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Features of a Working Process and Characteristics of Irrotational Centrifugal Pumps

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Abstract

The present study investigated the working process and characteristics of irrotational centrifugal pumps with the help of mathematical models of three-dimensional flows incompressible fluid on the basis of equations of the Reynolds and «$k-\omega$» turbulence model. The results of optimization geometrical parameters are presented. The ratio of geometrical parameters are established, which one meet to two different working processes of pumping over.

Keywords: Mathematical modelling; vortex chamber; rotation; geometrical parametrs; pump; optimization; characteristics; working process.

1. Introduction

Development of different industries (coal, chemical, heat power, agriculture, transport), extension of building, creation of favorable conditions for a highly productive works in many respects depend on an overall efficacy of systems destined for transportation of fluid mediums. Common for these systems the presence of pumps which are pumping over different mono and multiphase fluid mediums is the overall efficacy which one by an essential influences on a production efficiency. In the unfavorable operation conditions, at effect of the different negative factors of external environments such as: the impact stresses, vibration, chemical aggressiveness and heat of fluids, presence of abrasive fragments in pumped mediums operating characteristics of dynamic pumps are restricted or reduced (Bansal [2]). These effects result in

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rapid wear of mechanical parts and seals of pumps, and at pumping over of liquid-gas mixtures with the large contents of gas – to failure of operation parameters.

The possible solution of a problem can be in applying jet pumps in conditions lowering operation parameters of dynamic pumps.

The jet pumps have high indexes of reliability and longevity, are simple construction and can work practically on any structures and concentrations of hydraulic fluids. However, the jet pumps have a low efficiency which is not superior 30 % (Sokolov and Zinger [9], Klinzing et al. [5]).

Thus, the perfecting of power characteristics of ink-jet superchargers is an actual problem, the solution by which one is searching more effective principles of transfer of power and engineering solutions in constructing ink-jet superchargers for pumping over mono and multiphase mediums, which one are, the jet pumps, designed and investigated in this study, with vortex chamber called as us, irrotational centrifugal pumps (Syomin and Rogovyi [8, 12, 13, 14]).

The results of investigation of irrotational centrifugal pumps, presented by Syomin and Rogovyi [8, 12, 14], have shown, that transferable medium goes in the vortex chamber by gravity, and its part, by not having time to gain a kinetic energy from a worker stream, together with it goes in a axled (drain) channel, that results in losses of medium, transferred by the pump, which one make up to 15 %. At the same time, results of investigations of vortex adjusting organs and hydropneumatics units the using of centrifugal force field, presented by Khalatov, Avramenko and Shevchuk [4], Syomin [10, 11], Beck Jeffrey L. [3], have shown, that value and the sizes of vacuums area on an axis of the vortex chamber depend on a ratio of the geometrical sizes of input/output channels from the chamber. However influencing of the geometrical sizes of vortex chamber of irrotational centrifugal pumps on the sizes of area and value of vacuum are not studied yet.

Therefore, in the basis of the present investigation is set a problem of a determination of the pumps most rational geometrical sizes with the objective exception of losses expenditure transferable fluid mediums and maximization efficiency, and also definition features of a working process and characteristics of irrotational centrifugal pumps.

2. Results of researches

The irrotational centrifugal pump (Syomin and Rogovyi [8, 11]) works as follows (figure 1).

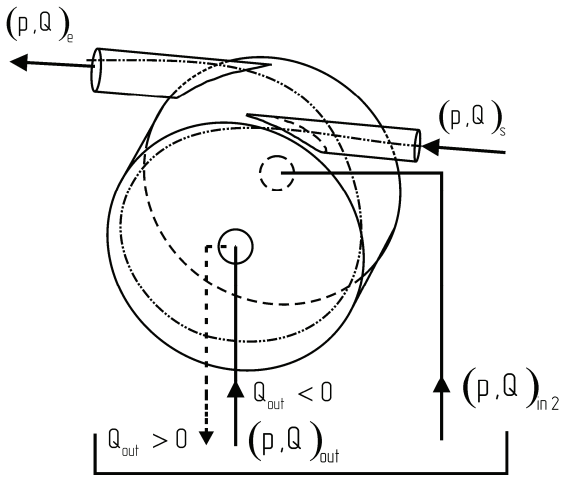


Fig. 1. The schematic diagram of the irrotational centrifugal pumps

The worker stream with volume flow Q_s and pressure p_s moves through a tangential channel of a supply into the vortex chamber and goes out it through an axial drain channel with volume flow Q_{out} and pressure p_{out}. The worker stream, by mixing up with a transferable stream with volume flow and pressure Q_{in} (Q_{in2} on figure 1) and p_{in} correspondingly, goes in a tangential channel of an exit with volume flow Q_e and pressure p_e. The main deficiency of the presented construction are the losses of transferable fluid mediums through an axial drain channel ($Q_{out} > 0$).

As have shown our trial experiments, change of a reciprocal ratio of the areas (or diameters) tangential channels of an supply and exit, and also axial channels of an input and exit (drain) can change of a working process of the pump and characteristics, and thus, to change of a function of a drainage channel as channel of drop of fluid medium, on a channel of a sucking of transferable fluid medium. Consequently, the irrotational centrifugal pump will work as follows (figure 1): the worker stream with volume flow Q_s and pressure p_s moves through a tangential channel of a going into vortex chamber and goes out it through a tangential channel of an exit. The worker stream, by mixing up with a transferable stream going through two axial channels of an input with volume flows Q_{in1} ($Q_{out} < 0$) and Q_{in2}, with pressure p_{in1} and p_{in2}, goes in a tangential channel of an exit with volume flow Q_e and pressure p_e.

Thus, it is possible to speak about change of a working process of pumping over by irrotational centrifugal pump. In both constructions the transfer of power by transferable medium is operation of a centrifugal force. However transfer mechanism of power from the worker stream to rotary core in the vortex chamber is various. In the first construction all worker stream goes out through a drain channel, accordingly to a principle of conservation of momentum. In the second construction all worker stream goes out in an exit channel, transferring rotation to a core by forces of turbulent friction, similarly to ejectors. It explains a variance in distribution of parameters on radius of the vortex chamber and difference in characteristics of irrotational centrifugal pump.

The geometrical sizes of irrotational centrifugal pumps can be presented by vector of dimensionless parameters:

$$\mathbf{\Phi} = [\overline{f}_s, \overline{f}_{e,}\ \overline{f}_{in}, \overline{f}_{out}, \overline{H}], \tag{1}$$

Here $\overline{f}$ – cross-sectional area of the channel related to the area of a channel of supply. The indexes s, e, in, out correspondingly indicate the areas of channels of supply, exit, axial channel of an input and axial channel of an output or drain channel; $\overline{H}$ – the relative height of the vortex chamber, is related to diameter of a orifice of the vortex chamber. Then for irrotational centrifugal pump with a drain channel we have a following set of parameters:

$$\mathbf{\Phi}_1 = [\overline{f}_s, \overline{f}_{e,}\ \overline{f}_{in}, \overline{f}_{out}, \overline{H}]_1, \tag{2}$$

if $Q_{out} > 0$, $\mathbf{\Phi} = \mathbf{\Phi}_1$ and $Q_{out} \approx (0{,}01 - 0{,}1) Q_{in}$.

For irrotational centrifugal pump without a drain channel:

$$\mathbf{\Phi}_2 = [\overline{f}_s, \overline{f}_{e,}\ \overline{f}_{in}, \overline{f}_{out}, \overline{H}]_2, \tag{3}$$

if $Q_{out} < 0$, $Q_{out} = -Q_{in1}$ and $\mathbf{\Phi} = \mathbf{\Phi}_2$.

For determination of rational geometrical parameters of pumps the numerical experiment was made on the basis of methods design of experiments by the solution Reynolds averaged Navier-Stokes (RANS) equations for incompressible fluid with usage of a generalized hypothesis Boussinesq model, linking Reynolds stresses with average parameters of a stream by Anderson, Tannehill and Pletcher [1]. The fluid is accepted incompressible because in many transportations tasks fluids streams, gases and loose mediums with the help macrofluidics of operating pressures and the speeds are those, that with adequate accuracy, it is possible to consider flows in them incompressible. For closure of a mathematical model the equation of continuity is added to equations of motion. For calculation accepted zonal two equation $k-\omega$ turbulence models for aerodynamic flows by Menter [6,7], which one considered for features of flow about solid walls and in an external stream, and have satisfactory results in restricted walls of streams. The mathematical modelling was computed in a complex OpenFOAM (OpenCFD Ltd) at following values of boundary conditions: on all boundaries of calculated area the boundary conditions are adopted «rigid»: on a solid wall – the condition of an adhesion of a fluid $\bar{V}\big|_b = 0$, and in an inflow face of a supply channel was set a value of stagnation pressure $p\big|_b = p_s$, in exit channels – equality to zero pressure $p\big|_b = 0$.

At the definition of boundary conditions of axial exits and inputs of the vortex chamber was accounted that in a swirling flow the pressure is distributed on radius of a jet. Calculated area therefore was increased and the boundary conditions of an exit on the new boundary preset, where the pressure practically is equal to zero and does not vary on radius (Syomin [10]).

At holding numerical experiment the factors were selected, which one can essentially influence pumping characteristics ($\bar{f}_{e,}$ $\bar{f}_{in}$). Other geometrical parameters of the pump did not vary, because their best values obtained by optimization of vortex chambers for vortex adjusting organs and hydropneumatics units the using of centrifugal force field, presented by Khalatov, Avramenko and Shevchuk [4], Syomin [10, 11]. With the help of the prior information about pumping characteristics the values of the factors were defined, at which one the outcomes, close to optimal are received. These points at the design of experiments were considered as a zero (basic) level – $\bar{f}_e = 1,8$, $\bar{f}_{in} = 4$. Thus, the variation of the factors was realized in following ranges: $\bar{f}_e = 0,4...5$, $\bar{f}_{in} = 1,18...6,62$. In result the designs of experiments matrix contained nine experimental points was obtained. The calculated distribution of relative static pressure along radius of the vortex chamber is shown in a figure 2 (nine curves correspond to nine points of a designs of experiments matrix (1 – $\bar{f}_e = 0,8$, $\bar{f}_{in} = 2$, 2 – [0,8; 6], 3 – [2,8; 2], 4 – [2,8; 6], 5 – [0,39; 4], 6 – [3,21; 4], 7 – [1,8; 1,18], 8 – [1,8; 6,82], 9 – [1,8; 4]).

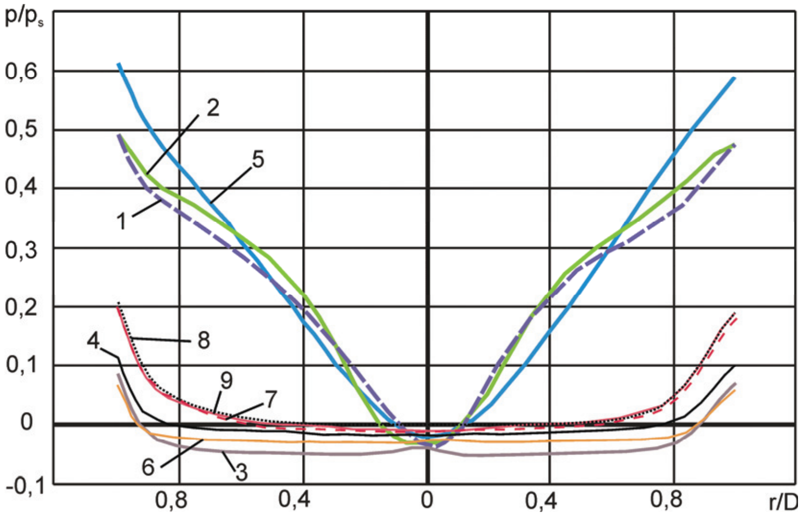
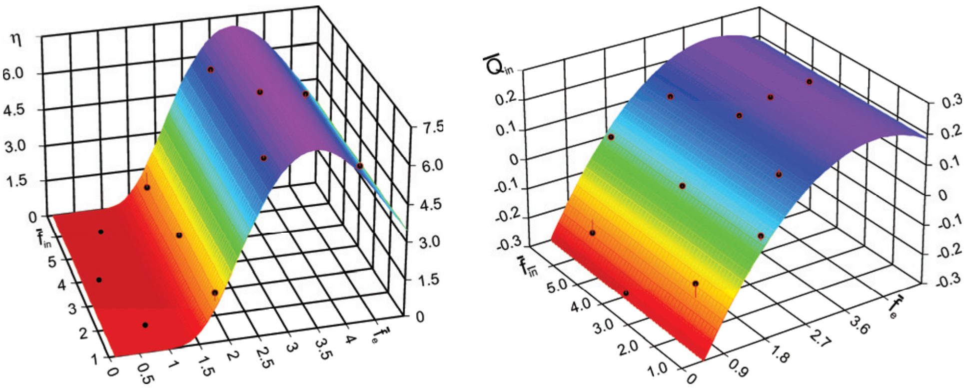


Fig. 2. Distribution of relative static pressure along radius of the vortex chamber (1,2,5 - Φ_1 , 3,4,6,7,8,9 - Φ_2)

The considerable pressure gradient and narrow area of vacuum in paraxial zone is characteristic for a construction Φ_1. The pressure gradient in the paraxial zone for a construction Φ_2 is that practically misses, and this zone is prolonged on rather large spacing interval from an axis.

Comparison of relative static pressures distributions along radius of the vortex chamber of both pumps constructions has shown, that in a construction Φ_2 peripheries pressure decreases approximately 4 times.

By results of numerical experiment the dependences efficiency and relative mass flow in a channel out $\overline{Q}_{in}$ from the varied factors (figure 3) were built.



a) b)

Fig. 3. Dependences efficiency (a) and relative mass flow in a channel out (b) from geometrical parameters of irrotational centrifugal pump

From a figure 3, it is visible, that the power pumping characteristics practically do not depend on the area of channels of a sucking (input) ($\overline{f}_{in}$) and it is possible to define a best value of geometrical parameters, at which one the maxima efficiency is reached: $\overline{f}_e = 3,72;$ $\overline{f}_{out} = 2,72$. Since $\overline{f}_e = 1,73$, the losses of transferable fluid medium in a drain channel fade, and there is a sucking of transferable fluid medium through both axial channels in end covers of the vortex chamber of the pump.

For an optimal construction of the pump the calculated way built a pumping characteristic, showed in a figure 4.

The experimental characteristic for a construction Φ_1 is published by Syomin and Rogovyi in [8, 13].

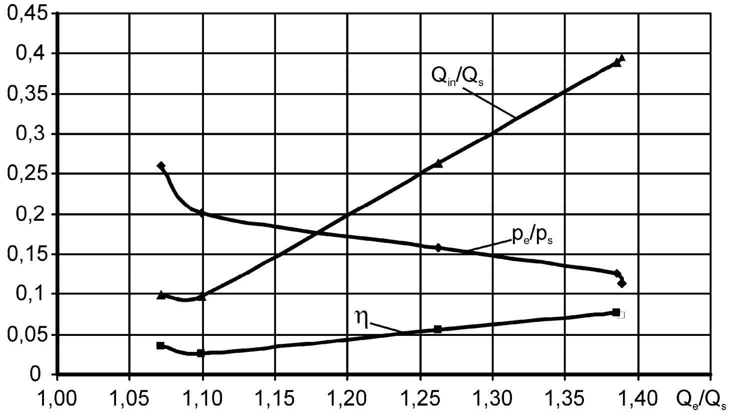


Fig. 4. Calculated characteristic of irrotational centrifugal pump of a construction Φ_2, with geometrical parameters $f_e = 3,72;\ f_{out} = 2,72$

From characteristic, showed in a figure 4, it is visible, that at increase of relative pressure $\overline{p}_e$, the power pumping curves are reduced: efficiency and mass flow of transferable fluid medium.

Conclusion

The geometrical ratio are defined, at which one two different operational modes of irrotational centrifugal pump are possible: with an ejection of fluid medium through a drain channel, and with a sucking. The mentioned working processes result in two different characteristics: first – with high pressure and low efficiency Φ_1, and second – with low pressure, but high efficiency Φ_2.

On the basis of methods design of numerical experiments on a mathematical model the optimization of geometrical parameters of the vortex chamber is investigated and the optimal ratio of the relative areas exit tangential $\overline{f}_e$ and input axial channels $\overline{f}_{in}$ for a maximum efficiency of irrotational centrifugal pump ($\overline{f}_e = 3,72;\ \overline{f}_{out} = 2,72$) are obtained.

Since $\overline{f}_e = 1,73$, the losses of transferable fluid medium in a drain channel fade, and there is a sucking of transferable fluid medium through both axial channels in end covers of the vortex chamber of the pump.

Comparison of relative static pressures distributions along radius of the vortex chamber of both pumps constructions has shown, that in a construction Φ_2 peripheries pressure decreases approximately 4 times.

The calculated way builds a pumping characteristic for a construction Φ_2, where it is visible, that at increase of relative pressure $\overline{p}_e$, the power pumping curves are reduced: efficiency and mass flow of transferable fluid medium.

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