Efficiency Criterion of CFD-modelling for Studying the Ultrasonic Flowmeters

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Annotation *– The paper presents a efficiency criterion of CFD-modelling for the research of ultrasonic flowmeters. He is a relative error of reproduction of mass flow rate in the i-th section 3D layout measuring pipeline. The authors investigated the influence of this criterion of effectiveness various options CFD-modelling.*

Key words – criterion of efficiency, CFD-modelling, flow rate, relative error, ultrasonic flowmeter, basic mesh, modification mesh.

I. The purpose of research

A powerful tool for the research of gas-dynamic phenomena in measuring pipelines (MPL) is a method of computational fluid dynamics (CFD-modelling). These methods, combined with experimental results allow to build perfect models of gas-dynamic processes in the areas of MPL complex configurations. Based on these models there is the opportunity to explore the MPL configuration and design of various flowmeters, including ultrasonic flowmeters (USM), which are not covered, fully by experimental studies [1, 4].

CFD-research can be divided into stages:

1. Preparatory stage: formed 3D layout area MPL, formulated the necessary physical condition, divide the layout into calculation areas (discretization), set initial and boundary conditions for solutions of systems of Navier-Stokes equations that describes the flow [2, 4].
2. Calculation stage: computer, using certain algorithms, numerically solves system of the Navier-Stokes equations for determining flow parameters (flow velocity, flow pressure, flow density, flow temperature).
3. Analysis stage: display solutions and their analysis.

In applying CFD-methods for the study of gas-dynamic phenomena in MPL, you must define criterion of efficiency [1]. In this paper, the authors proposed a criterion of efficiency (1), and investigated the influence on it of the following parameters of CFD-modelling:

– The level of initial basic mesh (s);
– The number of points in a single section layout (n);
– The place for selection of flow rate (l).

II. The essence of research

The preparatory stage of research by the authors is realized in CAD-software of SolidWorks. For this investigate the 3D layout of circular shape straight MPL was created (length $L = 1.2$ m; internal diameter $d = 0.1$ m; the roughness of the inner surface is zero; wall thickness $ds = 0.002$ m).

Calculation stage of research by the authors is realized in CFD-application CAD-software SolidWorks – Flow Simulations (environment – air; turbulence model – k-ε; mass flow in the inlet lid layout 0.1 kg/s; static pressure on the output lid layout 101325 Pa).

Stage analysis of research by the authors is realized in the software for numerical analysis MATLAB 7.9.0 (R2009b).

The criterion of efficiency relative error proposed of reproduction mass flow rate (δ_{qm}) in the i-th section 3D layout MPL on the results of CFD-modelling, which is calculated by the formula

$$\delta_{qm}(i) = \frac{qm_{CFD}(i) - qm}{qm} \cdot 100\,, \qquad (1)$$

where qm – mass flow rate specified on the calculated stage CFD-research; $qm_{CFD}(i)$ – mass flow rate in the i-th section 3D layout MPL calculated on the results of CFD-modelling flow rate in accordance with the formula means or method of measurement. In this paper, for reproduction $qm_{CFD}(i)$ applied the so-called generalized formula velocity mass flow [3] is working on USM

$$qm_{CFD}(i) = \frac{\pi d^2}{4} \cdot \frac{\sum_{j=1}^{n} v(j)}{n} \cdot \frac{\sum_{j=1}^{n} \rho(j)}{n}\,, \qquad (2)$$

where $v(j)$, $\rho(j)$ – flow velocity and flow density in the j-th point of i-th section 3D layout MPL; n – the number of points of i-th section 3D layout MPL.

CFD-research conducted on a computer with the following characteristics: CPU (Intel (R) Core (TM) i5-2450M CPU, 2.50 GHz, 2 active cores, four logical processors); memory (DDR3, 6.0 GB); video-system (Intel HD Graphics 3000 (GT2 +), 2108 MB).

III. Research results

The level of initial basic mesh

In CFD-application Flow Simulations there is a parameter called *level of initial basic mesh* (s), which has a range of values from 1 to 8 [2, 4]. This parameter determines the size of the elementary cell base calculation mesh. The higher s, the denser is base calculated mesh (with smaller cells), allowing better take into account the peculiarities of geometry a 3D layout and thus accurately reproduce the flow rate. Of course that the increase of s requires more memory and CPU time on a computer where the CFD-modelling is going. Therefore, it is particularly important to determine the minimally sufficient value s. To investigate the s selected its three values: 5 (according to [4] considered minimally sufficient), 6 and 7.

The number of points in a single section layout

In CFD-application Flow Simulations there is an option *Point Parameters* to reflect the results of calculation of flow parameters in the points section. This work investigates the case when the points section formed by crossing lines of the so-called modification mesh imposed on the section of a 3D layout [2, 4]. Number of points modification mesh can be adjusted in two ways:

1) by specifying their number (n);
2) setting the distance between the mesh lines (m).

This paper investigated second way. Selecting the distance between the modification mesh lines by default, this mesh is similar to the basic mesh a 3D layout calculation in this section. If you set the distance between the lines of excellent standard (default), the flow parameter values at points such modification mesh will be determined as:

1) flow parameter calculated by program (if the same is the location coordinates of points of the basic mesh and modification mesh);

2) flow parameter approximated by program (when the modification mesh points do not coincide with a base mesh points).

In the last case, to determine the approximated flow parameters at the point of modification mesh, the values of its neighbouring points of base mesh were selected. For this investigation, three values of *m* were selected: 0.01 m (corresponds to the default value m_0), 0.005 m and 0.001 m. Results of the research parameters *s* and *m* (at $l = 0.6$ m) are shown in Table 1 and shown on Figure 1.

TABLE 1

RESEARCH RESULTS (#1)

s	τ – [min.]	*m* – [m]	*n*	δ_{qm} – [%]
5	01:41	0.01	82	-4.21
		0.005	157	-3.50
		0.001	279	-2.81
6	05:31	0.01	82	-2.46
		0.005	157	-1.67
		0.001	279	-1.25
7	32:00	0.01	82	-1.99
		0.005	157	-0.96
		0.001	279	-0.57

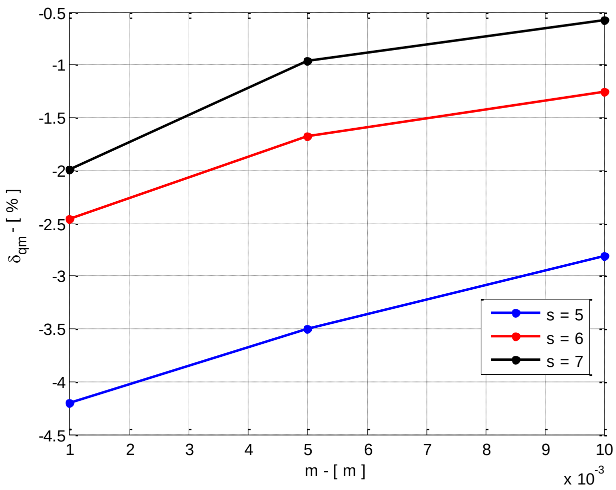

Fig. 1. Dependence of error δ_{qm} from parameters *s* and *m*

As can be seen from Fig.2 the minimum value of the error δ_{qm} achieved with maximum of the selected values level of initial basic mesh ($s = 7$) and the minimum distance between the mesh lines ($m = 0.001$ m).

However, increasing the parameter *s* from 6 to 7 increased the calculation time τ on 26.5 min., compared with 4 min. when increasing value *s* from 5 to 6 (see Table 1). Also, Table 1 shows that changing the value of *m* does not influence the time τ.

The place selection flow rate

According to [3] mass flow rate in the MPL section should be the same along the entire length of the pipeline. For confirmation of this axiom in CFD-application three sections of 3D layout MPL located at a distance *l* from the start were selected: 0.1 m (top a layout); 0.6 m (middle a layout); 1.0 m (end a layout). Results of the research are presented in Table 2.

TABLE 2

RESEARCH RESULTS (#2)

M – [m]	s	*l* – [m]	δ_{qm} – [%]
0.001	5	0.1	-2.83
		0.6	-2.81
		1.0	-2.91

As can be seen from Table 2, place selection flow rate *l* does not affect largely on the value of the criterion of efficiency δ_{qm} (maximum absolute deviation error is 0.1 %). This means that the place of selection flow rate (the location of the inlet cross-sectional of the USM) on a straight section of MPL does not influence the reproduction of mass flow rate by means of CFD-modelling.

Conclusion

The results of the research can highlight the following conclusions:

1) relative error of reproduction of mass flow rate in the *i*-th section of 3D layout (δ_{qm}) is offered as a criterion of efficiency of CFD-methods for research of gas-dynamic phenomena;

2) the most important parameters which influence the criterion of efficiency is the level of initial basic mesh (recommended condition $s \geq 6$) and the distance between the modification mesh lines in section a 3D layout MPL (recommended condition $m \leq m_0$);

3) to reduce δ_{qm} at $s = \text{const}$ is necessary to reduce the value of *m* at least 10 times from m_0;

4) the place selection of the inlet section of USM (on a straight section of MPL) does not affect the value δ_{qm}.

References

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