DESIGN OF A STANDARD ENDURANCE TESTING EQUIPMENT BASED ON PLC CONTROL

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This paper analyses the development and programming of standardized endurance testing equipment for automotive mechanical components, highlighting the advantages of its use. The test bench was designed to reproduce real operating conditions, integrating durable hardware components and control software that allows precise adjustment of test parameters. The programming includes control algorithms that monitor and adjust parameters in real time. Among the advantages of this system are the flexibility of testing different automotive components, the reduction of human errors, and compliance with industry standards, providing an objective assessment of the durability of these components.

Keywords: automation, flexibility, development, programming, testing

1. Introduction

The automotive industry is one of the most competitive and demanding sectors, where the reliability and durability of components are critical for the success of final products. In this context, endurance testing of automotive components [1], [2] is becoming a major priority for manufacturers. Modern technologies, especially PLC-based automated systems, have revolutionized the way these tests are performed. Typically, a PLC is not required to control automated systems, as the authors also mention in the article [3]. They used a different type of controller, which is suitable for domestic (home) systems. However, in the industrial environment, where the intensity of use and working conditions are much more severe, it is necessary to use control equipment (PLC) adapted to the most demanding operating conditions.

A PLC [4], [5] provides precise and flexible control of industrial processes, allowing full automation of test cycles. This optimizes resources, reduces testing time, and minimizes human intervention, thus increasing the safety and consistency

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of results. The integration of pressure sensors capable of measuring a wide range of values adds an additional level of versatility and adaptability, essential for managing dynamic operating conditions in the automotive environment.

In this article, we will explore how PLC-based automated systems are implemented for endurance testing of automotive components. The analysis will include the configuration of the electrical panel, the programming of the PLC, the integration of force sensors and other devices, as well as the collection and analysis of data in real time.

The configuration of the electrical panel and the programming of the PLC are the first essential steps in the implementation of an automatic test system. The correct configuration of the electrical panel involves selecting the appropriate components and ensuring the protection of the circuits, while the programming of the PLC defines the control logic and the operational sequences necessary to perform the tests.

The integration of force sensors and other devices is an important step to ensure accurate monitoring of test parameters. Force, pressure and other parameter sensors can be connected to the PLC, allowing real-time data collection. This data is essential for analysing the performance of the tested components and for identifying any weaknesses or defects.

Siemens PLCs are programmed using different languages and software tools within the TIA Portal (Totally Integrated Automation Portal) platform [6], [7]. This is a software platform also developed by Siemens for programming, configuring and monitoring industrial automation systems. TIA Portal integrates all the functions and tools necessary to develop, manage and maintain automation projects in a single unified work environment. Certainly, other brands of PLCs are also used in the industry, as demonstrated by the author in article [8], where a Bosch PLC was utilized for controlling automated transport systems.

TIA Portal also uses a range of programming languages to develop applications for Siemens PLCs. These include Ladder Logic (LAD), a graphical language that uses symbols similar to relay and contact circuits; Structured Text (ST), a textual language that resembles high-level programming languages such as C; Function Block Diagram (FBD), a graphical language that uses functional blocks to construct control logic; and Sequential Function Chart (SFC), a graphical language used to program sequences of operations, used in sequential processes. TIA Portal also supports Instruction List (IL), a textual language similar to the assembly language, although it is less used in the modern version of the platform. Authors of [9] present and exemplify these languages in figure 1, which provides a visual representation of their characteristics and applications.

However, without the help of a suitable electrical design environment, the project cannot be completed. It is necessary to create detailed and precise wiring diagrams, ensuring complete documentation and in accordance with international standards. EPLAN Electric P8 [10] is an electrical engineering software that enables the realization of these schematics, facilitating the implementation and maintenance of test systems.

This exploration highlights how the adoption of advanced automated technologies can meet the stringent requirements of the automotive industry.

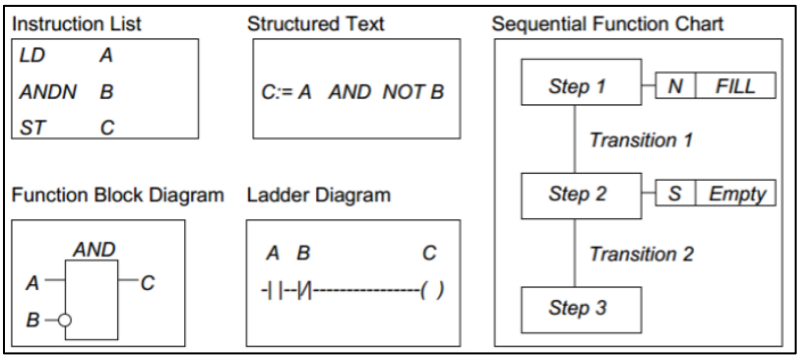

Fig. 1. Tia Portal programming languages

Through the combined use of automation platforms and electrical design environments, it is possible to develop endurance test systems that are reliable and efficient. In this way, the automotive industry can ensure high-quality and reliable products that can withstand the challenges of everyday use.

2. Overview of endurance test equipment

The proposed endurance test equipment is an integrated system designed to evaluate the durability and performance of mechanical components in the automotive industry, using state-of-the-art technologies, including PLC, pneumatic/hydraulic cylinder and interchangeable pressure sensors. The type of automation used in this project is flexible, offering adaptability for different types of components and test conditions. In [11], the authors highlighted the significance of flexible automation in industry, alongside other forms of automation.

The project focuses on the implementation of functions that include entering the value of the number of cycles required for each tested component, as well as setting the force applied to simulate various operating conditions.

The system provides real-time visualization of the test cycle curve, displaying essential parameters such as force as a function of time, via the HMI (Human-Machine Interface) [12]. The system's functionalities include displaying alarms when cycling problems occur, ensuring continuous monitoring of test parameters and triggering notifications in case of anomaly detection. The operator can manually operate the movements of the equipment for precise adjustments and quick interventions. At the same time, it can check the correct functioning of the signal lamps, identifying any malfunction detected.

All testing processes are automated, ensuring the accuracy and repeatability of the tests. The PLC manages critical functions, from hydraulic/pneumatic cylinder control to sensor data collection, and allows data storage and analysis for the generation of detailed test reports. The system is equipped with protective measures for operators, such as protective fences and emergency switches, preventing accidents during operation. Alarm and emergency stop functionalities protect both operators and tested components in case of malfunctions or abnormal operating conditions.

3. Block diagram of the project

Fig. 2 shows the block diagram of the automated system for operating a fuel door, integrating mechanical and electrical components, coordinated by a PLC.

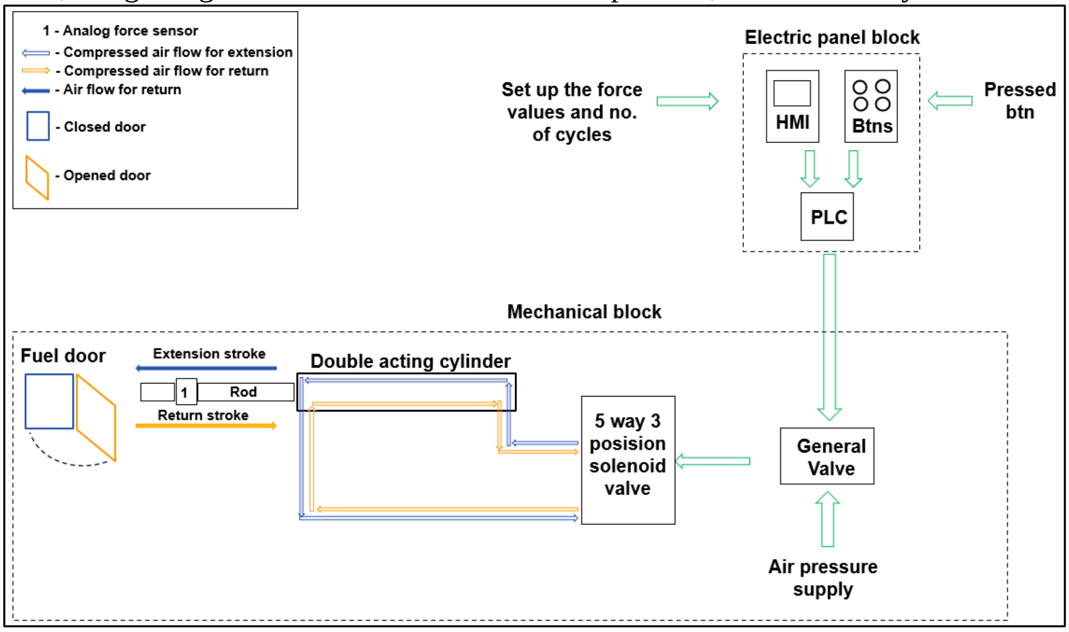

Fig. 2. Project block diagram

3.1.The structure of the system → is organized into two main blocks:

- Mechanical block:

It is centred around a double acting cylinder, which controls the movement of the fuel door. The cylinder performs an extension and retract movement, thus acting on the door. The force applied by the cylinder is measured by an analogue force sensor.

The direction of movement (extension or retraction) is controlled by a 5-way, 3-position solenoid valve. This distributes the flow of compressed air required to drive the cylinder in both directions. The compressed air is supplied by an air pressure source that is connected to the system through a general valve.

- Electrical Panel Block:

It is responsible for user interface and system control. It includes an HMI interface and buttons for configuring the applied force values and the number of operating cycles. The user-configured information is sent to the PLC, which coordinates the operation of the entire system.

The PLC takes the data from the HMI and the force sensor and, based on this, sends control signals to the solenoid valve to initiate the movement of the cylinder, ensuring the proper operation of the fuel door.

3.2.Operation of the system:

When a button is pressed by the user, the HMI transmits the configured data to the PLC, which interprets the commands and regulates the activity of the double-acting cylinder via the solenoid valve. Thus, the fuel door is opened or closed according to the preset specifications. The force sensor constantly monitors the applied force, and the collected data is used for dynamic adjustment of the pressure and movement of the cylinder.

This block diagram provides a clear visual representation of the interconnection between mechanical and electrical components, highlighting how they are integrated and coordinated in an automated system.

4. System hardware design

The hardware design of the control system is critical for ensuring reliable and efficient operation of the endurance testing equipment.

The programmable logic controller (PLC) system utilized in our project is the Siemens ET 200S, a modular and distributed I/O (input/ output) system specifically designed for industrial automation applications. Known for its flexibility and scalability, the ET 200S integrates seamlessly with Siemens SIMATIC controllers and supports a comprehensive array of I/O modules. Central to this system is the IM 151/CPU interface module, which functions as an intelligent slave, enabling the decentralized execution of control tasks. With its IP 20 protection rating, the IM 151/CPU [13] also allows the ET 200S to operate as an autonomous CPU, further enhancing the modularization and standardization of automation processes.

Our setup with the ET 200S includes several I/O modules: 8-channel digital input module (6ES7131-4BF00-0AA0) [14] and 4-channels DI (digital input) (6ES7131-4BD01-0AA0) [15] for receiving signals from sensors and switches; a 8-channels DO (digital output) module (6ES7132-4BF00-0AA0) [16] for controlling electrical elements such as actuators and lights; and a 4-channel AI (analogue input) module (6ES7134-4GD00-0AB0) for monitoring analogue signals like pressure and force.

To manage analogue output devices, the system includes a 2-channel AO (analogue output) module (6ES7135-4LB02-0AB0) [17], which generates the analogue signals needed to control actuators and other devices. This component can be used when hydraulic or pneumatic pressure needs to be controlled. An auxiliary power supply module (6ES7138-4CA01-0AA0) ensures a stable 24V power source for the PLC and its peripherals. The setup also features a termination module (6ES7193-4JA00-0AA0) [18] for proper communication pathway termination. Essential supporting components, such as module support bases, end plates, and memory cards, are also included to ensure proper functioning and configuration of the PLC system. This arrangement allows for flexible management and control within complex automation environments.

Each module is integrated into the PLC ET200S system with precise specifications to ensure seamless communication and operation. The power supply and its protective elements are selected to meet the system's electrical requirements, providing stability and protecting against electrical faults. This hardware design ensures the control system can handle the demands of endurance testing, maintaining accuracy, reliability, and safety throughout the testing process.

ET 200 S PLC assembly controls, for demonstration propose, a pneumatic mechanical system which make endurance on a door fuel tank automobile, consisted of a double acting pneumatic cylinder, pneumatic block valves and an air pressure supply system. A force sensor is used to measure the pressure exerted on closing and opening the fuel tank door of an automobile. Also, a machine guard for entire mechanical project was simulated by using a safety switch. This switch typically includes a mechanical interlock that prevents the machine from operating unless the guard or door is in a closed position.

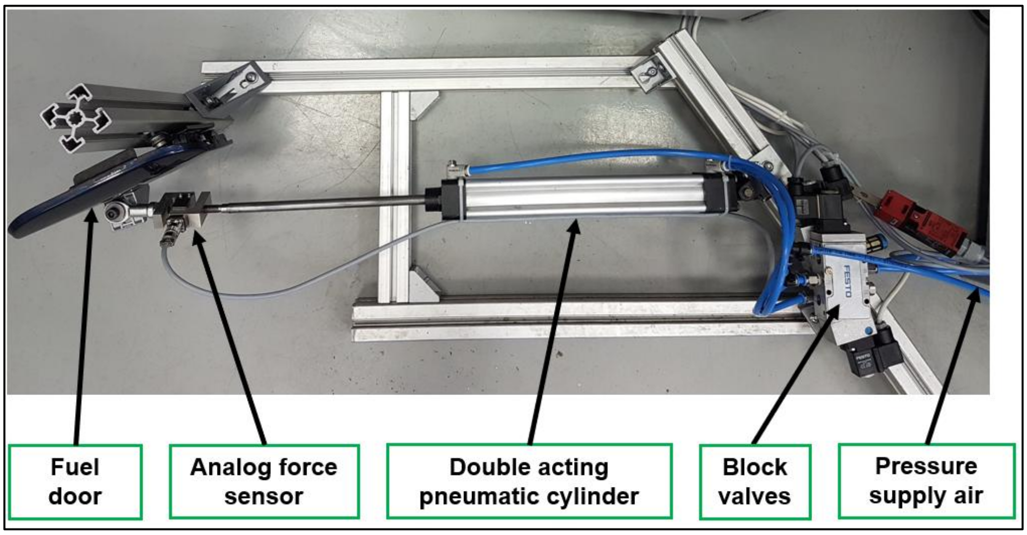

Fig. 3. Pneumatic testing system for demonstration propose

5. Electrical diagram

To create a complete and functional electrical diagram for the electrical panel it is essential to have a well-structured approach. For ease of schematization, Eplan Electric P8 use Macros that are stored in libraries. These libraries can be organized based on project types, components, or industries, making it easier to locate and use the appropriate macro. Here's how the scheme should be organized, and solutions can be easily identified.

5.1.Main power supply and protective elements

Overload protection devices can be used as automatic or overload relays to protect electrical circuits from excessive currents when the electrical equipment is connected to the grid. Short-circuit protection devices can also be automatic or fuses can be used to protect against this type of defect.

5.2.Secondary power supplies:

For the control system, a 24V power supply is used and this must be robust and provide stability. It is necessary to ensure that it is able to supply the necessary current to all components in the system plus a reserve value of 20%.

5.3.Protections for electrical equipment at 24V:

The electrical schematic of the control system must incorporate comprehensive protective elements to ensure the safety and reliability of the entire control panel (fig. 4). This includes integrating protection devices both upstream and downstream of the power supply to safeguard against electrical faults.

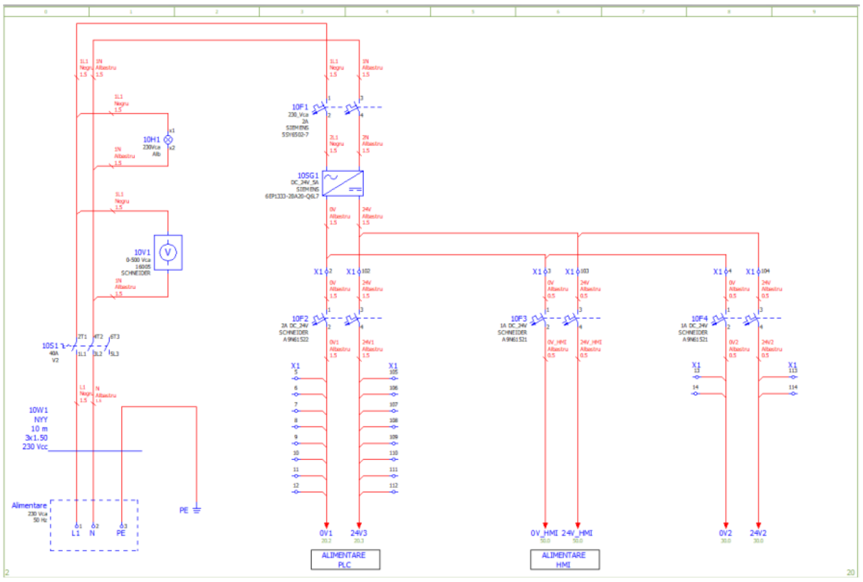

Fig. 4. Power supply and protective devices schematic for electric cabinet

The system requires a 24V DC power supply with the necessary current capacity and appropriate protection mechanisms to ensure stable and reliable power distribution throughout the control system.

5.4.Control System Centre:

The core of the control system is the PLC ET200 assembly (Fig. 5), which includes the parts described in system hardware design chapter.

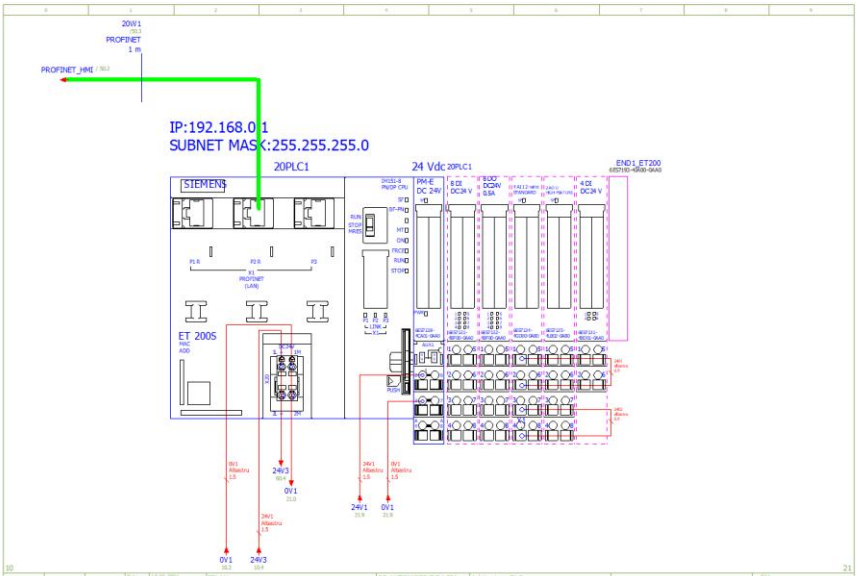

Fig. 5. Power supply and protective devices schematic for electric cabinet

5.5.Modules and sensors:

The circuit is designed to ensure that in the event of an emergency or if a safety guard is not in place, the machine or process will stop, or not start, ensuring the safety of operators and equipment (Fig. 6). The schematic follows a logical structure where safety inputs (emergency stop button, safety switch) are processed by the safety relay, which then controls outputs based on the safety status.

Main components of the circuit:

- ***60KOU1*** is the safety module designed to monitor emergency stop circuits, safety doors, or other safety-related functions;
- ***60PB1*** is an emergency stop button which is integrated into the safety circuit. The primary function of the emergency stop button is to provide a simple and quick way to disconnect power of equipment, bringing it to a safe state as quickly as possible. This button is typically located in easily accessible locations around machinery to ensure that it can be activated quickly during an emergency;
- ***60UC1*** represent a safety switch used for monitoring the status of protective guards (like doors or gates).

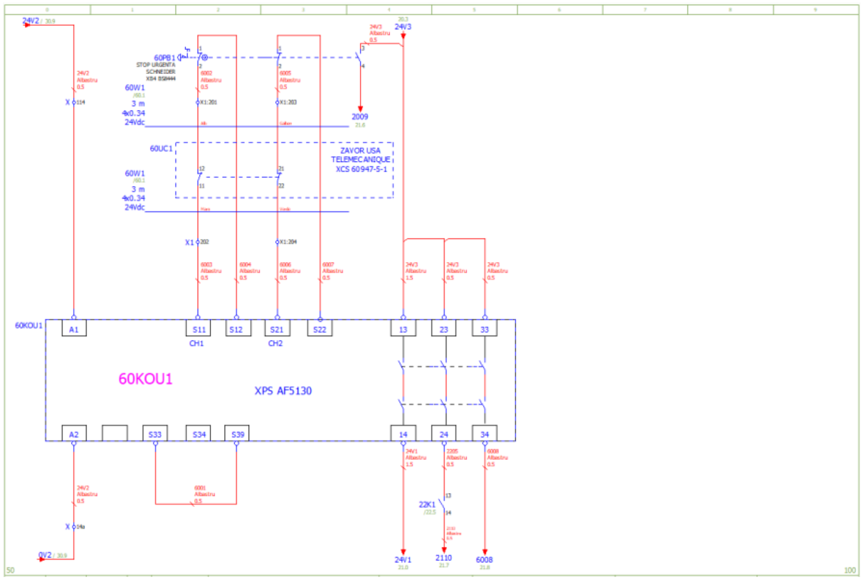

Fig. 6. Security module

The force sensor signal amplifier module (Fig. 7) receives the input and output signals via isolated electrical connections to prevent interference. The amplifier module can be configured to be compatible with a wide variety of force sensors.

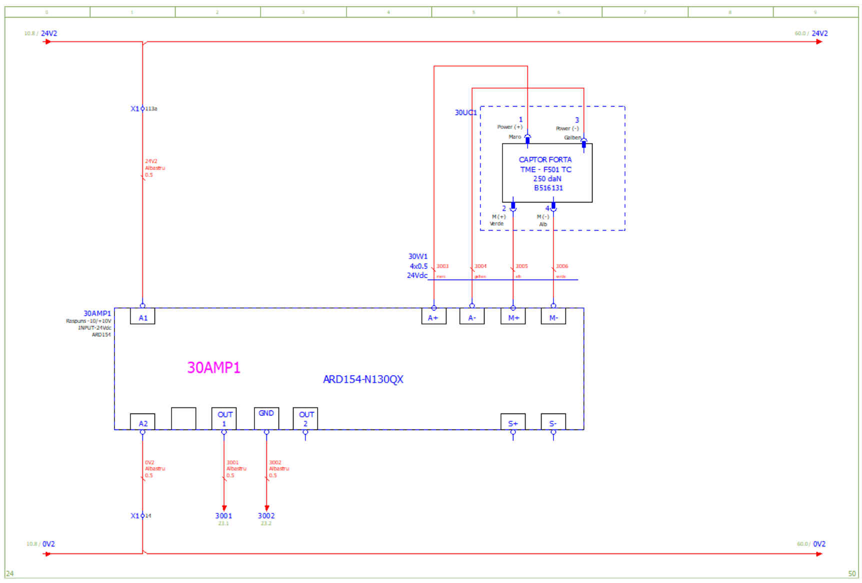

Fig. 7. Force sensor amplifier

5.6.Wiring and labelling:

The wiring is carried out in accordance with safety regulations and in compliance with the standards of splicing and protection [19]. Each cable must be properly labelled to facilitate maintenance and diagnostics. Examples can be seen in figures 4, 5, 6 and 7.

5.7.Verification and testing:

After the wiring is completed, each circuit is tested to verify proper operation and identify any problems. The electrical diagram will be updated with all the changes made and any relevant observations.

6. Software design

Software design in an automation project involves defining the architecture and structure of the program that will control and monitor industrial processes. In this context, the use of the Ladder programming language (LAD) is common due to its graphical way of representation, which facilitates the understanding of control logic, especially for engineers and technicians familiar with traditional electrical circuits.

Ladder is a graphical programming language that represents logic through diagrams that imitate relays and contacts used in control circuits. These diagrams allow for the clear organization of signal flows and decisions, making them easy to track and edit. In a software design, Ladder is often used for programming sequential control and safety interlocks, providing an intuitive view of component interactions.

The software design process includes modelling data flows and operational logic to clarify interactions between system components. The written code is clearly structured and modular, facilitating maintenance and subsequent updates. The implementation of logic allows for efficient testing and diagnosis, as each branch of the “ladder” can be checked individually, helping to quickly identify any problems.

In addition to functional aspects, software design in automation must take into account constraints related to performance, reliability, and security. This includes planning for redundancy and recovery in case of failures, ensuring continuity of operations. The result of a well-designed software design is a system that can be configured, monitored and maintained efficiently, contributing to the optimization of the industrial processes in which it is implemented.

It is necessary to configure the PLC architecture that includes the selection and definition of the hardware components and the logic structure of the automation system. This stage involves choosing the PLC model according to the requirements of the project, determining the number and type of I/O modules required, as well as configuring communication networks and interfaces. Similar to schematizing the PLC architecture in EPLAN Electric P8, configuring the architecture in TIA Portal requires careful analysis of the functional requirements and technical specifications to ensure system compatibility and efficiency.

In TIA Portal, the PLC architecture is built by adding and configuring the hardware modules defined at the beginning of the project, in an integrated graphical environment, where each component is associated with its technical parameters (Fig. 8). This process also involves defining the I/O addresses (Fig. 9) and the internal helper elements necessary for the HMI, but also setting the communication parameters and establishing the logical relationships between modules.

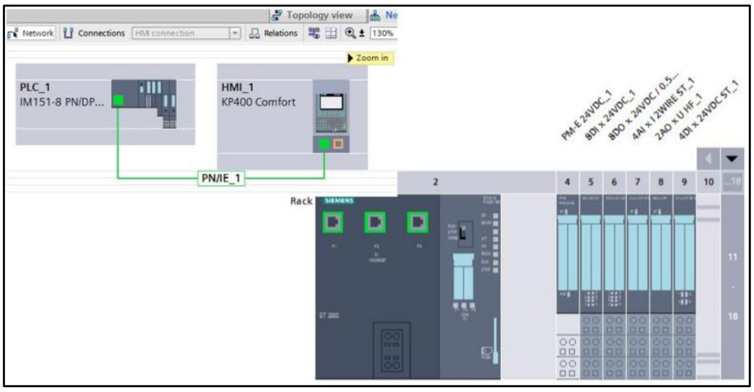

Fig. 8. PLC ET 200S architecture

DIGITAL INPUTS

	Name	Data type	Address	Retain	Acces...	Visibl...
1	PB_PNR_IN_SERV	Bool	%I0.0		✓	✓
2	PB_START_CICLU	Bool	%I0.1		✓	✓
3	PB_STOP_CICLU	Bool	%I0.2		✓	✓
4	PB_AVANSARE	Bool	%I0.3		✓	✓
5	PB_RETRAGERE	Bool	%I0.4		✓	✓
6	MOD_MANUAL	Bool	%I0.5		✓	✓
7	MOD_AUTO	Bool	%I0.6		✓	✓
8	PRESOSTAT	Bool	%I0.7		✓	✓
9	PB_STOP_URGENTA	Bool	%I1.0		✓	✓
10	FEEDBACK_PNR_IN_SERV	Bool	%I1.1		✓	✓
11	FEEDBACK_SECURITATE	Bool	%I1.2		✓	✓

Program PLC_V15.1 ▸ PLC_1 [IM151-8 PN/DP CPU] ▸ PLC tags ▸ Digital OUTPUTS [8]

Digital OUTPUTS

	Name	Data type	Address	Retain	Acces...	Visibl...
1	COL_LUMIN_VERDE	Bool	%Q0.0		✓	✓
2	COL_LUMIN_ALBASTRU	Bool	%Q0.1		✓	✓
3	COL_LUMIN_ROSU	Bool	%Q0.2		✓	✓
4	ELECTROVALVA_GENERALA	Bool	%Q0.3		✓	✓
5	COMANDA_PNR_IN_SERV	Bool	%Q0.4		✓	✓
6	LAMP_PNR_IN_SERV	Bool	%Q0.5		✓	✓
7	CILINDRU_AVANSAT	Bool	%Q0.6		✓	✓
8	CILINDRU_RETRAS	Bool	%Q0.7		✓	✓

Fig. 9. DI/DO designated

As the architecture is defined, it is possible to integrate it with the logic programming part, where the control sequences are created and the logic for the operation of the automated processes is implemented.

7. Programming

Making a diagram of the entire program before initiating the programming of a PLC and configuring the HMI is an important step in the development of the proposed automated system. This diagram (Fig. 10) provides a clear representation of the operational flow, making it easier to understand the steps and interactions between the components. By visualizing logical sequences, the diagram allows errors and gaps to be identified before actual implementation, which can save time and resources.

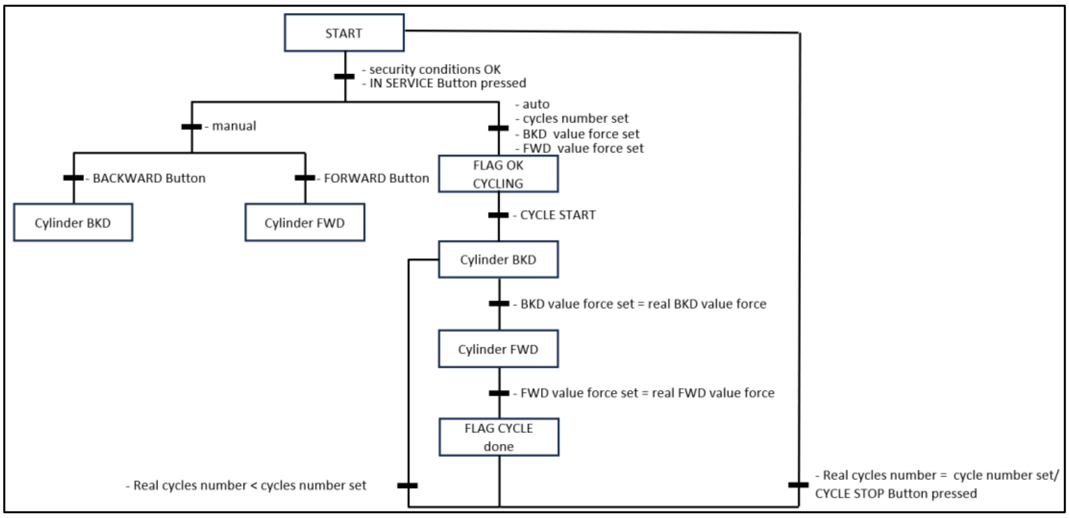

Fig. 10. Program diagram

Main structure of the program:

The PLC program is structured in logic blocks that include:

- ***the initialization block*** configures the initial values for the number of cycles and the operating forces of the cylinder;
- ***the manual operating block*** monitors the states of the manual buttons (FORWARD and BACKWARD) and controls the movement of the cylinder according to the operator's requirements;
- ***the automatic operating block*** manages the automatic cycle by tracking the set parameters and executing the cylinder movement sequences according to the safety conditions;
- ***the security block*** verifies that all security conditions are met before allowing the cycle to be initiated or continued.

Implementing logic sequences:

The programming of the logic sequences is done in the Ladder language, each having distinct roles.

The values of the forces and the number of cycles is entered by the operator via the HMI and are stored in the PLC registers for use during the automatic cycle.

The automatic cycle is initiated by a start command that triggers a sequence of movement, alternating between forward and retract, until the set number of cycles is reached or by the intervention of the human factor.

The monitoring and control of the forces is done with the help of the force sensor that monitors the real values during the movement of the cylinder, and the PLC program compares these values with the set ones. If the values deviate from the set parameters, the program can stop the cycle and issue an alarm.

Managing security conditions:

The PLC is programmed to check various safety conditions, such as the integrity of the housing system, the *Emergency Stop* button pressed, the verification of the pressure in the system or the power supply of critical electrical components. Only after all conditions are met, the automatic cycle can begin. This prevents unintentional activation of the cylinder and protects operators and equipment.

HMI Configuration:

The HMI is configured to display data about the system as well as subpage paths on the main page (fig 11), each having a specific role.

At the top of the interface is displayed an image of the tank door, which represents the physical component under monitoring and control. This image is not only decorative; It serves as a visual reference point for the user, directly indicating the physical condition of the tank door, including the open or closed position.

Below the image, the interface is organized in a grid of seven large buttons, each providing quick access to system functions by opening a subpage:

- the "HOME" button returns the user to the main page, which is the current one. It's a visual reset point for navigation;
- "MANUAL" allows manual control of the pneumatic cylinder operating the tank door, providing the possibility to advance or retract the cylinder by pressing the specific buttons;
- The "SET PARAM" page allows you to configure and adjust system parameters, such as the force required to operate the cylinder and other essential operational values. Here you can also view data entered into the system, such as the number of cycles set or the one in real time;
- "ALARMS" provides access to the system's alarm log, where the user can monitor and manage any errors or malfunctions;
- "TRACES" facilitates the plotting of the forces applied to the cylinder in real time, providing a detailed visualization of the system's performance during the advance and retract operation;

- The "TEST LIGHTS" section is dedicated to testing the lighting system, ensuring the correct functionality of the test bench;
- "PRESS F7 RESET" helps to quickly reset the system by restoring all settings to their default or original values.

Fig. 11. HMI *HOME* page configuration

The most used page of HMI:

Settings parameters (*SET PARAM*) is the most important page of the HMI configuration (Fig. 12). The screen is organized into distinct sections, making it user-friendly and allowing operators to quickly access necessary functions.

The color-coded elements are likely designed to convey different statuses or settings clearly: yellow for force value deviations, blue for real force values, and green for cycles information).

The displayed parameters assist in setting, controlling, and monitoring force values and the number of cycles:

- “Deviation Forward/Backward” displays the percentage deviation of the system in forward and backward directions. This is an indicative of how much the system is deviating from a set point;
- “Real Force Forward/Backward” shows the actual force in decanewtons (daN) being applied in both forward and backward directions. This is created for monitoring mechanical processes;
- “Set Force Forward/Backward” allows the operator to set the desired force values for forward and backward movements;
- “Number of Cycles” the system displays both the set number of cycles and the actual number of completed cycles, important for processes that repeat over time.

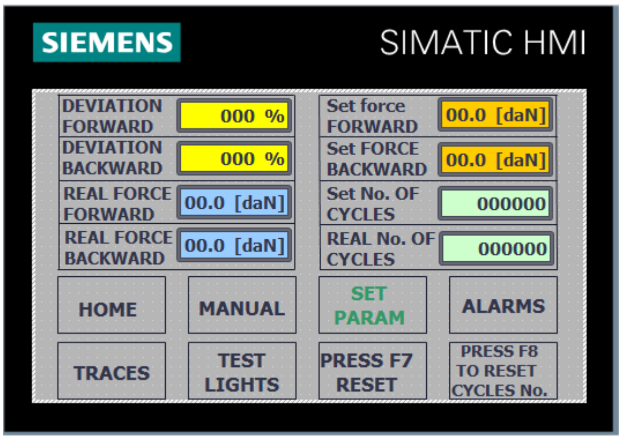

Fig. 12. HMI *SET PARAM* page configuration

TIA Portal uses variables such as BOOL (binary values), INT (16-bit signed integers), DINT (32-bit signed integers), REAL (floating-point values), TIME (time), STRING (strings), BYTE, WORD, DWORD (unsigned numeric values), STRUCT (data structures), ARRAY (data lists) and POINTER (memory addresses) [19]. Not all of them were used in programming this PLC because its moderate complexity.

8. Conclusions

Testing mechanical components in the automotive industry under conditions as close as possible to the real ones is essential to ensure safety and reliability in use. Although these components are designed according to international standards, the true test lies in their actual performance during use. Therefore, rigorous and well adapted testing helps to protect users and maintain quality standards in the industry.

This standard endurance testing equipment is designed and developed to ensure the quality and reliability of these components, meeting the requirements of the automotive industry by developing an efficient and accurate testing solution. The equipment simplifies testing activities by implementing automated testing, which reduces the time required for test execution, and minimizing the effort needed. Automation also eliminates the possibility of errors and adheres to standardized operating procedures, ensuring consistency in task execution.

A significant aspect of this project is the flexibility of the testing equipment, which allows the force sensor's measurement range to be adjusted. This adaptability broadens the range of automotive components that can be tested and enhances the operational performance of the equipment. As a result, the equipment increases its testing capabilities and helps ensure that automotive components comply with the quality and durability standards set by the industry.

Automating recurring tasks reduces monotony for employees and allows them to focus on more complex and satisfying tasks. This redistribution of tasks can have a positive impact on employees' overall productivity and stability at work, as they tend to be more motivated and keep their jobs for longer periods when they are engaged in activities that bring them professional satisfaction.

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