CONTROL AND MONITORING OF A TWO-AXIS AC-SERVO POSITIONING SYSTEM FOR DISPENSING APPLICATIONS USING PLC S7-1200

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(Received: 25 May 2024; Accepted: 23 June 2024; Published on-line: 1 July 2024)

ABSTRACT: The high-speed pulse train output (PTO) function is focused on in this paper, aiming to accurately control the speed and position of two-axis AC-Servo motors for precise dispensing applications. Additionally, attention is directed towards the design of the control interface and system monitoring using WinCC software. The control device used in this project is the PLC S7-1200. The main objective of this study is to develop a logic program that allows for the precise control of the position of the Servo motors and provides a control interface and monitoring system for assessing the system's operation and performance. The project encompasses the construction of the practical system, the programming of the PLC control device through TIA Portal software, the implementation of position control algorithms, the design of the control interface, the monitoring of actual positions, and the ensuring of safety measures. From the defined objectives and the completion of the hardware construction, software programming, and SCADA interface design, the following results have been obtained: optimized hardware design and construction, proper electrical panel wiring, accurate control of the position of the two-axis AC Servo, precise dispensing of the liquid solution, and an intuitive control and monitoring interface. Compared to previous studies, the novelty of our research lies in the ability to accurately control multiple axes with high-speed capability, accurately quantify the dispensed liquid through quantitative experimental results, and design a visually appealing and user-friendly control and monitoring interface.

KEY WORDS: Pulse Train Output (PTO), AC-Servo, WinCC, PLC

1. INTRODUCTION

1.1. Practical Requirements

The continuous development of science and technology entails the requirements for accuracy, and the responsiveness of machines must be faster and stronger; to meet that strict requirement, today's automation systems almost all use AC Servo motors in specific automation processes such as robotic arms, CNC machines, cranes and lead screw mechanisms, turntables.

Currently, there are quite a few technologies for filling water into bottles. Depending on the type of liquid, there will be different filling methods, such as concentrated liquid, carbonated water, and non-carbonated water. Therefore, with modern technology, many industrial processes are automated. The filling line is one of the most popular and widely used systems.

The advantage of automatic filling is that it is made according to modern technology and has two functions: filling and dosing. Through the dosing setting operation on the control system, raw materials and fuel are filled into bottles or bags automatically with high accuracy compared to conventional filling equipment.

Liquid product quantification involves extracting a certain volume of liquid product and pouring it into bottles, jars, and jars. A Liquid product dosing machine is widely used in many food production industries. When dosing by machine, it improves sanitary conditions, ensures high productivity, and ensures accurate product dosing.

1.2. Questioning

From the practical requirements, to meet those strict requirements, the following problems have arisen:

- Bottle positioning and orientation: For automatic bottle filling, the system must correctly locate the bottle and ensure the correct orientation to complete the filling process.
- Speed and Performance: The automatic bottle filling requires high speed and efficiency to meet mass production needs.
- Quality assurance: The automatic bottle filling must ensure the quality of the final product. Problems can arise when the system cannot measure and control quality, resulting in substandard or inconsistent products.
- Dosing of filling fluids: Dosing liquids during production and filling is an important factor because it directly affects the quality and performance of the final product.
- Piston filling mechanism: helps to ensure an accurate and uniform filling process.

1.3. Previous research works

In 2018, the authors Dieu and Dat, Industrial University of Ho Chi Minh City implemented the project "Automatic filling system using PLC S7-1200 to control Servo motor according to position" as presented in Fig.1 [1]. The author has accurately controlled the two-axis AC Servo position according to the position and designed the WinCC model monitoring and control interface. However, the author has not quantified the filling liquid level, and the equipment and controllers have not been constructed in the electrical cabinet.

Fig. 1. Automatic filling model by Tran Xuan Dieu and Nguyen Quoc Dat

In 2019, the authors Huy and Nam, from Ho Chi Minh City University of Technology and Education implemented the project "Control and supervision of filling lines using PLC S7-1200" as presented in Fig.2 [2]. The author has accurately controlled the rotation angle position of the rotating wheel using an AC Servo and designed a SCADA monitoring and control interface. However, according to the author, the conclusion is that the flow of filling fluid is not accurately stable and needs further improvement.

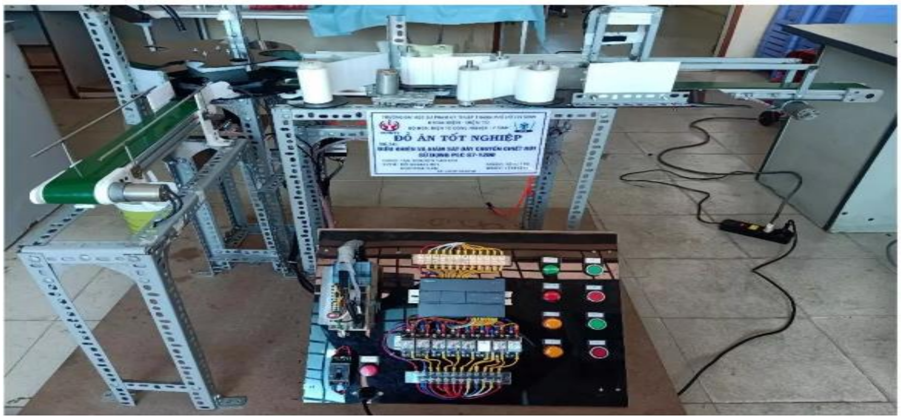

Fig. 2. Automatic filling model by authors Do Quang Huy and Ngo Hoai Nam.

1.4. Solving the Problem of Filling Position Control

A solution has been proposed to accurately control the position of the AC Servo two-axis to solve the problems that arise. The use of a two-axis AC Servo to perform filling has solved the following problems:

- Accurate Bottle Positioning: The AC servo two-axis system can accurately position the bottle. Servo sensors and controllers can ensure that the bottle is properly positioned before the filling process begins.
- Precise and flexible adjustment.
- Control of velocity and impact force.
- Fast response and compatibility.
- Reliability and maintenance: AC servo axes are typically highly reliable and require low maintenance. This helps minimize problems and keep the filling system running continuously and stably. If something goes wrong, replacing or repairing Servo components simply and quickly is easy.

Some important novelties in the application of AC Servo in precise position control are as follows:

1.4.1. Multi-axis control

An important novelty of this article is the ability to control multiple axes, namely the simultaneous control of two axes during the filling process. Typically, previous filling systems focused on controlling only one axis, while the other axis was often done manually [3]. Using AC Servo for both axes increases the flexibility and efficiency of the system, allowing for precise control and synchronization of the filling process on both axes.

1.4.2. Precise control and fast response

AC Servo is used in this article because of its fast response and high accuracy. This provides precise control of the axes' position, speed, and force during the filling process. AC Servo provides fast response and proportional adjustment, ensuring accurate and stable filling [4].

1.5. Methods and Solutions for Dosing Liquids

There are many methods and solutions to perform quantitative filling, including rating flask, extraction to a fixed level, extraction over time, and using a flow sensor. The most common method for liquid products is using a flow sensor to measure liquid ink [5]-[7].

Metering by means of a rating vessel: then the liquid is precisely dosed thanks to the rating vessel before pouring into each bottle [8].

Quantification through extraction to a fixed level: when the liquid is extracted in a bottle to a fixed level by filling, taking the offset volume out of the bottle, then the liquid level in the bottle will drop to a certain amount regardless of whether the bottle volume is the same or not. Besides, the vent tube will stop when the liquid is filled to the mouth. Dosing by extraction to a fixed level depends on the uniformity of the bottle, so the accuracy is not high [8].

Flow sensor dosing: Use a flow sensor to measure the amount of liquid that passes through during the filling process. By measuring the liquid flow and calculating the filling time, the volume of liquid that has been filled can be determined.

For this system, the solution of dosing liquid ink to be filled using flow sensors was used because of its high accuracy, continuous measurement, flexibility, high reliability, and reasonable price.

Another important novelty is the ability to automatically control the flow of liquids during the filling process. The system can accurately quantify the amount of liquid filled into bottles using liquid flow sensors and control algorithms; this ensures that the amount of liquid in each bottle is measured correctly and avoids possible errors when controlled manually.

1.6. Solution to Implement Filling Unit Control

For this article, the Z-axis control scheme by cylinder has been put forward to realize the control of the filling unit, namely the filling nozzle [9], doe to the following advantages:

- Quick response: The cylinder can quickly respond to the up and down movement of the filling nozzle. When receiving the control signal, the cylinder can move quickly and flexibly, increasing the filling process's efficiency and accuracy.
- High precision: The cylinder has a high precision ability to control the position of the filling nozzle.
- Low cost: The cylinder is an economical solution for Z-axis control.
- Reliable and straightforward: Using the cylinder as the Z-axis simplifies the control system. The cylinder is a simple mechanical device with high reliability. It does not require complexity in programming and operation, which minimizes the risk of failures and problems during the filling process.

1.7. Methods and Solutions to Build an Intuitive SCADA Monitoring and Control Interface

During the automatic filling process on two axes, the system has a graphical and intuitive SCADA interface, allowing the operator to monitor and control the filling process easily. Many methods and solutions are offered for system control and monitoring, such as monitoring WinCC or HMI. However, the monitoring and control of the system was chosen through WinCC because of its new features and advantages, such as cost savings, wide monitoring range, ability to accurately monitor and control the filling process, improved flexibility and performance, minimized errors, and increased system stability. The operator can view information about the position, speed, force, and amount of fluid being filled on each shaft. Control parameters and parameters such as filling speed, bottle liquid level, or other operations related to the process can be adjusted.

2. METHODS

2.1. Block Diagram Design

This section provides the general block diagram of the system with blocks that perform distinct functions (Fig.3).

- **Power Block:** Turn on the CB of the powered system, which includes the power to the honeycomb power, driver block, and indicator light (220VAC power). The honeycomb power supply provides 24VDC and 0VDC power for PLC blocks, input blocks, and indicator lights.
- **Input Block:** The PLC input devices use a 24 VDC power source supplied from the honeycomb source. They include push buttons (START, STOP, RESET), two optical sensors (Home), two limit switches, and pulses from the flow sensor read through an isolation circuit.
- **PLC Block:** Powered by 24V from the honeycomb source, which is the central controller, it receives Digital signals from the system's push buttons, sensors, and limit switches. The PLC outputs signals to the output block and PTO pulses to the Driver block.
- **Block Capacity:** Includes pumps, solenoid valves, and pneumatic valve coils.
- **Relay Block:** receives a signal from the PLC to control the power block on/off.
- **Driver Block:** The block receives the PTO pulse control signal from the PLC to command the operation of the Servo Motor.
- **Motor Block:** It has the task of running as desired because the Driver provides information and drives the rotary lead screw to bring the filling unit to the position to be filled.
- **Encoder Block:** Coaxial mounted behind the Servo Motor to collect and return the information of the number of revolutions of the motor to the Driver block.
- **Indicator Block:** Includes 220 VAC and 24 VDC power indicators.

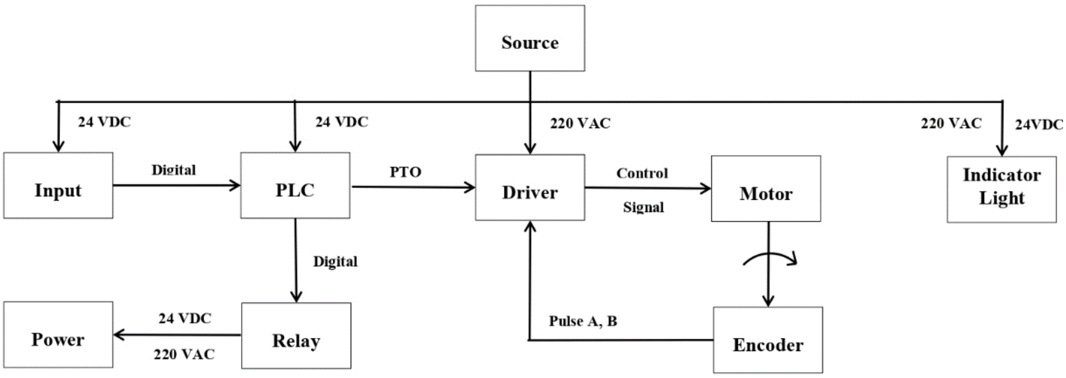

Fig. 3. General block diagram of the system

2.2. Hardware

The hardware is designed neatly and beautifully. Complete equipment required for this article. Reasonable design of components located in the electrical cabinet. Wiring meets industry standards.

2.3. Axis Configuration

2.3.1 Axis Configuration

In the General section, select the PTO pulse output type, and the position unit of measurement is mm (Fig. 4 and 5).

Switch to the Drive section to configure the pulse pin and the servo motor's running direction. Configure as shown below. Q0.2 will be the pulse transmission lane, and the direction will be the Q0.3 pin. The maximum pulse output frequency is 100kHz.

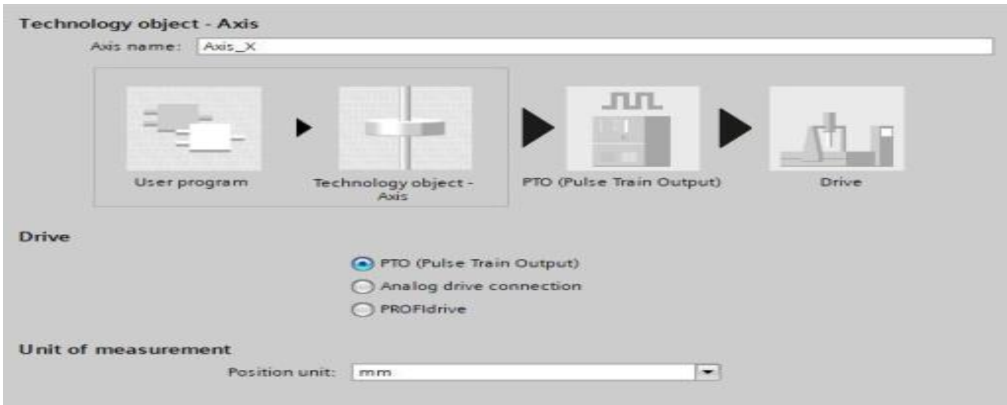

Fig. 4. X-axis pulse transmitter settings

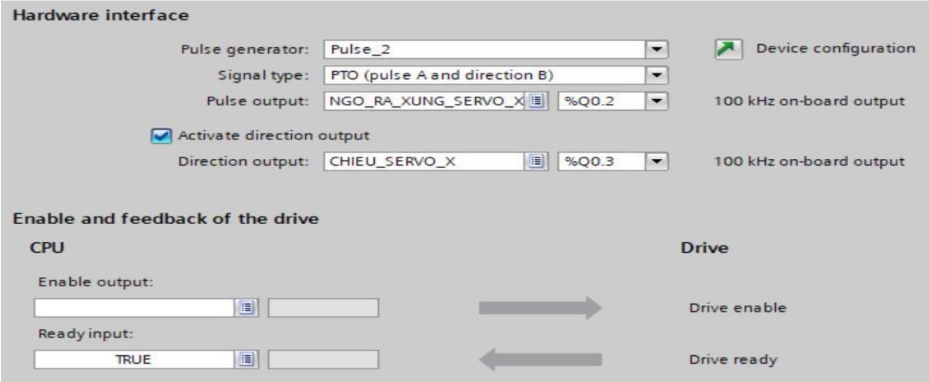

Fig. 5. Select the X-axis pulse pin.

Go to the Mechanics section to configure the resolution of the servo and lead screw (Fig. 6). The parameter, as shown in the picture, means that if 4000 pulses are emitted, the motor rotates 1 turn, 1 turn, and the lead screw will go 4mm, which is also the thread step of the lead screw.

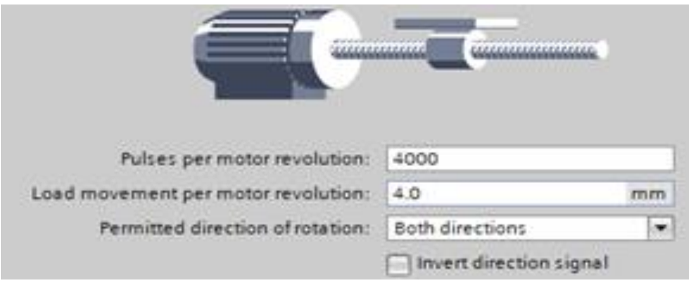

Fig. 6. Setting the number of X-axis pulses

To the Hardware and software limit switch, select Allow hardware and software limit travel (Fig. 7). The hardware is limited by a cruise sensor at the I0.7 pin when impacted at a high level. The hardware is limited by a cruise sensor at the I0.7 pin when impacted at a high level. The software is limited by measuring the distance directly on the X-axis: the X-axis can operate from -30 to 400mm.

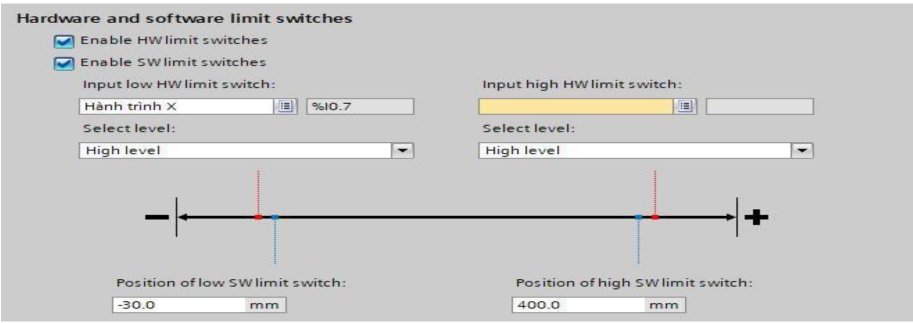

Fig. 7. X trip limit setting

https://doi.org/10.51630/ijes.v5i2.146

Dynamics–General: configure the speed section and the acceleration and deceleration time. The unit of velocity limits is selected as pulse/s. The maximum pulse output speed ≈ is 50,000 Hz, corresponding ≈ to 66.67 mm/s. The start and stop velocities ≈ 1000 Hz respectively ≈ 66.67 mm/s. The acceleration and deceleration time is 1s. The acceleration is 65.33 mm/s2, and the deceleration is 65.33 (Fig. 8).

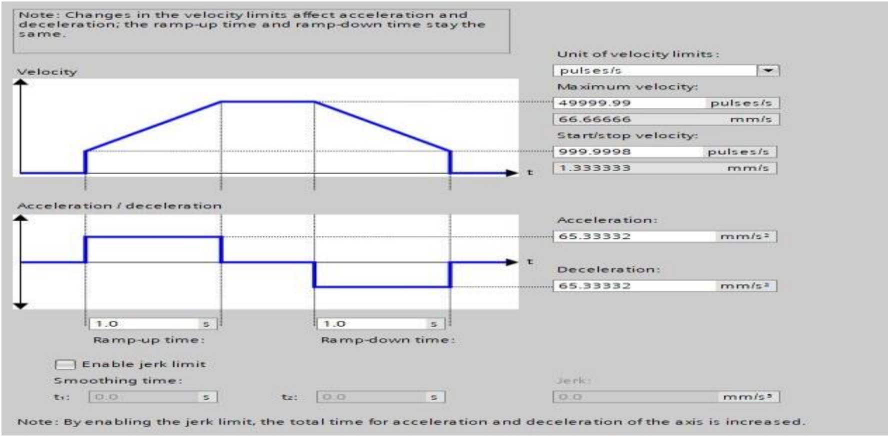

Fig. 8. X-axis pulse emission rate setting

Activate the Home (Digital input homing switch) feature: the home sensor is activated with the I0.5 pin at a high level. The trigger allows automatic reversal when the travel limit switch is touched while the Home probe is tracked. Home Detection Direction: The motor rotates in the opposite direction to detect Home. The speed when the Home axis is found is 25 mm/s, and the speed when the Home position has been found is 10 mm/s (Fig. 9).

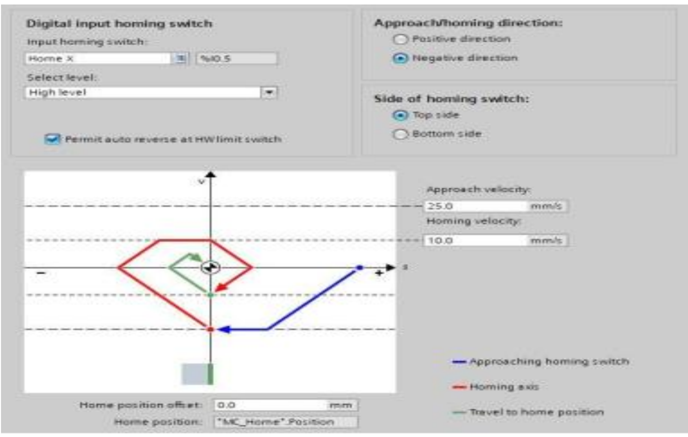

Fig. 9. The X-axis Home Setting

2.3.2 Configuration Axis Y

In the General section, select the PTO pulse output type and the position unit measurement unit is mm (Fig. 10).

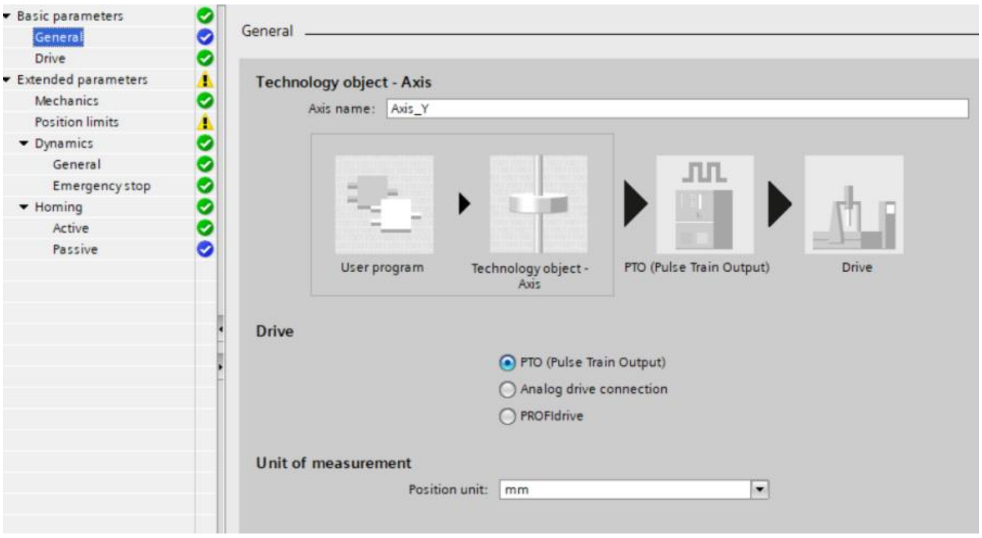

Fig. 10. Y-axis pulse transmitter settings

Switch to the Drive section to configure the pulse pin and the running direction of the servo motor. Configure as shown below. Q0.0 will be the pulse lane. Select the direction of the Q0.1 pin. The maximum pulse output frequency is 100kHz (Fig. 11).

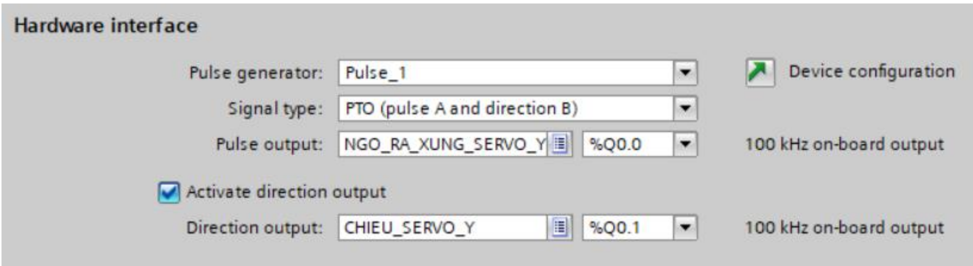

Fig. 11. Select the Y-axis pulse pin.

Go to the Mechanics section to configure the resolution of the servo and lead screw. The parameter, as shown in the picture, means that if the motor rotates 3000 pulses, the lead screw will rotate 1 turn, 1 turn, and the lead screw will go 4mm, which is also the thread step of the lead screw (Fig. 12).

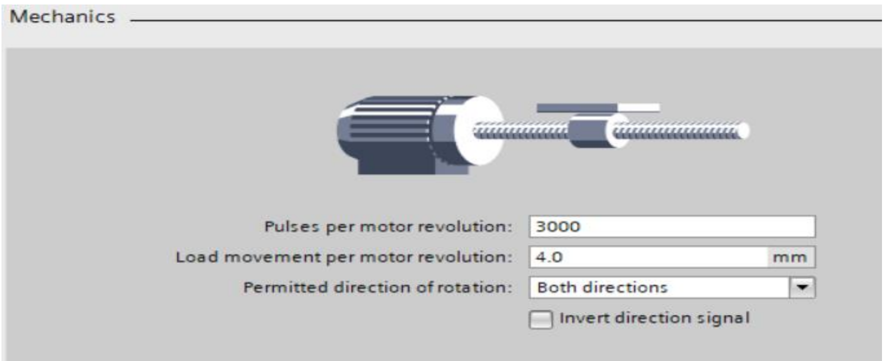

Fig. 12. Setting the number of Y-axis pulses

Under Hardware and software limit switches, select Allow hardware and software limit travel. The hardware is limited by a travel limit sensor at the I0.4 pin when impacted at a high level. The software is limited by measuring the distance directly on the Y-axis: the Y-axis is allowed to operate from -30 to 380mm (Fig. 13 and 14).

Dynamics - General: configure the speed section as well as the acceleration and deceleration time:

- The unit of velocity limits is selected as pulses/s.
- The maximum pulse output speed ≈ is 50,000 Hz, corresponding ≈ to 66.67 mm/s.
- The start and stop velocities ≈ 1000 Hz respectively ≈ 66.67 mm/s.
- The increase and decrease time is 1s; the acceleration is 65.3 mm/s^2, and the deceleration is 65.33 mm/s^2.

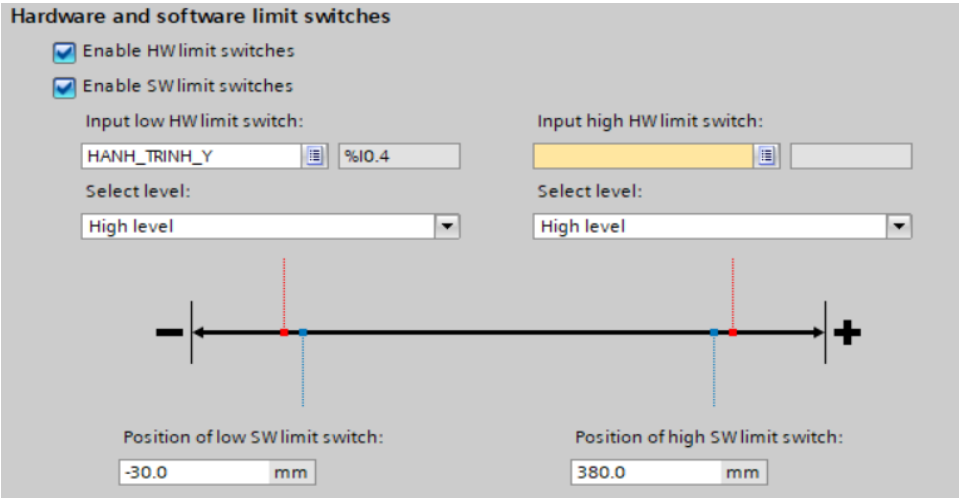

Fig. 13. Setting the Y travel limit

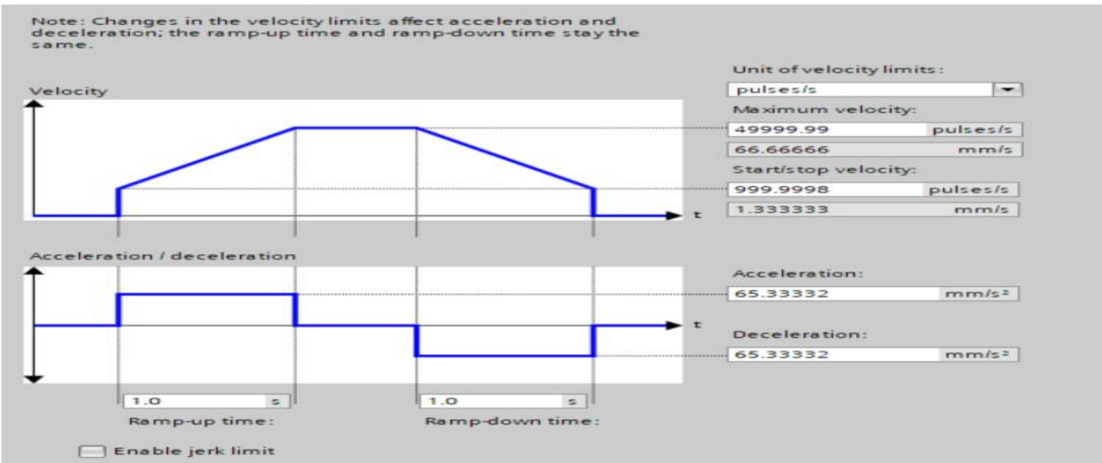

Fig. 14. Y-axis pulse emission rate setting

Activate the Home feature (Digital input homing switch): the home sensor is activated with the I0.2 pin at a high level. The trigger allows automatic reversal when the travel limit switch is touched while the Home probe is being tracked. Home Detection Direction: The motor will rotate in the opposite direction to detect Home. The speed when the Home axis is detected is 20 mm/s, and the speed when the Home position has been found is 10 mm/s (Fig. 15).

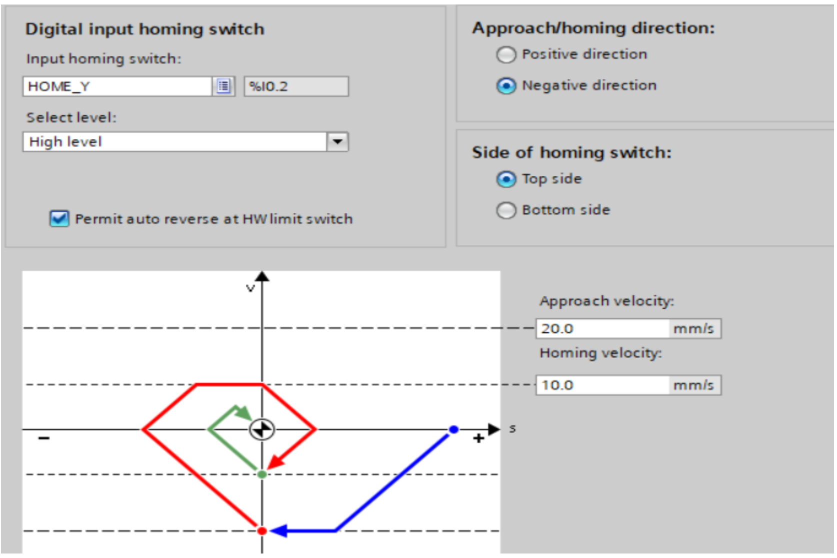

Fig. 15. The Y-axis home setting

2.3.3 Algorithmic Flowchart

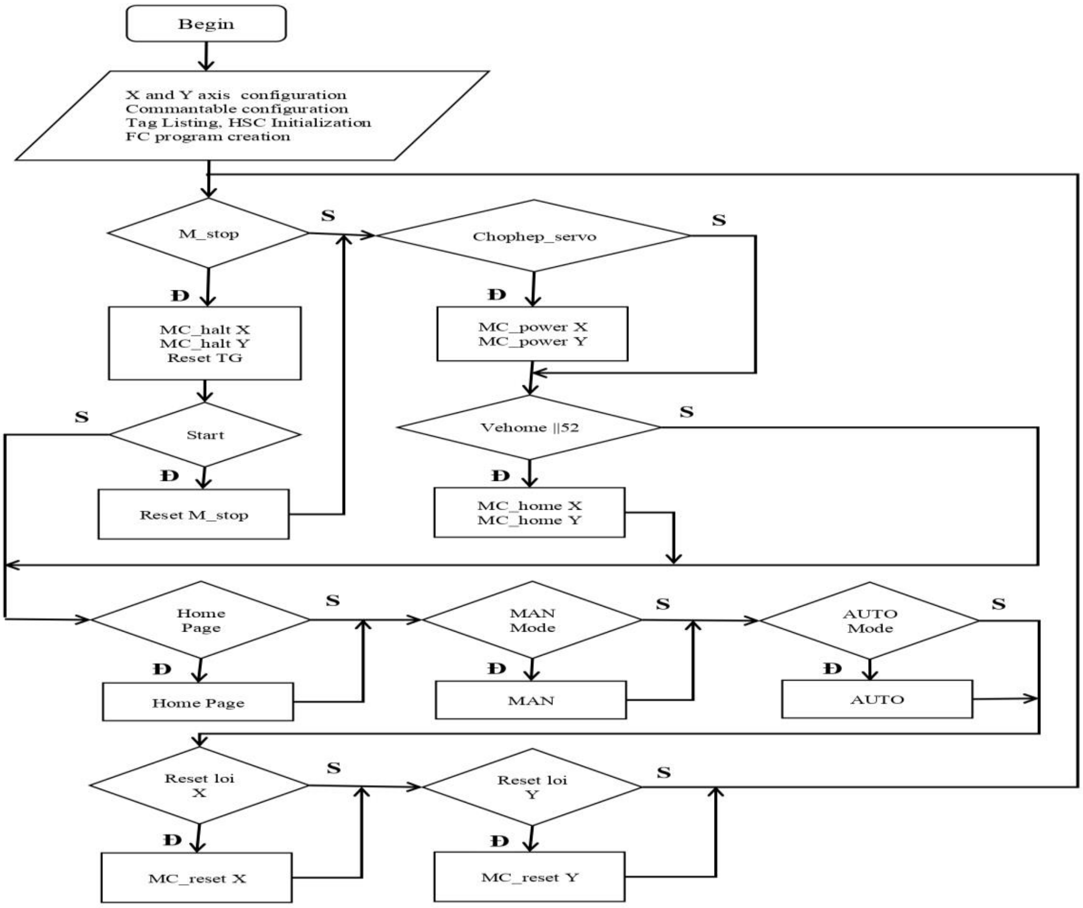

Fig. 16. Main Programs

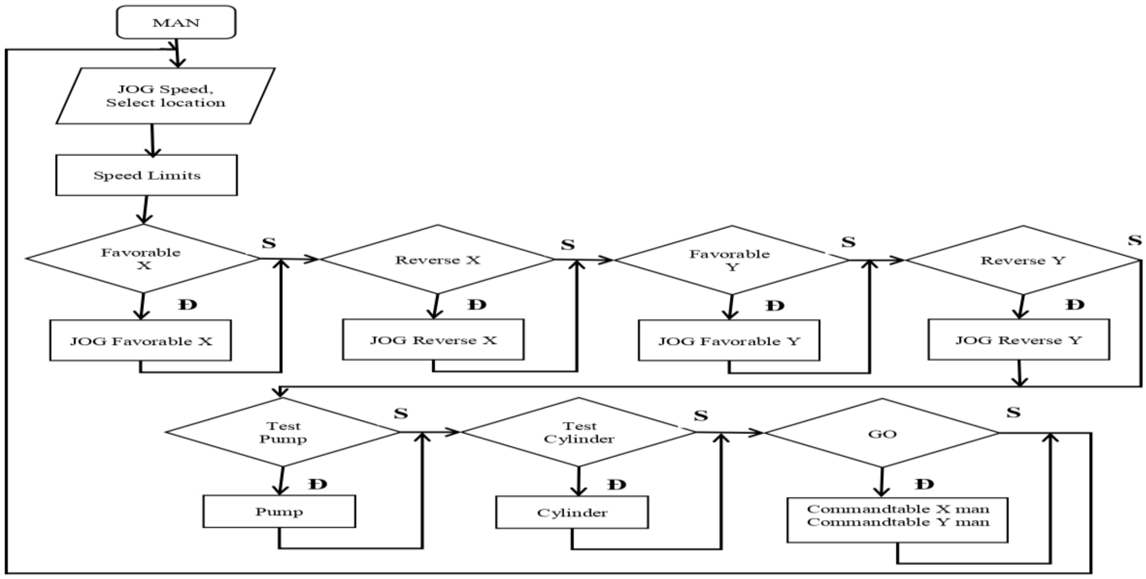

Fig. 17. MAN Subprogram

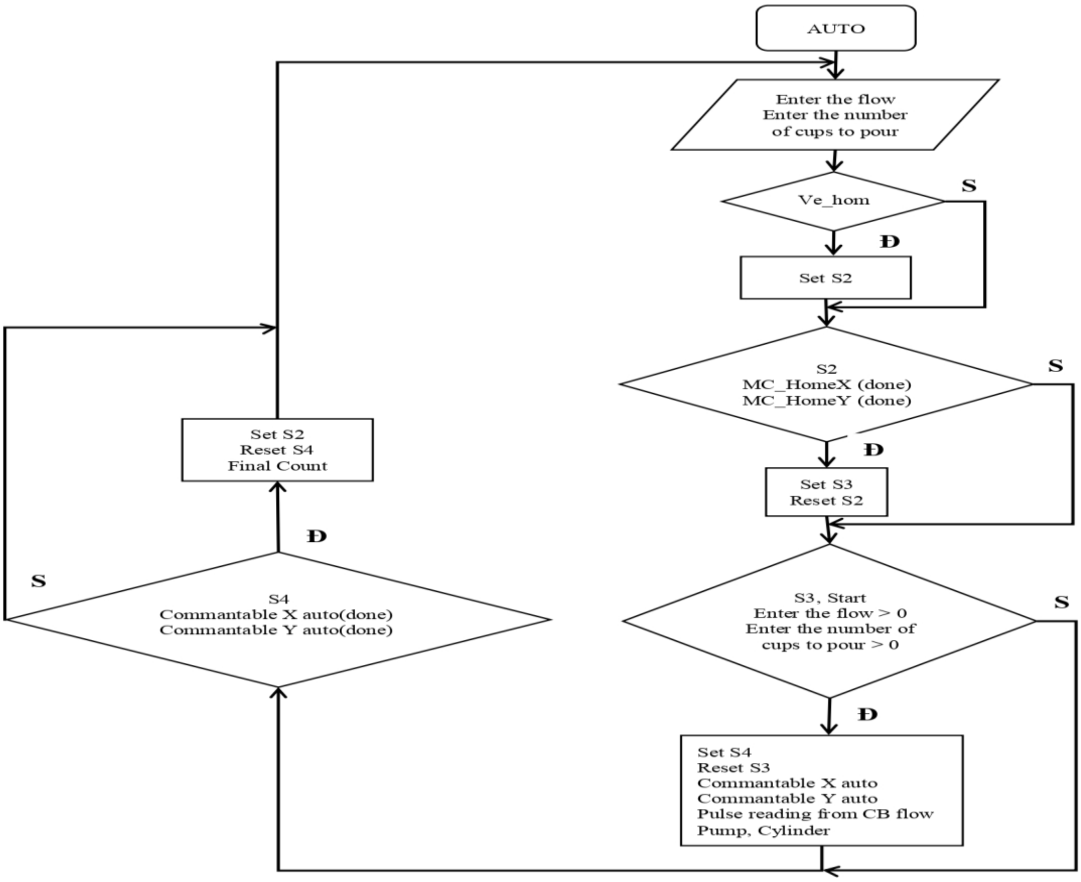

Fig. 18. AUTO Subprogram

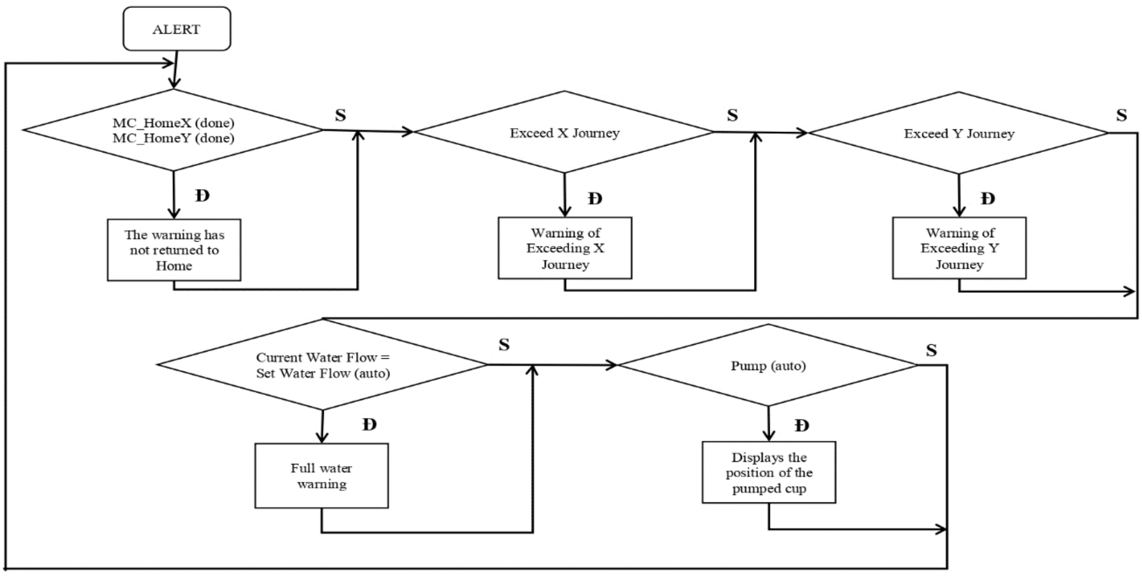

Fig. 19. Warning subprogram

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3. RESULT

3.1. Hardware Construction Results

Fig. 20. Actual model of filling system

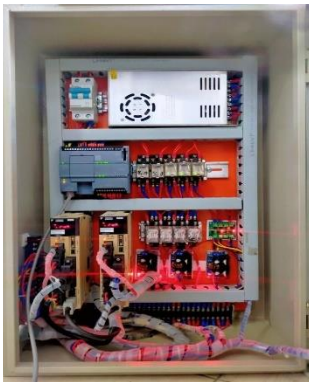

Fig. 21. Electrical Cabinet Control System

3.2. Software Construction Results

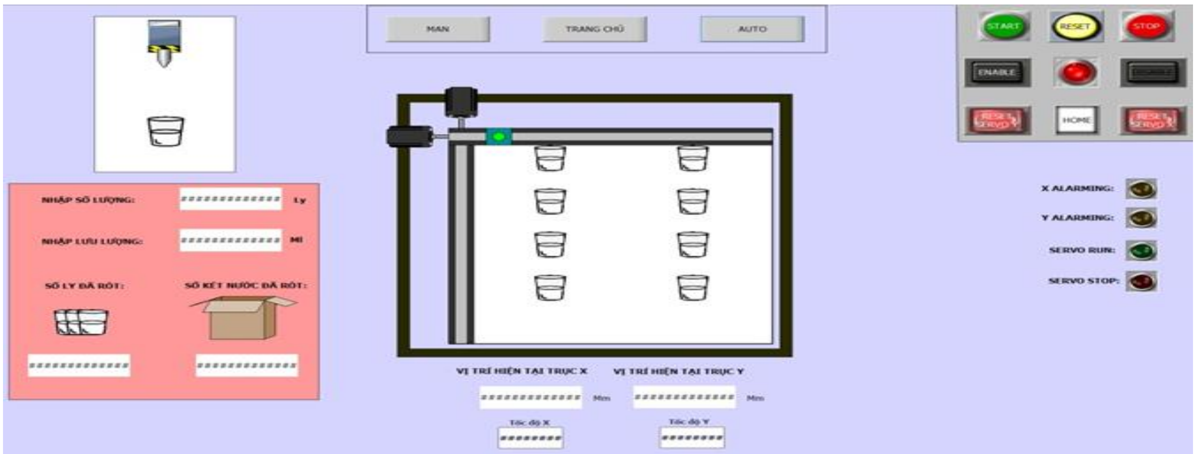

Fig. 22. WinCC Interface Auto Mode

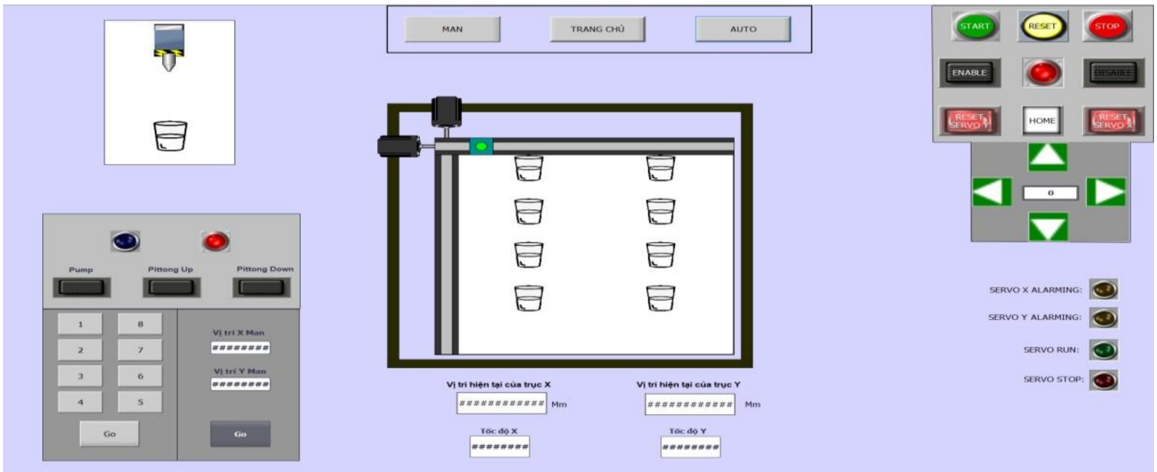

Fig. 23. MAN mode WinCC interface

3.3. Comments on results

Table 1: Flow error calculator

Attempts	Set Volume[ml]	Net Volume[ml]	Errors[ml]
1	50 ml	52 ml	2 ml
2	50 ml	54 ml	4 ml
3	50 ml	56 ml	6 ml
4	50 ml	54 ml	4 ml
5	50 ml	52 ml	2 ml
6	50 ml	54 ml	4 ml
1st Total	300 ml	322 ml	22 ml
1	100 ml	110 ml	10 ml
2	100 ml	108 ml	8 ml
3	100 ml	112 ml	12 ml
4	100 ml	106 ml	6 ml
5	100 ml	104 ml	4 ml
6	100 ml	106 ml	6 ml
2nd Total	600 ml	636 ml	36 ml
1st Average error	22/300× 100% = 7,33 %		
2nd Average error	36/600× 100% = 6 %		

The above test table shows that the flow error is relatively large, indicating that the water flow is not absolutely accurate.

4. CONCLUSION

Significant results have been achieved in this project, including the study of the use, connection, programming, and configuration of the PTO high-speed pulse generation function in the S7-1200 PLC. At the same time, Yaskawa AC Servo Motors and Drivers were studied to carry out signal connections and set parameters for AC Servo Drivers. The pulse reading, processing, and calculation from the flow sensor have been studied to control the flow of the filled liquid accurately, and the control and monitoring interface via SCADA has been designed. The advantages achieved from this result include a ruggedly designed hardware model, stable operation, and cost optimization; the ability to accurately control the two-axis AC Servo position with fast filling speed; Accurate dosing of filling liquid levels through flow sensors, intuitive, easy-to-use SCADA control interface. However, limitations have also been noted, including unstable X-axis, suboptimal operating code unsuitable for industrial environments, suboptimal operating time, flow errors that have not reached absolute accuracy, and water interference problems due to inertia have not been addressed. In the future, the system can be developed to run in random positions and control errors when the pump position does not have cups/bottles. Multiple signal pins from the CN1 of the Driver need to be connected to control the servo operations precisely, higher precision flow sensors need to be used for dosing liquids, the X-axis needs to be redesigned for optimization, and code needs to be added, repair to suit the industrial environment. In addition, the backlog of water noise due to inertia also needs to be overcome. S7-1200 has proven to be effective through this research. Future works can be applied to natural systems in [8] and [9]. The calculation can be solved in a computer, and signal control can be transferred to an accurate model in which a robust and solid controller controls.

ACKNOWLEDGEMENT

We want to thank Vi-Do Tran PhD (HCMUTE) for guiding the implementation of this topic.

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