

DEVELOPMENT IN ELECTROMAGNETIC INDUCTION FLOW MEASUREMENT

X.-Z. Zhang

Department of Engineering Physics, Tsinghua University
Beijing, 100084 P.R. China

Abstract: The paper reports some new results obtained in the theory of Electromagnetic induction flow measurement. These include the extending of the present theory to multiphase application, measurement of dielectric fluid and flow pattern reconstruction.

Keywords: Multiphase Flow, Dielectric Fluid, Flow pattern Reconstruction

1 INTRODUCTION

it has been more than 100 years since the first try of Faraday to use this electromagnetic induction law in measuring the flow of the Thames.

In 1962, Schercliff of the Cambridge University wrote a first book called "the theory of electromagnetic induction flow-measurement". The book gave a detailed summary of the research up to date. 1974, Schumartz of Germany published a book called "Induktive Strömungsmessung". Compared with Schercliff's work, it emphasized more on electronics.

The basic theory of the electromagnetic induction flow measurement of single phase fluid start at the following equations (see figure 1):

$$S = \int_t \vec{W} \cdot \vec{V} dt \quad (1)$$

$$\vec{W} = \vec{J} \times \vec{B} \quad (2)$$

where \vec{B} is the magnetic field \vec{J} is named "virtual current" which is determined by electrical boundary condition (including form and shape of the electrodes).

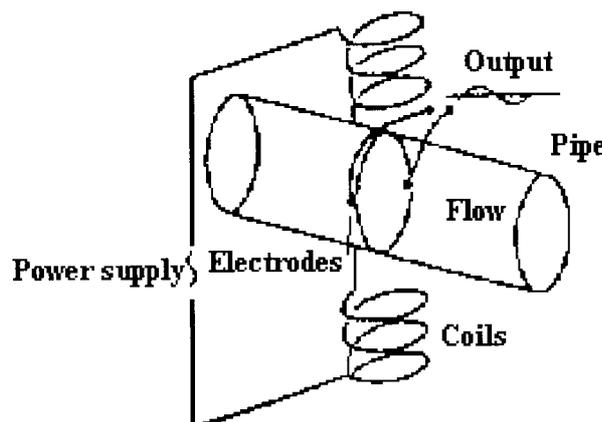


Figure 1. A model for the electromagnetic flow meter

Although electromagnetic flow meter, or magmeter called in north America, has been considered as conventional flow instrument, the development of the theory does not stop.

In this paper, the author would like to give a brief review of the works done in recent year. Owing to the limit of the author's interest, the review may not cover every aspect, particularly it does not include the techniques in this field. This never means they are not important.

2 MULTIPHASE FLOW

Traditional theory of the electromagnetic flow meter is basically on single phase. Owing to its non-obstructing property, an electromagnetic flow meter seems to be the promising flow Meter for multiphase flow. Early in 1980s', some researchers started to do experiments on the behavior of the electromagnetic flow meter in multiphase flow. Among them are Bernier and Brennen [1], Baker and Deacon [2]. Their results showed that this kind of flow meter were not as sensitive to bobbles than other conventional flow meters like turbine and orifice.

Kraft et al [3] investigated the use of electromagnetic flow meter for two-phase flow. They predicted the effect of a small bubble in different position on the output of the meter, which has shown a good agreement with their experiment.

Zhang presented a practical semi-analytical method to solve multiphase problem [4][5][6]. The method was used to obtain the solutions of the weight function of electromagnetic flow meter for irregular domains caused by the existence of bubbles. The solution is in series form, which can easily to analyze. The work showed the effect of a bubble in different positions over the cross section, or along the axis of a flow meter. The method was also extended to the case of several bubbles. Figure 2 shows a distribution of the virtual current [6].

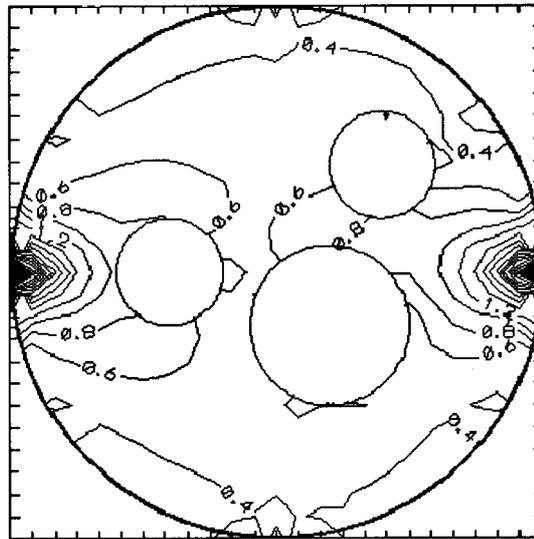


Figure 2. Distribution of the virtual current of the electromagnetic flow meter with 3 bubbles

Even we are able to work out the weight function of the flow meter in multiphase flow, we are still facing with difficulties. The key one is that the weight function is a “soft field” which changes as the phase distribution changes. The phase distribution is unknown. To make on-line measurement of the phase distribution is even more difficult.

3 DIELECTRIC FLUID

Use of the electromagnetic flow meter to measure the dielectric fluid has been considered early in 1900's, but there has not been any of this kind of flow meter in commercial until now. The down limit of the fluid conductivity is 10^{-2} s/m, while typical dielectric fluid such as petrol has a conductivity of about 10^{-5} s/m [7]. Very high impedance will cause problem of carrying static electric charges, which produce large noise in output signal.

Very recently, Ameare [8] designed a meter using comb-like large electrode with shields and some signal process techniques. A sinusoidal waveform at as high as 1.5 kHz was chosen for the magnetic field. His experiment showed a zero drift of about 1 % per hour of the full scale. This is a very good result. Maeare even gave an expression for the potential difference by

$$S = \frac{Q_n Z B}{2bK} \left(\frac{\sin a}{\left(1 + \frac{e_1}{e_2}\right) - \left(\frac{a}{b}\right)^2 \left(1 - \frac{e_1}{e_2}\right)} \right) \quad (3)$$

where Z is the flow meter impedance, a and b the inner and outer radius of the meter's tube respectively, Q_v the flow rate, α the semi-angle of the large electrode, ϵ_1 and ϵ_2 the permittivity of the tube and the fluid respectively, K a parameter. Equation (3) shows that S is small for high dielectric permittivity and thick wall of the tube.

4 FLOW PATTERN RECONSTRUCTION

A new concept has been born a few years ago to reconstruct the flow pattern by electromagnetic flow induction. Up to now, Honda and Tomita [9] in Japan, Trätcher and Wersdorf [10] in Germany and Zhang [11][12][13] in China are working on this problem. For many years, people have been working for obtaining a uniform weight function over the cross section of the electromagnetic flow meter. It may be a time to accept and made use of the non-uniformity of the weight function. Zhang [12] gave the mathematical basis in two-dimensional problem:

$$S = \int_A W(r, \mathbf{q}) V(r, \mathbf{q}) dA \quad (4)$$

where A is the cross section of the pipe.
By geometry discretization,

$$S = \sum_{j=1}^{M \times M} W_j V_j \Delta A_j \quad (5)$$

where we divide the cross section into $M \times M$ segments, W_j , V_j are the weight vector and velocity at j th segment of ΔA_j in one measurement. To obtain $V_{j=1, 2, 3, \dots, M \times M}$, at least $M \times M$ measurements should be made, so that we have

$$S_i = \sum_{j=1}^{M \times M} W_{ij} V_j \Delta A_j \quad (6)$$

$i = 1, 2, 3, \dots, M \times M$

Express this in matrix form,

$$[S_i]_{(M \times M) \times 1} = [W_{ij}]_{(M \times M) \times (M \times M)} [V_j \Delta A_j]_{(M \times M) \times 1} \quad (7)$$

$$[V_j \Delta A_j]_{(M \times M) \times 1} = [W_{ij}]^{-1}_{(M \times M) \times (M \times M)} [S_i]_{(M \times M) \times 1} \quad (8)$$

Figure 3 shows a reconstructed pattern by 4 coils and 8 electrodes [13].

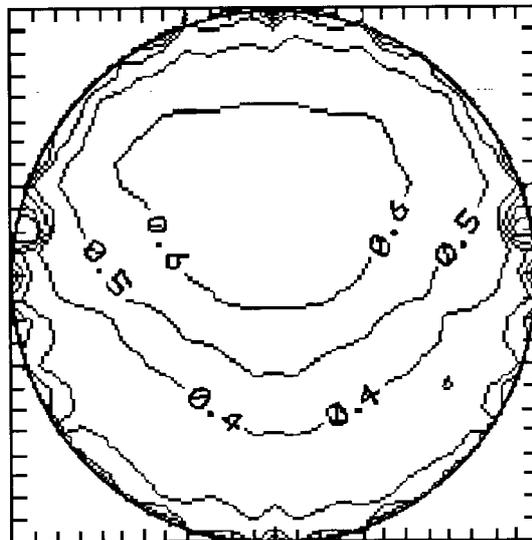


Figure 3. A reconstructed 2D flow pattern

This concept of reconstruction can be extended to 3D problem [12].

The main difficulty in this topic is the low resolution. Both magnetic field and the virtual current are related to harmonic function. The strength of the field and the current decrease quickly away from the sources (i.e. coils or electrodes).

5 SUMMARY

Electromagnetic flow meter is a conventional instrument. There are many things to do on it. In the theory, people continue to develop ideas to enlarge the applications. For multiphase flow, the effect of the bubble or other insulating phases on the distribution of the weight function can be found by a semi-analytical method. This gives us way to understand the behavior of the flow meter in multiphase flow. By introducing new electrode form and working magnet field, one can possibly measure insulating fluid such as oil. Further extending of the present theory, one can hope to reconstruct flow pattern by electromagnetic induction. Even though there are much more thing to do to put this new ideas into commercial application, the new development of the traditional technique encourages us to do further research.

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AUTHOR: Prof. Dr. Xiao-Zhang ZHANG, Department of Engineering Physics, Tsinghua University, Beijing, 100084, P.R. China, Phone Int. +86 10 62782496, Fax Int. +86 10 62770304
E-mail: xzzhang@thinker.ep.tsinghua.edu.cn