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Investigation of the influence of the angle of the installation of the blades of the impeller of the regenerative pump on its energy characteristics by the methods of hydrodynamic modeling

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Annotation. This paper focuses on the study of the influence of the vortex stage impeller blades angle installation in a centrifugal vortex pump. The mathematical model used in the numerical modeling is described. The 3 variants models of working regenerative impeller with different installation angles are considered. The paper shows the influence of the angle of the blades on the energy characteristics. The evaluation criteria were pressure, hydraulic efficiency and manufacturability. The results obtained during hydrodynamic modeling are presented in the form of velocity distribution vector fields. This paper will be of interest to specialists in the field of designing vortex hydraulic machines.

Introduction

The working part of a regenerative pump is the impeller [1] with radial or inclined blades. (Picture 1)

In practice closed regenerative pumps with impellers having an installation angle of 90 ° are most often found due to the ease of manufacture. But in the literature [1] mathematically is described the fluid flow process in pumps with impellers, which have a sickle-shaped cross-section in the blades. Changing the installation angle leads to an increase in pressure, this is due to the principle of operation of the regenerative pump.

However, practical studies of the influence of the angle of the impeller vanes in the regenerative pump are not given due attention.

Methods

The numerical simulation method is based on the solution of discrete analogues of the basic equations of hydrodynamics [2, 3, 4]. In the case of an incompressible fluid model (ρ = const), this is:

The mass conservation equation (continuity equation):

$$\frac{\partial u_j'}{\partial x_j} = 0;$$

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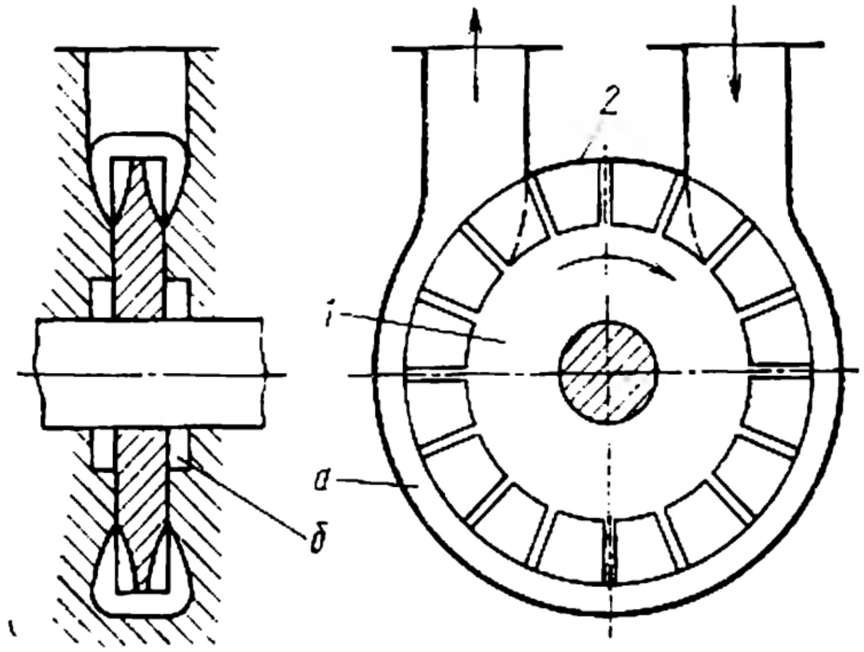

Figure 1. Diagram of a closed regenerative pump

Where u'_j — average value of fluid velocity in projection onto the j-th axis $(j=1,2,3)$;

Equation of conservation of momentum (averaging by Reynolds):

$$\rho\left[\frac{\partial U_i}{\partial t}+U_i\frac{\partial U_i}{\partial x_j}\right]=\frac{-\partial P}{\partial x_i}+\frac{\partial}{\partial x_i}\left[T'^{(v)}_{ij}-\rho u_i u_j\right];$$

Where U, P — averaged speed and pressure;

$T'^{(v)}_{ij}=2\mu S'_{ij}$ — Viscous stress tensor for incompressible fluid;

$S'_{ij}=\frac{1}{2}\left[\frac{\partial \tilde{u}_i}{\partial x_j}+\frac{\partial \tilde{u}_j}{\partial x_i}\right]$ —instant strain rate tensor;

$\rho u_i u_j$ — Reynolds stresses.

The introduction of the Navier-Stokes equation averaged by Reynolds makes the system of equations open, as additional unknown Reynolds stresses appear. To solve this system in this problem, a semi-empirical k-ω SST turbulence model was used, which introduces the necessary additional equations: the equations of transfer of the kinetic energy of turbulence and the relative dissipation rate of this energy:

$$\frac{\partial k}{\partial t}+U_j\frac{\partial k}{\partial x_j}=P_k-\beta k\omega+\frac{\partial}{\partial x_j}\left[\left(\nu+\sigma_k\nu_T\right)\cdot\frac{\partial k}{\partial x_j}\right]$$

$$\frac{\partial \omega}{\partial t}+U_j\frac{\partial \omega}{\partial x_j}=\alpha\cdot S^2-\beta\cdot\omega^2+\frac{\partial}{\partial x_j}\left[\left(\nu+\sigma_\omega\nu_T\right)\cdot\frac{\partial \omega}{\partial x_j}\right]+2\cdot\left(1-F_l\right)\cdot\sigma_{\omega 2}\cdot\frac{1}{\omega}\cdot\frac{\partial k}{\partial x_j}\cdot\frac{\partial \omega}{\partial x_j}$$

The flow part of the vortex stage of the pump was designed for the following parameters:

$H=40м$ — Head;

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$Q = 32\frac{м^3}{h}$ — Flow Rate;

$n = 3000rpm$ — Rotation speed.

The determining factors are the pressure (N), efficiency (η), and the manufacturability of the impeller [4, 5].

We study 3 variants of vortex wheels with installation angles of 45º, 60º, and 90 º (Figure 2)

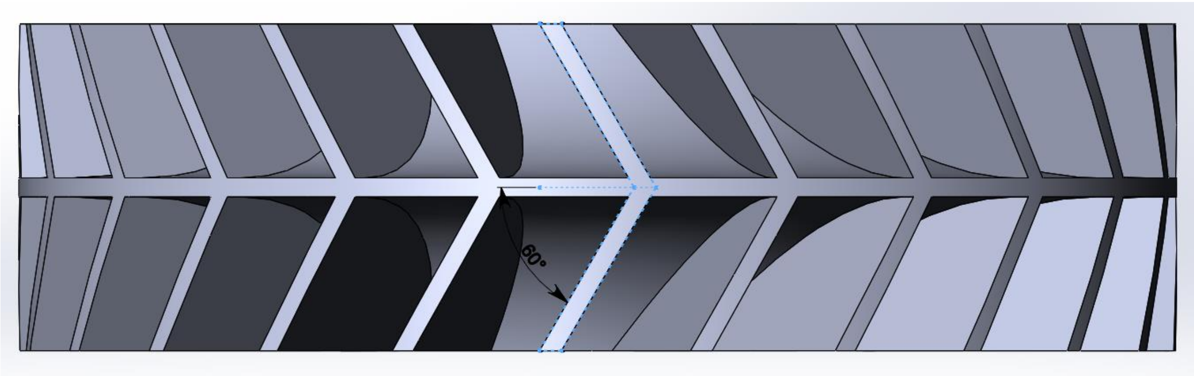

Figure 2. Regenerative impeller with an installation angle of 60º

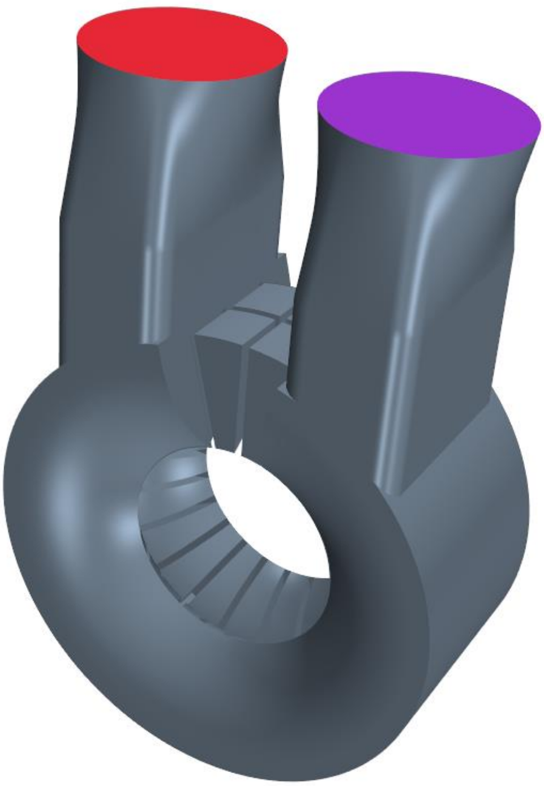

Figure 3. Calculation model

Figure 4. Design model of an impeller with an installation angle of 45º

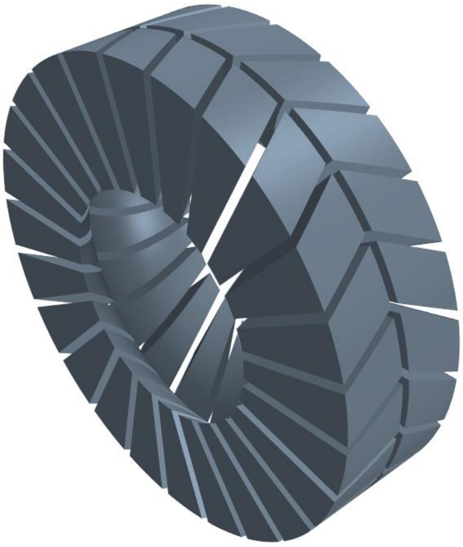

Figure 5. Design model of a wheel with an installation angle of 60º

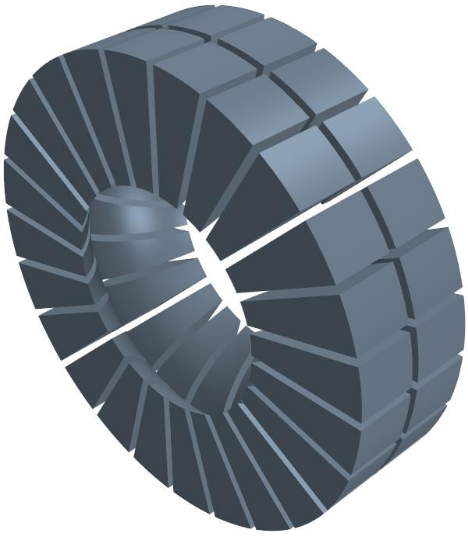

Figure 6. Design model of a wheel with an installation angle of 90º

To minimize the errors associated with numerical calculation, all models were calculated with the same parameters of the computational grid and with the same boundary conditions [6–10]. In the core of the flow cell, they have a multifaceted shape, at the solid walls of the pipe they have a prismatic shape. The computational grid for all models consisted of 600 thousand nodes (Figure 7).

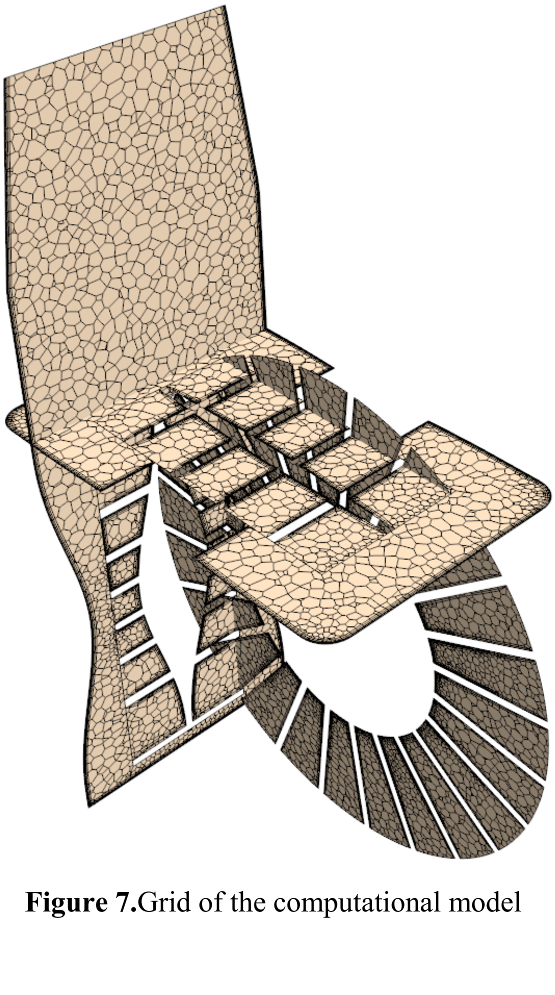

Figure 7. Grid of the computational model

As the boundary conditions were chosen: the total fluid pressure at the inlet (p = 0 Pa) and the fluid flow rate at the outlet. Time step equals to $t = 1e - 5c$.

Simulation results

The simulation results of 3 variants of the impellers are presented in figures 8-10 and are summarized in table 1.

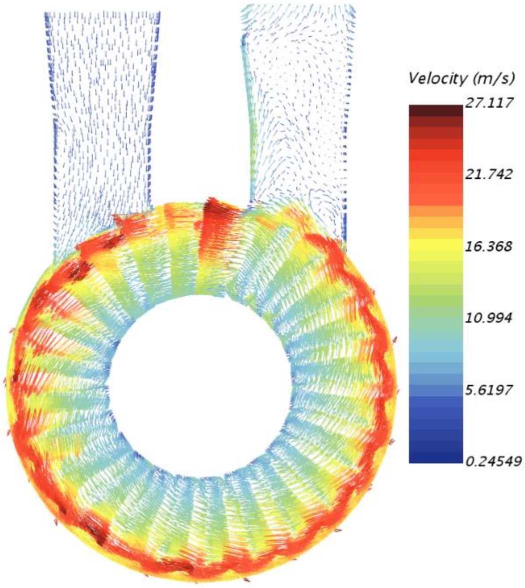

Figure 8. Vector field of velocity distribution in the flow part of the impeller with an installation angle of 45º

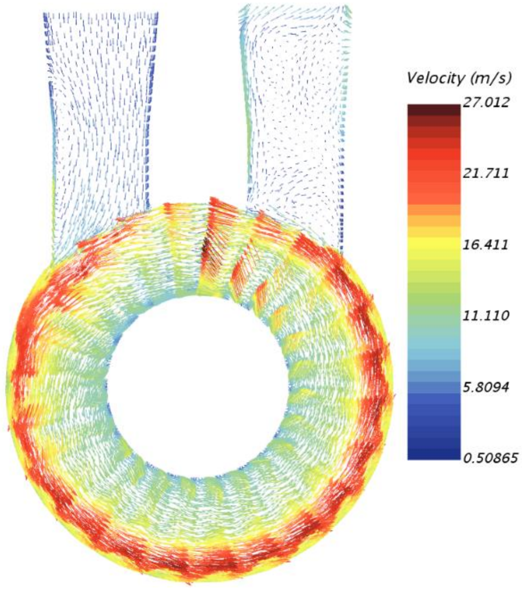

Figure 9. Vector field of velocity distribution in the flow part of the impeller with an installation angle of 60º

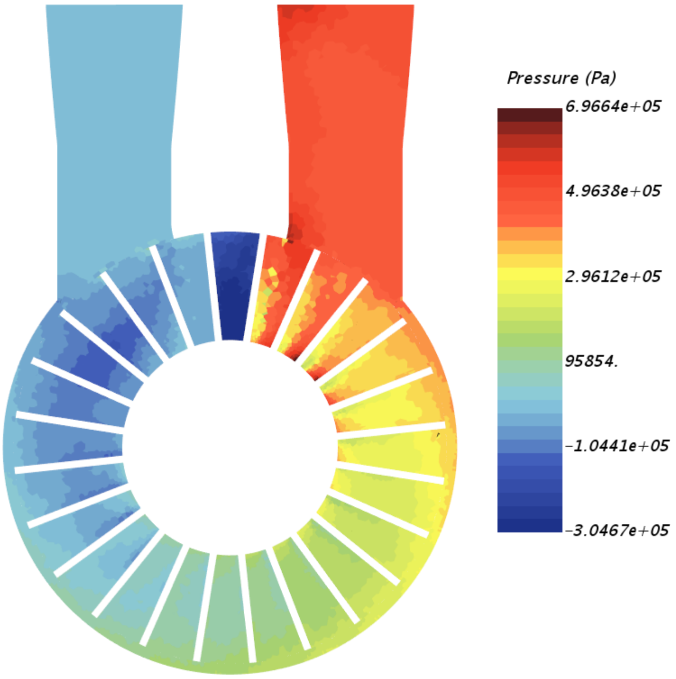

Figure 10. Scalar field of pressure distribution in the flowing part of the impeller with an installation angle of 90º

Table 1. Simulation results

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Models	Installation angle, º	Head, m	Efficiency, %	Manufacturability
1	45	54,8	50	–
2	60	65,6	54	–
3	90	51,4	49	+

The graphs show a comparison of the data obtained as a result of numerical simulation with the data obtained as a result of mathematical calculation [1].

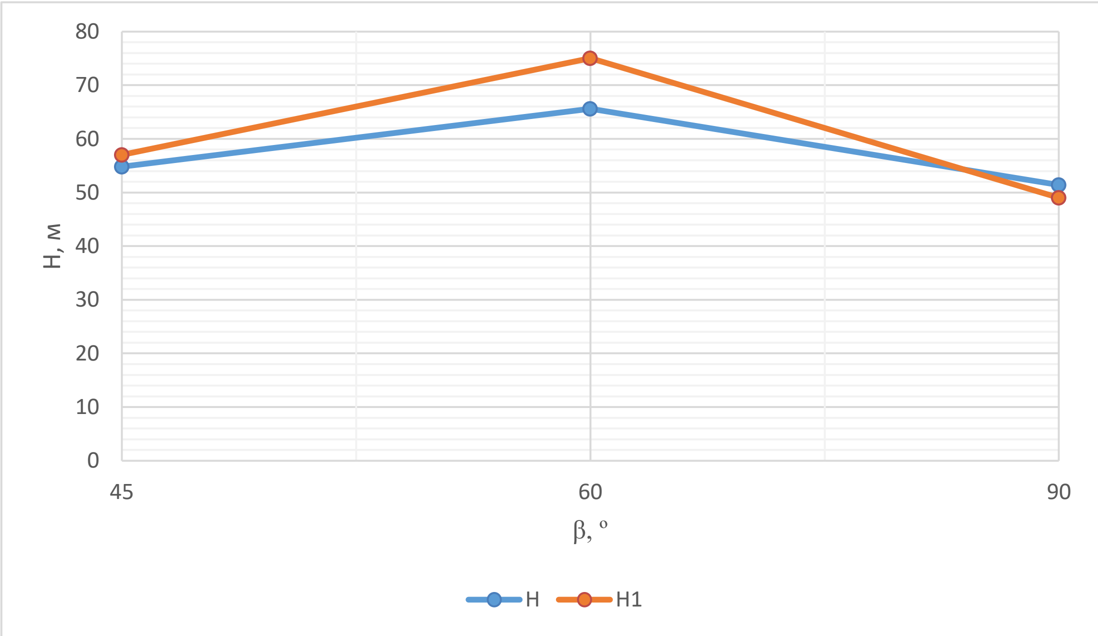

Figure 11. Head dependence on the blade angle

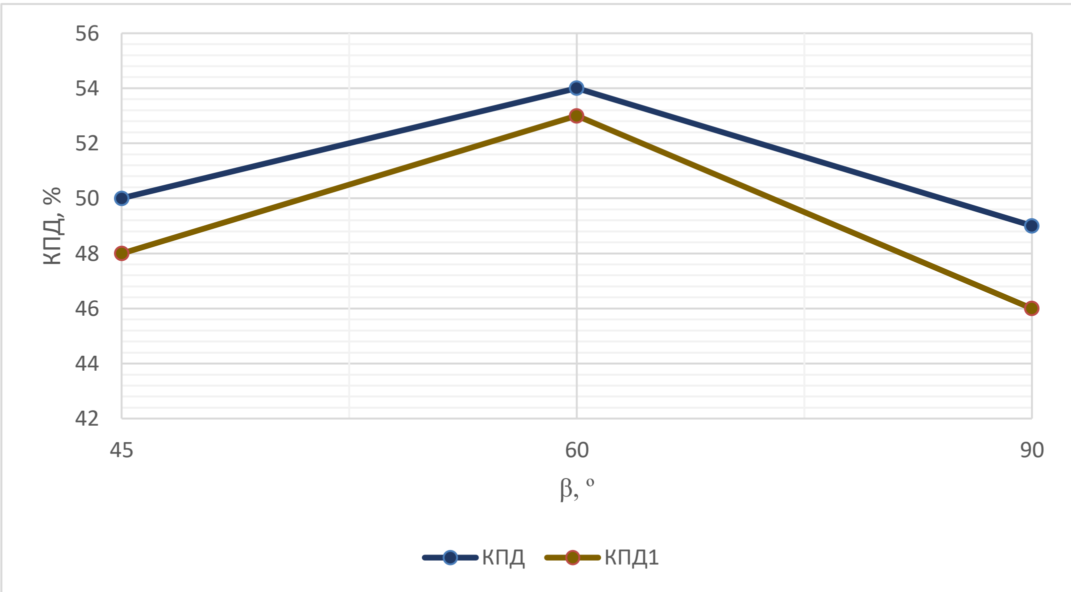

Figure 12. The efficiency dependence on the installation angle of the blades

Discussion

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1. As a result of numerical hydrodynamic modeling, it was determined that 3 impellers have the best energy performance, however, it is much more complicated to manufacture than the option 1;
2. Using this technique, in the future it is possible to study the impellers with other installation angles, since option 3 is probably not optimal according to the criterion of energy efficiency.
3. To determine the flow part with the best energy characteristics, it is necessary to use multi-parameter optimization.
4. Additional experimental studies of the flow parts of vortex pumps are needed to confirm the results of numerical simulation.

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