Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 150 (2016) 336 – 340

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Study of the Oscillation Modes of a Coriolis Flowmeter Using a Parametric Finite Element Model, Verified by the Results of Modal Testing

A.A. Yaushev[a,]*, P.A. Taranenko[a], V.A. Loginovskiy[b]

[a] *South Ural State University, 76, Lenin Avenue, Chelyabinsk, 454080, The Russian Federation*
[b] *Elmetro Grupp, Chelyabinsk, 454106, The Russian Federation*

Abstract

The paper describes the calculated and experimental determination of the oscillation modes of a Coriolis flowmeter. To define the estimated parametric oscillation modes, we formed a model of the volumetric flowmeter finite element. The model allows the evaluation of the impact of changes in the meter size and the medium density on the flowmeter frequency. The results of the calculations of the finite element model were verified by modal tests of the flowmeter.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: Coriolis flowmeter; finite element method; modal analysis;

A Coriolis flowmeter is used to measure the mass flow of liquids and gases. It consists of a case and two U-shaped oscillating tubes through which the fluid is moving. The body of the flowmeter and its measuring part are shown in Fig. 1. The tubes make steady forced oscillations with a resonance frequency in the opposite direction to each other from the XY plane. The translatory motion of the fluid in the rotational motion around the X axis of the tube causes Coriolis acceleration and, thus, Coriolis force. This force is directed against the tube movement it gets from the coil, that is, when the tube moves along the Z-axis, the Coriolis force for the fluid flowing inside is directed against the Z-axis. As soon as the liquid passes the tube bend, the direction of the Coriolis force is reversed. The Coriolis force causes a phase shift, being proportional to the mass flow rate, for the mechanical oscillations of two measuring tubes taking place at measuring coil installation.

---

* Corresponding author. Tel.: +7-351-272-37-44.
E-mail address: iaushevaa@susu.ac.ru

Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.027

A design overview of a Coriolis flowmeter is given in [1, 2], and a detailed description of the principle of operation is given in [3].

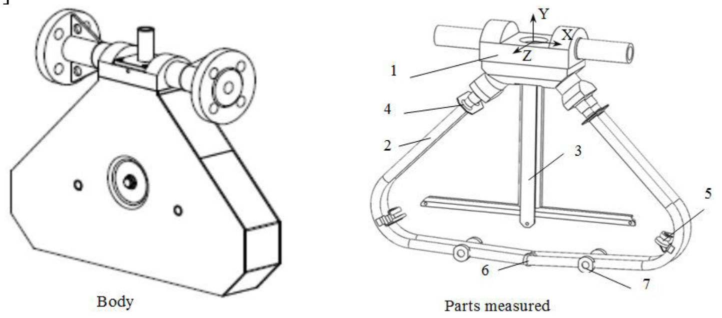

Fig. 1. Coriolis flowmeter: 1 – process connection flange; 2 – flow tubes; 3 – current controller; 4 – support; 5 –measuring coils; 6 – drive coil; 7 – weights

To understand the dynamics of mechanical systems is of great importance for the creation and improvement of new designs as well as for solving the problems associated with the mechanical vibrations of existing structures. An effective tool for studying the dynamic properties of the system is the modeling of the dynamic behavior of structures using the finite element method [4, 5]. Verification by mode test results is important for designing a finite element model [6, 7]. Using this model it is necessary to develop the flowmeter verification technology in site [8, 9].

Hence, to estimate the frequencies and modes of the flowmeter a finite volume model is formed (Fig. 2a). It consists of the elements of prismatic shape with twenty nodes and a tetrahedral shape with ten nodes. To determine the optimal size of the element, frequency calculations of flowmeter oscillations and forms for different sizes of elements were made. The dependence of the frequency of flowmeter oscillations on the number of nodes in the model, as the flowmeter operates, is shown in Fig. 2b.

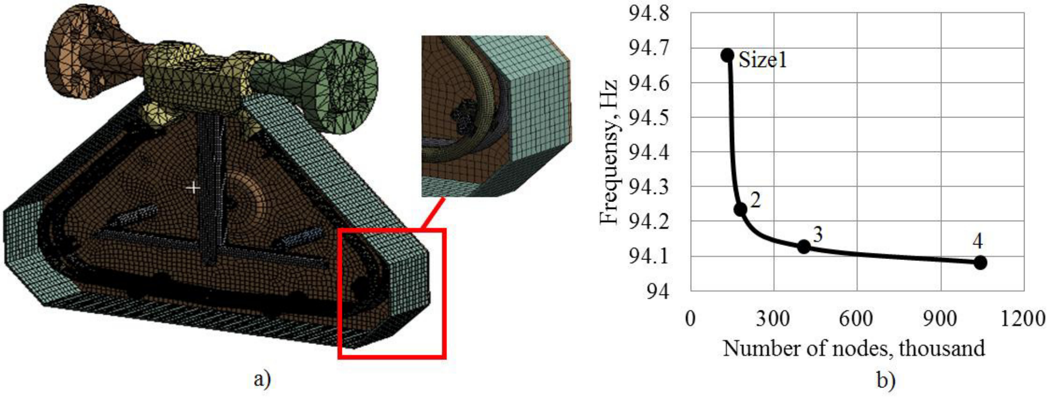

Fig. 2 Finite element model of flowmeter (a); dependence of the frequency of flowmeter oscillations on the number of nodes (b)

The accuracy of flow measurement is affected by the location of the flowmeter working frequency relative to other frequencies of the device parts. For example, in [10-13] the influence of the density of the medium measured, the tubes' pressure and the geometric sizes of the flowmeter on its first frequency are considered. To assess the impact of the geometrical and technical parameters on the forms of flowmeter oscillations a finite element model, verified by modal test results, is appropriate.

The generated finite element model is a parameterized one. To analyze the frequencies and modes of vibrations of the flowmeter the possibility to shift the support, and to change the mass of weights and the liquid density in tubes is provided. The weight mass varies due to changes in density of the materials used, and the density of fluid is changed by specifying the equivalent density of the tube material.

Modal tests of the flowmeter [14, 15] were made by using the following hardware and software:

- LMS SCADAS – a 40-channel measuring system for generating an excitation signal of vibrations, collecting and processing of dynamic signals;
- Spectral Testing module of software package LMS Test.Lab for modal testing and processing of the results;
- modal vibration shaker TMS2100E11;
- force sensor PCB 208C03 with sensitivity equal to 2,2 mV / N;
- three-piezoaccelerometers PCB 356A32 with the sensitivity of 100 mV / g;
- three-single-point Polytec CLV-3D laser vibrometer.

The test configuration is shown in Fig. 3, 4. The flowmeter is freely suspended on elastic ropes. The broadband random excitation signal is generated by the computer in the range of 20 to 400 Hz with the help of the LMS Test Lab program. The excitation signal is formed on the LMS Scadas generator, transformed to an amplifier and then to the modal shaker. The shaker is suspended with rods and connected to the case base of the flowmeter. To control the forced oscillations between the flowmeter and shakers the force sensor is installed. The three-laser vibrometer [16] measures in a non-contact way three components of the vibration velocity of the tubes. Opposite all of the coils on both sides of the flowmeter case six holes are made for technical measurements. Case oscillations are measured using three-component accelerometers mounted on its surface.

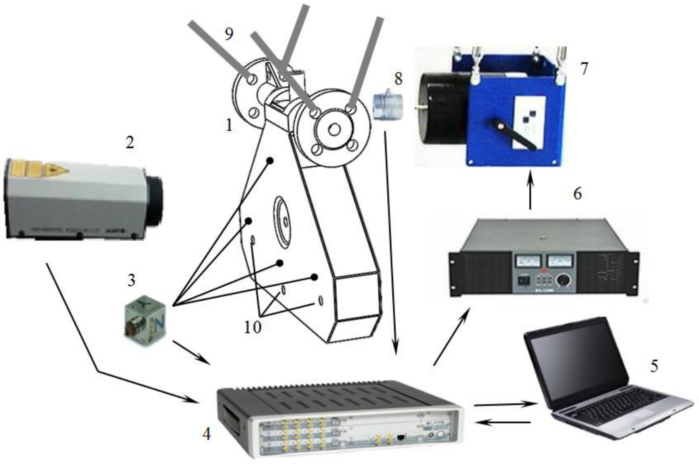

Fig. 3. Test configuration: 1 – flowmeter; 2 – laser vibrometer; 3 – accelerometers; 4 – SCADAS; 5 – computer; 6 – amplifier; 7 – modal shaker; 8 – force sensor; 9 – rodes; 10 – opening in the flowmeter for making measurements by laser vibrometer

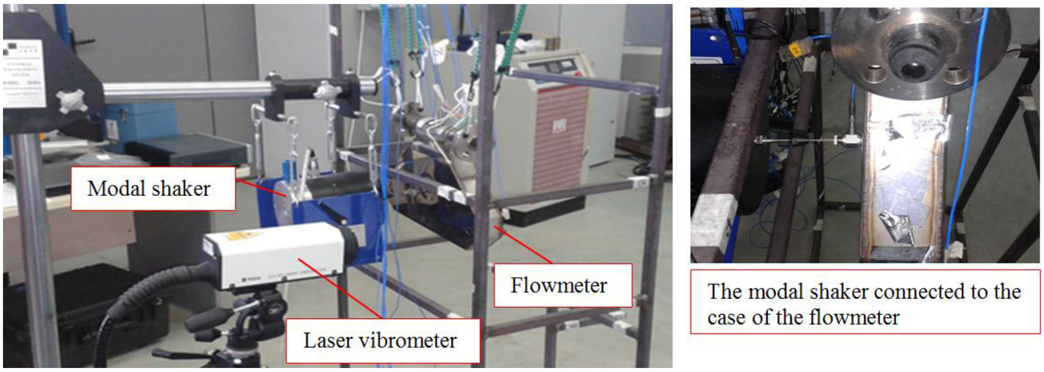

Fig. 4. Photos experimental stand

When the modal shaker excited oscillations, we recorded the excitation signal with a force sensor, measured the vibration velocities of the point on the tube with the three-laser vibrometer, and measured the case vibration accelerations with accelerometers. Calculating the excitation signals and the responses we obtained the frequency transfer functions. Then, the experiment was repeated with a laser vibrometer measurement at another point. We used 6 points on the tubes for measurements. The averaged frequency transfer functions obtained were processed using a PolyMax algorithm [17, 18] and we identified the characteristic frequencies, the shape and the decrements of the flowmeter oscillations.

In the frequency range under study, which is up to 400 Hz, we identified ten forms of natural vibrations of the tubes and three forms of the case vibrations. The forms of flowmeter oscillations, in the range less than 200 Hz, are of great practical value. The first natural frequency of the case oscillation is 236 Hz. The table 1 shows a comparison of the calculated and experimental forms and frequencies of natural oscillations of the flowmeter measuring tubes. The modal assurance criterion (MAC) is used to compare waveforms [18, 19].

Table 1. Comparison of the calculated and experimental forms and natural frequencies of the flowmeter tube oscillations

Form №	Description of oscillation forms	Experiment Frequency, Hz	Calculation Frequency, Hz	Error %	MAC
1	Antiphase oscillations of tubes in XY plane	88.8	91.9	3.5	0.93
2	Inphase oscillations of tubes in XY plane	94.0	95.5	1.6	0.87
3	Antiphase oscillations of tubes of the XY plane	116.8	117.4	0.5	0.79
4	Inphase oscillations of tubes in XY plane	128.6	126.8	1.4	0.76
5	Inphase oscillations of tubes in XY plane	157.4	162.4	3.2	0.91
6	Antiphase oscillations of tubes of the XY plane	174.7	175.4	0.4	0.97

The discrepancy between the calculated and experimental flowmeter frequencies does not exceed 4%, thus, the finite element model of the flowmeter reflects accurately the properties of the actual flowmeter design. Using the finite element model, we obtained for the first and six flowmeter frequencies the effect estimates for the support shifting, for changing both the mass of weights and liquid density placed in the tubes (Fig. 5). The frequency of forced vibrations coincides with the first natural frequency when using the flowmeter. The sixth form of natural vibrations is similar to a waveform of forced flowmeter of the Coriolis force.

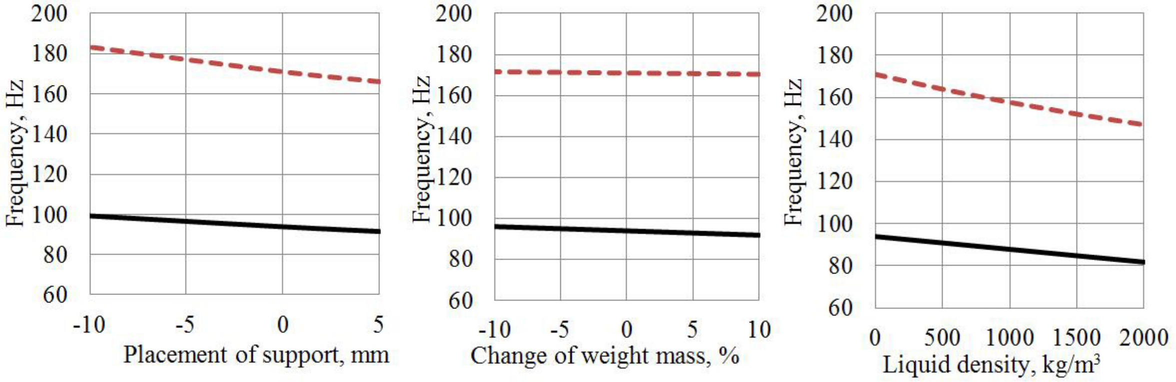

Fig. 5. Dependence of the first and second flowmeter frequencies on the flowmeter parameters

With the use of the finite element model created it is possible to avoid an unacceptable coincidence of the flowmeter natural frequencies and the three harmonics frequency of the electrical network when creating a new and improved flowmeter. The results obtained from the verified finite element model allow a sufficiently high reliability in assessing the changes of flowmeter frequencies and, correspondingly, the flow measurement accuracy when changing the geometric dimensions and technical parameters of the flowmeter system.

The experiments were carried out using the equipment center "Experimental Mechanics" SUSU.

References

[1] T. Wang, R. Baker, Coriolis flowmeters: a review of developments over the past 20 years, and an assessment of the state of the art and likely future directions, Flow Measurement and Instrumentation. 40 (2014) 99–123.

[2] K.O. Plache, Measuring mass flow using the Coriolis principle, in: R. Loxton, P. Pope (eds.), Instrumentation: A Reader, Springer US, 1990, pp. 55–62.

[3] H. Raszillier, F. Durst, Coriolis-effect in mass flow metering, Archive of Applied Mechanics. 3 (1991) 192–214.

[4] L.J. Segerlind, Applied finite element analysis, 2nd edition, Wiley, New York, 1984.

[5] K.J. Bathe, E.L. Wilson, Numerical Methods in Finite Element Analysis, New Jersey, Prentice-Hall, 1976.

[6] J. Melcer, Experimental Verification of a Computing Model, Applied Mechanics & Materials. 732 (2014) 345–348.

[7] V.S. Mezhin, V.V. Obukhov, The Practice of Using Modal Tests to Verify Finite Element Models of Rocket and Space Hardware, Space technics and technology. 4 (2014).

[8] T.J. Cunningham, An In-Situ Verification Technology for Coriolis Flowmeters, Micro Motion. (2009) 5.

[9] T.J. Cunningham, T. O`Banion, Allow Smart Meter Verifi cation to Reduce your Proving and Proof-Test Costs, Micro Motion. (2013).

[10] J. Kutin, I. Bajsik, An analytical estimation of the Coriolis meter`s characteristics based on modal superposition, Flow Measurement and Instrumentation. 12 (2002) 345–351.

[11] T. Wang, Pressure effects on Coriolis mass flowmeters, Flow Measurement and Instrumentation. 21 (2010) 504–510.

[12] S. Guirguis, Modeling of Coriolis mass flow meter of a general plane-shape pipe, Flow Measurement and Instrumentation. 21 (2010) 40–47.

[13] R. Cheesewright, S. Shaw, Uncertainties associated with finite element modeling of Coriolis mass flow meters, Flow Measurement and Instrumentation. 17 (2006) 335–347.

[14] O. Dossing, Structural Testing, Part 1, Mechanical Mobility Measurements, Brüel & Kjæ, Denmark, 1989.

[15] O. Dossing, Structural Testing, Part 2, Modal Analysis and Simulation, Brüel & Kjæ, Denmark, 1989.

[16] CLV-3D Compact 3-D Laser Vibrometer, For Simultaneous 3-D Measurement of Dynamics, Polytec, 2010.

[17] D.J. Ewins, Modal Testing: Theory, Practice and Application, Research Studies Press, Hertfordshire, 2000.

[18] W. Heylen, S. Lammens, P. Sas, Modal Analysis Theory and Testing, Catholic University of Leuven, 1997.

[19] R.J. Allemang, The Modal Assurance Criterion – Twenty Years of Use and Abuse, University of Cincinnati, Sound and Vibration. (2003) 14–21.