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Wet part hybrid optimization method of hermetic pump

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Abstract. The article is devoted to development of the hybrid method of the wet part of hermetic pump with low specific speed optimization. As an initial approximation for the gradient descent method the results of the optimization of the pump by LP-Tau search are used. A selection of optimization parameters is mentioned. The optimization sequence is described. The mathematical model used in the numerical simulation, the boundary conditions and the parameters of the grid are shown. The results of the optimization and conclusions about the effectiveness of the method used are introduced. The experimental validation of the method is presented.

1. Introduction

Due to the constant tightening of requirements for the energy efficiency of various purpose hardware reduction of energy consumption by increasing the efficiency of industrial plants is an important and urgent task. This paper is devoted to the study of the possibilities of improving the energy efficiency of pumping equipment based on modern design methods.

The active introduction of computational fluid dynamics methods into engineering practice and the constant increase in computational power have led to the possibility of significantly improving the quality of the flow parts of pumping equipment, including in terms of its efficiency. However, computational methods themselves do not solve the problem under consideration, since they are only a tool for mathematical modeling, and not a way to optimize.

The development of methods for optimal design of pump flow parts using computational fluid dynamics methods is currently underway around the world in various scientific organizations and many results have been published [10–15].

In articles [1], a complex genetic optimization algorithm is used to increase efficiency. To apply this method, a huge number of calculation points are required, and their number increases many times with the increase in the number of optimization parameters. In this regard, genetic algorithms are used for highly specialized tasks, require highly skilled calculators and take a lot of time. In works [2, 3], optimization is carried out according to the criterion of energy efficiency, while the optimization parameters and the number of design points are determined intuitively. The result of applying this method of optimization is highly dependent on the qualifications of the researcher, since they do not use formal mathematical algorithms. In most cases, intuitive methods are applicable with one or two optimization parameters, with a greater number of them, the relationship between optimization

parameters and objective functions goes beyond the scope of human imagination. In many works, for example, [4], the optimization of a specific element of the flow part was performed (in the work, a pump outlet device was selected). This method shows good results, but the lack of consideration for the mutual influence of individual elements of the flow path on each other leads to a limitation of the application of this technique. The use of the gradient method is described in [5].

This work is a continuation of the study [6], in which an attempt was made to optimize the entire pump flow section. However, in [6], the LP-Tau optimization algorithm [7] was used, which is stochastic, which means that the probability of finding the global maximum of the efficiency criterion using this method is extremely small. In this paper, this method has been modified. After the preliminary optimization of the LP-Tau method, it is proposed to use the methods of directional optimization (in this case, the gradient descent method [8]) to improve the results of the pre-optimization.

The aim of this work is to develop a method of combined optimization of the wet part of a hermetic pump based on the joint use of stochastic and directional optimization methods. According to the results of the study, it was obtained that performing pre-optimization using the stochastic method allows to obtain several models whose energy efficiency is close to the maximum. These models can be used as an initial approximation to perform a refinement optimization using the directional method. The directional method allows to further increase the energy efficiency of these models, since it is used to find the local maximum of the function in the vicinity of the point under study. Thus, the joint use of stochastic and directional methods can significantly improve the efficiency of hermetic pumps.

2. Selection of optimization parameters

In the LP-Tau search method, 7 geometric parameters of the wet part were selected. The use of such a large number of parameters in the gradient descent method leads to a strong complication of the optimization process, as well as a significant increase in optimization time.

Therefore, in this study, 3 parameters were selected that, according to the results of the analysis of the preliminary optimization results, had the greatest impact on the hydraulic efficiency (figure 1, figure 2):

1. The capacity of the channel outlet device (COD) A, mm

$$A = n \cdot b \cdot ln \frac{R_1 + a}{R_1}$$

where
n – pump shaft speed, rot/min
b – channel width of COD, mm
R_1 – radius of impeller, mm
a – channel height of COD, mm

2. The ratio of the area of output to the entrance of COD, Kd_2

$$Kd_2 = \frac{A_2}{A_1}$$

where
A_2 – channel area COD on outlet, mm^2
A_1 – channel area COD on inlet, mm^2

3. Radial clearance between the exit of the impeller and the entrance to the COD, δ, mm
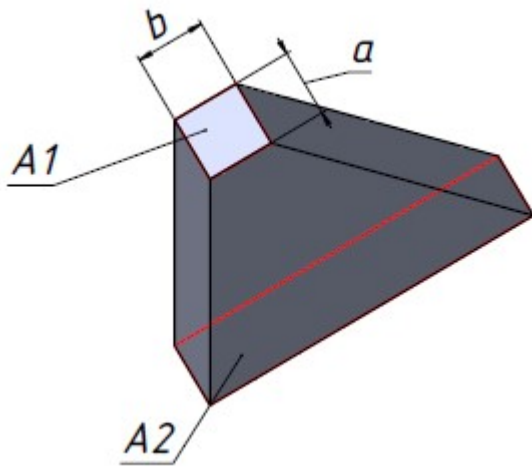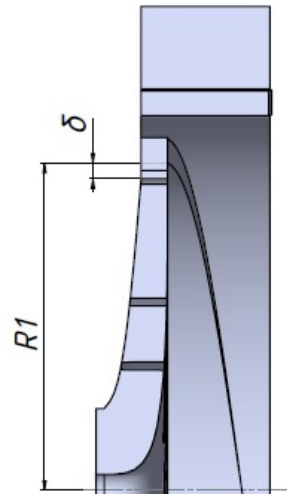
Figure 1. Channel scan of COD.

Figure 2. Meridional section of the wet part.

3. Gradient descent method

Since the functional dependence of the hydraulic efficiency value on the geometrical parameters of the pump wet part cannot be analytically derived (it is necessary to solve the basic equations of hydromechanics analytically), the algorithm for finding the global maximum of the hydraulic efficiency is carried out in the following sequence:

1. The study of the vicinity of the starting point. At this stage, all optimization parameters are reduced to a dimensionless form.

$$x_{i\delta} = \frac{x_i}{x_{i_{max}} - x_{i_{min}}} + x_{i_{min}}$$

where

$x_i - i$-th optimization parameter,

$x_{i\delta} - i$-th optimization parameter in dimensionless form,

$x_{i_{min}} - $ minimum value of i-th optimization parameter,

$x_{i_{max}} - $ maximum value of the i-th optimization parameter.

Then a step is made for each parameter, while the remaining parameters remain unchanged.

2. Calculation of the coordinates of the gradient vector by the equation:

$$A_i = \frac{\Delta y_i / \Delta x_i}{|A|},$$

where

$\Delta y_i - $ change in the value of hydraulic efficiency when changing the i-th optimization parameter by Δx_i,

$|A| = \sqrt{\sum_{i=1}^{n} A_i^2}$ – gradient vector modulus,

$n = 3$ – number of optimization parameters.

3. Gradient vector step. Step size varies from 0.005 to 0.2.

4. Repeat all operations from 1item for a new point.

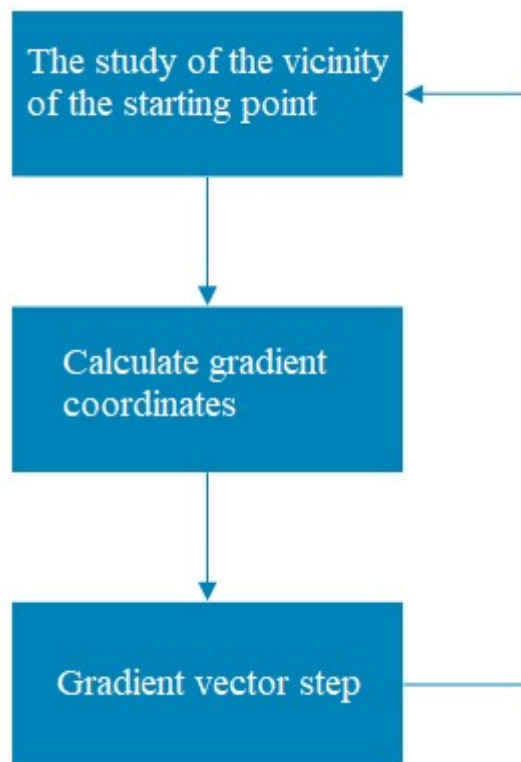Schematically, the optimization sequence is presented in figure 3.

Figure 3. Optimization sequence.

Each test model obtained was calculated using computational fluid dynamics (CFD) methods. Based on the obtained geometric parameters, a 3D model is created. The model of the wet part for one of the design points is presented in figure 4.

Figure 4. Three-dimensional model of the wet part.

The model of incompressible fluid was used (ρ = const). Numerical simulation is based on solving discrete analogs of the basic hydrodynamic equations.

The calculation is based on solving the following equations:

1. The equation of mass conservation (continuity equation),
2. The equation of conservation of momentum (Reynolds averaging),
3. The equation of kinetic energy of turbulence transfer,
4. The equation of the relative dissipation rate of this energy.

This mathematical model was successfully used in the calculation of pumps of other types [4]. The application of this mathematical model is described in more detail in [6].

Also, this model was successfully used in [16–20].

All models were calculated with the same parameters of the computational grid and with the same boundary conditions. As the boundary conditions, the inlet velocity value and the outlet pressure value from the wet part were specified.

The calculated grid for all models had from 1.5 to 2 million cells. In the flow core, the mesh cells have a polyhedral shape, and for solid walls — a prismatic one. The calculated grid is shown in figure 5.
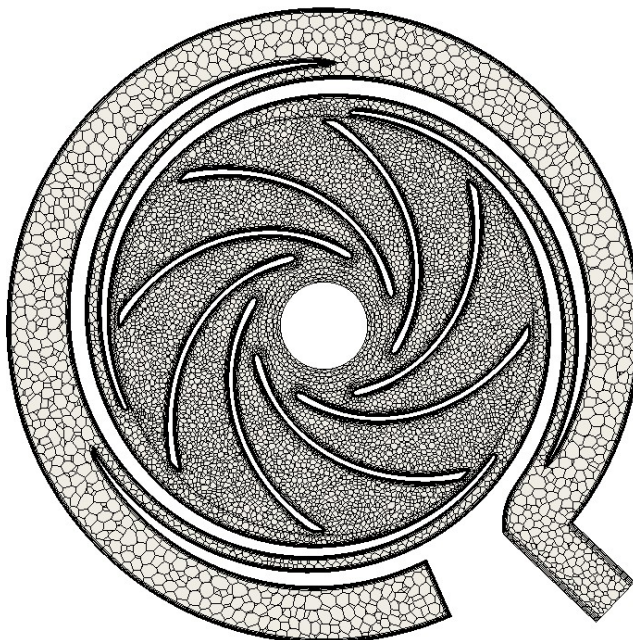

Figure 5. Calculated grid.

4. Optimization results

Optimization was carried out for two points obtained by the LP-Tau search method [6]. At the first point, the value of hydraulic efficiency was 75.4%, at the second — 74.8%.

The results of using the gradient descent method are presented in figures 6 and 7.

Thus, the value of hydraulic efficiency in the first point increased by 1.1% and amounted to 76.5%, and in the second point increased by 2.5% and amounted to 77.3%.

A comparison of the intensity of turbulent vortex formation at the optimum point obtained by the LP-Tau search method and at the optimum point obtained by the gradient descent method is presented in figures 8 and 9.

The results showed that the gradient descent method allows to improve the results obtained by the LP-Tau search method. The most optimal point obtained by the LP-Tau search method was not the most optimal starting point for the gradient method.
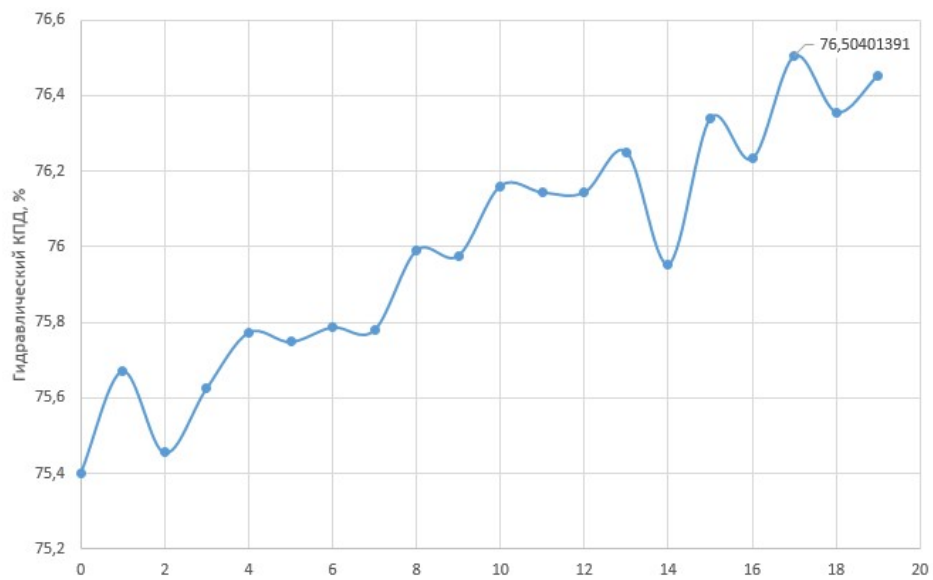
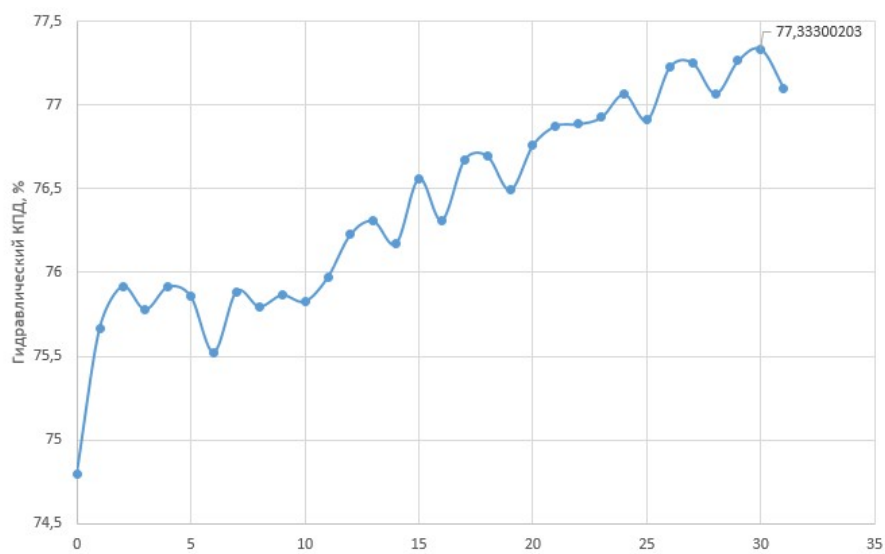**Figure 6.**Optimization by the method of gradient descent at point 1.

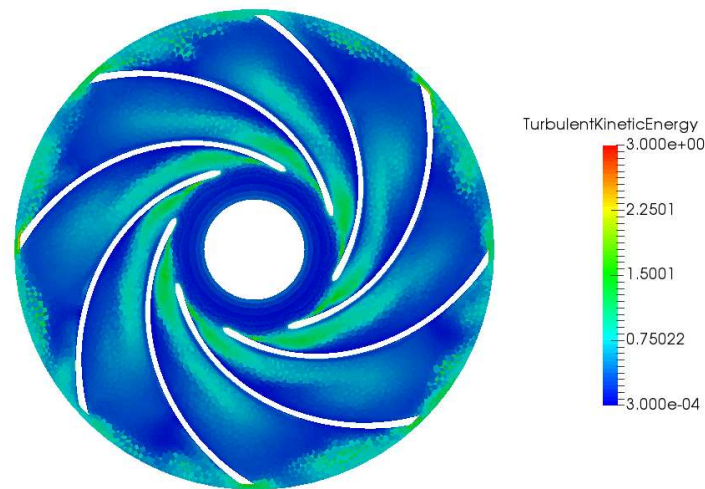**Figure 7.**Optimization by the method of gradient descent at point 2.

Figure 8. The intensity of vortex formation in the optimal model
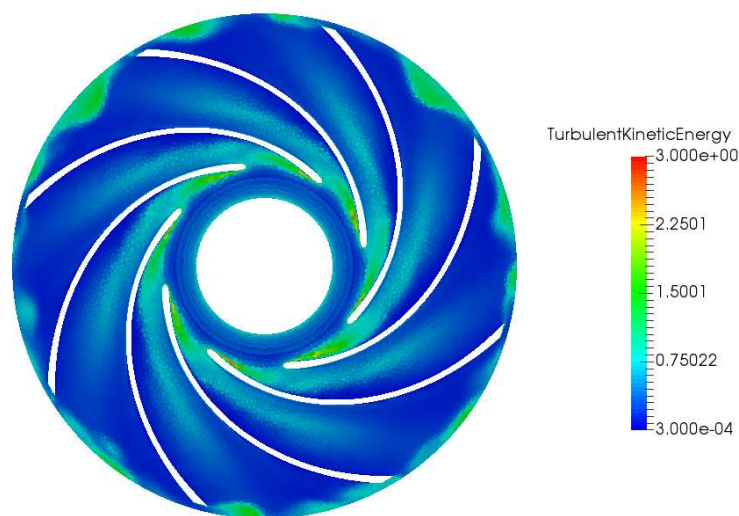obtained by the LP-Tau search method.

Figure 9. The intensity of the vortex in the optimal model
obtained by the method of gradient descent.

5. Experimental Testing
To confirm the effectiveness of the proposed method, the final model, obtained as a result of optimization, was manufactured and tested.

Details of the elements of the wet part of the prototype were made of plastic by 3D printing. The remaining parts are made of steel. The tests were carried out in the laboratory of the Department E10 BMSTU.

The fabricated prototype is shown in figure 10.

Figure 10. Model.

According to the test results, a normal characteristic of the prototype was built. Comparison of the calculated characteristics obtained by the methods of hydrodynamic modeling (CFD) with the experimental characteristic is presented in figure 11.
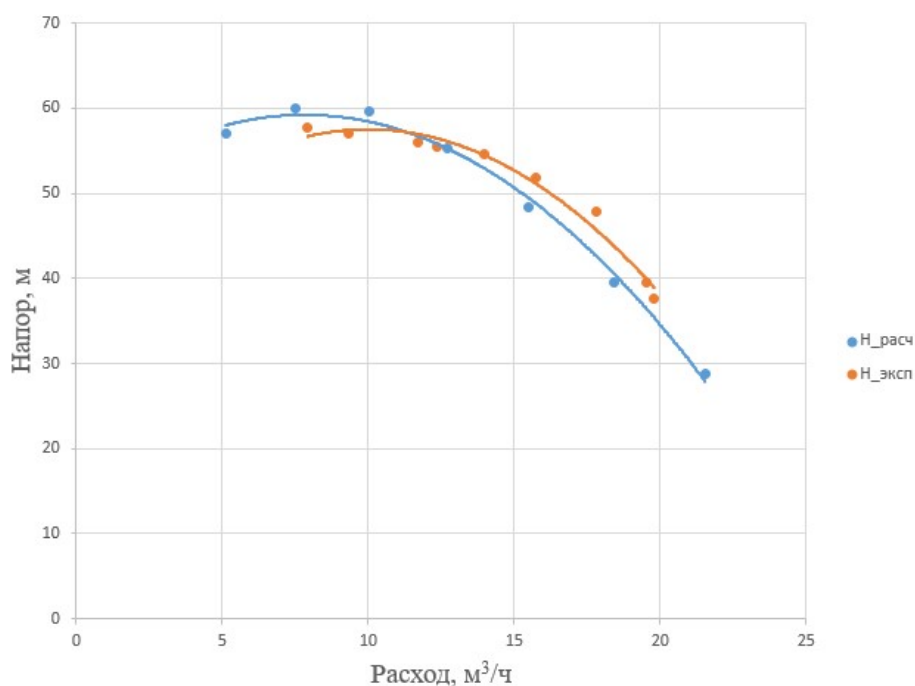

Figure 11. Comparison of the calculated and experimental characteristics of the pump.

The difference between the simulation results and the experimental data on the head near the optimal point of pump operation does not exceed 3%. Comparison of simulation results and efficiency calculations is a more difficult task, since in addition to hydraulic losses in the pump, there are other sources that reduce the efficiency of the pump. In pumps with a specific speed 34, as in this case, the share of non-hydraulic losses can reach 20-30% of power consumption.

The overall efficiency obtained experimentally was 55%, which is higher by 3-5% of the efficiency values of the analogues available on the market. In [9], a complex experimental study of pumps of various fastness was carried out. The graph of achievable efficiencies obtained in this work is given

below (figure 12). For the pump with the considered parameters, the maximum efficiency according to the given schedule is 50%.
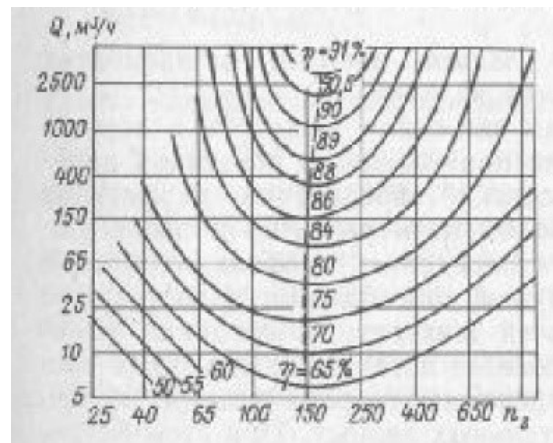

Figure 12. The effect of$n_s$on the efficiency of the pump [9].

6. Conclusion

The optimization method proposed in the paper allows profiling wet parts with high energy efficiency in a short time with a guaranteed result. Compared with the results obtained by stochastic optimization methods, the use of an integrated approach (stochastic plus directional method) makes it possible to further increase the efficiency of the wet part (in this example by 2-3%). Tests of the pump with the wet part obtained by the proposed method showed an increase in efficiency of about 5% compared with existing analogues.

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