

## Research Article

# Analysis and Design of PLC-based Control System for Automatic Beverage Filling Machine

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**Abstract:** Automatic filling system is the main equipment in the food machinery industry. With the development of beverage industry and increasing demand of the filling system. The relay control method in traditional Filling machine has low automation and integration level and cannot satisfy the rapid development of automatic production. PLC control method has advantages of simple programming, strong anti-interference and high working reliability, has gradually replace the relay control method. In this study, hardware and software for the automatic filling system based on PLC control is designed, especially the injection section servo control system which adopts the servo motor driver metering pump is carefully analyzed and the filling precision is highly improved.

**Keywords:** Filling machine, PLC control, servo control

## INTRODUCTION

Automatic filling system is widely used in food machinery industry, with the rapid development of beverage and oil industry; the requirement of the filling equipment is highly growing. Due to the later development of filling equipment and technology in China, the performance of most filling machine is relatively backward and its running speed, stability and precision is at a low level (Jiang *et al.*, 2011). The Foreign filling system develops more mature, with the mainstream of automatic filling control system based on PLC control system has advantages of smooth operation, low accident rate and high filling speed (Hu *et al.*, 2013). In order to improve the production efficiency and the filling accuracy, it is quite necessary to apply PLC (Programmable Logical Controller) in automatic filling system.

## MATERIALS AND METHODS

**Principle of automatic filling system:** Automatic filling system is mainly composed of bottle sending system, liquid injection filling system and capping system. The process is shown in Fig. 1.

The empty bottles are sent into filling area by the guide system, after online weighing and empty bottles confirm, the injection filling system started to fill in the filling position (Geng and Ge, 2014). After the empty bottles being fully filled and confirmed by the online weighing system, they are covered with caps and sent

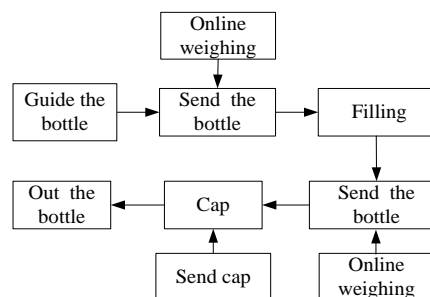


Fig. 1: Flow diagram of automatic filling system process

out. in the work process of the system, bottle sending system, filling liquid injection system and the capping system are all within the core of PLC controller, various types of sensors are as motion control input, servo motor and stepping motor are as the driving assembly and they mutually cooperate to complete the whole filling process (Chen and Hu, 2013).

**Hardware design:** The hardware of a type of filling system applies Mitsubishi FX series PLC as the core, which communicates with each underlying equipment directly. The PLC communicates with PC, access to product information and production parameters and based on all kinds of sensors in the production line, controls the action logic of filling head and the filling speed of conveyor belt, drives stepper motors to adjust control filling head; based on the filling volume given by PLC, complete servo driving and compensation of

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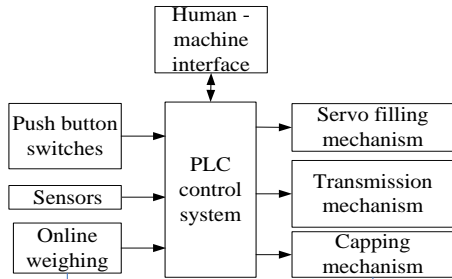


Fig. 2: Principle diagram of automatic filling control system

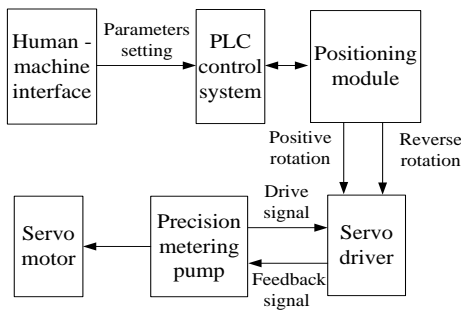


Fig. 3: Principle diagram of the filling measurement system

filling capacity, to realize the adjustment of the filling capacity (Gao *et al.*, 2006). At the same time by the compensating algorithm to calculate the compensation volume information, adding to the filling capacity adjustment.

In order to facilitate daily parameters adjustment, the human-machine interface mode is adopted for specialized management and site operator, mainly used for changing of filling system setting and process parameters and monitoring and displaying the production online running state (Lei, 2014).

The principle block diagram of automatic filling machine control system is shown in Fig. 2.

The functions of each part.

**Push button switch:** Control system's functions such as start, stop and reset, etc.

**Sensors:** Include bottle coming sensors, weighing sensors, capping sensors, encoder, etc. As detecting elements of the control system, according to the state of each sensor, PLC output the corresponding action logic.

**Online weighing:** The weight of empty bottles and full filled bottles is real-time transmitted to the PLC, as confirmation signal for un-fill and filled.

**PLC control system:** Adopts the Mitsubishi FX series PLC as the core, configured FX2N-20GM positioning module, as the whole filling system control center.

**Servo filling mechanism:** Servo motor drives the screw to control precision metering pump and filling capacity and the speed are set by the system parameters.

**Transmission mechanism:** The conveyor belt is driven by frequency conversion motor and the bottle sending speed adjusts according to the production speed.

**Capping mechanism:** After completely filled and confirmed by the online weighing system, bottles are capped.

Human-machine interface, real-time monitors the working parameters of the system and set relevant data according to work situation.

**Principle of filling measurement:** Filling mechanism is an important part of filling system, the filling process performance is mainly depends on the filling measurement precision. In the process of filling, if liquid suction or blow down stroke of metering pump is not enough, the filling volume might be insufficient; if press speed is too fast, the liquid may spill out. In order to improve the filling accuracy and adjust the speed, the system use PLC as the control core and servo electrical units drive precision metering pump to realize quantitative measurement and touch screen real-time monitors and adjusts the control parameters (Bo *et al.*, 2005). It can satisfy the system on response speed, closed loop control; ensure the accuracy of each liquid injection rate and injection fluid speed smooth. The principle diagram of the system structure is shown in Fig. 3.

**Design of filling measurement:** The inject drive system of filling system is composed of servo motor system. According to the control voltage signal, Servo motors rotate positively or reversely of which the speed is proportional to the voltage signal; once the control voltage signal is removed, the motor can stop immediately (Qiao and Zhang, 2009). The control signal is transformed into measuring piston stroke by the servo motor, namely content of filling quantity through the screw, nut and linear guide rail of the transmission system. Liquid injection system adopts servo motor control system; the control model includes position control, speed control and torque control, etc. What's more it also can set in position/speed control, speed/torque control and position/torque control, the combination control. Servo motor integrated control module is small in size and easy to install.

The Settings of Injection volume is directly converted into pulse discharge control of positioning module and the output of the positioning module pulse string, which is counted and stored in the deviation counter of the drive device of deviation. While the servo motor is rotating, the pulse generator connected to the servo motor will generate the feedback pulses, of which frequency is proportional to the rotation speed (Zhang *et al.*, 2012). Therefore the Servo motor rotation speed is proportional to the pulse frequency and the general servo motor rotation Angle is directly

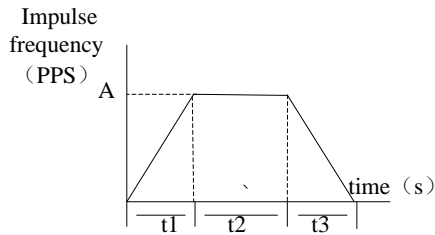


Fig. 4: Speed control curve of servo motor  
t1: Accelerate; t2: Tniform; t3: Decelerate

proportional to the total number of output pulses of the position module. By setting the number of output pulse of the positioning module by software, position control of the servo motor can be realized, to realize the adjustment of fluid injection volume of the filling system.

At the same time in order to prevent the system generating spills or bubbles in the process of injection, it is need to divide the inject process into three steps: acceleration, uniform speed, deceleration. It can set the output pulse frequency parameters of the positioning module to realize acceleration, uniformity and deceleration control of the servo motor the speed, so as adjust the fluid injection speed. The speed curve is shown in Fig. 4. All the parameters can be set through human-machine interface and real-time monitored.

The human-machine interface can communicates with PLC, server, etc., directly without the communication programing (Xiao *et al.*, 2011). By the means of master-slave communication, touch screen can transmit data to PLC; through the data storage area, all kinds of display and fault prompt can be realized (Liu and Xi, 2008). According to all kinds of possible faults in actual working condition, the alarm page is set and alarm lamps are displayed in the corresponding position. In the same time of displaying faults, fault resolution methods, times and frequency should be shown at the bottom of the page. In order to solve the problems in industrial field, a large number of help pages should be added on the touch screen page, including maintenance of injection servo system, usage and parameters Settings and so on.

## RESULTS AND DISCUSSION

**Software test:** In the aspect of software, according to the working process of the production line, the professional PLC programming software of Mitsubishi is used to compile control program of production line in the form of ladder diagram and write to the programmable logic controller, to realize the overall control logic and the production function of production line. The software block diagram is shown in Fig. 5.

The human-machine interface directly with the PLC communicate with each other, without programming, through the man-machine interface can complete the system parameter setting and monitoring.

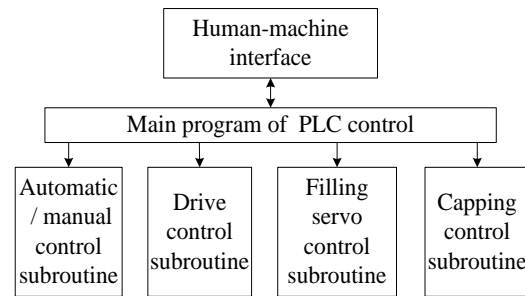


Fig. 5: Software block diagram

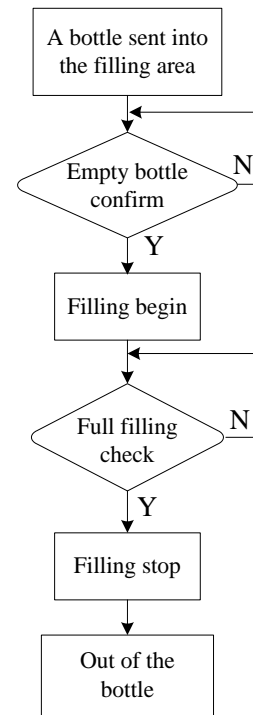


Fig. 6: Flow chart of filling program

**Automatic/manual control subroutine:** Complete automatic filling system to start, stop, reset and other functions and according to the actual condition of manual or automatic mode of operation.

**Drive control subroutine:** Completion of the main converter, speed control to adjust the frequency conversion motor; according to the filling speed adjust conveyor speed, so that the bottle feeding speeds and the filling speed matching.

**Filling servo control subroutine:** Mainly by adjusting the frequency and direction of the output pulse, drive servo drives, control precision filling pump lotion, liquid filling and filling speed.

**Capping control subroutine:** Control of capping mechanism cover cap on the filled bottle.

Filling metering section flow chart shown in Fig. 6.

**The flow of filling program:** When an empty bottle is sent into the filling area and confirmed by the online weighing system, the position detection sensor confirms the empty bottle is on the proper position. According to the different filling amount, the measurement parameters are set by the operator through human-machine interface and then stored in the system. After the filling head injecting, the full-filled bottle is sent to capping area by transmission system and filling head stop filling and then return and began to absorb liquid.

### CONCLUSION

This study designed the automatic filling control system controlled by PLC according to the filling technique requirement, which has high degree of automation, simple operation. This system adopted the servo drive control method, has the advantages of high precision measurement, adjustable filling capacity, simple structure, reliable operation, etc. The system can monitor the PLC interior and locale conditions and set the relevant parameters through the touch screen, the operation is flexible and convenient.

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