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Automatic Adjustable Filling and Capping Machine Using Programmable Logic Controller and Human Interface

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Abstract - *In today's fast-automated production, low cost automation (LCA) using programmable logic controller plays a very important role by its repeatability, tighter quality control, low power consumption, low operational cost, less maintenance, waste reduction or filling accuracy, increase in productivity and reduction of labor in the small scale sector. The application of low cost industrial automation (LCA), particularly in small scale industries with simple usage of devices like pneumatic, hydraulic actuators with electrical control to the existing conventional methods will yield higher productivity [Denish Kumar N. automatic bottle filling, capping and embossing using PLC]. The Automation plays an important role in today's world economy. One of the most important applications of automation process is in beverages and soft drinks industries, where continuous filling and capping process is carried out [Arun Kumar.M, H. Prasanna Kumar, Automatic bottle Filling System using PLC]. Automation is also the use of control systems and information technologies to reduce the need for human work in the production of goods and services. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provides human operators with machinery to assist them with the muscular requirements of work, automation greatly decreases the need for human sensory and mental requirements as well [Mallaradhya H. M., K. R. Prakash Automatic Liquid Filling to Bottles of Different Height using Programmable Logic Controller.*
]. To improve the traditional bottle filling operation, the adjustable filling and capping machine is designed to reduce the human efforts and labor requirement. Basic stages of a bottling plant operation are presented, i.e. the filling and capping process. At first a set of empty bottle is run by using a conveyor towards the filling section; the filled bottles are sent to the capping section. After successful capping operation, the sealed bottles move towards the exit and a new set of empty bottle arrive, and the process is repeated. PLC usage can be encountered in almost all fields of industry, not only in the manufacturing world but also with many other applications such as: elevators in office buildings, hotels, hospitals, and others. PLC's are user-efficient, cost-effective and easy to control. HMI (Human interface) is used to monitor the process by means of a System display.

Key Words: *Diffuse sensor, Sensors, Solenoid valves, Variable Frequency Drive, Servo motor.*

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I. Introduction

In recent years, automation techniques have become one of the effective strategies in the modern manufacturing process. Most of the manual operations involved in the production are being automated to get multifarious benefits. It has therefore become imperative for the firms to get themselves equipped with automation system to meet the growing demand of goods. With the advent of globalization and liberalization, it is necessary that industries explore methods of enhancing automation and thereby increase the productivity to acquire greater competitiveness in the market [John W Webb, Ronald A Reis, 2002, PLC Principles and Application; Prentice Hall's; "chap 5, 9 & 28"]. The main idea behind "automation" implies the control of industrial processes and machines with very little intervention of human operators. Companies in the industrial sector are therefore required to adopt flexible, cost effective and efficient processes to be competitive. Innovative industrial control and automation systems are more than ever needed within the process and manufacturing industries to boost their operations in terms of speed, reliability and product output [J. Dhiman and E.R. Dileep Kumar, Hybrid method for automatically filling of the chemical liquid into bottles using PLC & SCADA, International Journal of Engineering Research and General Science, Volume 2, Issue 6, ISSN 2091-2730, 2014, PP.1000 – 1007].

The machine is used for the quantitative filling of various gas-free liquids and semi-fluids. The machine automatically performs a series of operations such as counting, quantitative filling, capping, and bottle delivery [Jiangsu TOM Packaging machinery Co.Ltd instruction manual, DPG serial filling machine]. It can be used to satisfy the filling of materials with different characteristics. The machine is controlled by a Programmable Logic

Controller (PLC), a touch screen operation with stable and reliable work, easy operation, high production efficiency, high filling measurement accuracy, and wide application range.

This serial filling and capping machine is suitable for filling round and square bottles of various glass and plastic materials. It is ideal packaging machinery for food, medicine, cosmetic products, and fine chemical industry.

The existing manual systems are to be automated to get preciseness and accuracy in their operations. The preciseness and accuracy of the automation are achieved through its controller. A better controller always enhances the quality in its operations. Thus there is an everlasting demand to have better controller in the existing automation systems [Denish Kumar N. automatic bottle filling, capping and embossing using PLC].

This automatic adjustable bottle filling plant consists of two major sections: filling, capping and embossing. Each of them deals with one of the two aspects of the overall project.

The filling section mainly deals with the total filling process. The bottle comes from the conveyor to where it is going to be filled. The second section consists of the capping process, where a mechanical hand completes the capping by lowering down to the bottleneck and screwing the cap to the neck.

II. Design Objective

In order to design a solution for a problem related to automation, it is imperative for an Engineer to begin by defining the control task, that is, what needs to be done. This information will then provide the foundation for the control program. The main purpose is to reduce the man power and increase the throughput; in other word the productivity. To minimize errors, the control task should be defined by those who are familiar with the operation of the machine or its process. Proper definition of the control task is related to the success of the control program. The process has been adopted using PLC (Programmable Logic Controller), which can be altered according to the requirement at any time [John W Webb, Ronald A Reis, 2002, PLC Principles and Application; Prentice Hall's; "chap 5, 9 & 28"].

After going through previous research papers a tentative design is prepared. The basic block diagram and working of the entire setup are both explained in the subsequent sections. SOLIDWORKS 2016 was used to carry out the design of the entire machine.

III. Methods

3.1 MECHANICAL DESIGN AND STRUCTURE

3.1.1 Main machine structural design

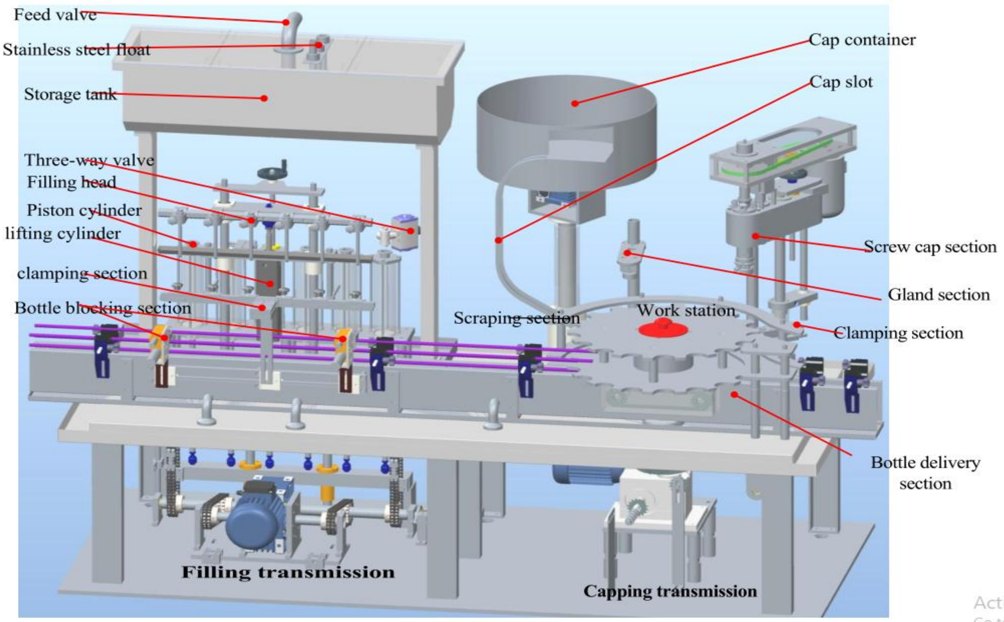


Fig -1: Main engine

3.1.1.1 Introduction to the main engine

a) Filling section

The filling section is composed of motors, three-way valves, injection cylinders, piston cylinders, filling heads and a transmission motor. To pump the liquid, the transmission motor drives the piston downwards, and the liquid is sucked into the cylinder; when pushing the liquid upwards, the three-way valves are converted into piston cylinders that communicate with the filling heads, the plugin valves are opened, and the transmission motor pushes the piston upwards to inject the liquid into the bottles.

b) Leakage groove

The leakage groove is used to stop drops of liquid from falling onto the conveyor at the end of each filling operation.

c) Bottle clamp

The bottle clamp is used for clamping and positioning of the bottles.

d) Bottle stoppers

Bottle stoppers are used to block the bottle when the incoming bottle count is complete.

e) Lifting cylinder

The lifting cylinder controls the filling section, by raising and/or lowering the filling head.

f) Conveyor belt

The conveyor belt is used to transport the bottles.

g) Storage tank

The storage tank is used to store materials (liquids). It is equipped with a liquid level switch, a feed valve and a discharge valve. When the liquid level is low, the feed valve opens up and the automatic feeding is turned on; when the liquid level becomes normal, the automatic feeding stops.

h) Gland section

The gland plays the role of capping and correcting the position of the cap.

i) Screw-cap section

The screw-cap is driven by a servo motor and has an adjustable head.

j) Cap container

The cap container adopts the principle of centrifugal motion to make the caps enter the track and undergo the positive and negative (reverse) cap detection.

The photoelectric detection of negative caps leads to a blow of compressed air to push them back into the container, and the positive caps are admitted to the cap slot. The cap container speed is adjusted by frequency conversion.

k) Cap slot

The cap slot transports well-arranged caps to the scraping head. The upper end is connected to the gateway of the container (cap sorter). The positive caps from the container are smoothly admitted cap receiving slot, and there should be no snoozing or jamming.

3.1.2 Cap elevator

Fig -2: Cap elevator

3.1.2.1 Cap elevator working principle

The proximity sensor in the cap container detects the low amount of caps, and transmits the signal to the PLC. The PLC output makes the KA coil energized, the inverter is energized and the cap elevator motor run, therefore the conveyor starts running and transports the caps to the cap container.

When assembling, according to the position of the cap container, the support rod screws are loosened to adjust the inclination of the cap elevator so that the caps smoothly fall into the container (cap container).

Before production, the cap elevator is run with an empty bucket to make sure the caps are transported in the correct direction (from bottom to top).

3.1.2.2 Advantages of the cap elevator

- Simple structure
- Convenient adjustment
- Easy disassembly and cleaning
- Low noise

3.2 MACHINE RUNNING METHODS

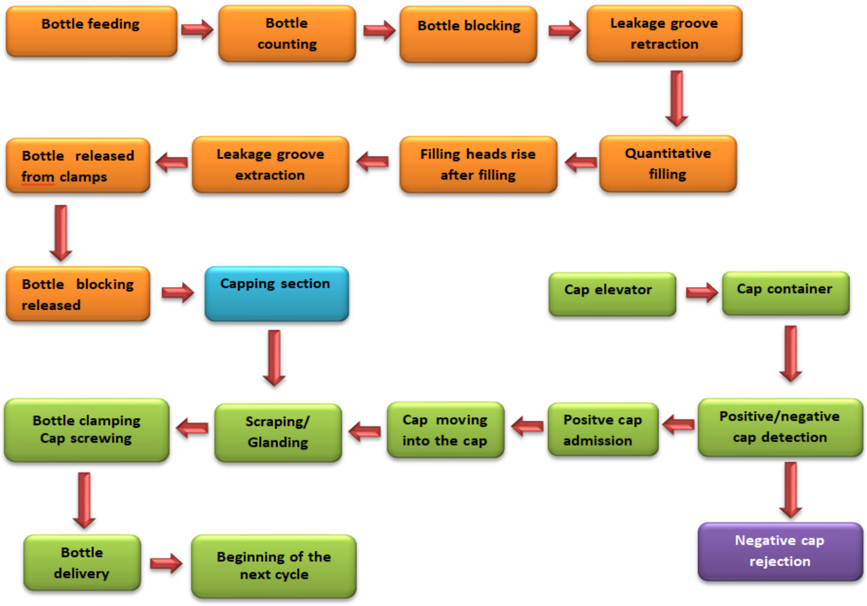


Chart -1: Machine working flow chart

3.2.1 Working principle

When the machine starts running, the bottles are fed into the filling section at the conveyor inlet. As they move onto the conveyor, the preset number of bottles is counted by the diffuse sensor which is positioned according to the bottle height. The blocking cylinders extend and/or retract as the bottles get under the filling head. The leakage groove cylinder retracts and the filling nozzles dive into the corresponding bottle mouth. The bottles are therefore quantitatively filled with the material (liquid).

The filling head rises up after the filling operation and the leakage groove extends to stop the drops of liquid from falling onto the conveyor. The filled bottles are released as the clamp and the blocking cylinders retract. The bottles are then sent to the capping section; at the same time, the cap elevator transports the caps into the cap container (cap sorter. In the cap container, positive and negative caps detection is performed by the helped of a photoelectric sensor; which makes way for positive caps down to the cap slot and sends a signal to the PLC input to blow off any negative cap upon detection. As the caps move down to the gland through the cap slot, the bottles also move toward the same location to allow the first cap to be scrapped to the first bottleneck.

The scrapped bottle moves toward the screw cap head where it is clamped and capped as the screw cap driven by a servo motor lowers down for that matter. The filled and capped bottle is sent out of the chain for further process and the process is repeated.

3.2.2 Material (liquid) feeding process

When the float (liquid level switch) in the storage tank detects the material (liquid) low level, the feed valve automatically opens to feed the tank with the material;

When the material (liquid) reaches its normal level, the float detects the corresponding level and sends the signal to the PLC which de-energizes the valve and therefore closes it. When the float detects an overflow, the alarm for liquid overflow is triggered and the machine stops running.

3.2.3 Quantitative filling process

The filling section **transmission system** drives the piston (metering cylinders) downward, and draws the material (liquid) from the storage tank into the metering cylinders. At this stage, the three-way control valves rotate, closing the feeding valve and opening discharge valve, and at the same time, the plugin control valves are opened. Then, the transmission system reversely drives the piston upward, and injects the material from the metering cylinder into the discharge pipes, and fills the bottles through the discharge nozzles.

3.2.4 Capping process

The bottles are transported to the filling station of the machine through the conveying rack, and at the same time, the cap container (cap sorter) aligns the caps through the cap slot and sends them to the scraper.

The work station turntable brings the bottle to the scraping section, and the cap is scrapped.

The work station turntable sends the bottle to the gland head which presses the cap against the bottleneck, the table forwards the bottle to the capping head, at that position, the bottle is clamped, the screw cap head lowers down and screws the cap to the bottle, the capping process is complete.

After capping the bottle, the capping head rises, the bottle clamping cylinder retracts to release the bottle, the table sends the bottle out of the station, and the conveyor belt transports the bottle out of the chain for further processes (labeling).

IV. Control System

4.1 PLC cylinder control system

All the cylinders are automatically controlled by the PLC relay output. When the photo-electric detects the presence or absence of a bottle, a signal is sent to the PLC X-input point which is processed by its processor; and the corresponding directional control valve relay output is energized (for extension), or de-energized (for retraction) through the PLC Y-output point.

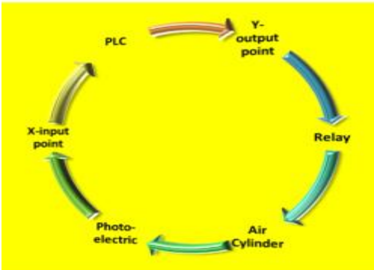


Chart -2: Cylinder control system

4.2 PLC motor control process

All the motors are automatically controlled by the PLC relay output (Contactor and/or Invertor). A photo-electric sensor is connected at the PLC X-input point to detect a signal (presence or absence of a bottle). The contactor and/or invertor is connected to the AC voltage for power supply, and also connected to the PLC Y-output point through the relay KA. When the photo-electric detects a signal and sends it to the PLC processor, an output signal is sent to the corresponding relay output which is then energized (motor runs), or de-energized (motor stops).

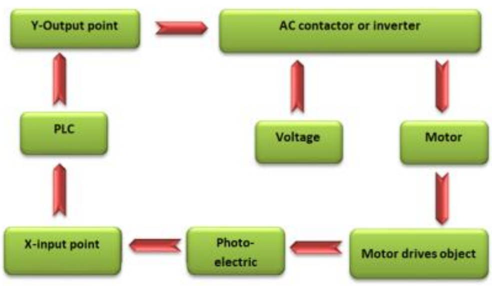


Chart -3: motor control system

V. Function Description Of The Touch Screen And Human Interface (Hmi)

5.1 Control panel

The machine is entirely controlled and monitored by the use an HMI touch screen function.
The KINCO MT4414TE Software is used to the set up the touch screen interface on the control panel.

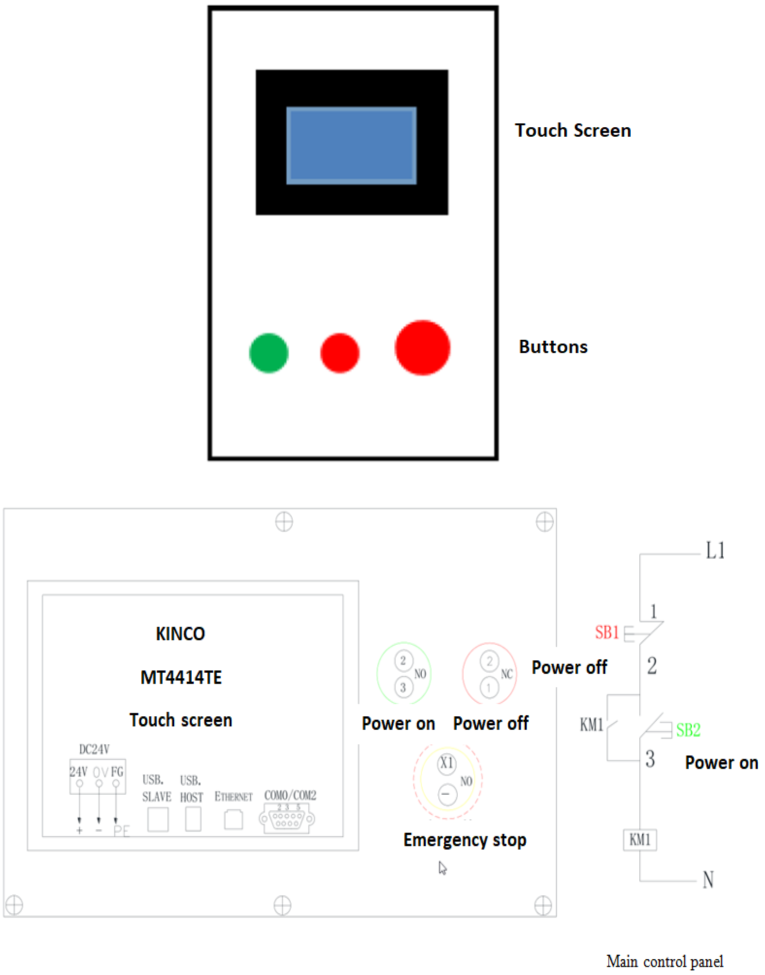


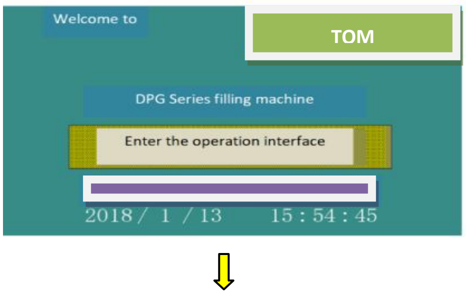
Fig -3: control panel

a) Power on
The machine is powered on; the touch screen displays, and the machine enters the working stating;

b) Power off
The whole machine is powered off and exits the working state;

c) Emergency stop
The machine stops running immediately after pressing the emergency stop button. The contacts of the start and jog buttons are therefore both opened. Only after the rotating the switch to the right and setting the reset command, the machine can be started again.

5.2 Touch screen "Welcome page"



The page below is accessed by pressing anywhere on the "**Welcome**" page. The six buttons on the screen are used to both manually and/or automatically control the machine best working state.

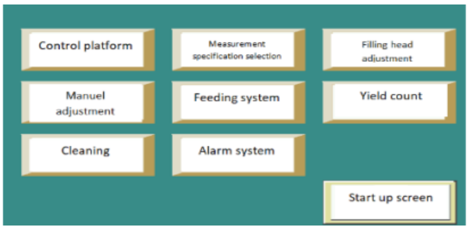


Fig -4: HMI screen catalog page

VI. PLC/HMI Simulation Results

A PLC (using the FPWin GR Panasonic software) program was set up for various instructions and commands on the touch screen to be executed.

6.1 Simulation

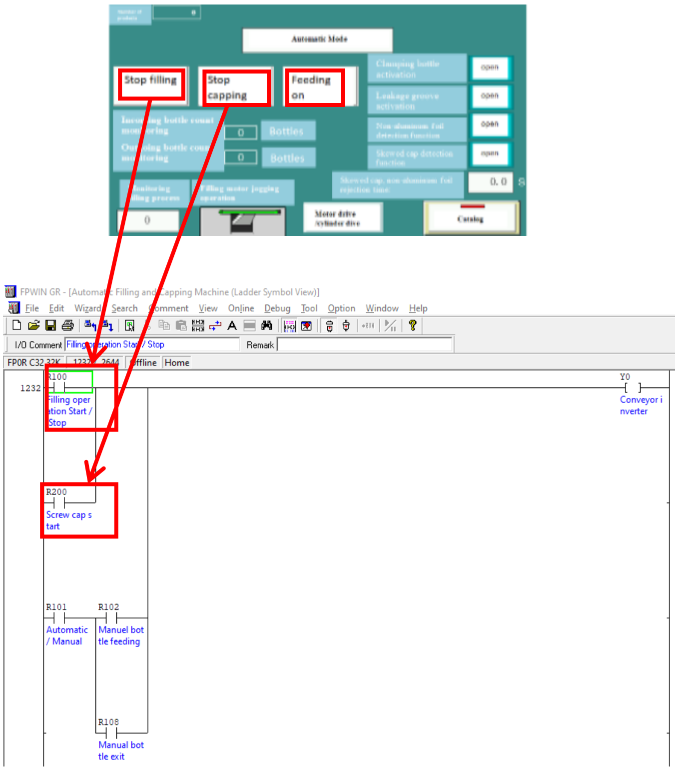
6.1.1 Control platform

The "control platform" page is used to run the machine in the automatic mode. Various operations have been simulated such as:

a. Start/Stop filling and capping operations

The touch screen below is the "Automatic mode". The machine starts running (Conveyor 1 inverter is energized) automatically under the following execution conditions:

- Filling operation start/stop internal relay input **[R100]** is on;
- Screw cap start/stop internal relay **[R200]** is on;



However, the machine is powered off when both instructions are reset.

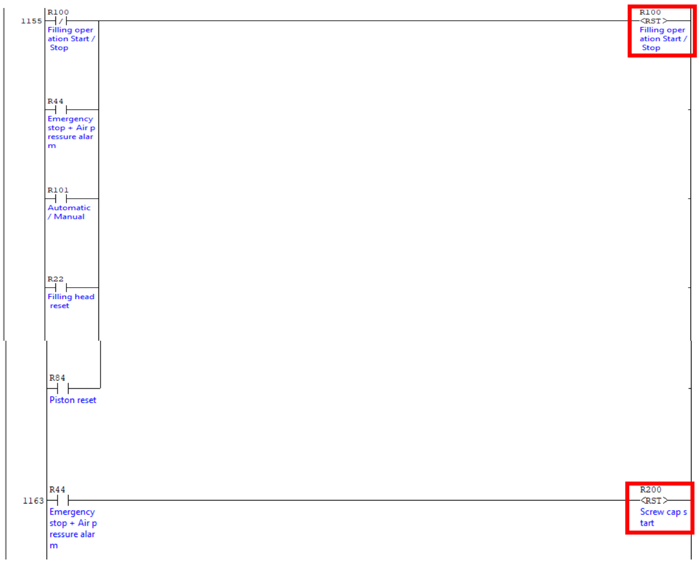


Fig -6: conveyor inverter start/stop program

b. Feed operation On/Off

The feed valve opens when the liquid level lower limit switch X4 (float), the middle limit switch X3 (float) in the storage detect the corresponding liquid level, after an on-delay time specified by the set value [SV 10] of the timer [TMX 10].

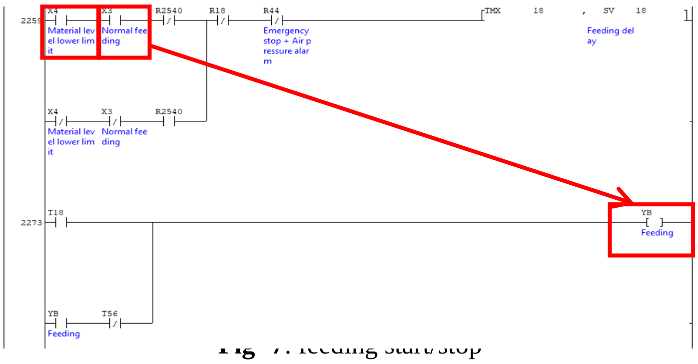


Fig -7: feeding start/stop

6.1.2 Measurement specifications selection

The page below displays five filling volume specifications, any of which can be selected as the current filling parameter.

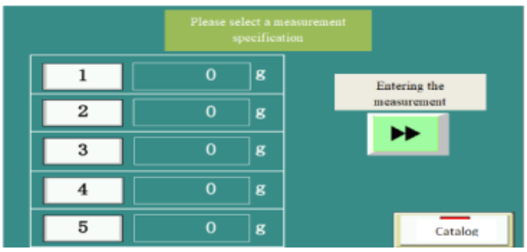
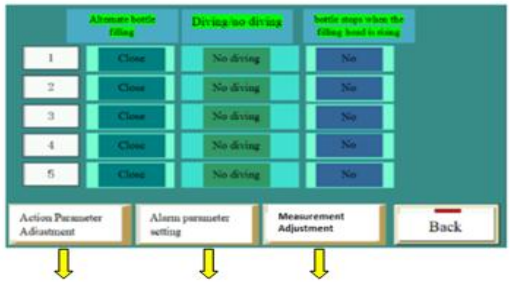


Fig -8: measurement specifications selection page

The page below displays the characteristics of the filling nozzles. When using three blocking knives at the filling section, the **"alternate bottle filling"** function is activated in the PLC program.



The page below is used to set the delay time of the machine alarm programs.

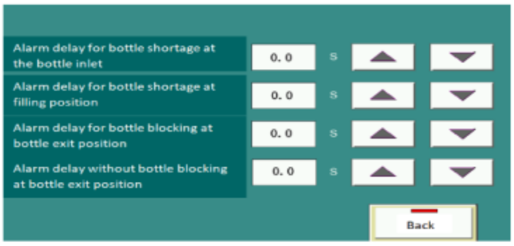
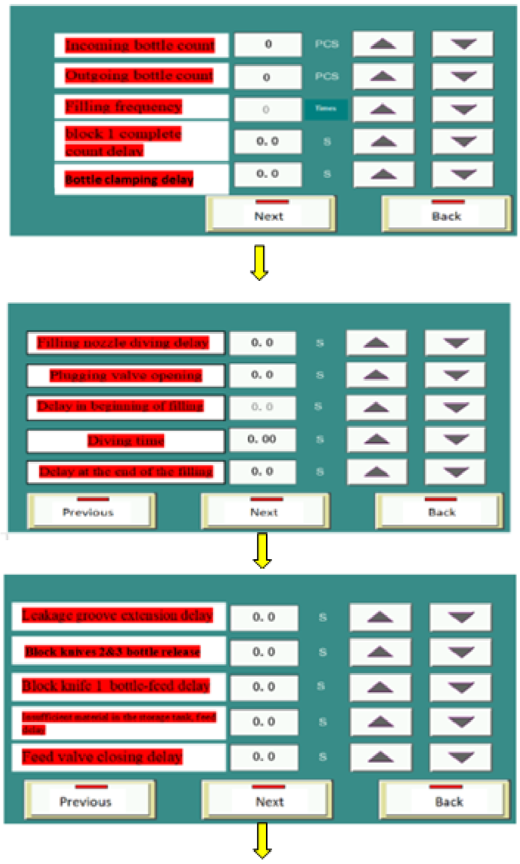


Fig -9: alarm parameter setting

These pages below are used to adjust the correlation time between various actions of the machine to obtain the best working state.



The page below sets the speed of the mechanical transmission system.

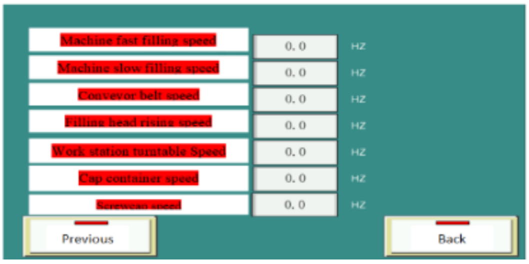


Fig -10: action parameter adjustment pages

Each filling head volume is adjusted by inputting the corresponding bottle volume into the **"measurement adjustment"** page below. The **"overall filling volume"** data value is added to the **"fine adjustment"** data value and stored into the **"head calculation result"** data register.

The page below displays the **"Measurement Adjustment"**. The "Overall filling volume" box is used to set the overall filling volume of all the bottles. (**Fast filling volume = overall filling volume – slow filling volume; slow filling volume ≦ fast filling volume**).

Fig -11: measurement adjustment page

The program below is used to automatically adjust the volume of each filling nozzle after the overall filling volume of the set of bottles had been previously determined.

Fig -12: measurement adjustment program

6.1.3 Manual Adjustment

The manual adjustment page is used to adjust each part of the machine when changing its **"adjustment specifications"** (when the bottle specifications change). The page below is the "Manual Adjustment" page on the touch screen.

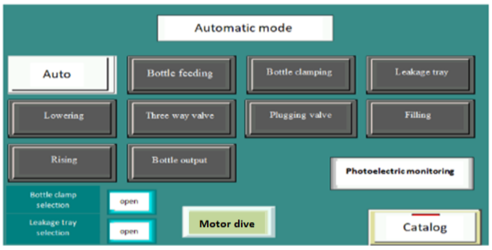


Fig -13: manual adjustment page

6.1.4 Filling head adjustment

The page below is used as emergency to close any faulty filling head during the machine running state. The filing heads 1-4 are in the "opened" state during normal operation, and the rest are in the "closed" state when four bottles are placed between blocking knife 1 and 2. Each number from 1 to 6 corresponds to a filling nozzle.

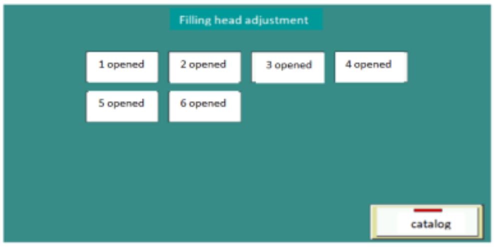


Fig -14: filling head adjustment

6.1.5 Cleaning

The cleaning page is used to clean the piston cylinders after the machine has been used for a certain period of time. The pistons have to be detached from their respective cylinders in order for the cleaning operation to take place. The **"Cleaning"** operation is performed under the **"Manual"** mode.

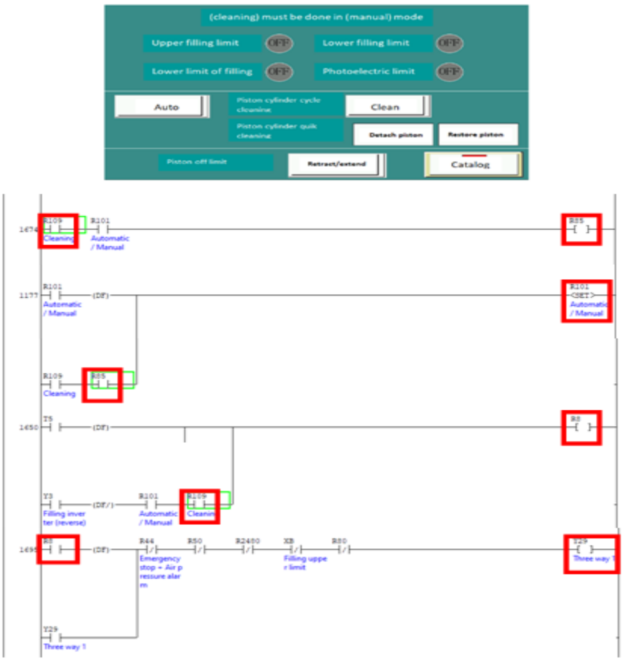


Fig -15: cleaning operation control program

6.1.6 Product Count

The current production quantity is displayed here.

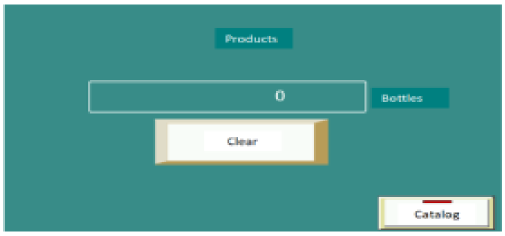
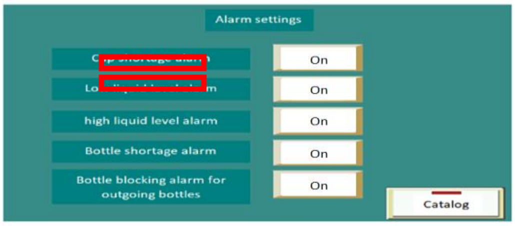


Fig -16: product count page

6.1.7 Alarm system

The alarm system page is used to turn on or off the machine alarm programs. Various alarm instructions among others have been simulated in the below PLC program.



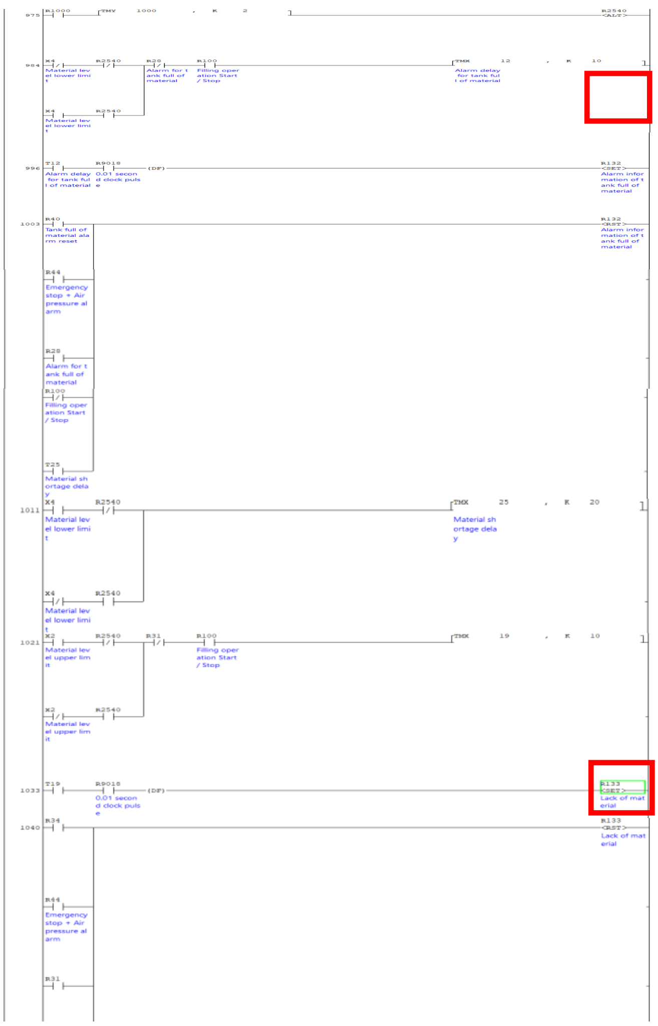


Fig -17: alarm system control program

6.1.8 Feeding system

When the material in the storage tank gets to the lower limit, the lower limit float detects the liquid level at that position and sends a signal to the PLC input. The feed valve opens after a certain delay (specified by [SV18]). The contact of the external relay output **YB** turns on and the external relay output **Y25** (feeding pump) is energized. The pump motor starts running and drives the liquid into the storage tank through the feed valve. The feeding operation automatically stops when the liquid reaches its normal level in the tank.

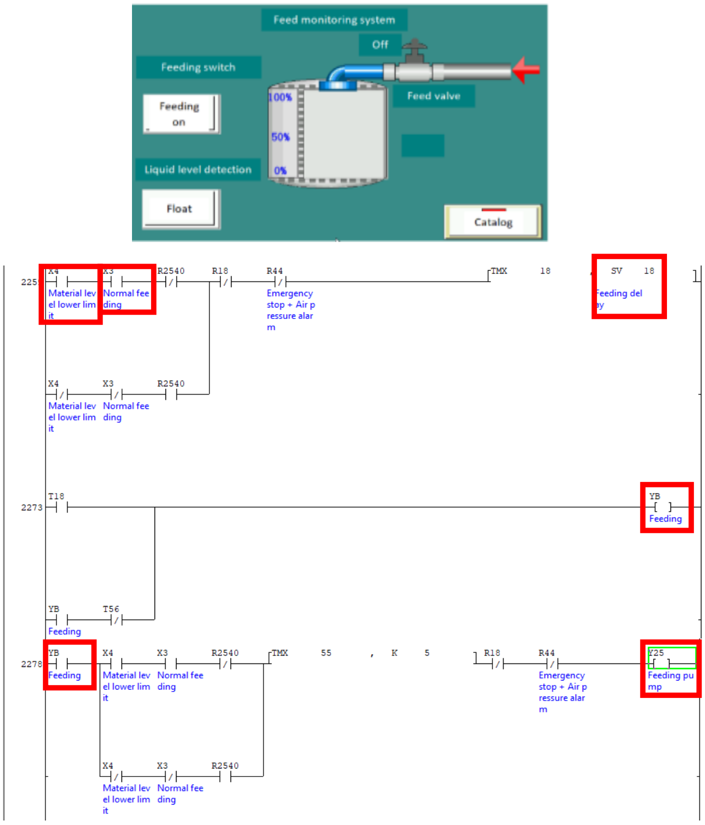


Fig -18: feeding system

6.1.9 Alarm display

To ensure a stable working performance of the machine, some optional alarm protection functions are set in the entire work process. When a malfunction is detected, the corresponding alarm is triggered and displayed on the HMI touch screen.

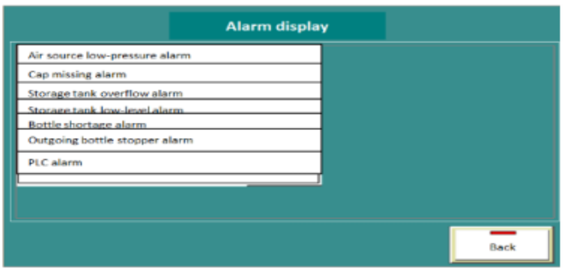


Fig -19: alarm display

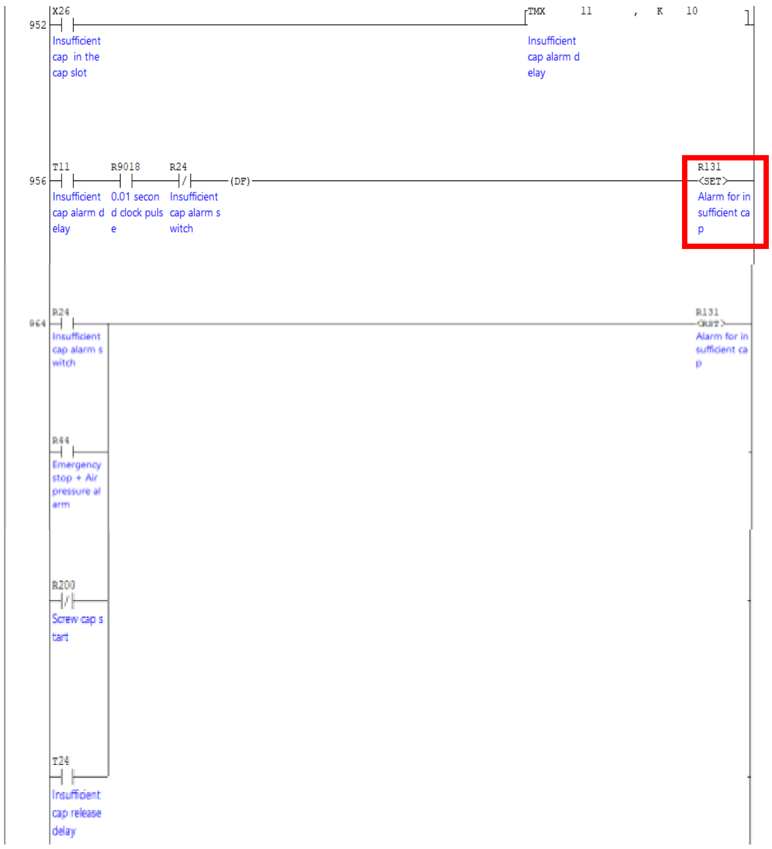


Fig -20: alarm info for insufficient cap

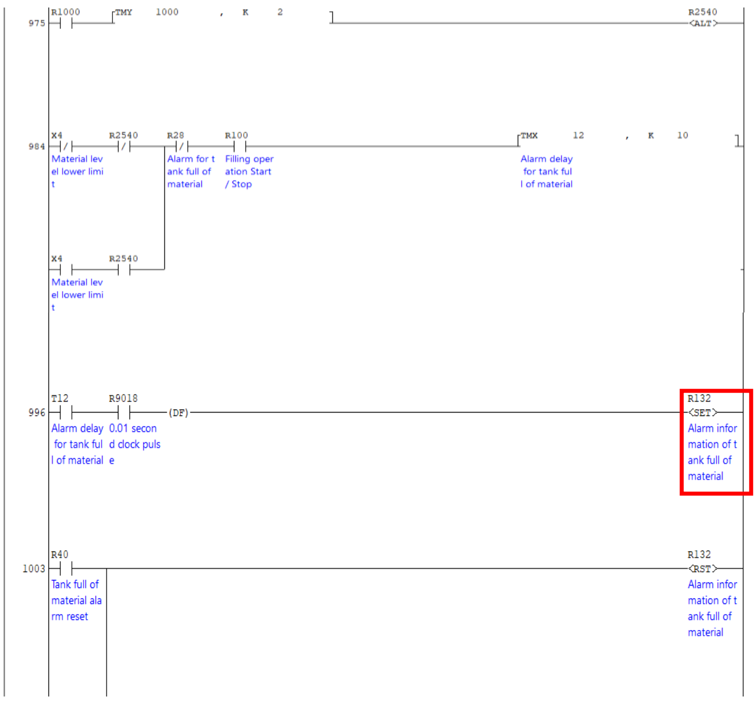


Fig -21: alarm info for tank full of material

The message below is displayed when the air pressure is less than the required pressure (0.6MPa) to start the machine.

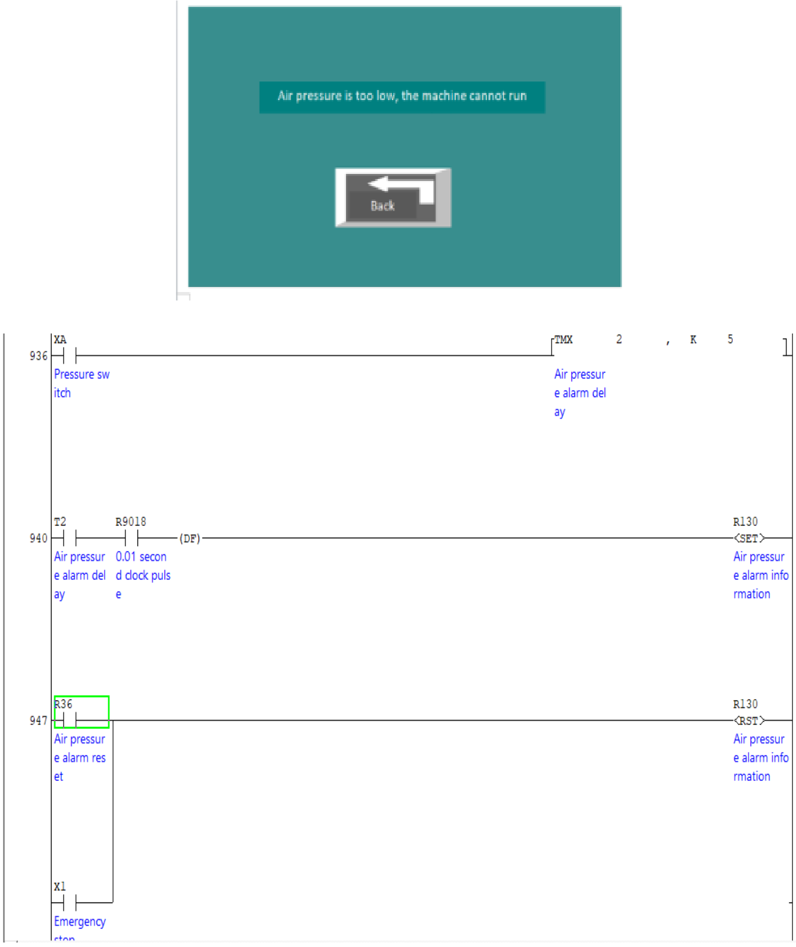


Fig -22: air pressure alarm information

VII. Mechanical Adjustment Steps

The machine is designed to allow a flexible filling and capping operations for different bottle sizes. It can be adjusted to mainly fill and cap three different bottle sizes as shown below.
These bottles have different dimensions (1000ml, 500ml, and 250ml); therefore different adjustment specifications are required to achieve a successful filling and capping operations.

Fig -23: different size bottles

The flow chart below describes various adjustment operations depending on the bottle specifications.

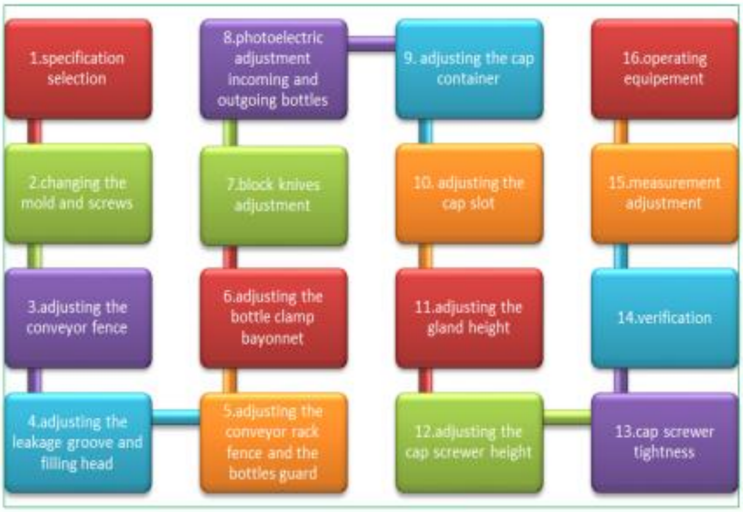


Chart -4: adjustment specifications

VIII. Plc Input/output Points Used In The Program

The input/ output point of the FPOR type Panasonic PLC is shown in the figure below. All the outputs are relay type

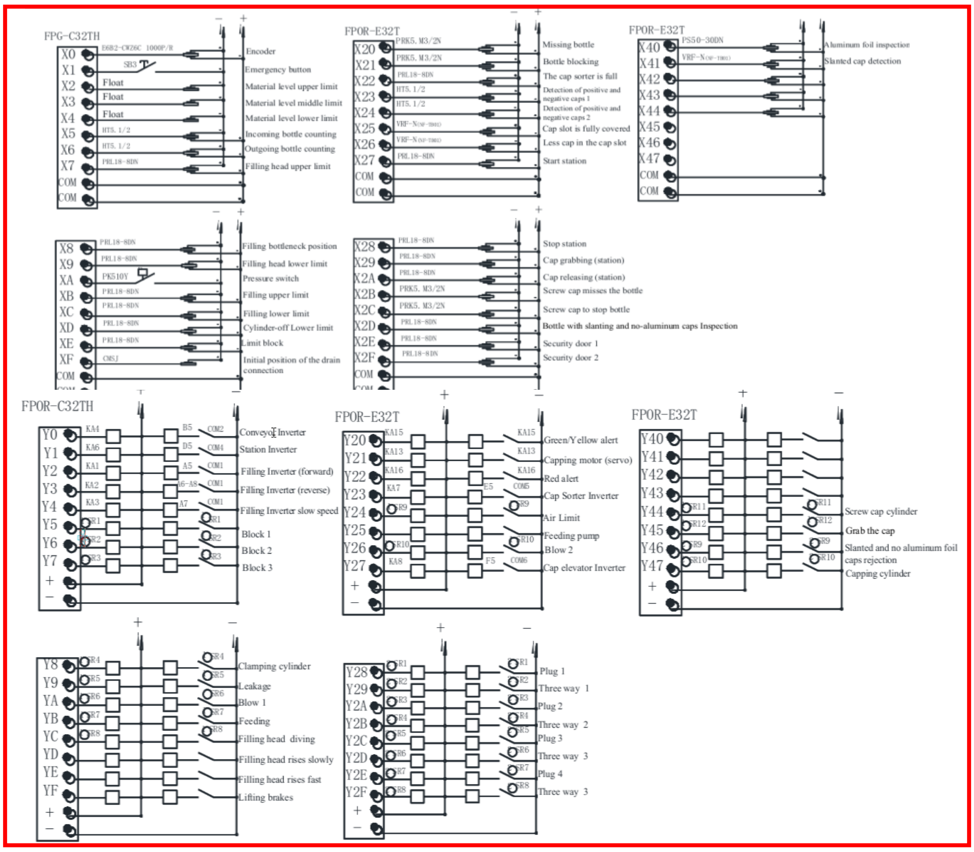


Fig -24: Inputs/Outputs wiring

IX. Materials And Descriptions

The following input/output devices were proposed and used in the PLC electrical wiring.

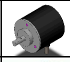
N°	DEVICE NAME	QUANTITY	DESCRIPTIONS
		INPUTS	
1	E6B2-CWZ6C 1000P/R incremental rotary encoder	1	 used at the conveyor to control its speed
2	SB3 Emergency push button	1	 used for emergency stop
3	Float (Liquid level switch)	3	 used for liquid level detection
4	HT5.1/2 diffuse sensor	4	 used for bottle count
5	PRL18-8DN inductive proximity sensor	14	 used for proximity detection
6	PRK5.M3/2N polarized retro-reflective photoelectric sensor	4	  used for missing bottles and caps detection
7	VRF-N (NF-TB01) fiber optic sensor	3	 used for slanted cap detection, missing cap along the cap slot
8	PK510Y pressure switch	1	 used to detect the machine normal working air pressure
9	CMSJ reed sensor	1	 used to detect the leakage groove initial position
10	PS50-30DN inductive proximity sensor	1	 used for aluminum foil inspection
		OUTPUTS	
11	4V230C-08 AIRTAC solenoid valves	22	 used to control various cylinders
12	MK300 inverter	6	 used to control 3-phase motor
13	3-phase WORM reducer	6	 used to drive mechanical output such as conveyors
14	Relays	11	 controls the inverters and their corresponding outputs
15	Capping servo drive Schneider	1	 controls the servo motor for the screw cap arm

Table 1: I/O devices

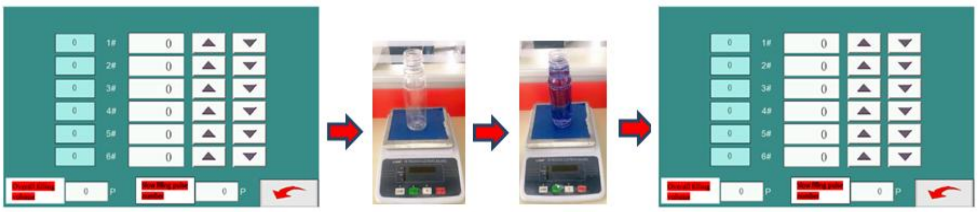
X. Experimental Results And Discussions

10.1 Measurement verification

To adjust the filling measurement according to the production specifications (of any container), an empty container is placed on the weighing machine to determine its tare weight. After manually filling the container to a desired volume (with water as medium), its gross weight is weighted. This helps determine the net weight with the following equation:

$$NET\ WEIGHT = GROSS\ WEIGHT - TARE\ WEIGHT \quad (1)$$

The result is entered in the corresponding filling nozzle measurement adjustment box.



In the table below, the tare weights and gross weights of four 500ml previously empty bottles were recorded (in the case of two blocking knives). After automatically filling the bottles, their respective net weights were computed.

N°	Tare weight (gram)	Gross weight (gram)	net weight (gram)
1	12.00	500.00	488.00
2	11.50	496.00	484.50
3	11.86	501.00	489.14
4	11.90	499.00	487.10

Table 2: measurement accuracy verification

10.2 Filling error calculation

The total error is used to find the measurement of error between a set of estimates (ER) and the actual results (AR).

a) Percentage error (PE)

$$PE = \left|\frac{ER - AR}{AR}\right| * 100 \ (2)$$

0 %, 0.8%, 0.2% and 0.2% are the percentage error of bottle 1, 2, 3 and 4 respectively. The average of these percentages is the total error TE:

$$TE = \frac{PE1 + PE2 + PE3 + PE4}{4} (3)$$

TE = 0.3 % is the total error of the 500ml estimated filling volume. The result shows that 0.3 %< 0.5% which is the machine allowable filling error.

10.3 Main technical parameters

- Filling specifications 100-1000ml
- Filling error ≤±0.5% (with water as the medium)
- Filling head number 4
- Number of gland head 1
- Number of capping head 1
- Production capacity ≤1200 bottles/hour
- Total power 3.5 KW

10.4 Equipment work requirement

- Temperature * 5～35℃
- Relative humidity ≤85%
- Power supply AC380V 50/60Hz; DC24V
- Air source pressure 0.6MPa clean and stable gas source

10.5 Working environment

- The machine is isolated from all sources of strong electromagnetic fields. (It is strictly forbidden to use the machine in a potentially explosive environment).
- The actual working environment is determined according to the characteristics of the packaging materials.

10.6 Blocking knives

The positions of the block knives are adjusted according to the bottle specifications (size and shape). When using two blocking knives, only 4 bottles are needed between block knife 1 and block knife 2, and then their position is adjusted accordingly so that the knives intercept and release the bottles.

The result shows that when adjusting the blocking knife to the bottle height, it is best to adjust it in such a way that it blocks the middle position of the bottle. The knife at a low or a high position will cause the bottle to fall.

For round bottles, the blocking knife 1 only blocks the bottle body at extension; therefore the rear bottle is not squeezed onto the front bottle. This also prevents the bottles from falling.

Fig -25: blocking knives adjustment

10.7 Negative cap blower

The function is to detect a cap lying on its front and let the air blow through the solenoid valve to push it back into the container. According to the height of the cap, the photoelectric detector is positioned accordingly and the strength of the photoelectric signal is adjusted to achieve an effective detection.
The result of this experimental is shown in the PLC program below.

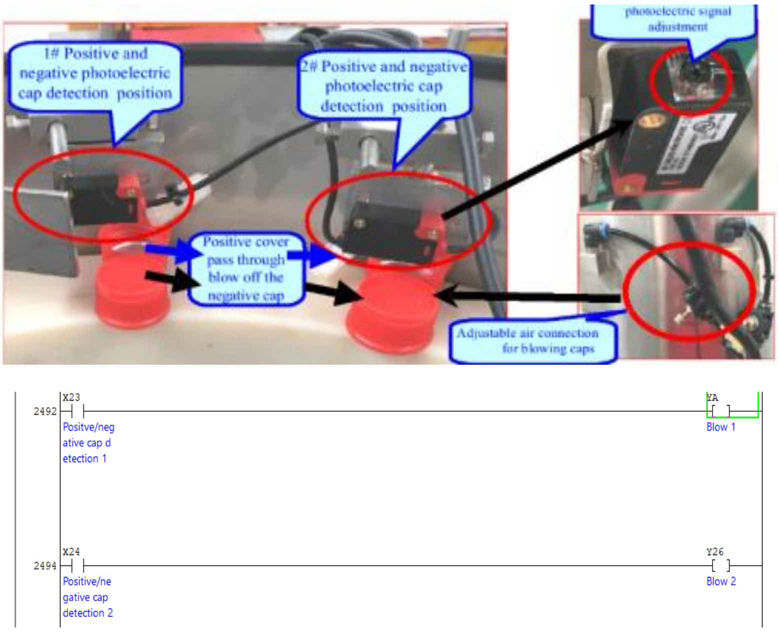


Fig -26: cap blower

XI. Circuit Diagram

The diagram below is the PLC inputs/outputs wiring including the frequency inverters and the relays.

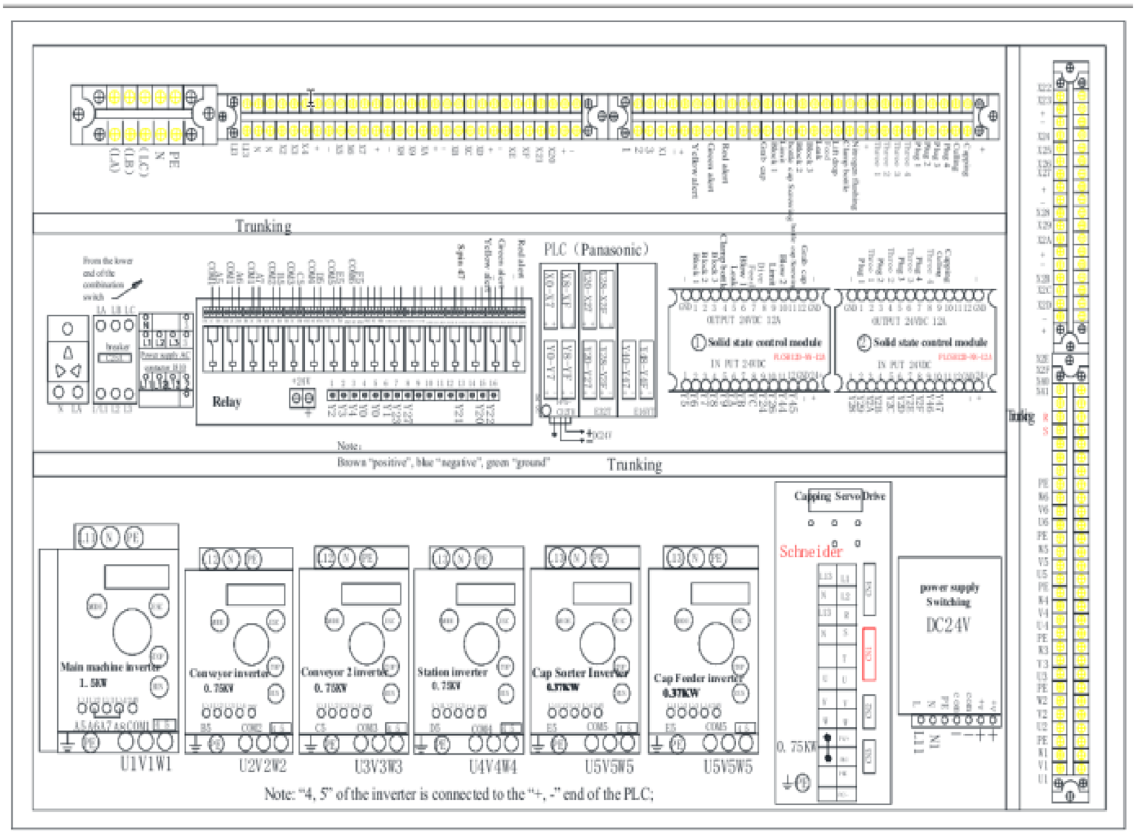


Fig -27: circuit diagram

XII. Motors Electrical Wiring

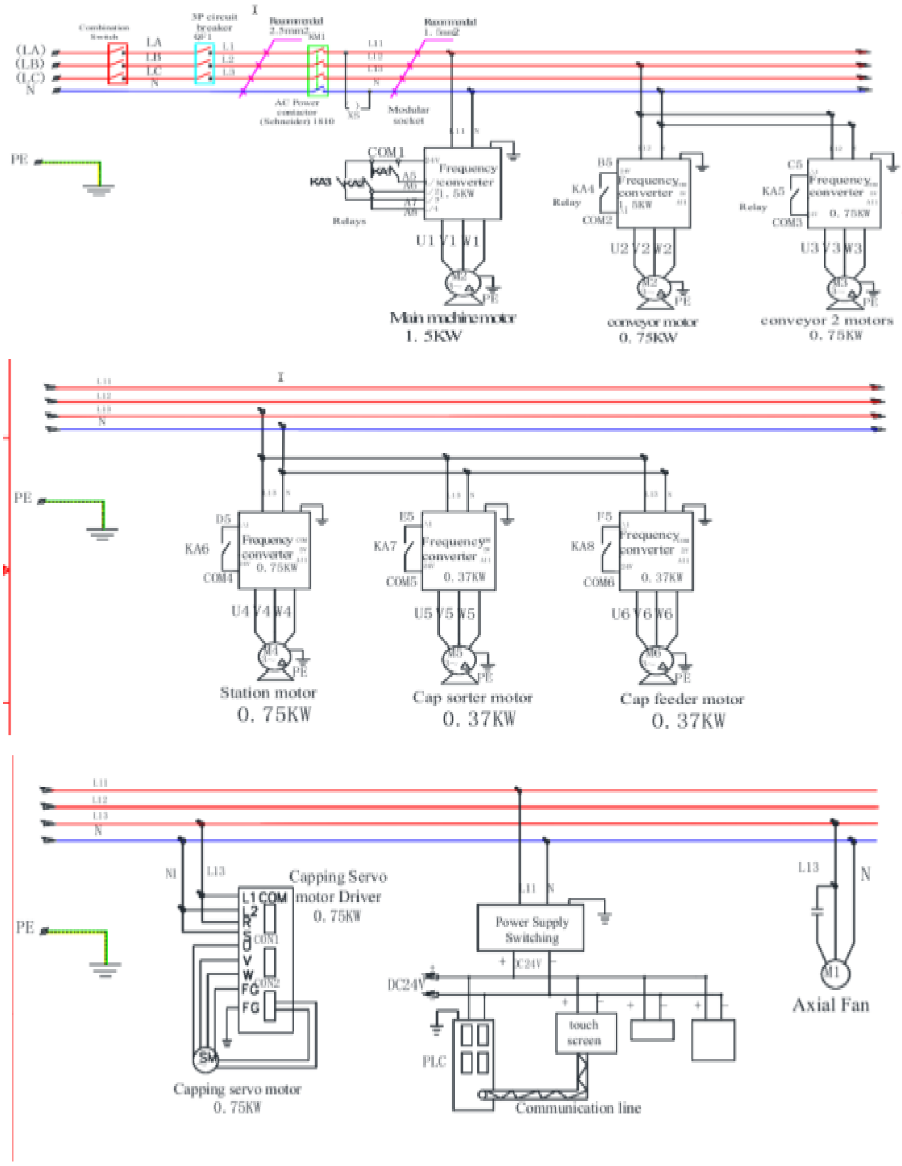


Fig -28: motors electrical and control wiring

XIII. Conclusion

In this study, an automatic adjustable filling and capping machine was designed. The proposed design is suitable for the filling and capping of different size and/or shape bottles based on its mechanical adjustability. To attain the desired filling accuracy and production throughput, a PLC program with high-level instructions including communication protocols was developed using the FPwin GR Panasonic PLC software and hardware. An HMI system was also designed to automatically and/or manually control the machine working and/or jogging states.

After various experiments and simulations, the results show that the allowable filing error cannot exceed 0.5% of the estimated volume, regardless of the bottle size and shape within the range of 100-1000ml. the results also show that the blocking knives adjustment depends on the size and shape of the bottles to be filled; where the use of three blocking knives as opposed to two blocking knives is required to allow an accurate alignment and smooth diving of the filling nozzles into their corresponding bottle mouth. Further experiments were conducted to determine the best position of the blocking knives when they are extended to the body of the bottle.

In the end, reliable performance and an increase in productivity were achieved with a production capacity less than or equal to 1200 bottles per hour depending on the bottle size and shape, a reduction of the need for man power, less energy consumption, and material wastage. Future studies and challenges would be focused on the automatic adjustment instead of manual adjustment using hand wheel and screws which is a drawback to the even bigger production yield since the course of production has to be interrupted for the manual adjustment.

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