Optimization of axial volumetric drive aviation pump

A Protopopov\textsuperscript{1,2}, A Mukhlaeva\textsuperscript{1} and E Melnichuk\textsuperscript{1}

\textsuperscript{1}Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation

\textsuperscript{2}E-mail: proforg6@yandex.ru

Annotation

This article discusses a volumetric drive aircraft axial pump and solves the problem of its optimization by the Sobol method. The optimization criteria were the radial dimension and the power expended. In this case, the non-uniformity of the pump operation over time and the variable value of the pressure consumed by the network were taken into account. The last two parameters act as constructive variable parameters. As a result of the work, we obtained a compromise curve. The radial dimension is the power expended.

Introduction

Methods for calculating dynamic pumps \cite{1} - \cite{4} are widely reported in the literature. Of greatest interest are publications \cite{5} - \cite{12}.

When developing axial pumps for aviation technology, the essential characteristics are mass and power consumption and both parameters should be as small as possible. As the size of the pump impeller increases, its efficiency increases, thereby reducing power consumption. But at the same time growing mass. As both parameters increase, it is necessary to find the optimal diameter of the pump with high efficiency, provided a relatively small mass - a priority parameter for aviation. Additionally, the mass can be reduced by using high-speed machines with relatively low pressure. Therefore, this study considers a hydraulic unit consisting of an axial pump and an axial-piston motor with an inclined disk.

The indicated problem is widely reported in the literature \cite{13} - \cite{16}, where the main emphasis is on the use of labor-intensive methods, such as hydrodynamic modeling. In this work, a less labor-consuming LP-Tau search method is used in its application to the considered area of mechanical engineering.

According to the efficiency of a small axial-piston hydraulic motor, which rotates the pump, it can be assumed constant; the same applies to the mechanical efficiency of an axial pump. Its volumetric efficiency is approximately equal to 1, which simplifies the task, and the hydraulic efficiency can be estimated using the Lomakin formula. The required flow rate of the axial pump determines the power consumption, which is thus the focus of the paper. The mass and power consumption of the pump, among other parameters, are influenced by the pressure and the relative operating time of the hydraulic unit, the reduction of which entails an increase in the pump flow rate and, therefore, pressure losses along the length of the pipeline.
Methods
For the analysis, we use LP-Tau search, since this method does not imply a precise definition of the objective function. It generates points in a quasi-random manner in the selected interval for the two parameters we are considering — head and relative pump operation time: the relationship between pump durations and aircraft flight time. The head $H$ can vary from 5 to 15 m; the relative operating time of $t_p / t$ is from 0.05 to 1. Then the field of generated work points will be a rectangle (Fig. 1).

The calculated points obtained using LP-Tau search are in the table.

![Figure 1. Point generation area.](image)

| Point # | $H$, m | $t_p / t$ | Point # | $H$, m | $t_p / t$ | Point # | $H$, m | $t_p / t$ | Point # | $H$, m | $t_p / t$ |
|---------|--------|-----------|---------|--------|-----------|---------|--------|-----------|---------|--------|-----------|
| 1       | 10     | 0,5250    | 17      | 10,3125| 0,0796    | 33      | 10,156 | 0,3320    | 49      | 10,46  | 0,7773    |
| 2       | 7,5    | 0,7625    | 18      | 7,8125 | 0,3171    | 34      | 7,6562 | 0,0945    | 50      | 7,9687 | 0,5398    |
| 3       | 12,5   | 0,2875    | 19      | 12,8125| 0,7921    | 35      | 12,656 | 0,5695    | 51      | 12,96  | 0,0648    |
| 4       | 6,25   | 0,6437    | 20      | 6,5625 | 0,1984    | 36      | 6,4062 | 0,4507    | 52      | 6,7187 | 0,8960    |
| 5       | 11,25  | 0,1687    | 21      | 11,5625| 0,6734    | 37      | 11,406 | 0,9257    | 53      | 11,718 | 0,4210    |
| 6       | 8,75   | 0,4062    | 22      | 9,0625 | 0,9109    | 38      | 8,9062 | 0,6882    | 54      | 9,2187 | 0,1835    |
| 7       | 13,75  | 0,8812    | 23      | 14,0625| 0,4359    | 39      | 13,906 | 0,2132    | 55      | 14,218 | 0,6585    |
| 8       | 5,625  | 0,9406    | 24      | 5,9375 | 0,4953    | 40      | 5,7812 | 0,2722    | 56      | 6,0937 | 0,7179    |
| 9       | 10,625 | 0,4656    | 25      | 10,9375| 0,9703    | 41      | 10,781 | 0,7476    | 57      | 11,093 | 0,2429    |
| 10      | 8,125  | 0,2285    | 26      | 8,4375 | 0,7328    | 42      | 8,2812 | 0,9851    | 58      | 8,593  | 0,4804    |
| 11      | 13,125 | 0,7031    | 27      | 13,4375| 0,2578    | 43      | 13,281 | 0,5101    | 59      | 13,593 | 0,9554    |
| 12      | 6,875  | 0,3468    | 28      | 7,1875 | 0,8515    | 44      | 7,0312 | 0,6289    | 60      | 7,3437 | 0,1242    |
| 13      | 11,875 | 0,8218    | 29      | 12,1875| 0,3765    | 45      | 12,031 | 0,1539    | 61      | 12,34  | 0,5975    |
| 14      | 9,375  | 0,5843    | 30      | 9,6875 | 0,1390    | 46      | 9,5312 | 0,3914    | 62      | 9,8437 | 0,8368    |
| 15      | 14,375 | 0,1093    | 31      | 14,6875| 0,6140    | 47      | 14,531 | 0,8664    | 63      | 14,843 | 0,3617    |
| 16      | 5,3125 | 0,5546    | 32      | 5,15625| 0,8070    | 48      | 5,4687 | 0,3023    | 64      | 5,0781 | 0,6808    |

Each point corresponds to values of the diameter of the pipeline, equal to the diameter of the impeller of an axial pump, and the power expended, which can be obtained by the following:

$$D_t = \frac{0.0827Q^2L_p\lambda}{H}.$$


\[ N = \frac{\rho g Q H}{\eta} \]

After calculations (Table 2), it is possible to construct the distribution of all calculated points in the coordinates \( D_t \) — \( N \).

**Table 2.** Calculated points of power consumption and diameter of the pipeline equal to the diameter of the pump

| Point # | \( N, V_t \) | \( D, m \) | Point # | \( N, V_t \) | \( D, m \) | Point # | \( N, V_t \) | \( D, m \) | Point # | \( N, V_t \) | \( D, m \) |
|---------|--------------|------------|---------|--------------|------------|---------|--------------|------------|---------|--------------|------------|
| 1       | 861          | 0.047      | 17      | 5217         | 0.099      | 33      | 1335         | 0.056      | 49      | 634          | 0.04       |
| 2       | 454          | 0.043      | 18      | 1062         | 0.06       | 34      | 3268         | 0.098      | 50      | 663          | 0.049      |
| 3       | 1892         | 0.057      | 19      | 771          | 0.038      | 35      | 1024         | 0.043      | 51      | 8031         | 0.103      |
| 4       | 438          | 0.048      | 20      | 1378         | 0.075      | 36      | 624          | 0.055      | 52      | 350          | 0.041      |
| 5       | 2795         | 0.072      | 21      | 800          | 0.041      | 37      | 594          | 0.036      | 53      | 1244         | 0.05       |
| 6       | 949          | 0.053      | 22      | 473          | 0.038      | 38      | 597          | 0.043      | 54      | 2104         | 0.073      |
| 7       | 756          | 0.036      | 23      | 1457         | 0.047      | 39      | 2791         | 0.063      | 55      | 1015         | 0.04       |
| 8       | 278          | 0.042      | 24      | 528          | 0.053      | 40      | 897          | 0.068      | 56      | 386          | 0.046      |
| 9       | 1024         | 0.049      | 25      | 545          | 0.036      | 41      | 677          | 0.04       | 57      | 1957         | 0.063      |
| 10      | 1505         | 0.068      | 26      | 533          | 0.043      | 42      | 401          | 0.038      | 58      | 798          | 0.05       |
| 11      | 880          | 0.04       | 27      | 2257         | 0.059      | 43      | 1190         | 0.045      | 59      | 696          | 0.035      |
| 12      | 856          | 0.06       | 28      | 393          | 0.041      | 44      | 613          | 0.051      | 60      | 2413         | 0.089      |
| 13      | 689          | 0.038      | 29      | 1436         | 0.052      | 45      | 3267         | 0.074      | 61      | 952          | 0.043      |
| 14      | 731          | 0.046      | 30      | 2879         | 0.08       | 46      | 1073         | 0.053      | 62      | 556          | 0.039      |
| 15      | 5419         | 0.082      | 31      | 1118         | 0.041      | 47      | 814          | 0.036      | 63      | 1829         | 0.05       |
| 16      | 424          | 0.052      | 32      | 292          | 0.045      | 48      | 768          | 0.066      | 64      | 335          | 0.049      |

The obtained results allow us to construct a compromise curve.

**Results**

![Figure 2. Distribution of calculated points and a compromise curve constructed from them.](image)
According to this distribution, we build a compromise curve according to the following rule: with the same value of one parameter, the point with the minimum value of the second is considered optimal.

Conclusion
According to this distribution, we build a compromise curve according to the following rule: with the same value of one parameter, the point with the minimum value of the second is considered optimal. This is seen from the compromise curve obtained - when considering 64 LP-tau sequence points, 13 of them entered the Pareto set and formed a compromise curve, but with a power consumption of more than 4000 W, only two points hit the curve. Thus, the described method is recommended when calculating high-speed low-power axial pumps.

List of 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] T Valiev and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012038
[5] V Cheremushkin and V Lomakin 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012039
[6] 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
[7] Sengpanich, K., Bohez, E. L. J., Thongkruer, 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
[8] 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
[9] 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
[10] 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
[11] 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
[12] 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
[13] N Egorkina and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012015
[14] K Dobrokhodov and A Petrov 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012016
[15] N Isaev 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012026
[16] A Shablovskiy and E Kutovoy 2019 IOP Conf. Ser.: Mater. Sci. Eng. 492 012035