Resource Efficiency Compromise for Centrifugal Pump

A Protopopov¹,², A Mukhlaeva¹ and B Tkachuk¹

¹Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation

²E-mail: proforg6@yandex.ru

Annotation
The main characteristics of centrifugal pumps, like many other mechanisms, include resource and efficiency. Often these are two competing parameters - while increasing the first, we sacrifice the second. This is because with an increase in the rotational speed of the pump rotor, the life of the bearings drops rapidly, and the efficiency, on the contrary, increases. There is a need to find a compromise solution, when at the selected value of one parameter the second is maximum.

Introduction
The resource and efficiency of such a pump, among other parameters, are influenced by the axial clearance between the impeller and the pump casing and the frequency of rotation of the pump rotor. Modeling the front axial clearance using hydrodynamic methods [1] - [8] is extremely difficult due to the unevenness of the computational grid. Also, the use of other methods for calculating centrifugal pumps [9] - [15] for such optimization is difficult, too. Therefore, it was decided to use the LP-Tau search method, since this method does not imply an exact definition of the objective function.

Note that the currently existing methods of finding a compromise between the resource and efficiency are for small rotational speeds of the pump shaft, which creates significant errors in the calculation of the parameters of the high-speed low-flow pump.

Methods
The LP-Tau search allows generating points in a quasi-random manner in a specified interval for two parameters. For the investigated pump axial clearance, we will vary in the range of 0.5 ... 1.5 mm, the rotor speed n — in the range of 3,000 ... 8,000 rpm. Then the field of generated work points will be a rectangle (Fig. 1).

The critical effect on the radial force is the supply of pump fluid so that we will build a family of trade-off curves for different feed values. We start construction for the case when \( Q = Q_o \).

For this distribution, we build a compromise curve for the following reasons: for the same value of one parameter, the point with the highest value of the second is considered to be the "winning." From this, the compromise curve must pass through these "winning" points (Fig. 2).

Similarly, we construct the trade-off curves for different flow rates \( Q = 0,5Q_o, 0,75Q_o, 1,25Q_o, 1,5Q_o \) (Figures 3–6).
Figure 1. Points generation area.

Figure 2. Compromise curve ($Q = Q_o$)

Figure 3. Compromise curve ($Q = 0.5Q_o$)
Figure 4. Compromise curve ($Q = 0.75Q_o$)

Figure 5. Compromise curve ($Q = 1.25Q_o$)

Figure 6. Compromise curve ($Q = 1.5Q_o$)
Results
Figure 7 shows the resulting trade-off curves in one coordinate system.

![Figure 7](image)

Figure 7. The family of compromise curves at different flow rates.

Conclusion
Analysis of the obtained family of curves suggests that it is undesirable to use this pump in under load conditions. This is explained quite simply. The hydrodynamic radial force with this arrangement of the diverting device is directed downwards, as a result of which a large reaction occurs in the bearing. Reducing consumption contributes to an increase in the hydrodynamic component of the radial force, which, in turn, leads to an increase in the load on the bearing, and this causes a decrease in the resource. When the pump is operating in overload conditions, the hydrodynamic radial force changes direction, as a result of which the effect on the bearing decreases. This causes a decrease in the equivalent dynamic load, which leads to an increase in resource. Efficiency increase, on the contrary, hurts efficiency. This, again, is due to the resulting dependence of efficiency on flow. Even though the increase in consumption leads to an increase in resource, the use of this pump in overload modes is unacceptable. Firstly, it does not provide the necessary pressure, as can be seen from the predictive characteristics. Secondly, the efficiency of the pump reduces.

As a result of the analysis of this family of trade-off curves, the deviation from the optimal operation mode has a substantial impact on the resource and efficiency. Therefore, it is necessary to ensure the operation of the pump in the mode as close as possible to the optimum. The obtained family of curves also allows us to estimate the effect of the rotor speed and axial clearance between the outlet body and the impeller on the resource and efficiency of the pump. Also, the constructed family of curves makes it possible to conclude that the use of frequency regulation is advisable.

References
[1] P Chaburko and Z Kossova 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012011
[2] V Lomakin et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012012
[3] A Gouskov et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012013
[4] N Egorkina and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012015
[5] K Dobrokhodov and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012016
[6] N Isaev 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012026
[7] A Shablovskiy and E Kutovoy 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012035
[8] A Petrov et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012036
[9] Zhang, S., Li, H., & Xi, D. (2019). Investigation of the integrated model of side chamber, wear-rings clearance, and balancing holes for centrifugal pumps. Journal of Fluids Engineering, Transactions of the ASME, 141(10) doi:10.1115/1.4043059
[10] Sengpanich, K., Bohez, E. L. J., Thongkrue, P., & Sakulphan, K. (2019). New mode to operate centrifugal pump as impulse turbine. Renewable Energy, 983-993. doi:10.1016/j.renene.2019.03.116
[11] Zhang, Z.-., Chen, H.-., Ma, Z., He, J.-., Liu, H., & Liu, C. (2019). Research on improving the dynamic performance of centrifugal pumps with twisted gap drainage blades. Journal of Fluids Engineering, Transactions of the ASME, 141(9) doi:10.1115/1.4042885
[12] Pirouzpanah, S., Patil, A., Chen, Y., & Morrison, G. (2019). Predictive erosion model for mixed flow centrifugal pump. Journal of Energy Resources Technology, Transactions of the ASME, 141(9) doi:10.1115/1.4043135
[13] Yousefi, H., Noorollahi, Y., Tahani, M., Fahimi, R., & Saremian, S. (2019). Numerical simulation for obtaining optimal impeller's blade parameters of a centrifugal pump for high-viscosity fluid pumping. Sustainable Energy Technologies and Assessments, 34, 16-26. doi:10.1016/j.seta.2019.04.011
[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