A New Approach for The Parameter Measurement of Fluid Conductivity in An Electromagnetic Flow-meter

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Abstract

This paper introduces a new approach for the parameter measurement of fluid conductivity in an electromagnetic flow-meter. Based on dual excitation method, one magnetic excitation is used for flow rate measurement, and the other electric excitation is for fluid conductivity measurement. Dual-frequency electric excitation is employed to get fluid conductivity in a wide range with high precision. A calculation model for fluid conductivity is proposed. A dual-excited electromagnetic flow-meter based on photovoltaic(PV) Cell was designed and verified. Simulation experiment based on resistors and experiment based on different fluid conductivity were carried out. This new approach is proved to be feasible and promising。

1 Introduction

Electromagnetic flow-meter(EMFM) has been widely used for its advantages such as no internal moving parts, wide turndown, high measurement accuracy and so on. But the conductivity of measurable fluid for a conventional electromagnetic flow-meter(EMFM) is generally greater than 5μs/cm[1]. The determination of the fluid conductivity can be used to alarm a rather low conductivity, which will lead to a measurement error. It can also be used as a parameter to rectify the flow-rate measurement of low conductivity, to improve the measurement accuracy and to broaden the conductivity of measurable fluid. In addition, this method can be used to distinguish the electrode adhesion level and detect the empty pipe.

By now, without any separate sensor dedicated to fluid conductivity measurement, the method of dual excitation is used for measuring the flow rate and the fluid conductivity simultaneously[2-7]. Li Bin and Cao JinLiang proposed the concept of dual excitation[7], in which magnetic excitation is for flow-rate measurement and electric excitation is for other parameters measurement such as wetted electrode resistance of the EMFM. Generally, two approaches have been used for dual excitation, mainly differing in whether the electric-excited module is in parallel or in series with the measurement loop. In the parallel one, however, the equivalent input impedance of the instrumentation amplifier will be reduced to affect the measurement accuracy.

This paper proposes and validates a new method for fluid conductivity measurement employing dual excitation based on photovoltaic(PV) cell[8],with electric excitation source in series with the main measurement loop. This method ensures excellent flow-rate measurement with no reduction in the equivalent input impedance of the instrumentation amplifier theoretically. And it also provides an easy way to control the electric-excited module, minimizing the interference from the outside. A calculation model for fluid conductivity is proposed in this paper. Experiments based on both resistors and different conductivity fluid were carried out。The experimental results proved that this method is promising and feasible.

2 Principle

The principle block diagram of a dual-excited EMFM based on PV Cell is illustrated in Fig.1. The measurement loop consists of an instrumentation amplifier, a pair of PV converters and a pair of sensing electrodes. Each PV converter is regarded as a voltage source, which is composed of a PV Cell and a resistor, activated by an adjacent led controlled by Micro Control Unit. It is called electric excitation when the voltage E_a and E_b generated by the PV converters.

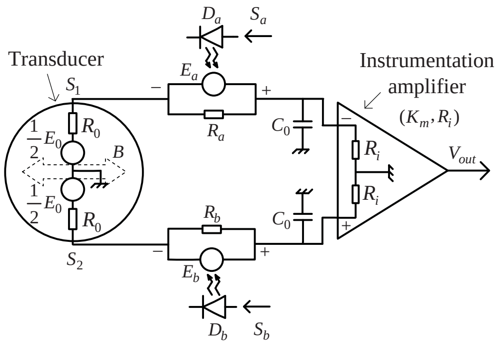

Fig 1: Principle block diagram of a dual-excited EMFM based on PV Cell.

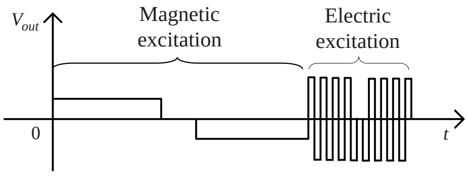

Fig 2: Illustration of time share of dual excitation in one measuring cycle. t denotes the time, and V_{out} denotes the output voltage of the measurement loop.

Moreover, each input end of the instrumentation amplifier is in parallel with a capacitance of C_0, which leads to different equivalent input impedance of the amplifier with different frequency of the input signal for magnetic excitation and electric excitation. Z_{eq}, the equivalent input impedance of the amplifier, can be given by $Z_{eq} = Z_{C0} // R_i$, in which Z_{C0} is the equivalent impedance of C_0 , R_i is the input resistance of the instrumentation amplifier。 C_s denotes the capacitance between the electrode and fluid, and can be ignored when $C_0 >> C_s$ selected. Provided $R_p = R_a = R_b$, $E_p = E_a + E_b$, the output of the amplifier can be given by

$$V_{out} = \frac{Z_{eq}}{R_0 + R_p + Z_{eq}}(E_0 + E_p) \qquad (1)$$

As shown in fig.2, in each measurement period, magnetic excitation alternates with electric excitation. During magnetic excitation, $E_p = E_a = E_b = 0$. The PV converter works only as a small resistor($R_p < 5k\Omega$) in serial with the measurement loop. The effect of C_0 can be ignored due to enough low magnetic excitation frequency. At the basis of the Faraday law of magnetic induction[9], the corresponding flow rate can be calculated by

$$V = \frac{V_{out}}{K_m \times K_0 \times B \times D} \times \frac{R_0 + R_p + R_i}{R_i} \qquad (2)$$

K_m --- amplification factor of the instrumentation amplifier; K_0 --- coefficient of the flow-meter; B---magnetic flux density; D---pipe diameter.

During electric excitation, $E_0 = 0$. The equivalent input impedance of the instrumentation amplifier Z_{eq} should be as the same order as R_0 so that R_0 can be measured well. Electric excitation was carried out with the square wave signals of two different frequencies. Provided that $R_i >> Z_{C0}$, R_0 can be given by

$$R_0 = \frac{1}{2\pi C_0} * \sqrt{\frac{V_{out2}{}^2 - V_{out1}{}^2}{(V_{out1} f_1)^2 - (V_{out2} f_2)^2}} - R_p \qquad (3)$$

Where V_{out1} and V_{out2} are respectively the corresponding output voltage of the amplifier to the two different electric excitation frequencies f_1 and f_2。

In this paper, R_0 ranged from 1kΩ to 1MΩ, whose equivalent fluid conductivity ranged from 1ms/cm to 1μs/cm. The frequency of electric excitation should be low enough so that the fluid can be seemed as a pure resistor[10]. Thus the frequencies lower than 4kHz were tried for electric excitation. When AD620 was chosen as the instrumentation amplifier, 470pF of C_0 was a better choice.

3 Experimental results

Three experiments were carried out, including

(1) Experiment for electric-excited module.

(2) Simulation experiment for fluid conductivity measurement based on resistors.

(3) Experiment for fluid conductivity measurement based on fluid of different conductivity.

Experiment(1) proved that the PV cell, Si photodiode S1133-01 in this research, is controllable and stable. And the electric potential of 10mv was selected for electric excitation.

Experiment(2), simulation experiment based on resistors, was conducted with a circuit model as shown in Fig.2(a). R_0 ranged from 1kΩ to 10MΩ.

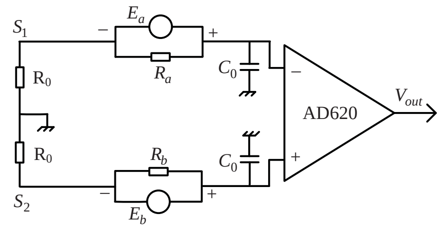

Fig 2(a): Circuit model of simulation experiment based on resistors

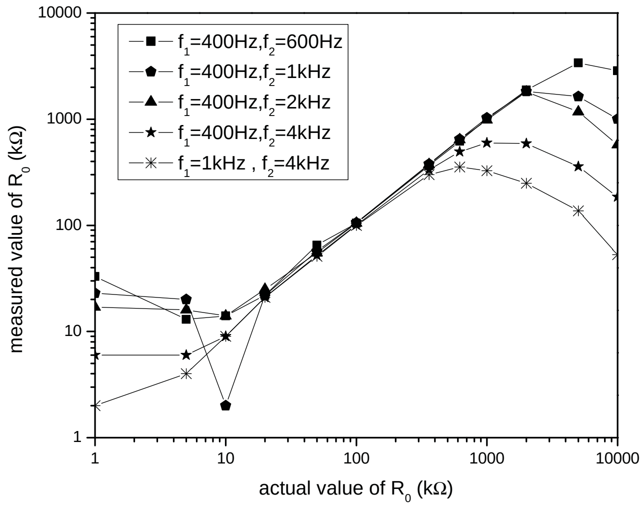

Fig 2(b) Actual value of R_0 vs. measured value of R_0

The experimental results (fig2(b)) showed that when the electric excitation frequency is lower than 2kHz, R_0 which is bigger than 10kΩ and smaller than 2MΩ can be measured well. With electric excitation frequency higher than 2kHz, R_0 smaller than 400kΩ can be distinguished well. Obviously, with low electric excitation frequency, R_0 of small value can not be distinguished well because Z_{eq} is too big. And when R_0 is large enough, much higher the excitation frequency is, more serious the distributed capacitance affects.

Experiment(3) based on fluid of different conductivity was carried out with an EMFM in vertical with bottom sealed, whose nominal diameter is 100mm. The measured fluid conductivity ranged from 215μs/cm to 1.43μs/cm in this experiment.

Fig.3. shows the experimental results. Obviously, the fluid conductivity lower than 20μs/cm can be detected well with the electric excitation frequencies of 400Hz and 1kHz,whilst the conductivity higher than 5μs/cm can be detected well with the frequencies of 400Hz and 4kHz. Thus, combining these two sets of experimental data, the measured value of R_0 is almost linear with the fluid conductivity.

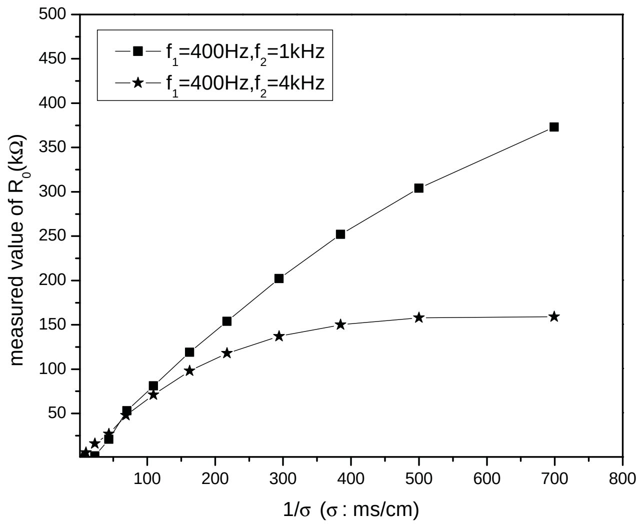

Fig 3 $1/\sigma$ vs. the measured value of R_0. σ denotes the fluid conductivity.

4 Conclusion

A new approach for fluid conductivity measurement, a calculated model for fluid conductivity, and a dual-excited EMFM based on PV Cell was presented in this paper. Experiments based on both resistors and different fluid conductivity were carried out. The experimental results fully proved that when the electric excitation frequency is low enough, this method can distinguish different conductivity well in a wide range. This method also ensures excellent flow-rate measurement theoretically and provides an easy way to control the electric-excited module, minimizing the interference from the outside.

In this paper, the fluid is taken as a pure resistor. But the double-electric layer can not be ignored. The impedance spectroscopy for fluid needs further research and analysis. And the experiment on flow rate should be carried out. This method can also be used to the diagnostics of EMFM such as electrode adhesion and empty pipe.

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