



MECHATRONICS ENGINEERING

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Automation of a Hydraulic Cylinder Tester

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Aprobación del Tutor del Trabajo de Integración Curricular

Yo Angélica Verónica Quito Carrión, en calidad de tutor del Trabajo de Integración Curricular denominado: *Automation of a Hydraulic Cylinder Tester*, realizado por Carlos David Arcentales Lucas, ha sido orientado y revisado en todas sus partes y considero que cumple los requisitos establecidos por la institución. En virtud de ello doy mi aprobación a fin de continuar con el proceso académico correspondiente.



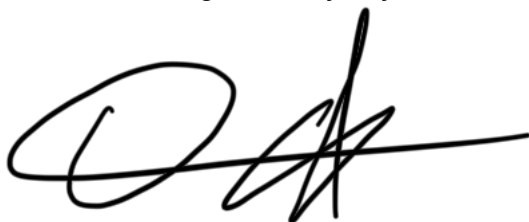
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Dedicatoria

A mi familia, que aun en la distancia estuvo presente en cada etapa de este camino. Gracias por acompañarme con su amor, su confianza y su apoyo incondicional, por celebrar mis avances y por sostenerme en los momentos en los que el cansancio y la incertidumbre parecían más grandes que la meta.

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Summary

This project presents the automation of a hydraulic cylinder tester through a PLC-based control architecture, real-time pressure measurement, HMI supervision, and computer-based acquisition of pressure-time records. The original testing process depended strongly on manual actuation, direct interpretation of analog pressure gauges, and the operator's experience. To reduce this dependence, an electrical control cabinet was implemented to integrate the three-phase motor, directional solenoid valves, pressure transducers, HMI, safety devices, and Ethernet communication. The implemented system controls cylinder extension and retraction, acquires pressure from both cylinder chambers, displays the measurements in psi, and records data for later analysis. Validation was performed progressively through three prototype stages. The first stage identified commissioning issues such as incorrect motor rotation and engineering-unit configuration. The second stage verified complete cylinder movement and digital pressure monitoring at approximately 500 psi. The final validation stage produced a pressure-time record with pressure levels near 1,800 psi, demonstrated data storage on the computer, and enabled a complementary Fourier analysis of the acquired signals. Overall, the results demonstrate the feasibility of converting the existing manual bench into an instrumented and repeatable testing platform with improved traceability and operator supervision.

Keywords: automation, hydraulic cylinder, PLC, pressure acquisition, HMI, data logging.

Abstract

This work develops an automated control and monitoring system for a hydraulic cylinder test bench. The solution combines a Siemens PLC, an HMI, two industrial pressure transducers, an electrical control cabinet, and computer-based data acquisition through Ethernet communication. The system controls the hydraulic power unit and directional valves, supervises safety conditions, measures the pressure in both cylinder chambers, and generates pressure-time records that can be stored for traceability and post-processing. Experimental validation was carried out progressively. Initial commissioning tests exposed and corrected motor rotation and pressure-unit configuration issues. Subsequent tests verified cylinder extension and retraction, HMI supervision, and computer monitoring. In the final recorded test, the measured pressure reached approximately 1,856 psi in the extension chamber and approximately 1,834 psi in the retraction chamber during different phases of the operating cycle. A Fast Fourier Transform was also applied to the stored pressure signals as a complementary method to characterize the low-frequency content associated with the test cycle and pressure transitions. The implemented prototype demonstrates that the manual testing process can be transformed into a more objective, traceable, and repeatable procedure while preserving the operator's role in the final technical evaluation of the cylinder.

Keywords: automation, hydraulic cylinder, PLC, pressure transducer, HMI, data acquisition, Fourier analysis.

TABLE 1
ABET Criteria/Final Report Cross Reference Table

ABET Criterion Outcome	Target	Level	of	Best Examples with
	Mastery			Section Numbers
1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Create, Apply	Evaluate,		Sections 6.3, 8.3
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Apply			Sections 1.6, 2
3. An ability to communicate effectively with a range of audiences.	Analyze			Sections 6.9, 9.8, 10.8, 11.2
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	Apply, Evaluate			Sections 5.2, 13.3
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	Understand			Sections 4.1, 6.1, 14
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	Apply, Analyze			Sections 6.1–6.5, 11, 12
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	Analyze, Evaluate			Sections 5.2, 15

Source: Author's elaboration based on Bloom's taxonomy and the project development.

Chapter I

Introduction

Hydraulic cylinders are among the most widely used actuators in industry because of their ability to produce high forces, provide accurate positioning, and operate with versatility in important sectors such as manufacturing, construction, heavy machinery, lifting systems, and process automation [1], [2]. However, in order for these actuators to function properly, they must remain in good mechanical and hydraulic condition, especially regarding the seals. In addition, the pressure behavior during operation must be adequate, and internal or external leaks must be avoided, since any degradation may compromise the efficiency, safety, and reliability of the system [1–4].

In this sense, hydraulic cylinder testing is essential to certify their condition and proper operation before maintenance or reuse. In the current context of this project, the testing procedure is still performed manually, which increases the evaluation time and maintains subjective criteria when deciding whether the cylinder meets the required conditions. In addition, leakage detection usually depends on visual inspection, and the results are manually recorded, which makes traceability and subsequent analysis difficult. Therefore, the proposed project focuses on automating the tests through the recording and visualization of pressure-time curves, with the objective of verifying the performance and tightness of each cylinder based on repeatable and objective data.

The reviewed literature shows that, in recent decades, hydraulic test benches have evolved from manual or semi-automatic configurations to instrumented platforms with PLC, data acquisition, HMI, pressure sensors, flow sensors, temperature sensors, and supervision software. These benches allow tests to be executed with higher safety and repeatability, real-time variables to be recorded, reports to be generated, and experimental behavior to be compared with desired parameters [5–9]. In different works, the test bench is presented as a multifunctional system capable of evaluating pumps, valves, hydraulic blocks, and cylinders, integrating criteria related to energy efficiency and industrial automation [5, 7, 8].

In the case of hydraulic cylinders, several studies have proposed test benches with PLC integration to increase the automation level of the process and reduce human error. The PLC coordinates operation sequences, activates valves and pumps, and manages analog and digi-

tal signals; this allows previously defined test protocols to be executed [6, 7]. In the same way, other studies include touch interfaces, data storage, remote tests, and SCADA-type supervision, which shows the current trend toward the digitalization of hydraulic tests [8, 9].

On the other hand, part of the reviewed literature focuses on leak detection and cylinder condition monitoring. Internal leakage is one of the most relevant failures because it usually cannot be seen, reduces effective pressure, and disturbs the behavior of the cylinder, which can also affect the performance of the entire system [1, 3, 4]. To address this problem, several authors have studied methods based on pressure signals, applying wavelet transform, Hilbert-Huang analysis, energy analysis, and Kalman filters to identify patterns associated with different leakage levels [1, 3]. These works show that the pressure signal contains relevant information for diagnosis and that its analysis allows behavior variations to be detected without the need to disassemble the actuator [1, 3, 4]. As a complement, research that applies acoustic emission as an information source for seal monitoring and early leak detection has also been developed. These studies indicate that acoustic emission signals can offer high sensitivity to incipient defects and allow certain indicators, such as RMS value and specific frequency bands, to be linked to the beginning of wear or to an increase in leakage rate [2, 4]. Even though these approaches present promising results, they usually require more specialized instrumentation, more signal processing, and well-controlled experimental conditions, which may make their application more difficult in less complex solutions or in routine maintenance environments [2, 4]. Based on the review, two main directions can be identified: on one hand, the design of automated test benches with PLC and data acquisition; and, on the other hand, the development of techniques for diagnosing leakage and hydraulic cylinder degradation through pressure signals, vibration, or acoustic emission [1–9]. However, a relevant gap is identified between experimental developments and the needs of industrial environments where manual, subjective, and non-traceable tests still predominate [5–9].

The bibliographic review also shows that many solutions developed in industrial hydraulic systems share principles directly applicable to the proposed test bench. For example, in constant-pressure water systems, the integration of a variable frequency drive, PLC, and sensors is highlighted to maintain stable operating conditions, improve fluid distribution, and optimize energy consumption [10]. Likewise, in irrigation water pumping applications, PLC, instrumentation, electrical protection, and hydraulic sizing criteria are incorporated to achieve safe and controlled operation [11]. In addition, the development of experimental benches with two pumps

operating at constant pressure shows the relevance of pressure feedback, variable frequency drives, and PLC-based control to analyze hydraulic behavior and energy efficiency [12]. These backgrounds are important because they show the importance of automatic pressure control and continuous monitoring of hydraulic variables

In the context of industrial machinery that uses hydraulic systems, several studies show how automation improves repeatability, safety, and operator-system interaction. The automation of a hydraulic press for an SME involves the integration of electronic modules, an HMI interface, a pressure gauge, a double-acting cylinder, and a PLC as key components for reliably processing and delivering process data [13]. Likewise, the design of a semi-automatic hydraulic press for pressure control in the tile pressing process shows that pressure is a central process variable and that its regulation directly influences the quality and uniformity of operation [14]. Similarly, the automation of thermal hydraulic presses and hydraulic drilling machines demonstrates the usefulness of integrating sensors, actuators, control interfaces, and safety devices in industrial hydraulic applications [15, 16].

The redesign of an electro-hydraulic process in an automatic control laboratory proposes the monitoring and control of speed and pressure through the use of transducers, solenoid valves, and tools such as MATLAB, Simulink, and LabVIEW, highlighting the usefulness of combining modeling, data acquisition, and remote supervision [17]. In the same line, the development of a hydraulic training module with a pumping system using a three-phase motor shows how hydraulic and electrical circuits can be organized to operate, analyze, and learn from systems that include motors, pumps, solenoid valves, and cylinders [18].

Finally, the literature review also shows that digitalization and real-time data logging are consolidated trends in modern control systems. In an IoT-based quality control system for raw milk, the importance of displaying parameters in real time and storing data in the cloud for later analysis is emphasized [19]. In addition, PLC and HMI-based filling systems show the relevance of parameter configuration, process visualization, sensor-based control, and automated operation in mechatronic systems [20]. These contributions are relevant to this research project because they underscore the need to transform a manual test into an instrumented procedure, in which pressure data can be acquired, stored, and plotted objectively to support the technical evaluation of the cylinder.

Chapter II

Methodology

Conceptual Design Requirements and Constraints

In this chapter, the needs of the manual system of hydraulic cylinders are transformed in measurable requirements, design restrictions, and validation criteria that will be useful to select the conceptual solution.

The scope of the project are divided in:

- Automation of the hydraulic cylinder test cycle
- Acquisition of pressure as a function of time
- Data recording and visualization
- PLC control
- HMI interaction
- Basic safety functions

The project limits are defined as follows:

- The existing hydraulic test bench will not be mechanically redesigned.
- The system will support technical evaluation through recorded pressure data; it will not issue an automatic pass/fail diagnosis.
- The implementation is constrained by the sensors, actuators, and equipment available for the project.

Needs to Requirements

Table 2 identifies the principal needs and translates them into system requirements.

TABLE 2
Identification of the system needs

Need	System requirement
Reduce human error	The system shall acquire the pressure signal automatically from the pressure sensors and display the scaled pressure value on the HMI during the test, reducing the dependency on manual pressure readings.

Continued on next page

TABLE 2
Identification of the system needs (continued)

Need	System requirement
Improve test repeatability	The system shall execute the same testing sequence for each hydraulic cylinder, using predefined parameters such as pressure setpoint, test time, and number of cycles.
Facilitate system operation	The operator shall be able to enter the test parameters, start the cycle, monitor the process, and stop the operation through the HMI interface.
Increase operational safety	The system shall prevent dangerous operating conditions by avoiding the simultaneous activation of opposite solenoid valves and by stopping the process when an emergency stop or excessive pressure condition is detected.
Supervise cylinder behavior	The system shall display and record the pressure behavior of the hydraulic cylinder chambers during the test, allowing the operator to analyze the pressure-time response.

Design Constraints

Several components were already available and had to be incorporated into the final design. These existing elements therefore became project constraints:

- Pressure transducers with 4–20 mA analog outputs.
- A double gear pump with 6 cc/rev and 12 cc/rev stages.
- A 5.5 hp, 220 V, 1800 rpm three-phase induction motor.
- A 220 VAC, 4/3 directional solenoid valve.

Validation Methods

The inspection method will be used to verify the correct installation and integration of hydraulic, electrical and instrumentation components. Demonstration will validate the interaction between the operator and the system, including the execution of automatic sequences and the visualization of process variables. Analysis methods will be applied to evaluate pressure signal behavior and verify the consistency of the acquired data. Finally, experimental tests will be carried out to confirm the automatic execution of test cycles, pressure acquisition and

real-time visualization of the pressure-time curves.

TABLE 3
Validation matrix of the system requirements

ID	Requirement	Validation Method	Expected Result
R1	The system shall reduce dependence on manual pressure readings	Demonstration	The pressure values are automatically displayed and registered during the test
R2	The operator shall enter cylinder test parameters, start the cycle, and supervise the process	Demonstration	The operator can interact with the HMI and execute the test correctly
R3	During the test, the system shall allow the operator to observe the pressure behavior in both cylinder chambers	Test	Pressure-time curves are visualized during the operation

During the first verification stage, each subsystem was planned to be validated independently. Manual and automatic operating modes, electrical control, analog-input acquisition, and HMI communication were checked before complete system integration. Before connecting the motor and solenoid valves, the control logic was verified by observing the corresponding contactors in the electrical cabinet. The field devices were then connected and tested under actual operating conditions. For pressure measurement, the 4–20 mA transducers were first checked for a valid live-zero signal and then verified at the PLC analog input after signal conversion. For HMI validation, the operator had to be able to configure the test parameters, command the process, and visualize the relevant operating data. The transferred variables were also verified at the PLC level. Finally, the data acquisition and visualization subsystem was validated by confirming that the pressure signals were represented correctly as pressure-time curves and that the acquired data were stored for later review. After the subsystems operated correctly, the complete system was validated through an integrated test with a hydraulic cylinder. The validation was considered successful when the system completed the configured cycles, recorded the pressure values, and displayed the pressure-time curves.

Project Activity Schedule

The activity schedule was included in the methodology chapter because it organizes the design, implementation, validation, and documentation stages required to complete the automation of the hydraulic cylinder tester. The schedule is presented as a planning reference and may be adjusted according to component availability, commissioning results, and final validation needs.

TABLE 4
Project activity schedule

Phase	Main activities	Period	Expected output
Problem defini- tion	Identification of the manual testing lim- itations, project scope, objectives, and expected automation functions.	Sep. 2025	Project plan and initial require- ments
Research and requirements	Review of hydraulic test benches, PLC- based automation, pressure acquisition, and leakage detection references.	Oct.–Nov. 2025	State of the art and requirement list
Conceptual design	Comparison of alternatives, selection of PLC-based architecture, and definition of the functional block diagram.	Dec. 2025	Selected concep- tual solution
Electrical and instrumentation design	Definition of the electrical cabinet, PLC inputs and outputs, pressure sensor connection, and signal conditioning.	Jan.–Feb. 2026	Electrical and instrumentation design
PLC and HMI development	Programming of manual and automatic modes, HMI screens, setpoints, inter- locks, and alarms.	Mar.–Apr. 2026	Functional control and HMI logic
Communication and data acqui- sition	Configuration of Ethernet communica- tion, pressure visualization, data logging, and pressure-time graph generation.	Apr.–May 2026	Monitoring and data acquisition system

Continued on next page

TABLE 4
Project activity schedule (continued)

Phase	Main activities	Period	Expected output
Prototype validation	Manual tests, automatic cycle tests, pressure acquisition validation, and correction of detected integration problems.	May.–Jun. 2026	Validated prototype results
Documentation and final review	Technical report writing, correction of tables, validation evidence, conclusions, recommendations, and final formatting.	Jun.–Jul. 2026	Final technical document

Conceptual Design

Alternative 1: System based on PLC. In this alternative, the PLC executes the operating sequences, controls the actuators, supervises operating conditions, and exchanges information with the HMI and the monitoring computer. The architecture is oriented toward industrial robustness and separates deterministic control from data visualization and storage. **Main components**

- Hydraulic power unit: motor, pump, tank and security valves.
- Hydraulic cylinders.
- Pressure sensors
- PLC
- Button, emergency stop and lights.
- Software in the PC

Operation. The operator starts the test and selects the previously configured test parameters. The PLC then executes the sequence, energizes the hydraulic power unit, commands the directional valves, and performs the defined cycle. During operation, both chamber pressures are measured, transmitted, processed, and recorded to generate pressure-time graphs.

Advantages.

- Greater closeness to an industrial environment.
- Greater electrical and operational robustness.
- Higher reliability for automatic and repetitive sequences.
- Straightforward integration with industrial communication and data-transfer methods.

Limitations.

- Advanced graph generation and long-term data storage require an external computer.
- Advanced numerical data processing is less flexible inside the PLC than on a general-purpose computing platform.

Alternative 2: System based on microcontroller. In this alternative, a microcontroller is used as the control and data-acquisition unit. It executes the test logic, reads the pressure signals, and sends the information to a computer for processing, storage, and real-time visualization.

Main components

- Hydraulic power unit.
- Hydraulic cylinder.
- Pressure sensors.
- Microcontroller as data reader.
- Relays to valves and motor action.
- Computer with visualization and storage software.

Operation. The microcontroller executes the programmed sequence, actuates the system through interface relays, acquires the sensor signals, and transmits the measurements to the computer. The software records the information, generates graphs, and stores the data. **Advantages.**

- Greater flexibility for data acquisition and graph generation.
- Flexible and adaptable programming.
- Lower initial hardware cost.
- An excellent option for academic development, prototypes, and experimental validation.

Limitations.

- Lower robustness against electrical noise, vibration, and harsh industrial conditions.
- Requires more care in electric and signal conditioning.
- Lower industrial acceptance and maintainability compared with a PLC-based solution.

Functional Block Diagram. Figure 1 summarizes the functional architecture of the proposed tester. The main process path connects the operator interface, PLC control logic, hydraulic power unit, directional valves, cylinder under test, pressure transducers, and data acquisition system. Dashed connections represent measurement feedback, Ethernet communication, and the safety shutdown path.

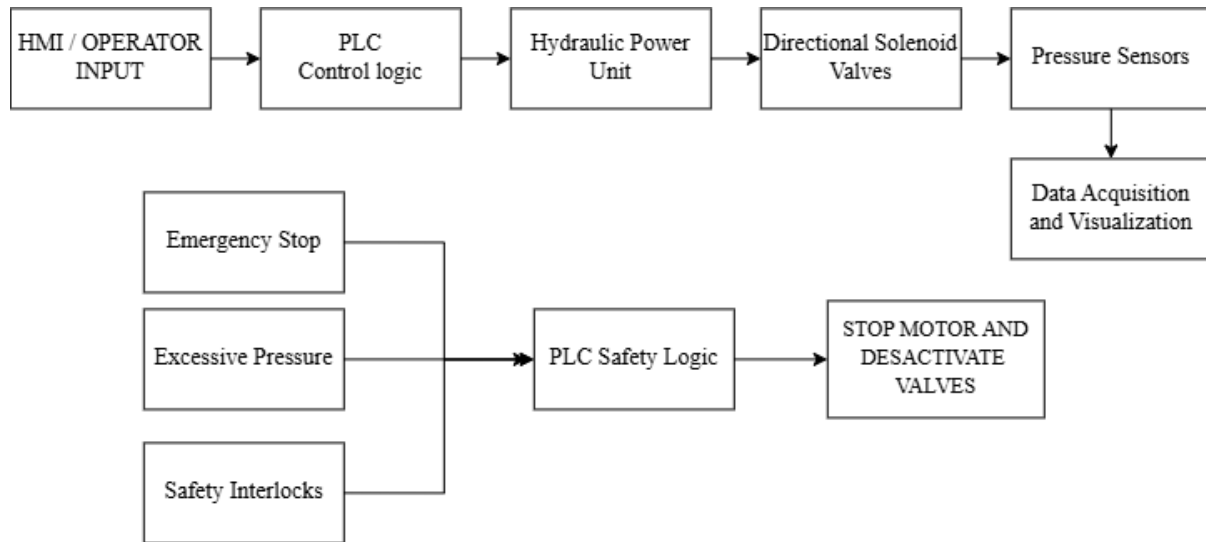


Fig. 1. Functional block diagram of the automated hydraulic cylinder tester

Research of Prior Art. Previous work shows that hydraulic systems can be improved by integrating electronic control, sensors, and operator interfaces. In industrial environments, PLCs are commonly used to execute sequential logic and coordinate field devices, while supervisory platforms provide real-time visualization and data management. These concepts are directly related to the proposed architecture. The literature also highlights the importance of pressure measurement in hydraulic test benches because the pressure response provides useful information about actuator behavior and test stability.

Morphological Analysis. Table 5 presents the morphological chart used to compare the principal functional alternatives.

TABLE 5
Morphological Chart for the Automated Hydraulic Cylinder Tester

Function	Alternative A	Alternative B
Control device	Microcontroller-based control	PLC-based control
Operator interface	PC-based interface	Industrial HMI
Pressure measurement	Digital pressure indicator	4–20 mA pressure sensors connected to PLC analog inputs
Hydraulic actuation	Solenoid directional valves with manual supervision	Solenoid directional valves controlled by PLC

Continued on next page

TABLE 5
Morphological Chart for the Automated Hydraulic Cylinder Tester (continued)

Function	Alternative A	Alternative B
Pump operation	Motor activated by local control panel	Motor activated by PLC through contactor
Hydraulic flow configuration	Full flow during the whole test	High–low configuration using the double gear pump
Test sequence	Semi-automatic operation	Automatic sequence controlled by PLC
Data visualization	HMI numerical display	Pressure–time curve visualization and data record
Data storage	Local screenshots or manual notes	Digital record of test data
Safety response	Emergency stop and visual alarms	Emergency stop, pressure alarm, and PLC interlocks

Method of selecting final conceptual design. Table 6 presents the decision matrix used to compare the three conceptual alternatives.

TABLE 6
Decision Matrix for the Final Conceptual Design Selection

Selection Criterion	Weight	Candidate A	Candidate B
Compatibility with the existing hydraulic bench	15	3	5
Automation level	20	3	5
Pressure data acquisition and visualization	20	3	5
Safety and interlocks	15	3	5

Continued on next page

TABLE 6
Decision Matrix for the Final Conceptual Design Selection (continued)

Selection Criterion	Weight	Candidate A	Candidate B
Implementation feasibility	10	3	4
Operator usability	10	3	5
Repeatability and traceability	10	3	5
Total weighted score	210	300	490

Final selection comparisons and rationale. Based on the decision matrix, Candidate B was selected as the final conceptual design. This alternative obtained the highest weighted score and provided the best balance among automation capability, data acquisition, operator usability, and industrial robustness. Candidate A offered greater flexibility for data processing and acquisition; however, robustness, maintainability, and compatibility with the industrial environment were more important for this application.

Preliminary Design

In this stage, the conceptual design selected in the previous section is refined into a more defined control architecture. This project focuses on the control, monitoring, communication, and data acquisition subsystems. Therefore, the preliminary design does not include the structural or hydraulic redesign of the bench. The hydraulic system is considered as an existing process, while the main design effort is concentrated on the automation system that controls the motor, solenoid valves, operator interface, safety logic, pressure measurement, and pressure-time data visualization.

The selected preliminary solution is based on a Siemens LOGO! 8 PLC as the main controller, a Kinco HMI as the operator interface, pressure sensors connected to the analog inputs, relay outputs for solenoid valve control, and an Ethernet network for communication between the PLC, HMI, and data visualization system. The use of a switch and a wireless access point is considered to support local communication and remote visualization from a computer connected to the same network.

The project plan for the preliminary design phase was refined according to the main tasks required to implement the control system summarized in Table 7.

TABLE 7
Task Plan for the Preliminary Control Design Phase

Task	Description	Expected Output
PLC input and output assignment	Define the digital outputs, analog inputs, and internal memory variables required for the control system.	Preliminary I/O list and control variable structure
Pressure acquisition setup	Scale the analog pressure signal into engineering units and prepare it for HMI display, alarms, and data recording.	Scaled pressure variable available in the PLC
HMI preliminary design	Define the screens, buttons, setpoints, indicators, and alarms required for operator interaction.	Preliminary HMI interface structure
Communication network setup	Define the Ethernet connection between PLC, HMI, switch, router, and monitoring computer.	Preliminary communication architecture
Data acquisition and visualization	Define the method to record pressure data and generate the pressure-time curve.	Preliminary data acquisition and visualization flow
Preliminary validation	Check basic operation of communication, pressure reading, manual commands, automatic sequence, and safety conditions.	Initial evidence of control system feasibility

Baseline control system architecture

The preliminary design was organized into two main subsystems: the control subsystem and the pressure measurement and data acquisition subsystem.

The control subsystem includes the Siemens LOGO! 8 PLC, the Kinco HMI, the motor command, and the solenoid valve commands. The PLC is the main control unit of the system and executes the manual and automatic operating logic. The HMI allows the operator to select the operating mode, enter the test parameters, and monitor the system status.

The pressure measurement and data acquisition subsystem includes the pressure sensor, analog scaling in the PLC, Ethernet communication, the network switch, the wireless access point,

and the PC. This subsystem allows the pressure value to be measured, displayed, transmitted, and recorded as a pressure-time curve.

Fig. 2 shows the baseline control architecture in the preliminary design.

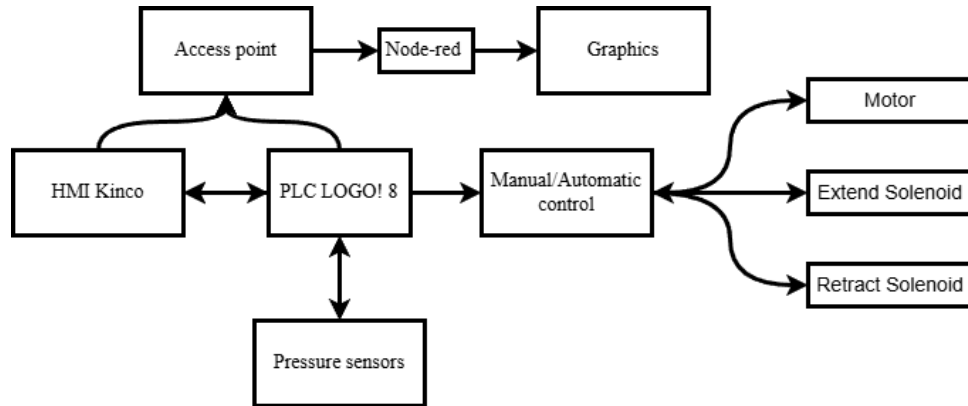


Fig. 2. Control System Architecture

Pressure measurement and data acquisition design. The data-acquisition flow starts at the pressure transducers and ends with the pressure-time graph. The PLC is responsible for reading and scaling the signals, while the HMI provides local visualization. Node-RED on the monitoring computer receives the transmitted values, displays the trends, and stores the acquired data. The resulting architecture is shown in Figure 3.

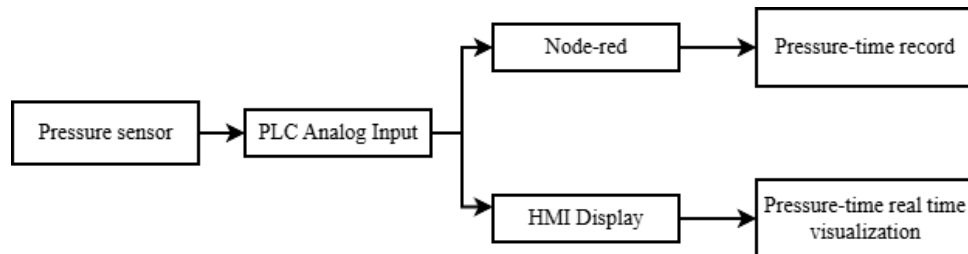


Fig. 3. Pressure and data acquisition system

Control logic. The logic of the automated cycle is shown in Figure 4.

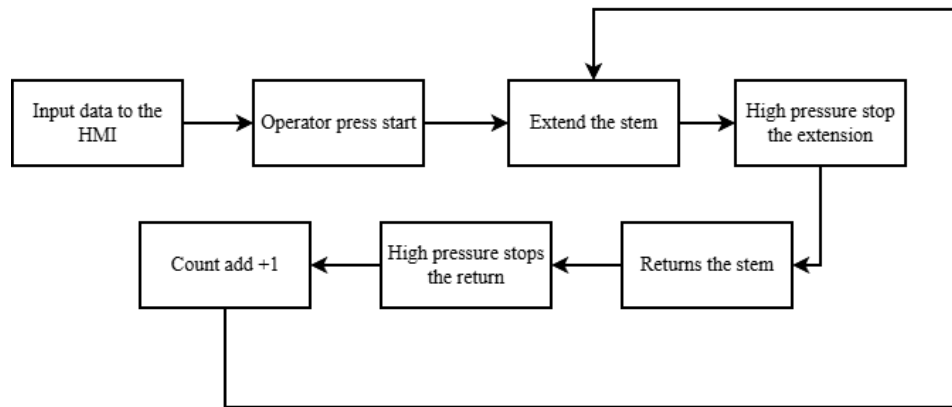


Fig. 4. Control Logic

Specific Design

This stage defines the specific components, control logic, HMI functions, communication method, and pressure data recording structure. Each area was developed and tested individually before being integrated into the complete system.

Control system flowchart. Figure 5 shows the detailed control sequence used by the automated system.

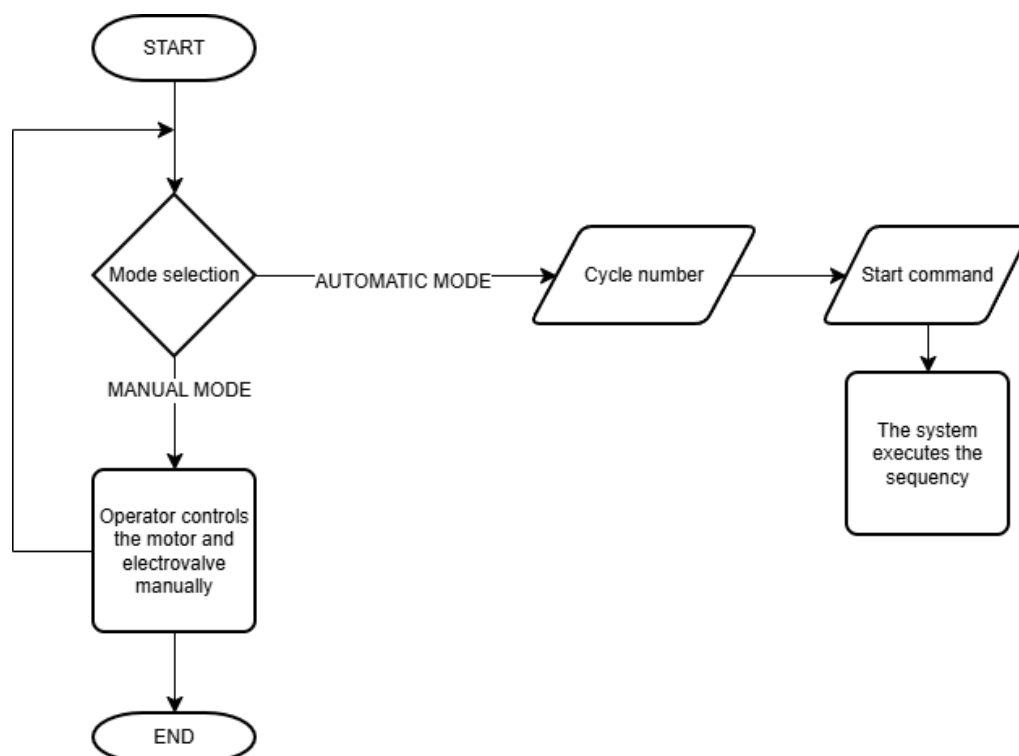


Fig. 5. Control system flowchart

Hydrostatic Test Standard Reference. The pressure-holding stage of the proposed test sequence was defined using ISO 10100:2020 as the main reference, because this standard spec-

ifies acceptance and function tests for hydraulic fluid power cylinders [21]. In addition, ISO 4413:2010 was considered as a general safety reference for hydraulic fluid power systems and components used on machinery [22]. Therefore, the purpose of stopping the cylinder and recording pressure for a defined time is not arbitrary; it provides an observation window to evaluate whether the pressure remains stable and whether external or internal leakage symptoms appear during the test.

For the scope of this project, the bench does not certify cylinders as a laboratory accredited under ISO 10100. However, the test sequence was aligned with the logic of the standard: moving the cylinder, pressurizing one chamber, holding the position, observing leakage, and recording the pressure response. This is appropriate for a maintenance-oriented hydraulic cylinder tester because a cylinder with sealing problems can show pressure decay, abnormal pressure stabilization, or visible leakage during the holding period.

TABLE 8
Reference criteria for the hydraulic cylinder pressure test

Criterion	Reference value	Application in this project
Low-pressure leakage check	Approximately 5–10 bar, depending on cylinder bore and test condition	Used as a functional reference to verify movement, rod seal behavior, and basic external leakage before applying higher pressure
Piston seal leakage check	Rated pressure of the cylinder, or a user-specified pressure	Used as the reference for the pressure-holding stage when the objective is to observe pressure stability and possible internal leakage
Proof or external leakage check	1.5 times the rated pressure or recommended operating pressure of the cylinder	Considered only as a proof-test reference. It must not be applied unless the cylinder, hoses, valves, sensors, fittings, and relief valve are rated for that pressure

Continued on next page

TABLE 8
Reference criteria for the hydraulic cylinder pressure test (continued)

Criterion	Reference value	Application in this project
Minimum holding time	At least 10 s as a reference for acceptance-test observation	The HMI holding time can be configured for a longer period to capture pressure decay more clearly and to generate a useful pressure-time curve
Pressure limitation	The system pressure must be limited by the safest rated component and by the relief valve adjustment	The test pressure shall not exceed the lowest rated pressure of the cylinder or the hydraulic bench components

According to the hydraulic power unit calculations, the low-flow stage of the existing pump and 5.5 HP motor has an estimated theoretical pressure capability of 227.8 bar. This value is only a theoretical limit because real losses, pump efficiency, valve restrictions, and the relief valve setting reduce the actual available pressure. For this reason, the test setpoint must be selected according to the rated pressure of the cylinder under test and the safe pressure rating of the complete bench. In the validation stage, the system reached approximately 500 psi, which was sufficient to verify pressure acquisition, visualization, and graph generation; future acceptance or proof tests would require a prior verification of all hydraulic component ratings and pressure relief settings.

Hydraulic power unit justification. The hydraulic power unit was considered as an existing part of the hydraulic cylinder test bench. Therefore, the objective of this section is not to redesign the hydraulic system, but to justify the compatibility between the existing pump and the selected electric motor.

The system uses a double gear pump with two displacement stages: 12 cc/rev and 6 cc/rev. This configuration allows the system to work with a higher flow during the initial cylinder movement and with a lower flow during the pressure generation stage. The electric motor selected for the hydraulic power unit is a (5.5 HP) three-phase induction motor operating at approximately 1800 rpm.

The theoretical pump flow was calculated using:

$$Q = \frac{D \cdot n}{1000} \quad (2.1)$$

where (Q) is the theoretical flow rate in (L/min), (D) is the pump displacement in (cc/rev), and (n) is the motor speed in (rpm).

For the high-flow condition, both pump stages are considered:

$$D_{high} = 12 + 6 = 18 \text{ cc/rev} \quad (2.2)$$

$$Q_{high} = \frac{18 \cdot 1800}{1000} = 32.4 \text{ L/min} \quad (2.3)$$

For the low-flow condition, only the (6 cc/rev) stage is considered:

$$Q_{low} = \frac{6 \cdot 1800}{1000} = 10.8 \text{ L/min} \quad (2.4)$$

The motor power was converted from horsepower to kilowatts using:

$$P_m = 5.5 \cdot 0.746 = 4.10 \text{ kW} \quad (2.5)$$

The hydraulic power relation is given by:

$$P_h = \frac{p \cdot Q}{600} \quad (2.6)$$

where (P_h) is the hydraulic power in (kW), (p) is the pressure in (bar), and (Q) is the flow rate in (L/min).

Rearranging the equation, the approximate theoretical pressure capability can be estimated as:

$$p = \frac{600 \cdot P_m}{Q} \quad (2.7)$$

For the high-flow condition:

$$p_{high} = \frac{600 \cdot 4.10}{32.4} = 75.9 \text{ bar} \quad (2.8)$$

For the low-flow condition:

$$p_{low} = \frac{600 \cdot 4.10}{10.8} = 227.8 \text{ bar} \quad (2.9)$$

These values are theoretical and do not include losses due to pump efficiency, motor efficiency, pressure drops, or valve restrictions. However, they show that the selected motor is compatible with the existing double gear pump. The high-flow condition is suitable for fast cylinder movement at lower pressure, while the low-flow condition is more suitable for pressure generation during the test.

Therefore, the (5.5 HP) motor was considered adequate for the hydraulic power unit because it allows the existing pump to operate under the expected test conditions. The automation system does not modify the hydraulic design; it controls the activation of the motor and the directional valves through the PLC and HMI.

TABLE 9
Hydraulic Power Unit Calculation Summary

Parameter	Calculated Value	Design Justification
Pump displacement, stage 1	12 cc/rev	Existing pump stage used for high-flow operation
Pump displacement, stage 2	6 cc/rev	Existing pump stage used for low-flow and pressure generation operation
Motor speed	1800 rpm	Nominal speed used to estimate theoretical pump flow
High-flow displacement	18 cc/rev	Combination of both pump stages, 12 cc/rev + 6 cc/rev
High-flow rate	32.4 L/min	Suitable for faster cylinder movement at lower pressure
Low-flow rate	10.8 L/min	Suitable for pressure generation during the test stage
Motor power	5.5 HP = 4.10 kW	Selected to drive the existing hydraulic pump

Continued on next page

TABLE 9
Hydraulic Power Unit Calculation Summary (continued)

Parameter	Calculated Value	Design Justification
Theoretical pressure at high flow	75.9 bar	Indicates that high-flow operation must be used mainly for low-pressure movement
Theoretical pressure at low flow	227.8 bar	Indicates that the low-flow stage is more appropriate for pressure generation

Figure 6 shows the 5.5 hp three-phase motor configured in delta.



Fig. 6. 5.5 hp three-phase motor in a delta configuration

The three-phase motor was configured in delta connection because the available supply voltage for the hydraulic power unit is 220 VAC. For a motor with a 220/380 V winding configuration, the delta connection allows each winding to receive its rated voltage when connected to a 220 V three-phase supply. A star connection was not selected because, under the same 220 V supply, each winding would receive a lower phase voltage, reducing the available starting torque and making the motor less suitable for driving the hydraulic pump.

The nominal current of the motor is 15 A; therefore, this value was used as the main

electrical selection criterion for the protection devices, contactor, and conductors. The motor contactor and protection elements must be rated for at least the motor nominal current and suitable for inductive motor loads, while the overload protection must be adjusted according to the 15 A rated current to protect the motor during abnormal operating conditions.

Electrical Control Cabinet and Wiring Design. Table 10 summarizes the principal electrical cabinet components and their functions.

TABLE 10
Electrical Control Cabinet Components and Functions

Component	Controlled Element	Function in the System
Main circuit breaker	Main electrical supply of the control cabinet	Protects and disconnects the electrical cabinet from the main power supply
Emergency stop button	Control power supply circuit	Interrupts the control system in case of an unsafe condition
Physical start button	24 VDC power supply contactor circuit	Allows the operator to energize the control power supply
Physical stop button	24 VDC power supply contactor circuit	Allows the operator to de-energize the control power supply
24 VDC power supply contactor	24 VDC power supply input	Turns the 24 VDC power supply on and off through the physical start and stop buttons
24 VDC power supply	PLC and HMI power terminals	Provides the required DC voltage for the PLC and HMI operation
Siemens LOGO! 8 PLC	HMI, pressure sensor, motor contactor, and valve contactors	Executes the control logic and activates the outputs according to the HMI commands and safety conditions

Continued on next page

TABLE 10
Electrical Control Cabinet Components and Functions (continued)

Component	Controlled Element	Function in the System
Kinco HMI	PLC through Ethernet communication	Allows the operator to control the motor and solenoid valves, configure test parameters, and monitor the system
Motor contactor	Hydraulic motor power circuit	Starts and stops the hydraulic motor according to the command sent from the HMI through the PLC
Small contactor for extension valve	Extension solenoid valve coil	Activates the solenoid valve responsible for cylinder extension
Small contactor for retraction valve	Retraction solenoid valve coil	Activates the solenoid valve responsible for cylinder retraction
Extension solenoid valve	Hydraulic directional valve	Allows the hydraulic cylinder to extend during manual or automatic operation
Retraction solenoid valve	Hydraulic directional valve	Allows the hydraulic cylinder to retract during manual or automatic operation
Pressure sensor	PLC analog input	Sends the pressure signal required for monitoring, alarms, and data acquisition
Terminal blocks	Field devices and internal cabinet wiring	Organize the electrical connections between the cabinet and the external components

HMI and Communication Configuration. The Ethernet switch connects the PLC, HMI, and monitoring computer within the same local network. A wireless access point is connected to the switch when wireless monitoring from the computer is required. The monitoring computer is used only for data visualization and pressure-time recording; the control decisions remain

inside the PLC. Figure 7 shows the HMI and communication architecture used in the system.

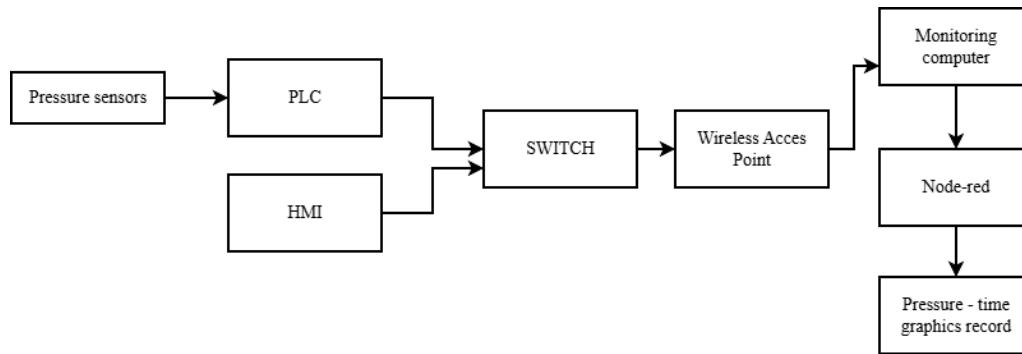


Fig. 7. Communication configuration

The PLC also sends information back to the HMI, including the current pressure value, active operating mode, sequence status and cycle count. This allows the operator to supervise the test without directly interacting with the electrical cabinet during normal operation.

Pressure Measurement and Data Acquisition Configuration. The system uses two industrial pressure transducers, one for each hydraulic chamber of the cylinder under test. The transducers provide a standard 4–20 mA current-loop output and have a nominal measurement range of 0–600 bar, equivalent to approximately 0–8,702 psi. Their supply range is 8–36 VDC, which allows them to be powered from the 24 VDC control supply used in the electrical cabinet. Figure 8 shows one of the installed transducers.



Fig. 8. Industrial pressure transducer used for chamber-pressure measurement

TABLE 11
Pressure transducer characteristics used in the implementation

Parameter	Implemented value or characteristic
Measured variable	Hydraulic pressure
Measurement range	0–600 bar (approximately 0–8,702 psi)
Output signal	4–20 mA current loop
Supply voltage	8–36 VDC; operated from the 24 VDC control supply
Number of sensors	Two, one per cylinder chamber
Signal destination	Siemens LOGO! 8 analog inputs through a shunt resistor
Displayed engineering unit	psi

Although the cable assembly available with the sensor contained four conductors, the pressure measurement channel was verified during commissioning as a two-wire current loop. The brown conductor was used for the positive supply and the blue conductor as the loop return. The black and white conductors were not required for the analog measurement in the implemented connection. This conclusion was obtained experimentally after the initial four-wire interpretation produced a zero-voltage reading at the PLC input despite the sensor's expected 4 mA live-zero output.

Because the Siemens LOGO! 8 analog input accepts 0–10 V rather than 4–20 mA directly, a shunt resistor was used to convert the loop current into a measurable voltage. The maximum theoretical resistance that keeps the 20 mA signal within the 10 V PLC limit is obtained from Ohm's law:

$$R_{max} = \frac{V_{max}}{I_{max}} = \frac{10 \text{ V}}{0.020 \text{ A}} = 500 \Omega \quad (2.10)$$

A 462 Ω resistor was selected. Therefore, the expected input voltage range is:

$$V_{min} = 0.004 \text{ A} \cdot 462 \Omega = 1.848 \text{ V} \quad (2.11)$$

$$V_{max} = 0.020 \text{ A} \cdot 462 \text{ } \Omega = 9.24 \text{ V} \quad (2.12)$$

The wiring used for each measurement loop was therefore: +24 VDC to the brown sensor conductor; blue sensor conductor to the PLC analog-input measurement node; and a 462 Ω resistor from that node to 0 VDC. The PLC measures the voltage drop across the resistor and scales it to pressure. For the 0–600 bar range, the linear conversion can be expressed as:

$$P_{bar} = 600 \left(\frac{V - 1.848}{9.24 - 1.848} \right) \quad (2.13)$$

and the value displayed to the operator is converted to psi using:

$$P_{psi} = 14.5038 P_{bar} \quad (2.14)$$

This configuration provided a stable electrical interface between the industrial current-loop transducers and the PLC voltage inputs while preserving the 4 mA live-zero behavior required to distinguish a valid low-pressure signal from a disconnected loop.

Chapter III

Results

Experimental Validation Approach

The validation stage was organized as a progressive commissioning process rather than as a single final test. This approach made it possible to identify electrical, control, hydraulic, communication, and instrumentation problems independently before evaluating the complete system. The main validation question was whether the implemented automation platform could command the hydraulic cylinder test bench, acquire pressure from both cylinder chambers, display the measurements in real time, store the data on a computer, and provide sufficient information for later technical analysis.

The observed variables were the activation of the hydraulic power unit, the correct switching of the extension and retraction solenoid valves, the physical movement of the cylinder rod, the pressure values displayed on the HMI, the pressure values transferred to the monitoring computer, and the pressure-time records generated during the test. Each complete extension and retraction sequence was treated as one functional test cycle. The PLC, HMI, pressure transducers, electrical cabinet, hydraulic power unit, and Ethernet communication network remained fixed throughout the validation stages.

Prototype 1: Initial Commissioning

The first prototype test focused on basic system integration. The pressure transducers were connected to the hydraulic lines using tee fittings so that the digital pressure acquisition could operate in parallel with the existing hydraulic instrumentation. The installed pressure connections are shown in Figure 9.



Fig. 9. Pressure transducers installed in the hydraulic lines during commissioning

The complete test bench assembled for the validation stage is shown in Figure 10. At this point, the PLC outputs, HMI commands, motor contactor, solenoid-valve actuation, and pressure acquisition chain had already been integrated into the same control architecture.



Fig. 10. Automated hydraulic cylinder test bench used for experimental validation

Two relevant commissioning problems were identified during this first stage. First, the three-phase motor initially rotated in the wrong direction, which prevented the hydraulic pump from producing the expected flow and pressure. The correction consisted of interchanging two motor phases, after which the hydraulic power unit operated in the correct direction. Second, the pressure was initially displayed in bar, whereas the operating practice of the test bench and the project interface were based on psi. The scaling and visualization configuration were

therefore corrected so that the HMI and the computer displayed the same engineering unit.

The HMI used during the manual commissioning stage is shown in Figure 11. The interface allowed the operator to command the motor and cylinder direction while directly observing the pressure in both chambers.



Fig. 11. HMI during manual-mode commissioning and pressure verification

The first hydraulic cylinder selected for the test did not extend correctly. Comparison with the mechanical pressure gauges indicated that the limitation was not caused by the new control system but by the tested cylinder itself. The behavior was consistent with an internal sealing problem, so a second cylinder was selected for the following validation stage. The first tested cylinder is shown in Figure 12.



Fig. 12. First hydraulic cylinder evaluated during commissioning

Prototype 2: Functional Cylinder Movement and Digital Monitoring

After correcting the motor rotation direction, pressure scaling, and the test-cylinder selection, a second prototype test was performed with the cylinder shown in Figure 13. In this stage, the objective was to verify complete rod extension and retraction while simultaneously monitoring both chamber pressures.



Fig. 13. Second hydraulic cylinder used for the functional validation stage

The cylinder rod extended and retracted correctly, and the solenoid valves responded according to the PLC control logic. During extension, the pressure increased in the corresponding chamber while the opposite chamber decreased; during retraction, the pressure relationship changed as expected. At this stage, the test reached pressure levels of approximately 500 psi, which were sufficient to verify the complete chain from physical actuation to sensor acquisition, PLC scaling, HMI visualization, and computer communication.

This prototype was important because it confirmed that the pressure behavior observed on the HMI was consistent with the physical direction of cylinder motion. It also demonstrated that the operator could supervise the test from the interface without manually reading the analog gauges throughout the complete movement.

Prototype 3: Final Pressure Test and Computer Data Acquisition

The final prototype stage focused on obtaining a complete digital pressure record at a higher operating pressure and confirming that the computer-based acquisition system could preserve the measurements for later analysis. The pressure trend displayed during the tests on the HMI is shown in Figure 14. Although the HMI provides immediate supervision, the computer record is the primary source used for detailed post-processing because it stores both pressure

channels as a function of time.

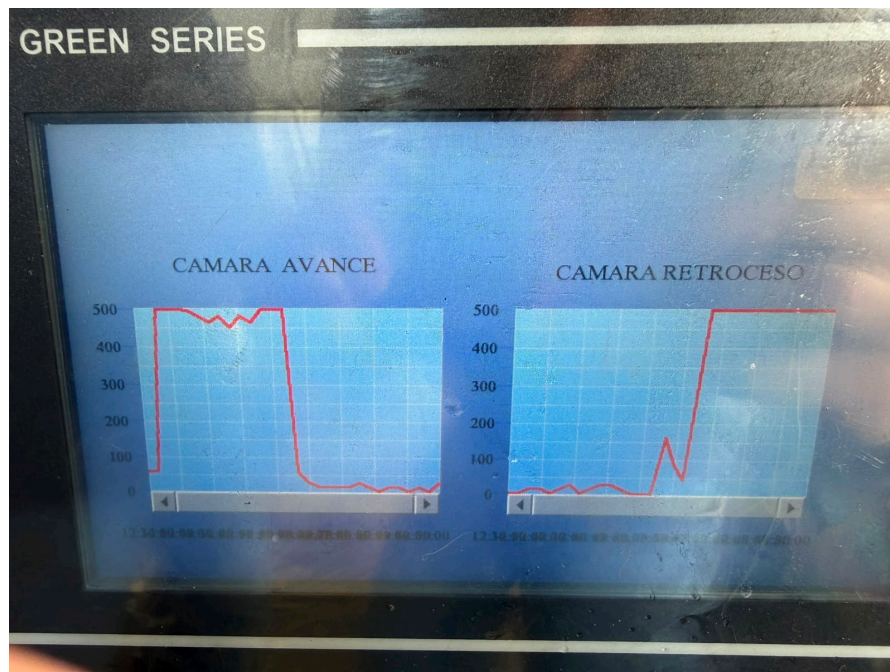


Fig. 14. Real-time pressure trends displayed on the HMI during a cylinder test

Figure 15 shows the pressure-time record generated from the final test data. The extension chamber reached a maximum value of approximately 1,856 psi, while the retraction chamber reached approximately 1,834 psi during a different phase of the cycle. The graph also shows intermediate pressure levels during directional transitions and the expected exchange of the high-pressure condition between the two chambers.

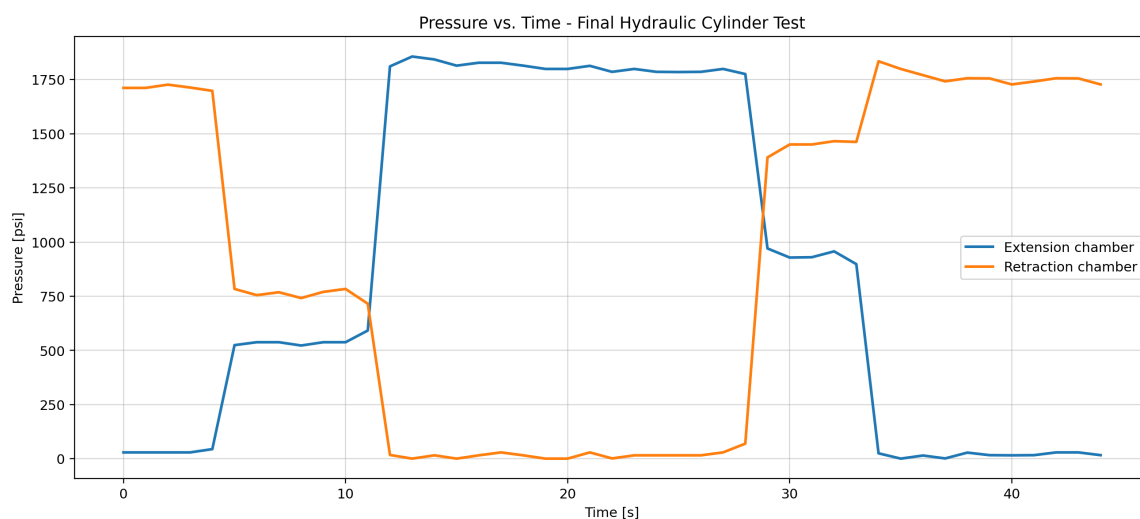


Fig. 15. Computer-generated pressure-time record from the final hydraulic cylinder test

The most important result of this stage was not only reaching a higher pressure, but

also preserving the full sequence as digital evidence. This makes it possible to compare tests, identify the maximum pressure reached in each chamber, review pressure holding behavior, and perform additional signal processing without repeating the physical test.

Representative Acquired Data

The monitoring application stored the measurements with a date-time reference and separate columns for the extension- and retraction-chamber pressures. Table 12 reproduces a representative excerpt of the acquired dataset in an editable format. The values illustrate the transition from an intermediate-pressure region to the high-pressure holding stage in the extension chamber.

TABLE 12
Representative excerpt of the pressure data acquired during the final test

Date	Time	Extension [psi]	Retraction [psi]
24/06/2026	11:26:47	29	1711
24/06/2026	11:26:48	29	1711
24/06/2026	11:26:49	29	1726
24/06/2026	11:26:50	29	1711
24/06/2026	11:26:51	29	1726
24/06/2026	11:26:52	537	754
24/06/2026	11:26:53	537	754
24/06/2026	11:26:54	537	769
24/06/2026	11:26:55	522	740
24/06/2026	11:26:56	537	769
24/06/2026	11:26:57	537	783
24/06/2026	11:26:58	551	740
24/06/2026	11:26:59	1842	0
24/06/2026	11:27:00	1856	0
24/06/2026	11:27:01	1842	15
24/06/2026	11:27:02	1813	0
24/06/2026	11:27:03	1827	15
24/06/2026	11:27:04	1827	29
24/06/2026	11:27:05	1813	15
24/06/2026	11:27:06	1798	0

The stored data show that the high-pressure region was not represented by a single isolated sample. Instead, several consecutive samples remained close to 1,800 psi, with small variations between approximately 1,798 and 1,856 psi. This behavior is consistent with a pressure-holding stage and provides a more useful basis for evaluating the test than a single maximum value observed on an analog gauge.

Fourier Analysis of the Pressure Signals

A Fast Fourier Transform (FFT) was applied to the final stored pressure signals as a complementary post-processing tool. The objective was not to replace the direct pressure-time interpretation, which remains the primary method for evaluating the hydraulic test, but to determine which frequency components dominate the measured pressure variation and to demonstrate that the stored data can support additional engineering analysis.

For a discrete pressure sequence $x[n]$ with N samples, the frequency-domain representation was calculated from:

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-j2\pi kn/N} \quad (3.1)$$

Before calculating the FFT, the mean value of each pressure signal was removed. This suppresses the dominant zero-frequency component associated with the average pressure level and makes the variations produced by cycle transitions easier to observe. The analyzed record has approximately one-second spacing between stored samples, corresponding to a logging frequency close to 1 Hz. Therefore, the frequency-domain result is limited to low-frequency components below the Nyquist frequency of approximately 0.5 Hz. It should consequently be interpreted as an analysis of the overall test-cycle dynamics rather than as a vibration or high-frequency hydraulic-ripple analysis.

The extension-chamber spectrum is shown in Figure 16. Its dominant non-zero component is approximately 0.022 Hz, corresponding to a period close to 45 s, which is consistent with the duration of the complete recorded sequence and the major transition between pressure states.

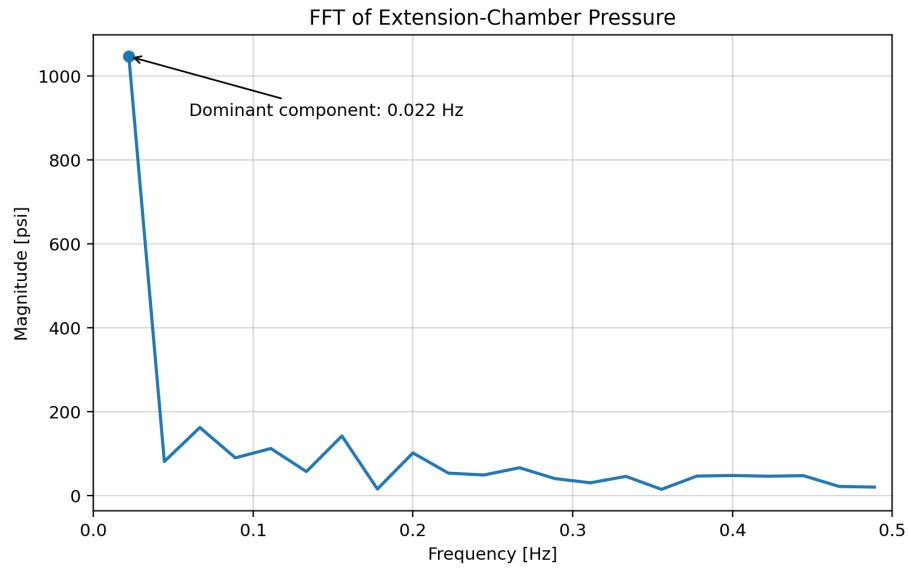


Fig. 16. Frequency spectrum of the extension-chamber pressure signal

The retraction-chamber signal presents the same dominant component near 0.022 Hz, as shown in Figure 17. This similarity is expected because both pressure signals belong to the same hydraulic cycle and respond to the same directional transitions, although with opposite pressure states during the principal extension and retraction phases.

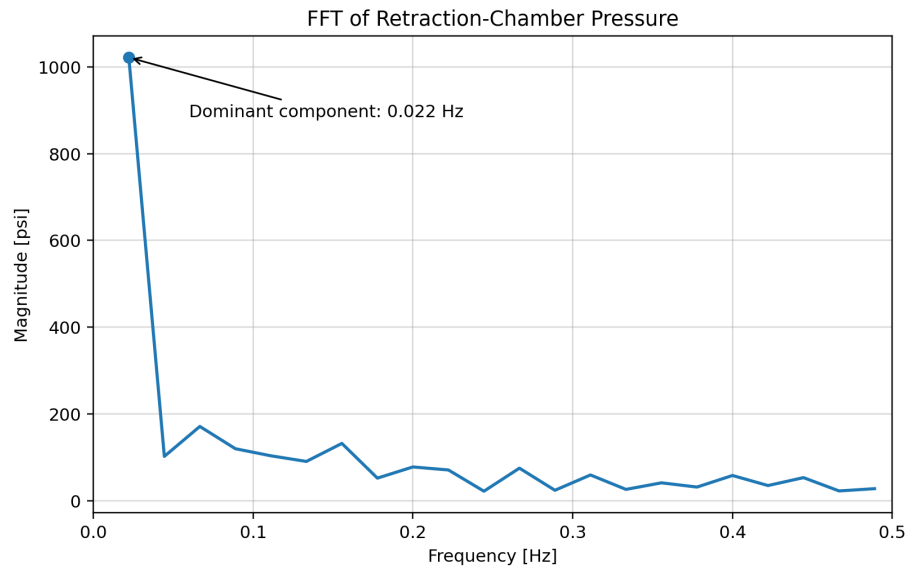


Fig. 17. Frequency spectrum of the retraction-chamber pressure signal

Secondary components appear at higher frequencies within the available 0–0.5 Hz band. These components are mainly associated with the sharp pressure changes produced when the directional state changes and with the intermediate pressure plateaus observed in the time-domain signal. The FFT therefore confirms that the recorded signal is dominated by the

low-frequency test sequence rather than by a continuous high-frequency oscillation. A higher data-logging frequency would be required in a future version if the objective were to analyze pump ripple, valve-induced pressure pulsation, or fast transient phenomena.

Validation Summary

Table 13 summarizes the principal functions verified during the prototype stages and the evidence obtained from the final implementation.

TABLE 13
Summary of functional validation results

Function	Validation evidence	Result
Motor control	Hydraulic power unit started and stopped from the implemented control system	Passed
Directional control	Cylinder extension and retraction were commanded through the PLC outputs and solenoid valves	Passed
Pressure acquisition	Both chamber pressures were read, scaled, and displayed in psi	Passed
HMI supervision	Operating mode and pressure values were available to the operator	Passed
Computer visualization	Pressure-time curves were generated from the transmitted measurements	Passed
Data storage	Date-time referenced pressure data were stored for later analysis	Passed
Signal post-processing	Stored pressure data were successfully analyzed using an FFT	Passed
Safety logic	Emergency-stop and interlock functions were integrated into the control architecture	Passed

Discussion

The three validation stages show a clear progression from commissioning to complete data acquisition. Prototype 1 exposed practical integration problems that could not be identified from the design documentation alone, particularly the motor phase sequence, pressure-unit configuration, and the condition of the first test cylinder. Correcting these issues before the

final test prevented them from being incorrectly attributed to the automation system.

Prototype 2 demonstrated that the main control architecture was functional. The PLC commanded the hydraulic power unit and the directional valves, the cylinder completed extension and retraction movements, and the pressure measurement was available on both the HMI and the computer. The approximately 500 psi reached during this stage was sufficient for functional verification, even though it was not yet the final high-pressure test condition.

Prototype 3 provided the strongest evidence of the project's contribution. The system generated a complete digital record with pressure levels close to the 1,800 psi validation target, preserved the measurements with time references, and made the data available for post-processing. The pressure-time record shows that the two sensors provide complementary information: when one cylinder chamber is pressurized, the other is comparatively unloaded, and the relationship changes when the movement direction changes. This behavior confirms that the acquisition system is measuring the physical hydraulic sequence rather than simply reproducing a fixed or duplicated signal.

The digital record also improves traceability compared with the previous manual process. An analog gauge can indicate the instantaneous pressure, but it does not preserve the complete evolution of the test. The implemented system stores the sequence and allows the operator or engineer to review maximum pressure, pressure stability, transitions, and possible abnormal behavior after the test has finished. The Fourier analysis further demonstrates the potential of the acquired dataset for additional diagnostic methods, while also showing the present limitation imposed by the relatively low logging frequency of the stored record.

Cost Summary

The project scope corresponding to this work is primarily the automation, instrumentation, electrical control, and monitoring system. Table 14 summarizes the estimated cost of the main components required for the implemented solution.

TABLE 14
Cost summary of the electrical control, instrumentation, motor, and implementation

Item	Description	Qty.	Unit [USD]	Total [USD]
PLC	Siemens LOGO! 8 12/24RC	1	130.04	130.04
HMI	Kinco GL070E 7" with Ethernet	1	126.18	126.18

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TABLE 14

Cost summary of the electrical control, instrumentation, motor, and implementation (continued)

Item	Description	Qty.	Unit [USD]	Total [USD]
Power supply	24 VDC, 5 A industrial power supply	1	38.50	38.50
Cabinet	Metallic cabinet 60 × 40 × 30 cm	1	50.92	50.92
Mounting rail	DIN rail 35 mm	1	1.06	1.06
Wiring duct	Slotted wiring duct 40 × 25 mm	1	3.11	3.11
Terminal blocks	Terminal blocks and accessories set	15	0.44	6.60
Emergency stop	Mushroom emergency-stop button and label	1	2.77	2.77
Pushbuttons and indicators	Start/Stop buttons and pilot lights	1	7.09	7.09
Protection devices	DIN breakers for motor and control circuit	1	3.31	3.31
Control wiring	18 AWG control wire rolls	1	14.23	14.23
Power wiring	3 × 12 AWG power cable, 10 m	1	16.25	16.25
Wiring accessories	Ferrules and cable terminals set	1	22.93	22.93
Motor contactor	Contactor for 5.5 hp motor, AC-3 ≥ 18 A	1	25.00	25.00
Thermal protection	Overload relay, 12–18 A range	1	18.00	18.00
Control contactor	Contactor for 24 VDC power-supply activation	1	15.00	15.00
Valve relays/contactors	Auxiliary relays/contactors for solenoid valves	2	10.00	20.00
Signal conditioning	Shunt resistors for pressure-signal conversion	2	0.50	1.00

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TABLE 14

Cost summary of the electrical control, instrumentation, motor, and implementation (continued)

Item	Description	Qty.	Unit [USD]	Total [USD]
Motor	Three-phase induction motor, 5.5 hp, 220 V, $I_n = 15$ A	1	250.00	250.00
Pressure transducers	0–600 bar range, 8–36 VDC supply	2	157.00	314.00
Labor	Assembly, wiring, PLC/HMI configuration, and testing	30 h	6.00	180.00
Subtotal without VAT				1245.99
Estimated VAT, 15%				186.90
Estimated total				1432.89

Chapter IV

Conclusions and Recommendations

Conclusions

The project successfully transformed the principal functions of the existing manual hydraulic cylinder test bench into a PLC-based automated and instrumented system. The implemented architecture integrates motor control, directional solenoid-valve actuation, HMI supervision, two pressure transducers, safety logic, Ethernet communication, and computer-based data acquisition within a single operating platform.

The progressive prototype strategy was essential to the final result. Initial commissioning identified practical problems such as incorrect motor rotation, pressure-unit configuration, and a defective first test cylinder. After these issues were corrected, the system completed extension and retraction movements reliably and demonstrated consistent correspondence between the physical hydraulic behavior and the pressure values displayed by the digital monitoring system.

The final validation confirmed that both cylinder chambers could be monitored independently and that the acquired information could be stored as a pressure-time record. The final dataset reached approximately 1,856 psi in the extension chamber and approximately 1,834 psi in the retraction chamber during different phases of the cycle. The presence of several consecutive samples near the high-pressure level demonstrated that the system records more than an isolated peak and provides useful information for evaluating pressure holding and test stability.

The pressure-acquisition solution based on 4–20 mA industrial transducers and a 462 Ω shunt resistor provided a practical interface with the 0–10 V analog inputs of the Siemens LOGO! 8. The measured voltage range of approximately 1.848–9.24 V remained within the PLC input limits while preserving the live-zero characteristic of the current loop. This configuration allowed the HMI and the monitoring computer to display the pressure in psi using the same engineering scale.

The implemented monitoring and data-logging functions improve the traceability of the cylinder-testing process. In contrast with a manual procedure based mainly on instantaneous gauge observation, the automated system preserves the complete evolution of both pressure

signals and allows the results to be reviewed after the physical test has finished. The stored data also enabled a Fast Fourier Transform analysis, demonstrating that the acquired records can support additional post-processing methods beyond basic real-time visualization.

The Fourier analysis showed that the dominant non-zero component of both pressure signals was approximately 0.022 Hz, which is consistent with the overall duration and major transitions of the recorded hydraulic cycle. Because the stored dataset used approximately one-second spacing between samples, the frequency-domain analysis is limited to low-frequency cycle dynamics. The result is therefore useful as a proof of post-processing capability, but not as a high-frequency vibration or hydraulic-ripple analysis.

Overall, the project demonstrates that the proposed automation concept is technically feasible and provides a stronger basis for repeatable hydraulic cylinder testing. The system does not replace the final engineering judgment of the operator, particularly for visual leakage inspection and acceptance criteria, but it provides objective pressure data, repeatable sequences, and digital evidence that support more consistent technical decisions.

Recommendations and Future Work

A future version should increase the computer data-logging frequency and ensure a fixed sampling interval if detailed transient, valve-switching, pump-ripple, or frequency-domain analysis is required. A faster sampling rate would also improve the resolution of pressure peaks and short-duration events that cannot be fully represented in the present one-second stored record.

The pressure-test protocol should also be formalized for each cylinder family by defining the applicable test pressure, pressure-holding time, number of cycles, and acceptance criteria according to the cylinder manufacturer's specifications and the relevant industrial standard. The implemented system already allows these parameters to be integrated into the automated sequence, but the final acceptance limits must be defined for each application rather than assumed as a universal value.

For industrial deployment, it is recommended to add automatic test reports containing the cylinder identification, operator, date and time, configured setpoint, number of cycles, maximum pressure, holding time, and attached pressure-time graph. This would further improve traceability and make the system suitable for maintaining a structured historical record of repaired or tested cylinders.

Finally, the system could be expanded with additional variables such as oil temperature,

cylinder position, or flow measurement. These signals would provide a more complete description of the test and could support future diagnostic algorithms for identifying internal leakage, abnormal friction, slow movement, or other hydraulic faults from combined sensor data.

References

- [1] Q. Na, G. Feng, and T. Tian, "Real-time leak detection in high frequency hydraulic cylinder based on intelligent control," *Wireless Communications and Mobile Computing*, vol. 2022, p. 4753328, 2022.
- [2] J. F. Pedersen, R. Schlanbusch, T. J. J. Meyer, L. W. Caspers, and V. V. Shanbhag, "Acoustic emission-based condition monitoring and remaining useful life prediction of hydraulic cylinder rod seals," *Sensors*, vol. 21, no. 18, p. 6012, 2021.
- [3] A. Vietor, D. Lukjanec, and Z. Balint, "Detection of hydraulic cylinder leakage," Master's thesis, Aalborg University, 2016.
- [4] P. Zhang, X. Chen, and Z. Cheng, "Leakage detection based on ceemdan analysis for hydraulic cylinder using acoustic emission technique," in *Journal of Physics: Conference Series*, vol. 2166, 2022, p. 012064.
- [5] K. A. Elshorbagy, H. Kandil, and M. R. Latif, "Development of a multi-functional hydraulic test stand," *Journal of Scientific and Engineering Research*, vol. 5, no. 1, pp. 123–132, 2018.
- [6] D. Su and Y. Yang, "Research about hydraulic cylinder test bench based on plc," in *Advanced Materials Research*, vol. 422, 2012, pp. 200–203.
- [7] S. Yurekli, S. Uzel, and I. S. Dalmis, "Design and implementation of plc based hydraulic test unit design for diagnostics and testing of hydraulic equipment," *Journal of Balkan Science and Technology*, vol. 1, no. 3, pp. 147–155, 2022.
- [8] D. Rodríguez Nieto, "Sistema de control de una planta experimental hidráulica mediante dispositivos para la automatización de siemens," Master's thesis, Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid, Madrid, España, 2023.
- [9] D. F. Castañeda Marín, N. López Correa, and C. S. Barrera Ordoñez, "Control y supervisión de un proceso hidráulico con una plataforma scada," Pereira, Colombia, 2014.
- [10] B. López Sánchez, "Diseño e implementación del sistema de control y monitoreo automático para prensa hidráulica térmica industrial ubicada en empresa textil tejidos especiales sas," Colombia, 2023.
- [11] J. E. Lopez Ostaiza, "Diseño de un sistema de control automatizado para una perforadora hidráulica," Guayaquil, Ecuador, 2020.
- [12] D. A. Rumipulla Cochay and I. J. Ullauri Espinoza, "Diseño y construcción de un banco experimental con un sistema de control hidráulico de dos bombas a presión constante," Cuenca, Ecuador, 2024.
- [13] H. Díaz, G. Trujillo, and A. Roman-Gonzalez, "Diseño de un sistema de control para obtener presión constante de agua," in *XXII Congreso Internacional de Ingeniería Eléctrica, Electrónica, Computación y Afines – INTERCON 2015*, Huancayo, Perú, 2015.
- [14] D. A. De la Cruz De la Cruz and C. A. Placencio Carrillo, "Implementación de un sistema de control para el bombeo de agua de regadío en la comunidad cruz loma, cantón latacunga, provincia de cotopaxi," Latacunga, Ecuador, 2022.
- [15] D. Aldás and C. Román, "Módulo de entrenamiento hidráulico con sistema de bombeo a través de un motor trifásico," *Revista Nexos Científicos*, vol. 7, no. 1, pp. 23–36, 2023.
- [16] R. F. Bermeo Sarmiento and V. H. Baculima Yunga, "Diseño e implementación de un sistema de control para la calidad de leche cruda mediante un sistema iot a bajo costo," Cuenca, Ecuador, 2022.
- [17] J. C. Rocha-Hoyos, "Automatización de prensa hidráulica para el taller mecánico de una pyme."
- [18] P. R. Campoverde Gaibor and L. S. Mejía Correa, "Diseño de una prensa hidráulica semiautomática de 25 toneladas para el control de presión en el proceso de prensado de baldosas," Cuenca, Ecuador, 2023.
- [19] J. Alarcón, J. Jaén, and J. Del Pozo, "Rediseño e implementación de un proceso electro-hidráulico, usado en el laboratorio de control automático de la espol, para controlar velocidad y presión me-

diante matlab-simulink y/o labview,” Guayaquil, Ecuador.

- [20] R. A. Izquierdo Sánchez and A. F. Valarezo Sánchez, “Implementación de un módulo mecatrónico de un sistema de llenado de envases galoneros con control de flujo mediante plc y simulación hmi,” Guayaquil, Ecuador, 2024.
- [21] International Organization for Standardization, “ISO 10100:2020 Hydraulic fluid power – Cylinders – Acceptance tests,” International Standard, 2020, edition 3.
- [22] —, “ISO 4413:2010 Hydraulic fluid power – General rules and safety requirements for systems and their components,” International Standard, 2010.