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Control Performance of Proportional Hydraulic Pressure Valve Using Load Sensor

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Abstract

There are many applications of hydraulic systems used by lifting mechanisms. It is one type of pressure-control valve. Its function is to balance the lifting forces to reduce power consumption, manually adjust to a specific pressure, and provide an equivalent load. This work aims to investigate the control performance between the valve and the sensor. An automated system is proposed that controls a proportional pressure relief valve, load cell, and pressure sensor via a programmed controller. In a way that keeps the variable load actuator in its position regardless of the value or time of its load pressure. verify the function of the system, it was simulated using FluidSim software V4.2. When a certain weight is lifted, we get variables such as valve pressure, cylinder position, speed, and sensor voltage output. A laboratory crane was also used to test the system. This is to verify the performance in the laboratory. The error values were (5.01, 4.39, and 2.29) at pump pressures (5, 10, and 15 bar), respectively. As a result, the system's work and performance are acceptable.

Keywords: Crane, Load Sensing, Pressure Relief Valve, Proportional Valve, Variable Weight.

1. Introduction

Electrohydraulic solutions for hydraulic circuit load management applications are desirable and economical, as they help minimize machine maintenance costs while increasing dependability and safety. To provide the opposing hydraulic force, most variable-hydraulic-loading devices use a standard counterbalance valve. Valve pressure regulation can be manual, one-time, or fixed, depending on the manufacturer. This would necessitate human interaction and ongoing observation of the valve, which is positioned distant from the control system's panel.

As a literature survey, several points from past studies were utilized. Energy efficiency is a fundamental consideration in the design of lifting equipment. Bonavolontà et al. [1] investigated the losses from the pump to the hydraulic cylinder to assign them. Ly et al. [2] developed a car brake control system to compensate for the pressure drop and achieve the required power and accuracy. Ding et al. [3] implemented open-loop synchronous control and sensors, thereby improving speed regulation, energy efficiency, and synchronization accuracy. Lisowski et al. [4] used a proportional multi-valve hydraulic system to reduce power. Casoli et. al. [5] investigated a mathematical model that simulates an excavator with electrical components and an old load-sensing machine. The energy efficiency of the new light and solution was compared. Siebert et. al. [6] created A new hydraulic excavator simulation system to sense load while minimizing latent pressure loss. The results showed that the hydraulic circuit improved the overall energy machine efficiency. Berne et. al. [7] proposed a method for analyzing the power requirements of hydraulic systems equipped with load control valves. This method can be useful for hydraulic machine lifting devices when selecting the appropriate valve for energy-saving applications. Chikhalsouk et al. [8] studied load-sensing hydraulic systems, controlled by adjusting the pump valve arrangement, to determine the pump's hydraulic characteristics. They improved the plotting of pump pressure and flow rate. Garrity et.al. [9]developed in the field of high-speed hydraulic, proportional, and digital on/off valves. Proportional force control, large stroke capacity, and flow rate at low pressure are all possible with on/off response time. Zhong et al. [10] used a simulation model to analyze the relative hydraulic loading system of the seat belt anchor point force testing device. The original proportional control system using the PID control and optimization method is greatly improved. Wang et. al. [11]studied a pre-designed electro-hydraulic servo control system in the field of hydraulic fluid lubrication that can effectively and stably adjust and monitor the constant pressure gain of variable hydraulic lubricating oil. Stosiak et. al. [12]examined how mechanical vibrations in the working environment of cyclic hydraulic systems affect changes in frequency. A technology has been developed to reduce vibration transmission to the directional control valve body. Li et. al. [13]studied a model of a hydraulic manipulator operating with a nonlinear proportional valve and high-precision lifting motion control technology. The performance of the developed control base is confirmed by comparing simulation results. Lyu et.al. [14] developed tunnel-boring machines to increase efficiency and safety during construction. According to the study results, dual cylinders operating under unbalanced loads can simultaneously implement high-precision motion tracking and high-level synchronization. Gao et. al. [15] improved the nonlinear reverse search algorithm for electrohydraulic birds. The model's applicability exceeds 97.54%. Canuto et al. [16]focused on converting an old industrial analog control into a digital control while studying the outer loop. The digitizer gives the required position derivatives. Liu et al. [17] improved the performance of the mobile boom system load control valve. A deeper investigation into the inner workings and effects of the load control valve's basic design parameters was conducted. Dengler et al. [18] demonstrated the simulation of the dynamic effects on hydraulic piston motion caused by switching valve actuation or fluctuating loads. The proportional valve allows precise actuator control and continuous flow with load-sensing.

In this proposal, the hydraulic system is studied to influence the load. The pressure is controlled using load control sensors without human interaction. The proportional pressure indicator control valve is observed to measure the electronic load pressure. The objective of this work is a load cell using a proportional pressure control valve.

The design idea, the hydraulic system's working method, and how to use the software will be explained, and a laboratory device suggested for the purpose of comparing the simulation with the laboratory application. Then the results and conclusions will be presented.

2. Methodology

One of the most important uses of hydraulic systems is cranes, hydraulic elevators, and any hydraulic lifting systems. There are many types and applications. Counterbalance valves are usually used. This is for safety, as well as reducing power consumption, using high pressure, and also to prevent vacuum pressure in case of overload. The critical task of securely managing an actuator that may be keeping weight requires the use of counterbalance valves. To stabilize loads, prevent equipment damage, and deal with hose failure, and other problems, they help manage the pressure brought on by impacts and loads. Standard counterbalance valves aid in preventing the unintentional or uncontrolled movement of static or dynamic loads. Counterbalance valves help prevent equipment damage in instances where pressure spikes are caused by machine operation by allowing line relief valves to function normally. Fully balanced relief valves aid in stabilizing systems with high back pressure variations.

Counterbalance valves are of the pressure control type, and they are set in advance, according to the required load or the highest possible load. Because the valve is of the fixed-type control in each case. It is not preferred to change the control every time because the process is complex and difficult and requires effort and time. This is done manually. But when using a proportional pressure control valve, the process becomes possible, easy, and automatic without manual control. And any according to the required load each time.

This determines the actuator's necessary holding pressure. Fig. 1 shows a schematic proposed hydraulic circuit of a proportional pressure control system for a load actuator that is overrunning.

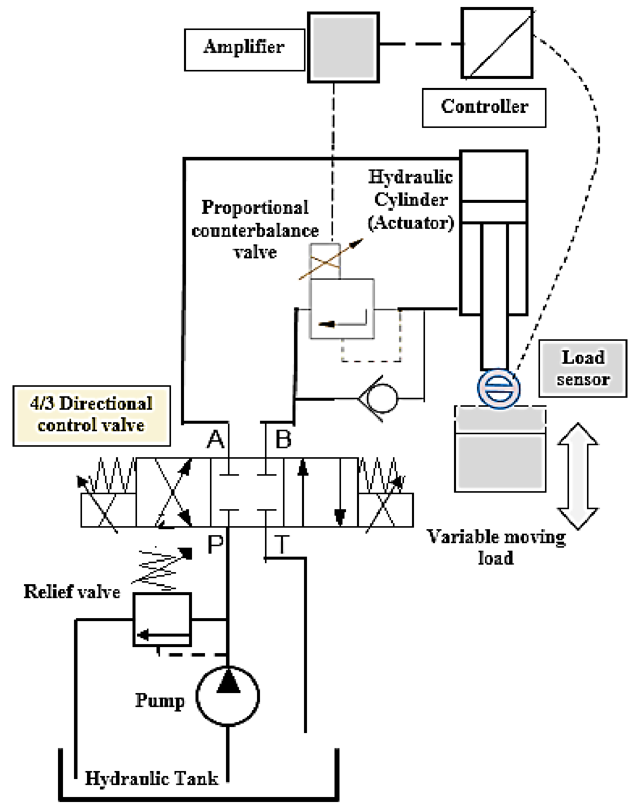

Figure 1 shows the proposed system.

In process control, load sensing is a well-established and dependable technique regularly used to measure the load effect, track structural strain, and assess container fill levels. The most common method is to employ a load cell, which is a mechanism that emits an electric signal in response to a physical force applied to it. Strain gauges are used to create the load cell. The structure is made up of a spring component, which is a selected and manufactured metal frame, as well as a bridge built of strain gauges. A spring component deforms when a physical force is applied to it. The Wheatstone Bridge transforms the spring component's deformation into an electric signal. S-type load cell sensors have been employed because they are highly accurate strain gauge-based sensors. The electrical interface is a braided shield 4-wire round cable with a loading range of (0-50) Kg. As indicated in Fig. 2, the load cell is tensioned using the loading.

Figure 2 shows the load cell.

2.1. Components of Hydraulic Lifting System

The proposed system can be applied to mobile shop cranes. Fig. 3 shows the proposed mobile shop cranes. The main hydraulic components of the suggested design are:

Hydraulic pump, tank, pressure relief valve, directional control valve, proportional pressure control valve with bypass check valve, and hydraulic cylinder.

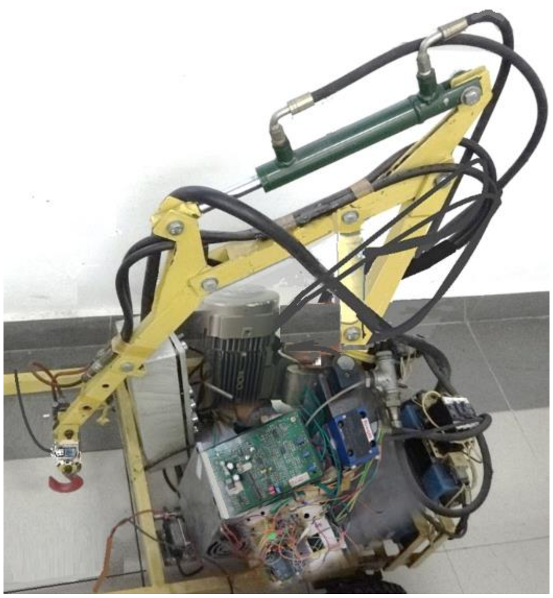

Figure 3. shows the suggested system.

A Directional Control Valve (DCV) features four ways and three positions (4/3) solenoid control to direct fluid flow to the hydraulic cylinder and change the direction of motion [19].

The proportional pressure relief valve is a type of Proportional Pressure Control Valve (PPCV) under code (DBEP6A06-13/45AG24K4M) from Rexroth, controlled by a proportional solenoid. It is equipped with a bypass check valve. The input electrical signals are converted into pressure output signals using these devices proportionally. These types of valves are controlled to keep a system's pressure under control. A proportional amplifier of type controls the proportional pressure relief valve's circuit (VT-VSPA1K-1). Fig. 4 shows the valve and its amplifier.

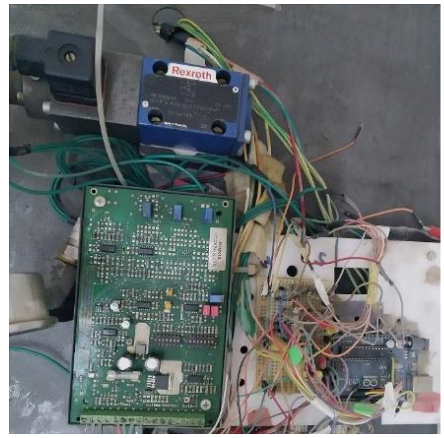

Figure 4. The Proportional Pressure Control Valve and its amplifier under test.

The (5.1) cm^2 piston area and (2.19) cm^2 annular area (rod side) hydraulic cylinder were used to move the crane link. The hook is attached to the load cell and connected at the end of the link. The schematic diagram of the link connected with the hydraulic cylinder load system analysis is shown in Fig. 5. The equilibrium loads of the system appear in equation (1).

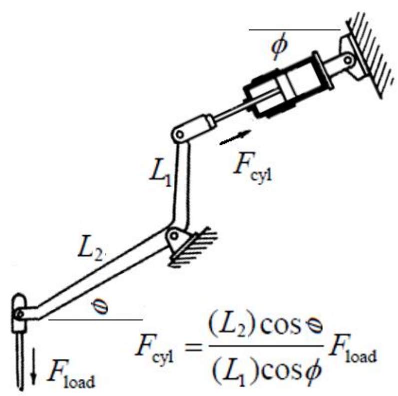

Figure 5. shows the load system analysis.

$$P_2A_2 - P_1A_1 = F_1 - F_{fr} \quad (1)$$

Where P_1 is the supply pump pressure (bar), which can be written as (P_{supply}), P_2 is the pressure (bar) that is used to hold the load using the (PPCV), which can be written as (P_{hold}), A_1 is the cylinder piston area (5.1) cm^2, A_2 is the annular area (2.19) cm^2 (rod side), F_1 is the weight load in kgf (F_{cyl}), and F_{fr} is the friction force. It is considered negligible. The equation becomes:

$$P_{hold} = \left(5.1 * P_{supply} + F_{cyl}\right)/2.19 \quad (2)$$

The valve pressure will automatically adjust with changes in load to keep the actuator fixed in position.

The simulation analysis was performed using FluidSim software V4.2. This is a fully suitable software that enables the user to create and simulate hydraulic circuit designs [20]. This application was used to build and simulate a hydraulic system for a variable load (overrunning) actuator. Because there is no library available to represent the load cell in the program. The cell is represented as a cylinder with the same specifications as the main cylinder. A pressure sensor is connected to it, which will act as a load cell. In the project worksheet, the components of the hydraulic system are connected as in the actual system, and all parameters are selected, as shown in Fig. 6, to study the possibility of developing and improving the system's work performance. It has been suggested to replace the conventional valve included with the pump with a proportional pressure relief valve. The goal is to sense the pressure and automatically regulate itself according to the applied load. This is only done in the simulation. Fig. 7 depicts the system's simulation operation proposal when using two proportional pressure relief valves.

The electronic circuit has been built using simple electronic components for experimental work. The schematic diagram of the electronic circuit is shown in Fig. 8. Connecting the circuit with pressure sensors, the load cell, and a (VT-VSPA1K-1 control card) is shown in Fig. 9.

2.2. Procedure and Experimental Work

Use a digital voltmeter to calibrate a load cell with a load range of (0- 30 kg) to determine the relationship between load and voltage. Fig 10 depicts this relationship curve.

Use a pressure gauge and a pressure sensor to calibrate the (PPCV) when attaching it to the proposed hydraulic system that produces consistent pressure. PPCV has a wide range of applications (0- 50 bar). The calibration curve is depicted in Fig. 11.

The analysis of the hydraulic system under the variable load can be determined using (2) to obtain component limitations and appropriate instances.

3. Results and Discussion

The electro-hydraulic system was created using the fluidsim software V4.2, and the function of its operation was represented as a result. Strong oscillations can be noticed in the case of the counterbalance valve; likewise, the velocity peak shifts constantly as a result of the load effect on the cylinder. Anytime the PPCV is employed, however, the essential setting pressure for controlling the variable load system is provided. The cylinder's dynamic behavior is improved as a result of avoiding a major oscillation. Figs. 12 to 17 show that when the hydraulic pump relief valve is set at pressures of 5 bar, 10 bar, and 15 bar, respectively, the signal control voltage of the pressure control valve is measured proportional to the required pressure at various loads. In Fig. 12, when the weight is 10 kg and the system pressure is set at 5 bar, the weight sensor gives a voltage value of approximately 1.1 volts. The weight value is also proportional to the pressure in the proportional pressure valve. It operates at a pressure of approximately 5.1 bar. This is what allows the pregnancy to come down on demand. Loading is also allowed upon request. While it is suspended when there is no demand. This is what the steering control valve controls.

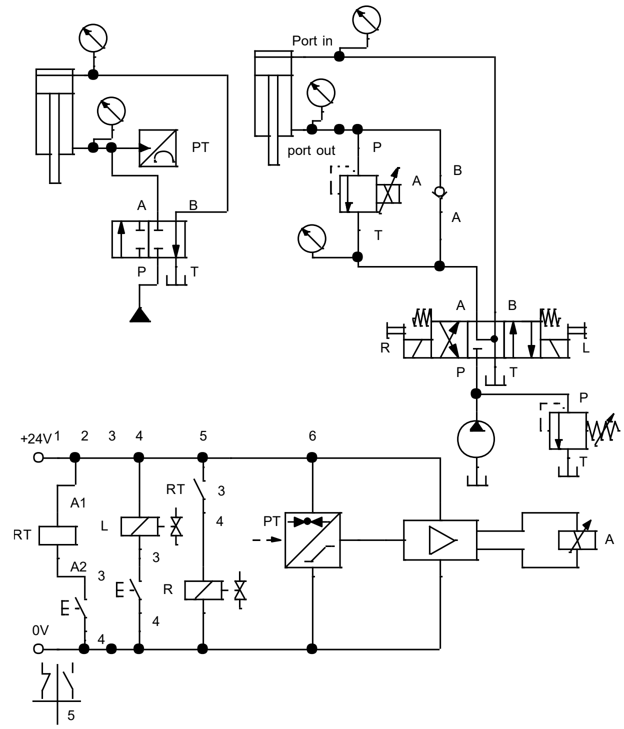

Figure 6. The hydraulic circuit in FluidSim software.

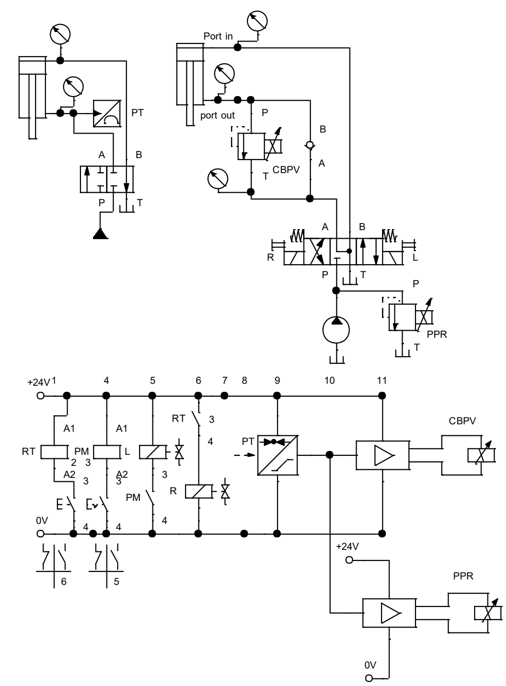

Figure 7. The proposed hydraulic circuit with two proportional pressure relief valves in FluidSim software.

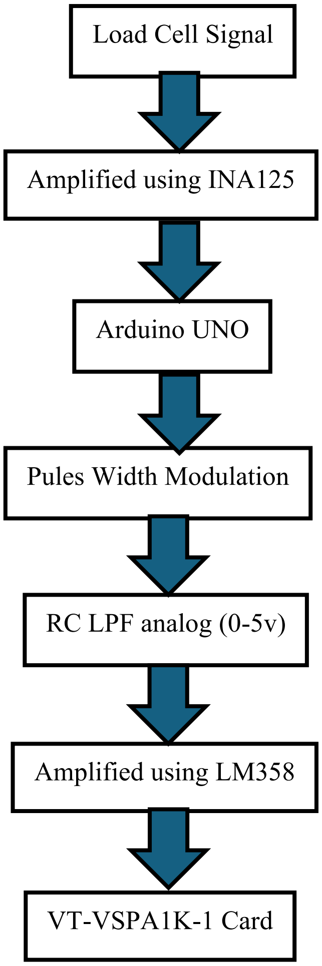

Figure 8. Block diagram of the electronic circuit.

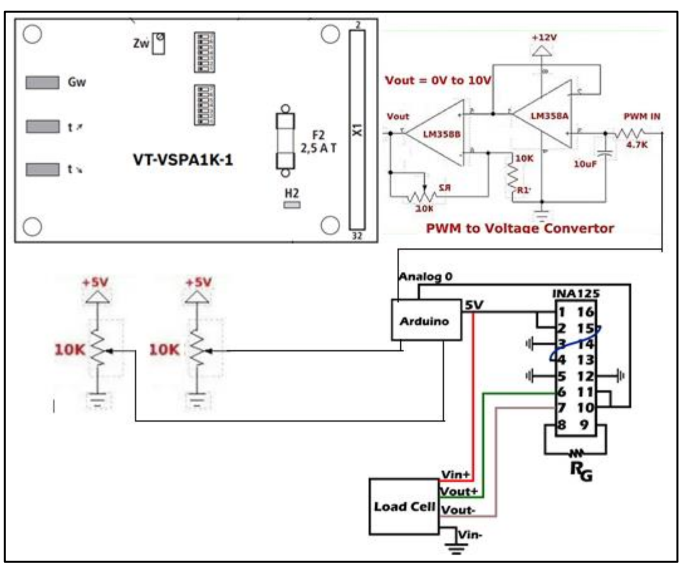

Figure 9. Electronic circuit block diagram and electronic circuit connections.

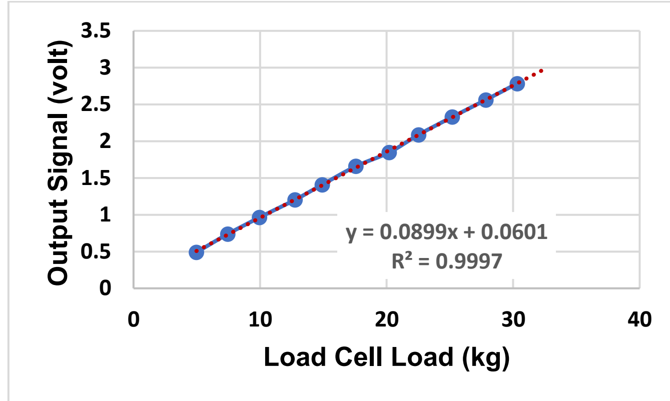

Figure 10. shows the relationship between the output signal (volt) and the load cell load.

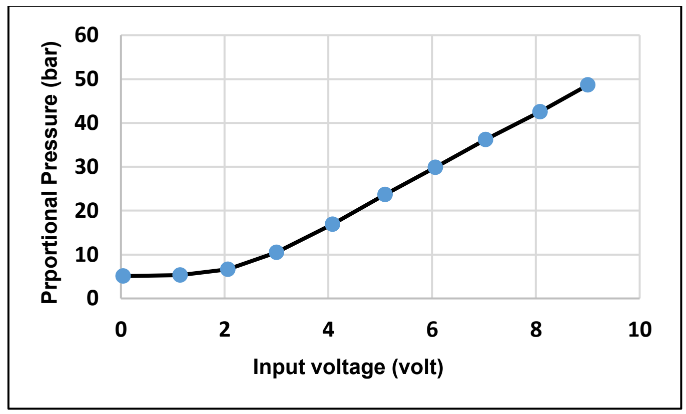

Figure 11. shows a calibration diagram for a proportional pressure control valve.

The same behavior was observed in the case shown in Fig. 13, where the load was 20 kg. But the voltage was higher, around 2.2 volts, and the proportional pressure control valve was set to 10.2 bar. Any change occurred when the weight value changed. The system continued to operate, descending, ascending, and stopping normally.

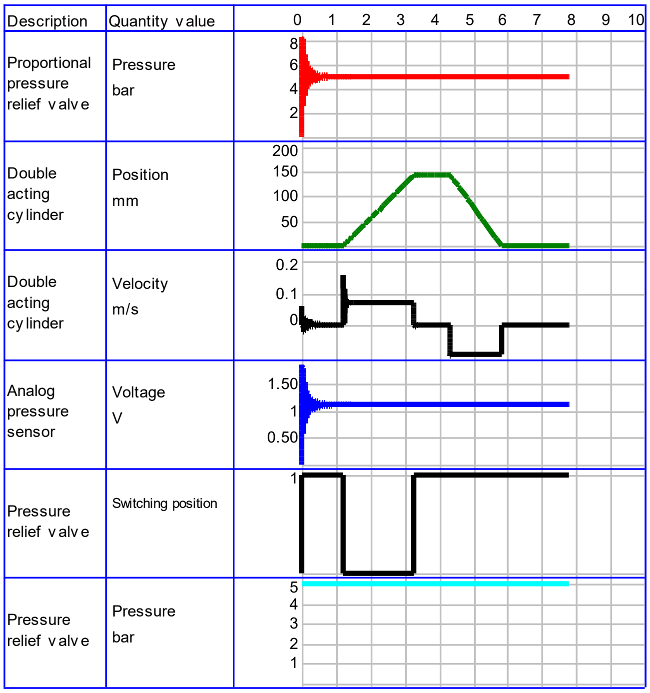

Figure 12. shows the measured data for a proportional pressure control valve under 10 kg load and a 5-bar pump pressure.

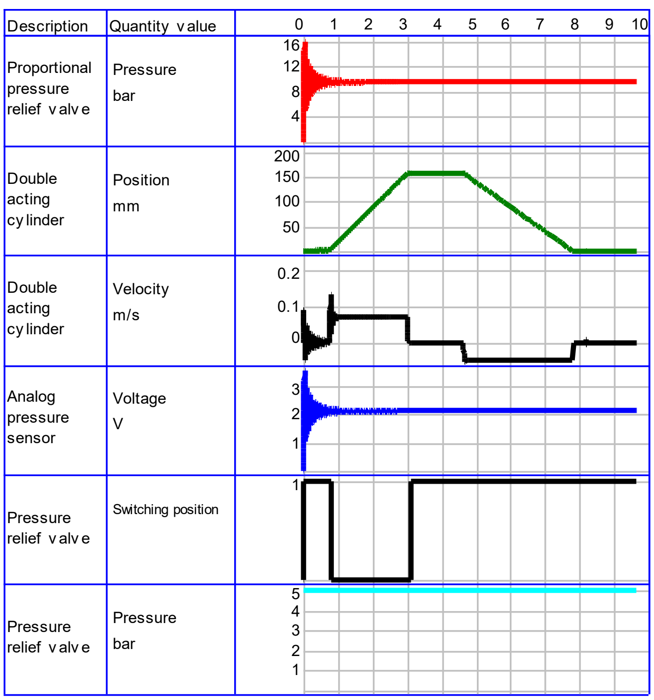

Figure 13. shows the measured data for a proportional pressure control valve under a 20 kg load and a 5-bar pump pressure.

Fig. 14: When the weight is 30 kg, and the system pressure is set at 5 bar, the weight sensor gives a voltage value of approximately 3.25 volts. The weight value is also proportional to the pressure in the proportional pressure valve. It operates at a pressure of approximately 14.2 bar. When controlling the steering control valve, allows the load to be reduced upon request. While it is suspended when there is no demand. However, it is not allowed to carry a load upon request. The reason is that the system pressure of 5 bar is not enough to lift the weight. Therefore, the system pressure regulation must be changed to a higher value. This was actually done, with a pressure of 10 bars. This allowed the system to lift the weight, as shown in Fig. 15. The same thing was observed in the case shown in Fig. 16 when the load was 40 kg. But the voltage value was higher, around 4.2 volts, and the proportional pressure control valve was regulated at a pressure of 20.2 bar. The system pressure was 10 bar. Although there was a change with the change in the weight value, the system did not work when requesting to climb. This forced the pressure value to change from 10 bar to 15 bar. The system continued to operate, descending, ascending, and stopping normally, as can be seen in Fig. 17. This means that the system must always be set to high pressure. If it were possible and working, then when there is no request to descend or ascend, the hydraulic pump would operate at full capacity. It must be turned off and on when descending or ascending, which is most likely. Which may cause energy waste.

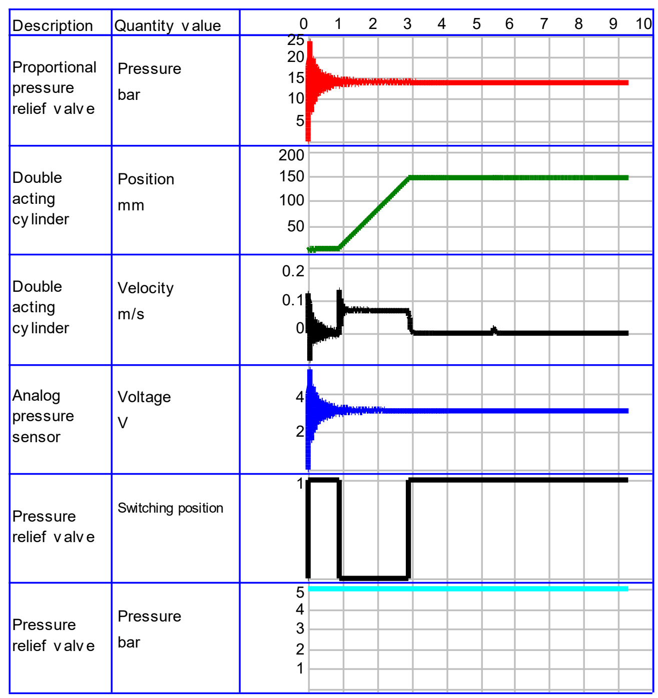

Figure 14. shows the measured data for a proportional pressure control valve under 30 kg load and a 5-bar pump pressure.

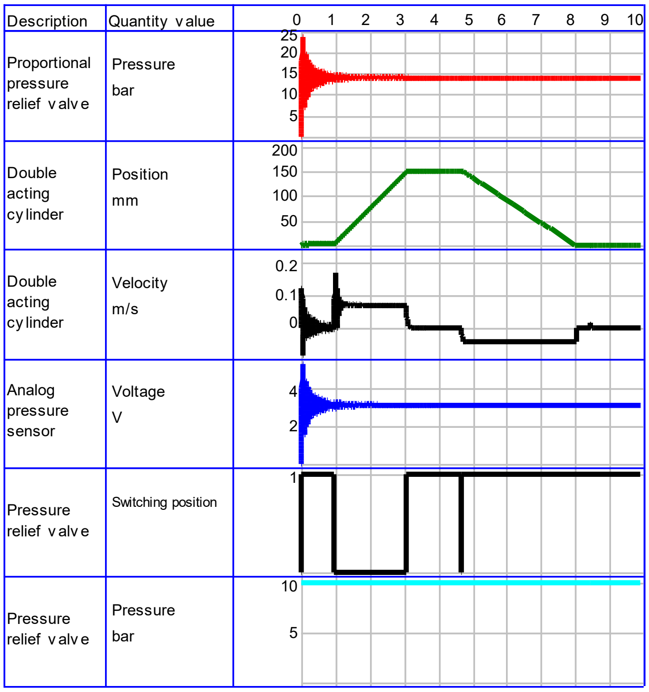

Figure 15. shows results from measurements made of a proportional pressure control valve under 30 kg load and a pump pressure of 10 bar.

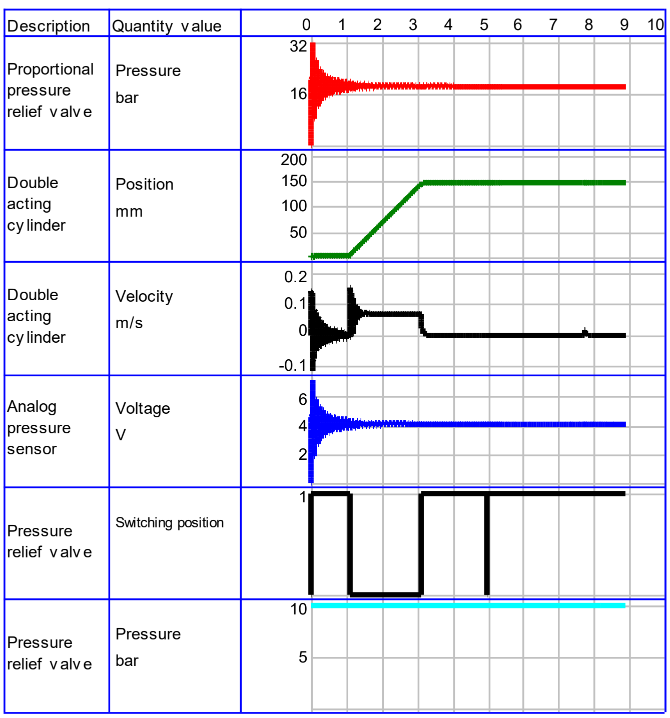

Figure 16. Data from measurements of a proportional pressure control valve under 40kg load and a 10-bar pump pressure.

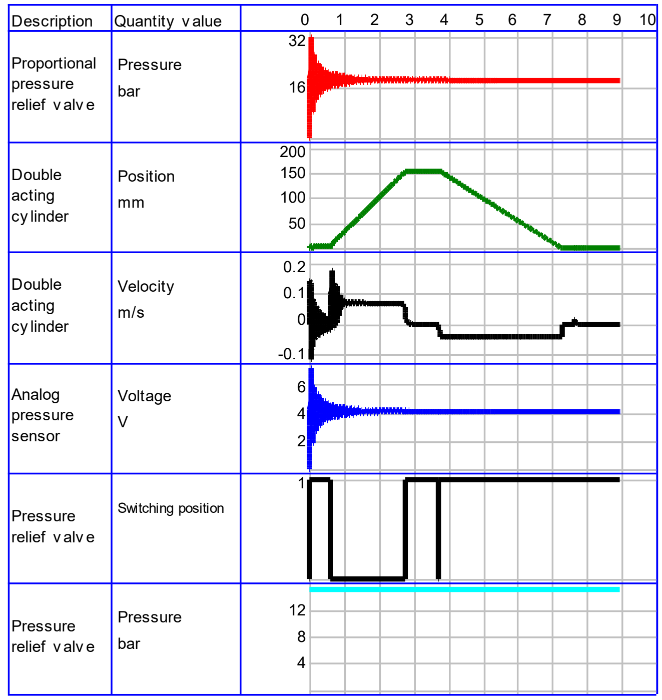

Figure 17. Data from measurements of a proportional pressure control valve under 40kg load and a 15-bar pump pressure.

Therefore, it was proposed to replace the traditional system pressure-control valve (relief valve) with a proportional pressure-control valve, as shown in Fig. 7, which uses the same signal from the weight sensor. This is proportional to the value of the weight lifted. Fig. 18 to Fig. 21 show the extent of regularity and sensitivity to the same value of voltage and pressure for the two proportional valves for weights from 10 to 40 kg, respectively.

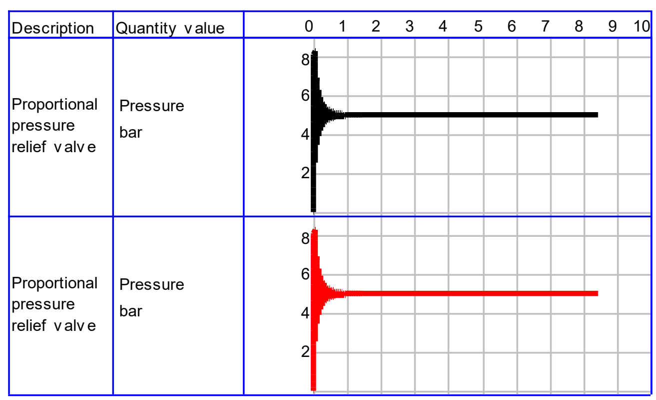

Figure 18. When the load is 10 kg load.

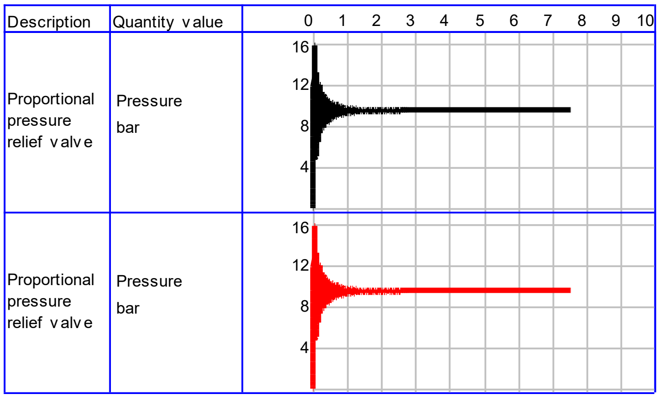

Figure 19. When the load is 20 kg.

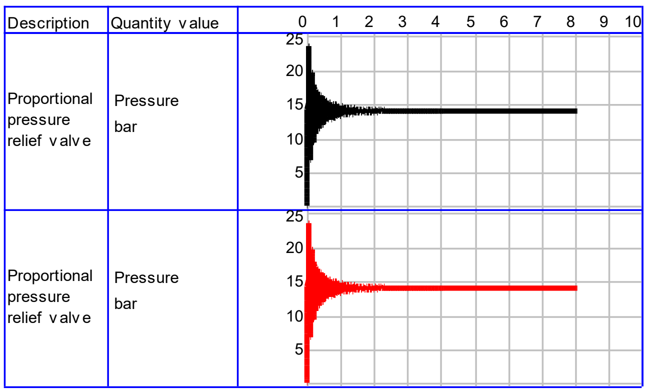

Figure 20. When the load is 30 kg

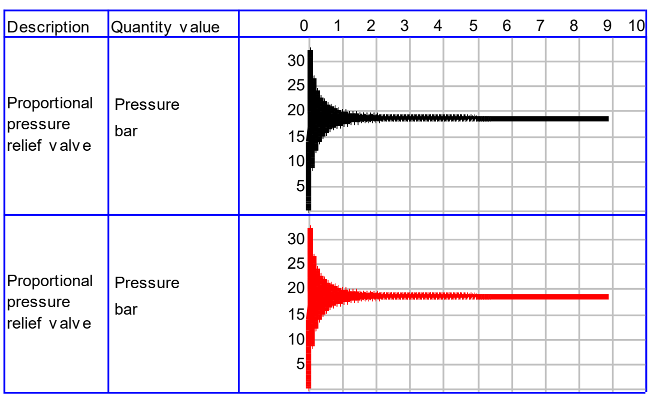

Figure 21. When the load is 40 kg.

The results of the experimental test were done using the proposed system.

The comparison of the variable load withholds pressure setting for the PPCV at various providing pressures from the hydraulic system using experimental, and simulation results. To evaluate the agreement between the simulation results and the experimental results. The root mean square error (RMSE) was chosen to compare the simulation data and the experimental results. As shown in Figs. 22, 23, and 24 respectively, three cases were tested at 5 bar, 10 bar, 15 bar, and switch on pump supply pressure. It can be seen that the simulation holding pressure paths are very consistent, implying that the excrement system.

As a comparison of the simulation data and experimental results, Fig. 22 to Fig. 2 show that the root mean square error (RMSE) value at 5 bar of the hydraulic pump delivering pressure is the highest, while at 15-bar pressure, it is the lowest. This indicates that the higher the hydraulic pump delivering pressure, the better the performance.

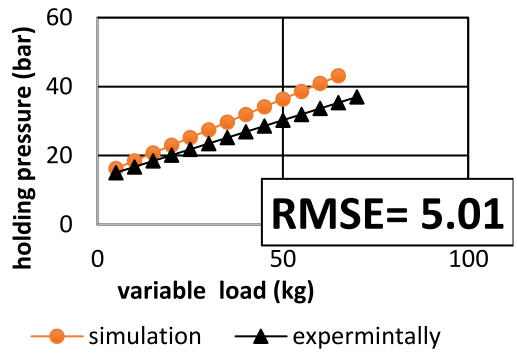

Figure 22. Variation of holding pressure with variable load when the relief valve is set at 5 bar.

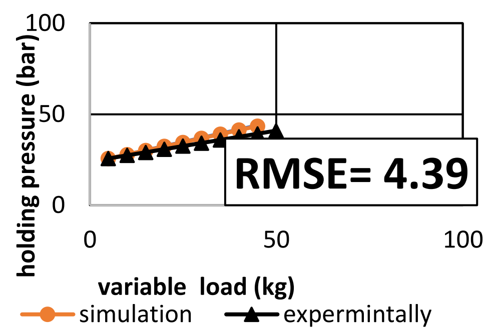

Figure 23. Holding pressure variation with varied load at a 10-bar hydraulic pump.

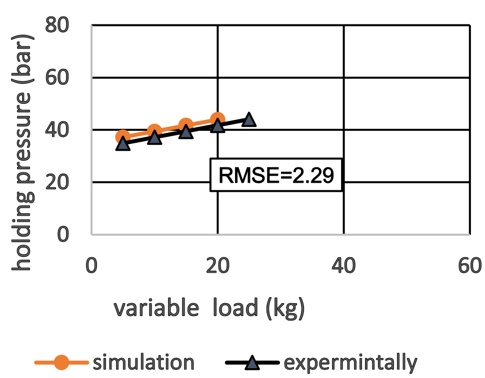

Figure 24. Holding pressure variation with varied load at a 15-bar hydraulic pump delivering.

It is clear that as the load increases, the experimental holding pressure path deviates more and more from the simulated holding pressure path when each supply case is compared with the last two cases. This can be caused by a variety of factors, including mechanical losses, pressure drops in pipelines and hoses, and pipe flow resistance.

4. Conclusions

The goal is to design an intelligent hydraulic system. It is used to lift variable weights during lifting. The work requires a sensor and an actuator working together. Through work and experiments, a station for the system was developed. it found the possibility of achieving this design and its success. As a result, energy waste was reduced without human intervention. It was also suggested that a more effective and efficient method with a slight increase in cost be developed. This is what was found while testing the system as a simulator. Upon practical application, there was a convergence in the work, with a slight difference in the results of the operation, and the reason is the nature of the mechanical losses that exist in every system. The higher the pressure of the hydraulic pump delivering, the better the performance. With this work, a suitable design was reached that can be adopted in many applications, such as cranes and lifting devices. For comparison with previous work, there is no similar work to compare performance, but the work was laboratory-acceptable. That is, it achieved the objective.

Conflict of interest

The author declares that the research was conducted without commercial or financial relationships that could be construed as potential conflicts of interest.

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