Theoretical and experimental substantiation of the applicability of PTFE-4 for sealing movable seals in vacuum milking systems

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Abstract. The article describes the results of theoretical calculations of the loads acting on the radial surface of the blade of a plate-type vacuum pump used in milking systems. On the basis of experimental studies of Fluoroplast-4, its use for sealing highly loaded movable seals in vacuum systems is substantiated. The results of experimental studies on the dependence of the actual contact area and specific pressure on the load of 0-100 N are presented. An analysis of the data showed that in the range of loads of 0 to 10 N, the dependence is almost linear. In the range of 20 to 100 N, the specific pressure reaches a limiting value and ranges from 47.3 to 57.8 MPa, i.e. it stabilizes. These data indicate that for sealing the most loaded and critical movable seals in milking vacuum systems, it is possible to use Fluoroplast-4.

1. Introduction

The automation and robotization of agriculture impose increased requirements on all systems of the technological process. Vacuum systems are one of the most demanded systems in milk production due to the fact that they are used to perform various technological processes: milking, milk transportation, equipment drive, degassing of working areas, etc. [1, 2]. Therefore, to ensure the reliability of these systems, increased requirements are imposed on the methods of calculation, design and manufacture. The reliability and efficiency of technological equipment depend on the correctness of design solutions. It becomes necessary to substantiate the decisions made, especially at the stage of designing vacuum milking systems and its individual elements.

One of the main indicators that determine the efficiency and reliability of vacuum systems are ultimate vacuum and pumping speed. A decrease in these indicators causes a sharp deterioration in the quality of technological processes, which affects the quality of products and economic costs of production [3, 4, 5]. For example, insufficient vacuum in the milking system decreases the milk yield of cows which contributes to the development of mastitis. As the practice of operating vacuum systems shows, the main reasons affecting these indicators are gas leaks through the movable seals of the elements of vacuum systems. Such seals include a ball valve and a seal in the ball valve, a wedge and a wedge seal ring in the gate valve, a valve and its seat, end and radial surfaces of blades and a vane-type vacuum pump housing [6, 7, 8].

All this creates prerequisites for improving the performance of elements of the vacuum systems, through the use of modern technologies and high-tech materials. Fluoroplastic-4 polymer is used as a seal in ball valves; however, its use in other movable joints of vacuum systems is poorly studied, since...
they all have different design characteristics and operating conditions. Therefore, the aim of this article is to study operating conditions of movable seals of vacuum systems, using the example of radial seals of a blade-housing of a vane-type vacuum pump and the use of fluoroplastic-4 material.

2. Materials and methods

Fluoroplast-4 is a high-molecular crystallized polymer, a high-tech unique material. It has become widespread due to the presence of unique physical and chemical properties: absolute chemical resistance, low friction (0.02 for steel), strength, stability and workability in the temperature range from 269 to +260°C. Foreign analogues are Soreflon (France), GOSTflon (Germany), Teflon (USA), Fluon (England), Agloflon (Italy), Polyflon (Japan).

Research methods imply a theoretical calculation of possible loads in the zone of the movable seal blade-housing of a vane-type vacuum pump to study properties of the PTFE-4 material.

Since in terms of tightness of the movable seal, the most important indicator is the actual contact area, the laboratory unit was designed to determine it (Figure 1).

![Figure 1. The laboratory unit for determining the area of actual contact](image)

The experimental research technique using the designed laboratory unit was as follows. On the end surface of the sample (2.5 mm long; radius of rounding 2 mm), the long-drying polymer paint is applied. The sample is fixed between the thrust bearing and the base plate fixed on the bed. The arrow is set to zero on the scale. Using the screw, a force is created. It is transmitted through the sleeve to the spring with a known deformation ratio. The force from the spring is transmitted through the center bearing to the sample forcing it to deform in the contact zone with the center bearing leaving an imprint of the contact area.

Linear dimensions of the imprint of the contact of the material sample with the thrust bearing were measured using the digital caliper TSCHTSTS-I-150 0.01 GOST 166-89.

3. Results

One of the most critical movable seals are vane-type radial vane-casing vane-type seals, since their unsatisfactory operation affects characteristics such as pump performance and ultimate vacuum, which affects the quality characteristics of the vacuum system.

The main parameters affecting the performance of this movable seal is a contact area of the radial surface of the blade and the inner surface of the pump casing and the pressure in the contact zone. Analyze the diagram of the main forces acting in the contact zone of the blade with the pump casing (Figure 2).
Figure 2. The diagram of forces acting at the point of contact between the blade and the casing of the vane-type vacuum pump.

The pressure at the contact point will be influenced by all the projections of forces on the X-axis. Since the projection of the friction force is always directed tangentially to the radius of movement, its projection onto the X-axis will be zero, as well as the projection of the Coriolis force arising due to the eccentrically positioned rotor. Therefore, the resulting sum of forces $F_s$ is determined by the vector sum of gravity $mg$ and centrifugal force $F_1$:

$$\overrightarrow{F_s} = \overrightarrow{F_1} + mg$$

(1)

Making transformations and passing from a vector sum to a scalar sum, we have:

$$F_s = m\omega^2 R \left( 1 + \frac{e}{R} \cos \alpha - \frac{(\frac{e}{R})^2}{2} \sin^2 \alpha \right) - mg \cos \alpha$$

(2)

where:
- $m$ – plate mass, kg;
- $\omega$ – angular speed, degrees/sec;
- $R$ - radius of the inner surface of the pump cylinder, m;
- $e$ - eccentricity, m;
- $\alpha$ - blade rotation angle, degrees.

Substituting the actual parameters for the vacuum pump PBH 40/350 in the formula, the graph of the dependence of force $F_s$ on the angle of rotation of the pump rotor can be built (Figure 3).

Figure 3. Dependence of $F_s$ on the pump rotation angle.

An analysis of the graph shows that the resulting sum of all forces acting on the radial surface of the blade varies from 73.59 N to 91.61 N. These data allow us to determine the specific pressure in the
contact zone of the blade and the pump casing. Taking into account the fact that the linear dimensions of the blade for the pump brand RVN 40/350 are 200x36x5.5 mm, we obtain that the theoretical area of the end surface of the blade is $S_t = 0.0011 \text{ m}^2$. Therefore, the theoretical specific pressure in the P$_t$ contact zone will vary in the range of 66.9 ... 83.3 kPa. However, operational studies of the vacuum pump blades have shown that the actual contact area is less than the theoretical one $S_f \ll S_t$. This is due to the fact that the blade moves along the curved path with a variable radius. In addition, the blade is made of PCB, which has a fairly high hardness, and does not deform under pressure. The end surface of the blade does not have a constant contact patch, and force $F_s$ is distributed over a much smaller area, which increases the specific pressure in the contact zone, which reaches values up to 100 MPa. In this case, the increased specific pressure in the contact zone increases the wear in the blade-housing friction pair and heats the contact zone. Heating increases the hardness, as a result of which the wear of the cast-iron inner surface and the tightness of the movable seal decrease.

An analysis showed that in the contact zone of the blade-housing of the vane-type vacuum pump, to ensure the tightness of the movable seal, it is necessary to use the blade-housing in the friction pair, to limit the contact of the radial surface of the blade made of PCB with the inner surface of the housing made of cast iron, while maintaining the tightness of the movable seals. To this end, the authors suggested using Fluoroplast-4. It has a number of unique properties, which indicates its high potential as a material for sealing movable seals in vacuum systems. Previous studies of friction pairs using this material showed its high potential [9, 10] For this purpose, we conducted an experiment using the laboratory setup described above. The results are shown in Figure 4.

![Figure 4](image)

**Figure 4.** Dependence of the actual contact area on the specific pressure of the force.

An analysis of the data presented in Figure 4 showed that in the load range from 0 to 10 N, the dependence of the actual contact area and specific pressure on the force is almost linear. In the range from 20 to 100 N, the specific pressure reaches a limiting value and ranges from 47.3 to 57.8 MPa, that is, it stabilizes. The actual contact area in this load range increases with an increasing force. At loads over 70 N, as a result of plastic deformations, the sample does not restore its original shape. To prevent plastic deformations in the PTFE-4 material, the blade mass should be reduced, due to which the resulting force $F_s$ will also decrease. It is planned to solve a number of issues such as: fastening the PTFE-4 to the end of the blade and testing.

4. **Conclusion**

The theoretical calculations and experimental studies allow us to conclude that fluoroplastic-4 can be used for sealing the most loaded and critical movable seals in vacuum milking systems. This material can reduce the coefficient of friction, and the heating and wear of this seal. It significantly increases
the area of actual contact, which will ensure the greater sealing of the contact area. All this will contribute to a stable vacuum and a more effective process of milking.

References
[1] Merkle U 2018 *Vakuum in Forschung und Praxis* 30(2) 54-57
[2] Burgmann W, Göhler K 2013 *Metallurgist* 57(5-6) 516-525
[3] Kapustin I V, Grinchenko V A, Gritsay D I, Kapustina E I 2016 *Research Journal of Pharmaceutical, Biological and Chemical Sciences* 7(2) 1414-1419
[4] Łój P 2018 Exploitation of rotary vane vacuum pumps *Modelowanie Inżynierskie* 38(69) 56-59
[5] Zoellig U, Dreifert T 2011 *MPT Metallurgical Plant and Technology International* 34(3) 98-104
[6] Krasnov I N, Krasnova A Y, Miroshnikova V V 2018 *EurAsian Journal of BioSciences* 12(1) 83-87
[7] Burgmann W 2013 *Journal of Iron and Steel Research* 25(5) 1-7
[8] Łój P, Cholewa W 2021 *Studies in Systems, Decision and Control* 313 103-115
[9] Zakharin A V, Lebedev A T, Pavlyuk R V, Lebedev P A, Iskenderov R R 2021 *IOP Conference Series: Earth and Environmental Science* 659(1) 012026
[10] Zakharin A V, Lebedev A T, Pavlyuk R V, Lebedev P A 2018 *Engineering for Rural Development* 17 97-101