Development and research of hydraulic disk pump

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Abstract. The article is devoted to the development of the disk pump driven by a hydraulic motor at Bauman Moscow State Technical University Department of Hydraulics. The relevance of the dynamic pumps of this type has been described, and the necessity to investigate the mechanism of disk impellers operation using the tools of numerical hydrodynamic modeling, has been shown. The article presents the mathematical model used in computer simulation of the flow and the description of the testing bench. A comparison of numerical and full-scale experiments to confirm the adequacy of the mathematical model is introduced. A research showing the influence of some basic parameters of disk impellers on their characteristics (head, efficiency) has been performed. The figures of the scalar physical quantities distribution in the flow part of the pump and graphs of the pressure and efficiency dependences on the studied parameters are presented for a visual illustration of the results.

1. Introduction

The dynamic pumps for various purposes: oil, water, chemical, food, slurry systems and other are widely used nowadays. It should be noted that most of these pumps are centrifugal. Their widespread use is caused by the relatively high efficiency. However, the design features of the impeller, as well as the mechanism of the working fluid flow in the inter-blade channel, limit their ability to pump viscous and highly contaminated liquids.

It is advisable to use disk impellers, the efficiency of which does not decrease with the viscosity increase [1] (figure 1), for viscous polluted liquids. Thus, in some enterprises, disc pumps have replaced successfully centrifugal slurry, screw pumps for pumping thickened sediment from the sumps of a water purification system. Some works are devoted to the use of disk pumps for blood pumping, including ones with imitation of the real heart pulsations. Such a field of application is justified by the ability of these pumps for gentle pumping, without introducing significant perturbations into the flow structure [2, 3, 4]. This property provided a niche for disc pumps in the food industry.

It should be noted, however, that there are few works devoted to the development of the theory of disk pumps at present days. Compared to the works that have been published quite a long time ago [5, 6, 7, 8], practically no changes were made to this theory. There are also very few works related to the numerical hydrodynamic simulation of disk pumps, which in its turn can significantly expand the understanding of the capabilities of these hydraulic machines.

This work is related to the research being conducted at the Department of Hydraulics of the Moscow Bauman State Technical University. Two variants of the design of a hydraulic disk drive
pump, shown in figure 2, were developed, manufactured and tested on the base of the department. In order to check the compliance of the flow part with the declared characteristics, a numerical hydrodynamic simulation of fluid flow in the pump was performed. According to the tests results, experimental characteristics of pumping units were compiled and compared with the results of computer analysis.

![Figure 1. The disk impeller with ribs.](image1)

![Figure 2. Variants of the disk hydraulic drive pump installed on the testing bench.](image2)

Also, numerical analysis has been carried out aimed at the research of the general influence of the disk impellers geometrical parameters on their characteristics.

2. Mathematical model and methods.
The method of numerical hydrodynamic modeling used in the work is based on solving discrete analogs of the equations of the continuous viscous medium dynamics. In the case of an incompressible fluid model ($p = \text{const}$), it can be found in [9, 10, 11]:

- Mass conservation equation (continuity equation)
\( \frac{\partial u_j}{\partial x_j} = 0, \)

where

\( \bar{u}_j \) – the averaged value of the fluid velocity in the projection on the \( j \)-th axis \((j = 1, 2, 3)\).

The equation of the momentum change (Reynolds averaging) in a nonstationary statement

\[
\rho \left[ \frac{\partial U_j}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} \right] = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i} \left[ T_{ij}^{(v)} - \langle p u_i u_j \rangle \right],
\]

where

\( U, P \) – averaged speed and pressure;
\( T_{ij}^{(v)} \) – viscous stress tensor for incompressible fluid;
\( s_{ij} = \frac{1}{2} \left[ \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right] \) – instant strain rate tensor;
\( \langle p u_i u_j \rangle \) – Reynolds stresses;
\( \rho \) – fluid density;
\( \mu \) – fluid viscosity coefficient.

The Reynolds stresses were simulate using the \( k-\omega \) SST turbulence model, which was approved during dynamic pumps analysis [12, 13, 14, 15].

For the numerical solution by the finite element method in such software complexes, a mesh is used. In this case, the cells are polyhedral in the flow core and prismatic - near the walls (figure 3). The thickness of the prismatic layers which is necessary to ensure the value of \( Y^+ < 100 \), which is recommended for high-Reynolds models like \( k-\omega \) SST.

Tests of pumping units were carried out at the testing bench at the Hydraulics department, the scheme of which is shown in figure 4.
3. Results and analysis
The comparison of the results of flow part numerical simulation of the developed pumps and the results of bench tests are shown in figure 5. A fairly accurate coincidence of the characteristics of the head and efficiency shows the adequacy of the applied mathematical model with respect to disk pumps.
Figure 5. The graphs of the dependences of the head and the efficiency of the pump performance obtained experimentally (black) and by simulation (green).

After confirming the mathematical model performance, a simulation of many variants of flow parts with various geometrical characteristics was performed. As a result, it was found that the ribs located on its disks have a significant influence on the characteristics of the disk impellers. Figure 6 shows a comparison of these characteristics for impellers of 10 and 15 mm width with different configuration of the ribs.

Figure 6. The variants of the disk impeller ribs with a total height as a percentage of the distance between the disks: a) 50%; b) 100%.
Figure 7. Dependencies of head and efficiency at distances between the disks: a) 15mm; b) 10mm. Black color — the height of the edges is 50%, red and purple colors — 100% of the distance between the discs.

In each figure, each impeller configuration corresponds to 5 graphs for five different viscosities: 1, 1000, 3000, 5000 and 10,000 cSt (from top to bottom). The presented graphs show the working capacity of disk impellers with ribs, including the full width of the impeller, at high viscosities.

4. Conclusions

As a result of the conducted research, the applicability of the numerical simulation method with respect to disk pumps was shown. According to the results of the study of disk impellers with different geometrical parameters at several viscosities, it can be concluded that the addition of radial ribs to the disks leads to an increase in pump’s head and efficiency. At low viscosities, this increase is up to 20 m and 30%, respectively, and the blades retain their effectiveness up to 10,000 cSt. The obtained results require experimental studies, as well as further development of the numerical modelling.

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