

Design and Simulation of a Liquid Mixing Control System Based on PLC

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Abstract: Liquid mixing is an indispensable process in chemical, pharmaceutical, food and beverage industries, and the accuracy of the mixing ratio and the uniformity of mixing directly affect product quality and production efficiency. However, most liquid mixing operations involve flammable, explosive, toxic or corrosive media, and the harsh on-site environment makes manual operation unsuitable, while manual and semi-automatic control suffers from low proportioning accuracy and insufficient automation. To address this problem, this paper takes the proportional mixing of three kinds of vegetable oils as the research object and designs and simulates a liquid mixing control system based on the Siemens S7-1200 PLC. The system adopts the stirring-motor mixing method, realizes dual detection of liquid level and weight with a floating-ball level sensor and a pressure sensor, compiles the control program with the sequential control design method and step ladder instructions, and completes configuration simulation with TIA Portal V16 and WinCC. Simulation results show that with a set output of 80 g and a mixing ratio of 1:2:3 for materials A, B and C (10 g, 20 g and 30 g), the single-cycle actual output is 60 g; the system automatically completes feeding, weighing, stirring and discharging and repeats feeding cycles until the cumulative output reaches the set value. The stirring motor runs alternately in forward rotation for 5 s and reverse rotation for 5 s, giving uniform mixing and stable operation. The system is simple in structure, low in cost and highly automated, and can serve as a reference for the automation of small and medium-sized liquid mixing processes.

Keywords: Liquid Mixing Control System; Siemens S7-1200 PLC; Sequential Control Design Method; Step Ladder Instruction; WinCC Configuration Simulation

1. INTRODUCTION

Liquid mixing is an indispensable production link in chemical, pharmaceutical, food and beverage industries, and the accuracy of the mixing ratio and the uniformity of mixing directly affect product quality and production efficiency [1]. However, most liquid mixing operations involve flammable, explosive, toxic or corrosive media, and the harsh on-site environment makes manual operation unsuitable; traditional manual and semi-automatic control can hardly meet the requirements of accurate proportioning and reliable control [2]. Since the emergence of the programmable logic controller (PLC) in the late 1960s, liquid mixing control has developed rapidly and gradually replaced the traditional relay control mode; the PLC is simple in structure, highly automated and widely used in industrial control systems [12]. At home, various types of stirring tanks and mixers have been developed, and research has been carried out on flow field analysis and mixing quality evaluation, but the process control still relies heavily on manual experience, and the proportioning accuracy and automation level need to be improved. Abroad, more mature experience has been accumulated in the design, manufacture and quality control of mixing equipment as well as in flow field simulation and physical property research. Overall, existing systems generally suffer from a single control mode, lack of monitoring means and poor program modifiability, and there is still much room for improvement in automatic mixing systems oriented to specific ratios and outputs.

To address the above problems, this paper takes the automatic proportional mixing of three kinds of vegetable oils as the research object and designs a liquid mixing control system based on the Siemens S7-1200 PLC. The system adopts the stirring-motor mixing method and realizes the dual detection of liquid level and weight with a floating-ball level sensor and a pressure sensor, so as to ensure that the three raw materials are added accurately according to the set ratio. The control program adopts the sequential control design method, and step ladder instructions are used to realize the sequential connection of each working procedure, making the program structure clear

and easy to debug and modify. In terms of software, TIA Portal V16 is selected to complete the ladder diagram programming, and the WinCC configuration software is used to build the monitoring screen to realize real-time display and remote monitoring. The innovations of this system are as follows: first, weighing, liquid level detection and sequential control are combined to realize automatic weighing and cyclic feeding of the three liquids according to the ratio; second, the integrated simulation environment of TIA Portal V16 and WinCC is adopted, so that the joint debugging of the control logic and the monitoring interface can be completed without physical equipment; third, a closed-loop output judgment is set, and the next cycle is automatically started when the output is insufficient until the output reaches the standard.

Simulation results show that the system runs stably under the conditions of a set output of 80 g and a mixing ratio of 1:2:3 for materials A, B and C. The single-cycle output is 60 g, and the motor stirs alternately in forward rotation for 5 s and reverse rotation for 5 s, which ensures uniform mixing and automatic circulation until the output reaches the standard, verifying the correctness and feasibility of the design scheme. The system is simple in structure, low in cost and highly automated, and has certain reference significance for the automatic transformation of small and medium-sized liquid mixing processes and the design of similar sequential control systems.

2. EXPERIMENT

2.1 Basic Principle

The core of this experiment is to use the PLC to implement sequential control of the liquid mixing process. The PLC executes the user program in a cyclic scanning manner, completing input sampling, program execution and output refresh in turn, and its internal relays, timers and counters provide a reliable basis for sequential control [7]. The basic principle of liquid mixing control is as follows: according to the set ratio, the valve of each raw material is opened in sequence, and the weighing and liquid level detection signals are used to judge whether the feeding is completed; after all the

three raw materials enter the mixing pool, the stirring motor is controlled to run alternately in forward and reverse rotation for full mixing, and finally the discharge valve is opened to output the mixed product ^[1].

The liquid level detection adopts a floating-ball level sensor, which outputs an on/off signal according to the floating position of the float ball and is used to judge whether the liquid level reaches the set height. The weight detection adopts a pressure sensor, which converts the weight of the liquid in the weighing bin into an electrical signal to realize accurate metering of the feeding weight. The system adopts the PN/IE (PROFINET/Industrial Ethernet) communication protocol to connect the PLC with the configuration computer, realizing program download, data exchange and remote monitoring ^[8].

2.2 Experimental Equipment and Selection

The Siemens S7-1200 PLC is selected as the controller. Compared with the Mitsubishi FX2N, which requires external equipment for simulation and is relatively expensive and complicated in programming, the S7-1200 can be simulated directly through TIA Portal V16, is cheaper and easier to program, and is therefore selected as the lower computer of the system.

A floating-ball level sensor is selected for liquid level detection. The piezoresistive level sensor has high accuracy, but its structure is complex and its price is high; the floating-ball sensor is simple in structure and low in price. Although its corrosion resistance is weak, the mixing objects in this experiment are non-corrosive liquids such as vegetable oil, and its accuracy can meet the requirements of liquid level detection.

The stirring motor selected is the FLYGT 4352, with a maximum flow rate of 317 m³/h, a maximum head of 25 m and a power range of 1.7-10.8 kW. It features easy installation, convenient maintenance, strong anti-clogging capability and high reliability. The drainage pump selected is the KSB Amarex N, which is efficient, wear-resistant and reliable; it is installed at the bottom of the mixing pool to discharge the mixed liquid through a DN 800 outlet.

In terms of software, TIA Portal V16 is used as the software for ladder diagram drawing and system simulation. It has excellent programming capability, powerful monitoring functions, and supports multiple communication protocols and data exchange. WinCC is used for the configuration of the monitoring screen to realize real-time display of the system running state. The system also includes raw material silos, feeding motors, solenoid valves (YV1-YV6), weighing bins, a mixing pool, indicator lights, timers and other auxiliary equipment.

2.3 Experimental Method

The sequential control design method is adopted to compile the control program. First, a sequential function chart is drawn according to the process requirements to clarify the conversion conditions between each working procedure, and then the ladder diagram is designed according to the sequential function chart. Step ladder instructions are used for programming, with the conversion as the center to organize the program structure, making the program concise and easy to debug and modify ^[6]. The system allocates 8 digital input points (I0.0-I0.7) and 14 digital output points (Q0.0-Q1.5); the main address allocation is shown in Tables 1 and 2. The overall design of the system is shown in Figure 1, and the whole mixing process is divided into three parts: liquid inflow, liquid mixing and stirring, and final product output.

Table 1. Digital Input Address Allocation

No.	Name	Address
1	System running	I0.0
2	System stop	I0.1
3	Level switch A	I0.2
4	Level switch B	I0.3
5	Level switch C	I0.4
6	Mixer fault	I0.5
7	Emergency stop	I0.6
8	System auto start	I0.7

Table 2. Digital Output Address Allocation

No.	Name	Address
1	Material A valve	Q0.0
2	Material B valve	Q0.1
3	Material C valve	Q0.2
4	Stirring motor	Q0.3
5	Feeding motor A	Q0.4
6	Feeding motor B	Q0.5
7	Feeding motor C	Q0.6
8	Mixed material D valve	Q0.7
9	Decanter	Q1.0
10	Stirring motor control relay	Q1.1
11	Blower	Q1.2
12	Mixed material D feeding motor	Q1.3
13	Blower	Q1.4
14	Running indicator	Q1.5

It can be seen from Table 1 that the system running, system stop and system auto start signals are used to control the start-stop logic of the system; level switches A, B and C correspond to the liquid level detection of the three raw materials respectively, and the mixer fault and emergency stop signals are used for abnormal protection. It can be seen from Table 2 that the output points control the raw material valves, feeding motors, stirring motor, discharge valve and other actuators respectively, and the running indicator is used to indicate the current working state of the system.

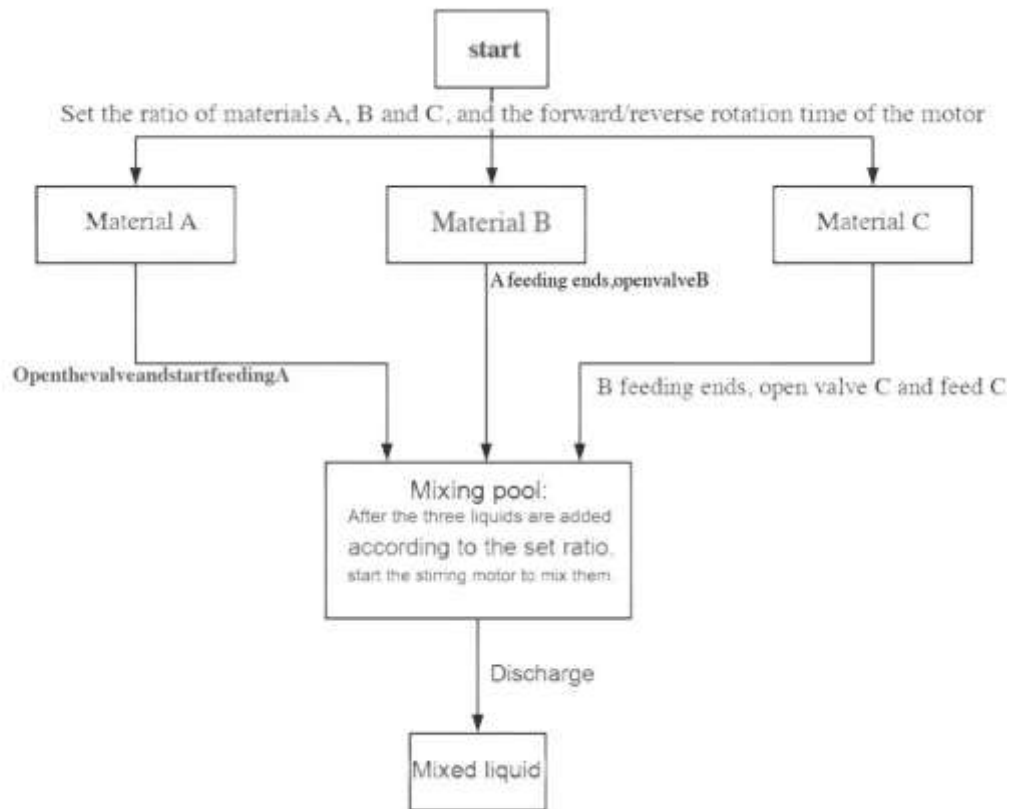


Figure 1. Overall system design block diagram

2.4 Experimental Procedure

The experiment completes the program writing and simulation debugging in the TIA Portal V16 environment. The specific process is as follows.

(1) Parameter setting: before the system starts, the target output of the mixed raw material (set to 80 g in this experiment) and the input amounts of materials A, B and C (10 g, 20 g and 30 g respectively, with a ratio of 1:2:3) are set, and the forward and reverse rotation times of the stirring motor (5 s each) are set.

(2) Feeding of material A: the valve of material A and the feeding motor are opened, and material A is weighed by the pressure sensor in the weighing bin; when the actual weight is less than the set value of 10 g, feeding continues; when the set value is reached, the valve is closed and the weighing gate is opened to send material A into the mixing pool. Meanwhile, the addition counter records the cumulative feeding weight.

(3) Feeding of materials B and C: the feeding process of material A is repeated to complete the addition of material B (20 g) and material C (30 g) in turn, and the cumulative weight of the three raw materials is recorded.

(4) Stirring and mixing: after all the three raw materials enter the mixing pool, the stirring motor is started and runs in forward rotation for 5 s and then in reverse rotation for 5 s according to the set time, so that the three liquids are fully and uniformly mixed.

(5) Output judgment and circulation: after one mixing cycle, the mixed liquid is discharged and the actual output is recorded; the actual output is compared with the set output. If the cumulative output is less than the set value, the system automatically starts the next cycle (without resetting the

parameters), until the cumulative output is greater than or equal to the set output after a cycle, and then the system stops and completes all tasks.

(6) System stop: when the stop button is pressed or a fault occurs (the buzzer alarms and the normally closed contact opens), the system stops running. The above six steps form the complete mixing procedure, in which the whole process from parameter setting, proportional feeding, stirring and discharging to closed-loop output judgment is automatically executed by the PLC.

3. RESULTS AND ANALYSIS

3.1 Simulation Results

The program is compiled and simulated in TIA Portal V16, and the monitoring screen is built in WinCC to realize visualized monitoring of the whole mixing process. The monitoring screen provides parameter display areas for the set output, current output, set weights of the three raw materials and motor forward/reverse rotation times, together with process equipment models of the raw material silos, feeding motors, valves, weighing bins, stirring motor and discharge valve; it is also equipped with auto/stop buttons and running state indicator lights (red means stopped and green means running).

After the start button is pressed, the system runs automatically according to the set ratio of 1:2:3. Material A is first transported from the raw material silo to the bin by the feeding motor and enters the weighing bin through the valve, where the pressure sensor displays the weight in real time. When the reading reaches the set value of 10 g, feeding stops and the weighing gate is opened to send material A into the mixing pool;

materials B (20 g) and C (30 g) are then added in turn by the same process.

After all the three raw materials are added, the stirring motor is started and runs in forward rotation for 5 s and then in reverse rotation for 5 s according to the setting; during this period the forward and reverse indicator lights of the motor light up in turn while the other motors remain off. After stirring, the indicator lights go out and the system opens the discharge valve to output the mixed liquid.

The closed-loop output judgment process runs as follows. After one cycle, the system records the actual output and compares it with the set output: if the actual output is less than the set value, the next cycle is restarted; if the cumulative actual output is greater than or equal to the set value, the process ends. In this experiment, the amounts of materials A, B and C are 10 g, 20 g and 30 g respectively, and the actual output of a single cycle is 60 g, which is less than the set output of 80 g, so the system automatically starts the second cycle; the cumulative output reaches 120 g, satisfying the stop condition, and the system stops. The results show that the system can accurately realize proportional feeding, timed stirring and closed-loop output control; the actions of each working procedure are correct and the operation is stable, and the monitoring screen can reflect the running state of the system in real time.

In addition, the set output, current output and weight reading areas in the monitoring screen display the weighing values of each weighing bin in real time, and the data recording function can save the feeding amount and output data of each cycle, which is convenient for production statistics and quality tracing; the running indicator changes in real time with the switching of the working procedures, and operators can judge the current stage of the system accordingly.

3.2 Comparison with Existing Studies

In recent years, many studies have been carried out on PLC-based liquid mixing control systems. Chen ^[1] designed an automatic liquid mixing control system based on PLC, which realizes the sequential mixing of multiple liquids, but does not involve accurate weight metering and closed-loop output control. Gao ^[2] designed a PLC control system for automatic mixing of multiple liquids, focusing on the implementation of the control program, with relatively simple monitoring means. Zhao ^[3] adopted PLC frequency conversion control to realize multi-liquid mixing and improved the stirring effect through variable-frequency speed regulation, but the system cost is relatively high. Sun et al. ^[4] and Chen ^[5] built PLC simulation training systems based on MCGS and self-developed software respectively, focusing on teaching simulation with little combination with industrial field processes. Compared with the above studies, this system has the following characteristics: (1) pressure weighing is combined with liquid level detection to realize the accurate addition of three raw materials according to the set ratio; (2) a closed-loop output judgment is set, and cyclic feeding is carried out automatically without manual intervention when the actual output is insufficient; (3) the integrated environment of TIA Portal V16 and WinCC is adopted to complete programming and configuration simulation, and the simulation logic is consistent with physical debugging, with a short development cycle and low cost; (4) step ladder instructions are adopted for the control program, which is clear in structure and convenient for maintenance and expansion. The above differences make this system advantageous in proportioning accuracy, automation degree and engineering implementation cost. It can be seen that this system takes into account proportioning accuracy,

development cost and engineering practicability while ensuring complete control functions, and its comprehensive performance is better than similar schemes.

3.3 System Advantages

According to the simulation results, the main advantages of this system can be summarized as follows: (1) high automation degree: from feeding, weighing and stirring to discharging, the whole process is completed automatically, and only the parameters need to be set before startup; (2) accurate proportioning control: the pressure sensor weighs in real time to ensure that the three raw materials are added accurately according to the ratio of 1:2:3; (3) intuitive monitoring: the WinCC screen can display the running state of each device and the output data in real time, which is convenient for operation and fault location; (4) simple structure and low cost: the floating-ball level sensor and the S7-1200 PLC are selected, giving the whole machine a high cost performance; (5) strong program modifiability: the sequential control structure makes it convenient to add, remove and adjust working procedures and parameters.

3.4 Limitations and Prospects

This experiment still has some shortcomings. First, the system is only verified in the TIA Portal V16 simulation environment and has not been debugged jointly with the physical PLC and field equipment; in actual operation, hardware factors such as sensor accuracy and motor response may affect the control effect. Second, the alarm and protection functions are not perfect: only the emergency stop and fault buzzer are set, and the protection against abnormal working conditions such as over-high liquid level and abnormal temperature needs to be strengthened. Third, parameters such as the mixing output need to be set manually in advance, and the intelligence level is limited. Fourth, the system is designed for non-corrosive liquids, and its adaptability to strongly corrosive and high-viscosity media is insufficient. To solve the above problems, subsequent research can be improved from the following aspects: first, build a physical experimental platform to verify and correct the control parameters; second, introduce a frequency converter to realize continuous adjustment of the stirring speed and improve the mixing uniformity; third, add multi-parameter alarm linkage of liquid level, temperature and pressure to improve safety protection; fourth, combine artificial intelligence and data acquisition technology to realize automatic optimization of proportioning parameters and remote intelligent monitoring, further improving the adaptability and reliability of the system ^{[10][11]}.

4. CONCLUSION

Aiming at the automation demand of the liquid mixing process, this paper designs and simulates a liquid mixing control system based on the Siemens S7-1200 PLC. The system adopts the stirring-motor mixing method, uses a floating-ball level sensor and a pressure sensor to realize liquid level and weight detection, compiles the control program with the sequential control design method and step ladder instructions, and realizes the integration of programming, configuration and simulation through TIA Portal V16 and WinCC. The simulation results show that the system can automatically complete the weighing and feeding of materials A, B and C according to the ratio of 1:2:3; the single-cycle output is 60 g, and the stirring motor runs alternately in forward rotation for 5 s and reverse rotation for 5 s, with a total stirring time of 10 s, giving uniform mixing and stable operation; through the closed-loop output judgment, the system automatically circulates until the cumulative output reaches the set value of 80 g and then stops, realizing the fully

automatic control of liquid mixing. The system is simple in structure, low in cost, highly automated and intuitive in monitoring, and can meet the production requirements of small and medium-sized liquid mixing processes; it has reference value for the design of similar systems. Subsequent work will focus on physical debugging and the improvement of alarm functions.

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