COMMON PROBLEMS OF AUTOMOBILE TRANSPORT

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INFLUENCE OF THE MEASURING TOOLS ON THE FLOW CHARACTERISTICS IN VORTEX CHAMBER PUMP

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Abstract. Problem. *Perturbation of the flow by measuring instruments forces researchers to choose optical research methods. But these methods significantly increase the cost of experimental research, due to the high cost of optical-type measuring equipment. On the other hand, using contact methods for measuring the flow velocity, such as Pitot tubes, hot-wire anemometers, the researcher must be sure that the measurement results can really be compared with the calculations results and the equipment influence on the flow parameters is minimal.* ***The aim*** *of this work is to study the measuring tool influence on the flow characteristics in the swirl chamber pump, as well as to compare the results obtained due to the measurements with the parameters of the undisturbed flow. The research* ***methodology*** *consisted of two stages: 1) modeling the flow in the model pump; 2) comparison of flow characteristics, as well as the values of velocity and pressure at the points of installation of the measuring tool.* ***Results.*** *Although the total velocity at the measuring point is practically independent of the measuring tool, the tangential component of the velocity is significantly reduced. It indicates that there is a significant error in velocity measuring. For a more accurate rotational velocity component measurement, it is necessary to orient the instrument perpendicular to the measured component.* ***Scientific novelty.*** *Installing the measuring tool in the end cover of the swirl chamber reduces the flow rate sucked by the pump through the lower axial channel. The size of the tool has practically no effect on the energy characteristics of the swirl chamber pump.* ***Practical value.*** *To ensure measurement accuracy, the ratio of the swirl chamber dimensions and the tool should be ensured in the way that the relative diameter of the tool does not exceed 0.25 of the swirl chamber neck diameter.*

Key words*: swirl chamber pump, velocity measurement, instrument, numerical simulation, flow patterns.*

Introduction

Today, aerohydromechanics is developing in three main directions: theoretical, experimental and computational. Each of the three directions has its own characteristics and is used by almost all researchers in solving any problems of fluid dynamics [1]. Often, all three directions are closely intertwined due to the need for experimental verification of both theoretical and computational results. However, during experimental research, the problem often arises of the influence of measuring equipment on the object of measurement, in particular, on the flow of liquid or gas in closed or open spaces [2].

Perturbation of the flow by measuring instruments forces researchers to choose optical research methods [3]. But, these methods significantly increase the cost of experimental research, due to the high cost of optical-type measuring equipment. On the other hand, using contact methods for measuring the flow velocity, such as Pitot tubes, hot-wire anemometers, the researcher must be sure that the measurement results can really be compared with the calculated results and the influence of the equipment on the flow parameters is minimal.

Analysis of publications

A fairly large number of papers are devoted to the study of the techniques of the aerohydromechanical experiments [3–6]. Typically, these techniques do not take into account the influence of the instrument, considering it insignificant, or such that distortion cannot be avoided. On the other hand, it is obvious that the influence of the tool depends on the nature of the fluid flow. In rectilinear flows, the problem of flow around cylindrical and spherical bodies was solved in many papers [7–9] numerically, analytically and experimentally. Researchers concluded about a significant possible impact of the tool on the flow kinematic characteristics. However, the influence of the measuring equipment on the integral characteristics, such as pressure loss can be quite easily calculated based on the determination of the loss coefficient at local resistances [10].

Energy losses, as well as the flow around cylinders in curvilinear flows similar to flows in vortex chamber pumps [11], are devoted to an extremely small number of studies. Vortex chamber pumps (VCP) are pumps in which the working process is implemented on the basis of a combination of the centrifugal and direct-flow jet pumps working processes [12]. Jet pumps have low pumping energy efficiency, which prompts the search for ways to improve the efficiency of jet technology [13] by looking for possible combinations of working processes and the use of centrifugal force [14].

The hydrodynamic patterns of flow in VCP research is an urgent problem due to the fact that VCP has higher indicators of the efficiency of pumping bulk materials in comparison with direct-flow jet pumps [15] and significantly higher indicators of reliability and durability in comparison with centrifugal pumps [16].

Purpose and objective

The aim of this work is to study the measuring tool influence on the flow characteristics in the vortex chamber pump, as well as to compare the results obtained as a result of measurements with the parameters of the undisturbed flow. Predicting a possible experimental error will make it possible to correctly select the vortex chamber size of the pump for experimental studies.

Influence of the velocity measuring instrument on the vortex chamber pump performance

VCP belongs to the jet-type pumps and has all the main advantages of jet technology: high reliability and durability, the ability to pump almost any mediums. The increased pump efficiency, in comparison with direct-flow jet pumps, is realized through the use of centrifugal force. Thus, the positive properties of centrifugal and jet pumps are used. The use of centrifugal force leads to the creation of a vacuum near the rotation axis of the flow in the vortex chamber and an increased gauge pressure at the periphery of the chamber.

Generally speaking, there are two different designs of VCP, realizing two different working processes: the discharge of the medium through the axial drainage channel and the suction of the pumped flows through the two axial channels. In this paper, a VCP with a second working process is considered. Although, the features of the measuring tool influence on the flow in the VCP are expected to be approximately the same. It is assumed that the conclusions drawn regarding the size ratio of the measuring tool and the vortex chamber size or axial channel sizes will not depend on what kind of work process is implemented by the VCP. The design features and characteristics of the pump can be found in [11, 12, 14–17].

The research methodology consisted of two stages: 1) modeling the flow in the model pump; 2) comparison of flow characteristics, as well as values of velocity and pressure at the points of installation of the measuring tool.

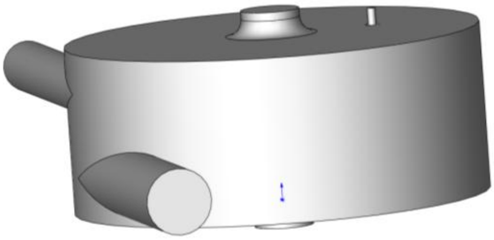
Mathematical modeling of the flow is based on CFD (computational fluid dynamics) simulations. The mathematical model consisted of the Reynolds-averaged Navier-Stokes (RANS) equations, the continuity equation and the SST (Shear Stress Transport) turbulence equations. The mathematical model is not presented in this paper, but it can be found in [11, 16, 18]. Errors in determining the vacuum arising near the axis of rotation are minimized by applying a correction of streamline curvature and system rotation [18–20].

To calculate the mathematical model, the OpenFoam software package was used [21].

The verification of the software package, the mathematical model of the flow in the VCP, was carried out in [11, 16] based on a comparison of the simulation results with experimental data.

The calculations were carried out in stationary and non-stationary formulations. The Courant-Friedrichs-Levy number was set at no more than 0.5. The method of control volumes and PISO-algorithm (Pressure Implicit with Splitting of Operators) and numerical schemes of the second order were used. The calculation ended when the residuals of the equations reached the values 10^{-5}. The second necessary condition for the completion of the calculation is the constancy of the flow rate over iterations or over time. The criterion for the constancy of the flow rate was chosen as 1 %.

The mesh was used unstructured, built on the basis of tetragonal and prismatic elements near solid walls. Determination of the minimum sufficient grid was carried out on the basis of comparing the results with four different grids: 1, 3, 6 and 12 million elements. Since the integral calculation results on grids starting with 3 million elements differed by no more than 1 %, it was decided to use grids with 3 million elements for all calculations. The value y^+ was controlled not exceeding 4 [22].



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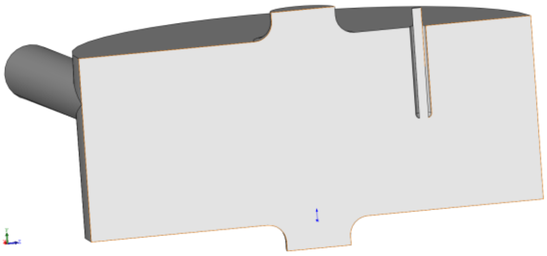

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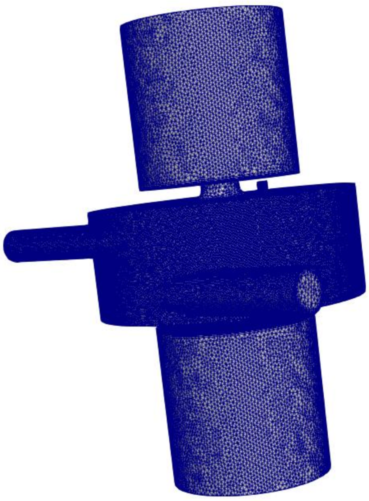

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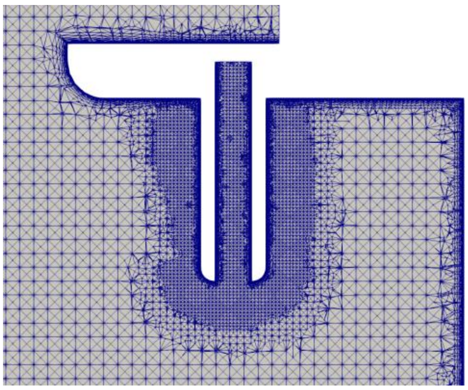


d

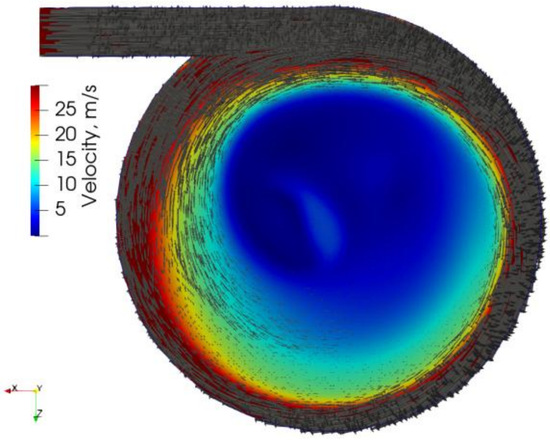
Fig. 1. Calculated solid (a, b) and grid (c, d) models

Boundary conditions: inlet channel – total pressure; two axial channels – open boundary with zero relative static pressure; outlet channel – zero relative static pressure; solid walls – no slip wall; an inlet channel simulating a measuring tool is an open boundary with an average static pressure equal to the pressure inside the vortex chamber, which was selected during the calculation. The fluid is water with a density of 997 kg/m^3.

Fig. 1 shows the design scheme of the VCP in the form of a solid model for calculations, as well as the mesh and features of mesh refinement near the introduction of the measuring tool in the end cover of the pump.

The measuring tool was installed in the meridional plane in the hole in the end cover of the pump at a distance of half the radius of the vortex chamber. The influence of the tool relative size on characteristics, flow patterns and values of velocity and pressure at the measurement point was investigated. The tool diameter was related to the diameter of the vortex chamber throat.

The turbulence intensity is set at 5 %, according to [23]. The value of the total inlet pressure was set so as to guarantee turbulent flow regimes with Reynolds numbers in the range $\mathrm{Re} = 10^3..10^7$.



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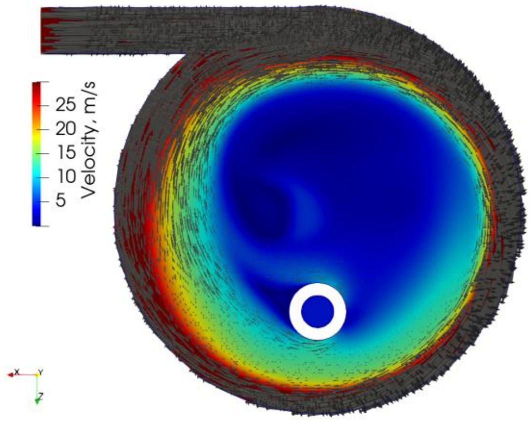


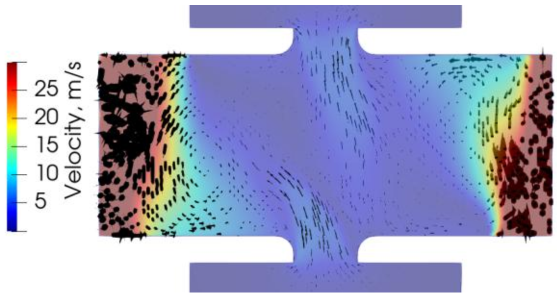
b

Fig. 2. Velocity distribution in the horizontal plane, drawn at a distance of 0.5 of the vortex chamber throat diameter: a – without tools; b – with tool $\bar{d} = 1.0$

Investigated relative instrument sizes: $\bar{d} = 1.0;\ 0.75;\ 0.5;\ 0.25;\ 0.125$. Obviously, the largest of the considered tool sizes will have the greatest impact on performance indices of the pump. Therefore, Fig. 2-4 show a comparison of flow patterns in a pump with and without a tool in different planes.

The distribution of velocities in the vortex chamber is typical for the flow around a circular cylinder (Fig. 2b).

The installation of the measuring tool in the end cover of the vortex chamber leads to a decrease in the flow rate sucked by the pump through the lower axial channel (Fig. 3b). In addition, vortex crushing is noticeable at the top end cap, which leads to a slight decrease in a vacuum near the axis.



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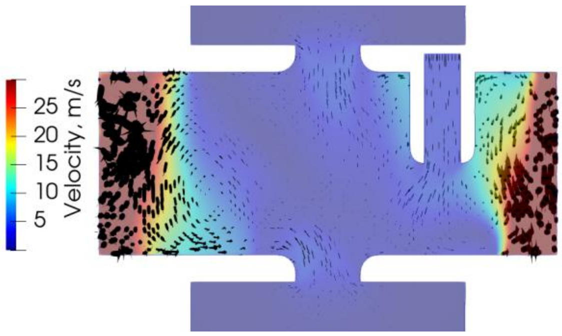

b

Fig. 3. Velocity distribution in the meridian plane: a – without tools; b – with tool $\bar{d} = 1.0$

Fig. 4 shows the change in the main energy parameters of the pump depending on the relative diameter of the measuring tool. In addition, the measured velocity and pressure values were plotted on the graph. It can be seen that almost all indicators remain unchanged, and a decrease in pressure is observed at the measurement point of the order of 10 %. Analyzing the graph, one can conclude that the size of the instrument has practically no effect on the energy characteristics of the VCP. To ensure the measurement accuracy, the ratio of the vortex chamber dimensions and the tool should be ensured so that the relative diameter of the tool does not exceed 0.25 of the vortex chamber throat diameter.

The VCP operation parameters shown in fig. 4: $\bar{V}$ is the relative velocity at the point of measurement; $\bar{p}$ is the relative pressure at the point of measurement; $\bar{\eta}$ is the relative efficiency of the pump; $\left(\overline{Q_{in} / Q_s}\right)$ is the relative coefficient of flow (ejection) of the pump [24]. All parameters are referred to the parameters of the pump without a measuring tool.

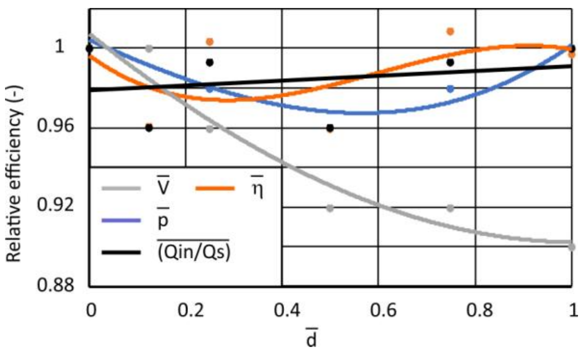

Fig. 4. Dependence of VCP performance indicators on the relative size of the measuring tool

The only parameter influenced by the measuring tool is the tangential velocity component at the measuring point. Obviously, this is due to the fact that fluid in the measuring channel does not have time to reach the tangential velocity of the main liquid in the vortex chamber. The values of the relative tangential velocity component are summarized in table 1.

Table 1 – The relative tangential velocity component at the measurement point

$\bar{d}$	0.125	0.25	0.5	0.75	1.0
$\bar{V}_\tau$	0.24	0.24	0.24	0.16	0.16

Analyzing fig. 4 and table 1 it can be seen that, although the velocity at the measuring point is practically independent of the measuring tool, the tangential component of the velocity is significantly reduced. This indicates that there is a significant error in measuring the velocity. For a more accurate measurement of the tangential velocity component, it is necessary to orient the instrument perpendicular to the measured component.

Conclusion

On the basis of numerical simulation of the flow in a vortex chamber pump, the measuring tool influence on the flow characteristics was investigated, and the results were compared with the results of the undisturbed flow parameters measurements.

1. The distribution of velocities in the vortex chamber is typical for the flow around a circular cylinder.

2. The installation of the measuring tool in the end cover of the vortex chamber leads to a decrease in the flow rate sucked by the pump through the lower axial channel.

3. The size of the instrument has practically no effect on the energy characteristics of the VCP. To ensure the measurement accuracy, the ratio of the vortex chamber dimensions and the tool should be ensured so that the relative diameter of the tool does not exceed 0.25 of the vortex chamber throat diameter.

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Вплив вимірювального інструменту на характеристики течії у вихорокамерному насосі

Анотація. Проблема. *Збудження потоку вимірювальними приладами стає причиною того, що вчені вибирають оптичні методи дослідження. Але ці методи значно збільшують вартість експериментальних досліджень внаслідок високої вартості вимірювальної апаратури оптичного типу. З іншого боку, використовуючи контактні способи вимірювання швидкості потоку, зокрема трубки Піто, термоанемометри, дослідник повинен бути впевнений в тому, що результати вимірювання дійсно можна порівнювати з результатами розрахунків і вплив апаратури на параметри течії є мінімальним.* ***Метою*** *роботи є дослідження впливу вимірювального інструменту на характеристики течії в вихорокамерних насосах, а також порівняння результатів, які були отримані під час вимірів, з параметрами незбуреного потоку.* ***Методологія*** *досліджень складалася з двох етапів: 1) моделювання течії в модельному насосі; 2) порівняння характеристик течії, а також значень швидкості та тиску в точках встановлення вимірювального інструменту.* ***Результати.*** *Незважаючи на те, що повна швидкість у точці вимірювання практично не залежить від вимірювального інструменту, обертальна компонента швидкості значно знижується. Отже, наявна суттєва похибка вимірювання швидкості. Для більш точного вимірювання обертальної компоненти швидкості необхідно орієнтувати інструмент перпендикулярно вимірюваній компоненті.* ***Наукова новизна.*** *Встановлення вимірювального інструменту в торцевій кришці вихрової камери призводить до зменшення витрати, що всмоктується насосом крізь нижній осьовий канал. Розмір інструменту майже не впливає на енергетичні характеристики вихорокамерних насосів.* ***Практична цінність.*** *Для забезпечення точності вимірювання необхідно забезпечити співвідношення розмірів вихрової камери та інструменту в такий спосіб, щоб відносний діаметр інструменту не перевищував 0,25 діаметра горла вихрової камери.*

Ключові слова: *вихорокамерний насос, вимірювання швидкості, інструмент, чисельне моделювання.*

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