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Optimization of centrifugal pump radial guide vanes

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Abstract

Centrifugal multi-stage pump hydraulic efficiency and, as a result, its optimal mode of operation depend primarily on guide vanes. Radial crossover guide vanes were optimized in order to increase pump hydraulic efficiency. Three geometric parameters and the number of guide vane channels were chosen as optimization parameters, and pump hydraulic efficiency was chosen as the criterion. Automatic parameterized design method produced 128 design models; hydraulic efficiency in work mode was calculated with the help of hydrodynamic simulation. Optimization brought about significant increase of pump hydraulic efficiency.

Introduction

More and more research papers on centrifugal pumps are published today [1]-[15]. Various methods of mathematical modeling gain increased importance in those research papers. Most interesting are publications [16]-[20] and in most cases attempts to increase pump efficiency are focused on the impeller with guide vanes relegated to a secondary role. However professor S.S. Rudnev from NPO«GIDROMASH» and his team showed that a diverting device was no less important than the impeller. Hydraulic losses – and consequently pump hydraulic efficiency and optimal work mode – depend to a large extent on the diverting device.

Guide vanes are a certain type of diverting devices. As a result, optimizing guide vanes should be the primary task when increasing centrifugal multi-stage pump hydraulic efficiency. Guide vanes are used primarily in multi-stage pumps with $n_s < 120$ and in single-stage pumps with $n_s = 250-500$. Guide vanes collect liquid and supply it to the next stage of the pump, converting kinetic energy to potential energy and decreasing moment of velocities.

The CPS 300-500 pump has 5 stages and the following rated parameters: $Q = 300 \text{ m}^3/\text{h}$ - flow rate, $H = 500 \text{ m}$ - head, $n = 2900 \text{ r/min}$ - rotational speed, $n_s = 97$ - specific speed.

Guide vanes consist of direct, crossover and inverse channels. There are several types of guide vanes, including radial crossover with vane less crossover channel, radial crossover and radial crossover with vane less space. Also guide vanes can be divided into blading and channel categories. The research was carried out with the use of radial crossover guide vanes (Fig. 1).

As a result of preliminary calculations, which most heavily influence the chosen criterion of optimization (hydraulic efficiency), 3 geometric parameters of guide vanes were obtained: inlet diameter of the guide vanes (D_3), inlet to outlet diameters ratio (D_4/D_3) and diffusion airfoil angle of a channel in radial direction (Θ). z – number of guide vane channels – was also used as an optimization



parameter because it seriously influences pump efficiency. Optimization parameters values are shown in Table 1.

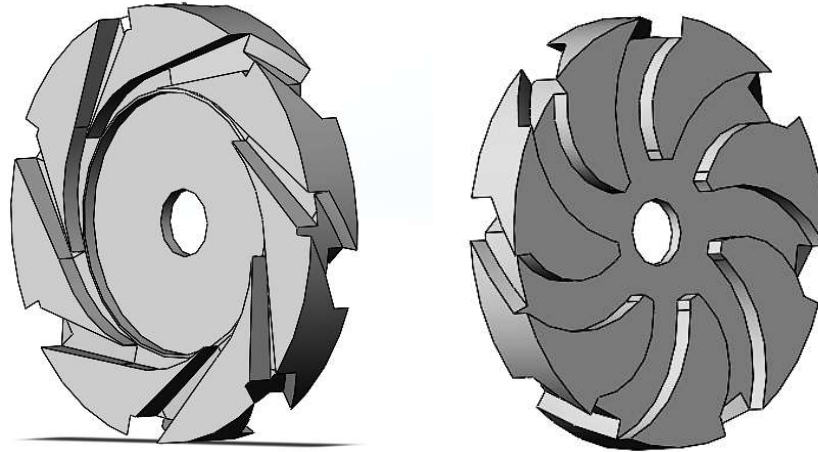


Fig. 1.Radial crossover guide vanes with vane less crossover channel.

Table1.Guide vanes optimization parameters.

Parameter	Min	Max
D_3 , mm	292	300
D_4/D_3	1,3	1,5
Θ , °	8	12
z	6	9

Sobol sequences (LP-tausequences) were used as a pseudo-random sequence generator to produce initial values, because this method delivers more uniform population of parameter space compared with other generators. 128 models were generated with different values of geometric parameters for different values of z .

Table2.Combinations of guide vanes geometric parameters.

Nº of model	D_3	D_4/D_3	Θ
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

Окончание табл. 2

№ of model	D_3	D_4/D_3	Θ
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
25	294,75	1,444	10,375
26	298,75	1,344	8,375
27	293,75	1,469	8,875
28	297,75	1,369	10,875
29	295,75	1,319	9,875
30	299,75	1,419	11,875
31	292,125	1,459	11,813

Calculation of guide vanes characteristics was carried out using methods of hydrodynamic simulation in STARCCM+ software package. The model data was built for all 128 parameter combinations by automatically creating parameterized models in SolidWorks. The example of a solid state model is shown in Fig. 2.

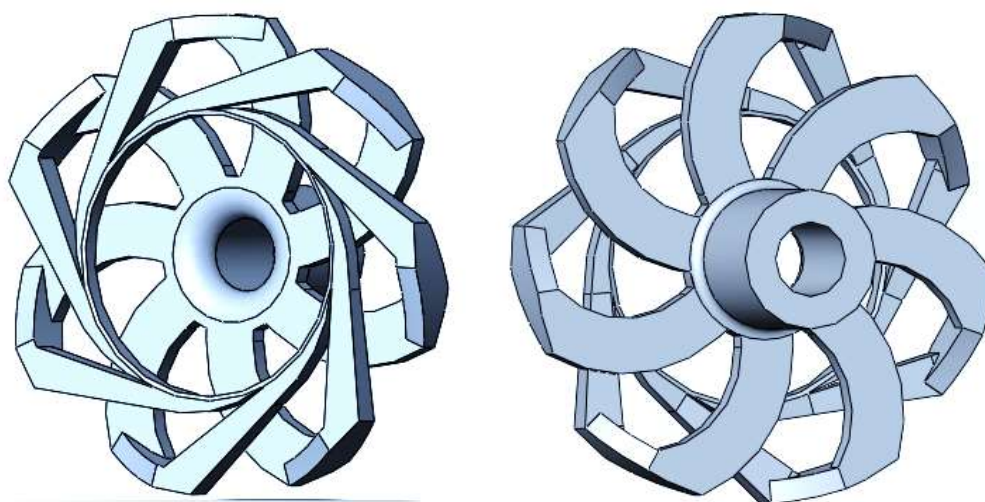


Fig. 2. Solid state model of the inner liquid volume in guide vanes.

Pump efficiency values were obtained under nominal value of pump flow rate for all 128 models. They are shown in Table 3.

Table 3. Pump efficiency values for concerned 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
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 better understanding Fig. 3 shows pump efficiency distribution bar chart depending on the number of design model for z=9.



Fig. 3. Pump efficiency distribution bar chart depending on the number of design model for $z=9$.

In order to analyze the obtained results let's look at dependence of efficiency on optimization parameters in more detail. Fig. 4 shows dependency of efficiency on value calculated as ratio of diameters of guide vanes inlet and wheel outlet D_3/D_2 , where D_2 is a diameter of wheel outlet for different values of z .

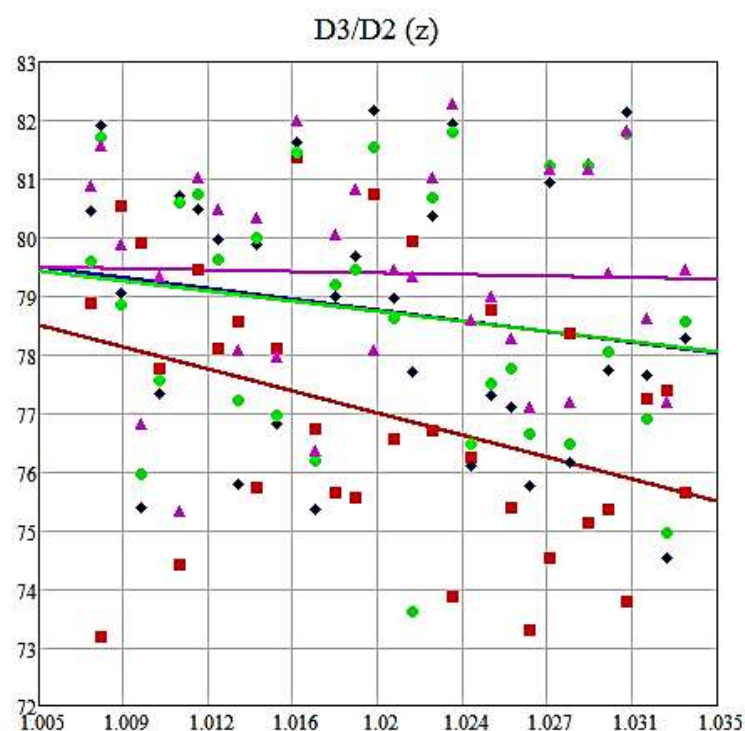


Fig. 4. Dependency of efficiency on value D_3/D_2 , where red represents dependency at $z=6$, blue – at $z=7$, green – at $z=8$, pink – at $z=9$.

Fig. 5 shows dependency of efficiency on ratio of outlet and inlet diameters of guide vanes D_4/D_3 for different values of z .

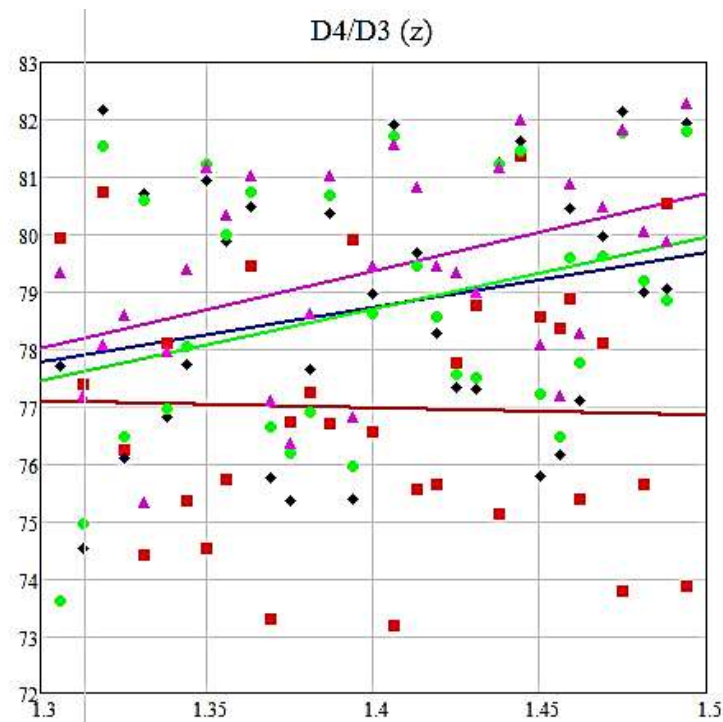


Fig. 5. Dependency of efficiency on D_4/D_3 value, where red represents dependency at $Z=6$, blue – at $z=7$, green – at $z=8$, pink – at $z=9$.

Fig. 6 shows dependency of efficiency on diffusion airfoil angle of a channel, Θ , for different z values.

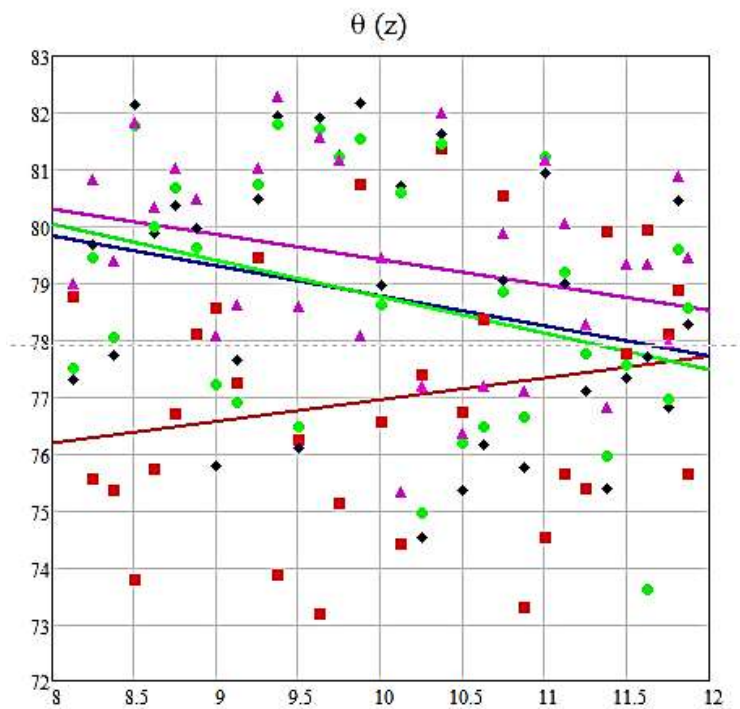


Fig. 6. Dependency of efficiency on Θ , where red represents dependency at $z=6$, blue – at $z=7$, green – at $z=8$, pink – at $z=9$.

Let's analyze dependency of the number of channels z on efficiency and build a corresponding pie chart (Fig 7). The maximum efficiency is achieved at $z=9$ in 56% of cases.

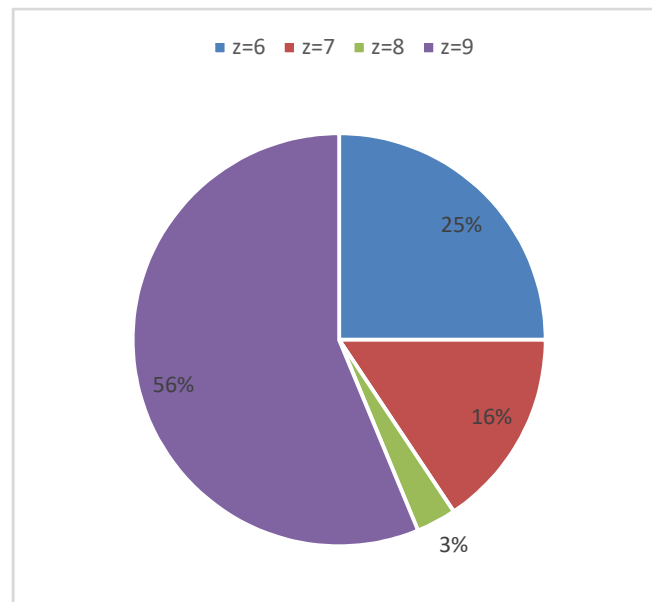


Fig. 7. Pie chart of maximum efficiency values at different z .

The best combination of geometric parameters for the pump is achieved with model №24 at $z=9$. The efficiency of this model is 82,29 %, almost 10% more than that of the model with the smallest efficiency. Parameter values and efficiency of that model are represented in Table 4.

Table 4. Optimal model.

№ of model	D_3 , mm	D_4/D_3	Θ , °	z	η , %
24	296,75	1,494	9,375	9	82,29

Conclusion. This paper determines how major geometric parameters of centrifugal multistage pump guide vanes influence pump efficiency. Patterns of influence of parameter values on optimization criterion were formulated after analyzing results of hydrodynamic simulation. These patterns can serve as recommendations when designing pump guide vanes.

In the future it is planned to expand parameter space and conduct a similar research for other types of guide vanes. This will allow to increase pump efficiency even further.

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