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# A review on the employment of the hydraulic cylinder for lifting purposes

**Istabraq Hassan Abed Al-Hady, Farag Mahel Mohammed, Jamal Abdul-Kareem Mohammed**
Departement Electromechanical Engineering, University of Technology, Baghdad, Iraq

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**ABSTRACT**

The hydraulic elevator is both a cost-effective system and results in extremely clean building exterior lines since the usual penthouse-type machine room is eliminated. Without the need for wires, counterweights, or pulleys, this elevator can transfer people between levels. One of the most significant factors to consider when designing people's elevators is that they should not be disturbed when going between levels and that the elevators should stop accurately. As a consequence, innovative technologies such as the electro-hydraulic servo system (EHSS) may be employed with a traditional hydraulic elevator. This technology may employ speed and position input to provide the desired degrees of speed control, riding comfort, and leveling precision. The EHSS is a closed-loop control system that operates as a drive unit, raising and lowering the elevator cabin in response to a variable like position, velocity, or force. This paper examines various types of hydraulic systems for lifting purposes, as well as the application of servo system principles to hydraulic control valves, to credibly provide the traditional hydraulic elevator with a selectable diversity of precise and smooth transport characteristics across floors. This study also looks at how elevators employ telescopic hydraulic cylinders efficiently for lift purposes in the elevator.



***Corresponding Author:***

Istabraq Hassan Abed Al-Hady
Departement Electromechanical Engineering, University of Technology
Baghdad, Iraq
Email: eme.19.22@grad.uotechnology.edu.iq

## 1. INTRODUCTION

Elevators have become vital vertical transit aids in people's lives as the economy has grown and a vast number of city buildings have been constructed, and their technology has advanced significantly [1]. Elevators are lowering or hoisting appliances, designed to transmit passengers that normally move in secure assists and leaders to two or multiple levels [2]. Elevators are classified depending on a variety of factors, but the driving mechanism determines the design and element manufacturing processes. Elevators are classified into three categories based on how they are powered; Electric traction elevators [3]-[9], Hydraulic elevators [10]-[14], and Pneumatic elevators [15]-[17]. A typical hydraulic elevator consumes significantly more energy than a traction elevator. Since 1997, energy-regenerative hydraulic elevators have been developed to minimize power installation needs and energy consumption. In comparison to traditional elevators, the new generation of hydraulic elevators may save a substantial amount of energy [18].

The electro-hydraulic system (EHS) [19] originally appeared in fluid power technology in the early 20th century, when it was first introduced by French physicist Braise Pascal in the 1640s. The EHS generally consists of three main units including the power unit which is responsible for increasing the power of the fluid, the control unit, which is responsible for controlling the pressures, directions, and velocities with the time in the system, and the operating unit, which is responsible for obtaining the useful work of the system [20]. The electro-hydraulic system offers several benefits, including a wide speed range, fast response, high durability, and a high power-to-weight ratio, and it is extensively employed in industrial manufacturing, agricultural machinery, and armament systems [1], [14], [21], [22].

In today's world, transferring hydrostatic fluid force into rotational or translational mechanical power is commonplace. To achieve the necessary movement, a hydraulic actuator is generally used in hydraulic connection with an appropriate hydraulic circuit, as well as mechanical connection with its surroundings [23]. One of the most common forms of elevators is the hydraulic elevator, which is a typical mechatronic system with embedded controls [24]. Since the 1980s, with today's advanced technology, the hydraulic elevator system has increased in reliability, safety, and operational performance, with computer-aided design and manufacturing being employed in elevator design and production [25]. Proportional–integral–derivative (PID) and programmable logic controller (PLC) controllers are now being used by an increasing number of scientists, businesses, and worldwide enterpriser organizations for their innovation, research, manufacturing, and marketing [4]. The hydraulic lift systems are inefficient, owing mostly to their reliance on throttling-based control. Scientists and researchers have devised a variety of strategies to regulate and decrease these issues.

## 2. COMPREHENSIVE REVIEW OF LITERATURE:

Many studies have been published in the literature which deal with various types of hydraulic elevators powered by various control approaches. Li *et al*. [26] designed an electro-hydraulic elevator with two symmetrically positioned cylinders on either side of the cab, as well as cab speed adjustment and cylinder synchronization control. The system utilizes three flow-control proportional valves. The arrangement of cylinders is necessitated by the vast size of the electro-hydraulic elevator cab. A restricted step proportional-derivative (PD) controller keeps the non-synchronous deviation of ±2 mm between the two cylinders. Flow control is the sole way to lessen the cylinders' non-synchronization. The results of the tests revealed that the non-synchronous difference in error can be maintained to less than ±2 mm. The difference between the expected and real velocity patterns is caused by hysteresis occurring in the electro-hydraulic proportional valves.

Keles and Ercan [27] studied the open and closed-loop performance of a hydraulic system controlled by a pulse-width modulated (PWM) technique both theoretically and empirically, as shown in Figure 1. To begin, a mathematical system model and methods for determining system responses to PWM inputs were developed. PWM step and sinusoidal inputs were used to determine the servo valve response, as well as, the open-loop, and closed-loop hydraulic systems. The impact of pulse frequency on sinusoidal response was studied. An experimental set-up was built that included a PC as a controller, PWM, feedback components, and a servo valve-driven hydraulic system. PWM inputs in electro-hydraulic control systems have been shown to offer precise position control in experiments. According to the findings obtained for sinusoidal reference inputs, for the best performance of the tested system, the pulse frequency must be more than 50 times the frequency of the reference input if the reference signal has a frequency of less than 10 Hz.

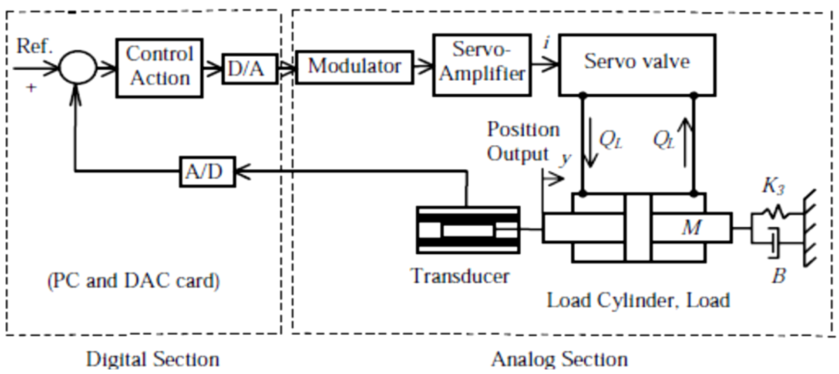


Figure 1. System structure

By utilizing a discrete sliding mode control, Ghazali *et al*. [28] demonstrated the position tracking capabilities of an electro-hydraulic hydraulic actuator system. The suggested control using a two-degree-of-freedom control structure was tested using an experimental study based on point-to-point trajectory.

According to experimental findings, the position tracking control of the DMSC with a 2-DOF structure is extremely robust and able to handle errors and disturbances that may arise for various point trajectories. Additionally, it was demonstrated that the suggested controller can outperform traditional linear–quadratic regulator (LQR) and PID controllers in terms of tracking performance.

Sha *et al*. [29] focused on creating a new hydraulic elevator model that included a realistic dynamic friction model. This model was employed in a discrete adaptive sliding mode control technique with integral action that was dependent on input-output data. A nonlinear output feedback system along with a sliding mode was adjusted. This algorithm is distinguished by an on-the-fly updating of the hyperplane factors and integral gain, which improves control loop response. The novel controller has unknown external disturbances, better model uncertainty, change in operation circumstances robustness, and significantly improved features for tracking velocity, as compared to an ideally tuned PID controller employed on a hydraulic elevator system.

Park and Chang [30] proposed a time delay control and command-less input shaping mechanism to solve the issue of vibration occurrence in a hydraulic telescopic handle shown in Figure 2. The technique achieved the greatest productivity, and operate the system in a high-speed mode without vibration in the arm when lifting goods to higher positions. The control command is applied with minimal input shaping method and time delay control.

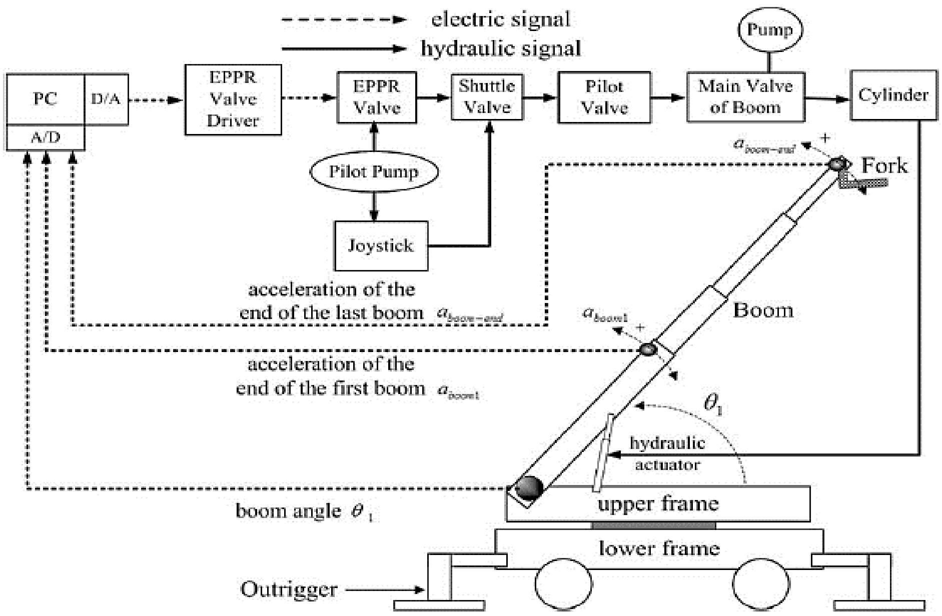


Figure 2. Structure of the control system

Huayong *et al*. [31] used a variable voltage, variable frequency (VVVF) technology to control the speed of hydraulic elevators. The control system's computational models based on the PID control algorithm were established. Numerical simulation was carried out with MATLAB/Simulink. The elevator's uphill and downhill operating speeds were also subjected to testing. Both simulated and experimental tests indicated that when the elevator initially starts up, there is significant flutter and an oscillating behavior in the hydraulic system. However, as speed rises, these phenomena diminish. Figure 3 shows the control system.

Kim *et al*. [32] addressed the problem of robust velocity control for hydraulic elevators. The mechanical and hydraulic aspects of the analysis were separated. A complicated mathematical model for mechanics was created for simulation, however, the control system design was done with a simpler model that was simplified from the comprehensive one. Experiments were used to represent three key characteristics; pump friction, cylinder friction, and pump leakage. Temperature and pressure were used to characterize the leaking property. The Lyapunov redesign technique was used to develop a nonlinear two-stage robust controller for controlling velocity tracking. In the first stage, a reliable mechanical part controller was created to produce the necessary cylinder pressure to make reference velocity tracking. A sturdy controller for the hydraulic portion was designed in the second stage for tracking the reference pressure created by the first controller. According to simulation results, the suggested technique is robust to nonlinearities and uncertainties.

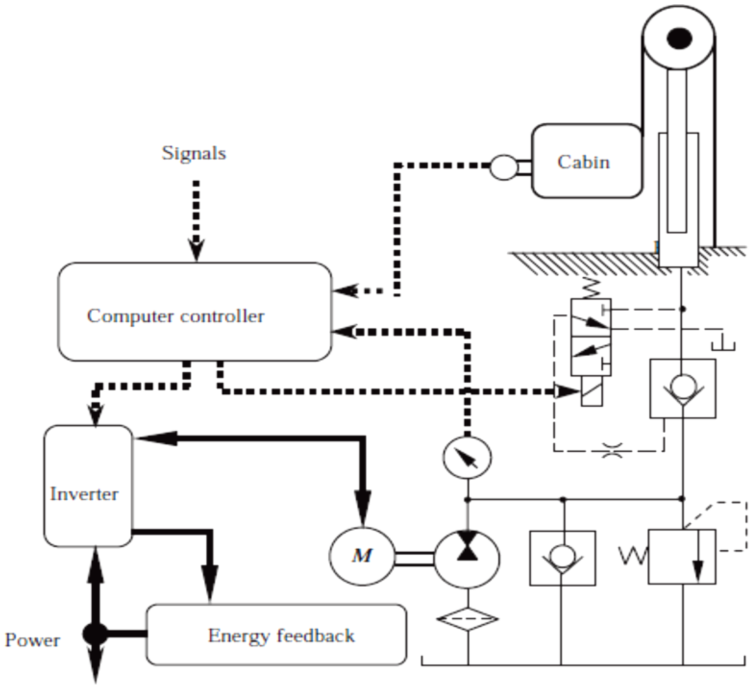


Figure 3. Control system of VVVF hydraulic elevator

The hydraulic telescopic cylinder has been employed in many applications. Derlukiewicz and Przybyłek [33] built a telescopic jib installed on a movable platform with a variety of calculations, such as jib profile selection, stable area of operation definition, and so on finite element method (FEM) strength analysis may be used to enhance these computations, allowing for faster building design optimization. Using Pro/E and ANSYS, X.-hua and D.-jun [34] built and studied a 3-stage hydraulic cylinder for usage in dump trucks. The findings revealed that the cylinder design can effectively satisfy the elevating force, reduce the cylinder stroke, and enhance the overall strokes. At the same time, it may assure the hydraulic cylinder's lateral rigidity and stability. Khudhur [35] performed a finite element (FE) study on the telescopic crane boom using two methods: manual computation and the ANSYS package software, as well as analysis utilizing the strength of materials technique.

Zhao *et al*. [36] used a disturbance-decoupled adaptive observer to estimate the joint state parameters of a hydraulic system with unknown disturbed inputs using a hydraulically propelled elevator. An unknown input observer (UIO) is integrated into the parameter estimate process by the suggested robust adaptive observer (RAO). The simulated test results showed the observer's accuracy and robustness to both perturbations and measurement noises.

To assure conveyor speed control precision, Li *et al*. [37] used the electro-hydraulic proportional control technique to manage the speed of a lead cathode walking-beam conveyer. The system was corrected using PID based on the simulation findings. Furthermore, the corrected system reaction speed has been substantially increased, and the PID has provided a better response.

Wang *et al*. [38] used secondary element as a sort of sophisticated approach with good control and application features in the network of hydrostatic transmission with secondary regulation. This approach has a lot of potential in the field of energy communication. The authors offered a variety of energy-saving and energy-reuse technologies with Secondary Regulation, as well as thorough analysis and explanation of their research objectives and application prospects in the hydraulic elevator system.

Carter and Selvaraj [39] designed and implemented an elevator controlled by PLC. They explained the operation of an elevator driven by an AC motor. The elevator is controlled by the inputs received from the sensors to accomplish the operator commands represented by forward-motoring and reverse-motoring, opening and closing the cabin door, motor working, as well as different sensors located on each floor and at the end of the door, when opening or closing the door, are incorporated in the logic software.

A double-telescopic prop of the 360-type was studied by Xuewen *et al*. [40] for the analysis of FE strength. The outcomes indicated that the prop's structural strength complies with design specifications. Additionally, the prop has a 2x axial pressure and 1.1x off-center 0.3R load capacity. This hydraulic support prop won't buckle, its operating resistance and mining height will grow, and its strength, stability, safety, and dependability will all go up.

Xu *et al*. [41] evaluated and improved the system safety brake performance for a hydraulic elevator system at over-speed dropping. A new indicator called residual vibration energy was established to easily quantify the cushion performance of the lifting actuators. It was concluded that better cushion performance could be achieved by employing a smaller control orifice diameter. It should be mentioned that the diameter should be less than a certain threshold level; otherwise, the effect would be higher.

Liu and Gao [42] had developed a high-speed on-off valve to produce experimentally precise position control of a hydraulic cylinder (HSV). The HSV is a modern type of electro-hydraulic digital valve with fast switching capabilities, high repeatability, and anti-pollution, and the past flow may be regulated by modifying the valve's open and closed duration. The result of the experiments and simulation showed that the HSV may be used to provide accurate position control by altering the PWM signal. Figure 4 shows the experimental hydraulic loop.

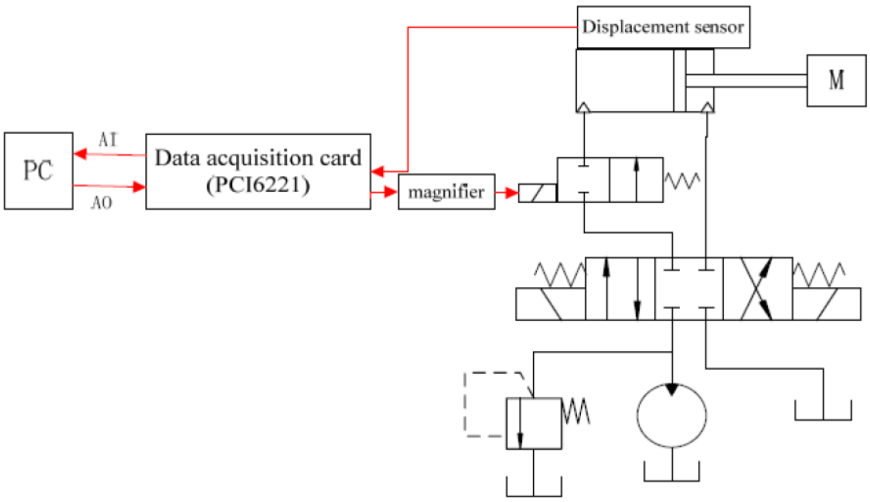


Figure 4. The experimental hydraulic loop

Kumar *et al*. [43] built a PLC-based control elevator system as an internal control implemented by human-machine interference (HMI) to obtain a system with dependable and stable performance. The outcome was offered to enhance elevator safety, which adds to the monitoring system field section PLC's dependable operation and ensures communication between the server machine and the system. An embedded system can also be integrated with a PLC to improve the system's efficiency and intelligence.

Liu *et al*. [44] proposed a new drive control system scheme for the hydraulic elevator in which the P-Q valve was utilized. Theoretical analysis and a prototype of the elevator mechanical drive and hydraulic drive systems were presented. The findings showed that the hydraulic drive control system offers the advantages of a smooth beginning, efficient control, and little effect in the event of an emergency stop.

Peña and Leamy [23] introduced the hydraulic architecture of a hydraulic elevator system's energy regeneration and speed control. A simulation was run to compare the efficiency of the new design to that of an electro-hydraulic elevator architecture that used a generator/motor to capture and return energy. It has been demonstrated that the suggested design offers up to a 13% gain in actuation efficiency when compared to the electro-hydraulic system, and up to a 23% decrease in the input energy for a day's work.

Mohammed *et al*. [15] used a pneumatic elevator system that was PLC-based to accomplish learning objectives. Electrical and pneumatic parts made up the elevator system. The PLC-based controlled elevator system model, according the claim, enables students to apply their knowledge of PLC applications to real-world situations. Installing a second PLC with the exact same configuration will cure any PLC problems and protect the system. The second PLC sends orders to the elevator if the first PLC malfunctions.

Salloom *et al*. [46] proposed a smart system working with an industrial load cell, a proportional pressure control valve, addition to an electronic pressure sensor combined with an Arduino controller. The controller was Labview-programmed to handle an actuator with variable load in four scenarios of hydraulic pump pressure supply. The smart system was simulated by the Automation Studio program to ensure its work function. As a consequence, in all situations, a proportionate relationship between the holding pressure and the load sensor at the load actuator was achieved, resulting in an effective variable load actuator. It has been shown when the providing pressure value grows, the hydraulic actuator's variable loading capacity diminishes, resulting in a decrease in proportional pressure limitation.

Patil *et al*. [47] created an industrial telescopic jack "Hydrau Solutions" in Belgaum. CATIA was used to model a two-stage hydraulic jack. They are susceptible to strong side forces. These pressures, together with the payload being pushed, threaten to damage the telescopic assembly. As a result, the configuration design was investigated using FEM under various loading situations and parameters. The results revealed that the load-carrying capability of the hydraulic jack had a considerable effect on its load-carrying performance. The FEM results agreed well with the jack theoretical solution under varied stresses.

Xu and Wang [48] introduced two different controllers to implement excellent speed tracking, a traditional PID controller and a self-tuning Fuzzy PID controller, whose performance is evaluated by examining its track feature, step response curves, error curves, and ideal speed response curves. Elevator system modeling, control, and simulation have been done using the MATLAB/Simulink software package. The outcomes of the simulation model revealed that the introduced controller of fuzzy PID controller has a more reliable control performance compared to the traditional one. Mute *et al*. [49] built a Telescopic Hydraulic Jack System for Tata Nangia Motors Pvt. Ltd. Hingna MIDC Nagpur, Maharashtra to solve the problem of lifting automobile components such as engines and transmissions, they formed a gearbox inside the ram (chamber made inside the ground where the washing and repairing of chassis being carried out). This system eliminates the need to manually lift the component and also analyzes the Telescopic Hydraulic Jack, plate, cylinder, hydraulic oil, wheel, and tank by using ANSYS software. Finally, a comparison was made between theoretical arithmetic and standard values and program validation findings.

Using output feedback controllers with matched and mismatched disturbances rejection, Yanga and Yao [45] suggested motion control of double-rod electro-hydraulic servo actuators. They all make use of a linear extended state observer to get in-the-moment predictions of the unquantified states of the system and matched disturbance, as well as a nonlinear disturbance observer to simultaneously estimate the mainly unmeasured mismatched disturbance. Theoretical investigation revealed that each control method guarantees the stability of the entire closed-loop system. Additionally, tests in various working environments are used to validate the usability of each control strategy.

Uzny and Kutrowski [50] tried to identify numerical simulations of the critical load of the telescopic hydraulic system based on load head characteristics. They spoke about the stability problem of a hydraulic telescopic cylinder exposed to a public load with a force directed towards the positive pole. It was constructed using the kinetic stability criterion. The effect of the load head characteristics was taken into account during the numerical calculations (loading radii and receiving head, bolt length). Based on the numerical calculation method, sections of the load head parameters are displayed where the evaluated cylinder's load-bearing capability is at its highest from a buckling perspective.

Mohammed *et al*. [11] examined theoretically and experimentally an electro-hydraulic servo mechanism system for regulating the speed and increasing the performance of a three-story elevator prototype model utilizing a proportional valve with a PID controller. The elevator was built with a height of 76 cm. The Arduino UNO board combined with data acquisition (DAQ) system was dedicated to fully automating the hydraulic elevator system. The hydraulic elevator system was controlled by LabVIEW software via DAQ board and L298 DC drive. Experimenting yielded the best PID improvements.

Mohammed *et al*. [12] created a model of an elevator prototype that replicates a genuine hydraulic elevator. It was constructed with three levels of around 300 cm in height to hoist a payload of 30 kg and was operated by a PLC controller. WPSOFT2 46 Ladder diagram software is used to design the programmable logic controllers (PLC) program for calling the elevator cabin across three floors and enabling it to arrive at the specified floor. The elevator cabin descent is accomplished by the use of a proportional valve under the PLC supervision. It was shown that using this collaboration between the proportional control valve and PLC in the model produced great outcomes for system control, efficiency, responsiveness, and smoothness.

Al-Hady *et al*. [13] analyzed the performance of a three-stage telescopic cylinder, shown in Figure 5. The hydrrualic system has been implemented with the assistance of the FEM. Also, the MATLAB Simulink package was utilized to build a comprehensive hydraulic telescopic cylinder's dynamic model shown in Figure 6. The proposed model was employed for lifting purposes in elevators.

Hady *et al*. [14] employed the 4-stages telescopic cylinder in building a PLC-based elevator system for lifting purposes as shown in Figure 7. The study findings, which included typical curves for cylinder position and speed, demonstrated the simulated model's correctness and believability. This program has provided a foundation for assessing and constructing hydraulic telescopic cylinders with any number of stages. According to the results of the simulation, a rapid change in hydraulic pressure caused by a phase change will result in multi-phase vibration. Figure 8 shows the curves of position and speed versus time when the elevator transferred between floors from F1 to F2, from F2 to F3, from F3 to F4, and vice versa.

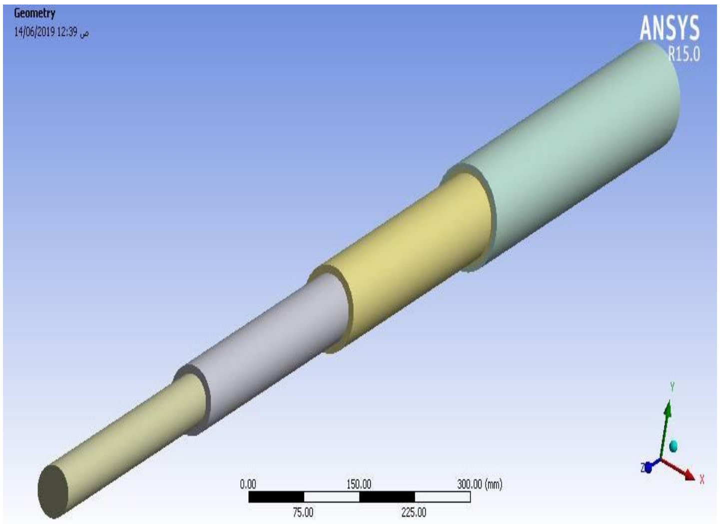


Figure 5. Solving the 3-stage telescope with FEM

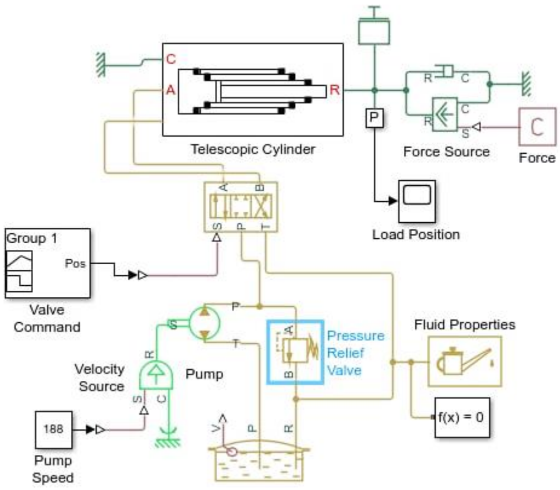


Figure 6. Telescope model with MATLAB Simulink

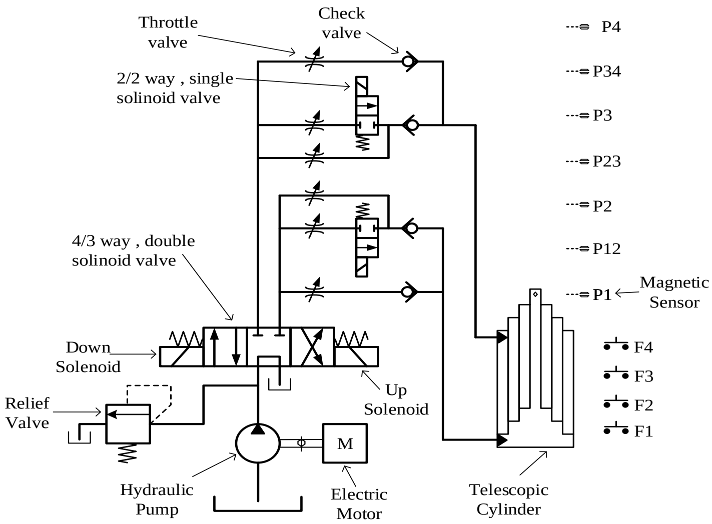


Figure 7. Telescopic hydroelectric elevator system

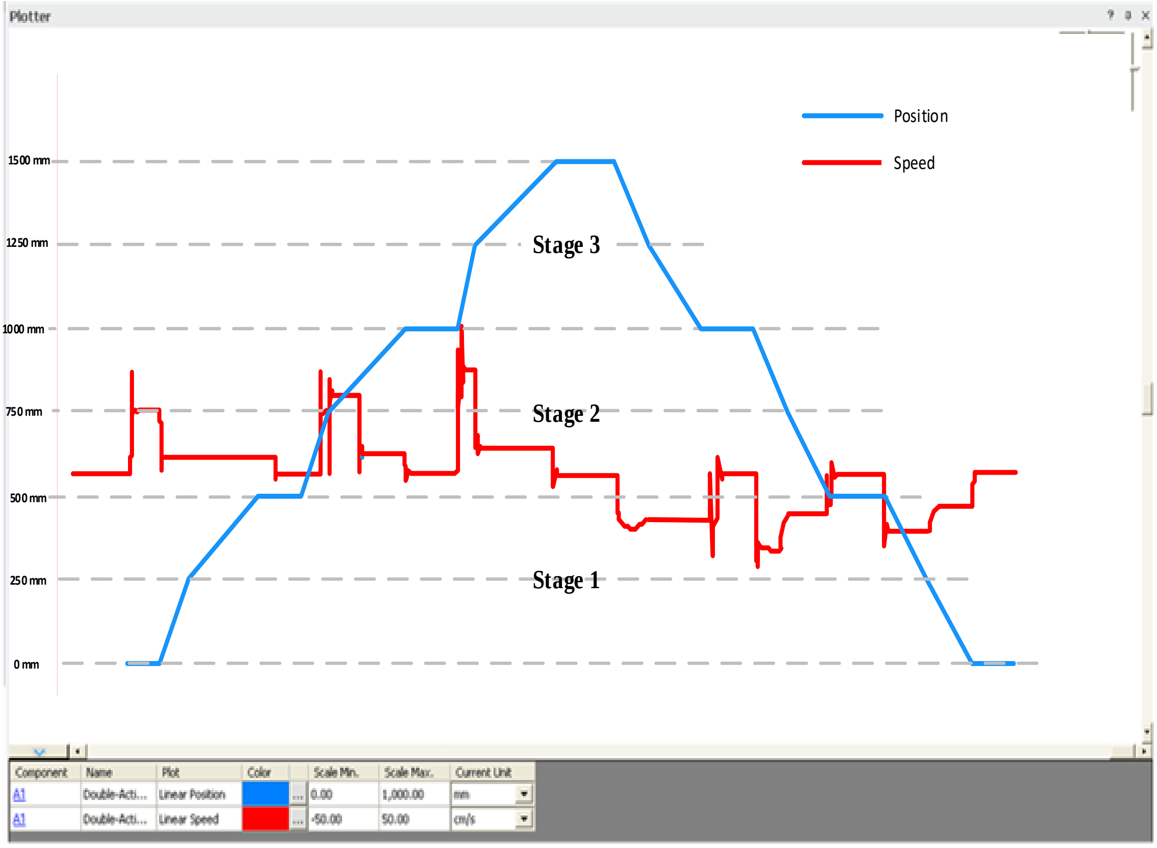


Figure 8. Curves of position and speed vs. Time

## 3. COMPARATIVE ANALYSIS

The aforementioned studies differ among them in terms of the type of software analysis, control methods, and the system performance. To explain these differences, the formulas are summarized as listed in two Tables 1 and 2. The tables indicate the most significant changes between past research in terms of software analysis, control methodologies, and system performance.

Table 1. Software analysis

| Authors | Software analysis |
|---|---|
| Al-Hady *et al.* [13] | Analyzed the performance of a 3-stage telescopic cylinder with FEM. MATLAB Simulink was devoted to building a full design of the cylinder's dynamic model |
| Derlukiewicz and Przybyłek [33] | Selected a jib profile and defined a stable operation area via FEM strength analysis |
| hua and jun [34] | Studied with ANSYS the supporting stability of a 3-stage hydraulic cylinder |
| Xuewen *et al.* [40] | Presented a 360-type double-telescopic prop finite element strength analysis |
| Patil *et al.* [47] | Designed and analyzed a telescopic hydraulic cylinder with ANSYS at a stroke of 980 mm and a max. lifting capacity of 7000 kg and |
| Mute *et al.* [49] | Used ANSYS to analyze the plate, the cylinder, the wheel, and the tank of the hydraulic telescopic jack system |
| Uzny and Kutrowski [50] | Simulated a telescopic hydraulic jack with ANSYS to solve the stability boundary issue of a telescopic hydraulic cylinder under a universal load with a force |

The theoretical analysis of the telescopic hydraulic cylinder is represented by all of the studies in Table 1, while the studies in Table 2 are concerned with designing and implementing an effective and smooth control of the motion of the telescopic hydraulic cylinder. The elevator system in the studies [13,14] differs from the all previously mentioned cylinders or lifting systems in that it is constructed using a telescopic hydraulic cylinder as a driving mechanism.

Table 2. Control technique used and performance for the lift system

| Authors | Control technique | System performance |
|---|---|---|
| Xue *et al.* [1] | Depended on the speed feedback control scheme to achieve real-time cabin speed correction | Results show that the improved scheme has a better dynamic response |
| Çağrı *et al.* [2] | Designed optimal model for a linear multi-car elevator system | Safety procedure and set up the required circumstances to operate properly |
| Knezevic *et al.* [3] | Vector controlled technique for induction motor | Indirectly manage the jerk since modern drives can regulate speed |
| Shreelakshmi and Agarwal [5] | Attempted to smooth elevator speed and assure Comfort by using a pre-defined non-instant jerk pattern. | Offer a better riding and reduced steady-state losses |
| Mohammed *et al.* [10], Mohammed *et al.* [11] | Controlled the hydraulic elevator speed using a proportional valve and PI controller | Effectiveness of using Electro-hydraulic servomechanism to get high comfort & smoothness |
| Mohammed *et al.* [12] | Hydraulic elevator controlled by PLC | Great outcomes for system control, efficiency, reactivity, & smoothness |
| Al-Hady *et al.* [13], Al-Had *et al.* [14] | Employed a telescopic hydraulic cylinder to build PLC-based elevator | The elevator transfers efficiently, smoothly, and quietly between floors |
| Mohammed *et al.* [15], Mohammed *et al.* [17] | Controlled an elevator with PLC | Implemented an electro-pneumatic elevator for learning objectives |
| Peña and Leamy [23] | Efficient design for hydraulically counter-weighting an elevator system with retaining cabin speed control | Over an electrohydraulic system, there is a 13% actuation efficiency gain & a 23% input energy drop over day course |
| Xu *et al.* [25] | Applyed a new flow rate inferential measurement technique on elevators | Hydraulic systems' costs and energy usage can be reduced with this strategy |
| Li *et al.* [26] | Established a synchronization control for the two employed cylinders on an electro-hydraulic elevator. | Presented a speed regulation of the cab |
| Sha *et al.* [29] | Provided an effective and improved solution to control the hydraulic lift | Improved a dynamic friction model for the hydraulic lift system |
| Park and Chang [30] | Applied command with minimal input shaping method & time delay control | Solved the problem of the vibration |
| Kumar *et al*. [43] | Designed a PLC-based control for an elevator system | Achieved a reliable, stable, and stable speed easily system |
| Liu *et al.* [44] | Utilized P-Q valve | Efficient speed control of the elevator |
| Xue *et al.* [45] | Two output feed-back controllers to control electro-hydraulic servo actuators (LESO) & (NDO). | Achieved stability of the entire closed-loop system |
| Xu and Wang [48] | Controlled a hydraulic elevator by the fuzzy logic controller | More reliable control compared to conventional PID controller |

## 4. CONCLUSIONS

After a thorough review of the literature on the use of hydraulic cylinders for lifting purposes, the following conclusions may be drawn: i) The hydraulic telescope cylinder has a good design, and the simulation results are comparable with the real-world elevator based on a multi-stage hydraulic cylinder; ii) The simulation model's correctness and believability are demonstrated by the findings for typical curves of telescopic cylinder position and velocity. This package will serve as a starting point for evaluating and developing hydraulic cylinders of any size or number of stages; iii) When lifting huge weights, the elevator powered by a telescoping hydraulic cylinder is more portable than conventional hydraulic elevators, hence it's used in high-load buildings and enterprises. As a result, elevator systems can benefit from this type of cylinder.

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## BIOGRAPHIES OF AUTHORS

**Istabraq Hassan Abed Al-Hady** was born in Iraq, in 1992. She obtains her B.Sc. of Electromechanical engineering degree in 2014 from University of Technology, Baghdad. Currently, she is a Graduate student at the Department of Electromechanical Engineering, University of Technology. Her research interests include Electromechanical systems, Hydraulic Elevators. She can be contacted at email: eme.19.22@grad.uotechnology.edu.iq.

**Farag Mahel Mohammed** was born in Iraq, in 1965. He obtained his B.Sc. of Mechanical Engineering degree in 1988 and his M.Sc. of Mechanical Engineering degree in 1995. His Ph.D. degree was awarded in 2003 by University of Technology- Iraq. He is a Professor at the Department of Electromechanical Engineering, University of Technology. His research interests include Applied Mechanics, Electromechanical, Mechanical properties, and renewable energy (solar). He has published above to 40 papers and has supervised several M.Sc. and Ph.D. theses. He can be contacted at email: 50127@uotechnology.edu.iq.

**Jamal Abdul-Kareem Mohammed** was born in Iraq, in 1967. He obtained his B.Sc. of Electrical Engineering degree in 1996 and his M.Sc. of Electrical Engineering degree in 2002 from University of Technology, Baghdad. His Ph.D. degree was awarded in 2007 by University of Technology, Iraq-Baghdad. He is an Assistant Professor at the Department of Electromechanical Engineering, University of Technology. His research interests include electrical machines, electrical drives, power electronics, Elevators, and renewable energy (solar). He has published close to 40 papers and has supervised several M.Sc. and Ph.D. theses. He can be contacted at email: 50128@uotechnology.edu.iq.