International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 36 العدد
Part 2 المجلد

http://www.doi.org/10.62341/anar2704

Received	2025/03 /29	تم استلام الورقة العلمية في
Accepted	2025/ 04 /26	تم قبول الورقة العلمية في
Published	2025/ 04 /27	تم نشر الورقة العلمية في

Processing Control Monitoring Using Microcontroller: Implementation at Tajora LPG Manufacturing Factory

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Abstract

Liquefied Petroleum Gas (LPG) cylinders are manufactured in accordance with international standards, necessitating rigorous testing prior to market release. This research aims to develop a cost-effective control system to address challenges identified at the hydrostatic pressure testing station of the Tajora LPG Manufacturing Factory. The primary objective is to automate and monitor the hydrostatic pressure testing process, ensuring product safety and compliance with quality standards.

This study developed a microcontroller-based control system for automating and monitoring the hydrostatic pressure testing process of LPG cylinders at the Tajora Manufacturing Factory. By replacing expensive PLCs with microcontrollers, the system effectively manages various components, ensuring product safety and quality compliance. Extensive simulations validated the system's performance, and the software was adapted for similar applications, demonstrating its versatility and cost- effectiveness.

Keywords: LPgas, Embedded system, Proteus simulator, Level & Pressure sensor, Elevator Sensor.

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مراقبة عمليات التحكم باستخدام المتحكم الدقيق: التنفيذ في مصنع تاجوراء لتصنيع الغاز المسال

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الملخص

تُصنّع أسطوانات غاز البترول المسال (LPG)وفقًا للمعايير الدولية، مما يستلزم اختبارات دقيقة قبل طرحها في السوق .يهدف هذا البحث إلى تطوير نظام تحكم فعال من حيث التكلفة لمواجهة التحديات التي تم تحديدها في محطة اختبار الضغط الهيدروستاتيكي بمصنع تاجوراء لتصنيع غاز البترول المسال .الهدف الرئيسي هو أتمتة عملية اختبار الضغط الهيدروستاتيكي ومراقبتها، مما يضمن سلامة المنتج وامتثاله لمعايير الجودة . طوّرت هذه الدراسة نظام تحكم قائم على وحدة تحكم دقيقة لأتمتة عملية اختبار الضغط الهيدروستاتيكي لأسطوانات غاز البترول المسال ومراقبتها في مصنع تاجوراء من خلال استبدال وحدات التحكم المنطقية القابلة للبرمجة (PLC) باهظة الثمن بوحدات تحكم دقيقة، بحيث يُدير النظام مكونات مختلفة بفعالية، مما يضمن سلامة المنتج وامتثاله للجودة .أثبتت عمليات المحاكاة المكثفة أداء النظام، وتم تكييف البرنامج لتطبيقات مماثلة، مما يُظهر تنوعه وفعاليته من حيث التكلفة.

الكلمات المفتاحية :غاز البترول المسال، نظام مدمج، مُحاكي بروتيوس، مستشعر المستوى والضغط، مستشعر المصعد

1. Introduction

Control engineering is a multidisciplinary field focused on modeling, analyzing, and regulating dynamic systems whose states evolve over time. These systems can be mechanical, electrical, fluidic, thermal, or combinations thereof. Control systems employ artificial means to modify system behavior, with each controller designed to meet specific objectives. Control systems can be categorized based on their operational characteristics [1]:

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Continuous control systems operate over a continuous range of inputs and outputs, often described by differential equations. Linear control systems follow linear relationships between inputs and outputs, adhering to the principle of superposition. Non-linear control systems exhibit non-linear relationships, making their analysis and design more complex. Logical control systems operate in discrete states, switching between 'on' and 'off' conditions based on specific thresholds. Sequential control systems follow a predetermined sequence of operations, while conditional control systems respond to specific conditions or events. Hybrid control systems combine elements of both control to manage complex processes [1].
Modern control systems often utilize computational devices for implementation. Distributed Control Systems (DCS) are employed for large-scale operations, medium-sized computers cater to mid-scale processes, and Programmable Logic Controllers (PLCs) or microcontrollers are used for smaller applications. Microcontrollers, in particular, have gained prominence in artificial intelligence applications and nanotechnology due to their cost-effectiveness and versatility.

2. Tajora LPG Manufacturing Factory

Established in the mid-1990s, the Tajora LPG Manufacturing Factory is a prominent producer of high-quality hot-rolled steel cylinders designed for storing compressed gases as shown in figure 1. These cylinders, constructed from materials such as copper and steel, are widely utilized in domestic, industrial, and automotive settings.

Figure 1. Tajora Factory, Hydrostatic Pressure Station

The factory initially produced cylinders with a capacity of 15 kilograms and a working pressure of 15 bar. Subsequent modifications have enabled the production of 11-kilogram

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cylinders, each with a maximum volume of 26.3 liters and a wall thickness of 3.5 millimeters. The facility maintains a daily production rate of approximately 400 cylinders, adhering to stringent quality and safety standards to meet diverse market demands.

Heat treatment is used in mechanical processes to increase strength, improve machining characteristics, reduce forming forces, and restore ductility. 90% of heat-treating operations are on steel [2-4]. LPG cylinders undergo regular and random tests, including hydrostatic pressure tests and pneumatic leakage tests. Figure 2 shows the mechanical tests which include tensile, bending, and wall thickness tests[5-7].

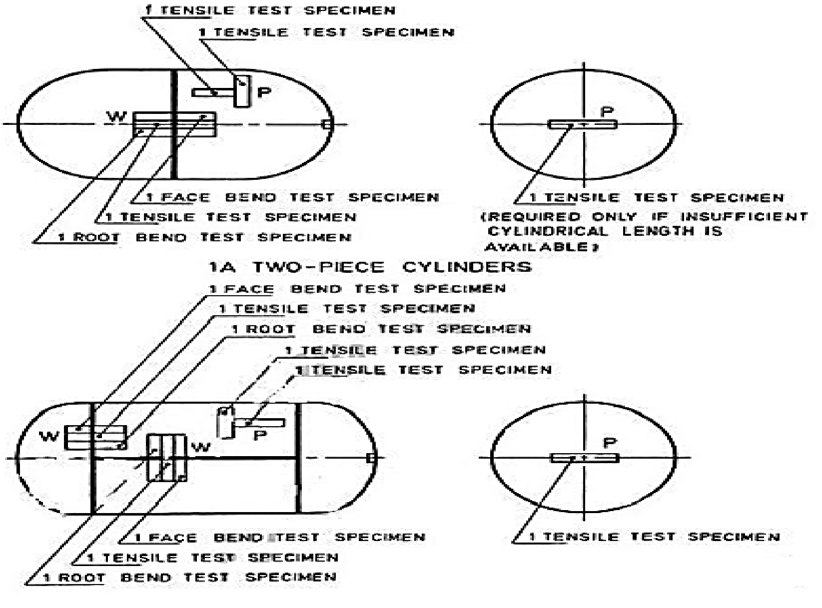

Figure 2. Mechanical Tests :Tensile test, Bending test, Wall Thickness test [2]

The Tajora LPG Manufacturing Factory is seeking a cost-effective control system to automate and monitor its hydrostatic pressure testing station for LPG cylinders. Current methods, often expensive PLCs, increase costs and complexity. The solution involves developing a microcontroller-based system that can control and monitor various operations using sensors and actuators. The system must ensure accurate, safe, and efficient testing of LPG cylinders,

http://www.doi.org/10.62341/anar2704

meet international quality and safety standards, and provide fault detection and alarms to prevent process errors.
The solution involves designing, simulating, and implementing a microcontroller embedded system that enhances automation and safety in the testing process.

3. System Components

The hydrostatic pressure testing station for cylinder manufacturing factories consists of various systems, including transportation, filling head elevator, water filling, compressed water, and water discharge systems [8,9]. The system includes a PIC16F877A microcontroller, sensors like level, pressure, position, and flow detectors, actuators like solenoid valves, conveyor motors, and water and air pumps[10-13]. Control software is developed in PicBasic and Proton+, and simulation is conducted using PROTEUS VSM for real-time interaction testing.

The reference input signals were obtained by connecting some switches between the 5 V dc supply and the microcontroller input pins (current sourcing mode).

$$R = (5-2)/10mA \quad (2)$$

For output as simulation all outputs are simulated as LEDs connected to output pins of the microcontroller " a single-pole, single-throw switch SPST with pull-down resistor as current sourced" 10K<=R <100K .

3.1 PWM Module

Figure 3 shows the pulse width modulation (PWM) mode which produces a PWM output at 10-bit resolution. A PWM output is basically a square waveform with a specified period and duty cycle.

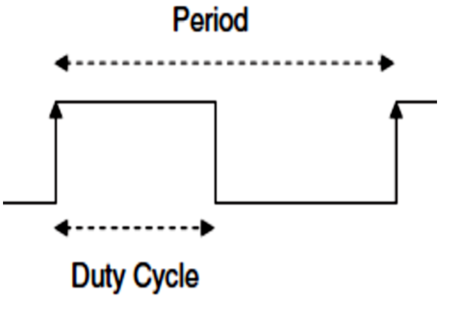

Figure 3. Typical PWM waveform [1]

The module is controlled by Timer 2. The PWM period is given by:

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$$PMWperiod = (PR2 + 1) * TMR2PS * 4 * Tosc \quad (1)$$
$$PR2 = \frac{PMWperiod}{TMR2PS * 4 * Tosc} - 1$$

Where: PR2 is the value loaded into Timer 2 register, TMR2PS is the Timer 2 prescaler value, Tosc is the clock oscillator period (seconds). The PWM frequency is defined as 1/ (PWM period). The PWM duty cycle has a 10-bit resolution, selected by writing the eight most significant bits into the CCPR1L register and the two least significant bits into the CCP1CON register.

3.2 The comparator module

The comparator module consists of two analog comparators, multiplexed with I/O port pins RA0 through RA3, and eight modes of operation. The CMCON register controls input and output multiplexers as illustrated in figure 4.

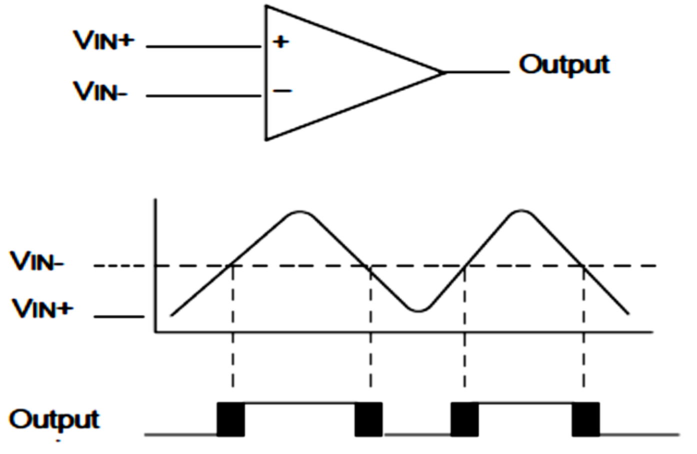

Figure 4. Input and Output of the Comparator [1]

3.3 The proposed system design sequence is:

When the cylinder has been finished its heat treatment, the hanged cylinder has to be put on belt conveyer as shown in figure5.

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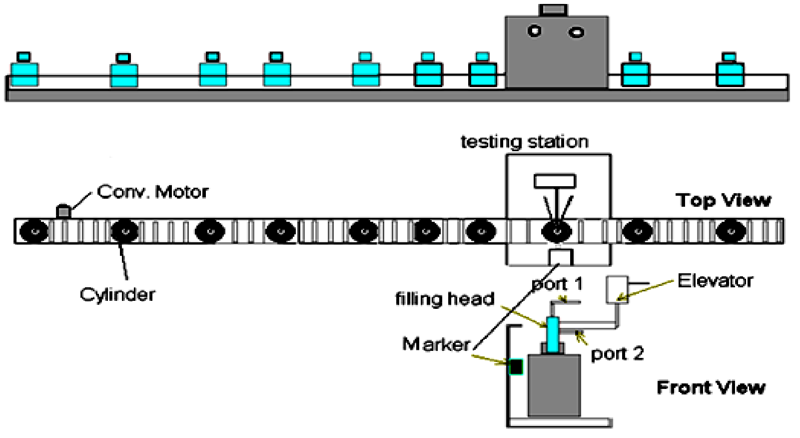

Figure 5. system design sequence of HPTS [2]

The automated hydrostatic testing process for LPG cylinders involves initiating the system in automatic mode, which activates the water pump, opens the return valve, and starts the conveyor to position the cylinder at the testing station. A position sensor ensures accurate placement, after which a pneumatic elevator raises the cylinder to connect with the filling head. If the elevator does not complete this action within a set time, the system halts and issues an alarm to signal an error.

3.4 Control Strategy

Activating the master switch and selecting automatic mode initiates the system by starting the water supply pump, opening the bypass water valve, and turning on the start switch (SW1). as shown in figure 6.

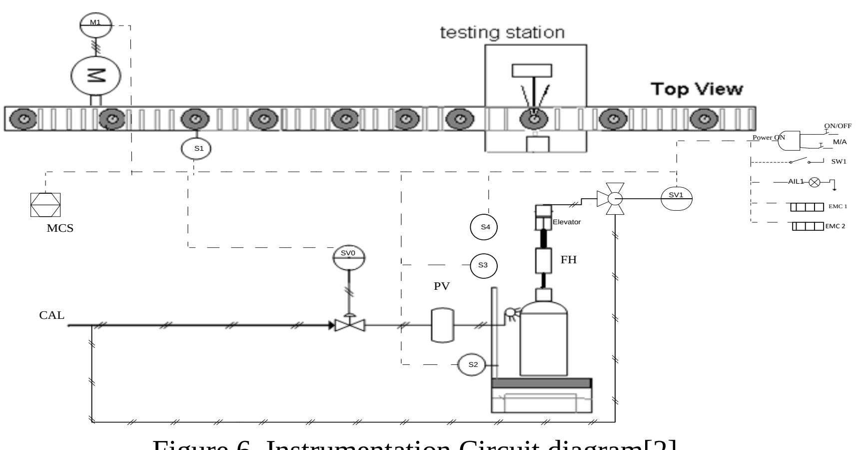

Figure 6. Instrumentation Circuit diagram[2]

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The automated hydrostatic testing process for LPG cylinders involves a series of controlled steps: transporting the cylinder to the testing station, aligning the filling head, pressurizing the cylinder to 35 bars for one minute, and marking cylinders that pass the test. The system employs multiple timers and sensors to monitor each phase, ensuring precise operation and safety. Any deviations, such as delays in reaching pressure thresholds or sensor feedback anomalies, result in the process halting and alarms being activated. Continuous monitoring of water levels and air pressure ensures the system operates within safe paramet.

3.5 Flow charts

Figure7 shows the main process flow chart

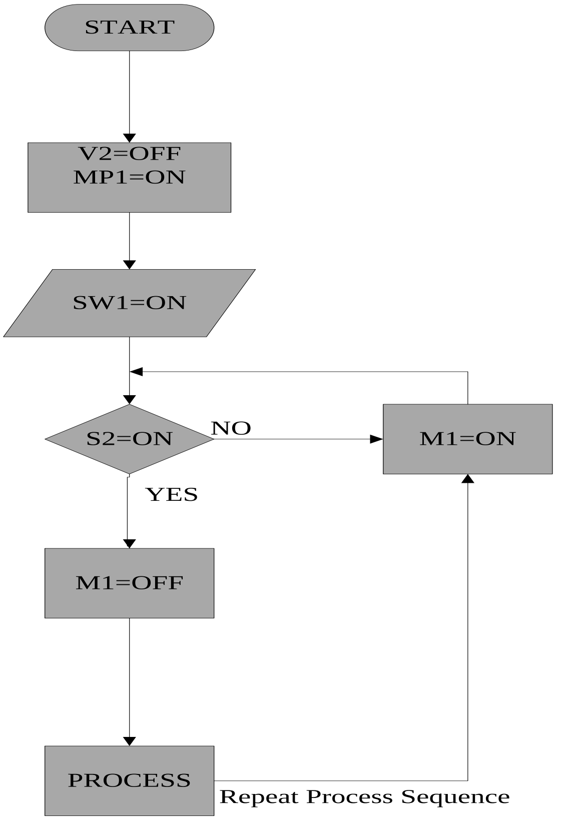

Figure7. Main Program Flow Chart [2]

4. Results and Discussion

Figure 8 shows a data acquisition system with sensors for position, level, pressure, valve feedback, and flow detectors. It uses a microcontroller and actuators to control various devices. Measured

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signals are sent to signal conditioning circuits, which adapt input signals for microcontroller digital inputs and output signals for output equipment. These circuits are omitted for simulation.

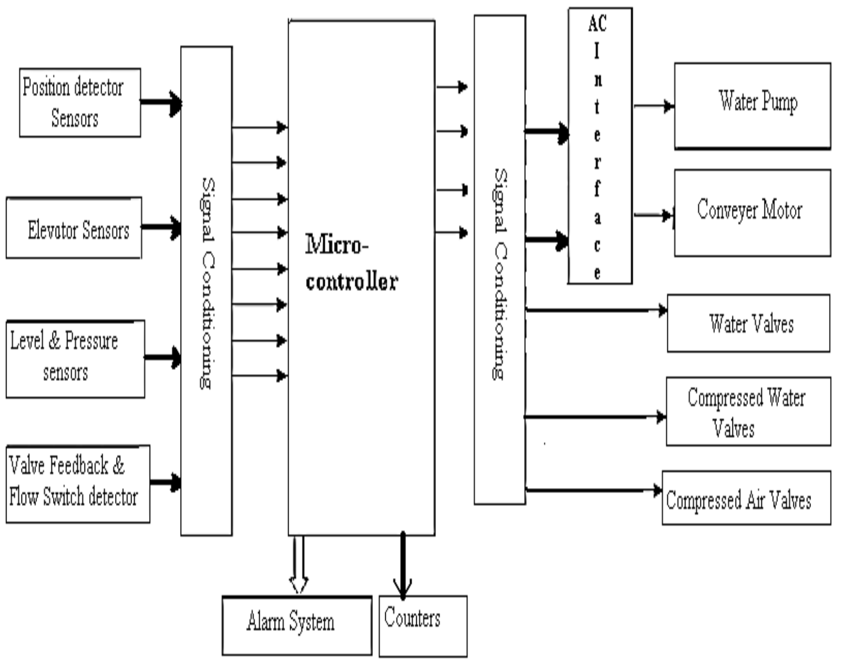

Figure 8. Schematic of the system block diagram

4.1 Simulation Task

MPLAB IDE is a Windows-based platform that integrates essential development tools for PIC and dsPIC microcontrollers, streamlining the development process. Complementary tools like the Proton+ compiler and Proteus simulator enhance this environment by providing additional functionalities for application creation and simulation, respectively.

After debugging and generating the necessary files, the HEX file was programmed into the microcontroller using the Leaper-48 Universal IC Writer. This device offers a user-friendly interface and supports a broad array of components, streamlining the programming process.as shown in figure 9 and figure 10 respectively.

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- Simulator Panel and Microcontroller Board

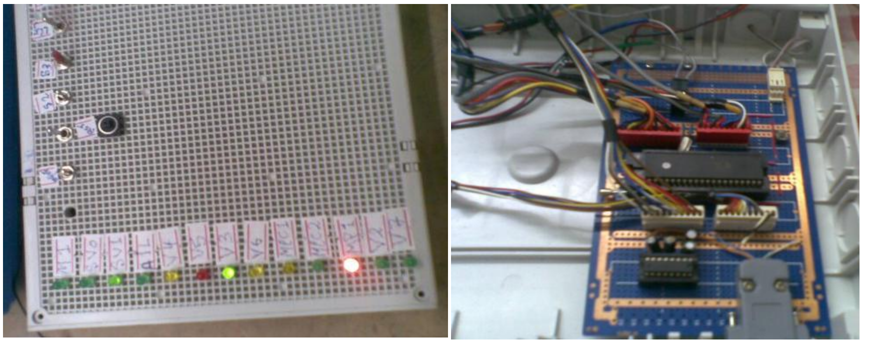

Figure 9. Simulator panel and Microcontroller Board

- Microcontroller system–Leaper IC_ writer– Electronic Bench

Figure 10. Leaper IC_ writer – Electronic Bench

Proteus VSM Simulator by Labcenter Electronics provides a comprehensive platform for designing and simulating electronic systems.

By supporting real-time interaction between microcontrollers and their peripherals, it facilitates efficient development and testing of embedded applications as shown in figure 11.

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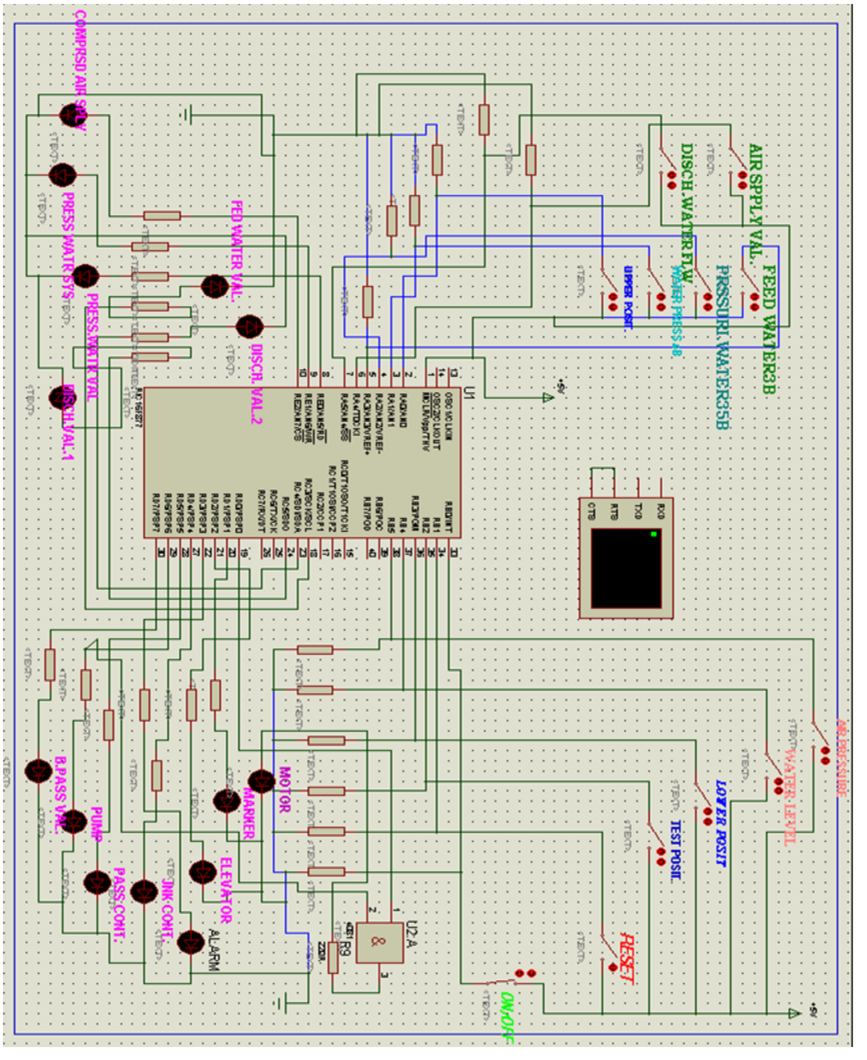

Figure11. simulation process by using PROTEUS SOFTWARE

4.2 Samples of Program Flow Charts

(produced by Visustin V5 trail version Software) as shown in figure 12.

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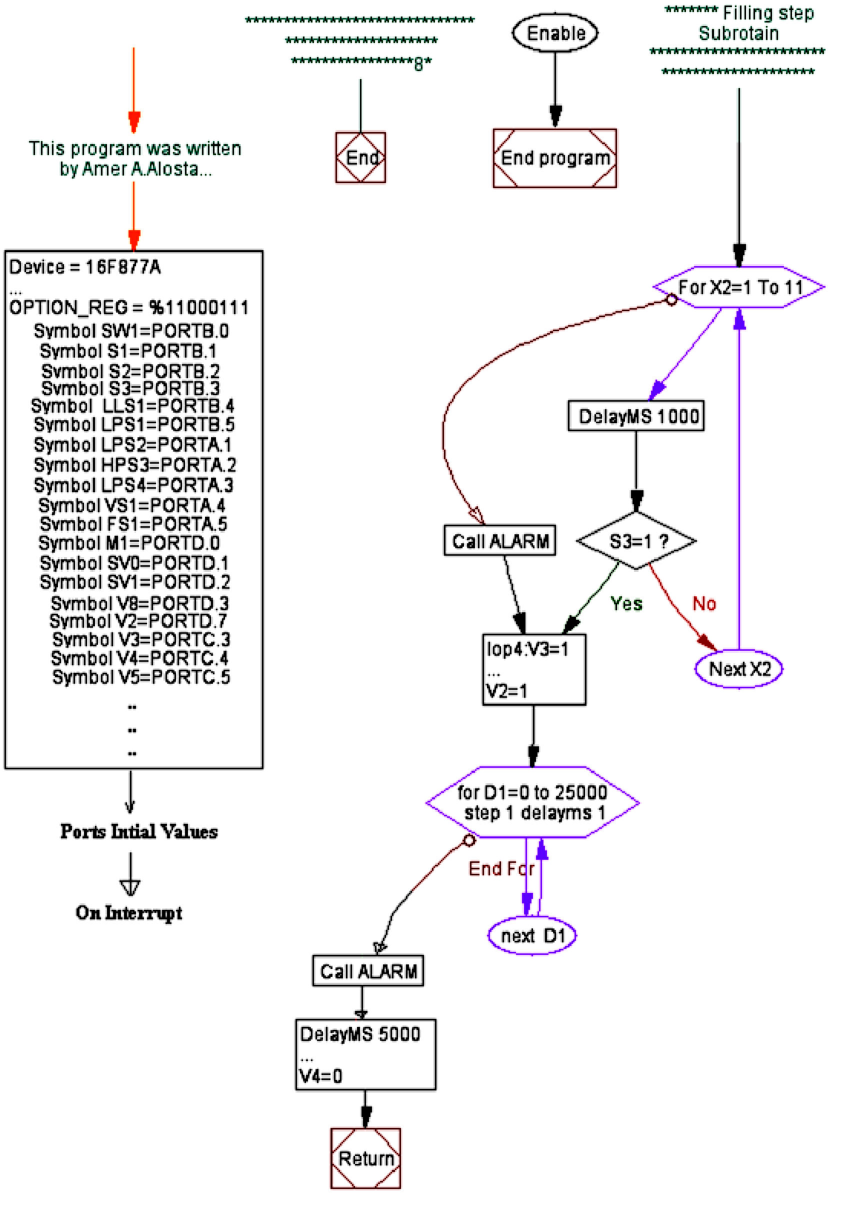

Figure 12. The program Flow Charts

4.3 Pressurizing, Discharging and Alarm Subroutine

The figure 13 illustrates the system flowchart

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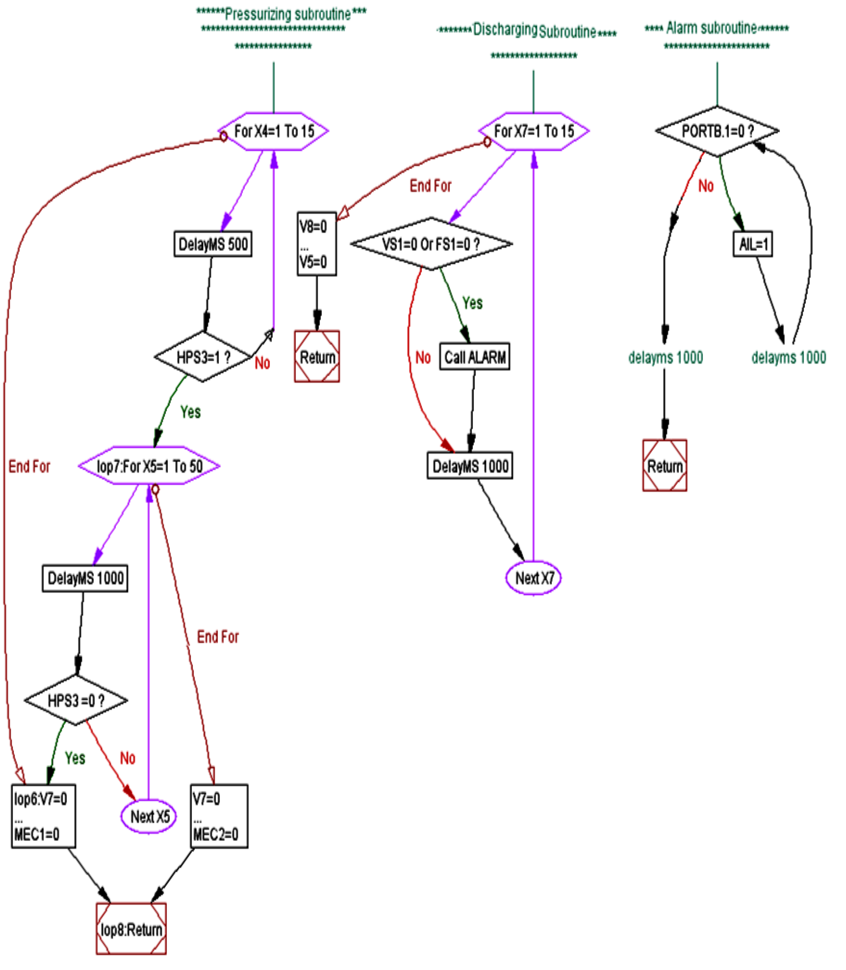

Figure 13. Pressurizing, Discharging and Alarm Subroutine flowchart

The control system hardware consists of a PIC-based circuit board with a control program written in PIC memory and a simulator circuit with switches and LEDs representing various processes. The system was tested in simulation mode and tested on both software and hardware simulators. To transition to real operating mode, operating and waiting times must be configured according to the equipment specifications. Two options for monitoring and control panel are traditional switches and LEDs or a computer screen panel, which requires modifications to the program. A multi-head station can be used for high-capacity production, with each head operating with its own controller within a network control system. The software is adaptable and offers advantages such as ease of programming, straightforward maintenance, and affordability. Key

http://www.doi.org/10.62341/anar2704

observations include accurate cylinder handling, effective pressurization control, and a reliable alarming system. Table 1 shows the key observations include:

1. Accurate Cylinder Handling: Position sensors triggered motor halt precisely.
2. Effective Pressurization Control: Maintained pressure at 35 bar for 60 seconds.
3. Reliable Alarming System: Alarm and shutdown executed upon sensor failure or time overrun.

Table 1. Summary of testing outcomes.

Condition	System Respons	Result
Cylinder Misalignment	Stop conveyor and raise alarm	Passed
Pressure < 15 bar	continue pressurizing	Passed
Pressure ≥ 35 bar	Hold for 60 sec, monitor stability	Passed
Water not discharged on time	Trigger alert and stop system	Passed

4.4 Discussion

The use of microcontrollers in replacing PLCs has reduced costs without compromising reliability. The modular design allows for future upgrades or expansion. The design can be scaled to multi-head stations, managed by individual controllers linked via a distributed control network. Compared to traditional systems, microcontrollers offer flexibility, lower hardware costs from 60-70%, and simpler training for technicians with basic embedded system knowledge.

5. Conclusion

The study developed a microcontroller-based control system for the hydrostatic pressure testing station at the Tajora LPG Manufacturing Factory, replacing expensive PLCs with a cost-effective solution. Utilizing the PIC16F877A microcontroller, the system automates key processes, and simulations confirm its reliability. This approach enhances safety and efficiency in LPG cylinder testing and is adaptable for similar manufacturing environments. Future efforts should focus on hardware implementation and system integration to further optimize the process.

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