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THE MEASUREMENT QUALITY EVALUATION OF AN ULTRASONIC FLOW SENSOR WITH A COMPLEX MEASURING PATH TRAJECTORY

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Over the past ten years, ultrasonic measuring instruments have become most widespread in industrial measurements of the flow and quantity of various energy resources. Such instruments differ in design, method of obtaining the output signal, number and topology of acoustic waves propagation and, accordingly, have different metrological performances.

The accuracy of the measured signal formation is determined by the quality of the flow sensor. At the same time, the components of quality are metrological performances, manufacturability of the design, ease of setup, cost and others.

The purpose of the work is to compare, analyze and evaluate the quality of flow measurements when using a single-channel ultrasonic sensor with a complex trajectory of the measuring beam and a multi-path (multichord) ultrasonic sensor.

As a result of simulation modeling, distributions of flow velocities in longitudinal sections and cross sections were obtained, correction factors for the measured signal were determined, and pressure losses were calculated.

A comparative analysis of the measurement quality of the investigated flow sensors made it possible to identify the advantages of using a single-path flow transducer with acoustic wave reflection. We are talking about the possibility of accurately outputting a useful signal, higher metrological sensitivity, higher measurement accuracy, as well as minimal impact on the measured medium due to the creation of smaller geometrically sized local hydrodynamic resistance along the length of the measuring path.

The further research prospect is the study of ultrasonic flow measuring sensors with different topologies of acoustic channels when measuring and recording flow and quantity for different flow regimes of the measured medium.

Keywords: *measurements quality; gas; flow sensor; beam reflection; ultrasonic flow sensor; conversion response; simulation.*

Introduction

Saving natural energy resources has always been relevant and requires the use of modern technologies and achievements for their effective use. An organization of effective measurement and registration in all sectors of the national economy is one of the key aspects of saving and rational use of natural energy resources.

To measure the flow and quantity of natural gas, flow meters and meters are used, the functioning of which is based on various physical principles. Such instruments provide different metrological performances. One of the directions for increasing the accuracy of measuring equipment is the readings correction by recalculating the gas volume to standard conditions [1]. For this purpose, measuring systems and complexes are created, the structural elements of which are sensors of pressure, temperature, flow rate and computing units. Also, increased measurement accuracy is ensured by the use of automated data transmission systems based on wired, wireless and combined technologies [2, 3].

However, despite the widespread use of computational algorithms, the quality of measurements is based on the quality of the flow sensor (FS). The accuracy of the measuring signal formation and its further processing directly depend on the physical principle of operation and design features of the flow sensor.

A comprehensive effectiveness assessment of using a specific measuring instrument is the quality of measurements. The components of measurement quality are metrological characteristics, manufacturability of design, setup simplicity, cost, and others. At the same time, the requirements for metrological performances are high accuracy, reliability, repeatability of measurement results, minimal influence of the sensor on the measured medium, and others.

Over the past decade, acoustic (ultrasonic) measuring instruments have become most widespread in industry in the world for measuring and recording the flow rate and quantity of energy resources with various physical and chemical properties and purposes.

Problem statement

There are ultrasonic flow meters with different designs and methods of generating the output signal, both in terms of the topology of acoustic wave propagation and the principle of operation.

For the effective use of ultrasonic measuring transducers (USFS), it is necessary to investigate several such measuring transducers, based on different topological schemes.

Two flow sensors were selected for the study: the operating principle of the first sensor is based on the use of multiple wave reflection, which forms a complex trajectory of the measuring beam when using one pair of transmitters-receivers [4]; the second flow sensor is multi-path. The chords number of such sensor corresponds to the number of direct sections of the acoustic signal from the transmitter to the mirrors and from them to the next signal reflection device, and, finally, to the receiver.

There are various configurations with signal reflection, which can propagate in one (diametrically) or several planes [5]. For the study, a configuration with fourfold spatial reflection of the measured signal was chosen. The second configuration is implemented on the principle of multi-path placement of piezoelectric transducers in a multi-channel ultrasonic measuring transducer. The trajectory of the beams in this configuration corresponds to the placement of reflectors in the first one.

The purpose of the work is to compare, analyze and evaluate the quality of flow measurements when using a single-channel ultrasonic sensor with a complex trajectory of the measuring beam and a multi-path (multichord) ultrasonic sensor.

Investigations of ultrasonic flow sensors with different topological configurations

For ultrasonic flow sensors with a multi-path arrangement of measuring channels, the flow rate is determined in accordance with the expression [5]

$$q_v = kS\sum w_i v_i . \qquad (1)$$

Where k is the hydrodynamic factor, the value of which depends on the flow regime and the presence of hydraulic resistance [6 – 11]; S is cross-sectional area of the measuring channel; w_i is weight factor on the i-th section of the beam; v_i is speed on the i-th section of the beam.

The main task for obtaining information about flow is to calculate the values of the factors k and w_i, which make a correction in accordance with the location geometry of the measuring beams and their total number.

To identify the functioning features of the investigated flow sensors and study the hydraulic phenomena that occur, modern computational software systems based on the finite element method were used.

The computational experiment involves:

– constructing three-dimensional geometric models of flow sensors;
– creating computational grids of geometric models;
– selection of the boundary regions of the measured flow;
– operating parameters settings of the measured medium (substance, temperature, pressure);
– selection of hydrodynamic flow model;
– determination of modeling boundary conditions;
– carrying out the computational process;
– processing and analysis of the obtained results.

To evaluate the advantages and disadvantages of using USFS with reflection and multichords sensor**s**, three-dimensional geometric models of measuring transducers for DN 50 were created in the SolidWorks software package (Fig. 1).

The design of a single-beam ultrasonic sensor with quadruple reflection of the informative beam is adopted as the basis. This beam in cross-section creates a triangular topology for sensing the moving measured medium (Fig. 1, a). In accordance with the parameters of the reflectors (mirrors) placement, a model of a flow sensor was created using separate piezoelectric transducers (Fig. 1, b). In both configurations, flow measurement is implemented along five beams, which are located at the same inclination angles and diametrical distance to the measured flow.

Methane gas was chosen as the measured medium at operating conditions: absolute pressure in the pipeline is 0.3 MPa, temperature is equal to 20 °C.

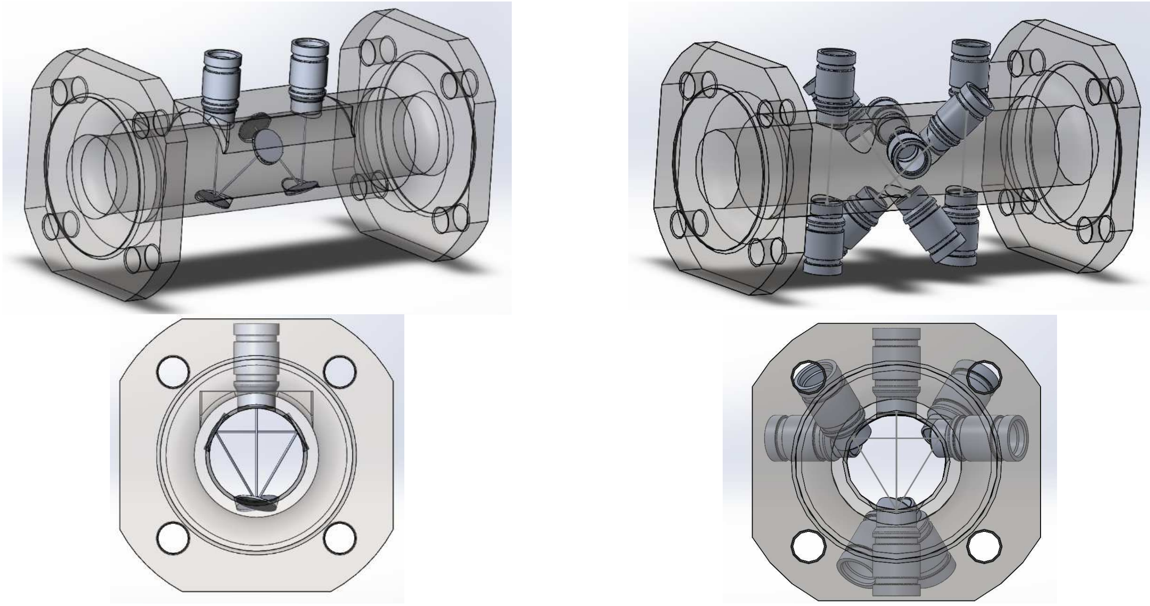
The simulation was carried out for five operating modes. As boundary conditions, the values of the inlet flow velocity are set, which correspond to the minimum Q_{min} = 0.15 m^3/h, nominal Q_{nom} = 15 m^3/h, maximum Q_{max} = 30 m^3/h flow rate, as well as 0.2 Q_{max}, 0.7 Q_{max} of the operation of the ultrasonic flow meter. The simulation was carried out in a stationary flow mode (Steady State mode), uniformly distributed in the inlet section. The k-ε turbulence model is applied.

The simulation results were obtained in the form of velocity distribution in longitudinal (Fig. 2) and transverse (Fig. 3) sections of the measuring channel, as well as in the form of numerical values of speed along the propagation lines of the measuring signal between the piezoelectric transducers.

Velocity diagrams were obtained for cross-sections that are located at distances of 1 DN, 1.5 DN, 2 DN, 3 DN and 4 DN from the inlet section of the model geometry (Table 1).

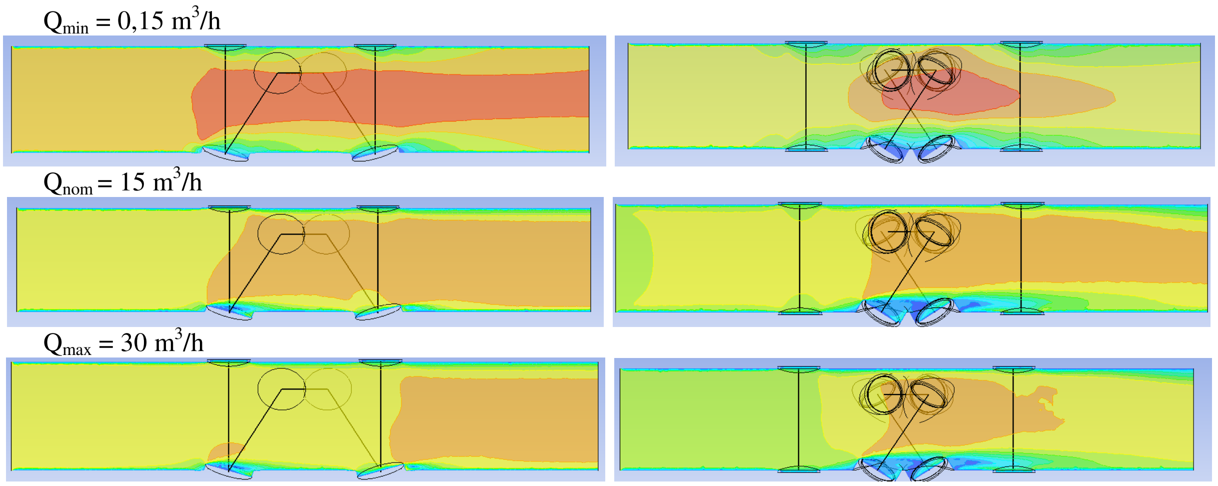
Table 1 shows the velocity profiles in the indicated cross-sections for the structures under study at minimum, nominal and maximum flow rates. Designations: 1 – configuration with beam reflection, 2 – multi-path flow configuration.

Comparison of the velocity distribution in identical cross-sections at different flow rates for the investigated configurations allows us to see a change in the velocity distribution due to changes in the internal geometry of the working areas of the flow sensors.



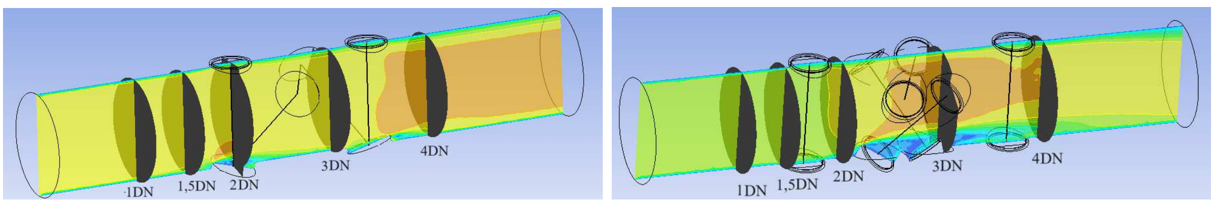
a b

Fig. 1. Flow sensors under study: with the measuring beam reflection (a); multi-path sensor (b)



a b

Fig. 2. Flow velocities in the longitudinal section of flow sensors at minimum, nominal and maximum flow rates: with beam reflection (a); multi-path (b)



a b

Fig. 3. Arrangement of cross-sections along the length of the flow sensor: with beam reflection (a); multi-path (b)

As a result of numerical simulation, correction factors for the measured signal were determined.

The conversion response of the studied time-pulse ultrasonic flow sensors were determined as a result of modeling, taking into account the speed of ultrasound in the measured medium and the average speeds along the lines of the measuring beams (Fig. 4). The pressure losses on the flow sensors between the input and output cross-sections of the model geometry were calculated (Fig. 5).

Table 1. Velocity profiles in cross-sections of flow sensors

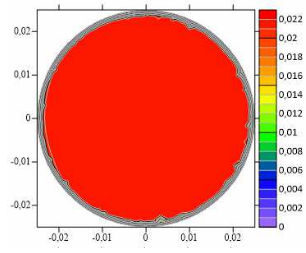
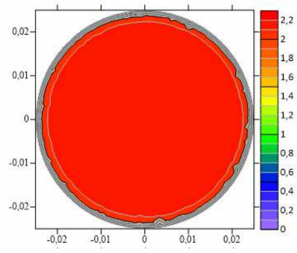
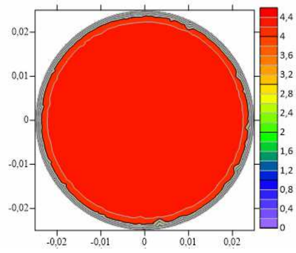
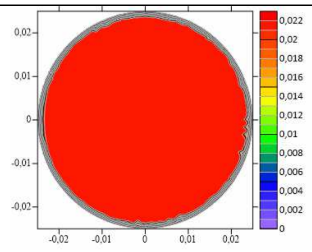
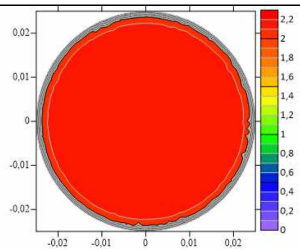
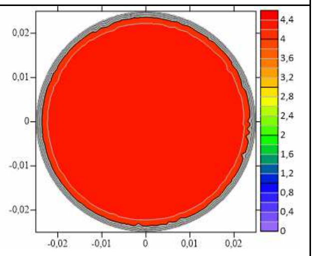
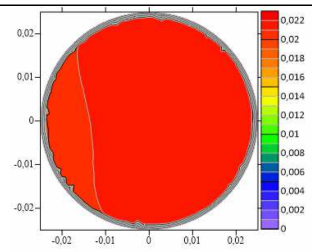
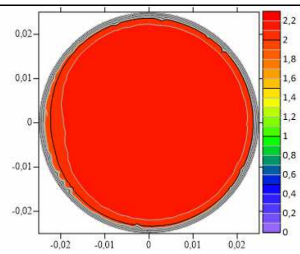
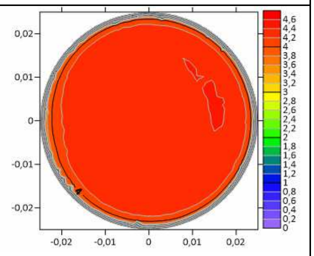
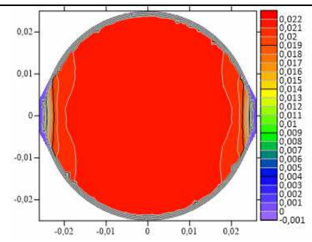
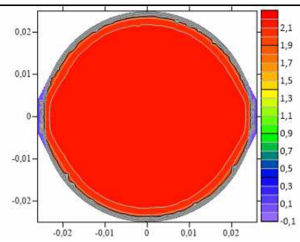
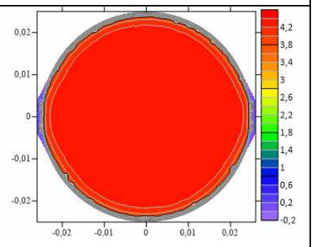
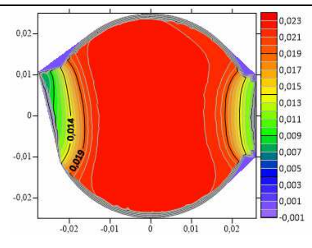
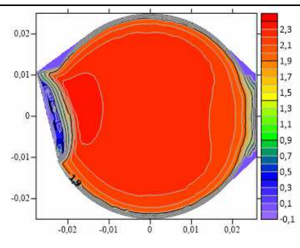
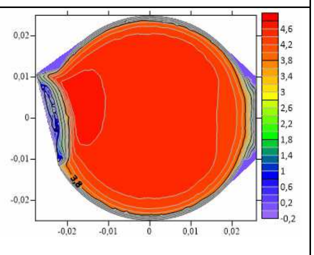
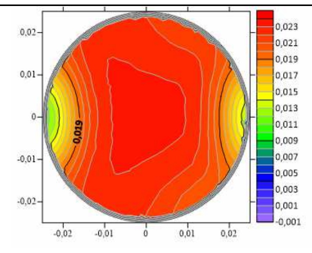
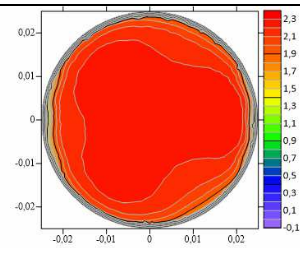
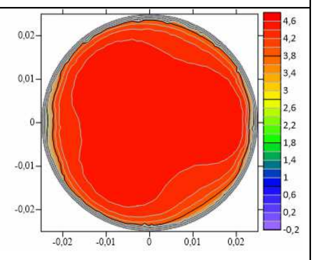
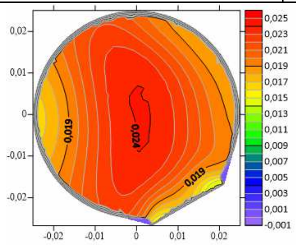
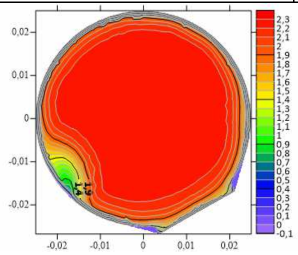
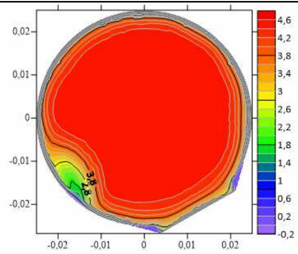
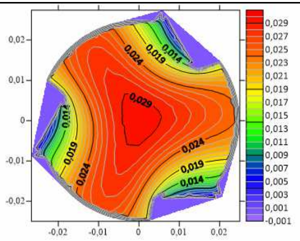
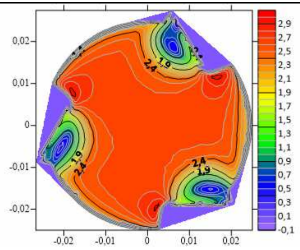
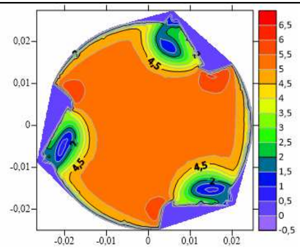
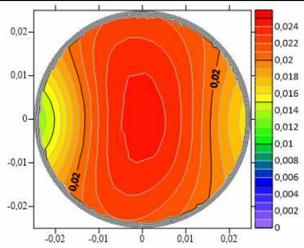
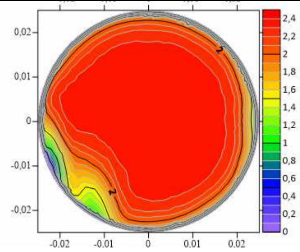
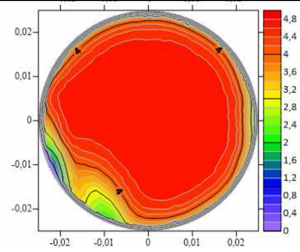
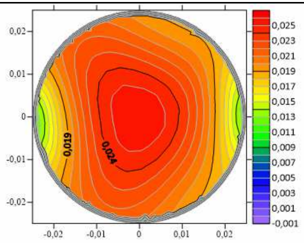
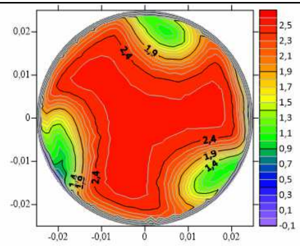
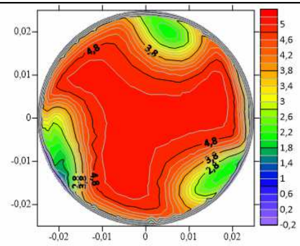
Distance	Flow rate / Configuration	Q_{min}	Q_{nom}	Q_{max}
1 DN	**1**			
	2			
1.5 DN	**1**			
	2			
2 DN	**1**			
	2			

Table 1. Continued

Distance	Flow rate / Configuration	Q_{min}	Q_{nom}	Q_{max}
3 DN	**1**			
	2			
4 DN	**1**			
	2			

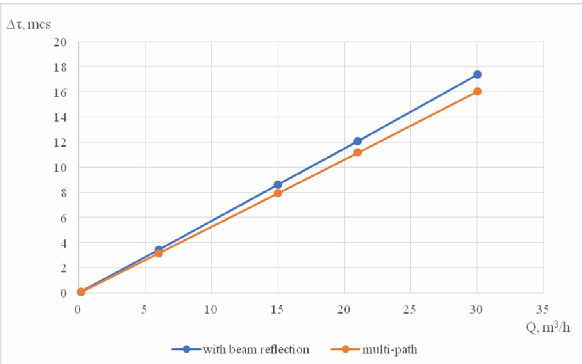


Fig. 4. Conversion response of flow sensors

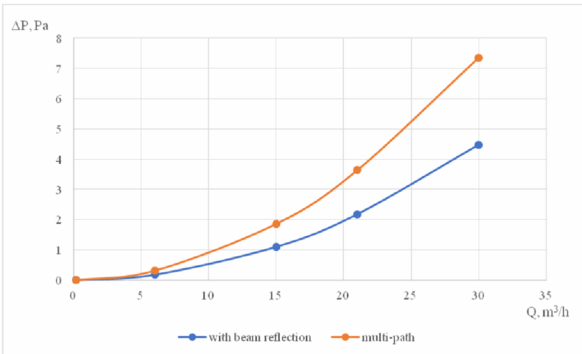


Fig. 5. Pressure loss on flow sensors

Conclusions

To assess the flow measurements quality of a single-channel ultrasonic sensor with the measuring beam reflection, simulation modeling of two flow sensors was carried out. A multi-path sensor was selected as the second one. The trajectory parameters of the measuring beams of the two configurations are identical.

The distributions of flow velocity in longitudinal and transverse sections were obtained as modeling results. This made it possible to study the distortion of the velocity distribution due to changes in the internal geometry of the working areas of ultrasonic flow sensors. The correction factors calculation for the measured signal contributed to the determination of the conversion characteristics taking into account the ultrasound speed in the measured medium and the average speeds along the measuring beams. Pressure loss determined.

The measurement quality comparative analysis of the investigated flow sensors indicates the following:

– the advantage of the first design is the ability to accurately output the useful signal, since the use of a longer measuring path makes it possible to determine with higher accuracy the difference in the time of ultrasound passage in the measured medium;
– the higher metrological sensitivity is the advantage of the first design;
– higher measurement accuracy is an advantage of the first design; since the sum of errors in independent measurements of the difference in the time of an acoustic signal passage along the flow and against it in individual sections is greater than in the overall length of the trajectory;
– minimal influence on the measured medium is typical for a sensor with acoustic wave reflection, due to the creation of smaller geometrically sized local hydrodynamic resistances along the measuring path length;
– from the point of view of design manufacturability and its simplicity, it is advisable to use multichords flow sensors;
– the flow sensor cost directly depends on the number of used piezoelectric transducers pairs.

The further research prospect is the study of ultrasonic flow measuring sensors with different topologies of acoustic channels when measuring and recording flow and quantity for different flow regimes of the measured medium.

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ОЦІНКА ЯКОСТІ ВИМІРЮВАНЬ УЛЬТРАЗВУКОВОГО ПЕРЕТВОРЮВАЧА ВИТРАТИ ЗІ СКЛАДНОЮ ТРАЄКТОРІЄЮ ВИМІРЮВАЛЬНОГО ПРОМЕНЯ

Протягом останнього десятиріччя найбільшого застосування у промислових вимірюваннях витрати та кількості різних енергетичних ресурсів набули ультразвукові вимірювачі. Такі прилади відрізняються за конструкцією, методом отримання вихідного сигналу, кількістю та топологією розповсюдження акустичних хвиль і, відповідно, мають різноманітні метрологічні характеристики.

Точність формування вимірюваного сигналу окреслюється якістю первинного перетворювача витрати. Складовими якості при цьому є метрологічні характеристики, технологічність конструкції, зручність налаштовування, вартість тощо.

Метою роботи є порівняння, аналіз та оцінювання якості вимірювань витрати при застосуванні одноканального зі складною траєкторією вимірювального променя та багатоканального (багатохордового) ультразвукових перетворювачів витрати.

За результатами імітаційного моделювання отримано розподіл швидкості потоку у повздовжніх та поперечних перерізах, визначено коефіцієнти коригування виміряного сигналу, розраховано втрати тиску.

Порівняльний аналіз якості вимірювань досліджуваних перетворювачів витрати дозволив виявити переваги застосування одноканального перетворювача витрати з відбиттям акустичної хвилі, а саме: можливість точного виведення корисного сигналу, більша метрологічна чутливість; вища точність вимірювання, а також мінімальний вплив на вимірюване середовище, в наслідок створення менших за геометричними розмірами місцевих гідродинамічних опорів по протяжності вимірювального тракту.

Перспективою подальшої роботи є дослідження ультразвукових вимірювальних перетворювачів витрати з різною топологією акустичних каналів при вимірюванні та реєстрації витрати і кількості за різних режимів плину вимірюваного середовища.

Ключові слова: якість вимірювань; газ; перетворювач витрати; відбиття променя; ультразвуковий перетворювач витрати; характеристика перетворення; імітаційне моделювання.

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