Electromagnetic Flow Detection based on Correlation Theory

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Overview

1. Introduction

2. Theory & Literatures

3. Methodology

4. Design & Verification

Introduction

- Electromagnetic flow meters detect flow by using Faraday's Law of induction.

- Inside an electromagnetic flow meter, there is an electromagnetic coil that generates a magnetic field, and electrodes that capture electromotive force(**voltage**).

- It is widely used in petroleum and chemistry industries, food and medicine manufacturing, and also in sewage processing, channel flow measurement, and reservoir resource transfer.
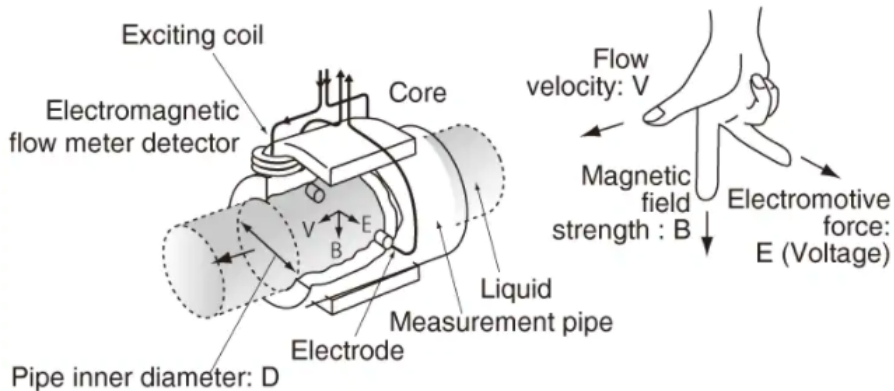
Theory

Under Faraday's law of induction, moving conductive liquids inside of a magnetic field generates an electromotive force (voltage) in which the pipe inner diameter, magnetic field strength, and average flow velocity are all proportional. In other words, the flow velocity of liquid moving in a magnetic field is **converted** into electricity. (E is proportional to $V.B.D$)[1]

> **Note**
>
> According to Faraday's law, the frequency of effective signal (BvD) in the electrode output of the electromagnetic flowmeter should be the same as the frequency of the excitation signal.

Traditional Method

Exciting coil

Electromagnetic
flow meter detector

Core

V E
B

Flow
velocity: V

Magnetic
field
strength : B

Electromotive
force:
E (Voltage)

Liquid

Measurement pipe

Electrode

Pipe inner diameter: D

Merits

1 Unaffected by the temperature, pressure, density,or viscosity of the liquid.

2 Able to detect liquids that include contaminants (solids, air bubbles)

3 There is no pressure loss and No moving parts (improves reliability)

Literature Review

Sl No:	Paper Title	Publication	Note
1.	Li, N. Chu, P. Yan, D. Wu and J. Antoni, "Cyclostationary approach to detect flow-induced effects on vibration signals from centrifugal pumps"	*Mech. Syst. Signal Process.*, vol. 114, pp. 275-289, Jan. 2019.	Flow-induced effects of a centrifugal pump with splitter blades are studied. vibration signals from pumps are taken into account.
2.	M. Vauhkonen, A. Hänninen and O. Lehtikangas, "A measurement device for electromagnetic flow tomography",	*Meas. Sci. Technol.*, vol. 29, no. 1, Jan. 2019.	Estimating velocity fields utilizing several excitation coils and a set of measurement electrodes attached to the surface of the pipe. Uses both square wave and sinusoidal signal
3.	Y. Yang, D. Wang, P. Niu, M. Liu and S. Wang, "Gas-liquid two-phase flow measurements by the electromagnetic flowmeter combined with a phase-isolation method"	*Flow Meas. Instrum.*, vol. 60, pp. 78-87, Apr. 2019.	Image processing technique is adopted to measure the void fraction. riginal phase distribution is not uniform.

Literature Review

Sl No:	Paper Title	Publication	Note
4.	S. M. R. Hasan, "Design of a low-power 3.5-GHz broad-band CMOS transimpedance amplifier for optical transceivers"	*IEEE Trans. Circuits Syst. I Reg. Papers*, vol. 52, no. 6, pp. 1061-1072, Jun. 2019.	low-cost CMOS process implements a transimpedance amplifier- Opitcal measurement [Si Tech]
5.	Lock-in-detection in ^{87}Rb—^{129}Xe/^{131}Xe atom spin gyroscopes	J. Phys. B-Atomic Mol. Opt. Phys. 2020	On- and off-resonance operation of atoms, signal acquisition is costlier due to intensive white noise.
6.	Study on Weight Function Distribution of Hybrid Gas-Liquid Two-Phase Flow Electromagnetic Flowmeter	MDPI, Sensors 2020, 20, 1431	Weight function of the gas-liquid two-phase, gas bubble approaches the electrode sensor- Noise and error in measurement.

Correlation Theory

Correlation is a mathematical operation to compare two signals, a form of convolution operation between two signals. Correlation of two signals is the convolution between one signal with the functional inverse version of the other signal. The resultant signal is called the **cross-correlation** of the two input signals. The amplitude of cross-correlation signal is a measure of how much the received signal resembles the target signal.

Weak signal detection technology based on the correlation detection principle.
In Effect: It can reduce the bandwidth and suppress noise effectively using the periodic transmission of signal and noise randomness

Signal Spikes
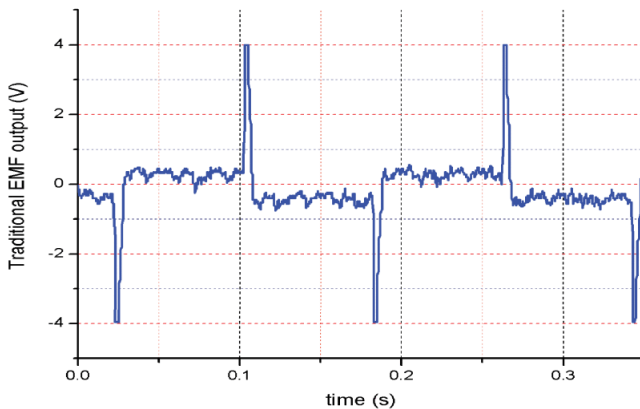
Figure: Output signal of electromagnetic flowmeter with interference signals.[3]

Interference

$$E = BvD + \mathrm{k}_1 \frac{dB}{dt} + k_2 \frac{d^2 B}{dt^2} + e_c + e_d + e_z$$

- **Components:**
  1. Power-line
  2. Differential
 3. Commom mode
 4. Serial and electro-chemical

Elimination of Interference

- To improve under the conditions of low flow rate, strong external interference, and slurry interference.
- Hence, reduction in measurement error, and improvement of measurement accuracy.
- Currently, circuit compensation (hardware processing) and software filtering are mainly applied.

Design
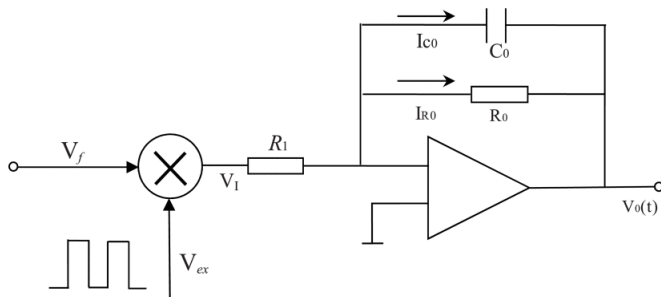
Structure of Differential Correlator
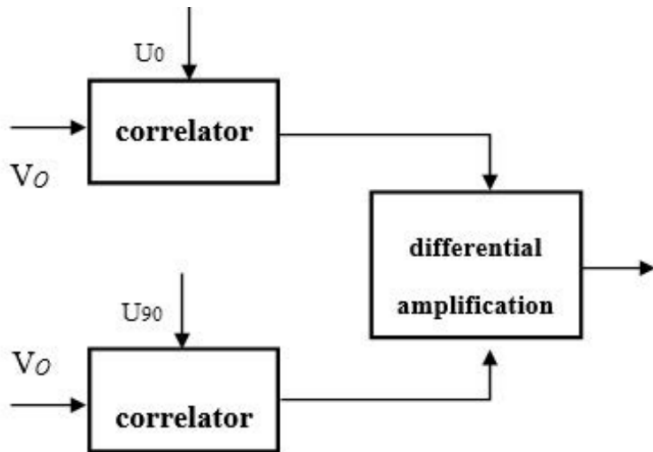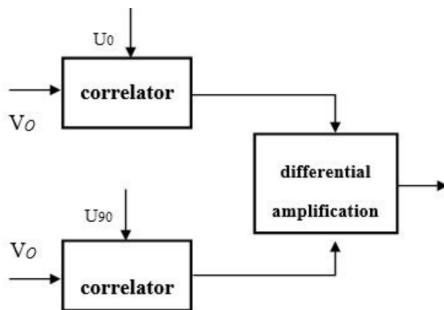
- Reference signal has 90 degrees phase difference to flow signal.
- Rectangular wave is used for phase shifting.
- Rapid and more effective than other noise feedback methods.

Conclusion from analysis study

According to the research on cross-correlation detection methods [3], when the integration time is long enough, and the excitation reference frequency is the same as the frequency of the electromagnetic flow signal, the cross-correlation between the noise n(t) and the excitation reference signal is 0.

$$\frac{4}{\pi} V_{am} \sum_{n=0}^{\infty} \frac{1}{2n+1} \sin(2n+1)\omega_R(t+\tau)$$

Inferences

- When there is interference signal in the output signal, the result of correlation between the output signal and the excitation reference signal is the cross-correlation function between the flow signal and the reference signal, which is independent of the interference signal amplitude.

- Output DC voltage signal is linearly related to the phase difference ϕ between the two rectangular waves.

- When Phase difference $= 0$ between the electrodes amplitude of the electromagnetic flow signal V_{am} is directly related to output voltage of lock-in amplifier.

Correlation Detectors- Block Diagram
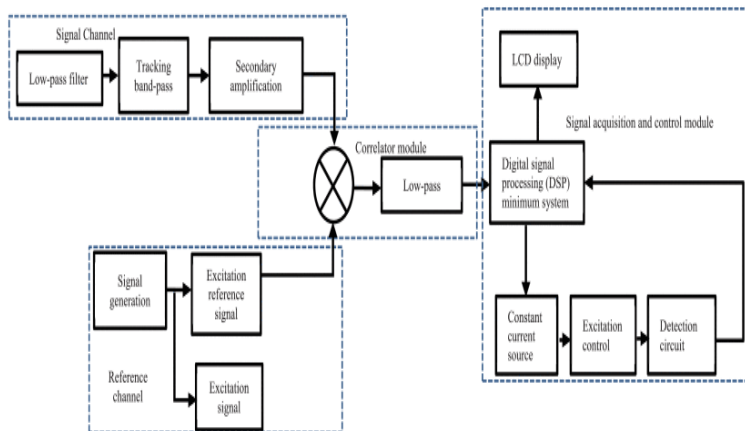
Working: Reference and Signal Channel

System Realization

- **Lock-in Amplification**
  1. Two-stage amplification was used to meet the requirements
  2. Flow signal may still be mixed with high-frequency spike noise and small DC components in the output signal of the sensor.[Removed by a band-pass filter]
  3. Filtering method are optimized by automatic tracking frequency filtering technology. [4]

System Realization

- **Correlator Module:**
  1. Both correlation function & correlation detection, there are multiplications of two functions[signal]: **Mixer**
  2. Output signal frequency can be transformed from ω to 2ω
  3. Filtered by a low-pass filter [5]

Output

Signal Acquisition and Control Module:

1. Composed of constant current source, excitation control, detection circuit, DSP, & LCD

2. Process Involved: acquisition, processing, analysis

3. Reference signal [square wave] generated by PWM module in a DSP

Experiment Method
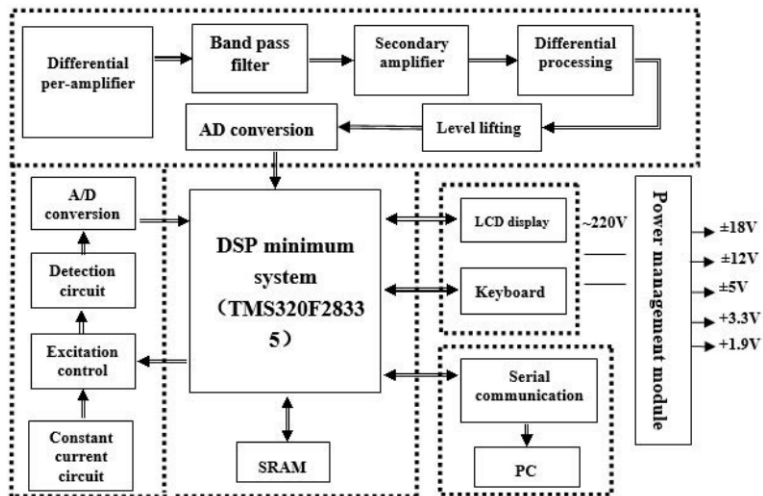
Experiment Method

Calibration

- Divided into real flow calibration and non-real flow calibration.
- Flow calibration experiment with clean tap water.
- By changing the working frequency of the frequency converter, the flow rate of the fluid in pipeline could be adjusted.

Found from the curve distribution that when the flow rate is lower than 4.0 m^3/h—that is, when the flow rate of the fluid in pipeline is lower: **relative error** of a single test is higher. (Ge et al. [3])

Results & Analysis

For **Low Flow Rate Experiment**: Through the data fitting analysis, when the velocity is low, the signal output voltage of the differential correlation detection electromagnetic flowmeter has a linear relationship with the flow rate, and the square value of the linear trend linear fitting degree index R is 0.98923.

It can fully meet the requirements of the flow test at a low flow rate.

System output voltage and flow
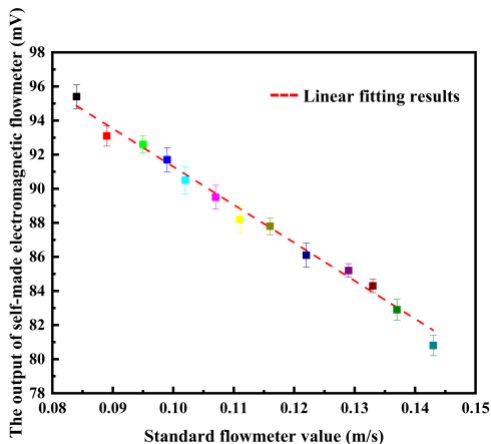
Under Strong External Interference

By differential correlation detection, the **signal to noise ratio** of the signal was further **improved**, compared with the fluctuation of 15 mV in the experiment on lock-in amplification technology under strong external noise. The maximum fluctuation in the maximum value was only 10 mV, so the anti-interference ability and measurement accuracy were improved.

# Differential correlation detection under strong noise
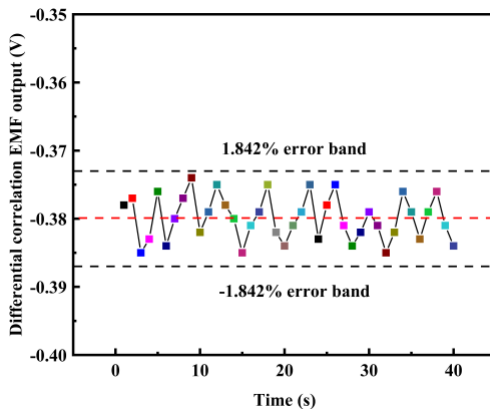
On Comparison Experiment:
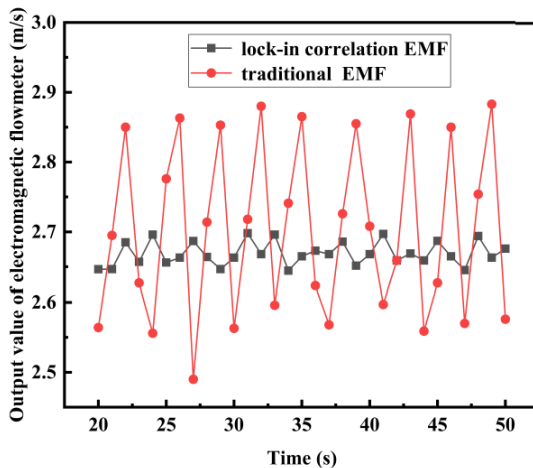
Conclusion

- The fluctuation amplitude is significantly smaller than that of the traditional electromagnetic flowmeter and lock-in correlation electromagnetic flowmeter. This method can suppress the slurry interference and improve the measurement accuracy.

- Correlation principle have unique advantages in external strong noise interference suppression.

Electromagnetic Flowmeter [2]
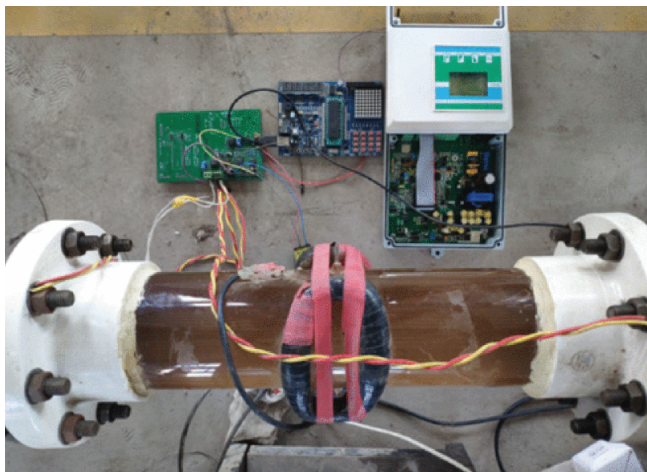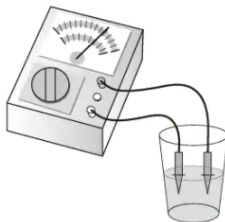
Thank You

References

[1] Roger C Baker. *Flow measurement handbook*. Cambridge University Press, 2011.

[2] Liang Ge et al. "Electromagnetic Flow Detection Technology Based on Correlation Theory". In: *IEEE Access* 8 (2020), pp. 56203–56213. DOI: 10.1109/ACCESS.2020.2982474.

[3] Liang Ge et al. "Study on a new electromagnetic flow measurement technology based on differential correlation detection". In: *Sensors* 20.9 (2020), p. 2489.

[4] Di Han et al. "A case study on common mode electromagnetic interference characteristics of GaN HEMT and Si MOSFET power converters for EV/HEVs". In: *IEEE Transactions on transportation electrification* 3.1 (2016), pp. 168–179.

[5] Yanjun Wang et al. "Novel downhole electromagnetic flowmeter for oil-water two-phase flow in high-water-cut oil-producing wells". In: *Sensors* 16.10 (2016), p. 1703.