On the centrifugal pump optimization question

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Abstract
There is a wide range of rotor rotational frequencies and cavitation cavitation margins used in the industrial centrifugal pumps. The effect of these parameters on the dimensions criteria and cavitation characteristics of a pump is studied in this paper, the Sobol method is proposed for it and the task is to find the minimum number of point sat which the best ratio of the parameters will be achieved.

Introduction
There is a huge abundance of researches [1] - [11] in the area of centrifugal pump analysis. The studies [12] - [22] are of particular interest. A common feature of these studies is the use of complex computational methods involving various empirical formulas and hydrodynamic modeling. These methods are quite difficult to implement and therefore there is a need to find less time-consuming methods for centrifugal pumps optimization.

The main characteristics of centrifugal pumps for general industrial use are considered to be overall dimensions and cavitation qualities, characterized by the value of the suction specific speed, which determines the risk of cavitation occurrence in the pump. Cavitation destruction in the pump, the value of efficiency, pump head depend on how good the cavitation properties of the hydraulic machine are, and the compactness and amount of consumed material for manufacturing depend on the dimensions of the impeller.

The solving of the optimizing task for these characteristics is possible using the LP-tau search method, which generates points in a quasi-random manner in a selected interval of two parameters. For the considered centrifugal pumps these parameters are the cavitation margin (the overpressure of the working fluid at the pump inlet above the pressure of its saturated vapor) Δh will be varyed from 1 to 9 m of height of water and the rotor rotation speed n – from 500 to 12000 rpm. Then the generated work points field will be a rectangle.

Methods
Thus, in order to find the variables we need, we will use the formulas known from the literature that define the radial dimension of the impeller D₂ and the suction specific speed C. Rudnev's formula for calculating C:
where $Q$ – pump flow, m$^3$/s. The formula for calculating $D_2$, obtained from Euler's formula, taking into account the efficiency of the pump $\eta$:

$$D_2 = 2 \sqrt{\frac{H \cdot g}{\eta \cdot \omega^2}},$$

where $H$ – pump head, m, $\omega$ – angular velocity, rad/s. The number of calculation points will be determined as follows. A dimensionless generalized quality factor $\Phi$ is introduced. It is determined by the dependence

$$\Phi = \left( \frac{D_2}{D_{2(1)}} \right)^2 + \left( \frac{C}{C(1)} \right)^2,$$

where $D_{2(1)}$ and $C(1)$ – values of diameter (in m) and suction specific speed (dimensionless) for the first design point. The smaller the ratio, the better the quality of the centrifugal pump is. After calculating the generalized quality factor for 64 points, its minimum values for a certain number of points will be chosen: for 4, 8, 16, 32 and 64 points. Then the dependence $F_{\text{min}}(n)$ will be formulated, where $F_{\text{min}}$ is the minimum the value of the generalized quality factor for a given number of points, $n$ – the number of points. To formulate this dependence, we'll calculate the values of the generalized quality factor depending on the number of the test point and put it in the table.

Table 1. The calculated points of the suction specific speed and wheel diameter

| Point No | $n_p$, rpm | $\Delta h$, m | $C$ | $D_2$, m | $F$ | Point No | $n_p$, rpm | $\Delta h$, m | $C$ | $D_2$, m | $F$ |
|----------|-------------|----------------|-----|----------|-----|----------|-------------|----------------|-----|----------|-----|
| 1        | 6250        | 5.50           | 1458| 0.111    | 1.991| 33       | 6429        | 3.67           | 2031| 0.107    | 2.877|
| 2        | 3375        | 7.75           | 609 | 0.205    | 3.574| 34       | 3554        | 1.42           | 2287| 0.194    | 5.525|
| 3        | 9125        | 3.25           | 3158| 0.076    | 5.157| 35       | 9304        | 5.92           | 2053| 0.074    | 2.43 |
| 4        | 1937        | 6.62           | 393 | 0.357    | 10.388| 36       | 2117        | 4.79           | 547 | 0.326    | 8.78 |
| 5        | 7687        | 2.12           | 3659| 0.090    | 6.953| 37       | 7867        | 9.29           | 1238| 0.088    | 1.347|
| 6        | 4812        | 4.37           | 1333| 0.144    | 2.508| 38       | 4992        | 7.04           | 966 | 0.138    | 1.994|
| 7        | 10562       | 8.87           | 1721| 0.065    | 1.74 | 39       | 10742       | 2.54           | 4464| 0.064    | 9.71 |
| 8        | 1218        | 9.43           | 190 | 0.567    | 26.087| 40       | 1398        | 3.10           | 500 | 0.494    | 19.918|
| 9        | 6968        | 4.93           | 1763| 0.099    | 2.26 | 41       | 7148        | 7.60           | 1307| 0.097    | 1.561|
| 10       | 4093        | 2.68           | 1634| 0.169    | 3.567| 42       | 4273        | 9.85           | 643 | 0.162    | 2.315|
| 11       | 9843        | 7.18           | 1879| 0.070    | 2.06 | 43       | 10023       | 5.35           | 2384| 0.069    | 3.059|
| 12       | 2656        | 3.81           | 816 | 0.260    | 5.801| 44       | 2835        | 6.48           | 584 | 0.244    | 4.976|
| 13       | 8406        | 8.31           | 1439| 0.082    | 1.522| 45       | 8585        | 1.98           | 4302| 0.080    | 9.231|
| 14       | 5531        | 6.06           | 1199| 0.125    | 1.942| 46       | 5710        | 4.23           | 1621| 0.121    | 2.423|
| 15       | 11281       | 1.56           | 6763| 0.061    | 21.82| 47       | 11460       | 8.73           | 1890| 0.060    | 1.975|
| 16       | 859         | 5.78           | 193 | 0.804    | 52.45| 48       | 1039        | 3.39           | 348 | 0.665    | 35.923|
| 17       | 6609        | 1.28           | 4598| 0.105    | 10.832| 49       | 6789        | 7.89           | 1208| 0.102    | 1.527|
| 18       | 3734        | 3.53           | 1215| 0.185    | 3.471| 50       | 3914        | 5.64           | 895 | 0.176    | 2.905|
| 19       | 9484        | 8.03           | 1666| 0.073    | 1.736| 51       | 9664        | 1.14           | 7336| 0.071    | 25.731|
| 20       | 2296        | 2.40           | 996 | 0.301    | 7.807| 52       | 2476        | 9.01           | 398 | 0.279    | 6.388|
Thus, we have the opportunity to construct the dependence of the minimum value of the
generalized quality criterion $F_{\text{min}}$ on the number of calculation points $n$ (see figure).

Results

![Graph showing the dependence of $F_{\text{min}}$ on $n$]

**Figure 1.** Dependence of the minimum value of the generalized quality criterion on the number of points

Conclusion

For successful application of the LP-tau sequence, at least 32 points have to be used to find
a compromise between the dimensions and the suction specific speed. This can be clearly seen from
the resulting curve - the graph $F_{\text{min}}(n)$ approached the shape of the horizontal line at $n > 32$ when 64 points
of the LP-tau sequence are considered. Thus, the above method can be recommended for cavitation analysis of centrifugal pumps in order to achieve a high degree of protection against cavitation.

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