Wear resistance of the main friction pairs of serial and upgraded plate type vacuum pumps

A V Zakharin, A T Lebedev, R V Pavlyuk, P A Lebedev and R R Iskenderov

Stavropol State Agrarian University, 12, Zootechnicheskiy lane, Stavropol, 355017, Russia
E-mail: Anton-zaharin@mail.ru

Abstract. Plate type vacuum pumps are used in various industries and agriculture due to their high specific efficiency and simple design. The disadvantage of this type of pump is a low inter-repair resource, which is caused by an increase in internal gas flows due to wear of the main friction pair "cast iron-textolite". To modernize the design of a plate-type vacuum pump, the authors proposed using an anti-friction material PTFE, and as a result, replacing the main friction pair "cast iron-textolite" with friction pairs "cast iron-PTFE" and "textolite - PTFE". Therefore, this article presents the results of a comparative experiment to determine the wear resistance of friction pairs of a serial and upgraded pump. Analysis of the experiment results showed that the "cast iron-PTFE" and "textolite-PTFE" friction pairs are more wear-resistant when changing the speed of relative movement and pressure in the contact zone than the "cast iron-textolite" friction pair, but they are more demanding to the presence of abrasive in the contact zone. The use of PTFE material is promising as a material for the surfaces of friction pairs of vacuum pumps. However, it requires protection measures and cleaning of the contact zone from wear products of the pump friction pairs themselves and the abrasive coming from the pumped medium.

1. Introduction
Plate type vacuum pumps are widely used both in industry and in agriculture for various technological processes (drive of machine tools, transportation of liquids, drying, degassing, etc.). This wide distribution is due to their high specific efficiency, high productivity and simplicity of design. However, when the operating time reaches 800-900 hours, due to wear of the working surfaces of the rubbing parts of the pump, there is an increase in internal gas flows, which leads to a decrease in performance and stability of its operation. This, in turn, leads to negative consequences such as: a decrease in the quality of products, an increase in energy consumption and a deterioration in the health of farm animals [1, 2]. Therefore, their further operation is not economically feasible, and therefore they have to be repaired.

The wear rate of the working surfaces of the parts of plate-type vacuum pumps affects the increase in gaps in the friction pairs, an increase in gas leaks and a decrease in the actual pump supply, which is the determining factor for sending the pump for repair. Therefore, according to literature sources [3, 4, 5], in relation to plate type vacuum pump, the main parameters that affect the wear rate of the main friction pairs are:
- the type and properties of the materials used for making contact parts and the quality of processing of the working surfaces of the pump parts (M);
- the degree of changes in load, speed and contact pressure (υ and P);
- type, conditions and modes of lubrication (Кl);

Published under licence by IOP Publishing Ltd
- the concentration of abrasive at the contact points ($C_a$).

A distinctive feature of the operation of the considered working surfaces of pump parts is that they all work under conditions of boundary friction. The process of wear of the pump friction pairs is further intensified by the arrival of abrasive with the pumped air, and abrasive, which is the products of wear of the pump. Insufficiently stable lubrication conditions of parts, high contact speeds (up to 15 m/s), in the presence of abrasive and high coefficients of friction, lead to intense wear. Therefore, the authors proposed a modernized design of a plate-type vacuum pump (patent RU 2333392) due to the use of PTFE material.

The purpose of these studies is to identify the most significant factors that affect the wear resistance of the main friction pairs of serial and upgraded pumps.

2. Materials and methods

Due to the multivariate influence of the studied parameters on the characteristic (wear rate), it was decided to conduct a multi-factor experiment to determine the most optimal operating modes, materials of friction pairs of a plate-type vacuum pump ("cast iron-textolite" (I-T), "cast iron-PTFE" (I-P), "textolite-PTFE" (T-P)) and the degree of influence of individual parameters on wear resistance.

To implement a multi-factor active experiment, a three-level second-order Box-Behnken plan for three factors was adopted. It belongs to the group of almost D-optimal plans, in which the variance of reproducibility of experimental results is evenly distributed over all points of the response surface. The second-order mathematical model derived from such plans has the same statistical characteristics in all directions.

The following factors were selected as variation factors for all the studied friction pairs:
- the speed range $X_1 (\nu)$ is from 2 to 15 m/s, chosen because in series pumps the speed of the end surface of the blade can reach 15 m/s, and in the upgraded version it is on average 2 m/s for different pumps;
- the range of pressure variation $X_2 (P)$ from 52 to 84 MPa is selected because the average pressure exerted by the blade on the body during operation is in this range;
- the range of variation of the $X_3 (C_a)$ abrasive concentration from 0 to 10% is chosen because: 0% - ideal working conditions (in real operation of vacuum pumps is practically not achievable), and 10% - the maximum possible concentration of the abrasive in the friction pair (excess abrasive is not retained in the contact zone and is removed with grease).

The wear rate ($\gamma$) of the studied friction pairs was chosen as the optimization parameter (response function).

The most informative and reasonableness in making a decision about the choice of materials in friction pairs is given by the evaluation through indicators of relative wear resistance, which are relations:

$$k_\nu = \frac{\gamma_{\text{umin}}}{\gamma_{\text{umax}}} \times 100\%$$  \hspace{1cm} (1)

$$k_\rho = \frac{\gamma_{\text{pmin}}}{\gamma_{\text{pmax}}} \times 100\%$$  \hspace{1cm} (2)

where $k_\nu$ – indicator of relative wear resistance of the change in the speed $\nu$ of the movement, at $P = \text{const}$;

$k_\rho$ – index of relative wear resistance of pressure change $P$, at $\nu = \text{const}$;

$\gamma_{\text{umin}}$ and $\gamma_{\text{umax}}$ – the values of the wear rate at the minimum speed of $\nu_{\text{min}} = 2$ m/s and the maximum speed of $\nu_{\text{max}} = 15$ m/s, respectively, $\mu$m/h;

$\gamma_{\text{pmin}}$ and $\gamma_{\text{pmax}}$ – wear rate values at minimum pressure $P_{\text{min}} = 52$ MPa and maximum pressure $P_{\text{max}} = 84$ MPa, respectively, $\mu$m/h.

3. Results and Discussion

After processing the data obtained during the experiment, calculations of the relativity indicators $k_\nu$ and $k_\rho$ were performed, which are presented in table 1.
Table 1. Relative wear resistance indicators $k_u$ and $k_p$ 

| Relative wear resistance index $k_u$ and $k_p$ for $Ca = 5\%$ | Influence of the indicator on the increase in the wear rate of the friction pair, % | \( I-T \) | \( I-P \) | \( T-P \) |
|---|---|---|---|---|
| \( k_u \) at \( P = 52 \, MPa \) | \( 48.6 \) | \( 23.4 \) | \( 61.9 \) | \( 46.8 \) | \( 62.9 \) | \( 51.1 \) |
| \( k_u \) at \( P = 68 \, MPa \) | \( 61.5 \) | \( 37.8 \) | \( 73 \) | \( 59.3 \) | \( 74 \) | \( 63.9 \) |
| \( k_u \) at \( P = 84 \, MPa \) | \( 72.7 \) | \( 50.4 \) | \( 82 \) | \( 69.6 \) | \( 82.9 \) | \( 74.5 \) |
| \( k_P \) at \( v = 2 \, m/s \) | \( 14.6 \) | \( 14 \) | \( 23 \) | \( 20.5 \) | \( 24.7 \) | \( 21.1 \) |
| \( k_P \) at \( v = 8.5 \, m/s \) | \( 25.7 \) | \( 27.8 \) | \( 32.4 \) | \( 31.6 \) | \( 34.2 \) | \( 32.3 \) |
| \( k_P \) at \( v = 15 \, m/s \) | \( 33.2 \) | \( 39 \) | \( 38.3 \) | \( 39.2 \) | \( 40 \) | \( 39.8 \) |

Analysis of table data reveals the following patterns:
- increasing the speed of movement of friction surfaces ($k_u$) in pairs of friction with lubrication at \( P=\text{const} \) increases the wear rate significantly more intensively, compared to the same pair of friction without lubrication ($k_u$). For a friction pair (I-T), the difference in the wear rate with and without lubrication, depending on the pressure between the rubbing surfaces, is 22...25%, and for friction pairs (I-P) and (T-P) 8...15%. The higher increase in the wear rate in friction pairs with a lubricant compared to friction pairs without lubrication is due to the fact that the oil film on the contact surfaces allows you to retain and accumulate abrasives and wear products that worsen the working conditions of the friction pair. In the absence of lubrication wear products are easily removed from the surface when they are dynamically affected;
- an increase in the speed of movement of the rubbing surfaces gives a greater increase in the wear rate (48.6...82.9% in pairs with lubrication and 23.4...39.8% without lubrication) ($k_u$) than an increase in the pressure in the rubbing surfaces which gives respectively 14...39.8% in pairs with lubrication and 14.6...40% without lubrication ($k_p$);
- as the pressure increases, the change in the wear rate gives a smaller increase in the wear rate for all friction pairs, both with and without lubrication ($k_1$, $k_2$, and $k_3$). This is due to an increase in the area of actual contact of the surfaces, and as a result-a decrease in the specific pressure. So for the friction pair (I-T), the decrease with increasing pressure is 1.7-1.8%, and for the friction pair (I-P) and (T-P), the decrease is 2.1-2.2%;
- an increase in pressure at a speed of $v = 2 \, m/s$ in friction pairs with a lubricant gives a greater increase in the wear rate compared to friction pairs without lubrication, but with increasing travel speed, the increase in the wear rate becomes higher in friction pairs without lubrication. This is due to the fact that when the speed of movement of the rubbing surfaces increases, the hydroplaning effect appears, which reduces the degree of contact of the rubbing surfaces.

4. Conclusion
Studies have shown that the friction pairs (I-P) and (T-P) are more wear-resistant when changing the speed of relative movement and pressure in the contact zone than the friction pair (I-T), but more demanding to the presence of abrasive in the contact zone. The use of PTFE material is promising as a material for the surfaces of friction pairs of vacuum pumps. However, it requires protection measures and cleaning of the contact zone from wear products the pump friction pairs themselves and abrasives coming from the pumped medium.
References
[1] Krasnov I N, Krasnova A Y and Miroshnikova V V 2018 EurAsian Journal of BioSciences 12 (1) 83-87
[2] Kapustin I V, Grinchenko V A, Gritsay D I and Kapustina E I 2016 Research Journal of Pharmaceutical, Biological and Chemical Sciences 7 (2) 1414-1419
[3] Lebedev A T, Pavlyuk R V, Zakharin A V, Lebedev P A and Voronin S M 2018 Research journal of pharmaceutical biological and chemical sciences 9 (6) 780-784.
[4] Pavlyuk R V, Lebedev A T, Zacharin A V and Lebedev P A 2017 Engineering for Rural Development 16 207–211.
[5] Zakharin A V, Lebedev A T, Pavlyuk R V and Lebedev P A 2018 Engineering for Rural Development 17 97-101.