Research on multiphase flow measurement system based on electromagnetic correlation method

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Abstract. The phenomenon of oil-gas-water multiphase flow is common in oil wells in the middle and late stage of oilfield development. The accurate measurement of its flow is of great significance to the control of oil production process and the efficient development of oil fields. In the analysis and research on the existing problems of multiphase flow measurement technology at home and abroad and based on the proposed a flow measurement system based on conductance measurement technique design and the implementation plan, to achieve a kind of can expand production logging in multiphase flow of oil and gas flow measurement range, and with continuous measurement, no radioactive, low cost advantages, such as oil and gas water related method of flow measurement model of multiphase flow electromagnetic research, optimization of oilfield production and realization of intelligent well completion, and promote the development of new type multiphase flow instrument, with major production guiding significance and value.

1. Introduction

In the field of petrochemical production, multiphase flow has been widely concerned by experts and scholars at home and abroad because of its complex flow pattern, randomness and difficulty in measurement. With most of China's oil fields entering the stage of high-water-cut exploitation, multiphase flow detection technology plays an increasingly important role in scientific research and oil industry production. On-line measurement of multiphase flow is of great practical significance for the safety of the entire oil industry.

A multiphase flow is a flow in which two or more different mixtures exist simultaneously. The key parameters of multiphase flow mainly include flow rate, phase holdup and flow pattern, among which flow parameters are very important parameters in the detection and measurement of multiphase flow, which are of great significance to the measurement, control and reliable operation of the existing production process. Hasn't used in production logging and achieve good effect of multiphase flow metering device, the traditional method of multiphase flow metering is to put the oil and gas well liquid
into the three-phase separator, each separate measurement by the separator, the weight and volume of the three-phase separator metering system are very big, in the actual production logging applications, the measurement method for artificial operation, the measurement time is short, optional the gender is strong, can't satisfy the real-time and continuous measurement, the error caused by human factors. Adamovskii L A, using two electromagnetic flowmeter is applied to A large nuclear facilities of sodium coolant measurement signal correlation method operation[1], but two excitation coil electromagnetic flow easily interfere with each other Inada Yutaka USES A pair of detecting electrodes for measuring signals and related operations in order to improve the measuring precision[2], Li Xiaojing and others for electromagnetic flowmeter in low speed measurement, signal submerged by noise can't accurate measurement problem[3], introduces the correlation detection algorithm, improves the SNR of signal, performance improved substantially, Zhang Hongjian, Guan Jun electromagnetic flowmeter, introduced the related testing technique[4], which combines correlation method and electromagnetic flowmeter research makes the traditional electromagnetic flowmeter measurement threshold extension, Liu Xingbin was proposed based on conductance sensor measuring the moisture content and flow of high water cut oil well method[5], but these studies are based on the traditional electromagnetic flowmeter measurement uniflow traffic situation, does not involve flow measurement problem of multiphase flow, in view of the oil and gas well logging specific flow online measurement problem of multiphase flow measurement environment, this article on the basis of summarizing the existing electromagnetic related measurement methods, implements a real-time online measurement system based on electromagnetic correlation method, it has the advantages of small size, no radioactivity[6], wide measuring range, low cost and simple measuring structure.

The measurement signal of the system generates sinusoidal excitation through the quartz crystal sinusoidal oscillation circuit. STM32F103ZET6 built with ARM Coretex-M3 as the main control chip is used to collect and process the output signal[7]. A multiphase flow measurement system is formed by combining the flow measurement sensor using electromagnetic correlation method. An experiment platform for measuring the flow rate of oil, gas and water multiphase flow was built to verify the performance of the system.

2. Principle of electromagnetic correlation measurement

The electromagnetic correlation flow measurement method combines the electromagnetic flow measurement technology and the related flow measurement technology. The electromagnetic flow measurement technology is based on Faraday's law of electromagnetic induction to measure the flow, and the electromagnetic flow meter is a kind of sensor used to measure the flow velocity of conductive liquid based on the electrical characteristics[8]. The conductive liquid cuts the magnetic line of force in the magnetic field to generate the induced electromotive force, namely:

$$ E = KBDV $$

Where, K is the instrument coefficient. If the magnetic induction intensity B and the distance D between the detection electrode are known, the average velocity of liquid in the whole pipeline can be known by measuring the induced electromotive force U at both ends of the electrode. $\vec{V}$

When measuring high-water-cut oil, gas and water multiphase flow with traditional electromagnetic flowmeter, due to its low content of non-conductive substances (gas phase and oil tank), the measurement result is relatively prepared and has little influence. For non-high-water-cut oil, gas multiphase flow with high content of non-conductive substances, the measurement result has a large error and great influence. When the measured flow velocity is slow, the measurement error of the traditional flowmeter is greater[9], because the non-conductive contact causes the detection signal to be acquired by the detection electrode to fluctuate greatly.

Multiphase flow is a complex multivariable stochastic process, flow state is very complicated, may be due to the size of the discrete phase in the fluid particles, spatial distribution and the change of the local concentration of each component flow noise, such as density, viscosity, electrical conductivity and dielectric constant will with the change of composition and is in fluctuation condition, these characteristics to meet the requirements of the relevant measurement. Related electromagnetic flow
measurement is the internal fluid flow naturally produced by the random noise through gathering wave (oil phase and gas phase), by measuring the electrode to the fluid noise wave is converted to electrical signals, through the correlation method to measure the disturbance signal is calculated, then the flow rate, finally calculate the flow, as shown in fig.1 for electromagnetic flow measurement model.

Figure 1. Flow measurement model of electromagnetic correlation method

As shown in Fig.1, two pairs of detection electrodes with the same structure (A1 and A2, B1 and B2) are installed at an appropriate distance from the pipe of the fluid (A1 and A2, B1 and B2), respectively called the upstream detection electrode and the downstream detection electrode. Upstream or downstream from the detection electrodes extraction by measurement of body measurement signal x(t) and y(t), according to the "solidification model" hypothesis, the state of the fluid remains the same, as it passed the detection of upstream and downstream of the electrode in the same of the uniform magnetic field produced by the excitation coil, a good correlation between them, so to measure the signal x(t) and y(t) cross-correlation operations, the cross-correlation function is represented by Equation 2.

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

(2)

In the actual measurement system, signals X(t) and y(t) are all signals containing noise. Set:

\[
x(t) = X(t) + n_1(t) \quad (3)
\]

\[
y(t) = X(t-d) + n_2(t) \quad (4)
\]

Where, X(t) is the upstream electrode measurement signal, X(T-D) is the downstream electrode measurement signal, and the time delay of the output signal of the downstream electrode compared with the output signal of the upstream electrode is D, n1(t), and n2(t) is the additional noise of the electrode output signal, respectively. Substitute Equation (3) and Equation (4) into Equation (2), and then:

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

\[
= \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} [X(t) + n_1(t)][X(t+\tau - d) + n_2(t+\tau)] \, dt
\]

\[
= \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} X(t)X(t+\tau - d) \, dt + \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} X(t)n_2(t+\tau) \, dt
\]

\[
+ \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} n_1(t)X(t+\tau - d) \, dt + \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} n_1(t)n_2(t+\tau) \, dt
\]  

(5)

As the signal and noise between, noise N1(t), and n2There is no correlation between (t), so it can be known that the 2nd, 3rd and 4th items in Equation (5) are all 0, leaving only the 1st item, namely:

\[
R_{xy}(\tau) = R_{xx}(\tau-d)
\]  

(6)

According to formula (6), the cross-correlation function reaches the peak value \(\tau=d\). Thus, the delay d can be estimated. Since the distance between upstream and downstream electrodes L is known, the relevant velocity V of fluid flow can be known as shown in Equation (7) below.

\[
V = \frac{L}{\tau}
\]  

(7)
The signal processing

Mixed liquid

Detection electrode 1

Detection electrode 2

The signal processing

Fig 2. Flow measurement schematic diagram of correlation method

3. Composition of measurement system

The hardware measurement system based on flow measurement by electromagnetic correlation method is mainly composed of excitation circuit, signal processing circuit and data acquisition circuit. The block diagram of the system is shown in Figure 3.

3.1. Excitation Circuit

The excitation circuit is composed of sinusoidal excitation signal generation circuit and excitation signal power amplifier circuit. The power amplifier circuit USES ADI 8000 chip, which is an ultra-high speed, high performance and current feedback amplifier. The AD8000 chip can drive the load current of more than 100 mA, with very low distortion. By amplifying the voltage of excitation signal through operational amplifier, the output with load capacity is enhanced, and the amplified signal is taken as the excitation coil of the input electromagnetic flowmeter as the excitation signal.

3.2. Signal processing circuit

Signal processing circuit module amplifier circuit, filter circuit, invert circuit, sampling hold circuit and signal output circuit, as shown in Figure 4. The amplifier circuit is composed of a differential amplifier circuit. The input end is connected to the sensor's detection electrode, and the measurement signal at the sensor electrode passes through the pre-amplifier circuit to eliminate the common mode signal in the acquired signal and amplify the flow signal at the same time. The filter circuit then filters the signal, amplifies and inverts the signal, and the sampling hold circuit periodically samples the signal and keeps the sampling value unchanged within the time of AD conversion. The signal output circuit outputs the voltage signal corresponding to the flow. The induced ELECTRO motive force signal generated at the upstream and downstream detection electrodes is processed through a series of processes and finally transmitted from the signal output circuit. The signal processing circuit is shown in Figure 5.
3.3. Data acquisition circuit

Data acquisition system based on STM32F103ZET6 company as a main control chip, through chip internal ADC for measuring circuit of the output signal acquisition, and displayed on the LCD screen, at the same time through the DMA way real-time storage to NAND flash memory chips, and through the RS485 protocol to transmit the data to PC, RS485 circuit advantage is 485 compatible with TTL level, strong ability to resist common mode, data transmission speed, distance, through the PC to realize the data real-time processing and read and write operations. The flow chart is shown in Figure 6.

4. Flow measurement experiment

4.1. Experimental Platform

An indoor simulation experiment platform suitable for oil, gas and water multiphase flow, as shown in Figure 7, was built. Building the experiment platform of simple structure, complete function, the flow characteristics of oil and gas water multiphase flow can be a better simulation, can make two phase flow and three-phase flow simulation experiment, the different proportions of mixed oil and gas water to set the flow speed of multiphase mixture formation, and can conveniently change mixed fluid flow path, and a variety of flow simulation, is conducive to convenient for a variety of flow parameter measurement.

The main components of the simulation experiment platform are: frequency converter, screw pump, air compressor, flow control valve, one-way valve, gas flow meter, steady flow device, mixing tank and
mixer, etc. The general composition diagram is shown in Figure 7, and the physical diagram is shown in Figure 8.

![Figure 7. Composition diagram of indoor multiphase flow simulation experiment platform](image)

![Figure 8. Photo of indoor simulation experiment platform](image)

4.2. Analysis of experimental results

The multi-phase flow measurement experiment was carried out to measure the flow of gas-liquid two-phase flow and oil-gas-water three-phase flow respectively. The gas-liquid two-phase flow experiment was carried out by adding a certain amount of water into the mixing tank and providing a certain amount of gas through the air compressor to achieve the uniform mixing of gas-liquid two-phase through the static mixer. The screw pump is used to provide power for the fluid of mixed fluid. Its speed can be adjusted by frequency converter to control the flow rate of the fluid in the pipeline. The flow rate can be measured by calibrated flowmeter so as to facilitate the reference of measured flow rate. Oil, gas and water multiphase flow experiment: install a certain proportion of oil and water into the mixing tank for uniform mixing, and flow a certain amount of gas provided by oil and water mixture and air compressor through the static mixer to achieve uniform mixing of oil, gas and water three-phase fluid. Through the screw pump inverter to adjust the flow rate of multiphase mixed fluid, so as to carry out different flow simulation experiments. The measured data of gas-liquid two-phase flow and oil-gas-water multiphase flow are shown in Table 1 and Table 2 respectively. Curves of flow calibration value (Q_t) and actual measured value (Q_m) of multiphase flow are shown in Fig.9 and Fig.11 respectively. Curves of flow measurement error (Q_err) of multiphase flow are shown in Fig.10 and Fig.12.

| Frequency/Hz | Flow velocity measurement (m/s) | Flow measurement (m/h) | Calibration flow value (m/h) | Flow error value (%) |
|--------------|---------------------------------|------------------------|-----------------------------|---------------------|
| 5            | 0.221                           | 0.565                  | 0.6                         | 5.82                |
| 10           | 0.451                           | 1.146                  | 1.2                         | 4.51                |
| 15           | 0.666                           | 1.702                  | 1.8                         | 5.44                |
| 20           | 0.896                           | 2.279                  | 2.4                         | 5.04                |
| 25           | 1.082                           | 2.883                  | 3                           | 3.90                |
| 30           | 1.332                           | 3.387                  | 3.6                         | 5.92                |
| 35           | 1.583                           | 4.025                  | 4.2                         | 4.21                |
| 40           | 1.796                           | 4.568                  | 4.8                         | 4.83                |
| 45           | 2.027                           | 5.156                  | 5.4                         | 4.52                |
| 50           | 2.229                           | 5.668                  | 6                           | 5.53                |
Table 2 Experimental measurement data of oil-gas-water three-phase flow

| Frequency/Hz | Flow velocity measurement (m/s) | Flow measurement (m/h) | Calibration flow value (m/h) | Flow error value (%) |
|--------------|---------------------------------|------------------------|-------------------------------|----------------------|
| 5            | 0.254                           | 0.645                  | 0.6                           | 7.50                 |
| 10           | 0.443                           | 1.128                  | 1.2                           | 5.92                 |
| 15           | 0.659                           | 1.677                  | 1.8                           | 6.81                 |
| 20           | 0.876                           | 2.227                  | 2.4                           | 7.22                 |
| 25           | 1.113                           | 2.831                  | 3                             | 5.63                 |
| 30           | 1.304                           | 3.317                  | 3.6                           | 7.86                 |
| 35           | 1.570                           | 3.993                  | 4.2                           | 4.94                 |
| 40           | 1.762                           | 4.481                  | 4.8                           | 6.64                 |
| 45           | 1.954                           | 4.971                  | 5.4                           | 7.94                 |
| 50           | 2.204                           | 5.605                  | 6                             | 6.59                 |

Figure 9. Curves of the real value and measured value of the gas-liquid two-phase flow

Figure 10. Error curve of gas-liquid two-phase flow

Figure 11. Curves of the real and measured flow rates of oil-gas-water three-phase flows

Figure 12. Error curve of three phase flow of oil, gas and water
From table 1 experimental data shows that for gas water two phase flow, the flow measurement error within 6%, have relatively good accuracy, the experimental data from table 2 for oil and gas water three phase flow in measurement data shows that the flow measurement error within 8%, compared with the traditional electromagnetic flowmeter in mixed fluid to multiphase flow measurement, error of system has certain improvement, to achieve the expected design purpose.

5. Conclusion
A multiphase flow measurement system based on electromagnetic correlation method is designed in this paper. This system has simple structure, low manufacture cost, can be continuous measurement, easy to install, wide measuring range, improve the traditional electromagnetic flowmeter with low velocity of fluid and in non conductive material contain low rate when the error is bigger, integration in the practical application of electromagnetic flow measurement technology and related method of flow measurement technology, the advantages of the experimental results show that the system of high sensitivity, stability is strong, can be better applied to measuring the two-phase flow of the conductive material content is low, also can measure the conductive material containing rate range larger flow of two phase flow and multiphase flow.

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