TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2010, 10B, 232-240

POWER CHARACTERISTICS OF SUPERCHARGERS WITH VORTEX WORK CHAMBER

Dmitry Syomin, Andrey Rogovoy

Volodymyr Dal East-Ukrainian National University, Lugansk, Ukraine

Summary. The research results of a working process and power characteristics of new type superchargers that combine principles of power transmission centrifugal and jet pumps are presented. The methods of mathematical and physical simulation determined features of physicals weep processes happening in devices at their operation on single-phase and heterogeneous mediums. The mathematical simulation was made on the basis of numerical solutions Reynolds equations. The experimentally obtained operating brought to the universal characteristic.

Key words: fluidics, vortex chamber, power characteristics, efficiency, trajectory.

INTRODUCTION

In engineering processes coal, oil producing, chemical industries, agriculture, pipeline transportation, heat-and-power engineering etc. the pumping of different fluid mediums is realized by dynamic pumps. Efficiency work of this pumps effect on a production efficiency essentially. Thus, unfavorable external environments, such as the impulsive loads, vibration, chemical aggressiveness and heat of fluids, presence of abrasive fragments in pumped medium and enclosing environments, reduce or restrict service performances of dynamic pumps [Rogoviy 2007].

The jet pumps have high indexes of reliability and longevity, the values which one many times over exceeded by indexes of reliability and longevity dynamic pumps. Besides simplicity of a construction, capability of operation on leaky heterogeneous mediums with a different structure and density of phases are attached to them. However essential deficiency of jet pumps is the low efficiency which is not more then 30 %, and the accessible parameters of their operation on gases are restricted to features hypersonic flows [Sokolov 1989, Khalatov 1996].

The idea of joins advantage of superchargers that reviewed above brought to creation of a new type pumps - with vortex work chamber, called as vortex-fluid pumps (VFP) [Beck 1980].

RESEARCH OBJECT

The vortex-fluid pump (fig. 1) works as follows.

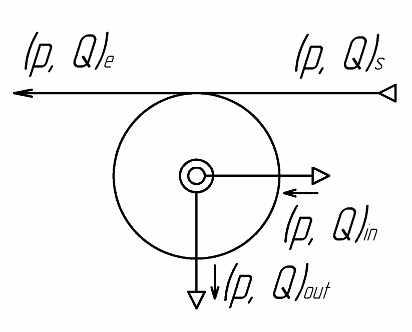

Fig. 1. The schematic diagram of the vortex-fluid pump

The worker stream with volume flow Q_s and pressure p_s moves through a tangential channel of supply into the vortex chamber, developing in it rotary motion, that accompanied by pressure suppression on a centerline of the chamber and a boost its peripherals. As a result of depression in paraxial region a sucking of pumped mediums with arguments Q_{in} and p_{in} in vortex work chamber is occurred. The part of a worker stream, being blended with pumped flow, goes into exit (pressure head) tangential channel, making a carrier flow with arguments (Q_e, p_e). The remaining floe goes out the camera through an axled (drain) channel with volume flow Q_{out} and pressure p_{out}.

Feature of a working process in VFP is that the power transmission to a displaced particle takes place in a area of an operation of centrifugal forces. Thus, the particles, that have density large, than density of working medium, are displaced to peripherals of the vortex chamber to the area with a smaller density - to an axis of rotation.

The principled capability of pump operation on mediums with a different aggregative state is presented in the table 1. The first under the order the working medium with density ρ_1 is indicate, second - pumped over medium by a density ρ_2.

The operation factors of the pump at a dropping liquid are restricted, through appearing on an axis of the chamber a gas vortex cord, which one reduces vacuum, and accordingly, decreases flow of pumped medium.

The cavitational conditions of the pump do not result in loss of its work capacity, and only decrease works operation factors.

Table 1. **Influencing of aggregative state and proportions of densities of working and displaced mediums on work capacity of the pump**

№	Type of working and pumped mediums	Capability of work	Notice
1	«Gas»-«Gas» ($\rho_1 < \rho_2$)	Yes	The arguments are restricted to features of hypersonic flows
2	«Gas»-«Gas» ($\rho_1 = \rho_2$)	Yes	Complication in determined of pumping characteristics
3	«Gas»-«Gas» ($\rho_1 > \rho_2$)	No	
4	«Gas»-«Liquid»	Yes	The arguments are restricted to features of hypersonic flows. Pumped over medium can be and working.
5	«Gas»-«Solid»	Yes	The arguments are restricted to features of hypersonic flows. The working medium – «Gas»
6	«Liquid»-«Gas»	No	
7	«Liquid»-«Liquid» ($\rho_1 < \rho_2$)	Yes	The presence of a rotational cord on a axis of the vortex chamber worsen characteristics.
8	«Liquid»-«Liquid» ($\rho_1 = \rho_2$)	Yes	Complication in determined of pumping characteristics
9	«Liquid»-«Liquid» ($\rho_1 > \rho_2$)	No	
10	«Liquid»-«Solid»	Yes	The presence of a rotational cord on a axis of the vortex chamber worsen characteristics. The working medium – «Liquid»
11	«Gas»-«Solid-Liquid»	Yes	The working medium – «Liquid»
12	«Liquid»-«Solid-Gas»	Yes	The presence of a rotational cord on a axis of the vortex chamber worsen characteristics. The working medium – «Liquid»

RESULTS OF RESEARCH

For determination of a physical flow pattern in the pump the mathematical simulation of three-dimensional turbulent flow was used on the basis of Reynolds equations for incompressible fluid [Patankar 1972]. For closure of a system Reynolds equations and equation of continuity the standard « $k-\varepsilon$ » model of turbulence is taken in which the turbulent viscosity is determined by a correlation of Kolmogorov-Prandtl. In a zone of a boundary layer (near to solid walls) special wall function for calculation of a turbulences kinetic energy and speed of its dissipation are used. For calculation of flow in VFP the following boundary conditions are formulated: on solid walls $\overline{V}\big|_b = 0$, in an inlet supply canal section stagnation pressure was preset $p\big|_b = p_s$, in a sucker and exit canal section pressure overpressure was taking up equality to zero $p\big|_b = 0$. After a determination of a field hydrodynamics parameters of flow the superposition method of motion of the insulated solid particle on calculated flow of fluid was used. The calculations are executed in program «FlowVision». The results of trajectory calculation of solid particle having density $\rho = 1400$ kg/m^3 in an air-medium, are displayed in a fig. 2.

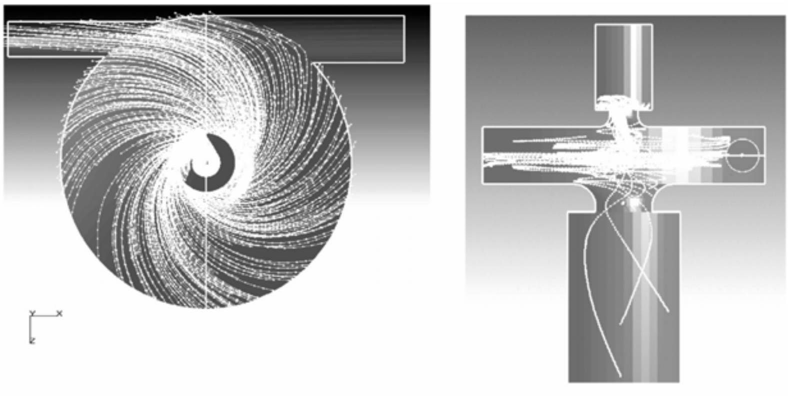

Fig. 2. Calculation of trajectory solid particle in the pump

It is well visible, that the majority of solid particles from the vortex chamber is passed to pressure channel, and the rest goes in a drain one. Thus, one part from them is gone in paraxial zone, as though «failing» from a sucker in drainage, and another - performs more composite path, being displaced in boundary layers on end walls of the vortex chamber. The flow patterns, obtained by a calculated way, in the pump well coincide by results of physical experiment [Rogoviy 2007].

The determined physical flow pattern in the vortex-fluid pump, allows to construct its simplified scheme (see fig.3), to explain the mechanism of losses of pumped medium and to reduce it in further to a minimum.

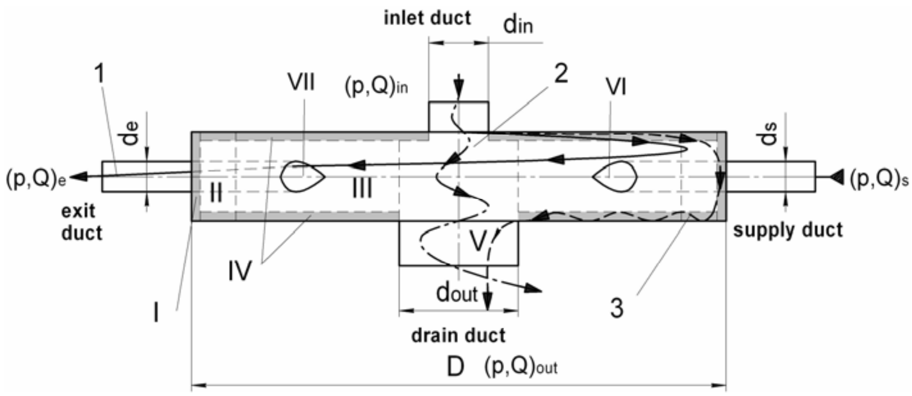

Fig. 3. The scheme of movement mediums in the vortex-fluid pump
1, 2, 3 – Possible trajectory solid particle ; I-VII - conditional zones of flow

The solid particles in the pump can be moved on three types of trajectory displayed in a fig. 3, and at trajectory 1 particles to get into output channel, and at trajectory 2 and 3 - in a drain channel.

Pumping characteristics and accessible operation factors

On the basis of the adopted scheme of flow in the vortex-fluid pump it is possible to execute an approximated estimation of accessible operation factors of work and to determinate its characteristics.

To main operation factors of the vortex-fluid pump (see fig. 3) treat: volum (mass) flow and pressure of interacting mediums in ducts of the pump (supply, sucker and drain), and efficiency η.

The pumping characteristics is under construction, by analogy with dynamic pumps, as dependence of volume flow of pumped over medium in an output channel from pressure in a channel of power supply. As a difference it is supplemented by similar dependences for volume flows in sucker and drain channel. At that, pressure in a sucker and a drain channels are supported by constants.

Dimensionless pumping characteristic receive from dimensional, by referring volume flows and pressures to similar arguments in an inlet fitting.

The accessible operation factors of the pump are determined on maximum ratings of volume flow and pressure in an exit of the pump, and also maximum efficiency. They can be defined from the following supposition. In a case, rated conditions of pump operation, at which one all volume flow of pumped medium Q_{in} falls in an exit pipe of the pump and is equals to volume flow Q_e, and all volume flow of an actuating medium Q_s goes in a drain channel and is equals to volume flow Q_{out}, then:

$$Q_e = Q_{in}; \qquad Q_s = Q_{out}. \tag{1}$$

The pressure on exit of the pump defined by proportions fair for vortex chambers [Syomin 2004]:

$$p_e = p_R = p_s \cdot \overline{p}_R,$$

where: p_R – pressure on peripherals of the vortex chamber; p_s – pressure in a tangential channel of a going into the vortex chamber, channel of power supply; $\overline{p}_R$ – relative pressure on walls of the vortex chamber:

$$\overline{p}_R = p_R / p_s.$$

The volume flow Q_e can be found, taking into account the first proportion (1), and supposing, that a fluid is incompressible:

$$Q_e = (\mu f)_{in} \sqrt{\frac{2 \cdot \Delta p_{in}}{\rho}}. \tag{2}$$

where: μ_{in} , f_{in} – accordingly, coefficient of volume flow and cross-section area of a sucker; ρ – density of a pumped over fluid medium; Δp_{in} – coerced pressure difference on a sucker.

The complication of calculation on a equation (2) consists in definition of coerced pressure difference, since the true pressure difference in a sucker essentially varies along his radius. Linking it with vacuum pressure on an axis of the vortex chamber, it is possible simplistically to consider at incompressible mediums and in the supposition of absence of a gas vortex cord

$$\Delta p_{in} = k_p p_{vac} = k_p \overline{p}_{vac} \cdot p_R = k_p \overline{p}_{vac} \cdot p_s \cdot \overline{p}_R .$$

Here: p_{vac} – vacuum pressure on an axis of the vortex chamber; $\overline{p}_{vac}$ – relative vacuum pressure on an axis of the vortex chamber; k_p – averaging coefficient.

An experimental way is determined, that the relative vacuum pressure on an axis of the vortex chamber principally depends on relative diameter of the vortex chamber. These results are displayed in a fig. 4 where $\overline{H} = H / d_o$ – relative height of the vortex chamber; H – height of the vortex chamber; d_s – diameter of a tangential channel of power supply.

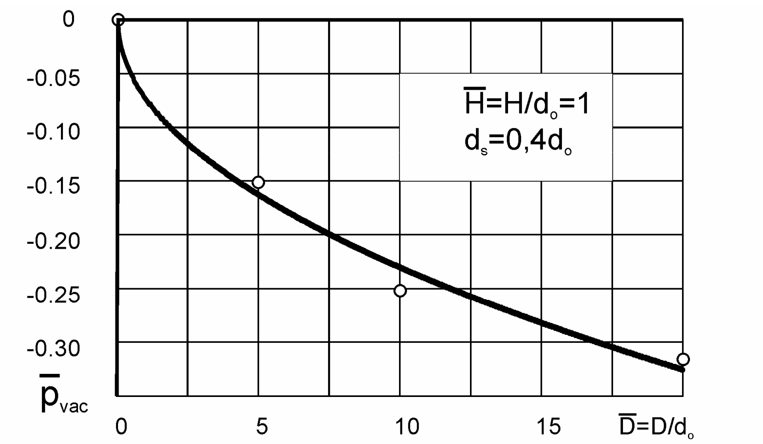

Fig. 4. Experimental dependence of relative vacuum pressure on an axis of the vortex chamber from its relative diameter

As it follows from fig. 4, the vacuum increases with extension of relative diameter of the vortex chamber, therefore, the flow of pumped medium increases also. However, at the same time the dimensions of the pump increase also, that in engineering practice is not always justified. Therefore it is necessary to search for the compromise settlement.

The efficiency can be found from following reasoning:

$$\eta = \frac{N_e}{N_s},$$

$$N_e = p_e Q_e = p_s \cdot \overline{p}_R \cdot (\mu f)_{in} \sqrt{\frac{2(k_p \overline{p}_{vac} p_s \cdot \overline{p}_R)}{\rho}},$$

$$N_s = p_s Q_s = p_s \cdot (\mu f)_s \sqrt{\frac{2(p_s - p_R)}{\rho}} = p_s \cdot (\mu f)_s \sqrt{\frac{2 p_s (1 - \overline{p}_R)}{\rho}},$$

Then,

$$\eta = \frac{\mu_{in}}{\mu_s} \cdot \frac{\overline{d}_{in}^2}{\overline{d}_s^2} \sqrt{\frac{k_p \overline{p}_{vac} \cdot \overline{p}_R^3}{(1 - \overline{p}_R)}}.$$

In previous our investigations was determined, that the rarefaction zone in the vortex chamber is restricted to radius $r \approx 0,5 r_o$ [Syomin 2004]. In view of this value, we shall receive $\overline{d}_{in} = 0,5$. Then:

$$\eta = \frac{\mu_{in}}{\mu_s} \cdot \frac{0,25}{\overline{d}_s^2} \sqrt{\frac{k_p \overline{p}_{vac} \cdot \overline{p}_R^3}{(1 - \overline{p}_R)}}.$$

Thus, the efficiency is defined in two geometrical arguments of the vortex chamber - relative diameter of a channel of power supply $\overline{d}_s$ and relative diameter of the vortex chamber $\overline{D}$, as on them depend relative pressure in equation. By our approximated estimations of vortex-fluid efficiency pumps can reach 50%, exceeding its values for jet pumps and remaining below, than for centrifugal pumps.

The experimentally obtained characteristics of the vortex-fluid pump (with the not optimized setting) for different pumped over mediums are introduced below. In a fig. 4 the characteristics VFP is displayed at its operation on incompressible working and pumped fluids. The maximum of efficiency at equality of relative volume flows of a sucking and on exit of the pump corresponds 34 %.

In case of pumped over by pumps of solid loose mediums, as follows from characteristics displayed in a fig. 6, the increase pressure of power supply results in increase of a mass flow of pumped over medium on exit of the pump and lowering of its losses through a drain channel.

Thus, for lowering losses of pumped medium it is necessary to increase an extent spin of a stream.

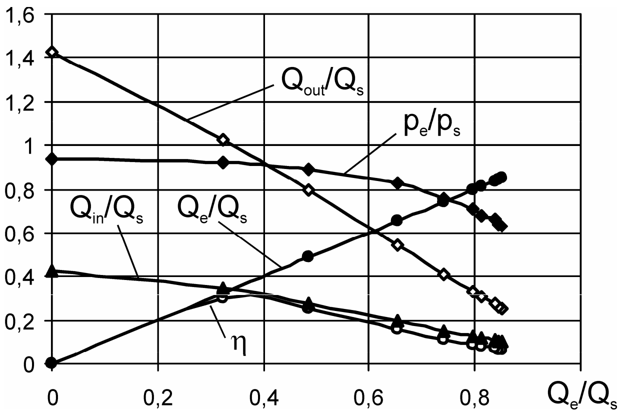

Fig.5. Characteristics of the VFP on single-phase actuating mediums

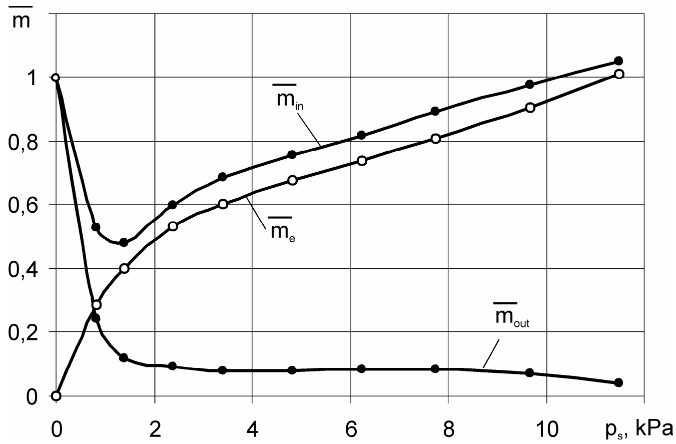

Fig. 6. Changes of mass flows of bulk material with a density 2600 kg/m^3 from pressure of power supply (all mass flows are related to m_{in} at $p_s = 0$)

CONCLUSION

On a foundation of data, obtained in this paper, experimental and analytical investigations it is possible to make following conclusions:

- usage of hydrodynamic effects of rotating streams of fluid mediums in restricted space, vacuum in paraxial zone and overpressure on peripherals of the vortex chamber, allows to construct the new type of pumps not having mobile mechanical parts;

- the methods of mathematical and physical simulation substantiate a principle and the physical flow pattern in the VFP is determined. VFP losses of pumped medium, because the solid particles after hit in a boundary layer on end wall of the vortex chamber are conveyed to a drain channel; and the part of particles immediately «falls» from a sucker in a drain channel at low extents of a curling of a stream are displayed. With increases of an extent of a spin of the stream in the vortex chamber, the losses of pumped medium are diminished;

- the power characteristics of VFP, obtained by an experimental way, are by the form similar to characteristics of centrifugal pumps, however have additional characteristic of a drain channel. Characteristic of an efficiency has a maximum, the value which one is higher, than for jet pumps are determined;
- at liquid actuating mediums the operation factors of the pump are restricted in consequence of origin of a gas vortex cord on an axis of the vortex chamber. For detailed analysis of influencing of vortex cords the additional experimental investigation are required.

REFERENCES

1. Beck Jeffrey L., 1980. Vortex injection method and apparatus. Patent USA № 4449862.
2. Khalatov A.A., Avramenko A.A., Shevchuk I.V., 1996. Heat Transfer and Fluid Flow in the Fields of Centrifugal Forces: 4-volume edition. – Kiev, Institute of Engineering Thermophysics of National Academy of Sciences of Ukraine. – Vol.1: Curvilinear Flows. – 290 p.
3. Patankar S. V., Spalding D. B., 1972. A Calculation Procedure for Heat, Mass and Momentum Transfer in Three-dimensional Parabolic Flows. — Int. J. Heat Mass Transfer, v. 15, - p. 1787—1806.
4. Rogoviy A.S., 2007. Perfecting of the power characteristics of ink-jet superchargers.- The manuscript. Thesis on support of a scientific degree of the candidate of technical science on a speciality 05.05.17 - Hydraulic machines and hydropneumatics sets.- Sumy State University, Sumy – 193 p.
5. Sokolov E.J., Zinger N.M., 1989. Jet device. – M: "Energoatomizdat", – 352 p.
6. Syomin D.A., 2004. Increasing of Cargoes Moving Efficiency of Pipeline Transport With Means of Fluidic Fittings. Thesis on deriving of a scientific extent of the doctor of engineering science on a speciality 05.22.12 - industrial carrier. – East Ukrainian National University named after Vladimir Dal, Lugansk, — 381 p.

ЭНЕРГЕТИЧЕСКИЕ ХАРАКТЕРИСТИКИ НАГНЕТАТЕЛЕЙ С ВИХРЕВОЙ РАБОЧЕЙ КАМЕРОЙ

Семин Д.А., Роговой А.С.

Аннотация. Приведены результаты исследований рабочего процесса и энергетических характеристик нагнетателей нового типа, сочетающих принципы передачи энергии центробежных и струйных насосов. Методами математического и физического моделирования установлены особенности протекания физических процессов, происходящих в устройствах при их работе на однофазных и гетерогенных средах. Математическое моделирование производилось на основе численных решений уравнений Рейнольдса. Экспериментально полученные рабочие характеристики сведены к одной универсальной.

Ключевые слова: струйная техника, вихревая камера, энергетические характеристики, коэффициент полезного действия, траектории частиц.