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MATHEMATICAL MODEL OF A MEASURING CONVERTER OF A JET FLOW METER OF LIQUIDS AND GAS

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Abstract:
The results of constructing a mathematical description of the process of measuring transformation of jet flowmeters for measuring low liquid and gas flow rates are presented. The measurement method is based on determining the value of the flow rate by the force of interaction between the controlled flow, formed into a jet, and a rigid baffle.

Keywords: jet flowmeters, measurement of low liquid and gas flow rates, measurement conversion scheme.

Introduction

Jet flowmeters, the sensitive element of the primary measuring transducer of which is a jet of liquid or gas flowing from the power supply channel of the jet element and creating pressure pulsations with a frequency proportional to the flow rate of the controlled medium, have appeared relatively recently and have not yet become widespread [1,2].

Until now, a complete theoretical description of the functioning of the primary measuring transducer, based on the considered measurement method, has not been obtained, which negatively affects the delay in the application of jet flow meters of this type. At the same time, the advantages of the analyzed flow measurement method are obvious and consist in: simplicity and reliability of the measuring transducer, the absence of moving elements, the possibility of measuring the flow of aggressive and cryogenic media. In addition, the advantages of the measurement method under consideration are that the characteristics of external factors and the controlled environment are little dependent on the characteristics of the environment. To this should be added the small inertia of the measurement, the ability to measure the flow rate of pulsating flows without a significant reduction in accuracy, formation of a frequency measuring signal convenient for measurement, explosion and fire safety, no exposure to the influence of electromagnetic fields. All this, taken together, allows us to speak about the prospects of the considered measurement method [3].

A jet method for measuring low flow rates of liquid and gas, based on determining the value of the measured parameter - the flow rate by the force of interaction between the controlled parameter formed into a jet and a rigid partition [4]. The scheme of interaction between a jet and a solid body is shown in Fig.1.

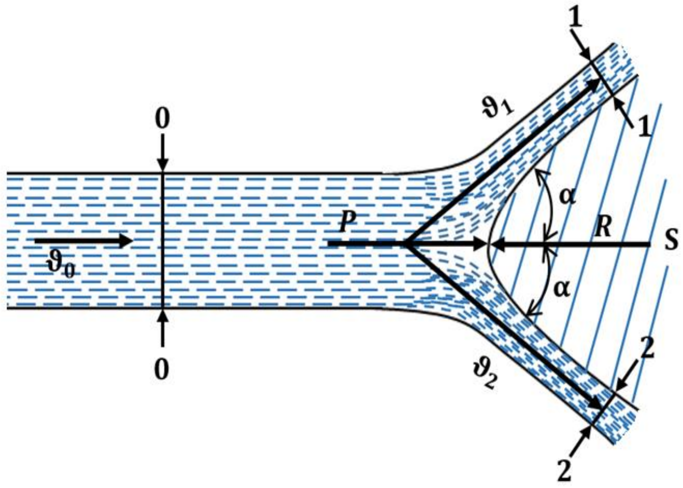

Fig.1. Scheme of interaction between a jet and a solid body.

After the impact of the jet on the solid body of the partition, it spreads over the surface, which has a curvilinear shape symmetrical about the axis S. The index S means that the projection of the change in the momentum and the acting forces is calculated for the direction S, which, after interaction with the partition, is characterized by the angle α. The interaction of the jet with the curvilinear baffle is such that the jet velocity and flow rates in two directions are the same due to symmetry, and the directions of force and reaction are the same. The equality of the projections of the second change in momentum to the sum of the projections of forces in the same direction determines the force of interaction between the jet and the baffle:

$$\frac{\Delta(m\upsilon)_S}{\Delta T} = \Sigma(p_i)_S. \tag{1}$$

Since, under the considered steady motion, the momentum in each of the sections remains constant, the second change in the projections of the momentum and the projections of forces on the S axis can be reflected using the following expressions:

$$\frac{\Delta(m\upsilon)_S}{\Delta T} = m_0\upsilon_0 - (m_1\upsilon_1 + m_2\upsilon_2)\cos\alpha\,, \Sigma(p_i)_S = R, \tag{2}$$

Where m_0, m_1, m_2 – second mass flow rates; $\upsilon_0, \upsilon_1, \upsilon_2$ – velocity of measured medium particles in sections 0-0, 1-1, 2-2; R – is the force of interaction.

In accordance with (1) we havem

$$R = m_0\upsilon_0 - (m_1\upsilon_1 + m_2\upsilon_2)\cos\alpha. \tag{3}$$

Symmetry conditions can be written as follows:

$$m_1 = m_2\ ; \upsilon_0 = \upsilon_1 = \upsilon_2\,; m_0 = 2m_1. \tag{4}$$

Taking into account conditions (4), we can write:

$$R = m_0\upsilon_0(1-\cos\alpha). \tag{5}$$

Expressing R in terms of volumetric flow, and taking into account that f – expresses the cross-sectional area of the jet, we get:

$$R = \rho \cdot \frac{Q^2}{f}(1-\cos\alpha)\,. \tag{6}$$

When the jet interacts with a solid body having the form of a flat partition, when $\alpha = \pi/2$ occurs

$$R = \rho \cdot \frac{Q^2}{f}\,. \tag{7}$$

At $\alpha = \pi$ the partition has a cup shape, for which the relation

$$R = 2\rho \cdot \frac{Q^2}{f}\,. \tag{8}$$

Calculations carried out according to the considered method, which is based on the theory of interaction of a jet with a rigid partition in relation to the above scheme, show that at a water flow rate of 100 l/h and a jet diameter of d=5 mm, the interaction force determined by the formula (8), is only about 0.008 N; at a water flow rate of 15 l/h and a jet diameter of d=3 mm, the interaction force is about 0.0006 N.

Experimental data indicate that the actual values of the developed forces and pressures differ from those calculated according to the above formulas (1) - (8) by no more than 4-8%.

The obtained force values are sufficient for measurement. As follows from the above calculation formulas, the viscosity of the liquid does not fundamentally affect the measurement results. Fluctuations in the density of the controlled medium affect the results of the measurement to the same extent as in the control of the flow of liquid or gas, based on the variable pressure difference method.

The jet flow meter under consideration is suitable for monitoring not only liquids, but also gases. Due to the negligible compressibility of the controlled liquid medium, the measured signal, which is a change in shock pressure, is converted into a force acting on a flaccid membrane or bellows [5-7].

When controlling the flow rate of the gaseous medium, the dynamics of the measurement conversion process due to the compressibility of the gas requires some time to create the required pressure in the membrane or bellows chamber by the jet of the controlled medium. The low flow jet method is similar to flow measurement with Pitot pressure tubes, which use velocity head. The formulas involving impact pressure and velocity head are very similar in structure.

Based on formula (7), pressure or head, expressed in terms of velocity in the jet measurement method (at $\alpha = \pi/2$), has the form: $p = \rho \upsilon^2$ and at $\alpha = \pi$, looks like this: $p = 2\rho \upsilon^2$. Velocity head $p_{ск} = \rho \upsilon^2/2$, i.e. two or four times less.

However, there is a difference between the compared methods, which consists in the fact that pressure tube measurements provide for the determination of the velocity at a given point in the flow and do not take into account velocity diagrams. The inkjet low flow measurement method takes into account the entire flow that passes through the pressure nozzle. The directly measured parameter in the device is the force, previously increased in accordance with the characteristics of the amplifier in the form of a bellows or membrane. There is no need for a differential pressure gauge [8-10].

In Fig.2. a variant of the execution of a dead-end nozzle is shown. The measured flow enters the receiving nozzle 1, located in the body 2. The flow formed by the nozzle into a jet hits the end of the body and creates shock pressure. The output of the controlled medium from the nozzle is carried out through chamber 3 and fitting 4. Fittings 5 and 6 are designed to take the pressure transmitted to the differential pressure gauge. Fitting 5 carries out pressure selection, which is the sum of static and total pressure. In this case, the static pressure signal enters through the fitting 6. The width of the chamber 3 is equal to or greater than the diameter of the nozzle. With a smooth entry of a controlled liquid or gas into a nozzle or tube from a pipeline or measuring vessel, the velocities at the beginning of the section are uniformly distributed over the section, which causes a rectangular shape of the velocity diagram both in laminar and turbulent flows.

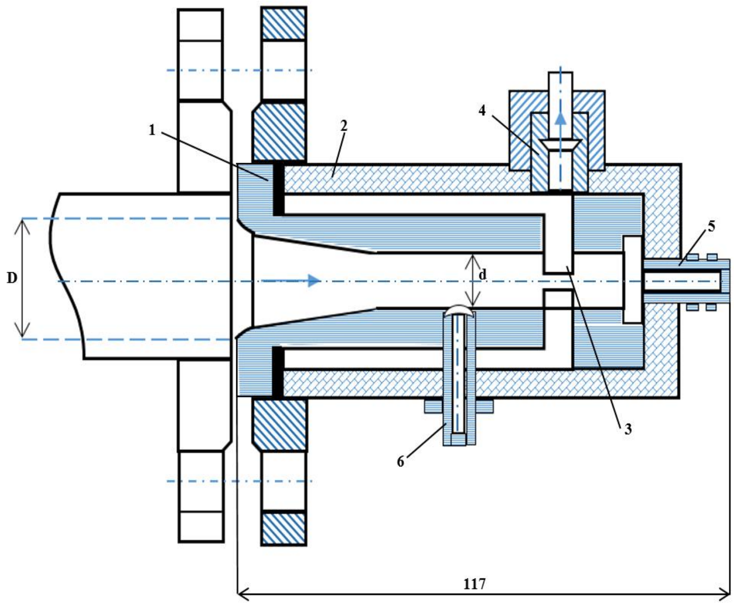

Fig. 2. Variant of the design of the dead-end nozzle:
1 - receiving nozzle, 2 - housing, 3 - chamber, 4, 5, 6 - fittings.

In accordance with the work, the length of the initial section at laminar pressure

$$l_н = 0{,}065 d \,\mathrm{Re}\,, \tag{9}$$

where d – is the pipeline diameter; Re – is the Reynolds number.

Expression (9) characterizes the section from the smooth inlet to the section in which the axial velocity is equal to 99% of the maximum velocity, which is predetermined by the distribution of velocities in a laminar isothermal flow in the form of a parabola. The nozzle length is so small that the distribution of velocities over the cross section can be considered as uniform. The section from the liquid inlet to the dead-end nozzle to the axis of the outlet is about (0.005-0.01) dRe.

The calculation formula for determining the differential follows from expression (8) for shock pressure. When measuring the shock pressure on the dead-end nozzle with a differential pressure gauge, the filler is a controlled liquid

$$P = \rho g H\,, \tag{10}$$

where H – is the differential pressure drop in the form of a level difference.

Value substitution P from expression (10) to the formula for shock pressure (7) gives the following result:

$$Q = f\sqrt{gH}\,. \tag{11}$$

We introduce the matching coefficient k_{10}, depending on the size of the nozzle and the design of the dead-end nozzle:

$$Q = 31{,}33 \cdot k_{10} \cdot f \cdot \sqrt{H}\ , \qquad (12)$$

$$[Q] = [см^3/с];[f] = [см^2];[H] = [см].$$

When measuring the differential with a liquid column with a density different from the density of the medium being measured, the formula for calculating the flow rate is:

$$Q = 31{,}33 \cdot k_{10} \cdot f \cdot \sqrt{\frac{\rho_1}{\rho} \cdot H}\ , \qquad (13)$$

Where ρ_1 – is the density of the liquid filling the differential pressure gauge.

For dead-end nozzles, shown in Fig. 2, with a nozzle diameter of d=10 mm and d=12.7 mm, the values of the matching coefficients were experimentally determined k_{10}, which for d=10 mm amounted to 1.399 and for d=12.7 - 0.968. During experiments on water in the range of Reynolds numbers Re=3200÷16800, the measurement error relative to the design pressure is less than 1%.

With a tenfold change in the Re numbers in the range from 300 to 3000 (experiments on a viscous medium), the flow rate error over the entire range was 2.0–2.5%. Comparing these results with the errors of normal narrowing devices, we can conclude that dead-end nozzles are of a certain scientific and technical interest as new measuring transducers at Reynolds numbers below the limit.

REFERENCES

1. Kremlevsky P. P. Flowmeters and counters of the amount of substance: a reference book / P. P. Kremlevsky; [ch. ed. E. A. Shornikov]. – Ed. 5th. - St. Petersburg: Polytechnic, 2004. - 412 p. – ISBN 5-7325-0709-4.

2. Treskunov S.L., Aristov P.A., Barykin N.A. // Devices and control systems. 1990. No. 11. p. 24-26.

3. Chaplygin E.I., Zemskov Yu.V., Korzin V.V. Mathematical model of a jet flow meter, Journal of Technical Physics, 2004, volume 74, no. 6, - p. 16-19.

4. Ivanushkin I.Yu. On the applicability of the jet method for measuring gas flow. // Collection of articles “Commercial accounting of natural gas. New gas measuring equipment and systems”, 2011- p.112-116.

5. N.R. Yusupbekov, Sh.M. Gulyamov, E.E. Ortikov. Classification of jet flowmeters for liquid and gaseous media // Collection of scientific papers of the international conference “The state and trends in the development of standardization and technical regulation in the world”, Tashkent -2022. October 13-14, Doi: 10.51346/tstu-conf.22.1-77-0038, p.143-146.

6. Ortikov E.E. Intelligent high sensitivity jet flow meter for low flow measurement // Chemical Technology. Control and Management / 2022, No. 4-5 special issues (106-107), p. 178-182.

7. N.R. Yusupbekov, Sh.M. Gulyamov, E.E. Ortikov / Investigation of the Influence of Unstationary Gas Flows on the Accuracy of Flow Measurement by the Variable Pressure Differential Method / International Journal of Discoveries and Innovations in Applied Sciences | e-ISSN: 2792-3983 | www.openaccessjournals.eu | Volume: 2 Issue: 11, p.17-21.

8. Kasimov A. M., Klimov A. N. Experience in the development of jet flow meters, Institute for Control and Automation Problems. All-Russian meeting, Moscow, 1998.
9. A.M. Kasimov, A.I. Popov. Inkjet transducers of volumetric and mass flow rates, XIII All-Russian Conference on Control Problems VSPU-2019. Moscow -p. 2735-2742.
10. Sh.M. Gulyamov, E.E. Ortikov. Modeling of the process of measuring conversion of the flow of liquid and gaseous media by the method of variable pressure drop // Chemical Technology. Control and Management: Vol. 2023: Iss. 1, DOI: https://doi.org/10.59048/2181-1105.1440, - p.45-52.