Research on the parameters of unit element indirect calibration method

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Abstract

The theory of unit element indirect calibration is introduced by this paper by the key parameters of unit element indirect calibration is how to precisely measure the induced electromotive force in the low cost cases. The relationship of measurement error between electromagnetic flow meter and small measurement tube was analyzed in detailed, and the specific expression was given. The comparison experiment was made between unit element indirect calibration and actual flow calibration; experimental results show that the analysis of small measurement tube precision is credible.

Keywords: unit element; indirect calibration; small measurement tube; measurement precision

1 Introduction

To make sure the measurement accuracy of electromagnetic flow meter, the flow meter must be calibrated. Large diameter electromagnetic flow meter is usually calibrated with actual flow calibration [1], but the actual flow calibration device is very expensive. For example a flow capable of handling 1.2m tubes requires a pump power of around 250kw to provide a water flow of around 1.5t/s. This represents an investment cost of about $3M [2]. The calibration rig of large electromagnetic flow meters considerably adds to the cost of the final product. Therefore, people was always pursuing a low cost method to calibrate it, and made some achievements, such as ion current calibration method [3], surface weight function method [4], eddy current calibration method [1, 5], etc.

But these methods have certain disadvantage more or less, taking ion current calibration method for example [6], it replaces the flow of virtual fluid by the ion flowing in fluid, and calibrates the flow meter by the value of ion electric current. Because of the ion electric current method does not need additional equipments, and it avoids the energy consumption to make the liquid flow, electromagnetic flow meters with any calibers can be calibrated accurately with very low cost. But the disadvantage is that the ion electric flow is slow and the ion electric current is weak, which will be easily influenced by other factors and leads to inaccurate measurement. Till now, the low cost calibration method still not widely used because of such condition.

The unit element indirect calibration method [7, 8] is a new calibration method for large diameter electromagnetic flow meter. It divides the whole calibration space into many small unit element based on unit element theory. When calibrating, the theoretical unit element is replaced by small measurement tube, measuring the space characteristics point by point. Reconstruct the flow field and electromagnetic field with the measured data. So the high precision and low costs of calibration results was achieved. The measurement precision of small measurement tube was analyzed based on the unit element calibration method. The experiment results proved that the design and simulation of small measurement tube is correct.

2 Unit element low cost calibration method

When fluid is flowing through the electromagnetic flow meter, see Figure 1 [9], the induced electromotive force E has difference between two electrodes according to Faraday Electromagnetic Induction Law. The EMF (Electromotive Force) as following [1]:

$$E = \frac{2}{\pi R}\int_0^R\int_0^{2\pi} W(r,\theta)\cdot B(r,\theta)\cdot v(r,\theta)\cdot r\cdot dr\cdot d\theta, \qquad (1)$$

where B is the magnetic field distribution, v is the flow velocity distribution, r is the radial coordinate, R is the pipe radius and θ is the azimuthally coordinate. W is the weighting function, used to express the contribution degree of fluid to electrode potential. The weighting function value of long tube could obtained through the following formula [9, 10]:

$$W(r,\theta) = \frac{1+(r^2\cos 2\theta)/R^2}{1+(2r^2\cos 2\theta)/R^2 + r^4/R^4}. \qquad (2)$$

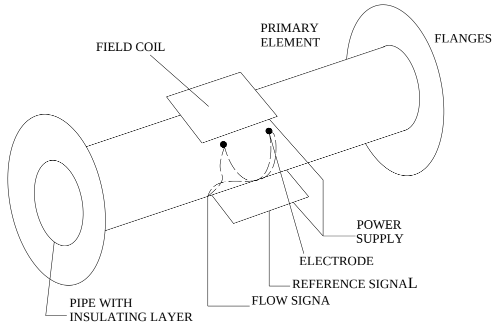


FIGURE 1 The principle of electromagnetic flow meter

If the whole flow meter is divided into many fluid micro elements with the same size, then the emf of unit element is given by:

$$e(r,\theta) = B(r,\theta)v(r,\theta)\Delta\tau , \qquad (3)$$

$\Delta\tau$ is the theoretical diameter of fluid element, so the emf of flow meter electrode can be expressed as:

$$E = \sum_{i=1}^{n} W_i(r,\theta)e_i(r,\theta) . \qquad (4)$$

Taking the small measurement tube as theoretical unit element, see Figure 2. Measuring the space characteristics point by point, Hence Equation (1) can be replaced by:

$$E = k_1 \sum_{i=1}^{n} W_i(r,\theta)e_i(r,\theta) , \qquad (5)$$

k_1 is the device coefficient caused by small measurement tube. Obviously, how to accurately measure the EMF of small measurement tube is the key factor of unit element calibration method. In the whole calibration process, just let conducting fluid with a certain flow rate run through the tube, needn't water tower, water pumps and other large device, and greatly reduce the cost, this is the basic principle of unit element low cost calibration method.

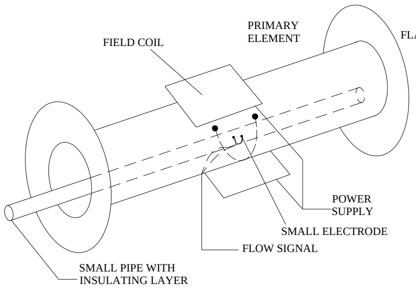


FIGURE 2 The principle of unit element low cost calibration

3 The precision of small measurement tube

As Equation (5) shown, the measurement results can be weighted composed with the measured value of small tube. Accordingly, it is very important for the whole measurement results to accurately measure the small tube.

3.1 THE ERROR COMPOSITION OF ELECTROMAGNETIC FLOW METER

Suppose the measurement error of electromagnetic flow meter only caused by small tube accuracy, the relation between each measured value e of the tube and EMF W can be expressed by the following function:

$$E = f(e_1, e_2, e_3, \cdots, e_m) , \qquad (6)$$

where m is the number of measure points. Hypothesis the measured flow meter is repeated calibrated at same condition, the measure times is n. $\delta_{\lim E}$ Indicate the whole random error of flow meter; δe indicate the random error of small measurement tube, then the measurement error of every point is

$$\begin{matrix} \delta e_{11}, \delta e_{21}, \delta e_{31}, \cdots, \delta e_{n1} \\ \delta e_{12}, \delta e_{22}, \delta e_{32}, \cdots, \delta e_{n2} \\ \vdots \qquad\qquad \vdots \\ \delta e_{1n}, \delta e_{2n}, \delta e_{3n}, \cdots, \delta e_{mn} \end{matrix} . \qquad (7)$$

The whole measurement error of every point is

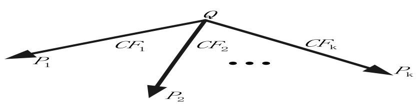
$$\begin{aligned} \delta_{E1} &= \frac{\partial f}{\partial e_1}\delta e_{11} + \frac{\partial f}{\partial e_2}\delta e_{21} + \cdots + \frac{\partial f}{\partial e_m}\delta e_{m1} \\ \delta_{E2} &= \frac{\partial f}{\partial e_1}\delta e_{12} + \frac{\partial f}{\partial e_2}\delta e_{22} + \cdots + \frac{\partial f}{\partial e_m}\delta e_{m2} \\ &\vdots \qquad\qquad\qquad \vdots \\ \delta_{En} &= \frac{\partial f}{\partial e_1}\delta e_{1n} + \frac{\partial f}{\partial e_2}\delta e_{2n} + \cdots + \frac{\partial f}{\partial e_m}\delta e_{mn} \end{aligned} . \qquad (8)$$

Add both sides of Equation (8) together after squared, divided by measurement times n, the results are as follows:

$$\begin{aligned} \sigma_E^2 = &\left(\frac{\partial f}{\partial e_1}\right)^2 \sigma^2 e_1 + \left(\frac{\partial f}{\partial e_2}\right)^2 \sigma^2 e_2 + \cdots \\ &+ \left(\frac{\partial f}{\partial e_m}\right)^2 \sigma^2 e_m + 2\sum_{i\neq j} \frac{\partial f}{\partial e_i}\frac{\partial f}{\partial e_j} \sum_{k=1}^{n} \delta e_{ik}\delta e_{jk} \Big/ n \end{aligned} . \qquad (9)$$

If the measurement times is big enough, $\sum_{k=1}^{n} \delta e_{ik}\delta e_{jk} \Big/ n$ namely the covariance of e_{ik} and e_{jk}.

Because the random error of every measurement values is independent of each other, when n big enough, correlation coefficient is zero; Hence Equation (9) can be expressed by



. (10)

Obviously, $\partial f / \partial e_i$ corresponding to the weighted function W_i of Equation (4), so Equation (10) can be replaced by

$$\sigma_E^2 = (W_1)^2 \sigma^2 e_1 + (W_2)^2 \sigma^2 e_2 + \cdots + (W_m)^2 \sigma^2 e_m . \qquad (11)$$

This is the relation between electromagnetic flow meter measurement error and the small measurement tube error.

3.2 THE MEASUREMENT PRECISION OF SMALL MEASUREMENT TUBE

Because the measured value of small measurement tubes is different at each point, the limited error is also different. First, pre-distribute the measurement error according to equivalents method, Assume the each factor of Equation (11) right side are equal

$$(W_1)^2\sigma^2 e_1 = (W_2)^2\sigma^2 e_2 = \cdots = (W_m)^2\sigma^2 e_m . \quad (12)$$

Obviously, the more weighting function is making less standard deviation. In the measuring process, we measured every point with the same small measurement tube, so the standard deviation of small tube is a determinate value, take the minimum value $\sigma_{\min}$ place of standard deviation, we get

$$\begin{aligned}(\sigma')^2_E &= (W_1)^2\sigma^2_{\min} + (W_2)^2\sigma^2_{\min} + \cdots + (W_m)^2\sigma^2_{\min} \\ &= \left[(W_1)^2 + (W_2)^2 + \cdots + (W_m)^2\right]\sigma^2_{\min} \le \sigma^2_E\end{aligned} . \quad (13)$$

Then the biggest measurement deviation of small measurement tube is given by

$$\sigma_{\min} = \frac{\sigma_E}{\sqrt{(W_1)^2 + (W_2)^2 + \cdots + (W_m)^2}} . \quad (14)$$

Apparently, the measurement precision of small tube only in relation to weighting function.

4 Experimental verification

According to the proposed theory, we get a unit element calibration device, see Figure 3. The entire calibration precision is beyond 99.5% according to the calibration requirement; selecting a standard meter to aided measurement, the various parameters of the standard meter as follows: caliber, DN400; instrument coefficient, 3.181; indication error, 0.179%, repeatability, 0.109%.

4.1 THE PRECISION OF SMALL MEASUREMENT TUBE

According to the theory of unit element calibration, we get a unit element made up of a small caliber circular tube with two electrodes, the caliber is DN20, see Figure 4. One end of the tube was fixed in the stepping motor, which movement was controlled by a pair of stepping motor. Take the center of the DN400 flow meter as origin and the length of 20mm as step size, measuring point by point within the region of [-160mm,160mm], see Figure 5. Overall sampling points is 153, the weighting function of each point could be calculated through Equation (2), then we get the measurement precision of small tube through Equation (13): In the condition of the total measurement error is not more than 0.5%, the measurement error of small measurement tube is no more than 0.031%.

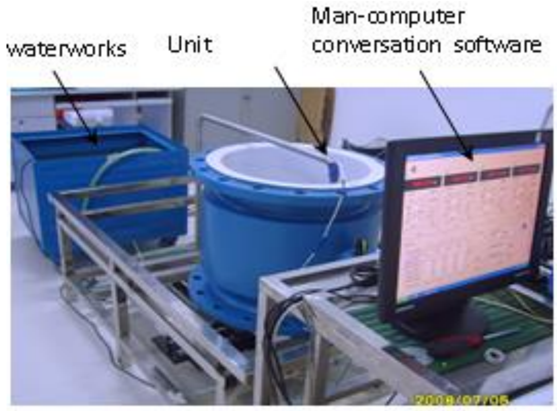


Figure 3 the unit element low cost calibration equipment

FIGURE 4 Small measurement tubes

FIGURE 5 Measuring order

4.2 FLUX SELECTION

The size of flow has certain effect on the experimental repeatability, so we should first determine the flow. The experimental aided by a known coefficient electromagnetic flow meter I and a standard flow meter. Sampling each point according to above measurement method, we found the collected data at 1.5 m^3/h flow accord with the theoretical flow distribution, see Figure 6.

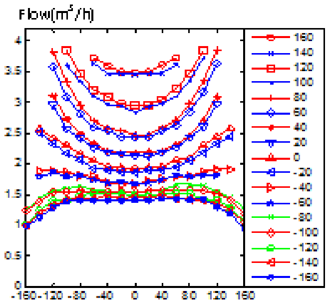


Figure 6 Collected data of

Take it as reference; we sampled four different flows many times, the results of repeatability as Table 1 shown:

TABLE 1 Repeatability

Flow (m^3/h)	**0.190**	**0.900**	**1.500**	**1.820**
***repeatability* (%)**	2.652	0.4883	0.0653	0.0827

Obviously, when the flux is 1.500m^3/h, the flow distribution and repeatability is the best. According to the measured data at 1.5 m^3/h flux, we get the equipment coefficient of flow meter I K= 854.4. Compared with the standard flow meter coefficient 854.6, the difference is only 0.02%, show the selection of flux is credible.

4.3 THE ELECTROMOTIVE FORCE OF ELECTRODE

First, we calibrated the measured electromagnetic flow meter with actual flow calibration device. When the flux is 1.5m3/h, we get the potential difference between two electrodes is 349.6, and the zero drift is 36.776. then measured it three times with unit element calibration device, the results as Table 2 shown:

TABLE 2 Calibration data

flux		**1.500m^3/h**	
Standard flux	1.481	1.476	1.476
Equipment coefficient	0.9076	0.9076	0.9076
Instrument coefficient	3.666	3.667	3.644
Zero drift	20	40	45.2
Electrode emf	333.3	352.2	359.2
Average electrode emf		348.22	

In Table 2, the average electrode EMF is 348.22, compared with the actual calibration result, the difference is only 0.243%. So from the point of test data, this device can meet the calibration precision demands.

5 Conclusion

Through the analysis of unit element indirect calibration method, point out the key parameter of unit element indirect calibration method is how to accurately measure the flow meter EMF in the low cost case. Analyzed the error relationship between flow meter and small measurement tube, get the measurement precision of small tube only in relation to weighting function. Through the basic experimental comparison, proved the analysis of small tube measurement precision is right. But, still have many factors influence the unit element calibration precision so far, such as numbers of measurement point, electrode shape and so on, these need more people, more experiment to analyze it.

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References

[1] Cai Wuchang 2004 *Electromagnetic flow meter* China petrochemical publishing company: Beijing

[2] Hemp J 2001 A technique for low cost calibration of large electromagnetic flow meters *Flow Measurement and Instrumentation* **12**(2) 123-34

[3] Li Bin 1996 The way of electromagnetic flow meter ion current calibration China Pantent NO. CN96116398.4

[4] Velt I D 2002 Metrological support to domestic heat meters Measurement Techniques **45**(12) 1282-5

[5] Fu Xin, Hu Liang, Xie Haibo, Yang Huayong 2007 Dry Calibration Technique of Electromagnetic Flow meter *Chinese Journal of Mechanical Engineering* **43**(6) 26-30

[6] Sun Xiangdong, Li Bin, Zhao Zifeng 2009 Researches on a new Dry Calibration Method of Electromagnetic Flow meter Based on Unit Element International Instrumentation and Measurement Technology *Conference Singapore* 270-3

[7] Libin 2008 A method for calibration of large electromagnetic flow meter China Patent No. CN 200810040040.3

[8] Sun Xiangdong 2010 *Researches on the dry calibration of large electromagnetic flow meters based on unit elemen* Shanghai University: Shanghai

[9] Baker R C 2000 *Flow measurement handbook* Cambridge university press: London

[10] Shercliff J A 1962 *The theory of electromagnetic flow-measurement* Cambridge University Press: London

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