Optimization of the radial channel guide vane of a centrifugal pump

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Abstract
The guide vane of a centrifugal multistage pump mostly determines the hydraulic efficiency of the pump and as a consequence the optimal mode of its operation. In order to increase the pump efficiency, the radial channel guide vane has been optimized. Three geometrical parameters and the number of channels of the guide vane were selected as optimization parameters. Hydraulic efficiency was chosen as a criterion. 128 computational models were obtained via hydrodynamic modeling. As a result, a significant increase in the pump efficiency was achieved.

Introduction
The majority efforts to increase pump efficiency are aimed at upgrading the pump impeller, while guide vane has a secondary role [1] - [11]. However, on the basis of VNIIGidromash, Professor S. S. Rudnev proved that the output device is not less important than the impeller. Hydraulic losses are largely determined by output device as well as the hydraulic efficiency of the pump and the optimal mode of its operation [12] - [14].

One of the varieties of output devices is a guiding apparatus. The primary direction of increasing the multistage centrifugal pump efficiency is an optimization of the guide vane.

Method
The considered pump CNS 300-500 has 5 stages and nominal parameters: Q = 300 m³ / h – volume flow, H = 500 m – pump head, n = 2900 rpm - pump shaft rotational speed, ns = 97 - pump specific speed. A radial channel transfer guide was selected for the study (Fig. 1).

Figure 1. Radial channel vane guide.
As a result of preliminary calculations of a guide vane, 3 geometrical parameters which have the greatest influence on the selected optimization criterion (hydraulic efficiency) were obtained. These are the entrance diameter of the guide vane \(D_3\), the ratio of the input and output diameters \(D_4 / D_3\) and the radial direction diffuser angle of the channel \(\Theta\). In addition, \(z\), the number of channels of the guide vane, was taken as an optimization parameter since it has a significant impact on the efficiency. The values of the optimization parameters are presented in Table 1.

Table 1. Vane guide optimization parameters.

| Parameter | Min | Max |
|-----------|-----|-----|
| \(D_3\), \(\text{мм}\) | 292 | 300 |
| \(D_4/D_3\) | 1.3 | 1.5 |
| \(\Theta\), \(\degree\) | 8  | 12  |
| \(z\) | 6  | 9   |

It was decided to use LP-tau search method as a quasi-random sequence generator to create an initial population. 128 models with different values of geometrical parameters for different \(z\) numbers were generated.

Table 2. Vane guide optimization parameter values.

| Modelno | \(D_3\) | \(D_4/D_3\) | \(\Theta\) |
|---------|---------|--------------|----------|
| 0       | 296     | 1.4          | 10       |
| 1       | 294     | 1.45         | 9        |
| 2       | 298     | 1.35         | 11       |
| 3       | 293     | 1.425        | 11.5     |
| 4       | 297     | 1.325        | 9.5      |
| 5       | 295     | 1.375        | 10.5     |
| 6       | 299     | 1.475        | 8.5      |
| 7       | 292,5   | 1.488        | 10.75    |
| 8       | 296,5   | 1.387        | 8.75     |
| 9       | 294,5   | 1.338        | 11.75    |
| 10      | 298,5   | 1.438        | 9.75     |
| 11      | 293,5   | 1.363        | 9.25     |
| 12      | 297,5   | 1.462        | 11.25    |
| 13      | 295,5   | 1.413        | 8.25     |
| 14      | 299,5   | 1.313        | 10.25    |
| 15      | 292,25  | 1.406        | 9.625    |
| 16      | 296,25  | 1.306        | 11.625   |
| 17      | 294,25  | 1.356        | 8.625    |
| 18      | 298,25  | 1.456        | 10.625   |
| 19      | 293,25  | 1.331        | 10.125   |
| 20      | 297,25  | 1.431        | 8.125    |
| 21      | 295,25  | 1.481        | 11.125   |
| 22      | 299,25  | 1.381        | 9.125    |
| 23      | 292,75  | 1.394        | 11.375   |
| 24      | 296,75  | 1.494        | 9.375    |
3d models were built for all 128 combinations of parameters. An example of a solid model is presented on Fig. 2.

The calculation was carried out by the methods of hydrodynamic modeling. The following equations were used: Reynolds averaged Navier-Stokes, mass conservation and two additional differential equations responsible for turbulence modeling. For the task the k-ω SST turbulence model was used [15, 16].

**Results**

According to the results of the calculation, the pump efficiency values at the nominal flow rate for 128 models were obtained and are summarized in Table 3.

**Table 3.** Efficiency values for the models.

| №  | z=6  | z=7  | z=8  | z=9  |
|----|------|------|------|------|
| 0  | 76,54| 78,97| 78,61| 79,46|
| 1  | 78,55| 75,79| 77,20| 78,07|
| 2  | 74,51| 80,95| 81,23| 81,17|
| 3  | 77,74| 77,32| 77,57| 79,32|
| 4  | 76,23| 76,10| 76,48| 78,60|
| 5  | 76,73| 75,35| 76,20| 76,36|
| 6  | 73,78| 82,14| 81,77| 81,83|
| 7  | 80,55| 79,06| 78,83| 79,88|
| 8  | 76,69| 80,36| 80,69| 81,03|
| 9  | 78,11| 76,82| 76,95| 77,97|
| 10 | 75,13| 81,25| 81,23| 81,17|
Окончание табл. 3

| №   | z=6 | z=7 | z=8 | z=9 |
|-----|-----|-----|-----|-----|
| 11  | 79,44 | 80,49 | 80,73 | 81,04 |
| 12  | 75,39 | 77,11 | 77,77 | 78,29 |
| 13  | 75,54 | 79,68 | 79,44 | 80,82 |
| 14  | 77,39 | 74,52 | 74,94 | 77,19 |
| 15  | 73,19 | 81,90 | 81,72 | 81,56 |
| 16  | 79,92 | 77,71 | 73,62 | 79,33 |
| 17  | 75,73 | 79,88 | 80,00 | 80,33 |
| 18  | 78,36 | 76,16 | 76,46 | 77,20 |
| 19  | 74,41 | 80,72 | 80,60 | 75,32 |
| 20  | 78,76 | 77,29 | 77,49 | 79,00 |
| 21  | 75,65 | 79,00 | 79,18 | 80,04 |
| 22  | 77,23 | 77,65 | 76,89 | 78,62 |
| 23  | 79,91 | 75,38 | 75,95 | 76,80 |
| 24  | 73,86 | 81,95 | 81,80 | 82,29 |
| 25  | 81,36 | 81,62 | 81,44 | 82,00 |
| 26  | 75,36 | 77,73 | 78,06 | 79,40 |
| 27  | 78,11 | 79,97 | 79,62 | 80,47 |
| 28  | 73,28 | 75,76 | 76,63 | 77,11 |
| 29  | 80,74 | 82,18 | 81,54 | 78,09 |
| 30  | 75,63 | 78,28 | 78,55 | 79,43 |
| 31  | 78,87 | 80,44 | 79,61 | 80,89 |

For the obtained results the dependence of the efficiency on the optimization parameters should be considered in more detail. Fig. 3 shows the dependence of the efficiency on a value equal to the ratio of the diameters of the entrance to the guide vane and the impeller output $D_3 / D_2$, where $D_2$ is the impeller diameter, for different $z$ numbers.

**Figure 3.** Dependence of the efficiency on $D_3 / D_2$, where $z=6$ with red color, $z=7$ with blue, $z=8$ with green, $z=9$ with violet.
Fig. 4 show efficiency dependence on the ratio of input and output diameters of the guide vane $D_4/D_3$, for different $z$.

![Figure 4 Effciency dependence on $D_4/D_3$, where fed dots mark $z=6$, $z=7$ - blue, $z=8$ - green and $z=9$ - violet.](image)

Figure 5 shows efficiency dependence on the channel diffusivity $\Theta$ for different $z$ numbers.

![Figure 5 Efficiency dependence on $\Theta$, where fed dot smark $z=6$, $z=7$ - blue, $z=8$ - green and $z=9$ - violet.](image)

Diagram on figure 6 illustrates $z$ influence on efficiency. Maximum efficiency value is achieve dot $z$ equal to 9 in 50% of all cases.
Fig. 6. Maximum efficiency value distribution diagram for different z numbers.

The best combination of geometrical parameters for the pump is model No. 24 with $z = 9$, the efficiency value of the model is 82.29%, which is almost 10% more than that of the model with the minimum efficiency value. Parameters value and KPD of the best model are presented in Table 4.

Table 4. Optimal model.

| №  | $D_1$, mm | $D_2/D_1$ | $\Theta_1$, ° | $z$ | $\eta$, % |
|----|-----------|-----------|---------------|----|----------|
| 24 | 296,75    | 1,494     | 9,375         | 9  | 82,29    |

Discussion

In this work, the influence of the main geometrical parameters of the guide vane of a multistage centrifugal pump on its efficiency was determined. After the results of hydrodynamic modeling were analyzed, the dependence of the parameter values on the optimization criterion was formulated. These regularities can serve as a recommendation when designing a pump guide vane. A significant increase of the efficiency was achieved. In the future, it is planned to expand the parameter space and conduct a similar study of other types of guide vanes, which will make further pump efficiency increase possible.

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