Design of Pipeline Flowmeter Calibration System Based on PLC Control

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Abstract. In order to solve the problems of error and data storage and calculation in the calibration process of traditional pipeline flowmeter due to human factors, a calibration system based on PLC control was designed on the basis of a standard method. PLC controls the frequency converter through CAN bus, and then controls the motor to supply water to the calibration system. At the same time, the PLC extended IO modules are used to collect the real-time flow data of the standard meter and the tested meter. PLC and upper computer through Ethernet information exchange, and the use of the Kingview software to achieve the basic control of the PLC and the data display, data storage, data calculation. The test data show that when the errors of the standard table meet ±0.5%, the errors of the tested meter can meet ±1%, and the calibration efficiency is high and the data are accurate. Therefore, compared with the manual calibration method, the calibration system based on PLC control can better control the errors, and is more convenient for data storage and calculation, and has higher practical value.

1. Introduction

Pipeline flow measurement is one of the important components in the field of modern measurement, playing a great role in social life, industrial production, scientific research and national defense construction and many other fields[1]. In the actual production process, in order to ensure that the pipeline flowmeter can accurately measure the work, the equipment needs to be calibrated during the factory inspection[2][3]. The traditional pipeline flowmeter output inspection and calibration process mostly adopts manual recording of data or semi-automatic process, which requires a long time and heavy workload, and has a high probability of error caused by human factors, leading to the failure to achieve the purpose of accurate measurement[4][5]. Data storage and data calculation in the calibration process are time-consuming and labor-intensive, which greatly restricts the industrialization development. Therefore, a calibration system of pipeline flowmeter based on PLC is designed, and the precision calibration of pipeline flowmeter is carried out by using the standard meter method, and the intelligent control of the calibration system is realized.

2. System calibration principle

The standard meter method is to use the flowmeter with high accuracy grade and good repeatability as the standard meter to realize the calibration in series with the tested meter. Since the standard meter and the tested meter are in the same pipeline, according to the continuity of flow, the flow through the two meters is the same. Therefore, the measurement data of the two meters can be compared to
calculate the measurement errors of the tested meter\cite{6}\cite{7}, and then adjust the parameters of the meter to achieve the purpose of calibration.

For the selection of the calibration method, the calibration process of traditional flowmeter at home and abroad generally adopts the weighing method or the volume method\cite{8} to ensure the accuracy of calibration. Compared with these two methods, the calibration accuracy of standard meter method is slightly lower, but within the allowable error range. The standard meter method has the advantages of easy automation, wide application range, simple operation and high calibration efficiency, and can be applied to the calibration of most pipeline flowmeters, including ultrasonic flowmeters.

By connecting the tested meter and the standard meter together in series into the pipeline system, the same acquisition rate and transmission rate are set for the standard meter and the tested meter, and then the system is started for real flow detection. The two flowmeters work at the same time and upload the measured data to the PLC through their respective transmission channels for real-time flow calibration. We write the measurement data of the standard flow meter as $Q_s$ and the measured flowmeter as $Q_i$, then the flowmeter error at the same sampling time point can be calculated as:

$$E = \frac{Q_i - Q_s}{Q_s}$$ (1)

In the calibration of industrial equipment such as flow meter, in order to improve the calibration accuracy of equipment, multiple measurements are usually carried out at multiple flow reference points, that is, multiple flow data are collected at one flow point. The repeatability test of the sensor is carried out through multiple data of the same flow point. The better the repeatability is, the smaller the error of the sensor is, and the higher the calibration accuracy of the sensor is. The repeatability calculation formula is as follows:

$$\delta = \frac{\sigma}{x} \cdot 100\%$$ (2)

$$\sigma = \sqrt{\frac{\sum (x_i - x)^2}{n-1}}$$ (3)

In equation (2) and equation (3), $n$ is the actual measurement times; $x_i$ is the result of each measurement; $x$ is the average value of multiple measurements; $\sigma$ is the standard deviation.

3. System design

3.1. System hardware design

3.1.1. Overall design of calibration system. As shown in figure 1, the upper computer inputs the flow detection point, the PLC controls the frequency converter and then controls the motor for water supply. The standard meter and the tested meter measure the flow data in real time and upload it to the PLC. The PLC calculates the errors of the two in real time through the configuration of the upper computer software, and adjusts the parameters of the tested meter in real time according to the calculation results. In order to improve the calibration accuracy, the calibration of multiple flow detection points is carried out, and the multiple flow detection points are input to the PLC through the upper computer. If the error of the current flow detection point meets the requirements, the calibration of the next detection point is carried out. The real-time flow data of the standard meter and the tested meter can be checked in real time by the upper computer software, and the errors and repeatability can be calculated automatically, so as to judge the calibration effect and accuracy.
3.1.2. **Standard meter design.** The standard meter is designed and improved on the basis of the electromagnetic flowmeter calibrated by the National Bureau of Metrology, and the measuring principle is shown in figure 2.

![Figure 2. Schematic diagram of standard meter measurement.](image)

According to the principle of standard meter measurement, we can get:

\[ U_E = BDv \]  \hspace{1cm} (4)  
\[ Q = S \cdot v = \pi \left( \frac{D^2}{2} \right) v \]  \hspace{1cm} (5)

In equation (4) and equation (5), \( U_E \) is the signal electrode voltage, V; \( B \) is magnetic field intensity, A/m; \( D \) is pipe diameter, m; \( v \) is the average flow rate, m/s; \( Q \) is volume flow, m³/s; \( S \) is the cross-sectional area of the pipeline, m².

In combination with equation (4) and equation (5), we can obtain:

\[ U_E = \frac{4BDQ}{\pi D^2} \]  \hspace{1cm} (6)

According to equation (6), the voltage between the signal electrodes \( U_E \) is in a linear relationship with the volume flow rate \( Q \), and the volume flow rate can be calculated according to the voltage under the condition of known magnetic field intensity and pipe diameter.

3.1.3. **PLC control module design.** The core control part of the calibration system adopts GCAN-PLC, which is composed of the programmable master control module GCAN-PLC-400, the expanded GC series IO module and a terminal resistance module GC-0001.
The upper computer writes the program into the PLC master control module through the controller programming interface. In order to ensure the reliability and real-time performance of the calibration system, the PLC master control module controls the frequency converter through the CAN bus mode, and connects with the frequency converter through the 4P terminal.

The PLC extends at least two GC series IO modules, one of which is connected to the tested meter and the other to the standard meter. The main control module can automatically allocate the address according to the position before and after inserting the IO module to realize the automatic configuration. In order to enhance the reliability of CAN communication and eliminate the interference of CAN bus terminal signal reflection, a GC-0001 terminal resistance module is installed at the right end of all IO modules of GCAN-PLC to ensure data transmission and power supply between GC series IO modules.

3.1.4. Inverter anti-interference circuit design. The frequency converter is connected to the PLC as a load. In order to avoid the crosstalk between the external power supply and the internal power supply of the frequency converter, the optical coupling and isolation module is designed to realize the electric-opto-electric conversion and effectively improve the anti-interference ability, as shown in figure 3.

![Figure 3. Inverter anti-interference circuit design.](image)

3.2. System software design

3.2.1. PLC internal program design. The PLC internal program design is the core of the calibration process, and determines the PLC control behavior. First, the upper computer input flow detection point, then PLC controlled inverter meter motor begin to supply water. In the process of water supply, the flow data of the standard meter and the tested meter are measured in real time and uploaded to the PLC. The PLC calibrates the meter according to the uploaded data. After calibration, it continues to judge whether the error between the meter and the standard meter meets the requirements according to the real-time data. If the error is too large, the calibration will be carried out again, and the cycle will continue until the calibration work of the tested meter is completed.

3.2.2. Upper computer control and display interface design. The Kingview software is used to design the control and display interface of the upper computer, as shown in figure 4. The flow value of the checking point in the interface is the fixed value input by the upper computer and remains unchanged in the calibration process. The flow value of the standard meter, the flow value of the tested meter and the flow meter errors are updated in real time according to the measurement data. Three buttons "START", "PAUSE" and "END" can control the calibration process. After the calibration process of different test points is completed, the historical data in the calibration process can be viewed through the "Historical Data Report" button, and the repeatability between the standard meter of each test point and the tested meter can be viewed through the "Repeatability Report" button.
4. Test results and data analysis

The standard meter is grade 0.5, and the calibration can be regarded as completed if the tested meter meets grade 1 standard during the calibration process.

When the flow value at the checking point is 100 m$^3$/h, the data of the standard meter and the tested meter as well as their historical error data are shown in Table 1. Due to the influence of the hardware of the calibration system, the flow value of the standard meter increases from 79.9 m$^3$/h. Under the control of PLC built-in PID program, the flow value increased to 122.9 m$^3$/h and began to fall, and finally stabilized around the test point. At the same time, the tested meter was adjusted and changed with the standard meter, and the errors of the two gradually decreased. Finally, the standard meter data meet the error range of ±0.5%, and the tested meter data meet the error range of ±1%. At this point, the calibration can be regarded as completed, and the calibration process can be manually ended to enter the calibration of the next marking point. As shown in Table 2, the situation is similar when the flow value at the detection point is 150 m$^3$/h.

The repeatable data will be generated after calibration of each check point, as shown in Table 3. When the detection point was 100 m$^3$/h, the repeatability of the standard meter and the tested meter was 0.1096 and 0.134, respectively. When the test point was 150 m$^3$/h, the repeatability of the standard meter and the tested meter were 0.1155 and 0.1347, respectively. The repeatability of the tested meter is not much different from that of the standard meter, which indicates that the calibration process of the tested meter is successful.

Table 1. Data of 100 m$^3$/h test point.

| Check point (Q) | Standard meter (Qs) | Tested meter (Qi) | Error (E) |
|----------------|--------------------|------------------|-----------|
| 100            | 79.9               | 69.6             | -0.129    |
| 100            | 91.5               | 83.4             | -0.089    |
| 100            | 97.1               | 90.1             | -0.072    |
| 100            | 108.0              | 102.6            | -0.050    |
| 100            | 122.9              | 119.8            | -0.025    |
| 100            | 116.6              | 114.1            | -0.021    |
| 100            | 100.1              | 99.5             | -0.006    |
| 100            | 100.3              | 100.8            | 0.005     |
| 100            | 100.0              | 99.6             | -0.004    |

Table 2. Data of 150 m$^3$/h test point.

| Check point (Q) | Standard meter (Qs) | Tested meter (Qi) | Error (E) |
|----------------|--------------------|------------------|-----------|
| 150            | 120.3              | 104.6            | -0.131    |
| 150            | 143.4              | 131.8            | -0.081    |
| 150            | 153.4              | 143.6            | -0.064    |
| 150            | 187.4              | 183.0            | -0.023    |
| 150            | 174.4              | 172.8            | -0.009    |
| 150            | 160.5              | 159.6            | -0.006    |
| 150            | 150.4              | 151.0            | 0.004     |
| 150            | 150.0              | 150.1            | -0.001    |
| 150            | 150.2              | 150.2            | 0.000     |
Table 3. Repetitive data.

| Check point | Repetitive data |
|-------------|-----------------|
| 100         | Standard meter 0.1096, Tested meter 0.134 |
| 150         | Standard meter 0.1155, Tested meter 0.1347 |

5. Conclusion

In this paper, aiming at the problems in the traditional pipeline flowmeter calibration system, a calibration system based on PLC control is designed. The system takes the PLC as the control core, the standard meter method as the basic calibration method, the Kingview PC software as the data display and storage center, and carries out a series of field tests.

According to the measured data, the system has higher calibration efficiency and precision control and error, data storage, and solves the traditional calibration error and factitious factors in the process of data storage and difficult problems. It also realizes the automatic control of the pipeline flowmeter calibration system, which has certain reference value to the development of other calibration systems.

Acknowledgments

First of all, I would like to thank my tutor for his patient guidance, which helped me learn how to arrange the content and wording of the paper. Secondly, thanks to my classmates and family for their help and support, which keeps me in a good state of mind in the process of writing the paper. Finally, I would like to express my gratitude to those reviewers who have never met before but have given me guidance. Your opinions and suggestions have helped me to make progress.

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