Research on Automatic Calibration and Correction Method of Intelligent Turbine Flowmeter

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Abstract. In the process of industrial automation production and daily life, the flow is an important parameter that often needs to be measured and controlled. In order to ensure the accurate measurement of flow meter, the flowmeter needs to be calibrated before production, during use and after maintenance. However, most of the existing calibration methods are complicated in the calibration process, and there are many human interventions. The functions of the intelligent flowmeter are not fully utilized, and the unified management requirements for equipment during large-scale deployment cannot be met. This paper provides a method for automatic calibration of intelligent turbine flowmeter, which can be applied to a variety of intelligent instruments. In the calibration phase, the flowmeter automatically completes the calibration data collection at each calibration point set by the user. After all calibrations are completed, the calibration data will be stored in the flowmeter inside and it also will be uploaded to the host computer through the wireless network. At the same time, the configuration information can be received remotely. In the measurement phase, according to the internal calibration data and the K value fitting method selected by the user, the flowmeter can realize the non-linear correction of flow measurement and improve the accuracy of measurement results. User also can self-configure the instrument parameters. Compared with the existing calibration and correction methods of flowmeter, it simplifies the calibration process, has a high degree of automation, improves the accuracy of measurement results, and gives full play to the functions of intelligent instruments.

1. Introduction
In the process of industrial automation production and daily life, there are many occasions that need to measure the flow. Flow rate is an important parameter that often needs to be measured and controlled. The measurement of fluid flow rate is essential for energy conservation, pollution prevention and production process. With the development of production technology, higher and higher requirements are put forward for the measurement of fluid flow and total volume, and more and more material need to be tested. In order to ensure the accurate measurement of flow meter, the flowmeter needs to be
calibrated before production, during use and after maintenance. However, the existing flow calibration methods are to connect the measured flowmeter to the computer of the calibration system, process the calibration data on the computer and then manually input the calibration results into the flowmeter to complete the data update. This increases the operation steps, has many human factors, and does not give full play to the function of intelligent flowmeter.

According to the requirements of JJG 1037-2008 verification regulation of turbine flowmeter, only linear section of instrument coefficient $K$ can be used for digital secondary instrument, that is, above 30% $Q_{\text{max}}$. This is due to the influence of physical characteristics of turbine flowmeter. Under 30% $Q_{\text{max}}$, the linearity of instrument coefficient $K$ is very poor. The actual $k-q_v$ curve will produce peak characteristics at 20% - 30% $Q_{\text{max}}$, as shown in Fig. 1. However, from the reality, if the flow section below 30% $Q_{\text{max}}$ meets the requirement that the repeatability is less than one fifth of its error, then these available non-linear sections with good repeatability are not actually used, which greatly reduces the use scope of turbine flowmeter and causes waste of resources. In addition, most of the existing flowmeters treat the $K$ value of the instrument coefficient as a constant, which will also bring a large measurement error in the non-linear section.

2. Design of Intelligent Turbine Flowmeter

The composition of the intelligent turbine flowmeter is shown in Fig. 2. The intelligent turbine flowmeter has a human-computer interface, which can operate and set the flowmeter with buttons and screens. All of the following operations are completed by human-computer interaction of intelligent turbine flowmeter. Intelligent turbine flowmeter has flash memory function, which can store device parameters and operation data. At the same time, it has a variety of data output methods to meet the requirements of different scenarios.

Before starting calibration, first select the instrument model to be calibrated. After selection, the intelligent turbine flowmeter will automatically load and display various parameters and historical
storage data corresponding to the selected model. If the parameters of the flowmeter need to be modified, enter the corresponding page for modification. The calibration and correction flowchart of intelligent turbine flowmeter is shown in Fig. 3 below:

![Calibration and correction flow chart of intelligent flowmeter.](image)

**Figure 3.** Calibration and correction flow chart of intelligent flowmeter.

### 3. Automatic Calibration Method

Install the tested meter on the pipeline of the calibration device to ensure that the front sensor of the flowmeter is installed in the correct position. The calibration algorithm uses the method of point by point to calibrate each flow point separately. The flow points to be calibrated need to be selected in order from small to large. When the calibration flow point is determined, the interval between each flow point is small when it is close to the lower flow limit, and large when it is close to the upper flow limit. This is because of the good linearity in the large flow range and the poor linearity in the small flow range, so more calibration points are needed in the small flow range to improve the fitting and measurement accuracy.

After setting a flow point value to be calibrated on the secondary meter of the flowmeter, adjust the standard flow output by the calibration device (such as the calibration bench) with the standard flow value, and then make the intelligent flowmeter start to calibrate this flow point. The internal frequency measurement algorithm flow is shown in Fig. 4. Using the input capture function of the STM32 to measure the pulse signal frequency by the periodic method.
At this time, the frequency value obtained is based on the single pulse period, which may not only have large error, but also have obvious numerical fluctuation. So we call the flow calibration algorithm to further process and optimize the obtained flow value, and the processing flow is shown in Fig. 5. First of all, we wait for 12 consecutive pulse frequency values, and take 12 frequency values as a group to eliminate the abnormal values (i.e. gross error). The method adopted here is the Grubbs’ test method, and the specific implementation method is as follows: rank the 12 data in the order of small to large, and calculate the average value $\bar{x}$ and standard deviation $s$, and then calculate the deviation between the minimum value and the maximum value. If the deviation value is large, it shall be regarded as suspicious value, and the formula shall be used $G_i = (x_i - \bar{x}) / s$ Calculating suspicious value $G_i$ Value. The detection level of the algorithm is 0.01, that is, the confidence probability $p = 0.99$, the number of measurements $n = 12$, and the critical value of Grubbs’ table is 2.55. Compare the critical value with $G_i$ Value, when the $G_i$ Value, when the $G_i$ value is greater than the critical value, it is regarded as an abnormal value to be eliminated. Calculate the remaining data according to the above steps until $G_i$ is less than the critical value. The rest of the data is filtered by arithmetic average to eliminate the random interference in the flow signal.

Then the limiting average filtering is carried out. Compare the new value obtained above with the previous value, if the cycle time deviation is less than 0.2us or greater than 10ms, the current value is invalid, abandon the current value and replace the current value with the previous value to overcome the pulse interference caused by accidental factors. Then a queue with length of 4 (Based on number of turbine blades) is added to carry out sliding average filtering. Put the new data into the end of the team, and discard the first data of the original team. The new filtering results are obtained by arithmetic average of the four data in the queue, which can restrain the periodic interference.

When the number of cumulative filtering results reach 50 times and the running time of the calibration algorithm reaches 10s, the calibration of this flow point is completed, the arithmetic average of the filtering results is taken, and the final frequency is output as the calibration data, thus the software

![Flow chart of frequency measurement of flowmeter.](image)

**Figure 4.** Flow chart of frequency measurement of flowmeter.
filtering algorithm is completed. The algorithm can effectively overcome the pulse interference caused by accidental factors and random factors, and has a good inhibition effect on periodic interference, high smoothness, and real-time ability to meet the use requirements.

Figure 5. Flow chart of flowmeter calibration algorithm.

After the calibration data is generated, the intelligent flowmeter is based on the formula (1):

$$K = \frac{f_{\text{calibration}}}{Q_{\text{calibration}}}$$

(1)

The instrument coefficient $K$ value of this calibration point is calculated automatically, and the frequency value of the calibration point and the corresponding $K$ value are stored in the flash as two groups of data for the use of nonlinear correction algorithm. After all flow points' calibration is completed, the calibration of this model is done, and all calibration data are updated and bound with this model. At the same time, the intelligent flowmeter packs the calibration data and sends it to the gateway through ZigBee wireless network, and then transfers it to the host computer for further processing, storage and management of the host computer software. The encapsulation format of calibration data is as follows:
Table 1. Upload data protocol format

| implication | field |
|-------------|-------|
| Frame head  | 0XFF  |
| MacID       | 2-Byte|
| Meter Model | 2-Byte|
| number of calibration points | 1-Byte|
| Flow of calibration point 1 | 3-Byte|
| Freq of calibration point 1 | 3-Byte|
| ...         | ...   |
| Flow of calibration point n | 3-Byte|
| Freq of calibration point n | 3-Byte|
| Frame tail  | 0XEF  |

At the same time, the host computer can select a specific flowmeter or broadcast all flowmeters to send configuration information. After receiving the configuration information, the flowmeter modifies the internal parameters and stores them in this machine. Only frame head and frame tail of the data encapsulation format of configuration information are different with TABLE I as the rest are the same. The frame head is changed to 0XDD and the frame tail is changed to 0XCD.

4. Automatic Correction Method

Enter the non-linear correction page, the user can choose the k-value fitting method or manually change the f-k curve data, fully realizing the user customizable. The data of F-K curve is the data of the last calibration, which is taken out from flash and displayed on the screen. Users can change any of these values, which will overwrite the original data in flash. And send the change information to the host computer wirelessly, update the configuration information in the database, and realize the synchronous management. The format of data sent is as follows:

Table 2. Modify data protocol format

| implication | field |
|-------------|-------|
| Frame head  | 0XAA  |
| Meter Model | 2-Byte|
| MacID       | 2-Byte|
| Frequency / K value? | 1-Byte|
| Order number of changed point | 1-Byte|
| Update value | 3-Byte|
| Frame tail  | 0XAB  |

The k-value fitting method including two methods: piecewise linear slope method and Polynomial approximation method. The former divides the f-K curve into polylines, and the inflection point is the calibration data point.

\[ \text{The actual } K \text{ value} = \text{the slope of the segmented interval} \times (\text{the measured frequency} - \text{the initial value of the interval frequency}) + \text{the initial value of the interval } K \text{ value}. \]

The latter uses the least square method to fit the polynomials of f-K relation, and directly substitutes the measured frequency into the polynomials to get the actual K value.

According to the fitting principle, the more the calibration points, the better the fitting effect, and the higher the accuracy of the K value. According to the measurement principle of turbine flowmeter,

\[ Q_\nu = \frac{f}{K} \]  

(2)
Using the optimized frequency measurement algorithm to achieve the accurate measurement of frequency value, using the K value subsection fitting or curve fitting to improve the accuracy of K value, so as to improve the accuracy of flow measurement.

5. Experimental Results and Conclusions
The experimental results show that the error of instantaneous flow indication is less than $\pm 0.3\%$. The measurement accuracy is improved obviously. The following is the experimental data. The calibration device is S064 flow tester, the calibration medium is red oil, the ambient temperature is room temperature ($22^\circ C$), the atmospheric pressure is 101325 Pa, and the full range of turbine flow transmitter used is 5L/min. TABLE III shows the calibration results after adopting the calibration and correction methods in this paper.

From TABLE III, the maximum indication error within the range is kept at within $\pm 0.3\%$, and the range of turbine flowmeter can be as low as 10% $Q_{\text{max}}$, which greatly expands the range of flowmeter. Using the automatic calibration and correction method in this paper, the following can be achieved:

- Highly customized users can set the instrument model, range, calibration point, K value fitting method, etc., and store them in the flowmeter, which is suitable for different occasions. At the same time, the data can be uploaded to the host computer through ZigBee wireless network or downloaded to the local computer for unified management.
- It simplifies the calibration process, reduces the human factors in the calibration process, improves the automation of the calibration process, and gives full play to the advantages of intelligent instruments. On the premise of meeting the use requirements, the non-linear section with good repeatability below 30% $Q_{\text{max}}$ has also been used, greatly expanding the range of turbine flowmeter.
- Provide a variety of k-value curve fitting methods, reduce the error caused by treating k-value as a constant, improve the measurement accuracy of flowmeter, and meet the measurement requirements of more occasions.

| Point number | Nominal flow (L/min) | Measured flow (L/min) | Indication error (%) | Average error (%) |
|--------------|----------------------|-----------------------|---------------------|-------------------|
| 1            | 5.0                  | 5.011                 | 0.22                | 0.207             |
|              | 5.0                  | 5.010                 | 0.2                 |                   |
|              | 5.0                  | 5.010                 | 0.2                 |                   |
|              | 4.0                  | 3.993                 | -0.175              | -0.1              |
|              | 4.0                  | 3.996                 | -0.1                |                   |
|              | 4.0                  | 3.999                 | -0.025              |                   |
|              | 3.0                  | 3.008                 | 0.267               | 0.256             |
|              | 3.0                  | 3.007                 | 0.233               |                   |
|              | 3.0                  | 3.008                 | 0.267               |                   |
|              | 2.0                  | 1.994                 | -0.3                | -0.267            |
|              | 2.0                  | 1.994                 | -0.3                |                   |
|              | 2.0                  | 1.996                 | -0.2                |                   |
|              | 1.5                  | 1.496                 | -0.267              | -0.267            |
|              | 1.5                  | 1.496                 | -0.267              |                   |
|              | 1.5                  | 1.496                 | -0.267              |                   |
|              | 1.0                  | 1.002                 | 0.2                 | 0.133             |
|              | 1.0                  | 1.001                 | 0.1                 |                   |
|              | 1.0                  | 1.001                 | 0.1                 |                   |
|              | 0.7                  | 0.699                 | -0.143              | -0.238            |
|              | 0.7                  | 0.698                 | -0.286              |                   |
|              | 0.7                  | 0.698                 | -0.286              |                   |
|              | 0.5                  | 0.500                 | 0                   |                   |
|              | 0.5                  | 0.499                 | -0.2                | -0.067            |
|              | 0.5                  | 0.500                 | 0                   |                   |
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References
[1] Lei Tianren, Pu Wentao, “Application of piecewise linearization in the calibration of turbine flowmeter,” J. Measurement technology, vol. 33 (S1), 2013, pp. 105-107.
[2] Pan Wei, “Research on flow calibration control system based on turbine flowmeter,” D. Dalian University of technology, 2006.
[3] Gou Lianmin, “Exploration and application of intelligent gas turbine flowmeter,” J. China Metrology, vol.04, 2010, pp. 121-122.
[4] Wang Zhangsheng, “Design of a multi bus protocol flowmeter calibration system,” J. Journal of Changjiang University (self SCIENCE EDITION), vol.11 (01), 2014, pp. 47-48 + 3-4.
[5] Liu Weiwei, “The influence of calibration medium on the meter coefficient of flowmeter,” J. Electronic test, vol.z1, 2018, pp. 127 + 129.
[6] Kong Lei, “Design of flow meter calibration system based on Kingview,” D. Qufu Normal University, 2015.