

Experimental Investigation on Zero Drift Effect in Coriolis Mass Flowmeters

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Abstract: It is claimed that Coriolis mass flowmeter (CMF) can accurately measure the mass flow-rate without being effected by temperature. However, evidences from practical industry applications show that sometimes CMFs still suffer so-called “zero drift (ZD) effect”: the origin of the flowmeter (reading at zero flow) varies as temperature changing. In this paper, series of experiments are carried out to systematically examine and analyze the performance of a Narrowed-U-CMF in a temp-changing environment. Based on the results of these experiments, possible reasons causing the ZD effect are analyzed, which provides a base for further solutions of the ZD effect.

Keywords: Coriolis Mass Flowmeter, Zero drift effect

1. Introduction

Mass flow rate measurement is very important in many occasions, such as salinity measurement in the dielectric analysis of the water ^[1], ingredients measurement in quality control of chemical reaction ^[2], and fuel measurement in range capability determination of an aircraft rocket ^[3] etc. As an instrument to measure the mass flow rate directly ^[4], Coriolis mass flowmeter (CMF) has attracted more and more interests in the past few decades, for its high accuracy, high rangeability and high repeatability ^[5].

A typical CMF is usually composed of a transducer and a transmitter. The transducer includes an electromagnetic driver (EMD), two parallel vibrating tubes (VT), two electromagnetic velocity sensors (EMVS. two EMVSs are usually installed symmetrically at upstream and downstream with the EMD respectively). The basic principle of operation can be explained using the CMF with Narrowed-U-shaped vibrating tube produced by tancy company ^[6], as shown in Fig.1.

At zero flow, the whole tube vibrates synchronously (in phase) as alternating current passing through the EMD. While there is flow passing through the tube, Coriolis force will be acted on the tube wall by the flow. The force has opposite directions on the upstream and downstream tube walls with the EMD, which distorts the tube and causes phase difference between the output signals of the two EMVSs. Thus, the mass flow Q_m can be determined by ST through measuring the time difference ΔT between the EMVSs' movements (proportional to the phased difference).

It is claimed that the Narrowed-U-CMF can accurately measure the mass flow rate without being affected by temperature (neither the atmosphere temperature nor the measured fluid temperature). However, evidences from practical industry applications show that sometimes it still suffer so-called “zero drift (ZD) effect” caused by the temperature change: the origin of the flowmeter (reading at zero flow) varies as temperature changing.

The existing of the ZD will fail the high accurate performance of the flowmeter, especially when measuring low flow rate ^[7]. N.M.KEITA analyzed the ZD effect based on a

phenomenological model in paper ^[8], and K.Kolahi presented a model-based ZD effect detection method in paper ^{[9][10]}, some qualitative conclusions about ZD effect were provided by these papers. However, the real causation of ZD effect still needs to be analyzed further based on quantitative experiments. In this paper, series of experiments are carried out to systematically examine and analyze the performance of a Narrowed-U-CMF in a temp-changing environment. Based on the results of these experiments, possible reasons causing the ZD effect are analyzed, which provides a base for further solutions of the ZD problem.

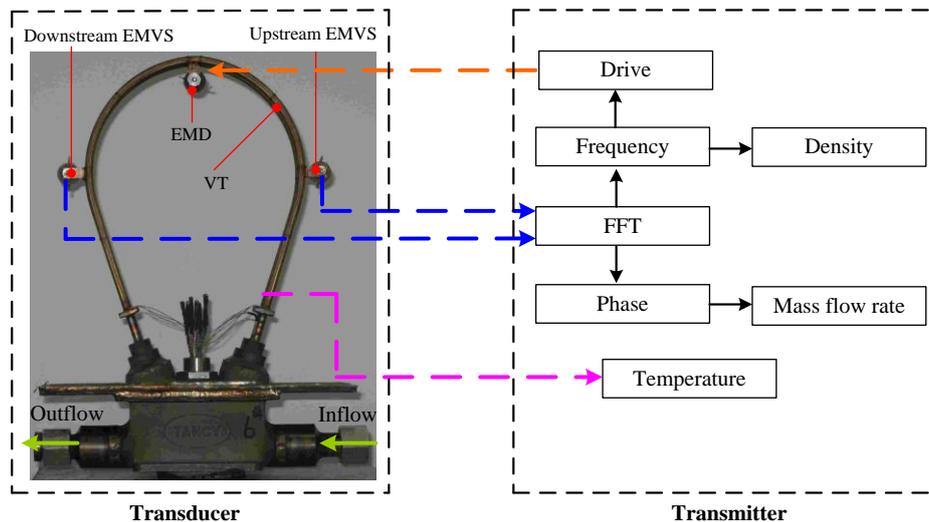


Fig.1. Principle of Narrowed-U-CMF.

2. Experimental setup

Schematic diagram of the experimental setup is shown in Fig.2.

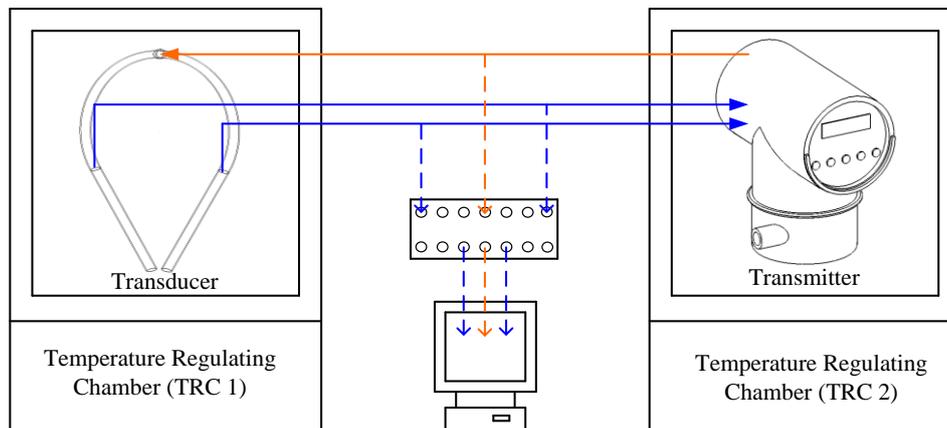


Fig.2. Schematic diagram of the experimental setup.

The components of the experimental setup are as follows:

1. A Narrowed-U-CMF including a transducer and a transmitter. Two parallel tubes inside the transducer vibrate at the fundamental frequency, with the driving force produced by passing alternating current through the EMD, and feed-back control technology is employed in the transmitter to realize precise and dynamical tracking of the transducer frequency even the flow conditions of measured fluid are changing rapidly.
2. Two temperature regulating chambers (TRC), which can raise temperature from $-40\text{ }^{\circ}\text{C}$ to $120\text{ }^{\circ}\text{C}$ in about 30minutes, and can hold any constant temperature between $-40\sim 120\text{ }^{\circ}\text{C}$.

In this experiment, the transducer and the transmitter are placed inside two TRCs separately so that they can be heated respectively.

3. A data acquisition system based on Advantech PCI-1716. The maximum acquisition frequency of this system can reach 250KS/s in 16 acquisition channels. The driving sinusoidal signal of EMD and velocity sinusoidal signals of EMVSs are acquired by this system.
4. A data analysis system in labview environment. As shown in the top and the middle graphs of Fig.3, sinusoidal signal coming from the acquisition system is analyzed with FFT method. The highest amplitude is detected and the corresponding frequency is treated as the fundamental frequency of the vibrating tubes. The phase of sinusoidal signal can also be detected according to the fundamental frequency as shown in the down graph of Fig.3. Then the phase difference between two velocity signals and the mass flow rate can be calculated.

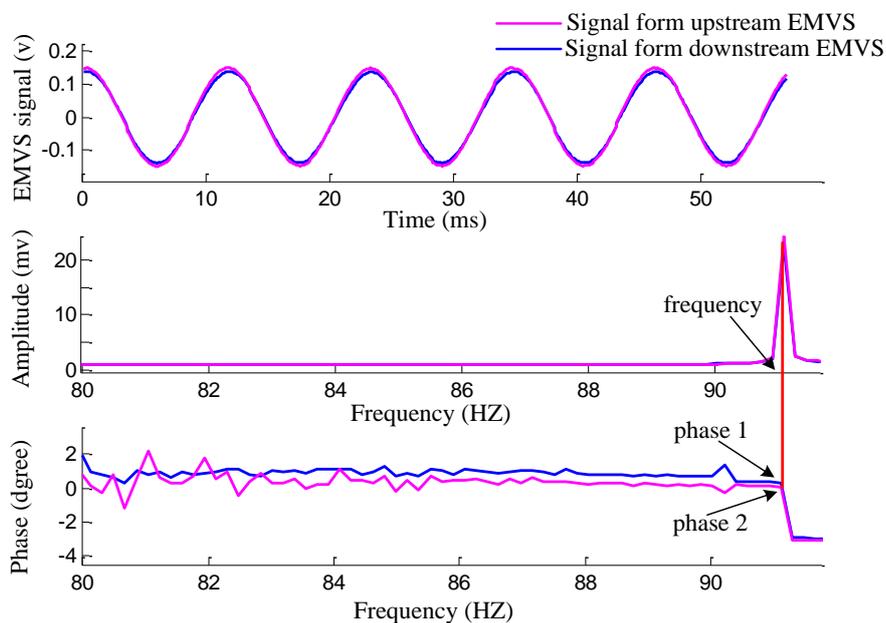


Fig.3. Principle of FFT method adopted in data analysis system.

3. Experimental procedure

The first experiment is conducted to test the performance of transmitter in a temp-changing environment, to determine whether the ZD effect is caused by the instability of transmitter. During the experiment, the temperature inside TRC 2 is raised from 15 °C to 65 °C in 30 minutes, while the temperature of TRC 1 is maintained at a constant value (room temperature 15 °C). Thus, the transducer placed in TRC 1 is considered not affect by the temperature variation, which means that two sinusoidal signals coming from the transducer and the phase difference between them can be treated constant. Then the reading of transmitter at different temperature levels are recorded and analyzed as shown in Fig.4.

According to the result of this experiment, the readings of transmitter can hold a stable value in the temp-changing environment, and it can be validated that there is no relationship between the ZD effect and the transmitter.

Similarly, the second experiment is conducted to test the performance of transducer in a temp-changing environment, to determine whether the ZD effect is caused by the instability of transducer. Contrast with the first experiment, the second experiment changes the temperature

inside TRC 1 15 °C to 65 °C in 30minutes, while holding the temperature constant (15 °C) inside TRC 2. The performance of transducer can be judged according to the readings of the transmitter or the readings of the data analysis system.

As shown in Fig.4, the readings of transmitter will decrease with the temperature rising, then the transducer is focused as the main source of ZD effect, and following experiments are further conducted against the transducer, by holding the transmitter temperature (15 °C) and varying the transducer temperature.

The third experiment is to find out whether there is one-to-one correspondence between the transmitter reading and temperature. If this correspondence does exist, then we can solve the ZD effect simply by compensating the readings in transmitter according to the measured temperature. Contrast with the first experiment, this experiment raises the temperature from 15 °C to 65 °C in 60minutes.

By comparing the results of the second experiment and the third experiment in Fig.4, It can be found that the transmitter readings will decrease in different trends when the transducer is heated by different heating patterns (heating from what temperature with what rate). So, it seems that the ZD effect can not be solved with a simple compensating method such as Table-Lookingup method.

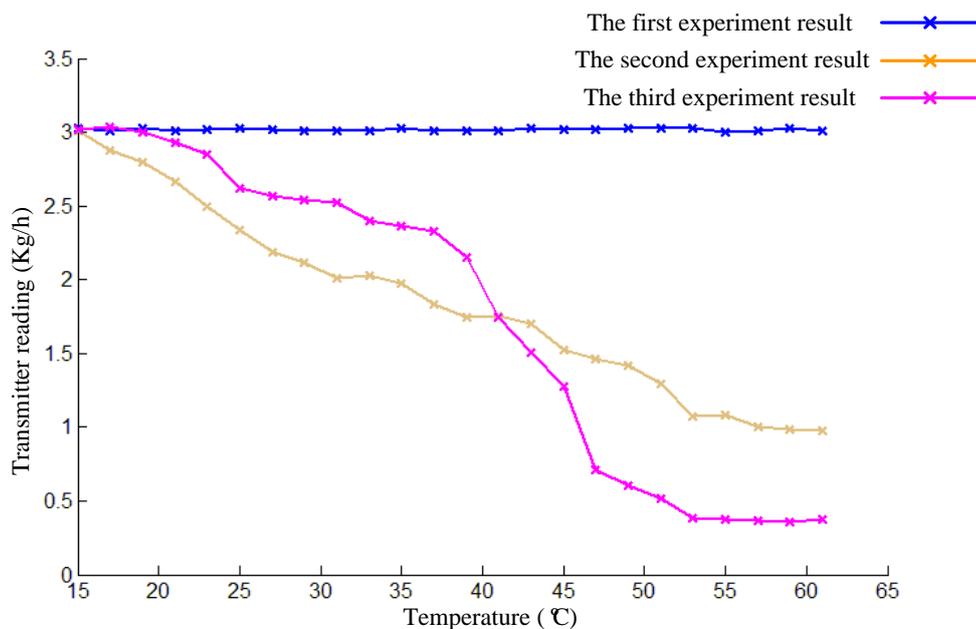


Fig.4. Results of the first three temperature experiments.

The fourth experiment monitors the vibration of the two VTs in a temp-changing environment, by analyzing the driving signal of EMD and velocity signals of EMVSs with FFT method. It is found that the amplitude of the driving signal rises with the temperature rising, while the amplitude of the velocity signals decline with the temperature rising. As for a harmonic oscillator, the energy varies in accordance with the square of the vibration amplitude, so it can be deduced that the vibrational damping of the EMD will rise with the temperature rising. It can also be found from Fig.5 that the amplitude of two EMVSs are different with each other, so there is non-symmetry between the dampings of two EMVSs. In this experiment, degrees of amplitude decline of two EMVSs are different with each other, so it can also be deduced that the non-symmetry will rise with the temperature rising.

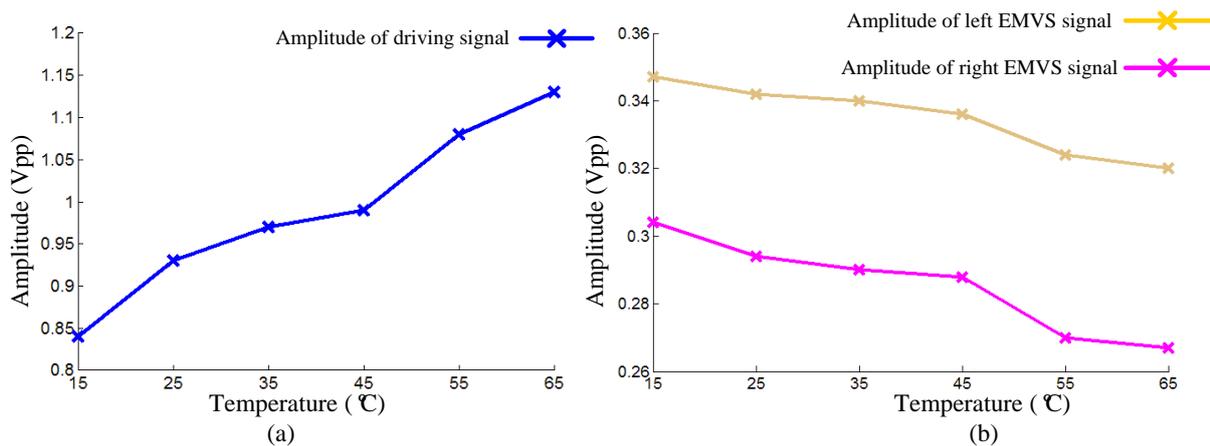


Fig.5. Testing result of vibrational performance of the transducer.

The changing of damping is probably caused by the changing of physical properties of the transducer, so in the fifth experiment, the parallelism between the two VTs are examined, by examining the distance between selected feature points (where EMVSs are installed) on the two VTs, as shown in Fig.6(a). In this experiment, three-dimensional coordinate of the feature points are measured by a coordinate measuring instrument (CMI, with the inaccuracy less than 0.1μ), as shown in Fig.6(b).

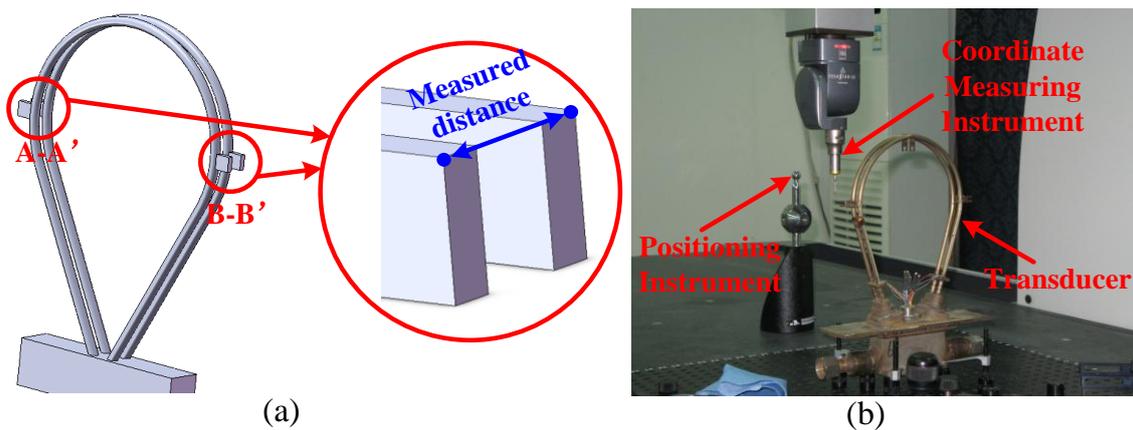


Fig.6. Schematic diagram of the physical properties examining experiment.

The distances between feature points are calculated as follows:

$$\begin{cases} L_A = \sqrt{(x_A - x_{A'})^2 + (y_A - y_{A'})^2 + (z_A - z_{A'})^2} \\ L_B = \sqrt{(x_B - x_{B'})^2 + (y_B - y_{B'})^2 + (z_B - z_{B'})^2} \end{cases}$$

During the experiment, the distances L_A and L_B are measured first in the room temperature (15 °C, which is assumed be constant during the experiment). Then the transducer is heated rapidly inside TRC1 from 15 °C to 65 °C in 30minutes and cooled down outside at room temperature, and the distances L_A and L_B are measured again. The result of this experiment is shown in Table 1.

Table 1: Physical properties examining result.

Temperature	Distance of point A-A' (L _A)	Distance of point B-B' (L _B)
First 15°C	18.0135 mm	17.3593 mm
Second 15°C	18.0147 mm	17.3666 mm
Variation	0.0012 mm	0.0073 mm

As can be seen in Table 1, the critical distance between feature points have changed, and the extent of change is inconsistent. The changing of parallelism between two tubes causes the changing of tube vibration properties including vibrational damping.

4. Conclusion

From several experiments described earlier in this paper, it is found that the performance of Narrowed-U-CMF will suffer so-called “ZD effect” caused by the temperature change: the origin of the flowmeter (reading at zero flow) varies as temperature changing.

It is also found that the ZD effect can not be solved with a simple compensating method such as Table-Lookup method, since the transmitter readings will decrease in different trends when the transducer is heated by different heating patterns.

During these experiments, the transducer is finally focused as the main source of ZD effect. The damping of the transducer, including the vibrational damping of EMD and the non-symmetry damping between two EMVSs, will change in accordance with the ZD effect.

Based on these findings, possible reasons causing the ZD effect can be analyzed: factors which are related the physical properties of the transducer, including structure asymmetry, remained stress, non-uniform thicknesses of the transducer etc, will cause the ZD effect when they are changed by temperature. This analysis can provide a base for further solutions of the ZD effect.

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