A POSSIBILITY TO DECREASE THE FLOW MEASUREMENT ERROR IN A CORIOLIS FLOWMETER BY EVALUATING ADDITIONAL PARAMETERS OF A TWO-PHASE FLOW

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Abstract: A Coriolis flowmeter is one of the most demanded instruments from different types of flowmeters. It allows us to measure mass or volume of a flow that passes through a controlled volume of the space per unit time (for example, a section of a pipeline). The main advantage of a Coriolis flowmeter is an insignificant error of the flow measurement, which usually does not exceed 0.25%.

However, this insignificant error is achieved only at a stable flow of fluid with a constant density. When a controlled flow has an inhomogeneous structure (multiphase or multicomponent flow), the error increases and can significantly exceed an acceptable value.

In this paper, we consider the possibility of providing the required error of the flow measurement for a two-phase flow in the Coriolis flowmeter. The possibility is realized by using additional parameters, that characterize the controlled flow.

Key-Words: Coriolis flowmeter, two-phase flow, gas-liquid flow, error correction, statistical characteristics.

1. Introduction

Additional components in a homogeneous flow lead to a significant increase of measurement errors [1]. The primary reason for errors growth is an uncontrolled measurement function variation of a Coriolis flowmeter. The measurement function variation occurs due to changed conditions of a "flowmeter-flow" system. Apparently, if we monitored flow conditions, we could correct the measurement errors. At the present time, there are various ways to correct the measurement errors in a Coriolis flowmeter under a two-phase flow condition. In the paper we understand a gas-liquid flow as a two-phase flow condition.

The first way is based on using additional measuring devices to define a two-phase flow condition. The authors in [2] used an ultrasonic flowmeter, in [3] used a device for measuring sound speed.

The second way is based on soft computing methods to correct measurement errors. The principal question of this methods is algorithms and input parameters. The authors in [4] used neural networks (NN) to correct the error of a liquid flowrate measurement in a two-phase flow condition. The apparent mass flowratre, the density drop, the damping and the temperature have been used as input parameters for NN.

The author in [5] used NN, support vector machine (SVM) and genetic programming algorithms (GP) to evaluate a flowrate of liquid and gas fractions under a two-phase flow condition. SVM algorithm achieved the best result. The mass flowrate, the density drop, the damping and the pressure drop have been used as input parameters for the algorithms.

The third way is based on own parameters of a Coriolis flowmeter when correcting measurement errors. For example, the authors in [6-8] used the flow density and the drive system current.

The fourth way is based on constructive solutions when increasing a stability of the measurement function of a Coriolis flowmeter in a two-phase flow condition. As example, the authors [9] decreased vibration frequency of flowtubes in a Coriolis flowmeter.

It can be seen, that a decrease of the measurement errors in Coriolis flowmeters under a two-phase flow condition represents considerable interest. In the paper we use statistical parameters to correct the measurement errors in the Coriolis flowmeter.

2. Methodology

A measuring device must provide a deterministic function between input and output variables. This function is called a measurement function or a calibration curve (CC) [10-11]. The measuring device consists of a sensor and a measuring transducer. Schematic structure of any measuring devices is presented on Figure 1.

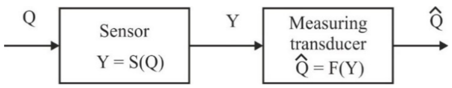


Fig. 1 – Scheme of a measuring instrument

The sensor perceives a measuring value and generates an output signal

$$Y = S(Q) \quad (1)$$

where Q – a value on the sensor input (mass flow, for example);

Y – a value on the sensor output (measurement signals parameters).

The measuring transducer transforms the sensor output signal to estimation of a measuring value by a function

$$\hat{Q} = F(Y), \quad (2)$$

where Y – a value on the transducer input (the sensor output);

$\hat{Q}$ – a value on the transducer output (an estimation of the measuring value).

Functions (1) and (2) is a sensor calibration curve (CC) and a transducer calibration curve (CC) respectively. A condition of an insignificant error $\hat{Q} \to Q$ defines a requirement to the transducer CC

$$F(Y) \to S^{-1}(Q) . \quad (3)$$

The transducer CC in a Coriolis flowmeter has next form in a one-phase flow condition

$$F(Y) = \hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi \quad (4)$$

where $\Delta\varphi$ – a phase difference between measuring coils signals;

$\hat{Q}$ – a mass flowrate estimation;

a_0, a_1 – coefficients of the transducer CC.

The authors in [12] discussed that the transducer CC in form (4) can provide the measurement error of a mass flowrate within 0.1%. However, the measurement error significantly increases in a two-phase flow condition.

The primary cause of the measurement errors increase is an uncontrolled transformation of the sensor CC

$$Y = S(\{Q, \vec{x}\}) = S(\{Q, \rho, T, \nu, ...\}) \quad (5)$$

where $\vec{x} = \{\rho, T, \nu, ...\}$ – a perturbation vector (components of the perturbation vector are ρ – density, T – temperature, ν – viscosity and other uncontrolled parameters).

Components of the perturbation vector $\vec{x}$ is changed in a two-phase flow condition, so the sensor CC transforms respectively.

Then, the transducer CC does not conform the condition of insignificant error.

A proposed approach for correcting the measurement error implies constructing the stable transducer CC. For this purpose, we entered a vector of secondary parameters. This vector is a function of the perturbation vector

$$\vec{z} = Z(\vec{x}) . \quad (6)$$

Function (6) is similarity to the sufficient statistics [13]. It helps to decrease a number of calculations and to simplify the sensor CC (5).

The basic task of the approach is evidence of an equality

$$Y = S(\{Q, \vec{x}\}) = S(\{Q, \vec{z}\}) \quad (7)$$

In the context of a practical task solution, we have made an assumption of a functional relation between components of the perturbation vector and parameters of measurement signals. Also, we have supposed that a gas void fraction (GVF) is a main component of the perturbation vector. The secondary parameters vector consists of statistical characteristics of measurement signals. These statistical characteristics have a functional relation with GVF. We have considered a standard deviation of the phase difference and a standard deviation of the vibration frequency of flowtubes as the statistical characteristics. Also, we have used the vibration frequency of flowtubes as a component of the secondary parameters vector.

3. Experiment

Detection a functional relation between the statistical parameters of the measurement signals and the perturbation vector was primary task of the experiment. The experiment has performed on the flow lab of Advanced Instrumentation Research Group Department of Engineering Science University of Oxford [4].

As an experimental flowmeter we have used the Coriolis flowmeter with 15 mm nominal diameter and with two flowtubes. The experiment was performed in an operational range of a mass flowrate of the experimental flowmeter for different values of GVF.

Table 1 shows parameters of the experiment, where GVF – the gas void fraction, T – the recording time of the measuring signal. The vibration frequency of flowtubes was $Fd = 88...92$ Гц, the sampling frequency of ADC was $Fs = 48$ кГц.

Table 1. Experiment parameters

Parameter	Value
Flowrate, kg/s	0.3; 0.5; 0.6; 0.8
GVF, %	0; 2; 4; 6; 8; 10; 15; 20; 25
T, c	22

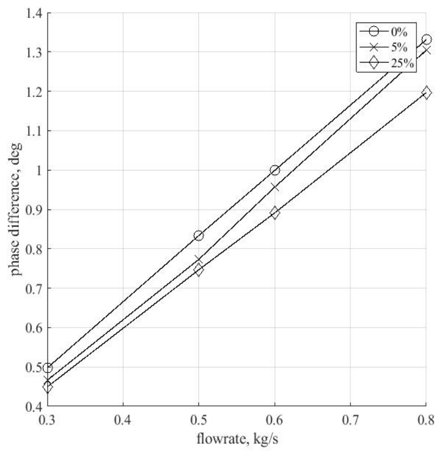


Fig. 2 – The GVF impact to transducer CC

Experiment results were represented as records of the measurement signals. As an algorithm for evaluating measurement signals parameters (the phase difference, the frequency and the statistical characteristics) was used well-known digital zero-crossing method.

4. Results

Obviously, GVF has an impact to the transducer CC in the Coriolis flowmeter. Figure 2 demonstrates the GVF impact.

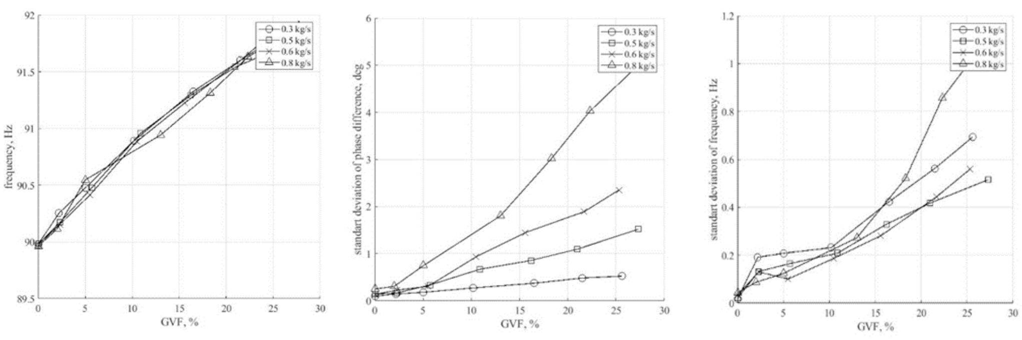
Transducer CC on Fig.2 under different GVF confirms two effects: a variation of coefficients and an occurrence of nonlinearities. These effects are expressed especially strong for medium GVF.

4.1 The analysis of the GVF impact to the secondary parameters

We have analyzed the GVF impact to the secondary parameters for assessment of a correction possibility of the transducer CC.

An additional parameter for the transducer CC must suit of basic characteristics, such as a sensitivity, a resolution and a selectivity [15]. Fig 3. shows functional relations between GVF and each of the secondary parameters.

Function $f(GVF)$ (Fig. 3a)) has high selectivity to mass flowrate, but the sensitivity of this function is insignificant. Function $\sigma_{\Delta\varphi}(GVF)$ (Fig. 3b)) has high sensitivity, but also has a functional relation with the mass flowrate that means two-parameter function. Function $\sigma_{\Delta f}(GVF)$ (Fig. 3c)) has medium



a) *b)* *c)*

Fig. 3 – The functional relations between different secondary parameters and GVF

characteristics, but also has a nonlinearity format.

Thus, the GVF impact on the secondary parameters does not allow for a uniquely determination of the additional parameters to correct the transducer CC. So, in chapter 4.2 different models of the transducer CC were analyzed.

4.2 The analysis of transducer CC models with secondary parameters

We have considered various models of the transducer CC for assessment of the correction possibility. Table 2 presents several models of transducer CC. An estimation of models' coefficients fulfilled by methods [11], which based on a criterion minimum of root-mean-square deviation.

We used a relative error of a mass flowrate estimation for comparison different models of the transducer CC. Figure 4a) illustrates the relative error of the mass flowrate estimation by model 0 (corresponds to (4)). As can be seen, usage simple transducer CC led to the significant error of the mass flowrate estimation for a two-phase flow condition.

Figure 4b) illustrates the relative error of the mass flowrate estimation by model 1 that corresponds to using an additional external device for the GVF estimation. As can be seen, usage of model 1 provided the maximum relatively error of the mass flowrate estimation about 4%.

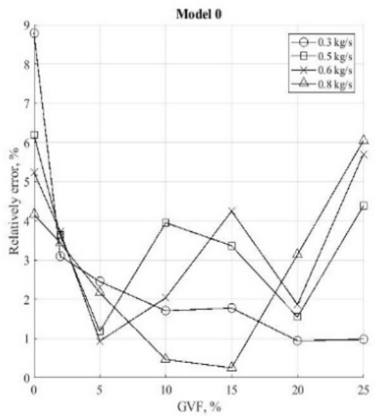
The group of linear models (models 2-5) have a linear functional relation between the main parameter (the phase difference), the secondary parameters and the mass flowrate. Figures 5a) and 5b) illustrate the relative error of the mass flowrate estimation by the linear models with the best result.

The group of quadratic models (models 6-9) have a quadratic functional relation between the main parameter (the phase difference), the secondary parameters and the mass flowrate. Figures 5c) and 5d) illustrate the relative error of the mass flowrate estimation by the quadratic models with the best result.

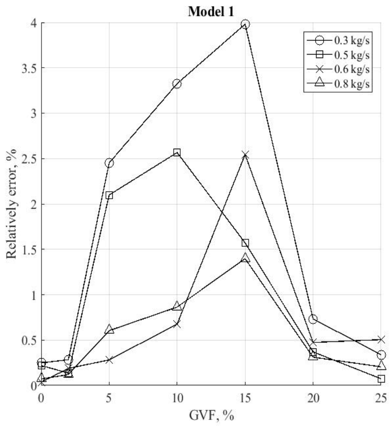
To compare different models of the transducer CC under different GVF we used several relative errors: the average relative error, the maximum

Table 2. Models of transducer CC

model	parameters	type	function
0	$\Delta\varphi$	linear	$\hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi$
1	$\Delta\varphi, GVF$	linear under known GVF	$\hat{Q}(\Delta\varphi) = a_0(GVF) + a_1(GVF)\Delta\varphi$
2	$\Delta\varphi, \sigma_{\Delta\varphi}$	linear	$\hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi + a_2 \sigma_{\Delta\varphi}$
3	$\Delta\varphi, f$	linear	$\hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi + a_3 \sigma_f$
4	$\Delta\varphi, \sigma_f$	linear	$\hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi + a_4 \sigma_f$
5	$\Delta\varphi, \sigma_{\Delta\varphi}, f, \sigma_f$	linear	$\hat{Q}(\Delta\varphi) = a_0 + a_1 \Delta\varphi + a_2 \sigma_{\Delta\varphi} + a_3 f + a_4 \sigma_f$
6	$\Delta\varphi, \sigma_{\Delta\varphi}$	quadratic	$\hat{Q}(\Delta\varphi) = b_0 + b_1 \Delta\varphi + b_2 \sigma_{\Delta\varphi} + b_3 (\Delta\varphi)^2 + b_4 \Delta\varphi\sigma_{\Delta\varphi} + b_5 \left(\sigma_{\Delta\varphi}\right)^2$
7	$\Delta\varphi, f$	quadratic	$\hat{Q}(\Delta\varphi) = b_0 + b_1 \Delta\varphi + b_2 f + b_3 (\Delta\varphi)^2 + b_4 \Delta\varphi f + b_5 (f)^2$
8	$\Delta\varphi, \sigma_f$	quadratic	$\hat{Q}(\Delta\varphi) = b_0 + b_1 \Delta\varphi + b_2 \sigma_f + b_3 (\Delta\varphi)^2 + b_4 \Delta\varphi\sigma_f + b_5 \left(\sigma_f\right)^2$
9	$\Delta\varphi, \sigma_{\Delta\varphi}, f$	quadratic	$\hat{Q}(\Delta\varphi) = b_0 + b_1 \Delta\varphi + b_2 \sigma_{\Delta\varphi} + b_3 f + b_4 (\Delta\varphi)^2 + b_5 \left(\sigma_{\Delta\varphi}\right)^2 + b_6 \left(\sigma_{\Delta\varphi}\right)^2 + b_7 \Delta\varphi\sigma_{\Delta\varphi} + b_8 \Delta\varphi f + b_9 \Delta\varphi\sigma_f$

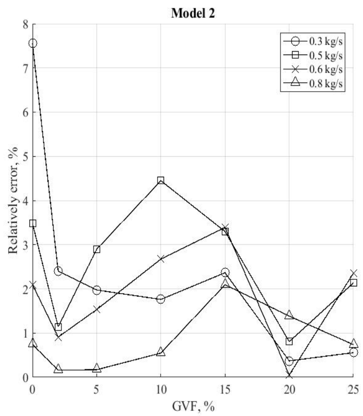


a)



b)

Fig. 4 –The relative error of the mass flowrate estimations by base models



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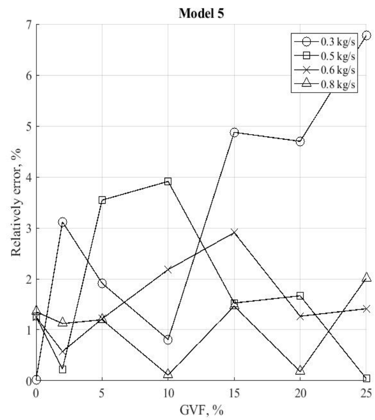

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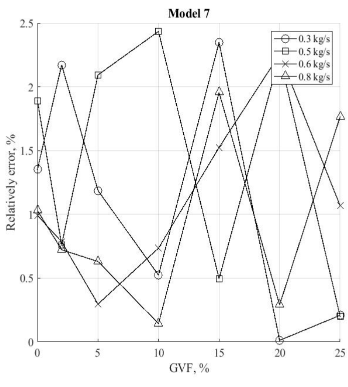
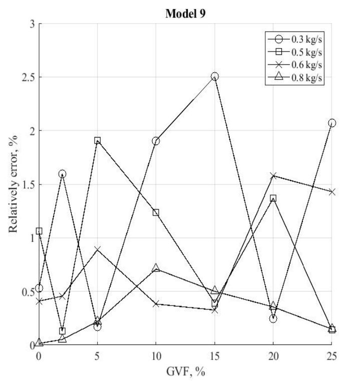


c)



d)

Fig. 5 – The relative error of the mass flowrate estimations by corrected models

Table 3. The comparison of different models of transducer CC

model	parameters	type	average δ_Q,%	maximum δ_Q,%	maximum δ_Q,% under GVF=0
0	$\Delta\varphi$	linear	3.1	8.8	8.8
1	$\Delta\varphi, GVF$	linear under known GVF	1.0	4.0	0.14
2	$\Delta\varphi, \sigma_{\Delta\varphi}$	linear	1.9	7.6	7.6
3	$\Delta\varphi, f$	linear	1.9	6.5	1.4
4	$\Delta\varphi, \sigma_f$	linear	2.2	7.0	2.9
5	$\Delta\varphi, \sigma_{\Delta\varphi}, f, \sigma_f$	linear	1.9	6.8	1.4
6	$\Delta\varphi, \sigma_{\Delta\varphi}$	quadratic	1.3	4.3	4.3
7	$\Delta\varphi, f$	quadratic	1.1	2.4	1.9
8	$\Delta\varphi, \sigma_f$	quadratic	1.5	3.7	2.9
9	$\Delta\varphi, \sigma_{\Delta\varphi}, f$	quadratic	0.8	2.5	1.1

relative error and the relative error under GVF = 0 (under a single-phase flow condition). Table 3 shows the comparison between models of the transducer CC.

5. Discussion

As has been shown in the article, statistical characteristics of the measurement signals represented the efficient instrument for decrease measurement errors in the Coriolis flowmeter under a two-phase flow condition. The measurement errors were decreased by using statistical characteristics. This method was realized by software of the flowmeter.

Different types of the transducer CC with several secondary parameters were considered in the paper. The standard deviation of phase difference, the standard deviation of the vibration frequency and the vibration frequency of flowtubes have were used as secondary parameters. As a result, we provided a comparison between the corrected models of the transducer CC. The quadratic models allowed to a two-fold decrease the relative error of the mass flowrate estimation. In future, we plan to increase the amount of experiments and take into account temperature factor, the flowmeter orientation and other.

It is worth noting, that usage of the statistical characteristics of measurement signals is required many independent counts of a measurement signal parameter. In the paper we used the digital zero-crossing method to estimate the signal parameters that allows to get only two counts of the phase difference and the frequency onto period. In future, we plan to use more faster algorithms to estimation signal parameters, such as the matrix pencil method [14].

6. Reference

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Acknowledgements

The work was conducted with the financial support of the Ministry of Education and Science of the Russian Federation of the Applied Scientific Research «Development of domestic mass Coriolis flow meter for oil and gas industry with the flow measurement function of multiphase flows». Agreement № 14.578.21.0191 from 03.10.2016. Unique identifier of the Applied Scientific Research is RFMEFI57816X0191.

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