Research on a Three-phase Flow Electromagnetic Measurement Method

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Abstract. For a long time, industrial and agricultural production has a wide range of requirements for energy saving and emission reduction. The flow parameter detection of water/gas/oil three-phase flow is of great significance in the control and optimization of the petroleum industry process. Using the principle of correlation method, a multi-electrode electromagnetic measurement method is designed to measure the three-phase flow. The system has the function of self-detection of the meter zero point. The finite element method is used to calculate and analyze the distribution of sensitive fields inside the flow measurement sensor and the influence of different physical parameters of non-conductive objects on the disturbance characteristics of the flow measurement sensor. And through experiments to prove the feasibility, stability and accuracy of the constructed measurement system.

Keywords: Multi-electrode, electromagnetic measurement method, three-phase flow.

1. Introduction
Since flow measurement is commonly used in the field of water supply and drainage and sewage monitoring, there are the characteristics of mud debris in the fluid that it is difficult to obtain the flow rate with one measurement parameter. These characteristics are usually difficult in the field of multiphase flow measurement, so it is sought to meet the actual application requirements The electromagnetic flow measurement method to solve the above difficulties is a challenging problem in the field of flow measurement research.

The traditional method of measuring three-phase flow in the petroleum industry is to decompose the liquid produced from the production well into three phases of oil, gas, and water by a three-phase separator, and then measure the three phases by flowmeters installed on the pipelines of each phase outlet of the separator. The flow rate of this fluid. Many scholars have carried out a lot of research on the measurement of three-phase flow. Liu Xingbin et al. proposed a conductivity sensor, which can measure the flow rate of oil wells with high water cut [1]. Kong Lingfu et al. studied the measurement method of oil-water two-phase flow [2]. Zhao Na and others will conduct research on the flow measurement of oil-water two-phase flow [3]. Meng Fanlei and others combined multiple flow measurement sensors to measure the flow of oil, gas and water multiphase flow [4]. However, this method has large errors, low efficiency and poor real-time performance, which is difficult to meet the development needs of modern domestic oil production.
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The traditional electromagnetic flow sensor has the advantages of no blocking and blocking parts, wide measurement range, high measurement accuracy, and convenient maintenance. In addition, the excitation coil of the traditional electromagnetic flow sensor can be a saddle type, which is conducive to the operation of the sensor in a small space. The above advantages make electromagnetic flowmeters widely used in the downhole petroleum industry with high water cut [5]. However, when the traditional electromagnetic flowmeter measures a multiphase flow with a low water content, the disturbance noise is large, which leads to a large error in the measurement result. Scholars such as Li Xiaojing [6] and Zhang Hongjian of Zhejiang University [7] used correlation methods to solve the problem of noise interference when electromagnetic flowmeters are measured at low speeds, but this method has not been applied to multiphase flow measurement. The electromagnetic flow sensor designed in this paper has four electrodes. According to the noise problem in the three-phase flow measurement, a zero-point self-detection function is designed in the converter part. The designed system can accurately measure the three-phase flow flow.

2. Background theory

The basic principle of electromagnetic flowmeter (as shown in Figure 1) [8], according to Faraday’s law of electromagnetic induction, under the action of a uniform magnetic field \( B \) (T), conductive flows in an insulated measuring pipe with a width of \( D \) (m), when moving along the direction perpendicular to the magnetic field at speed \( V \) (m/s):

\[
E_i = \frac{d\phi}{dt} = \frac{BdS}{dt} = B \frac{Ddl}{dt} = BDV
\]

(1)

The volume flow through a certain section of the pipeline is equal to the product of the area of the section and the flow velocity. For a round measuring tube, the volume flow \( Q \) (m\(^3\)/s) has:

\[
Q = \frac{\pi D^2 V}{4}
\]

(2)

Combining (1) and (2) can get:

\[
Q = \frac{\pi D E_i}{4B}
\]

(3)

![Fig. 1 Measurement principle diagram](image)

The principle of multiphase flow measurement is to use the flow noise of the fluid to determine the fluid velocity. Specifically, the flow velocity of multiphase flow is closely related to flow noise. The
speed of the flow noise is equal to the flow speed of the discrete phase, the fluid flows over a certain 
distance, and the flow noise of the fluid is measured to determine the flow velocity of the fluid [9-10].
That is, the flow noise generated by the fluid in the flow process is used to convert the flow rate 
measurement problem into a time interval measurement [11-12].

Install two pairs of electrodes with the same structure in the measuring pipeline, and the two pairs of 
electrodes are separated by L. The measurement signals of the two pairs of electrodes extracted from 
the measured fluid are x(t) and y(t) respectively. The correlation function of the two signals is R_{xy}(\tau):

\[ R_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} x(t) y(t + \tau) \, dt \] (4)

The transition of the fluid flowing through the detection electrode is \( \tau_0 \), and the relevant flow velocity 
V is as follows:

\[ V = \frac{L}{\tau_0} \] (5)

3. System Design

3.1. Sensor Part
In order to solve the flow measurement problem of oil, gas and water multiphase flow, a flow 
measurement model of electromagnetic correlation method for oil, gas and water multiphase flow is 
proposed. Figure 2 shows the sensor flow measurement model.

As shown in Figure 2, when a three-phase flow with a certain ratio flows through the measurement 
pipeline, two pairs of detection electrodes (AA' and BB') obtain measurement signals respectively. The 
distance between electrodes A and B (A' and B') is a fixed value L. According to the relevant 
measurement method and formula (5), the fluid can be measured.

3.2. Converter Part
The structure of the converter part of the electromagnetic flowmeter in this study is shown in Figure 3. 
The zero point stability of the electromagnetic flowmeter is related to the accuracy of the measurement. 
A self-feedback zero point adjustment function is designed in the circuit part. When measuring three-
phase flow, temperature drift and zero drift, especially various noise interference during three-phase 
flow measurement, will cause the zero point to change, and the self-feedback zero point adjustment 
function can stabilize the zero point when measuring multi-phase flow. The important role of, improves 
the accuracy of measurement.
The purpose of using this power supply is to improve the accuracy and stability of the measurement. This is because the induced electromotive force signal detected by the sensor is generally at the µV level, and a large amount of interference is superimposed, the signal is very weak, and the signal-to-noise ratio is very low. How to extract the weak signal is the primary requirement for the converter of the flowmeter. In order to improve the ability of the converter to process the signal, the requirement for the power supply is that the ripple of the supply voltage should be around 20mV. The dual power supply system requires good symmetry between the positive and negative power supplies. Therefore, the power supply module of this study is the switch power supply of VIPerX2A product, and its switching frequency is 60KHz.

b) Signal amplification module As shown in Fig. 3, the signal method module is divided into: pre-stage instrumentation amplifier and feedback signal amplification module.

1) Pre-stage instrumentation amplifier: Hope to improve the signal-to-noise ratio of the signal through the instrumentation amplifier. ANALOG’s precision instrumentation amplifier AD620 has the characteristics of high common-mode rejection ratio, high precision, low loss and low power. The calculation formula of gain G is [13]:

$$G = \frac{49.4k\Omega}{R_c} + 1$$  

(6)

Among them, $R_c$ is the external resistance of AD620, which can realize the adjustment setting of the amplifier gain from 1 to 1000.

In this study, $R_c$ is 10kΩ, from (6) the gain is 5.94 and the common-mode rejection ratio is 100dB from equation (6). Therefore, after the instrumentation amplifier AD620, the signal-to-noise ratio of the weak flow signal is greatly improved, and the common mode interference of the flow signal is suppressed.

2) Feedback signal amplifier module After the signal passes the first-level instrument method, it is adjusted by the feedback type amplifying module, as shown in Fig. 4 is the structure diagram of the feedback type signal amplifying circuit.
The feedback signal amplifying circuit performs feedback adjustment on the baseline of the flow signal during the zero excitation process of the rectangular wave excitation, that is, automatically adjusts the zero point to perform open-loop amplification and filtering on the signal during the positive and negative excitation cycles according to the adjusted baseline.

Fig. 5 shows the signal comparison of the signal through the amplification module. Vin is the input signal. The flow signal is very weak as shown by the oscilloscope, so it is difficult to distinguish the flow signal in the figure. The V_{out} signal is an adjusted, amplified and filtered signal. At this time, the signal has been amplified to a very reasonable range, and the baseline of the signal is always around V_{ref}. The amplification module not only amplifies the signal accurately and without distortion, but also realizes the automatic adjustment of the signal zero point.

![Fig. 5 Input and output waveforms of the amplifier circuit](image)

4. Experimental results and analysis

In the experiment, the measuring pipe is 50mm, the total fluid flow range is 0~150m3/d, and the water content range of the measuring flow point is 50%~100%. Fig. 6 shows the signal when the fluid in the measuring pipe is at rest.

![Fig. 6 Fluid static test chart](image)

Fig. 6 is the signal when the fluid in the measurement pipeline is at a static state. The signal is amplified by two stages, namely the instrument amplifier and the feedback amplifier module. After testing the automatic zero tracking function of the module at this time, the actual tracking zero value is: -17mm/s±2mm/s, and the actual flow rate detected after eliminating the tracked zero value is: -1mm/s→+1mm/s. After the output signal of the working sensor is amplified, the signal is very stable, and certain interference signals are eliminated.

The flow measurement results are shown in Fig. 7.
Fig. 7 shows the flow measurement results. As shown in the figure, when the water content of the three-phase flow of oil, gas and water is different, there is a linear relationship between the measured flow rate and the standard flow rate. The stability and reliability of the designed flowmeter are verified. And the relative measurement error is less than 4%, which can meet the measurement requirements.

5. In Conclusion
With the development of the petroleum industry, the research on the measurement of oil, gas and water three-phase flow has become a research hotspot. Based on a large number of related application research, this research analyzes the problems existing in the flow measurement of oil, gas and water three-phase flow. Comprehensively study the advantages and disadvantages of traditional electromagnetic flowmeters in multiphase flow measurement, design the converter of the flowmeter, and provide a solution and method for the correlation method combined with electromagnetic flow measurement. Experiments have proved that the designed electromagnetic flowmeter has the advantages of high stability, low cost and easy maintenance in the measurement of oil, gas and water three-phase flow.

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