Flow Measurement and Instrumentation 58 (2017) 120–129

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Study on magnetoresistive rotameter with high precision

Jie Chen, Xiaojie Zheng, Bin Li*, Yijie Cao, Na Fan

School of Mechatronics Engineering and Automation, Shanghai University, 140 Guangyan Road, Shanghai 200072, PR China

ARTICLE INFO

Keywords:
Magnetoresistive rotameter
Quadrupole magnet
Precision grade

ABSTRACT

Based on the detection mechanism of Quadrupole magnet, a high precision magnetoresistive rotameter is proposed in this paper. It mainly describes the signal processing method of rotameter, the design of system, the calibration experiments of the prototype and the result analysis. Offline simulation is carried out to improve the transducer structure, which shows that the meter's overall performance could be improved with the novel method. Experimental results and error analysis indicated that the precision of the magnetoresistive rotameter is better than 1%, with its grade at level 1.

1. Introduction

With the advantages of simple structure, reliable operation and low price, the metal tube rotameter is paid more and more attention to. Gradually, the low precision meter cannot meet the project requirements in the fields of energy saving, economic accounting and automatic control, etc. It is significant to study how to improve the rotameter's measurement precision and adaptability for its wide use.

Fig. 1 shows the measurement principle based on Miller's method [1]. A float is put into a vertical orifice metal tube, moving up and down with the flow rate changes. Then the annular area between the float and the pipe is changing. There are three forces acting on the float, i.e. gravity, buoyancy and pressure drag. The float will reach equilibrium position when the resultant force is zero. The detailed analysis of these three forces is as follows.

Because of throttling action, the differential pressure Δp will be generated with the upstream and downstream of float. When the fluid flows through float, there is a flow velocity μ in the annular channel between the float and the pipe walls. The differential pressure Δp is proportional to the square of the velocity μ. The functions is as follows:

$$\Delta p = C_1 \frac{1}{2}\rho\mu^2 \tag{1}$$

The pressure drag can be described as:

$$F_1 = \Delta p \cdot A_f \tag{2}$$

The buoyancy of float can be described as:

$$F_2 = V_f \cdot \gamma \tag{3}$$

The gravity of the float can be described as:

$$W = V_f \gamma_f \tag{4}$$

When the float reaches the equilibrium position, its gravity is equal to the lift force, which is described as:

$$W = F_1 + F_2 \tag{5}$$

So the fluid velocity of the fluid can be described as:

$$\mu = \frac{1}{\sqrt{C_1}}\sqrt{\frac{2V_f \cdot (\gamma_f - \gamma)}{A_f \rho}} \tag{6}$$

According to Fig. 1, the flow area of the float can be described as:

$$A = \frac{\pi}{4}(2D_f - 2h\tan\varphi)2h\tan\varphi \tag{7}$$

Where, h is the float displacement. Since μ is a constant, the volume flow is proportional to the flow area , which is described as:

$$q_V = A\mu \tag{8}$$

From Eq. (8), we can get the volume flow by Eq. (9).

$$q_V = \alpha\pi(D_f h\tan\varphi - (h\tan\varphi)^2)\sqrt{\frac{2gV_f(\rho_f - \rho)}{\rho A_f}} \tag{9}$$

Where, q_V is the volume flow; α is the flow coefficient; D_f is the maximum diameter of floating element φ is the float cone angle; ρ_f is the density of float; ρ is the fluid density; V_f is the float volume; A_f is the maximum cross section of the float perpendicular to flow direction.

In accordance with Eq. (9), it is known that the quadratic term can be ignored [2], when the cone angle of the float is below 1°. In the past, due to the neglect of the influence of the quadratic term, the precision of the meter is relatively poor. For example, the traditional glass

* Corresponding author.
E-mail addresses: jane.chen@shu.edu.cn (J. Chen), 1522990819@qq.com (X. Zheng), sulibin@shu.edu.cn (B. Li), cyjyear@163.com (Y. Cao), flala523@163.com (N. Fan).

https://doi.org/10.1016/j.flowmeasinst.2017.09.015
Received 1 December 2016; Received in revised form 23 August 2017; Accepted 19 September 2017
0955-5986/

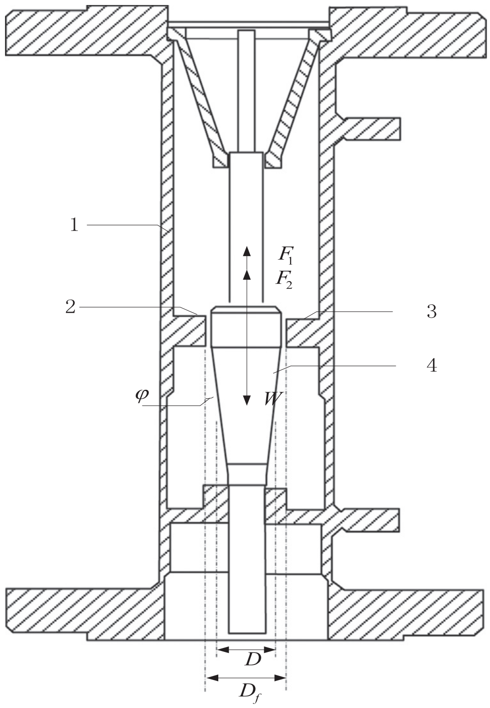

Fig. 1. Measurement principle of the rotameter (1 Conduit, 2 and 3 Orifice plate, 4 Float).

rotameter obtains the flow just by observing float displacement. However, it is hard to achieve such small angle in practical design, it's necessary to consider the influence of the quadratic term [3]. Metal rotameter cannot directly detect float displacement, which requires the adoption of an indirect method. Thus, the transducer is a vital part of the measurement system, and its performance also affects the performance of the meter [4–9]. To improve the performance of the meter, it can be seen that various parts of the measuring system must be seriously considered. Great efforts have been made by a number of researchers with different methods to solve these problems.

German scholars Bueckle [10] and Durst [11] applied the method of fluid dynamics simulation CFD (Computational Fluid Dynamics) to rotameter sensors and validated the feasibility of adopting Laser Doppler Anemometry (LDA) firstly. Pavan Kumar KP used CFD simulation software Ansys Fluent to simulate and analyze characteristics of flow field, and obtained the optimal taper design with the simulation result [12].

Xu et al. [13] used a robust high precision capacitive angular displacement transducer to detect the position of the floating element and microprocessor technique for smart signals processing. The experiment results showed that the precision of this kind of prototype investigated is better than 1%. Mandal [14] employed an improved inductance bridge network as the sensor of the rotameter and the calibration results showed that the maximum error of this design was within ± 5%.

Li et al. [15] proposed a measurement method of float displacement to achieve the signal distant transfer of glass tube variable area rotameter. The inductive sensor was designed with iron core embedded in the glass cone tube and the enameled wire winded on the outside of the glass tube. Mandal [16] used the LVDT (Linear Variable Differential Transform) as transducer for rotameter, which took the advantages of the LVDT output with a good linear variation and repeatability. The design cost of this system was very small and the service life of the detection part was longer.

Xu [17] put forward a mathematics model by the means of BP neural network based on the investigation of an intelligent metal tube floater flowmeter. An effective algorithm of float displacement measurement was obtained by combining the Levenberg-Marquardt algorithm with the Bayesian learning. Cao and Shen [18] used image processing method to obtain the float displacement. The cardinal principle was to extract scale and float images respectively through glass rotor flowmeter image and automatic identification technology. Kumar et al. [19] proposed an electro-optic type flow transmitter. The float movement of Rotameter was converted into an electrical signal with the help of inductive pickup coil and Maxwell Bridge.

Smigielski [20] completed the measurement of float displacement with the principle that the float displacement variation led to the change of induction electromotive force of external induction coil. Mo et al. [21] measured the float displacement by adopting a magnetoresistive sensor HMC1501. And they used the method of piecewise linear to fit the sensor output and float displacement. This system could automatically sample the flow signal, calculate the instantaneous flow rate, and display them on the LCD screen. Sinha [22] designed a non-contact rate measurement technique using Hall probe sensor and rotameter. In the design, a float carrying a thin circular permanent magnet is used, and a Hall probe sensor placed outside the rotameter tube has been used to sense the variation of magnetic field of the magnet with the variation of float position.

The mechanical structure, computational arithmetic and measurement precision of rotameter have been promoted by above work. However, many designers did not fully take into account the factors that affect the overall performance, such as the influence of external magnetic field, the influence of temperature changes, the limitation of sensor and the unstableness. It is still a difficult problem to improve the mechanical structure and measurement precision at present. Similar viewpoint was also presented in the paper of Baker [23]. Therefore, this design proposed a novel method to measure instantaneous flow rate in order to improve the mechanical structure and the measurement precision of the rotameter. This paper mainly includes the following 3 aspects.

(1) Magnetic field simulation is carried out to analyze rotameter external magnetic. The results and simulation analysis determine the reasonable magnetic rotation angle and the optimal position of magnetoresistive sensor and magnet, which can guide the practical meter design, reduce the design cost of the sensor and shorten the design procedure;
(2) A float displacement measuring system is put forward with the least square method, according to the magnetic field simulation characteristics;
(3) Through the hardware and software design of the system, the intelligent level and the accuracy of the meter are improved.

A high precision magnetoresistive rotameter is present in the paper. It uses a displacement transducer to detect the position of the float with the simulation software ANSYS Maxwell. The experimental results show that this approach can improve the performance and precision of rotameter. Furthermore, the design also meets the cost expectation of users of these rotameter. The paper is organized as follows: introduction to signal processing method in Section 2, system design in Section 3, experimentation and results in Section 4 and analysis in Section 5.

2. The introduction of the signal processing method

Fig. 2 shows the principle block diagram of the system of the magnetoresistive rotameter. It consists of five different units, i.e. a power supply unit①, a transducer unit②, a signal processing unit③, an output unit③and a temperature detection unit⑤. The STM32 microprocessor is the core of a signal processing unit. When the fluid flows through metal pipes from bottom to top, the transducer will produce an output voltage which will be converted to the volume flow by the signal processing unit. Finally, the volume flow is intuitively displayed on the LCD.

This design will be realized according to the block diagram in Fig. 2. The aspects that need to be improved for the meter are as follows: