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Analysis of influence of mechanical boundary conditions on zero point shift of Coriolis flowmeter

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Abstract

Coriolis flow meters determine mass flow rate by measuring the phase shift of the signal pick-up coils. Therefore, changes in the phase shift amount not related to the flow of the measured medium cause mass flow measurement errors. The article is devoted to the experimental evaluation of the effect of mechanical boundary conditions of the Coriolis flowmeter on zero point shift. Special equipment, allowing changing the stiffness of the pipeline, to which the flowmeter is attached, has been developed. Modal experiments on the Coriolis flowmeter without liquid for different lengths of pipe have been conducted. It has been found out that the maximum zero point shift is observed when the frequency of natural vibrations of the coupled system of the flow meter and piping tubes coincides with the drive frequency of tube vibrations. Tests to assess the influence of external vibration on the zero point shift have been conducted. The maximum zero point shift is observed in the coincidence of the external vibration frequency with the drive frequency of oscillation of tubes.

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Keywords: Coriolis flowmeter; zero point shift; experimental modal analysis; external vibration; steady forced oscillations.

1. Introduction

A Coriolis flowmeter is used for measuring mass flow of liquids and gases. The overview of designs of Coriolis flowmeters is given in [1-3]. The flowmeter shown in Fig. 1 consists of a body 2 and two arranged inside it U-shaped vibrating tubes 3 through which the measured fluid flows. Drive coil 4 is used to excite steady forced oscillations tube at the resonant frequency. The shape of the steady forced oscillations is a movement of the tubes in

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the opposite direction to each other from the XY plane. The translational motion of the liquids in the rotational motion around the X axis gives rise to the Coriolis acceleration and thus Coriolis force. This force is directed against the movement of the tube, given it by the coil, i.e., when the tube moves along the Z-axis, for the fluid flowing inside the Coriolis force is directed against the axis Z. The direction of the Coriolis force is contrarily reversed as soon as the liquid passes the tube bends. In Fig. 1 the tube bends correspond to the position of the motion sensors 5 and 6. Due to the action of the Coriolis force there is a shift of the phases of mechanical vibrations of two tubes in the places of installation of motion sensors proportional to the mass flow rate. A detailed description of the principle of operation of the Coriolis flow meter is given in [4].

The Coriolis flowmeters determine mass flow rate by measuring the phase shift of motion sensors signals. Therefore, changes in the phase shift amount are not related to the flow of the medium, lead to mass flow measurement error.

The zero point shift of the Coriolis flow meter is the value of the phase difference without the flow of the medium. It is about 1000 times less than the desired phase shift of the nominal flow. But it is essential with 0.1% accuracy of the sensor. Each flowmeters is characterized by a zero point shift, the value of which is individual and determined at the stage of the device manufacturing.

One of the features of the Coriolis flowmeter is that the attachment of the meter to the pipeline can lead to a zero point shift. In this case, phase value after installation is taken for the zero shift. Less common, but more dangerous, is a situation of unstable zero shift of an installed flowmeter, when it changes over time leading to uncontrolled growth of mass flow measurement error.

This article examines the influence of the mechanical boundary conditions of the Coriolis flowmeter to a zero point shift. To do this, the experimental modal analysis of a coupled the meter-piping system for different lengths of pipe has been conducted. An experimental evaluation of the influence of external vibration on the flowmeter zero shift has been conducted.

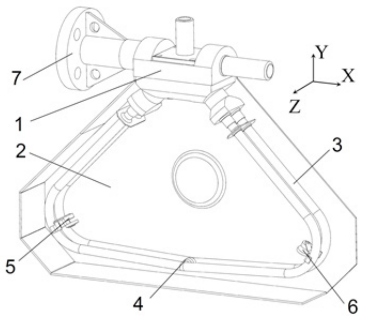

Fig. 1. Coriolis flowmeter:
1 - basis; 2 - housing; 3 - tube; 4 - drive coil; 5, 6 - motion sensors; 7 – flange.

2. Modal tests

To study the effect of various fixing conditions on the zero point shift there has been designed and manufactured a special equipment, allowing to change the stiffness of the pipeline by changing its length. These accessories are shown in Fig. 2. They consist of a base 1, which is a channel, and two tubes 2 with flanges welded on one end. The flowmeter 3 is attached by bolts to the flanges on the pipes. The tubes are joined by means of two fixed clamps 4 on the ends of the device. Movable clamps 5 run along guides 6. With two movable clamps the lengths of pipes L_1 and L_2 are changed.

The equipment is estimated with the impact of the lengths of pipes L_1 and L_2, to which the meter is attached, on a zero shift. Changing the length of the tubing affects the modes of the coupled flowmeter-piping system. To track the changes of these modes there have been held modal tests with different lengths of a pipeline.

Modal testing of the flowmeter, connected to the pipeline, was held on the flowmeter without liquid and with turned-off electronics (no excitation at the drive frequency). Firstly, there was a preliminary modal testing with lengths of pipe from 20 to 250 mm with a 50 mm increment. Then there were found the lengths at which the modal frequencies of the related system of a flowmeter and a pipeline converge with the drive frequency of the tubes. With all lengths of a pipeline after the modal test with standard processor unit the zero shift was measured.

Modal testing of the flowmeter [5, 6] are held with hardware and software, which include:

- 56-channel LMS SCADAS LAB measuring system for generating a signal of vibrations excitation, acquistion and processing dynamic signals;
- Impact Testing module for LMS Test.Lab for modal testing under shock excitation and subsequent identification oscilation modes;
- impact hammer PCB 086C03 with an integrated power sensor;
- three-axial piezoaccelerometers PCB 356A32 with sensitivity of 100 mV / g.

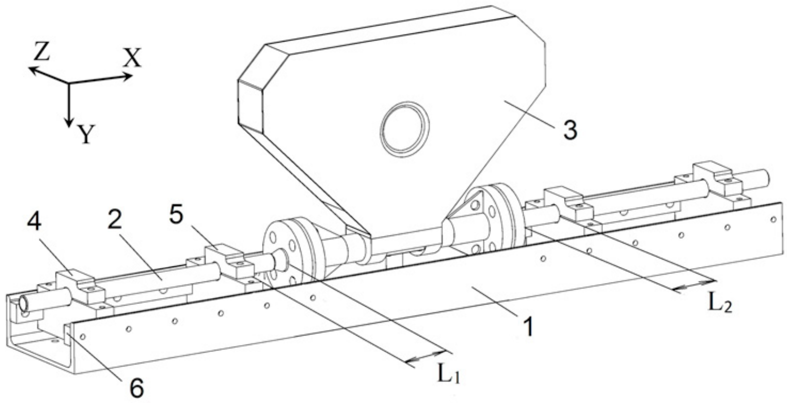

Fig. 2. Scheme of equipment for fixing the meter: 1 - basis; 2 - pipe; 3 - flowmeter; 4 - fixed clamp; 5 - movable clamp; 6 – guide.

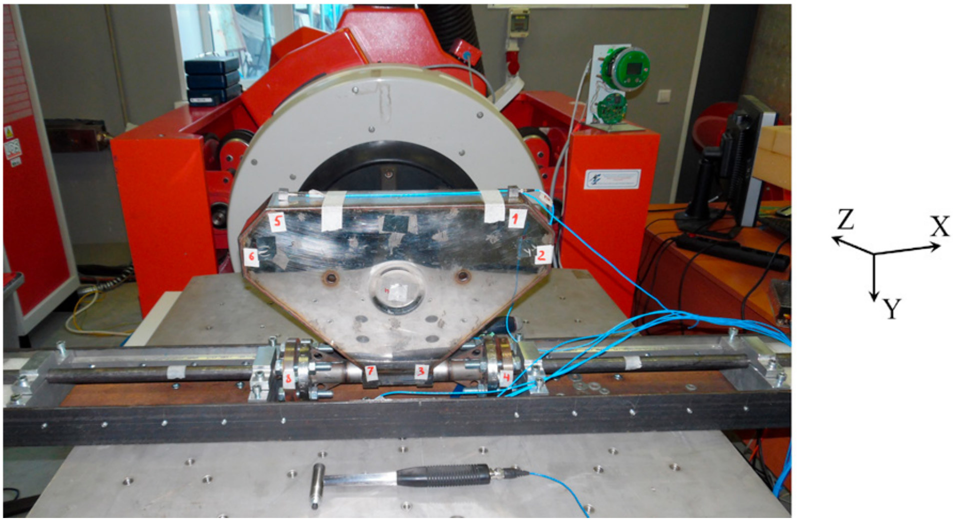

Fig. 3. Experimental setup.

Excitation of oscillations was carried out using the modal hammer at eight points (fig. 4) on the meter body and the pipes in three directions (X, Y, Z). The response is measured using the three-axial accelerometers located at three points on the housing (points 1, 5, 7 in Fig. 4). To determine the modal forms of oscillation of the flowmeter-pipeline system there has been developed wireframe model of the flowmeter housing in the LMS Test.Lab software. The nodes of the model coincide with the points where the accelerometers are mounted and where the oscillation excitation is conducted.

To excite oscillations a few impacts were applied consistently by a hammer in the selected point of the construction. After each impact the input shock pulse and feedback on the vibration acceleration in all measuring points of the structure were registered to obtain the frequency response functions. [7-9] Further, the experiment was repeated with excitation at another point. With the obtained averaged frequency response functions using the PolyMax algorithm [10-12] the modes of the flowmeter-pipeline system were identified.

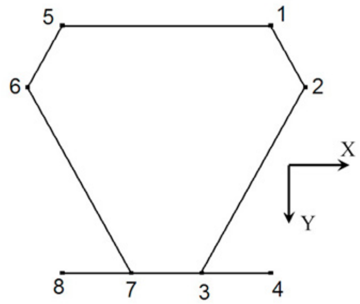

Fig. 4. The wireframe of the flowmeter body. Points 1 - 8 are places of oscillation excitation.
Points 1, 5, 7 - places where accelerometers are installed.

In the response spectrum of the impact there are lots of peaks, only three are considered which at changing the length of the pipeline from 20 to 250 mm converge to the drive frequency. The appearance of the three modal shapes is shown in Fig. 5. Modal shape 1 and 2 of this oscillation of the flowmeter-pipeline system of the XY plane. Modal shape 3 is the XY plane oscillation. Modal frequencies of the flowmeter-pipeline system and the zero point shift for different pipe lengths are shown in Table 1. Table 1 shows the results for identical lengths of the left and right pipes $L_1 = L_2$.

Fig. 6 shows the dependence of the zero shift from the length of the pipeline in case of equality of pipelines on the left and on the right $L_1 = L_2$. The maximum zero shift corresponds to the length of the pipe in which the modal frequencies of the flowmeter-pipe system converge to the drive frequency of vibrations of tubes. Changing the length of the pipeline about 5 - 10 mm results in restoration to the initial zero value.

If the length of the left and right pipes is not equal $L_1 \neq L_2$, the convergence of the modal frequencies of the flowmeter-pipeline system to the drive frequency of vibrations of the tubes will lead to a zero shift in the same way as if the pipe lengths are identical.

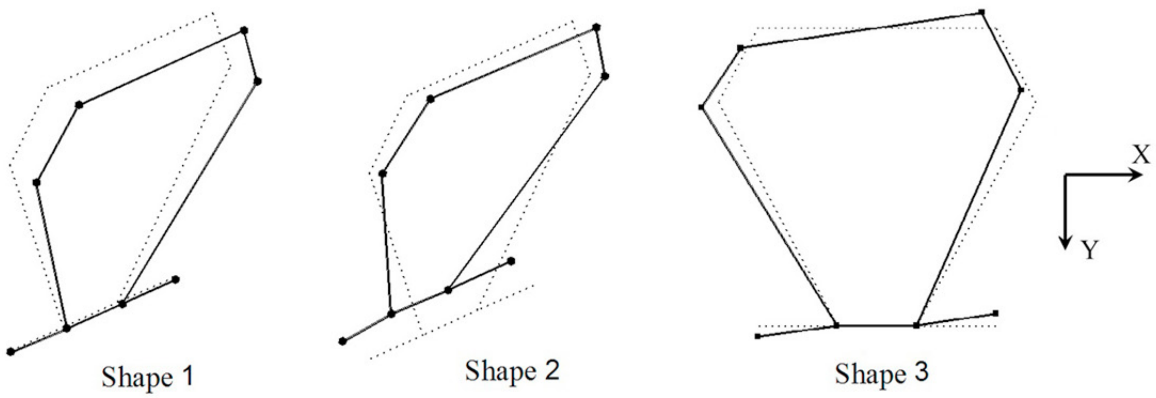

Fig. 5. Modal shapes of the flowmeter body.

Table 1. Modal frequencies of the flowmeter-pipe system and zero point shift for different pipe lengths

	Length of two pipes $L_1 = L_2$, mm					
	21	50	100	150	194	223
Drive frequency, Hz	100,8	100,8	100,8	100,8	100,8	100,8
Frequency of Shape 1, Hz	100,9	97,4	95,6	94,5	89,5	89
Frequency of Shape 2, Hz	273,5	209	169	124,9	100,6	99,3
Frequency of Shape 3, Hz	112,3	111,8	110,4	107,9	102,5	101
Zero point shift, 10^{-6} s	-0,4	0,02	0,04	0,04	-0,9	0,1

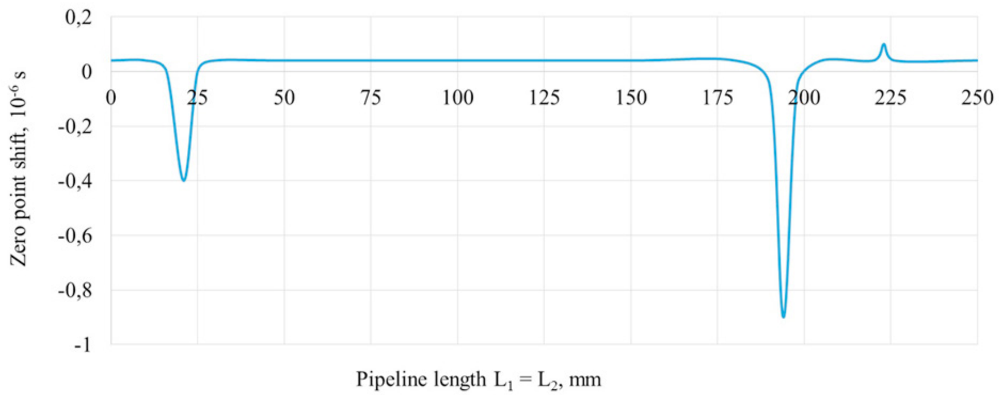

Fig. 6. Dependence of the zero point shift of the pipeline length.

3. Analysis of the flow meter operation with external forced vibrations

The articles [13,14] deals with the influence of external vibration on the accuracy of the measurement of mass flow of the Coriolis flowmeter, in which the liquid flows. The maximum measurement error is observed when the frequency of the external vibration coincides with the drive frequency of tubes.

To assess the influence of external forced vibrations on zero point shift there have been performed experimental studies [15,16]. The equipment is shown in Fig. 2, with a flow meter installed on a horizontal sleep table of LDS V875 setup. Excitation was performed at Z-axis (Fig. 3). During these tests, the meter is connected to the standard processor unit, tubes make steady forced oscillations at the drive frequency. Simultaneously via shaker setup sinusoidal oscillations were excited with a frequency sweep in a range from 20 to 120 Hz. The amplitude of the forced oscillations on the setup table was constant at 0,5g. Frequency change rate was linear - 1 Hz per second. The zero shift was measured by the standard processor unit. On the body of the flowmeter there were placed three accelerometers (points 1, 5, 7 in Fig. 4), as well as in modal testing.

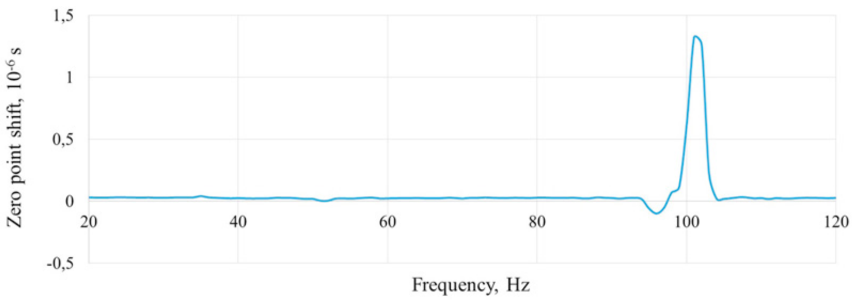

Fig. 7. Dependence of the zero point shift from the frequency of forced oscillations the pipe length of 50 mm.

The dependence of the zero point shift from the frequency of forced vibrations at the length of the pipelines $L_1 = L_2 = 50$ mm is shown in Fig. 7. With this fixation the modal frequencies of the flowmeter-pipeline system are diverged from the drive frequency of vibrations of tubes. When the frequency of forced oscillations is lower than the drive frequency, the zero shift remaines virtually unchanged and is up to $0{,}04\cdot10^{-6}$ seconds. The maximum zero shift is $1{,}4\cdot10^{-6}$ seconds at the coincidence of the forced oscillations with the drive frequency (101 Hz).

4. Conclusion

Changing the length of the pipeline leads to a change in oscillation modes of the coupled flowmeter-pipeline system. The convergence of the modal frequencies of the flowmeter-pipeline system to the drive frequency of tubes causes a significant change in zero shift.

The external vibration at a frequency far from the drive frequency of the flowmeter, has little effect on the zero point shift. The external vibration close to the drive frequency leads to zero shift.

Installation of the Coriolis flowmeter is necessary to evaluate on account of modal frequencies of the flowmeter-pipeleine system. In the case of convergence the modal frequency of this system to the drive frequency of tubes oscillation on the one hand it is enough to slightly change the pipe length to make the zero shift minimal. On the other hand, the drive frequency of tubes oscillation is strongly dependent on the fluid density inside the tube. It makes it difficult to choose the correct length of the meter fixing. In the future it is planned to develop a method of accounting the influence of modal shapes and the frequencies of the fixed meter on the zero shift, taking into account different densities of the fluid within the tube.

Acknowledgements

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