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COMPARATIVE ANALYSIS OF PERFORMANCE CHARACTERISTICS OF JET VORTEX TYPE SUPERCHAGES

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Abstract. *On the basis of mathematical modeling there was carried out a comparative analysis of characteristics of jet vortex type superchargers. Dependences of the energy performance of vortex ejector on the geometry parameters and the largest values in terms of efficiency as well as the coefficient of ejection are analyzed. There were built combined characteristics of vortex chamber pumps and vortex ejectors. Vortex chamber pump has advantage pressure in an exit channel over the vortex ejector, consequently there is a more effective power transmission from a working medium, besides the withdrawal of pumping medium in a tangential channel allows to avoid energy losses owing to rotation of a stream in an exit channel.*

Key words: *vortex ejector, comparative analysis, vortex chamber pump, numerical calculation, energy performance.*

СРАВНИТЕЛЬНЫЙ АНАЛИЗ РАБОЧИХ ХАРАКТЕРИСТИК СТРУЙНЫХ НАГНЕТАТЕЛЕЙ ВИХРЕВОГО ТИПА

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Аннотация. *На основе математического моделирования проведен сравнительный анализ характеристик струйных нагнетателей вихревого типа. Проанализированы зависимости энергетических показателей вихревых эжекторов от геометрических параметров и найдены максимумы по КПД и коэффициенту эжекции. Построены совмещенные характеристики вихрекамерных насосов и вихревых эжекторов.*

Ключевые слова: *вихревой эжектор, сравнительный анализ, вихрекамерный насос, численный расчет, энергетические показатели.*

ПОРІВНЯЛЬНИЙ АНАЛІЗ РОБОЧИХ ХАРАКТЕРИСТИК СТРУМИННИХ НАГНІТАЧІВ ВИХРОВОГО ТИПУ

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Анотація. *На основі математичного моделювання проведено порівняльний аналіз характеристик струминних нагнітачів вихрового типу. Проаналізовано залежності енергетичних показників вихрових ежекторів від геометричних параметрів і знайдено максимуми за ККД і коефіцієнтом ежекції. Побудовано сполучені характеристики вихрекамерних насосів і вихрових ежекторів.*

Ключові слова: *вихровий ежектор, порівняльний аналіз, вихрекамерний насос, чисельний розрахунок, енергетичні показники.*

Introduction

The present level of energy and technology development makes high demands on the quality of occurring in them energy, heat and mass transfer processes. In many industries: food, metallurgical, power, agriculture and transport there exists a problem of increasing the efficiency of energy conversion processes, especially in compliance with the conditions of efficiency, compactness and reliability. To meet many of the above requirements, there can be used gas and liquid energy-exchange systems that are based on the jet technology [1–4], which have high levels of reliability and durability. And the use of swirling flow properties - vacuum in the axial and overpressure zone at the periphery of the stream [1, 5, 6, 7], it enables to create compact systems. Use of jet pumps and ejectors in automotive and tractor industry takes place in a variety of vehicle systems such as the fuel system (additional pump which is used when the bottom of the fuel tank is divided into two chambers); reduction of the aerodynamic drag when the vehicle is moving due to the suction of the air flow by means of ejectors; exhaust devices of internal combustion engines and diesel engines in which vortex ejectors are used.

The swirling ejector having a small size and simple design became popular in the above mentioned kinds of industry, however, in spite of the accumulated theoretical and experimental data on its work [1, 5, 6, 7–11], at the moment there are issues that need further research. In addition, vortex-type ejectors have a low efficiency coefficient that does not exceed 10% [1, 7, 9].

Thus, improvement of energy characteristics of jet supercharges is an important task, the solution of which may be the search of more effective principles of energy transfer and appropriate technical solutions in the design of jet pumps, which are the developed and investigated in operation of vortex chamber pumps, in which they do not only use the effect of reducing the pressure in the axial zone (as in vortex ejectors), but excess pressure at the swirling flow periphery [10, 11].

Content Analysis

Research results of vortex chamber pumps characteristics given in works [10, 11] showed that their efficiency can be higher than that of vortex ejectors. However, the poorly understood pressure distribution along the axial region of the vortex ejector, the lack of adequate computational models [1, 5–7, 9] requires, first of all, comparing the characteristics of jet pumps of vortex type with each other, the original design of vortex ejector with optimal parameters by methods described in works [1, 7]. Further, in publications [1, 5–7, 9] there is practically no information regarding the dependency of the vortex ejector efficiency on its geometrical dimensions. According to the research conducted in works [4, 6, 12, 13], to use the equal comparison conditions, calculations can be performed, applying the same software package with the use of numerical simulations based on the calculation of Navier-Stokes equations, averaged according to Reynolds, closed by the $k-\omega$ turbulence model

Goal setting

The aim of the work is comparative analysis of characteristics of jet supercharges of vortex type, using numerical simulations based on solving the equations of Navier-Stokes averaged by Reynolds method and closed, using the Menter turbulence model

Comparison of jet supercharges of vortex type

Comparative analysis of jet supercharges was carried out by conducting a numerical experiment based on solution of the Navier-Stokes equations, averaged according the Reynolds method for an incompressible fluid, obtained using the generalized Boussinesq hypothesis, linking the Reynolds stress with the averaged flow parameters [12–14]. Liquid is accepted to be non-compressible due to the fact that in many problems of pumping liquids by means of jet-macrotechnology the working pressure and speed are such that with reasonable accuracy the flow in them can be considered to be incompressible [3, 4, 14]. To close the mathematical model, the continuity equation is added to the equations of motion. To calculate the flow, there was adopted the Menter's modified two-layer SST «$k-\omega$» turbulence model of shear stress transfer, which takes into account the flow around solid walls and in the main stream, and provides satisfactory results for the calculation of wall-bounded flows [13, 14]. Mathematical modeling was carried out in the software package OpenFOAM (OpenCFD Ltd) with the following values of boundary conditions: on all boundaries of the calculation region there were adopted «rigid» boundary conditions on the solid wall – the condition of liquid sticking $\left.\overline{V}\right|_b = 0$, and in the inlet section of the power channel there was set a value of braking pressure $\left.p\right|_b = p_s$, in output channels equal-zero pressure $p|_b = 0$. When setting the boundary conditions of axial outputs and inputs in the swirl chamber there was taken into account the fact that in the swirling flow the pressure is distributed over the radius of the jet. Therefore, the computational area was increased and the boundary conditions of the output on the new boundary were set, where the pressure is substantially equal to zero and does not change along the radius [4, 14].

To provide the similar conditions, jet supercharges of vortex type were chosen with the same geometric parameters of the active flow nozzle and the outlet channel. Pump constructs were selected with optimal characteristics according to [1, 6, 7]. The same boundary conditions were used for carrying out comparative calculations.

The adequacy of the obtained solutions was tested in different ways, in particular on a qualitative level - comparison of the calculated flow patterns with the flow patterns obtained experimentally and quantitatively - by comparing the distribution of static pressure along the axis of vortex ejector carried out in work [6], which confirmed the use of SST «$k-\omega$» turbulence model to describe the current processes of limited swirling flows [6, 13–15].

For the first time a vortex ejector was created by a group of researchers led by M. Dubinskiy [9].

The vortex ejector (fig. 1) works as follows: the ejected flow through the ejector nozzle 2 penetrates into chamber 1, where it forms a rotating flow with the axial low pressure region.

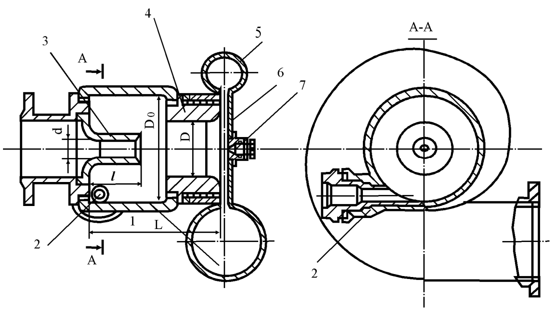

Fig. 1. Vortex ejector

The pumped flow is sucked into the given area through tube 3. The resulting in the chamber mixture through sleeve 4 is supplied into diffuser 6 and volute 5, where it slows down with the pressure increase. On the wall of the diffuser there is fixed control valve 7. The effluent volute stream is supplied into the process piping or released into the atmosphere (under vacuum closed volumes) [1, 5, 7, 9].

In the designs of vortex ejector examined by M. Besedin and I. Levichev [7] adiabatic efficiency reached 10 %, which is the biggest drawback of the given ejector designs.

The vortex chamber pump (fig. 2) operates as follows: the flow through the ejector nozzle 2 is supplied to chamber 1, where it forms a rotating flow with the axial low pressure region. The pumped flow is sucked into the given area through channels 4 and 5.

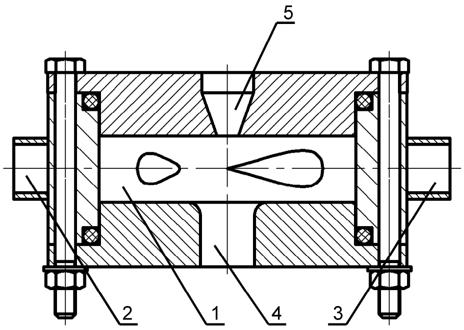

Fig. 2. Vortex chamber pump

The resulting in the chamber mixture through the tangential channel of outlet 3 is supplied to the outlet of the pump. The effluent from the pump flow is fed into the process pipeline or discharged into the atmosphere (under vacuum closed volumes) [10, 11, 15]. The main difference in the vortex ejector work and vortex chamber pump lies in the use of overpressure at the periphery of the swirling flow. Common for both pumps is the use of vacuum on the axis of the swirling flow in the short vortex chamber and sucking the pumped flow into it.

Calculation of the vortex ejector design with a spiral tap showed that the use of the spiral tap results in reducing the efficiency by 1.5 times due to the loss of output flow energy in the volute associated with flow swirling, and its separation from the walls, as confirmed by research conducted in works [6, 7]. Thus, to further compare the characteristics of vortex ejector pumps, there was adopted a design without using spiral diverting with liquid retraction immediately after the slot diffuser.

In fig. 3. There are shown the results of research on the influence of the nozzle diameter of the passive vortex ejector flow ($\overline{d}_{in} = d_{in} / D$ where D - the diameter of the vortex chamber) on the relative efficiency ($\overline{\eta} = \eta / \eta_{max}$; $\eta_{max} = \eta\big|_{\overline{d}_{in}=0,2}$), the ejection rate ($\overline{Q}_{in} = Q_{in} / Q_s$, where Q_{in} – volume consumption of the pumped medium; Q_s – volume consumption of the active medium) and vacuum ratio ($\overline{p}_{vac} = p_{vac} / p_R$, where p_{vac} – the vacuum pressure on the axis of the vortex chamber, p_R – pressure on the periphery of the vortex chamber).

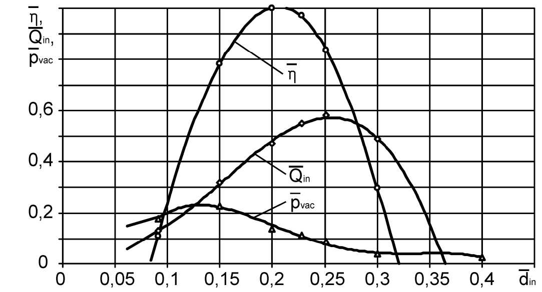

Fig. 3. The impact of the relative diameter of the vortex ejector passive flow nozzle on the efficiency, the ejection rate and vacuum on the chamber axis

Efficiency dependences, coefficient of both ejection and vacuum on the vortex ejector chamber axis (fig. 3) have the following maxima: efficiency maximum is reached at $\overline{d}_{in} = 0,2$, the maximum rate of ejection – $\overline{d}_{in} = 0,25$, the maximum of vacuum pressure on the vortex chamber axis – $\overline{d}_{in} = 0,13$, which is agrees with the data given in works [1, 6, 7], but in these studies , unfortunately, efficiency dependences are not given.

As it follows from fig. 4 the vortex chamber pump has high pressure in the outlet (pressure at the periphery of the vortex chamber) in comparison with the vortex ejector (pressure at the vortex chamber axis), whereby it becomes more efficient to transfer the energy from the active flow, besides selection of the pumped medium in the tangential channel makes it possible to avoid the loss of energy due to the flow rotation in the outlet channel.

Thus, the vortex chamber pump has a high rate of efficiency. On the other hand, the vortex ejector, due to the creation of more vacuum on the chamber axis (fig. 4, b), creates higher vacuum in evacuated volumes, which allows its use, first of all, as an ejector vacuum suction pump.

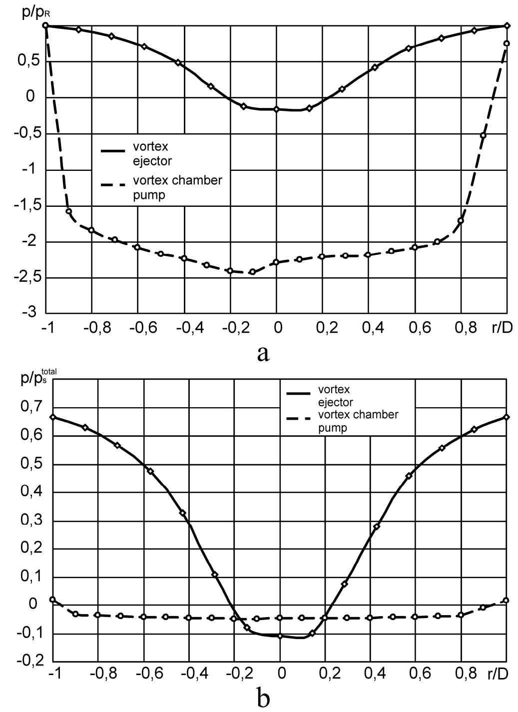

Fig. 4. Distribution of relative statistic pressure along the radius of the vortex chamber: a – pressure is related to the pressure on the periphery of the vortex chamber; b – pressure is related to the total pressure of the active stream in the nozzle channel

Fig. 5 shows combined characteristics of the vortex ejector and vortex-chamber pump.

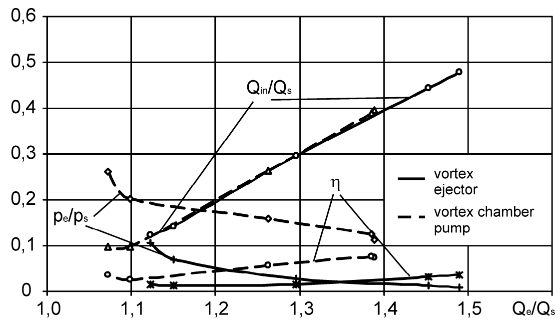

Fig. 5. Combined dimensionless characteristics of the vortex ejector and the vortex chamber pump

The above characteristics are built in a dimensionless form: the cost is attributed to the consumption of the ejection flow Q_s, the pressure – to the static pressure in the input nozzle of the ejection stream p_s. On the graph there is used the notation Q_e – the volumetric flow rate at the outlet of the pump; p_e – static pressure at the outlet of the pump.

Fig. 5 shows that at relative increase in pressure at the outlet of the pump, the energy characteristics of the pump reduce: efficiency and the amount of the pumped medium. Characteristics of the relative pressure at the outlet of the vortex ejector are below the similar characteristics of the vortex chamber pump, thereby the efficiency indexes of the vortex ejector performance also decrease.

Conclusions

On the basis of mathematical modeling there was carried out the comparative analysis of characteristics of the jet vortex type supercharges and it was revealed that the vortex chamber pumps have the efficiency, which is 2 times higher than that of the vortex ejectors.

Dependence of efficiency, the ejection rate and vacuum on the vortex ejector chamber axis have maxima: maximum efficiency is achieved at $\overline{d}_{in} = 0,2$, the maximum rate of ejection – $\overline{d}_{in} = 0,25$, the maximum of vacuum pressure on the vortex chamber axis – $\overline{d}_{in} = 0,13$.

The vortex chamber pump has high pressur in the outlet channel than the vortex ejector, whereby it becomes more efficient to transfer the energy from the active flow, besides selecting the pumping medium in the tangential channel makes it possible to avoid energy losses due to the rotational flow in the outlet channel. Thus, the vortex chamber pump has a higher rate of efficiency. On the other hand, the vortex ejector due to the creation of higher vacuum on the chamber axis creates higher vacuum in the evacuated volumes, which allows its use, first of all, as an ejector vacuum suction pump.

There were built combined characteristics of the vortex type jet supercharges, from which it follows that an increase in the relative pressure at the outlet of the pump, the energy characteristics of the pump reduce: efficiency and the amount of the pumped medium. Characteristics of the relative pressure at the outlet of the vortex ejector are below the similar characteristics of the vortex chamber pump, thereby the efficiency performance of the vortex ejector decreases

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