The Design of Hardware System of High Precision Dynamic Flow Controller

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Abstract. At present, the dynamic flow controller produced in China cannot meet the demand of pharmaceutical, food, beverage and other industries in terms of its precision. Therefore, a high precision dynamic flow controller detection device is designed to improve the control accuracy of the dynamic flow controller. The device also has the function of flow calibration. The experimental results show that the high-precision dynamic flow controller detection device designed in this paper has a great improvement in the control accuracy of dynamic flow controller and can realize the high-precision calibration function of the tested flowmeter.

1. Introduction

As we all know, dynamic flow controller is widely used in industry, agriculture, medical industry and daily life. However, the domestic dynamic flow controller market is monopolized by foreign countries [1]. In recent years, with the rapid development of domestic pharmaceutical, food, beverage and other industries, medical agents, beverages and health products and other products on the dynamic flow controller filling control accuracy requirements are higher and higher. However, the current domestic production of electromagnetic flow controller, its control precision cannot meet the needs of the above industries. Therefore, the research and development of dynamic flow controller detection device with independent intellectual property rights, improve the control accuracy of dynamic flow controller, has become the current research priority [2].

With the continuous development of economy and technology, relevant technologies have also been improved to some extent. At present, China has certain economic and technical strength to develop high-precision dynamic flow detection device for filling with independent intellectual property rights. The high demand of the market and the continuous improvement of technology provide the corresponding conditions and power for the development of dynamic flow controller detection device. The research and development of dynamic flow controller detection device with independent intellectual property rights cannot only meet the increasing demand of various fields in China, improve the accuracy of dynamic flow detection device, but also break the situation that domestic dynamic flow detection device is monopolized by foreign countries, and fill the gap in related fields in China [3].

The dynamic flow controller detection device designed in this paper mainly realizes the following two functions: rapid filling by controlling the dynamic flow controller; high precision calibration of meter by standard meter. Therefore, in the design of the high-precision dynamic flow controller detection device, the related accuracy requirements of the dynamic flow detection device in the
documents "JJG 643-2003 standard table method flow standard device" and "gbt34268-2017" are mainly referred to.

2. Overall design and implementation of the device
The hardware system of this device uses the high precision (0.1%) Coriolis mass flowmeter of RHM06 for flow measurement, and the high precision electromagnetic filling flowmeter of E+H Dosimag 5BH04 for filling. The controller unit adopts the industrial control host of Advantech and the upper computer development software-LabWindows/CVI of NI. The software system of the device provides an easy-to-use program for calibration and filling. Input work orders and verification parameters through the software system can be stored in the MySQL database, and the traceable calibration data can be stored locally through the database and WORD file format. Figure 1, figure 2 and figure 3 are the schematic diagram of the system design.

![Figure 1. Device top view.](image1)

![Figure 2. Part of the main view from the water tank to the inlet of the stabilizer tank in the main loop of the device](image2)

![Figure 3. Main view of tank outlet to water tank and test circuit in main circuit of device](image3)

The part label in the figure is as follows:
1-Tank; 2-Variable frequency pump; 3-Pressure stabilizing tank; 4-Electromagnetic flowmeter; 5-The first valve; 6-The first bellows; 7-The second bellows; 8-The second valve; 9-Check valve; 10-The third valve; 11-The fourth valve; 12-Standard flowmeter; 13-Filling flowmeter; 14-Cup; 15-Electronic scales; 16-The fifth valve; 17-The sixth valve; 18-The seventh valve; 19-First solenoid valve; 20-The second solenoid valve; 21-The first horizontal segment;
22-Vertical section; 23-The second horizontal segment; 24-The first branch; 25-The second branch; 26-Control desk; 27-Calibration station; P1-The first pressure sensor; P2-The second pressure sensor; P3-The third pressure sensor; P4-The fourth pressure sensor; P5-The fifth pressure sensor.

The control unit of this device is mainly composed of IPC-940 of Advantech, PCI series board card and ADAM data acquisition module. The control structure diagram is shown in figure 4.

**Figure 4.** Schematic diagram of system control structure.

IPC-940, as the upper computer of the whole system, is externally connected with Advantech's adam-4117 current data acquisition card, PCI-1715 high-speed voltage data acquisition card, and PCI-1780 high-speed counter board card. Among them, ADAM - 4117 modules realize the standard flowmeter, checked flowmeter and some of the current output of the sensor data acquisition function; PCI-1715 high speed voltage data acquisition board card to achieve the electromagnetic valve before and after the voltage output pressure sensor data collection function; PCI-1780 high speed counter board card can count the pulse output of the standard meter and the inspected meter as well as the function of starting and stopping the solenoid valve [4].

### 3. Innovative design of the device

Referring to the relevant requirements of this device in the documents of "JJG 643-2003 standard table method flow standard device" and "gbt34268-2017", the device shall meet the following indicators :(1) the overall measurement accuracy of the device shall reach 0.5%;(2) output stability of the device is 0.2%. Therefore, the device has high requirements on the stability of water circulation and the accuracy of filling performance.

#### 3.1. Design of water cycle stability

The stability of water circulation determines the excellent performance of the whole device. Therefore, the following two aspects are mainly considered when designing the water circulation system of the device: optimizing the water circulation control algorithm; optimize the hardware pipeline of water circulation system.
3.1.1. Optimization of water cycle control algorithm. The water circulation control system of the device is mainly composed of ACS355 inverter and Helix V603 pump, as shown in figure 5 and figure 6. The upper computer sends frequency conversion control instructions to ACS355 inverter through RS485 serial port communication to adjust the frequency output of the inverter, thus controlling the flow output of Helix V603 stainless steel multi-stage centrifugal pump.

![Figure 5. ABB ACS355 inverter](image1)

![Figure 6. Helix V603 stainless steel multi-stage centrifugal pump](image2)

The water circulation control system of this device adopts PID control algorithm, the standard table is the measuring feedback element; ABB frequency conversion, water pump and regulating valve are executive components; The flow standard device is the controlled object; The PID control algorithm module of Labwindows/CVI is the controller, and the block diagram of the control system is shown in figure 7.

![Figure 7. Basic block diagram of microcomputer process control system.](image3)

Due to the time delay of the feedback signal, namely the main loop electromagnetic flowmeter, in the process of signal acquisition and transmission, the PID control algorithm is easy to adjust the water source stability when there is a large fluctuation near the target value, the stability is not high. Therefore, the water source control algorithm is optimized in the design of this device. By reading the value of the feedback signal, it can judge whether the flow reaches the allowable error of the target value. When entering the error range, it can read the current output frequency of the inverter, close the PID control and open the output mode of frequency stabilization. Because in the acquisition of the signal delay of control system, frequency stabilization control on water stability of the control effect is better than the frequency conversion control, and so ended up in the device adopts the following algorithm: use PID algorithm to find within the set target error of inverter output power, find closed after frequency conversion control frequency stabilization control is used to improve the stability of the water [5].

3.1.2. Optimization of water circulation hardware pipeline. In the design of hardware pipeline, the device uses the method of large pipe diameter drainage of small pipe diameter to supply water to the test functional circuit. The working process of water source is as follows: firstly, the water pump is controlled by frequency converter to control the flow in the main loop of DN50 pipe diameter to a stable state; secondly, water is drawn from the main loop of DN50 pipe diameter for the test function loop of DN4 pipe diameter is shown in figure 8.
Figure 8. Large tube diameter drains small tube diameter

The pipeline design method of radial drainage by large pipe and small pipe diameter can effectively further reduce the influence of water source fluctuation on the measurement accuracy of equipment. Working principle is as follows: when the water wave of big diameter, as a result of fluctuations in water conductivity, when the fluctuation is conducted from DN50 pipe diameter to DN4 test function circuit, it will attenuate to some extent, so the function of the test circuit of the effect on the stability of the water will become smaller and tested to ensure that the water stability function circuit experiment.

3.2. Test function loop design

The test functional circuit mainly includes: calibration functional circuit and quick filling functional circuit, as shown in figure 9 and figure 10. When the calibration function is performed, open the valve on the left side of figure 10 and close the valve on the right side to introduce the calibration water flow into the water tank; In figure 9 the left side is the standard flowmeter, and the right side is the checked flowmeter. The ADAM4117 and PCI1780 boards are used to collect the output pulse and current signals of the checked flowmeter and the standard flowmeter, so as to calibrate the checked flowmeter. When carrying out the calibration function, open the valve on the right side and close the valve on the left side in figure 10, and introduce the filling water into the measuring cup. In figure 9, the checked flowmeter on the right is changed into E+H Dosimag 5BH04 high-precision electromagnetic filling flowmeter. The PCI1780 board card is used to collect the electromagnetic filling flowmeter for weighing and comparing with the electronic scale reading under the measuring cup.

Figure 9. Calibration function part of pipeline

Figure 10. Quick filling function part of pipeline

The solenoid valve is used to switch the filling flow in the hardware design of the quick filling function. However, the solenoid valve working principle of the defect: When the solenoid valve on electricity, by the electromagnetic force to close the coil, action time is short; after the loss of
electricity, by mechanical force to open the coil, the action time is slow. As a result, the speed of the switch controlling the filling water flow is not ideal [6]. Therefore, the design of this device adopts the mode of dual solenoid valve control, as shown in figure 10. Normally closed solenoid valve and normally open solenoid valve are installed successively before filling outlet. Normally closed solenoid valve is used to control water flow opening and normally open solenoid valve is used to control water flow closing. The purpose is to make the water flow in the opening and closing is driven by the electromagnetic force after the power, thus greatly improving the rapid filling performance.

4. Experimental analysis
According to the calculation method of flow stability verification in "JJG 643-2003 standard table method flow standard device", the stability analysis of the whole device was carried out. By weighing the same filling mass point through filling experiment, the repeatability of fast filling function is calculated. According to the above method, the device has passed the verification and inspection of Shanghai institute of metrology and testing technology. Experimental data are shown in table 1.

| Serial number | project            | Calibration results | Extended uncertainty(k=2) |
|---------------|--------------------|---------------------|---------------------------|
| 1             | Flow stability     | 0.12m³/h 0.06%      | /                         |
|               |                    | 0.63m³/h 0.08%      | /                         |
| 2             | Filling repeatability | 50g 0.20%          | $U_{rel} = 0.10\%$       |
|               |                    | 500g 0.03%          |                           |

5. Conclusion
The high-precision dynamic flow controller detection device designed in this paper can realize the functions of high-precision calibration and rapid filling of the tested flowmeter. Moreover, the stability of the flow rate of the device can reach 0.08%, and the repeatability of the filling function can reach 0.20%. The control precision of dynamic flow controller is improved, which can meet the control precision of pharmaceutical, food, beverage and other industries.

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