An Improved Electromagnetic Flowmeter

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Abstract. Electromagnetic flowmeters are widely used in industrial production or control. However, the structure of the traditional electromagnetic flowmeter makes it restricted in some applications. With the development of medicine, aviation and other fields, people's demand for multiphase flow measurement is increasing. However, the theoretical study of the multi-electrode electromagnetic flowmeter has always lacked systemicity, especially in the relationship between the tube wall, the electrical characteristics of the fluid and the output signal. Based on the existing research, this paper studies several key technologies of multi-electrode electromagnetic flowmeter. The structure of the existing electromagnetic flowmeter is improved, and a multi electrode non insulated pipe wall electromagnetic flow sensor is proposed. According to the equivalent circuit, the influence of the sensor structure on the measurement is analyzed, and the disturbance of the electrical characteristics of the tube wall to the output signal is obtained by combining with the weight function analysis. According to the results of theoretical calculation and analysis, a negative feedback circuit is designed. According to the experimental results, the accuracy and reliability of the novel electromagnetic flowmeter are verified.

1. Introduction
Electromagnetic flowmeter (EMFM) is widely used in petroleum, chemical industry, sewage treatment and other occasions due to its advantages of wide range, high precision, no pressure loss and moderate price. The measurement principle of EMFM is mainly based on Faraday's electromagnetic induction law, which converts the fluid velocity into electrical signal output. Traditional EMFM has an insulated tube wall with a pair of electrodes positioned at the diameter of the measuring tube wall. At present, the traditional EMFM can measure the single-phase axisymmetric conductive liquid with an error as low as ± 0.05%. Optimize the structure of traditional electromagnetic flow sensor to expand its application, such as multi electrode, tube wall conductive design, etc [1-3].

Among all the factors related to the output signal of the sensor, the weight function is an unmeasurable and critical parameter. Therefore, many researchers and engineers at home and abroad have discussed the weight function extensively. Shercliff[4] calculated weight function which represents the relative contribution of the axial fluid velocity at a given point in the flow cross section to the overall measured potential difference between the electrodes. Wang Zhuxi analyzed and studied the weight function by using the method of separating variables and other mathematical methods, and gave the expression of the weight function in two-dimensional case. Zhang [5] gives a semi analytical method of weight function, but the expression of weight function cannot fully represent the actual distribution of weight function because of too many simplifications. Based on the theory of virtual current, Xuejing Li [6] gave a weight function solution method based on weight field.
From design to practical application, the new electromagnetic flow sensor needs the support of perfect theory and signal processing method. This paper presents a novel electromagnetic flowmeter with 16 electrodes and non-insulated pipe wall. The flowmeter can not only measure the non-axisymmetric flow, but also can be used in special occasions, such as the measurement of high temperature fluid. At the same time, this paper also gives the signal processing method of the flowmeter, which ensures the accuracy and reliability of the actual measurement.

2. Theory analysis

2.1. Novel EMFM

Figure 1 shows the 16 electrodes EMFM with non-insulation pipe wall. 16 electrodes are placed at the pipe wall with the angular intervals of 22.5 degrees. Because the pipe is non-insulation, the electrodes are not tach the flow. They are on the outer side of the pipe. A pair of coils give the near uniform magnetic field. The novel sensor can overcome the asymmetry of velocity distribution and be used to measure multiphase flow or provide stable measurement in high temperature environment.

2.2. Theory of EMFM with non-insulation Pipe Wall

The measurement regime of EMFM almost corresponds to an electrical equivalent circuit. Figure 2 is the electrical equivalent circuit of EMFM transducer with non-insulation pipe wall.

![Figure 2. Electrical equivalent circuit of EMFM transducer with non-insulation pipe wall.](image)

The flow transducer is represented an emf source $E$, $r_f$ is liquid internal resistance, and $r_w$ is resistance of pipe wall. $\tau$ is the contact resistance. $U$ is potential difference at the outside of the pipe wall. So,

$$U = \frac{2r_w}{r_w + r_f + \tau} E$$  \hspace{1cm} (1)

We can assume that $r_w$ and $r_f$ much higher than $\tau$, then deduce following conclusions from Equation (1):
(1) If \( r_w = \infty \), then

\[ U = 2E \] (2)

which is the output of a EMFM having a pipe wall with insulation pipe wall.

(2) If \( r_w = r_f \), then

\[ U = E \] (3)

It can be seen from Eq. (3) that the conductivity of the tube wall will cause the induced potential short circuit between the electrodes, that is, the output signal of the sensor is not the response of all the induced potentials.

2.3. Numerical results and Analyze

The numerical computations are performed with the finite element software COMSOL Multiphysics (known as FEMLAB) [7-8]. The flow pipe is assumed to be made of stainless steel without insulation lining. The inner diameter of the flow pipe is 0.030 m and the outer diameter is 0.033 m. The length of the pipe is 0.15 m. The conductive of pipe is zero and conductivity of flow is 0.01S/m. In order to get the influence of the conductivity of the tube wall on the measurement, the weight function distribution of the new sensor is analysed (seen in the Figure 3 and Figure 4).

![Figure 3. Weight function of novel EMFM.](image)

The weight value with the pipe thickness is shown in Fig. 4 while the wall conductivity is unchanged and conductivity_wall/ conductivity_water=1/10000(conductivity_water=1.5e^{-2}[S/m]). The outer diameter of the pipe is 0.10m.
Figure 4. Weight function of novel EMFM with the pipe thickness.

Uniformity of the weight function is given by

\[ \varepsilon = \frac{\int \int (w - \bar{w}) dxdy}{\int \int w dxdy} \]  \hspace{1cm} (4) \]

Where \( \bar{w} \) is mean of weight value. The flow cross section is divided into N pixels, and \( w_i \) is the weight value in every pixel. So the

\[ \bar{w} = \frac{\sum_{i=1}^{N} w_i}{N} \]  \hspace{1cm} (5) \]

Then Eq. (5) can transform into

\[ \varepsilon = \frac{\sum_{i=1}^{N} |w_i - \bar{w}|}{\sum_{i=1}^{N} \bar{w}} \]  \hspace{1cm} (6) \]

For a uniform velocity profile, the relationship of the weight value uniform with the pipe conductivity is shown in Figure 5.
3. Experimental Results and Discussion

Let us describe the structure of the model of the new EMFM sensor. Electrodes is welded to the outer pipe wall. The inner diameter of the flow pipe is 30 mm and the outer diameter is 33 mm. Diameter of the electrode is 2mm, which can be considered as a point if compared with pipe inner diameter. Design of flowmeter converter shown in Figure 6.

The magnetic field is excited by current of constant amplitude and rectangular waveform of low frequency (50/16 Hz). The input impedance of amplifier first stage must be high enough. Otherwise, loading effect might cause an error and the compensation would not be perfect. Since the lower limit of liquid conductivity is usually about 5 ~ 10μS/cm for EMFM. The impedance between electrodes can be estimated at 500~1000kΩ.

Figure 7 shows the effect of fluid conductivity $\sigma_f$. And temperature is 18°C, the exciting magnetic field distribution $B$ is $81e^{-4}$ T, mean flow velocity is 0.8m/s.
Figure 7. Output voltage vs. fluid conductivity at constant flow rate.

4. Conclusion
In conclusion, on the basis of theoretical analysis and experimental data, the results of this investigation can be summarized as follows:

(1) The novel EMFM can measure multiphase flow, and used in special environment, such as high temperature.

(2) A boundary condition, which is equivalent to that of a non-conducting pipe wall, can be achieved by applying voltage to the conductive pipe wall of EMFM.

(3) Experimental results agree well with calculated data based on the theoretical analysis.

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