Modeling and simulation of electro-hydraulic telescopic elevator system controlled by programmable logic controller

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ABSTRACT

Traditional hydraulic cylinders are widely used in industry as load lifting tools. There is difficulty in employing these cylinders in narrow installation space like building elevators as well as they require a long working stroke, so solving this problem requires using the telescopic hydraulic cylinder instead. This cylinder is a unique hydraulic cylinder design that uses a sequence of decreasing diameters to create a long operating stroke in a compact-retracted form. In this work, the Auto Station software is used to build a telescopic hydraulic cylinder model that includes hydraulic elements such as double-acting hydraulic telescopic cylinders, pump, valves, pipeline, and filter, as well as electrical parts such as programmable logic controller (PLC), push-bottoms, and position sensors. The proposed model is operated by a PLC controller and has three floors with an overall height of around 300 cm for lifting a 100 kg payload. The accuracy and validity of this model in lifting big weights were demonstrated by the analytical findings of characteristic curves for cylinder position and velocity. This model can be used a basic reference to analyze and construct hydraulic cylinders with any number of stages. The findings of simulations reveal that a quick change in pressure due to phase change causes multi-phase vibration.

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1. INTRODUCTION

The vertical transportation system for both persons and loads has been exploited by mankind since antiquity [1]. The growing requests of industry led to the necessity for transferring a large number of raw materials, besides, the invention of steel beam construction tallest buildings has recently increased which led to broadening the horizons for elevator technology [2]. Elevators are a vertical transport mechanism used to transport payloads (people or goods) from one height to another without disturbing the load itself [3].

Traction elevators, hydraulic elevators, and pneumatic elevators are the three most often utilized elevators today. Traction elevators are better suited for higher buildings since they can move at greater speeds and high altitudes [4]. The traction elevators are divided into two types: i) geared-traction elevators are used for buildings of 9 floors or less and residential buildings of 18 floors or less and ii) gearless-traction elevators are used for high-speed and commercial buildings over 9 floors and residential buildings over 18 floors. Both types of traction elevators may be driven by rotary or linear, alternating current (AC) or direct current (DC) electric motors [5]-[11].

The Pneumatic elevators [12], [13] are modern types of domestic elevators employed in places to lift things or persons to four stories. These elevators do not require any machine room. These elevators are still used on a narrow scale because this technology is almost new and the cabin is often small well as it is used to transport a limited number of people for low rise buildings [14]. Hydraulic elevators are utilized in buildings for both freight and passenger services, with speeds ranging from 0.125 to 1.0 m/s and heights ranging from two to six stories.

The hydraulic elevators have the merits of more safety, more reliability, low noise, simple structure, smooth running, convenient maintenance, and comfortable ride [15]. Traditional hydraulic elevators have a sheave extending under the floor of the elevator hole and accepting the retracting piston when the elevator descends. The hydraulic cylinder is the most commonly used component of the hydraulic elevator. Traditionally, hydraulic cylinders are designed for a bucking load capacity utilizing the Euler equation and the safety factor [16]. The cylinder converts the pressure and flows the power of the fluid into velocity and force. The hydraulic cylinders are classified into single-acting hydraulic cylinders, double-acting hydraulic cylinders, and telescopic hydraulic cylinders. The single-acting hydraulic cylinder is simple in design. It involves a piston inside a barrel, which is the cylindrical housing. There is a port for the oil exit and entrance. The single-acting cylinder produces force in one way by the existence of the piston hydraulic pressure. The piston return is not accomplished hydraulically. In the single-acting cylinder, retraction is completed either by a spring or related to gravity. The pump flow is directed to the blank end port in double-acting cylinders, and the fluid is returned to the reservoir via the rod end port. The fluid returns to the tank from the blank end port, and the pump flow goes to the rod end port to track the cylinder [17]. A telescoping hydraulic cylinder is a unique hydraulic cylinder design that allows for a very long flight output from a very little retraction length. The collapsed length of this cylinder is usually around (20-40%) of the total extended length, depending on the level number of the stages. Hydraulic oil is usually used to drive the heavy-duty telescopic cylinder. Telescopic cylinders are also known as telescoping cylinders and multi-stage telescopic cylinders. They are commonly used in lifting apparatus for example elevator, tipper, launcher, and equipment of the construction. The barrel is the sleeve with the biggest diameter, while the stages are the smaller ones, and the plunger is the smallest stage [18].

Electro-hydraulic cylinders are modified hydraulic cylinders via combining a high-performance hydraulic cylinder, control valve, and precise feedback transducer, assembled in one package to improve its performance. Proportional integral and derivative controller (FOPID) controller is proposed to control the elevator sometimes [19]. A programmable logic controller (PLC) is one of the commonly controllers used in the industrial applications to control hydraulic cylinders [20]. Singh *et al.* [21] described programmable a logic controller PLC-based elevator control system. They focused on employing a PLC to control the system and constructing the elevator model. Effect sensor was used to determine the elevator position. Push buttons were utilized to call the elevator cabin. A display unit can be used to read the cabin position. In this paper, the auto station software for ladder logic program was used to simulate the elevator floors and the control system. A hydraulic driving control system depending on a P-Q valve to implement a hydraulic elevator has been introduced by Liu *et al.* [22] to get the advantage of smooth starting, high precise control, and small impact in the emergency stop case, which can realize an efficient hydraulic elevator. Mohammed *et al.* [23] implemented an electro-hydraulic elevator controlled by a PLC via a proportional control valve. Electro-hydraulic servo system to control the speed of cabin in a hydraulic elevator system prototype with the aid of a hydraulic proportional valve and PI controller was carried out by Mohammed *et al.* [24]. All the previous elevators utilized traditional cylinders which are suffering difficulty in narrow installation space like elevators' buildings as well as they require a long working stroke, so solving this problem requires the use of the telescopic cylinder instead in driving the elevator cabin. The present paper introduced a telescopic cylinder-based elevator, simulated with 4 floors and controlled by PLC. Saeed [25] had implemented fast devices; controller random access memory (RAM) in a fast field programmable gate array (FPGA) to control a prototype of elevator with minimum processing time and minimum size of memory.

2. HYDROELECTRIC SYSTEM SIMULATOR FOR TELESCOPIC ELEVATOR

Referring to Figure 1, the telescopic elevator simulator consists of a telescopic cylinder with a 1500 mm total stroke. The cabin is assumed to be moved between four floors. Four magnetic sensors P1, P2, P3, and P4 were used as position sensors for the desired floors. There is one position sensor between every two successive floors. The sensor is positioned to be used as a tag to start decreasing the elevator speed if it arrives at the desired floor in order to smoothly stop at the required floor. A fixed pump driven by an electric motor was used as a hydraulic pressure source. The maximum pump pressure was determined using a relief valve. The elevator was controlled via 4/3 way, with a double solenoid hydraulic valve and two 2/2 way, with single solenoid valves. The 4/3 valve was used to drive the elevator up or downward while the 2/2 valves with relief valves and check valves were used to decrease the elevator speed if it approaches the desired floor. The pushbuttons F1, F2, F3, and F4 were used to select the desired floor. The studies [5]–[7] illustrate how to explain research chronologically, covering research design, research technique (in the form of algorithms, pseudocode, or other), how to test, and data gathering. The progress of research should be described with references, so that the explanation may be accepted scientifically [2], [4]. As seen below and cited in the manuscript [5], [8]–[13], Figures 1-2 and Table 1 are given in the center. Figure 2 shows the telescopic elevator state diagram.

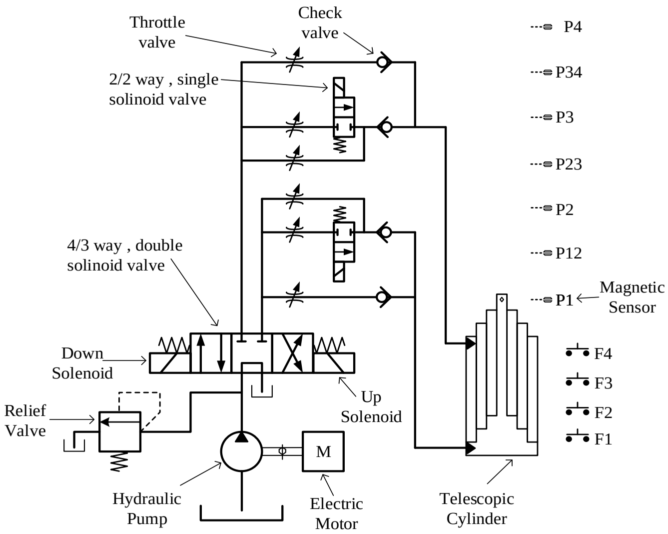

Figure 1. Telescopic elevator hydroelectric system

3. TELESCOPIC ELEVATOR CONTROL SYSTEM SIMULATOR

A PLC was used to control the telescopic elevator simulator system. The PLC program was designed depending on the state diagram shown in Figure 2. As shown in the state diagram, the simulator starts from floor one via the “First Pass” flag, then it starts moving upward to floor 2 if desired, or to floor 3 if desired and floor 2 was not desired, or to floor 4 if desired and floor 2 and floor 3 were not desired. And vice versa in descending downward. If the elevator is on floor 2, the priority is to move down towards floor 1. In the same case, if the elevator at floor 3 then the priority is to move upward to floor 4. All symbols in the figure are interpreted as in Table 1.

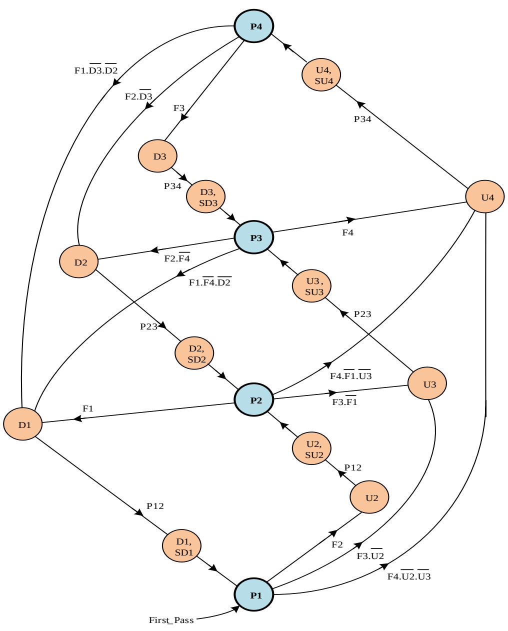

Figure 2. Telescopic elevator state diagram

Table 1. Symbols used in telescopic elevator state diagram

P1, P2, P3, & P4	Floors 1, 2, 3 & 4, respectively
U2, U3, & U	Moving upward to floors 2, 3 & 4, respectively
D1, D2 & D3	Descending downward to floors 1, 2 & 3, respectively
SU2, SU3 & SU4	Decreasing the elevator speed at moving upward to floors 2, 3 & 4, respectively
SD1, SD2 & SD3	Decreasing the elevator speed at descending downward to floors 1, 2 & 3, respectively

4. CONVERTING THE STATE DIAGRAM INTO A PLC LADDER DIAGRAM

To devise the PLC program from the state diagram in Figure 1, the instructions' equations should be concluded at first. These equations are then used to implement the ladder logic program as shown in Figure 3. The following equations represent the instructions for moving the elevator up/down taken from the state diagram.

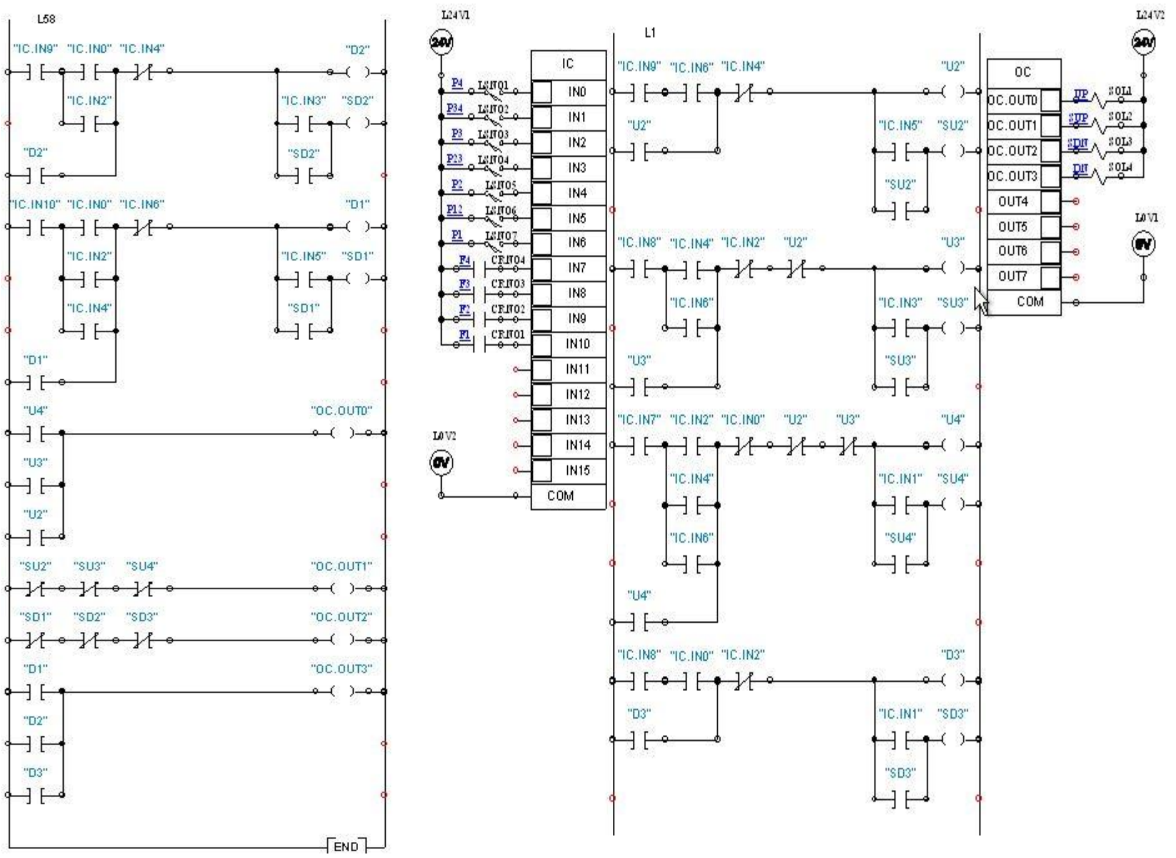

Figure 3. Logic ladder diagram for telescopic elevator system

a) Move up instructions

$\mathrm{U2} = (\mathrm{U2} + \mathrm{P1} \cdot \mathrm{F2}) \cdot \overline{\mathrm{P2}}$

$\mathrm{U3} = \big(\mathrm{U3} + \mathrm{F3}.(\mathrm{P1} + \mathrm{P2}\,.\,\overline{\mathrm{F1}})\big).\overline{\mathrm{P3}}\,.\,\mathrm{U2}$

$\mathrm{U4} = \mathrm{U4} + \mathrm{F4}.(\mathrm{P1} + \mathrm{P2}.\overline{\mathrm{F1}} + \mathrm{P3})).\overline{\mathrm{P4}}.\overline{\mathrm{U2}}.\mathrm{U3}$

$\mathrm{UP} = \mathrm{U2} + \mathrm{U3} + \mathrm{U4}$

b) Instructions to slow down "move up" speed

$\mathrm{SU2}=\mathrm{U2}\,.\;\mathrm{P12}$

$\mathrm{SU3}=\mathrm{U3}\,.\;\mathrm{P23}$

$\mathrm{SU4} = \mathrm{U4}\,.\,\mathrm{P34}$

$\mathrm{SU} = \mathrm{SU2} + \mathrm{SU3} + \mathrm{SU4}$

c) Move down instructions

$\mathrm{D3} = (\mathrm{D3} + \mathrm{F3}\,.\,\mathrm{P4})\,.\,\overline{\mathrm{P3}}$

$D2 = \left(D2 + F2.\left(P4 + P3\,.\,\overline{F4}\,\right)\right).\,\overline{P2}\,.\,\overline{D3}$

$D1 = \left(D1 + F1\,.\left(P4 + P3.\ \overline{F4} + P2\right)\right).\,\overline{P1}\,.\,\overline{D3}\,.\,\overline{D2}$

$DOWN = D3 + D2 + D1$

d) Instructions to slow down "move down" speed

$SD3 = D3\,.\,P34$

$SD2 = D2\,.\,P23$

$SD1 = D1\,.\,P12$

$SD = SD3 + SD2 + SD1$

5 RESULTS AND DISCUSSIONS

Figure 4 shows the simulation of the hydraulic telescopic elevator system using Automation Studio 6 Software. When the program is running, initially the elevator will be seen stopped on the first floor. As the button F4 is pressed, the system moves the elevator cabin (upper end of the rod) upward to floor 3. Figure 5 shows the curves of position and speed versus time as the elevator cabin is transferred from floor 1 to floor 4 and vice versa.

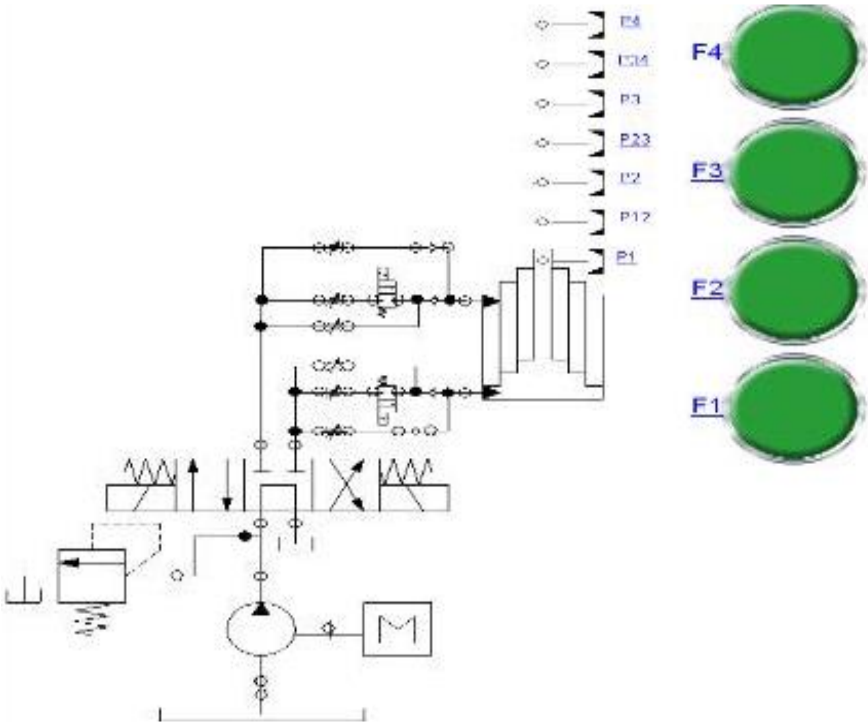

Figure 4. Simulation of hydroelectric telescopic elevator system

Referring to Figure 5, it is seen that the speed of the elevator changes as the elevator travels between intermediate stages (i.e. from floor no.1 to floor no.2 and from floor no.2 to floor no.3 and vice versa). This is due to the sudden change in the cylinder area. As it is explained in the mentioned figure, the elevator speed is increased when the cabin transfers from floor 1 to floor 2 (i.e. V2 > V1). The same thing occurs when the elevator travels from floor 2 to floor 3 (i.e. V3 > V2). This happens because the cylinder area of floor 2 is smaller than that of cylinder 1 and the cylinder area of floor 3 is smaller than that of cylinder 2, while the hydraulic valve discharge rate is not changed. The opposite thing is occurring when the elevator travels from floor 3 to floor 2 and from floor 2 to floor 1, where the speeds were decreased due to the sudden decrease of cylinder area during moving from a stage to downstage. The sudden change in speed happens due to the sudden change of cylinder area, this could not be avoided, which generates jerks during traveling between floors. As a result, it can be concluded that this type of elevator could be used for any application that requires high load transportation within a determined space but is not preferred for transferring people.

Figure 6 shows the curves of position and speed versus time when the elevator transferred from floor1 to floor 2, from floor 2 to floor 3, from floor 3 to floor 4, and vice versa. It is seen that the speed of the elevator decreases as the elevator moved across the approach sensor of a required floor, which tells the system to decrease the speed to stop at the selected floor. It is also seen that there is a sudden change in the elevator speed when it passes across the approach sensor of a required floor and this could be avoided easily by using a proportional valve, but it is not applied in the proposed simulation software.

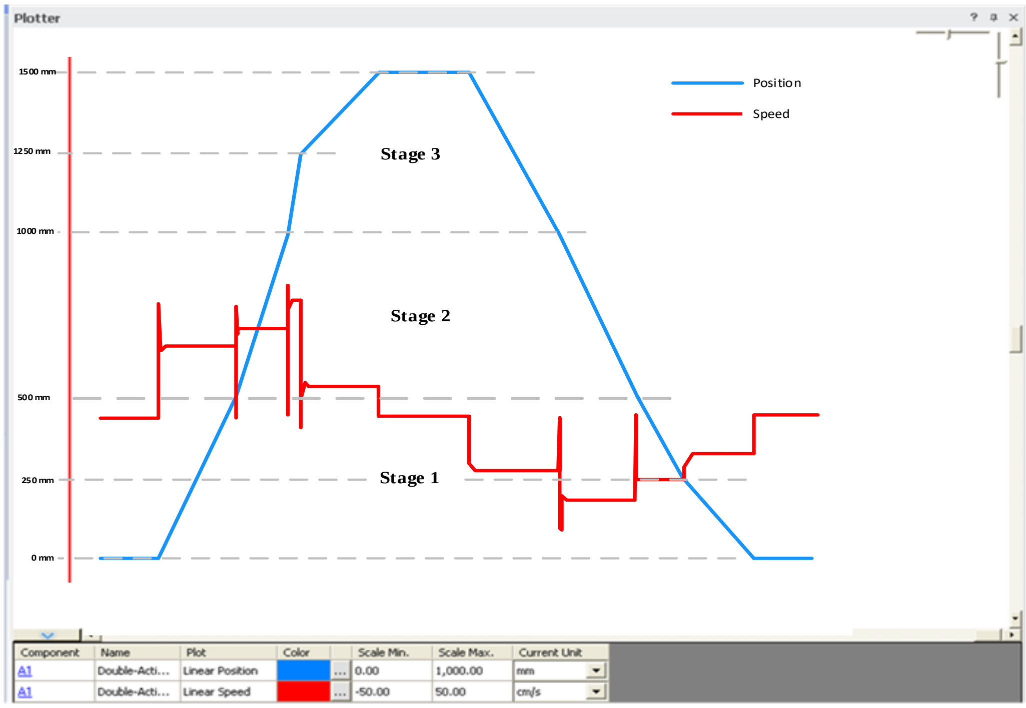

Figure 5. Position and speed versus time curves-A

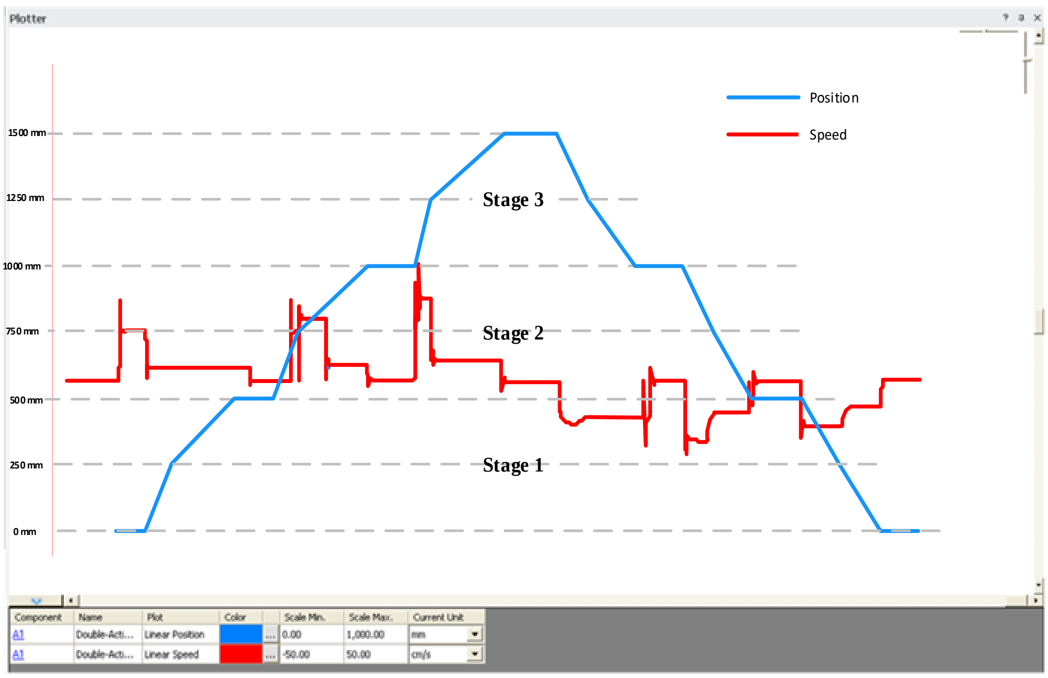

Figure 6. Position and speed versus time curves-B

6. CONCLUSIONS

The following are some of the conclusions drawn from this paper: a) a prototype model of the planned PLC-based hydraulic elevator system has been successfully developed. It has four levels and is fully automated, b) the simulation and modeling reveal a well-designed hydraulic telescope cylinder, with simulated results that are commensurate with the multi-stage hydraulic cylinder's actual scenario and c) The present elevator is more portable than other elevators when lifting heavy loads, hence it is employed in high-load buildings and factories.

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