Research on Electromagnetic Flowmeter Based on Double-frequency Trapezoidal Wave Excitation

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Abstract. Electromagnetic Flowmeter is widely used in industrial production and life, because it is characterized by high precision and little environmental interference in electromagnetic flow measurement. However, the commonly used low frequency rectangular wave excitation greatly reduces the measurement accuracy and measurement range of electromagnetic flowmeter due to in-phase interference, differential interference and other factors. Double-frequency trapezoidal wave excitation has the advantages of both excellent zero-point stability of low frequency excitation and strong ability to suppress the noise of slurry fluid and fast response speed of high frequency excitation. In this paper, a double-frequency trapezoidal wave excitation method for electromagnetic flow measurement is proposed. Then the experimental platform is established to verify the measurement accuracy and measurement range. According to the comparison with the instant flow of the standard meter, the measurement accuracy of double-frequency trapezoidal wave excitation is significantly higher than that of low frequency rectangular wave excitation, and in phase interference and differential interference are significantly reduced.

1. Introduction
Electromagnetic flowmeter is a kind of instrument based on Faraday's law of electromagnetic induction to measure the flow of conductive liquid. Since its accuracy is hardly affected by the medium performance, pressure loss or corrosion, it has has been widely used in all kinds of areas.[1] The excitation technology of the electromagnetic flowmeter determines the characteristics of the working magnetic field of the electromagnetic flowmeter, so the excitation technology greatly affects the measurement accuracy of the electromagnetic flowmeter. For excitation technology of electromagnetic flowmeter, As for the excitation technology, K.C.Liu et al proposed a DC excitation technology, where DC power is used in the electromagnetic flow sensor and permanent magnet is used to form constant magnetic field. It is hardly affected by the power-line interference, and the self-induction phenomenon can be neglected. X.M.Xv [3] proposed a signal processing method based on low frequency rectangular wave excitation. When the signal flows out of the sensor, the signal is filtered and preprocessed. After the signal is amplified, it is sent to the high-pass filter and low-pass filter. After filtering the high-frequency and low-frequency interference in the signal, sampling and collection are carried out to reduce interference in the signal, so as to improve the measurement accuracy and zero-point stability. J.Z.Jia
used low-frequency trapezoidal excitation to replace the rectangular wave excitation which decreases the differential interference and in-phase interference and improve the signal-to-noise ratio (SNR), zero-point stability as well as the measurement accuracy. Meanwhile the complementary push pull amplifier was sued to improve the signal power and realized better sampling method of zero-point dynamic compensation of the excitation.

In this paper, based on the study of the existing excitation mode of electromagnetic flowmeter, an electromagnetic flowmeter based on double-frequency three-value trapezoidal wave excitation is designed. Compared with the traditional three-value low frequency trapezoidal wave excitation, it also has the advantages of both excellent zero-point stability of low frequency excitation technology and strong ability to suppress the noise of slurry fluid and fast response speed of high frequency excitation technology. In addition, a measurement system is proposed to select different excitation modes according to different fluid characteristics, so as to match the best excitation mode for different fluids and improve the measurement accuracy.

2. Theory of electromagnetic flowmeter based on double-frequency trapezoidal wave excitation

2.1. Measurement theory of electromagnetic flow measurement

Faraday’s law of electromagnetic induction is obtained in an experiment in 1831, which shows that the magnetic flux changes in unit time with the conductor cutting through the magnetic lines of flux in a magnetic field. Thus the induction electromotive force can be produced between the two ends of the conductor. Then in 1984, Lenz Law was proposed, that is, the magnetic field produced by induction electromotive force always obstruct the variation of the magnetic flux. When the conductor is cutting through the magnetic lines of flux, the electromotive force can be expressed in equation (1):

\[ E_i = \frac{d\phi}{dt} = \frac{AdB}{dt} = B \frac{Ddl}{dt} = B\vec{v} \] (1)

where B is the magnetic induction intensity, A is the area variation of the magnetic flux, A is the conduction length, dl is the distance that the conductor moves through, \( \vec{v} \) is the velocity of the conductor and \( E_i \) is the induction electromotive force.

According to the Faraday’s Law of electromagnetic induction, the electromagnetic flow sensor is used to convert the flow signal into the voltage signal between the two ends of the conductor. Then the voltage signal is processed through amplification and filtering to correspond to the flow signal linearly. Finally the flow signal is displayed to measure the flow of conductive fluid and the flow accumulated in a period of time. The structure of the electromagnetic flowmeter is shown in figure 1.

![Figure 1. Structure of electromagnetic flowmeter](image-url)
2.2. Analysis of double-frequency trapezoidal excitation
The double-frequency trapezoidal wave excitation is researched in this paper, the low frequency of which is 6.25Hz, and the high frequency is 75Hz. The excitation wave is shown in figure 2. Since the low signal of the electromagnetic flowmeter is the same as the excitation signal, the electrode output signal is mainly composed of orthogonal interference and in-phase interference. Therefore, before being collected by the data acquisition system, the output signal needs to be processed by amplification and filtering circuit. Compared with the rectangular wave, the trapezoidal wave has the stable part, which increases the stability of the signal and the differential interference can be eliminated effective. Compared with the triangular wave, the trapezoidal wave has the rising edge and descending edge, which increases the utilization rate of the voltage. Meanwhile, by using the three-value trapezoidal wave excitation, the dynamic zero compensation can be used to improve the zero-point stability. In this method, the induction voltage produced by the sensor when the induction voltage is zero is largely correlated with the real zero drift value. Thus the zero-point stability can be improved by using dynamic zero-point compensation and trapezoidal wave excitation.

3. Measurement system design

3.1. Overall design of the measurement system
The block diagram of the whole system is shown in figure 3. The system is mainly composed of fluid characteristics sensor, signal processing circuit, micro-processing circuit, D/A excitation signal generator, frequency sweeping circuit, data processing module, and LCD display etc. MSP 430 micro-processing unit is the core of the system, which is used to control the D/A excitation signal generator to generate the trapezoidal wave, and switch the frequency of the excitation signal as a frequency sweep circuit.

Figure 2. double-frequency trapezoidal wave excitation waveform

Figure 3. block diagram of the electromagnetic flowmeter
3.2. Design of excitation signal generator

The structure of D/A excitation signal generator is shown in figure 4, which is mainly composed of MSP430, DAC0832 as well as OP1P operational amplifier. MSP 430 is a 16-bit micro-processing unit, with high operational speed, low power consumption, and 40ns period, and is composed of watchdog, analog comparator, timer, and hardware multiplier etc. It can be used for 12-bit analog-digit conversion, which greatly facilitates the solution of peripheral device problems. DAC0832 is an 8-bit D/A conversion chip, which is completely compatible with the micro-processing unit. It is cheap, with a simple interface and easy controlling system, and widely applied in the MCU system. DAC 0832 is composed of 8-bit input latch, 8-bit DAC register, 8-bit conversion circuit and conversion control circuit. Firstly, level control of P0-P7 pin can be realized by MSP430 programming, and the level signal is input into the DI0-DI7 pins. Since the excitation signal generated by DAC0832 is weak, and is easily influenced by the noises in the environment, the output signal by OUT2 and OUT1 is sent into the operational amplifier OP1P, and then sent into the oscilloscope for display.

![Figure 4. Excitation signal generator](image)

3.3. Design of sweep circuit

The sweep circuit which is used to generate the sweep signal is composed of micro-processing unit, direct digital synthesizer, low-pass filter, rectification and filtering, AD conversion circuit.

The sweep signal generated by the micro-processing unit is added to the A/D excitation signal generator. After receiving the address code produced by the signal processing circuit, the micro-processing unit starts the program to set the initial frequency, end frequency, and frequency interval. Then the corresponding frequency is used by the AD converter to generate the sweep signals of different frequencies, and measure the voltage signal at different frequencies. When the fluid in the pipe is regular, which cannot be measured using the excitation signal with a normal frequency, frequency scanning commences. When the flow rate is high, the frequency range is larger, from 6.25Hz to 2KHz, with a step of 0.2Hz, and a frequency interval of 0.1s. In the contrary, when the flow rate is low, the frequency range is small, from 6.25Hz to 1KHz, with a step of 0.25Hz, and with a frequency interval of 0.2s. The voltage signals measured by different frequency excitation waves are obtained. The data processing module samples the excitation unit of electromagnetic flowmeter to obtain the analog signals of excitation current and voltage. Finally, the data processing module selects the excitation frequency data with the smallest interference as the best excitation frequency through data comparison.
4. Experiment and analysis

4.1. Hardware debugging of the excitation system
First, the three-value trapezoidal wave can be generated by DAC0832 controlled by AT89S51. After that, in order to improve the accuracy of DAC and improve the stability, MSP430 micro-processing unit was used to control DAC0832 to generate 16-bit three-value trapezoidal wave, which makes the measurement more accurate. The hardware is shown in figure 3.
shown in figure 7. The slope of the rising edge and descending edge of the trapezoidal wave is excellent, which is effective to eliminate the differential and in-phased interference, and improve the measurement accuracy, especially in the low flow rate measurement.

4.2. System field test

The experimental platform is composed of water pump, pipeline, water tank, manual valve, electromagnetic flowmeter, signal conditioning circuit and signal acquisition system. The circulation system is composed of water pump, valve, standard flowmeter and electromagnetic flowmeter. Through the adjustment of standard flowmeter, the accuracy of trapezoidal wave excitation electromagnetic flowmeter can be calibrated. The flow in the pipeline can be controlled by the opening of the valve, and the signal is processed by filtering, de-noising and amplification of in the signal conditioning circuit. The signal sent to the sensor can be optimized by the signal conditioning circuit, and the flow signal can be finally displayed, and the data processing can be completed.

![Figure 8. System field test](image)

Insert the collected 26 data into the excel table in the form of line chart, and draw the flow voltage function diagram. Four electromotive forces of the stable parts of the excitation signal was chosen to calculate the voltage value with the zero compensation method. Under the same flow rate, the induction voltage was measured for several times and then averaged. The relationship between the induction voltage and the flow rate can be obtained, as shown in figure 1.

| Flow rate of standard meter (m³/h) | Voltage(V) | Flow rate of standard meter (m³/h) | Voltage(V) |
|----------------------------------|------------|----------------------------------|------------|
| 0.000                            | 0.002      | 44.061                           | 0.210      |
| 5.377                            | 0.026      | 50.094                           | 0.236      |
| 10.879                           | 0.085      | 56.842                           | 0.299      |
| 16.173                           | 0.080      | 63.510                           | 0.340      |
| 23.650                           | 0.130      | 69.506                           | 0.390      |
| 30.576                           | 0.184      | 76.079                           | 0.407      |
| 37.324                           | 0.210      |                                   |            |

According to the relationship between the voltage and flow rate, the induction voltage is proportional to the flow rate under certain conditions, which satisfies the equation Y=0.0053X+0.0063. Thus the voltage is positively proportional to the flow rate, which shows that this system has the function of flow measurement. Later by the comparison with the instant flow of the standard meter, the double-frequency trapezoidal wave excitation has more accuracy than the rectangular wave excitation.
5. Conclusion
In this paper, the electromagnetic flowmeter base on double frequency trapezoidal excitation. Then the excitation circuit is designed, and the frequency sweep circuit according to the different fluid characters is realized. The experimental platform is established to test the whole system of the electromagnetic flowmeter based on the double-frequency trapezoidal wave excitation. The experiment results show that the voltage is positively proportional to the flow rate, which satisfies the requirements to measure the electromagnetic flow. By comparison with the standard meter, the in-phase interference and differential interference can be reduced, and the accuracy can be improved.

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