Numerical Simulation Modelling for Velocity Measurement of Electromagnetic Flow Meter

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Abstract. An induced voltage EMF in the area of measuring single-phase flow rate in pipes has been used in many industrial areas. To measure the continuous phase velocity profile in multiphase flows where the continuous phase is an electrical conductor, Electrical capacitance and resistance tomography has been comprehensively investigated, except for continuous phase velocity profile measurement. This paper tries to design the numerical simulation model according to the basic electromagnetic induction law and to investigate the relationship between induced electric potential or potential drop and the velocity distribution of the conductive continuous phase in the flow. First, the 3-Dimension simulating module for EMF is built. Given the most simple velocity profile of the fluid in the pipe, the value of the induced potential difference between electrodes is obtained by simulation and theoretical computation according to J A Shercliff’s weight function. The relative error is 6.066%. This proves that the simulation model is accurate enough to investigate the characteristic of the induced potential difference of EMF. Finally, the relationship between induced potential difference and the velocity profile is analysed in detail where the complicated velocity profile is expressed as vₓ=1m/s when 0.02²<x²+y²<=0.0265² and vₓ=5m/s when x²+y²<0.02².

1. Introduction

EMF has been successfully and accurately used to measure the mean liquid velocity of single-phase fluid. With the technology of ERT (Electrical Resistance Tomography), ECT (Electrical Capacitance Tomography) and EIT (Electrical Impedance Tomography), electromagnetic flow meter for measuring the characteristics of two-phase flow has been continuously considered for its nature merits.

The principle of EMF [1] is that as the fluid flows through the magnetic field, the movement of electric charges induces the electric field and electrodes sense the difference of electric potentials on two or more separated points as an induced voltage. It has been continuously used to measure the mean liquid velocity of fluid in various industries, such as wastewater treatment, petrol and gas industry, chemical industry. However, there are many potential applications for EMF in many industrially important multiphase flows in which the continuous phase has a relatively high electrical conductivity whilst the dispersed phase or phases have a much lower conductivity or may even be insulators. There have also been continuous efforts [2–7] made to measure the characteristics of multiphase flow using EMF, since such meters do not introduce a pressure drop and can provide
a fast response to changes in the flow. Thus, there are many potential applications for EMF in multiphase flow.

Although many interesting works on how to measurement the flow rate of multiphase flow, the transient nature and complex flow geometries of multiphase flows cause fundamental difficulties when measuring flow velocity using an electromagnetic flow meter. So it is significantly important to investigate the multiphase flow velocity profile using EMT (Electromagnetic Induced Tomography).

In the present study, the electromagnetic flow meter that utilizes an alternating current (AC) sinusoidal excitation source [8] to excite the magnet coils of EMF was modeled and analyzed. The induced potential and potential difference at various virtual electrodes position of the cross section of fluid pipe under predefined velocity distribution, \( v_z = 1 \text{m/s (0.02}^2 < x^2+y^2 < 0.0265^2) \) and \( v_z = 5 \text{m/s (x}^2+y^2 < 0.02^2), \) that means the component z of fluid velocity relates with the coordinate value of axis x and y and the components x and y of the fluid velocity are 0, were simulated and represented in different figures. It is helpful to understand the conductive continuous phase velocity profiles in multiphase flows adopting EMT [9] technology.

2. Methods and key techniques
The conventional form of an electromagnetic flow meter has the characteristic that the magnetic field is transverse and the there is only one pair of electrodes perpendicular to the magnetic field. But more electrodes pairs are introduced in our research. Figure 1 illustrates the structure of EMF used in our research, where magnetic field along axis y is applied. The term \( \theta \) denotes the angle of electrode on circumference of pipe referring to the axis x. There are one fluid pipe with PTFE material and two identical excitation coils with copper material in this model. The fluid media flows in the pipe. The outer most cylinder surface in Figure 2 is used to limit the computing domain and its diameter is 0.12m. The inner diameter of fluid pipe is 0.053m and outer diameter is 0.065m. The length of the pipe is 0.15m. The inner and outer diameters of the two-excitation coils are 0.065m and 0.075m separately.

In order to measure the velocity of an electromagnetic flow meter in multiphase flow, the geometry and physical model (shown in Figure 2) of alternating current EMF was designed and simulated. The electrodes could be settled at any position of the internal circumference to meet the requirement of signals picking for induced potential. The magnetic field is generated with Helmholtz Coils. Its external current is expressed in equation (1).

\[
J_e = -J_0 \frac{z}{\sqrt{x^2+z^2}} i + 0j + J_0 \frac{x}{\sqrt{x^2+z^2}} k
\]

Where \( J_0 = 1.5 \times 10^7 \text{ A}. \)

3. Principles, theoretical integration and verification of the numerical model
The distribution of the potential \( U \) around the internal circumference of the fluid pipe of the EMF is described by the Poisson type equation (2).
\[ \nabla^2 U = div(v \times B) \] (2)

Where \( v \) is the velocity vector and \( B \) is the magnetic flux density vector. In the uniform and axisymmetric flow, the potential \( U \) is solved as equation (3) by Shercliff [1].

\[ U = 2aB / (\pi a^2) \int \{v(x,y)W(x,y,dy)\} \] (3)

Where \( a \) is the inner radium of the fluid pipe of EMF.

Shercliff [1] has given out the weight function of the flow meter that represents the degree of the contribution of the fluid velocity at each point in the cross section of a conduit to the output electric signal. It is described as equation 4.

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

In order to verify the correctness of the numerical simulation model, a simple fluid velocity, \( v_z = 5 \text{m/s} \), is adopted both in the numerical simulation research and the theoretical computation according to Shercliff’s weight function.

Solving the equation (3) with Matlab and using the preconditions that \( v_z = 5 \text{m/s} \), \( a = 0.0265 \text{m} \), \( x \) varies from \(-0.0265 \text{m}\) to \(0.0265 \text{m}\), \( y \) varies from \(-0.0265 \text{m}\) to \(0.0265 \text{m}\), and \( x^2 + y^2 \leq 0.0265^2 \). The magnetic flux density \( B \) is taken as the average value of magnetic flux density between \((-0.0265,0,0)\) and \((-0.0265,0,0)\) and its value is 21.7493 Gauss in the simulation model.

Finally, through simulation and theoretical computation, the induced voltage is work out as 0.578228mV and 0.574742mV respectively. Thus the absolute error is 0.003486mV and the relative error is 6.066%. It proved that the simulation result has good correlation with the computation result by integrating the equation 3 with Matlab. Therefore, the simulation model is correct enough to do simulation to investigate the characteristic of the induced potential of EMF. Based on this numerical model, a complex velocity profile is applied to the model to analyze the induced potential.

4. Investigation of the characteristic of induced potential

The signals of induced electric potential or potential drop from EMF under complicated flow conditions were obtained and analyzed. In this paper, the induced potential along the circumference of the fluid pipe, the distribution of induced electric potential and potential difference at different coordinate value \( y \), the relationship of potential difference and cord length are all given out and analyzed.

4.1. Velocity profile

In order to investigate the effect of velocity on the induced potential, the complicated velocity profile is applied to the numerical simulation model. The complicated velocity profile is expressed as \( v_z = 1 \text{m/s} \) when \( 0.02^2 < x^2 + y^2 \leq 0.0265^2 \) and \( v_z = 5 \text{m/s} \) when \( x^2 + y^2 \leq 0.02^2 \). The representation of the distribution of fluid velocity is shown in Figure 3 in different fashions.

![Figure 3. Velocity distribution of fluid.](image)
4.2. Induced potential distribution

Figure 4 shows the distribution of induced potential in the electrodes plane (x-y plane) where z=0. The potential values are expressed in different colors. From the potential figure, it is obvious that the induced potentials are positive at the right hand of the pipe and are negative at the left hand of the pipe. According to the spatial potential distribution, the potential differences between electrodes will be inferred directly. Furthermore, it may be useful to analyze the velocity profile of multiphase flow.

4.3. Further analysis of simulation result

4.3.1. Induced position vs the position angle of electrodes. In Figure 5, the induced potentials along the internal circumference of the fluid pipe were provided, where the horizontal coordinate denotes the position angles of electrodes located along the internal circumference of the fluid pipe. The angle was shown in Figure 1 and was expressed in term of \( \theta \). From the Figure 5, we can know that the potentials are almost constant when the value ranges of angle are from 0 to 60 degree, from 120 to 240 degree and from 300 to 360 degree. The reason is that the cord length is almost constant when the electrodes are at these positions.

4.3.2. Potential difference vs coordinate value of axis y. According to the induced potentials got along the internal circumference of the fluid pipe, the potential differences between the electrodes with the same coordinate value of axis y can be calculated. The relationship between potential difference and the coordinate value of axis y was plotted in Figure 6. When the coordinate values of axis y are greater than –0.02m and less than 0.02m, the potential differences vary very little. But the potential difference fluctuates in some small extent when electrodes locate at these positions due to the velocity distribution. When the coordinate values of y are less than –0.02m and greater than 0.02m, the potential differences vary sharply because the electrodes are closer to the wall of the fluid pipe and the fluid velocity decreases rapidly actually at these areas.

4.3.3. Potential difference over cord length vs coordinate value of axis y. Through further analyzing, Figure 7 gave out the relationship between potential difference over cord length and the coordinate value of axis y. It is found that the potential difference over cord length decreases to the smallest value when the coordinate values of axis y move to 0. The cord length is the distance of electrodes at the internal circumference of fluid pipe where the coordinate values of axis y are the same. So the cord length increases when the coordinate values of axis y move to 0.

5. Conclusion and further works

The important conclusion is that the induced electric potential and potential difference of EMF are critically decided by the velocity distribution of the fluid media. At the same time, the numerical simulation model is valid and effective to investigate the characteristics of the velocity of the
electromagnetic flow meter. Furthermore, the induced potential will be used to reconstruct the velocity distribution. With suitable reconstructing algorithm, the volumetric flow rate of multiphase flow can be obtained accurately.

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