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AUTOMATIC GALLON FILLING SYSTEM CONTROLLED BY PROGRAMMABLE LOGIC CONTROLLER-PLC

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ABSTRACT

This work consists of the automation and control of gallon filling for the liquid soap manufacturing process, consisting of 3 tanks fed by the main tank containing the raw material. The system is mainly composed of a conveyor belt where a detection sensor is incorporated, which activates a servo motor to position the gallon in the desired place for filling through an electro valve. Also, the level required in each gallon is measured with a capacitive sensor, all these actions are controlled by the PLC which allows the operator to manipulate and interact with the system to perform storage and dosing operations automatically or manually. As a result, the automated system will increase productivity, reduce operating costs, improve process safety, and optimize human resources.

Keywords: control, automation, servo motor, PLC, conveyor belt.

1. INTRODUCTION

Technology advances and promotes the automation and control of industries; that is why companies seek to improve production processes to achieve better performance, provide more safety to their employees, and efficiency in each of their areas. Electronics has a strong influence on these processes through its theories and implementation of mechanical, electronic, and computational devices that reduce the human intervention factor and improve the final product quality (Minian *et al*., 2017).

Significant work has been done in the gallon-filling automation area; for example, an automated bottle-filling system using PLC control is developed (Hasan *et al*., 2013). This project was built to withstand factory environments with greater immunity to noise and vibrations. The system was controlled by PLC, giving it greater reliability and security. In another related work, a commercial prototype for automatic bottle filling is designed using PLC and SCADA. This prototype's advantages are that it supplies the mixture of any quantity of liquids in any proportion and warns the operator of faults in the system (Dhiman and Kumar, 2014).

The productive sector of toiletries has had a high demand for products; however, in many companies, the production has not been enough because it is carried out manually by human operators. This project is developed in facilities with a production area made up of 3 tanks fed by the main tank containing liquid soap's raw material. Before this project, the filling was done manually utilizing a galvanized valve. In each tank, was made the mixture corresponding to the type of soap required, all this process carried out by a human operator.

It is possible to control the gallons filling liquid soap and prevent the liquid from being wasted through automation. Besides, the process is achieved in less time, the process's security is increased, and its human resources are optimized.

The content is organized as follows: Initially, the system without automation and the proposed automated system description are detailed. The selected components with their main characteristics are described, and PLC programming is shown in the next chapter. Finally, the automated system is presented, and the conclusions are offered.

2. MATERIALS AND METHODS

2.1 Tank Filling System without Automation

The chosen facilities to carry out this project have a production area where the liquid soap filling system was carried out manually, as shown in Figure-1. The main tank stored the raw material deposited in 3 tanks, each with a different soap type.

Figure-1. A filling system without automation.

The liquid mixing process was carried out manually; through a galvanized valve opening the main tank, the liquid was lowered by gravity to each tank. In each tank, the mixture corresponding to the type of soap required was made by the plant operator. These three tanks had a manually operated valve for the sequential filling of each gallon.

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2.2 Description of the Proposed Automated System

Figure-2 shows the proposed automated system schematic diagram. The components used to build the automatic liquid soap filling system are the SHAR2YOA21 detection sensor, LJC18A3-BZ / AX capacitive level sensor, Power HD AR 1201MG servomotor, 2W-160-15 solenoid valve, Siemen 7S-1200 PLC, Micromaster drive 420, motor, and conveyor belt.

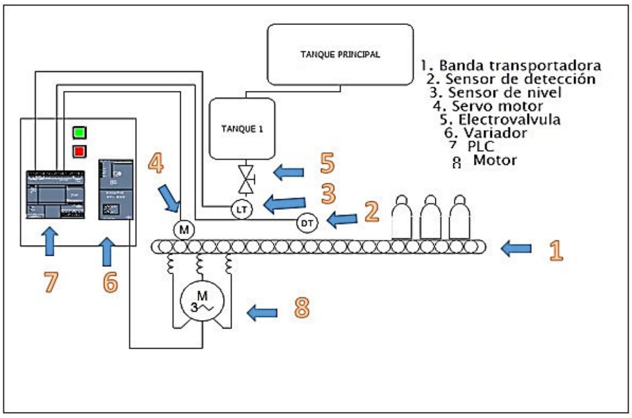

Figure-2. Schematic diagram of the automatic gallon filling system.

2.2.1 Conveyor belt

The conveyor belt is made up of a continuous conveyor system in which a belt moves between two drums, as shown in Figure-3.

Figure-3. Conveyor belt.

The conveyor belt is dragged by the friction of its drums, which in turn drives a motor. This friction results from applying tension to the conveyor belt, usually a tensioning screw mechanism. The other drum rotates freely, without any drive, and its function is to serve as a return to the conveyor belt. Rollers between the two drums support the conveyor belt, called support rollers.

2.2.2 Detection sensor

The detection sensor chosen to detect the gallon is the SHAR2YOA21 [11]. This sensor has a 10 to 80 cm sensing range and an analog voltage proportional to the gallon distance. The distance can be calculated, as shown below.

$$\text{Distance (cm)} = 16746{,}73 * V_{out}^{-1{,}2134}$$

The sensor must be powered between 4.5 and 5.5 volts, recommending that it be as stable as possible.

2.2.3 Capacitive level sensor

The capacitive sensor LJC18A3-BZ-AX was chosen as a proximity detection sensor up to 10mm. This sensor works with three connection cables and detects metallic and non-metallic materials, such as plastic, glass, water, and oil. This project is used for the liquid soap material detection located in the upper part of a base on the conveyor belt.

The capacitive level sensor is formed by an oscillator whose capacitance is formed by an internal electrode (part of the sensor itself) and an external electrode (consisting of a piece connected to the ground). The external electrode can be made in two different ways; in some applications, the electrode is the object to be sensed, previously connected to the ground. Then the capacity will vary depending on the distance between the sensor and the object.

2.2.4 Servo motor

The Power HD AR 1201MG servomotor is used, which has a strong motor with limited rotation. This standard three-pin connector incorporates an internal control circuit that allows it to be moved to the desired position from 0° to 180° and is used for the system braking gallons.

2.2.5 Solenoid valve

The reference solenoid valve 2W160-15 is chosen with an opening of 16mm, compatible with a 1/2 " thread, and it is usually closed. This valve's winding is made of copper wire with an aluminium-clad cooling module, although it is not recommended to work for long hours as this causes the coil to fracture due to self-heating.

2.2.6 Variable speed drive

The variator chosen is the Micromaster 420; it has a variable speed drive used in pumps, fans, and transport systems (Siemens, 2020). The drive is located inside the distribution box and is shown in Figure-4.

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Figure-4. Micromaster 420 variable speed drive.

2.2.7 PLC

PLC has been widely used in gallon-filling projects, such as designing one bottle of the liquid-filling machine simultaneously (Baladhandabany *et al.,* 2015). The Siemens S7-1200 PLC was chosen for this project, which is shown in Figure-5. It is a small-sized PLC that has the inputs and outputs necessary for the system's operation. The S7-1200 range includes different programmable logic controllers (PLCs) that can be used for many tasks (Siemens, 2019). The S7-1200 Programmable Logic Controller (PLC) offers the flexibility and ability to control various devices for various automation tasks.

Figure-5. PLC Siemens.

2.2.8 Three-phase motor

The B 80 A4 / EC Voges three-phase motor was chosen, shown in Figure-6. Three-phase electric motors are manufactured in the most diverse powers. A fraction of a horsepower to several thousand horse powers (HP) is built for practically all normalized voltages and frequencies (50 and 60 Hz). They are often equipped to operate at two different nominal voltages.

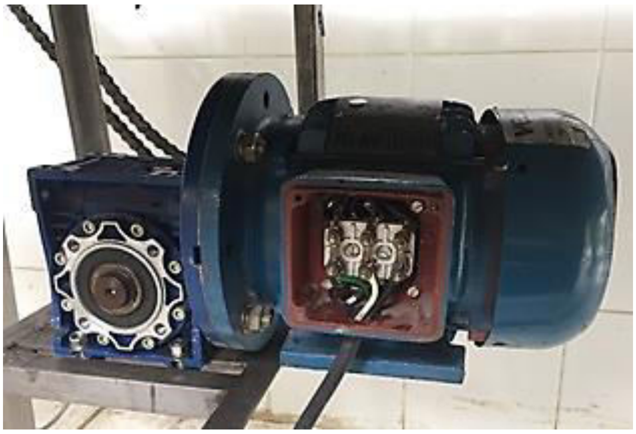

Figure-6. Three-phase motor.

3. RESULTS AND DISCUSSIONS

The implemented system's main objectives are to control the gallon filling, which has a capacity of 3.7 L, and increase the filling speed safely so that there are no liquid losses.

3.1 System Components

The system development is executed in 4 phases: operation panel development, circuit design, PLC configuration, and the variator configuration.

3.1.1 Operation board

The operation panel contains the PLC, the variator, the circuit breakers, the coupling circuits, and the power supplies, among others, stored in a plastic box with a hermetic seal to protect these elements. Figure-7 shows the operation panel distribution, divided into four sections: the inputs, PLC, outputs, and variator, marked with the numbers 1, 2, 3, and 4, respectively.

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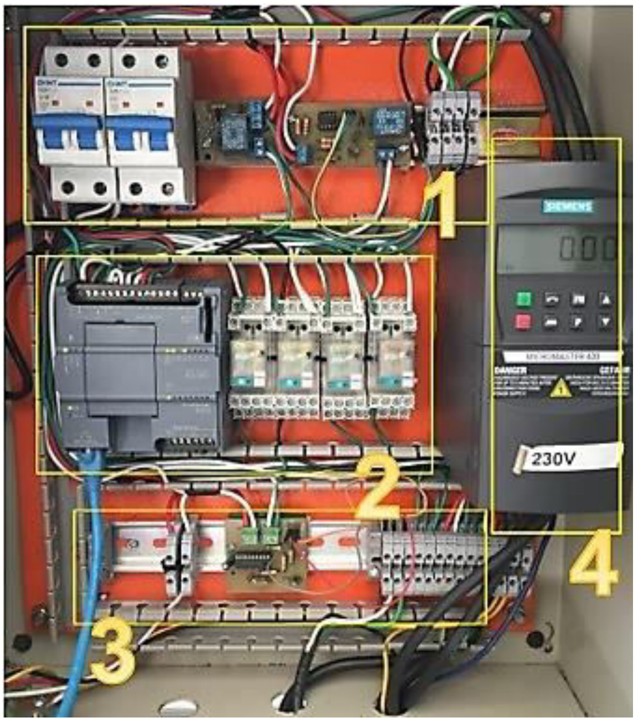

Figure-7. Operation board.

3.1.2 Electronic circuit design

3.1.2.1 Detection circuit

Figure-8 shows the detection sensor coupling circuit. Because the detection sensor sends values greater than 1.17V when it detects an object and less than 1.17V when it does not detect an object, the LM358 operational amplifier is used as a voltage comparator; In such a way that at the output, it generates 5V when an object is detected and 0V when not detected.

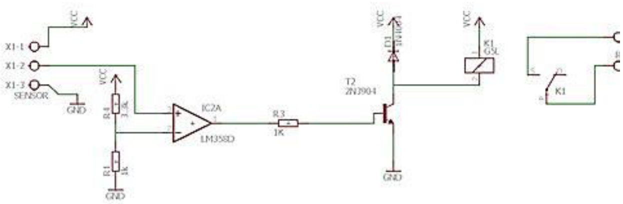

Figure-8. Detection sensor coupling circuit.

To properly configure the op-amp, a voltage divider is designed. The value of R1 is chosen as 1kΩ, and the value of R4 is calculated as shown below.

$$R4 = 1K\Omega * \frac{5V}{1.17V} - 1K\Omega = 3.27K\Omega$$

3.1.2.2 Level sensor circuit

Figure-9 shows the level sensor coupling circuit formed by a transistor configured in cut-off and saturation. In this circuit, the sensor's signal is a square wave switching between 0V and 5V depending on whether it detects an object or not.

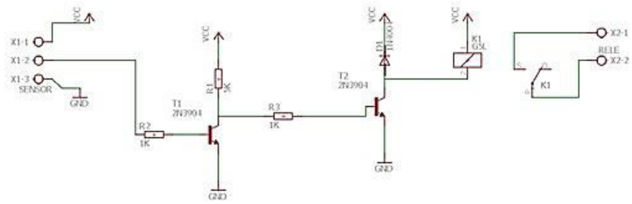

Figure-9. Level sensor coupling circuit.

3.1.2.3 Servo motor circuit

Figure-10 shows the servo motor coupling circuit. The configuration of the PIC16F83P is developed in the flow code environment, and the working frequency is 4 Mhz. Therefore, a crystal with this characteristic is implemented along with two 22pf and one 100μf capacitor.

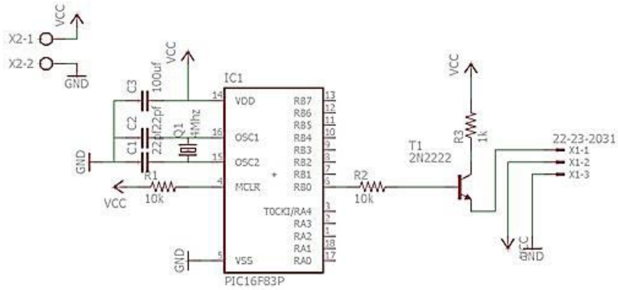

Figure-10. Servo motor coupling circuit.

The servomotor works through PWM (pulse width modulation), so a train of 5V and 0V pulses is sent to the RB0 output, pin 6, according to the angle required for the servomotor. It is also necessary to use a transistor in a common emitter configuration that works in cut-off and saturation.

3.2 PLC Configuration

3.2.1 Declaration of variables

Initially, the variables of the sensors and actuators to be used in the PLC programming are declared. As mentioned before, the PLC used is the Siemens S7-1200, which has eight digital inputs and six digital outputs. Four inputs and five outputs are chosen, as shown in Table-1.

Table-1. Declaration of PLC inputs and outputs.

Inputs	I	Outputs	Q
Distance Sensor	0	Servomotor	0
Level sensor	1	Solenoid valve	1
Start button	2	Activate the motor	2
Stop button	3	Activate engine speed	3
		Alarm	4

To the programming, the input variables are declared with the letter "I" starting from% I0.0 to% I0.7

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and the output variables with the letter "Q" starting from% Q0.0 to% Q0.5.

To the programming explanation, a state diagram is shown in Figure-11, where EV is a solenoid valve, MV is variator motor, V is belt speed, and B is the barrier. Levels 0 and 1 correspond to off and on, respectively.

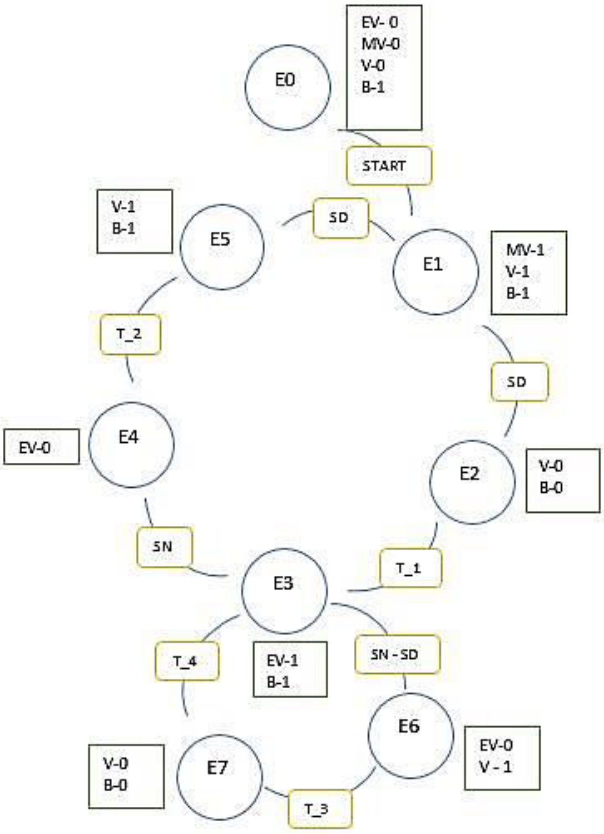

Figure-11. The state diagram for PLC programming.

State 0 (E0): The initial conditions are declared, the solenoid valve is in an inactive state so that the liquid does not circulate, the conveyor belt motor and the speed are off because the process has not been started, and finally, the barrier is vertical (B = 1).

State 1 (E1): Activated after the operator presses the START button. The motor is activated, and simultaneously, the conveyor belt starts operating at the speed programmed in the variator. Finally, the barrier is kept vertically as the solenoid valve maintains its previous condition in a closed state.

State 2 (E2): Activated when the detection sensor identifies that an object is in its detection range. In this case, an empty gallon is detected, then the conveyor belt stops, and at the same time, the barrier lowers and is positioned horizontally (B = 0) to set the gallon in the desired place.

State 3 (E3): After 3 seconds, the filling stage begins; the solenoid valve is activated and allows the passage of liquid to start filling the gallon. Since the gallon is in the desired location for filling, the barrier returns to its vertical state to allow the gallon to move once it is full.

Status 4 and 5 (E4 and E5): If the system detects that the gallon is full thanks to the level sensor and no gallon is found in the queue, the fill solenoid valve closes quickly; status five is activated where after 2 seconds. The belt speed is started and returns to state one so that the system continues working and the full gallon continues its movement.

Status 6 and 7 (E6 and E7): If the system detects that the gallon is full and at the same time it detects another gallon waiting, then the solenoid valve is closed. After that, the conveyor belt starts (E07), and after 1.8 seconds, it lowers the barrier so that the gallon that was on hold is positioned and then returns to state 3.

After the programming state definition, the TIA Porta V.13 program compatible with the PLC is developed. The software is included in the product and uses Ladder language widely used in PLC's programming (UNED, 2019).

3.3 Variable Speed Drive Configuration

There are several options to configure the drive. One of them is to access it from a PC through the serial port with a connection kit and configure it using the Drive Monitor software or Starter. Another way of configuration is by using panels that are connected to the variator. Table-2 shows the corresponding configurations for the mentioned drive.

Table-2. Micromaster 420 Drive Configurations.

INPUTS	TERMINALS	FUNCTION
Digital input 1	5	ON right
Digital input 2	6	Invert
Digital input 3	7	Accusing Faults
Analog input	3 /4	Frequency Setpoint

3.4 Automated System Operation

The automated system is shown in Figure-12, and the operation is performed as follows:

The operation panel is connected to a 220v AC outlet. Its initial configuration must have the breakers in the OFF state. The breakers must be activated manually to the ON state to turn on the system elements that must be activated simultaneously.

Figure-12. Automated system.

Pressing the RUN button (green color) sends a signal to the PLC to activate the drive. This drive activates the motor, and the conveyor belt starts working; the operator deposits the empty gallons at the beginning of the belt. As the detection sensor identifies the gallon, it sends a voltage to its coupling circuit, which sends the respective signal to the PLC through a relay. Consequently, the drive stops the motor speed, and the servo motor is activated to lower the barrier by 90° and position the gallon in the desired location. After 3 seconds, the solenoid valve is activated, the gallon filling begins, and the barrier returns to its place. When the gallon is detected by the level sensor, which sends a voltage to the coupling circuit, this transforms it into a PLC signal.

The PLC is programmed to perform two functions; the first is that if there is a gallon waiting, the belt is turned on for 2 seconds to pass the full gallon and locate the empty gallon with the barrier in the position. The second function is that the detection sensor is disabled. It returns to the initial state so that the conveyor belt allows passage to the full gallon and continues its regular operation, repeating the process repeatedly.

Pressing the STOP button (red color) sends a signal to the PLC to stop the process. Suppose the detection sensor is in deactivated mode within 20 seconds. In that case, the process automatically stops for safety and lights a buzzer (alarm) to warn that the process has ended and no gallons are waiting.

The gallon has been filled and is at the belt end, the operator must remove it, and if the process has been completed, it is necessary to lower the breakers to the OFF state to de-energize the system

4. CONCLUSIONS

An automatic control system was designed and implemented for the liquid soap gallon filling process. The developed system was made from a conveyor belt, and the necessary sensors and actuators were implemented. After the system implementation, it was possible to increase productivity, reduce operating costs, improve process safety, and optimize human resources.

Electronic devices such as the level sensor and the presence detection sensor were incorporated into a conveyor belt, to which a coupling circuit was designed for its correct operation. A system was also implemented to adapt the solenoid valve that allows the viscous soap liquid that contains the gallons to pass through. This action prevented the operator from making direct contact with the chemicals and ensured that overflow would not occur outside the gallon.

The system was built with the desired filling characteristics. The operation panel was designed to put the system into operation by activating the start and stop buttons and containing all the circuits, relays, breakers, PLC, and variator.

The software used to program the Siemens S7-1200 PLC is TIA Porta V.13. Since it is from the same manufacturer and therefore comes with its respective license, it is also easy to use. Its configuration has different programming languages, in our case, Ladder. The communication was carried out through an Ethernet cable between the computer and the PLC.

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