Optimization of a radial guide device with a no-vane transfer channel

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Abstract
Various studies show that the centrifugal multistage pump guide vane greatly determines the hydraulic efficiency of the pump and, as a result, the optimal mode of its operation. In order to increase the pump efficiency, the radial guide vane with a no-blade transfer channel was optimized. Three geometrical parameters and the number of channels of the guide vane were chosen as optimization parameters; the hydraulic efficiency was the optimization criterion. 128 computational models were made, and the efficiency values at the operating point were obtained by the method of hydrodynamic modeling. As a result, significant increase in the pump efficiency was achieved.

Introduction
Nowadays research of centrifugal pumps in our time are rising in number [1] - [10]. In these studies, various methods of mathematical modeling are becoming increasingly important. Publications [11] - [16] are of the greatest interest. It should be noted that for a long time the impeller was considered to be the main part of the pump, as it almost completely determines all its energy qualities. In the VNII Gidromash, Professor S. S. Rudnev together with the staff conducted a research, the results of which radically changed the status of the diverting device as a secondary pump unit. They have shown that the output device is no less important than the impeller. While the impeller determines the energy transfer to the fluid from the drive, the output device largely determines the hydraulic losses and, therefore, the hydraulic efficiency of the pump and the optimal mode of its operation.

One of the varieties of output devices is the guiding apparatus. Thus, the primary direction of a multistage centrifugal pump efficiency increase is the optimization of the guide vane.

The considered pump CNS 300-500 has 5 stages with nominal parameters: Q = 300 m³/h - volumetric flow, H=500 m - head, n = 2900 rpm - rotor rotation speed, nₛ=97 – specific speed coefficient.

Methods and results
The guide vane consisting of direct, transfer and reverse channels can be of several main types: radial with a no-vane transfer channel, radial channel and radial with a no-vane diffuser. Also guide vanes can be divided into blade and channel (tubular). For the study, the most common type of guide vane was chosen: a radial with a no-vane transfer channel (Fig. 1).
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 |
|-----------|-----|-----|
| $D_3$, мм | 292 | 300 |
| $D_4/D_3$ | 1,3 | 1,5 |
| $\Theta$, ° | 5 | 15 |
| $z$ | 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.**

| Model no | $D_3$, мм | $D_4/D_3$ | $\Theta$, ° |
|----------|-----------|------------|-------------|
| 0        | 296       | 1,4        | 10          |
| 1        | 294       | 1,45       | 7,5         |
| 2        | 298       | 1,35       | 12,5        |
| 3        | 293       | 1,425      | 13,75       |
| 4        | 297       | 1,325      | 8,75        |
| 5        | 295       | 1,375      | 11,25       |
| 6        | 299       | 1,475      | 6,25        |
| 7        | 292,5     | 1,488      | 11,875      |
| 8        | 296,5     | 1,387      | 6,875       |
| 9        | 294,5     | 1,338      | 14,375      |
| 10       | 298,5     | 1,438      | 9,375       |
The calculation of the characteristics of the guide vane was carried out via the hydrodynamic modeling methods. To carry out the calculations, it is necessary to have a solid model of the liquid in the guide vane (wet part) \cite{17,18}. These models were built for all 128 combinations of parameters. An example of a 3d model is presented on Fig. 2.

| Modelno | D₁, мм | D₂/D₃ | Θ, ° |
|---------|--------|--------|-------|
| 11      | 293,5  | 1,363  | 8,125 |
| 12      | 297,5  | 1,462  | 13,125|
| 13      | 295,5  | 1,413  | 5,625 |
| 14      | 299,5  | 1,313  | 10,625|
| 15      | 292,25 | 1,406  | 9,063 |
| 16      | 296,25 | 1,306  | 14,063|
| 17      | 294,25 | 1,356  | 6,563 |
| 18      | 298,25 | 1,456  | 11,563|
| 19      | 293,25 | 1,331  | 10,313|
| 20      | 297,25 | 1,431  | 5,313 |
| 21      | 295,25 | 1,481  | 12,813|
| 22      | 299,25 | 1,381  | 7,813 |
| 23      | 292,75 | 1,394  | 13,438|
| 24      | 296,75 | 1,494  | 8,438 |
| 25      | 294,75 | 1,444  | 10,938|
| 26      | 298,75 | 1,344  | 5,938 |
| 27      | 293,75 | 1,469  | 7,188 |
| 28      | 297,75 | 1,369  | 12,188|
| 29      | 295,75 | 1,319  | 9,688 |
| 30      | 299,75 | 1,419  | 14,688|
| 31      | 292,125| 1,459  | 14,531|

Fig. 2. 3d model of the wet part of a guide.
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 | 71.84615 | 74.63696 | 76.16436 | 77.1819 |
| 1 | 72.13242 | 76.23065 | 76.64311 | 77.45546 |
| 2 | 71.62466 | 72.60727 | 74.96188 | 76.17113 |
| 3 | 72.87196 | 78.00551 | 77.58177 | 78.30279 |
| 4 | 70.52284 | 72.61815 | 74.64398 | 75.71789 |
| 5 | 71.34676 | 75.12726 | 76.28521 | 77.16787 |
| 6 | 71.84011 | 72.46152 | 75.10506 | 76.2552 |
| 7 | 73.24223 | 78.91635 | 77.83937 | 78.81076 |
| 8 | 71.18466 | 73.72123 | 75.46981 | 76.33718 |
| 9 | 71.31495 | 74.97471 | 75.99549 | 76.92168 |
| 10 | 71.84262 | 73.04025 | 75.51601 | 76.71559 |
| 11 | 72.04613 | 75.78705 | 75.8797 | 76.6931 |
| 12 | 72.26775 | 74.44898 | 76.72787 | 77.88402 |
| 13 | 71.34509 | 74.24394 | 75.44609 | 76.60036 |
| 14 | 72.29774 | 70.85749 | 73.75359 | 74.99172 |
| 15 | 72.90423 | 77.96368 | 78.84712 | 77.7681 |
| 16 | 69.43522 | 72.98789 | 75.01044 | 75.90298 |
| 17 | 71.04041 | 74.76312 | 75.45487 | 76.1858 |
| 18 | 71.41798 | 73.67538 | 76.19555 | 77.38556 |
| 19 | 71.32955 | 76.05073 | 75.82998 | 76.78656 |
| 20 | 70.75869 | 73.10948 | 75.03615 | 76.04021 |
| 21 | 72.88367 | 76.25514 | 77.46307 | 78.55237 |
| 22 | 69.79679 | 71.75854 | 74.40408 | 75.585 |
| 23 | 72.67881 | 77.68059 | 77.02212 | 77.94046 |
| 24 | 71.88522 | 74.79831 | 76.82994 | 77.92008 |
| 25 | 72.46815 | 76.24634 | 77.14632 | 77.99227 |
| 26 | 69.34801 | 71.35854 | 73.70893 | 74.95876 |
| 27 | 72.66588 | 76.41285 | 76.60459 | 77.66013 |
| 28 | 70.46876 | 73.04595 | 75.29463 | 76.46306 |
| 29 | 70.02588 | 73.53144 | 75.06103 | 76.10218 |
| 30 | 70.35392 | 72.18364 | 75.38302 | 76.25135 |
| 31 | 73.93425 | 79.14716 | 78.13022 | 78.68652 |

For greater clarity, figure 3 shows a histogram of the pump efficiency distribution on the number of the computational model with z = 9.
Fig. 3. Histogram of efficiency distribution at $z=9$.

Fig. 4 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 output of the impeller, $D_3 / D_2$, where $D_2$ is the impeller diameter with $z = 6$.

Fig. 4. Efficiency dependence on $D_3/D_2$ at $z=6$. 
Figure 5 shows efficiency dependence on $D_4/D_3$, for $z=6$.

Fig. 5. Efficiency dependence on $D_4/D_3$ at $z=6$.

Figure 5 shows efficiency dependence on the channel diffuser angle $\Theta$, for $z=6$.

Fig. 6. Efficiency dependence on $\Theta$ at $z=6$.

Diagram on figure 7 illustrates $z$ influence on efficiency. Maximum efficiency value is achieved at $z$ equal to 9 in 90.2% of all cases which proves advisability of 9 channels.
The best option for combining geometrical parameters for the pump is model No. 7 with $z = 9$, the efficiency value of this model is 78.8%, which is almost 10% more than that of the model with the minimum efficiency value. Parameter values of the best model are presented in Table 4.

Table 4. Optimal model.

| № модели | $D_3$, мм | $D_4/D_3$ | $\Theta$, ° | $z$ | $\eta$, % |
|-----------|-----------|-----------|-------------|-----|----------|
| 7         | 292,5     | 1,488     | 11,875      | 9   | 78,81076 |

Conclusion.
In this work, the influence of the main geometrical parameters of a multistage centrifugal pump guide vane on its efficiency was determined. After analyzing the results of hydrodynamic modeling, the laws of the parameter values influence on the optimization criterion were formulated. These patterns can serve as a recommendation when designing a pump guide vane.

In the future it is planned to expand the parameter space and conduct a similar study of the radial channel translational and radial transfer guide vanes with a no-vane diffuser, which will make further pump efficiency increase possible.

References
[1] A Protopopov and D Bondareva 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012002
[2] A Protopopov and V Vigovskij 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012003
[3] P Chaburko and Z Kossova 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012011
[4] A Gouskov et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012013
[5] N Egorkina and APetrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012015
[6] K Dobrokhodov and APetrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012016
[7] N Isaev 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012026
[8] S Korsakova and AProtopopov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012032
[9] A Protopopov and C Jakovich 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012034
[10] A Shablovskiy and E Kutovoy 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012035
[11] A Petrov et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012036
[12] V Lomakin and O Bibik 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012037
[13] T Valiev and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012038
[14] Blume, M., & Skoda, R. (2019). 3D flow simulation of a circular leading edge hydrofoil and assessment of cavitation erosion by the statistical evaluation of void collapses and cavitation structures. Wear, 428-429, 457-469. doi:10.1016/j.wear.2019.04.011
[15] Yun, R., Zuchao, Z., Denghao, W., & Xiaojun, L. (2019). Influence of guide ring on energy loss in a multistage centrifugal pump. Journal of Fluids Engineering, Transactions of the ASME, 141(6) doi:10.1115/1.4041876
[16] V Lomakin et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012012
[17] V Cheremushkin and V Lomakin 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012039