Research on the Influence of Non-Conductor on the Weight Function of Electromagnetic Flowmeter

Xuejing Li 1, 2, a, *, Lijun Sun 3, b

1 Shanghai Institute of Measurement and Testing Technology, Shanghai 201203, China
2 Shanghai Key Laboratory of On-line Testing and Control Technology, Shanghai 201203, China
3 School of Electrical and Information Engineering, Tianjin University, Tianjin, 300072, China.

a, *Corresponding author e-mail: Lixj@simt.com.cn, b sunlijun@tju.edu.cn

Abstract. The demand for multiphase flow measurement is widespread in petrochemical and other fields. Due to its small size, easy maintenance, and no moving parts, electromagnetic flowmeters are widely used in single fluid measurement. With the increasing application of traditional electromagnetic flowmeters in petrochemical and other fields, the problems of traditional electromagnetic flowmeters in multiphase flow measurement applications have been discovered. How to optimize the structure of the electromagnetic flowmeter and how to improve the measurement accuracy has become a new research focus. On the basis of a large number of literature studies, this research is based on the finite element method, and systematically studies the influence of multiphase flow on the weight function of electromagnetic flowmeters. Firstly, modeling the existence of non-conductive objects in the electromagnetic flowmeter. Secondly, analyze the weight function characteristics of the non-conductive objects on the electromagnetic flowmeter from two angles of different radii and different positions. The conclusions of this study can provide a certain reference basis for the electromagnetic flowmeter in the measurement of multiphase flow.

Keywords: Multiphase flow; weighting function; electromagnetic flowmeter; finite element.

1. Introduction

A single state of homogeneous substances with the same composition and the same physical and chemical properties becomes a phase. Macroscopically, the "phase" is divided into solid phase, liquid phase and gas phase. Multiphase flow refers to fluids that include two or more [1-3]. Compared with single-phase flow, multiphase flow has more complex composition and more complicated flow characteristics, so it is more difficult to accurately measure multiphase flow.

Many measurement methods for single-phase flow are relatively mature, combined with the characteristics of multi-phase flow, scholars use these methods to study multi-phase flow. Electromagnetic flowmeter is a meter that measures the flow of single-phase conductive liquid based on...
the law of electromagnetic induction [4-6]. In fluid measurement, the structure of electromagnetic flowmeter has certain advantages, such as: there are no flow-blocking parts inside the pipeline, and it can quickly respond to changes in fluid flow, with high measurement accuracy, and the measurement result is not affected by the temperature, viscosity, and pressure of the fluid being measured. And other physical parameters [7-8]. Therefore, in recent years, electromagnetic flowmeters have gradually been widely used in multiphase flow measurement. However, due to the characteristics of multiphase flow, electromagnetic flowmeters need to be further optimized in terms of structure and measurement accuracy.

Weight function theory is a very important part of electromagnetic flowmeter theory. From a microscopic point of view, the measurement signal of the electromagnetic flow sensor is the sum of all the measured fluid units in the measurement pipeline to the sensor with different weights. The weight function reflects the ability of the induced electromotive force generated when the measured fluid in the measuring tube moves under the induced magnetic field to contribute to the flow signal of the electromagnetic flow sensor. When a non-conductor appears in the fluid during operation of the electromagnetic flowmeter, it will change the distribution of the induced electromotive force and cause a certain error in the measurement of the electromagnetic flowmeter. Therefore, the analysis of the influence of the non-conductor on the weight function of the electromagnetic flowmeter is Very necessary, but the current research on this issue is not yet complete. Hemp and Versteeg use the double Fourier series expansion method to solve the virtual current potential and magnetic scalar potential, which simplifies the calculation of the weight function to a certain extent [9]. Zhang Xiaozhang proposed a semi-analytical mathematical method of alternating iterative method, and used it to solve the distribution of the weight function of a single bubble in the measuring tube [10]. L. Hu and J. Zou used auxiliary surface and separation variable method to study the weight function of complex structure [11]. In this paper, using the finite element analysis method, modeling is carried out from the two angles of the size of the non-conductor and the position in the measuring tube wall, and the weight function characteristics of the multiphase flow are obtained. The research results can provide a certain reference basis for the structure optimization of the electromagnetic flow sensor for multiphase flow and the analysis of the measurement results.

2. Weight function theory

Macroscopically, the movement of the fluid is regarded as a conductor cutting magnetic lines of force in a magnetic field. When the conductive fluid flows through the space covered by the magnetic field, it will generate corresponding induced potentials at both ends of the measuring electrode. On the microscopic level, the velocity distribution of the measured fluid in the pipeline is not the same everywhere, and the induced potentials generated by the micro-elements with different spatial locations are not all the same. Through the weight function, the relationship between the output induced potential of the electromagnetic flow sensor and the fluid can be understood from the spatial relationship of the fluid micro-element.

As shown in Fig. 1, the traditional point electrode insulated pipe wall electromagnetic flow sensor model.

![Fig.1 Geometric model of electromagnetic flow sensor.](image-url)
In Fig. 1, \( e \) and \( e' \) are electrodes, tube diameter is 2a, the tube length is 2L, and the magnetic field strength is B. The measured incompressible liquid is a conductive medium with uniform electrical properties, and its flow state is symmetrically distributed on the central axis. Set the energized coil (not shown in the figure) to generate an induced magnetic field, and the magnetic field, the axis of the two electrodes, and the axis of the measuring tube are perpendicular to each other.

The induced potential at both ends of the electrode is

\[
\nabla^2 U_{ee'} = \nabla \cdot (\hat{v} \times \vec{B})
\]

(1)

Suppose the fluid is in the z direction, but has no component in x and y, as in equation (2)

\[
\begin{align*}
& v_x = v_y = 0 \\
& v_z = v
\end{align*}
\]

(2)

According to boundary conditions (3)

\[
\frac{\partial U_{ee'}}{\partial n} = 0
\]

(3)

The measurement equation of the electromagnetic flowmeter can be obtained as formula (4)

\[
U_{ee'} = \int vB W d\tau
\]

(4)

Where \( W \) is the weight function, and the weight function can be further expressed as

\[
W = \frac{a^2 (a^2 + x^2 + y^2)}{a^4 + 2a^2 (x^2 + y^2) + (x^2 + y^2)^2}
\]

(5)

\( x \) and \( y \) are the two-dimensional plane coordinates of the pipe section. The normalized weight distribution is shown in Figure 2.

![Fig.2 2D distribution diagram of weight function of traditional electromagnetic flowmeter.](image)

It can be seen from Fig. 2 that the maximum value of the weight function is at the electrode and gradually decays along both sides of the x-axis. It can be seen that the velocity change of the measured fluid near the electrode has a greater impact on the output signal of the sensor. Therefore, the distribution characteristics of the weight function can be used to analyze and design the sensor. In practical applications, it is hoped that the more uniform the weight function distribution is, the less the induced potential between the electrodes is affected by the fluid, that is, the lower the sensitivity. In order to quantitatively measure the characteristics of the weight function distribution, define the weight function unevenness \( \varepsilon \) as

\[
\varepsilon = \int_{\tau} \frac{W_i - \overline{W}}{\overline{W}} d\tau
\]

(6)

Where \( \tau \) is the solution domain.

Where \( \overline{W} \) is the average weight.

\[
\overline{W} = \frac{\sum_{i=1}^{n} W_i}{n}
\]

(7)
In the formula, $W_i$ is the weight of any micro element in the pipeline, and $n$ is the number of micro elements.

According to the above analysis, in order to reduce the influence of the flow velocity distribution on the output signal of the sensor, it is hoped that the non-uniformity $\varepsilon$ of the weight function should be small in terms of sensor design and structural optimization.

3. The influence of non-conductors with different radii on the weight function

3.1. Modeling

Establish a classic full-pipe symmetric flow sensor model. $e$ and $e'$ are the two electrodes of the electromagnetic flow sensor respectively, along the $y$-axis direction, the direction of the magnetic field $B$ is the $x$-axis direction (not shown), the radius of the measuring tube is $R$ and the radius of the non-conductor is $r$, as shown in Figure 3.

![Fig. 3. Analysis model of the influence of non-conductor size on weight function.](image)

3.2. Simulation results and analysis.

In the simulation, it is assumed that there is a non-conductor in the measurement area of the electromagnetic flow sensor, and the finite element simulation platform is used for analysis. In order to increase the universality of the research, the proportional relationship between the non-conductor radius $r$ and the measuring tube radius $R$ is set in the simulation calculation, that is, $r:R=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8$.

![Fig. 4. The influence of non-conductive phase size on weight function.](image)

Express the calculation result as a curve by formulas (6) and (7).
Fig. 5 The influence of the size of the non-conductor on the distribution characteristics of the weight function.

Fig. 5 shows the influence of non-conductors with different diameters in the fluid on the distribution characteristics of the weight function. In order to make the research conclusions have a certain universality, the abscissa is the ratio of the radius $r$ of the non-conductor to the radius $R$ of the measuring tube; the ordinate is the unevenness of the weight function $\varepsilon$. It can be seen from the figure that the larger the non-conductor relative to the measuring tube, the greater the influence on $\varepsilon$, that is, the larger the volume of the non-conductor at a certain position in the measured fluid, the greater the influence on the measurement result.

4. The influence of non-conductors in different positions on the weight function

4.1. Modeling.

Fig. 6 shows the analysis and modeling of the influence of the non-conductor position on the weight function characteristics. $e$ and $e'$ are the two electrodes of the electromagnetic flow sensor. The radius of the measuring tube is a constant value $R$, and the radius of the non-conductor is a constant value $r$. The distance between the non-conductor circle center $O'$ and the measuring tube circle center $O$ is $C$.

Fig. 6 Analysis model of influence of non-conductor position on weight function.

References are cited in the text just by square brackets [1]. Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under heading references, see our example below.

4.2. Simulation results and analysis.

The ratio of the radius of the non-conductor to the measuring tube is selected as $r/R=0.2$, and the position of $O'$ is on the $x$-axis and $y$-axis for analysis. Figures 7, 8, 9 and 10 show the calculation results of $O'$ on the $x$ and $y$ axes, respectively. Where $C=O'-O$. 
The calculation results are shown in Figs. 7 and 8. It can be seen that in the x-axis direction of O’, the closer the non-conductor is to the center O of the measuring tube, the greater the unevenness $\varepsilon$, and the smaller $\varepsilon$ near the tube wall. When O’ is in the y-axis direction, the closer the non-conductor is to the center O of the measuring tube, the greater the unevenness $\varepsilon$, and the smaller $\varepsilon$ near the electrode.

In the above experiment, the set non-conductor is at any position parallel to the x-axis or parallel to the y-axis in the measuring tube, and the respective characteristics of the weight function of the non-conductor in different positions are obtained. It provides a basis for data analysis in measuring multiphase flow.

References are cited in the text just by square brackets [1]. (If square brackets are not available, slashes may be used instead, e.g. /2/.) Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading References, see our example below.
5. Summary
The weight function, one of the important theories in multiphase flow measurement, is discussed in detail using finite element method. The non-conductor contained in the measured fluid is modeled, the weight function of the multiphase flow is analyzed using a numerical simulation platform, and the influence of different sizes of non-conductors on the inhomogeneity of the weight function is calculated. Using the built model, the influence of non-conductor in different radial positions on the inhomogeneity of the weight function is analyzed. The research results of this paper have obtained the influence of different sizes and positions of non-conductors on the weight function distribution, which provides a reference for the electromagnetic flowmeter in the measurement of two-phase flow.

Acknowledgments
The authors would like to acknowledge the financial support of Science and technology project of Shanghai market supervision and Administration Bureau (Research on fluid measurement technology of non- full pipeline 2019-20).

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