivalent strain on the telescope parts

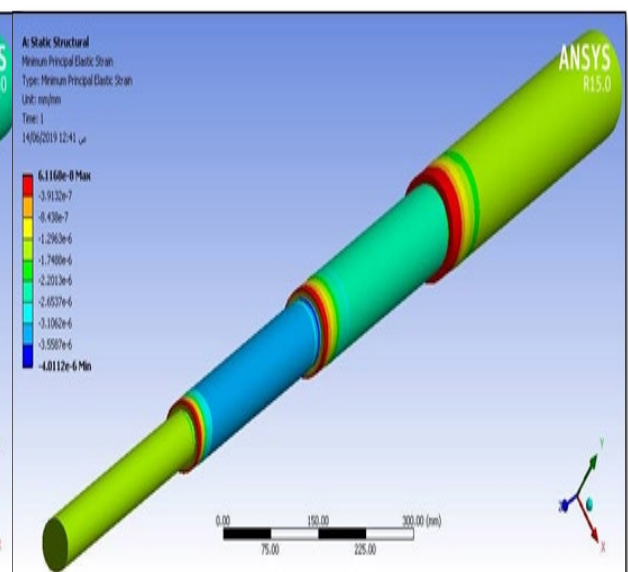


Figure 5: Equivalent principal Elastic Strain

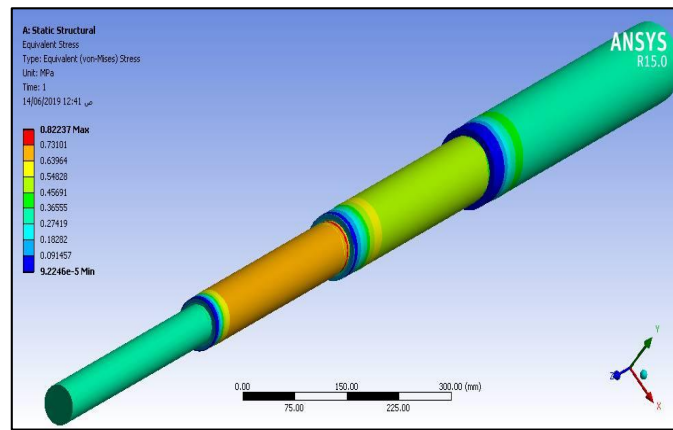


Figure 6: Equivalent stress on the telescope parts

For analyzing the dynamic performance of the multi-stage hydraulic cylinder, it is necessary to provide a position sensor in the MATLAB Simulink. Adding a position sensor to the system provides convenient observation and good analysis of the characteristics of the position of the hydraulic cylinder rod. The command of the slide valve will be governed by the input signal demonstrated in Fig.7. Figure 8 displays the displacement of pistons at all three-stage hydraulic cylinder working levels. By running the three-stage hydraulic cylinder system model, the dynamic performance diagrams for piston position, speed, and acceleration are obtained, respectively as shown in Figs. 9 to 11. The piston rod initially transfers simultaneously from the stage piston numbered 1, 2, and 3. When the movement stroke reaches the 1<sup>st</sup> stage piston limit position, the 1<sup>st</sup> stage piston bottom hits the cylinder end until it begins to stand. The movement of the 1<sup>st</sup> stage piston is restricted, while the 2<sup>nd</sup> and 3<sup>rd</sup> stage pistons continue the movement. When the cylinder movement reaches the limit position of displacement of the 2<sup>nd</sup> stage piston, this cylinder piston stops moving until the full extension of the hydraulic cylinder occurs. At the starting stage, as the hydraulic oil enters, the positive chamber pressure elevates until the load transfers. Then the sudden change of the cross-sectional area resulting from the stage change leads to a sudden difference in the pressure, as shown in Fig. 7, and this will affect the smooth functioning of the hydraulic system and often generate jerk or vibration. When the 3<sup>rd</sup> stage piston is moved, the positive chamber pressure elevates until the load transfers. The load movement direction will be changed, and the cylinder will be changed from the original pressure to the tension case, and this will cause decreasing of the pressure of the positive chamber and increasing the pressure of the reverse chamber. It is noted that extraordinary phenomena occur at the final arrival moment and retraction moment and correction of the hydraulic cylinder of the third stage. The cylinder vibration will occur in a range of about 1.5m in length at the 3<sup>rd</sup> stage piston at the moment 6 s as well as 12 s and it is then sometimes accompanied by an abnormal overshoot.

Under the effect of the control signal shown in Fig. 7, the 3<sup>rd</sup> rod acting as the first, it is uniform at a 0.2 m/s rate and travels 0.6m up. Then the 2<sup>nd</sup> rod is acting, and it is uniform at a 0.4m/s rate, and travels 1.2m upward. The last rod is at a speed rate of 1.5m/s and it reaches the cylinder ends under  $2.55 \times 10^7$  pa pressure to be maintained within 6 sec. The slide valve travels under the effect of the control signal to the right side. The relief valve back-pressure is  $3.4 \times 10^7$  pa. After that, the 1<sup>st</sup>-rod starts with a full descent, the last rod drops to the initial position, and the speed goes to zero during the period from 6-12 sec. The simulation results show that the extended duration of the multi-stage hydraulic cylinder is around 6 s, at which the maximum acceleration is up to  $13 \text{ m/s}^2$ .

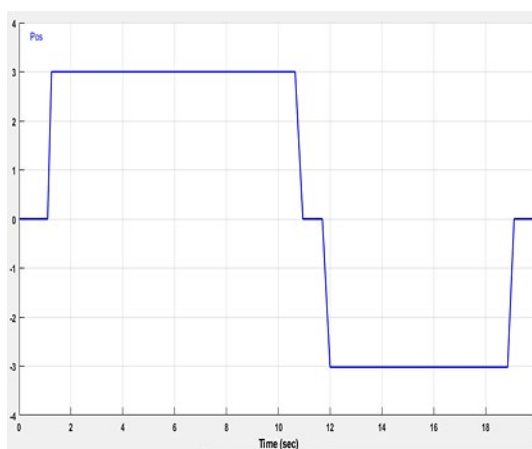


Figure 7: Control signal

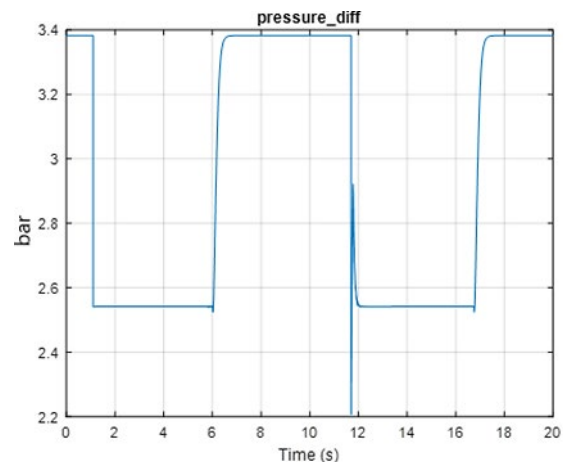
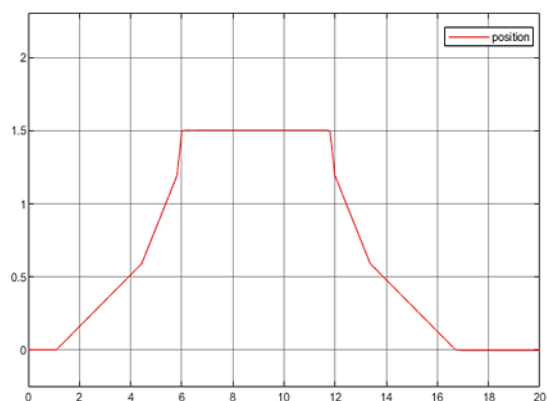
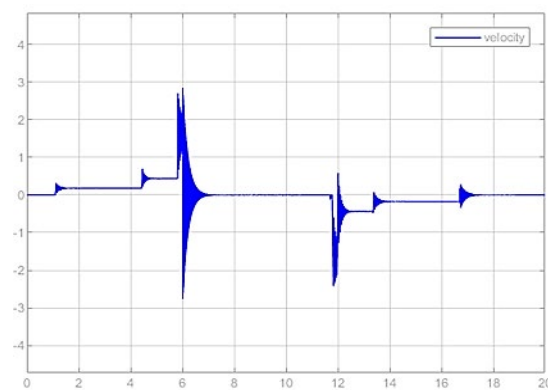


Figure 8: Pump pressure needed to deliver

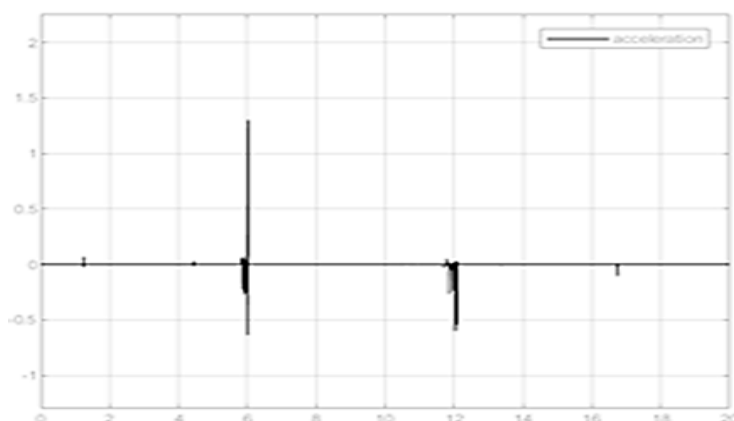




**Figure 9:** Position wave for telescopic cylinder



**Figure 10:** Velocity wave for telescopic cylinder



**Figure 11:** Acceleration wave for telescopic cylinder

#### 4. Conclusions

From the MATLAB, the Numerical simulation, and modeling results, the following conclusions may be drawn:

- 1) The simulation and modeling present a good design of the hydraulic telescope cylinder and the simulation results obtained are consistent with the actual situation of the multi-stage hydraulic cylinder.
- 2) The 3<sup>rd</sup> stage rod is subjected to the maximum stress compared to the other stage rods.
- 3) It is found that the extraordinary vibration is happening to the 3rd piston at the moment when the cylinder begins to reach the final position and also when it retracts, which occurs due to the inadequate guide distance from the 3rd stage piston of the multi-stage hydraulic cylinder.

#### Author contribution

All authors contributed equally to this work.

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#### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

#### Conflicts of interest

The authors declare that there is no conflict of interest.

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