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HEAT DISTRIBUTION IN A POLYMERIC ROD UNDER DRY FRICTION IN RECIPROCATING SEALS

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ABSTRACT

The paper presents some particular aspects of heat generation and distribution in a polymeric rod, part of a sealing system with rubber lip for a pneumatic drive. The reciprocating motion particularities like periodically zero values for the speed, static and dynamic friction alternating regimes, lead to a nonlinear tribological behavior of the sealing system. In order to identify the ways the heat is generated and distributed in the rod, a test rig was built. Based on the experimentally acquired data, a finite element model is proposed. This way the optimal polymeric material can be selected, ensuring the reliability of the sealing system.

Keywords: dry friction, heat generation, finite element analysis, sealing system, polymer rod, reciprocating motion

1. INTRODUCTION

In the case of the contact seals, like lip seal is, a very important parameter for the efficiency establishing is the behavior of the seal's components under thermal influence of the heat generated by friction [1]. Most of the lip rubber materials present a stiffness changing behavior when the functioning temperature exceed 100°C [2].

The pneumatic drives' sealing system is subjected to particular functioning conditions due both to the dry friction regime and to the alternating between static and dynamic friction. Even if the system steel rod - rubber lip offers a good tribological behavior, the designers often choose to use a non-metallic material for the rod. The latest polymeric materials brands offer mechanical characteristics as good as metals [3], with the benefit of low weight, leading to low inertia forces in reciprocating motions, higher corrosion resistance, higher compatibility with the functioning environment. The selection of the right polymeric material for a rod used in a specified design, is a matter of optimization procedure, taking into account, among other parameters, the behavior under the thermal conditions.

Due to the reciprocating motion, the sliding speed is not constant. At the end of the strokes, the speed value is zero and somewhere near of the stroke center the speed has a maximum value. Taking into account the friction force evolution in the linear motion presented in [4] (Fig. 1), it is obvious that the heat quantity generated by friction is not constant along the stroke length. Near the strokes' ends, where the speed is almost zero, the friction force have maximum values leading to a high heat generation rate.

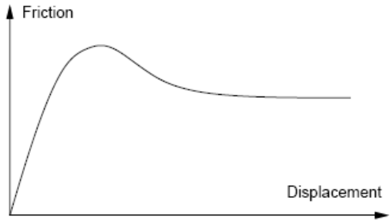


Fig. 1. The friction force evolution in a linear motion

As comparing to the metallic materials, the polymeric ones have lower heat transfer coefficient. As a consequence, the heat dissipation time is longer leading to a period when "heat peaks" appear on the rod, which may exceed the admissible values for the specified polymeric material.

2. EXPERIMENTAL MEASUREMENTS

In order to investigate the heat generation process in the reciprocating lip seals, a test rig was designed (Fig. 2).

Taking into account the test rig geometry and the corresponding testing regime, the speed variation during a stroke can be plotted (Fig. 3).

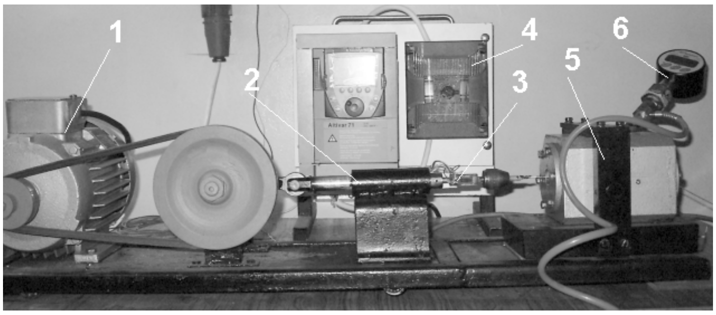


Fig. 2. Test rig for reciprocating lip seals investigation
1-electric drive; 2-bearing; 3-force gauge; 4-frequency variator; 5-pneumatic enclosure; 6-pressure gauge

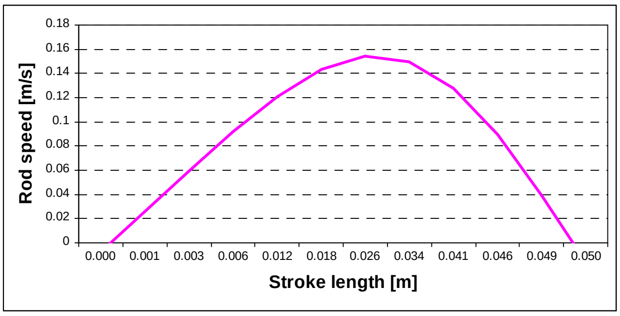


Fig. 3. The rod speed versus the stroke length

In order to investigate the heat generation, an infrared thermo-graphic camera was used, allowing for monitoring the temperature and for visualizing the thermal gradient along the rod (Fig. 4).

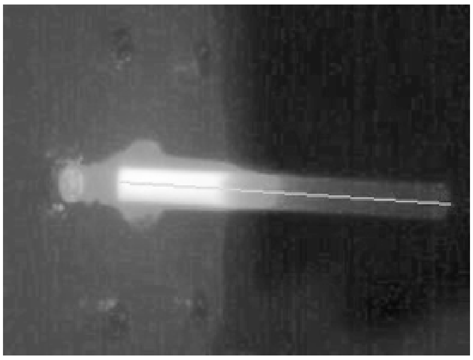


Fig. 4 A visualization of the rod thermal field as obtained with the help of a thermograph camera monitoring

As tested material for the rod, the polyamide PA-6 was used and the silicone rubber for the lip. The testing regime includes a sealed air pressure of 6 bar and a speed of 0.1 m/s.

During the tests, the rod temperature and the heat distribution along the rod were recorded, the stabilized values being presented in Fig. 5.

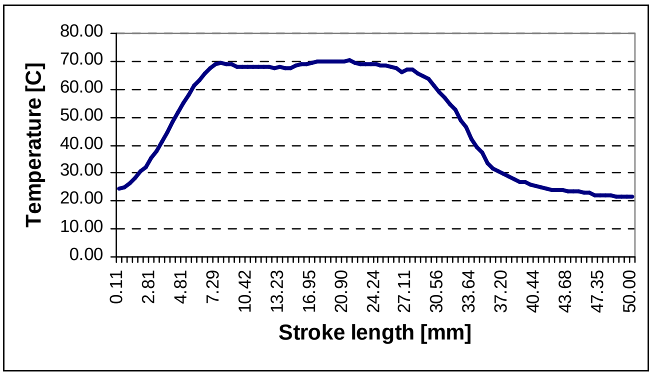


Fig. 5. The rod thermal gradient

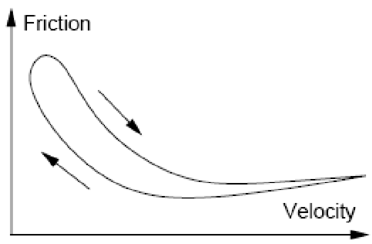


Fig. 6. The friction force versus the velocity, for a stroke

As one may see in Fig. 5, the maximum temperature is located in the first half of the stroke, leading to the conclusion that now the biggest amount of heat is generated in this zone. This is according to [4], which demonstrates that, in the sliding motion, the friction force is higher when the velocity is increasing and lower when the velocity is decreasing (Fig. 6).

The infrared analysis also allows for monitoring the temperature evolution in time. Due to the low thermal transfer coefficient of the rod material, an "inertial" phenomenon may be observed before temperature reaches a stabilized value (Fig. 7).

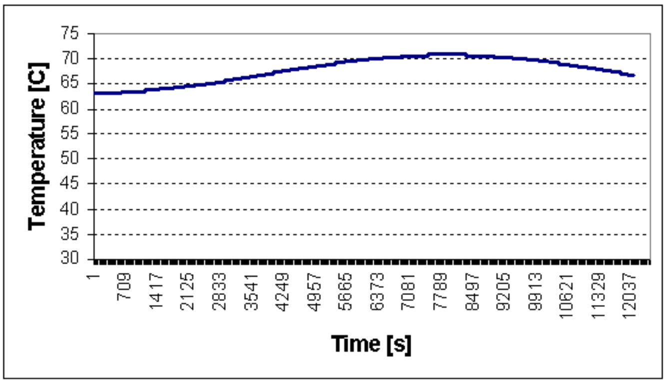


Fig. 7. The temperature evolution versus time

3. FINITE ELEMENT ANALYSIS OF THE ROD IN RECIPROCATING MOTION

In order to capture and investigate more precisely the ways that the heat is generated and distributed in the polymeric rods of reciprocating seals, a finite element model was build using CosmosM software.

Starting with the assumption that the heat generated by friction is equal to the friction power loss and based on the Eq. 1 [5], the heat quantity was computed as:

$$Q = \mu_k F_n s \tag{1}$$

where: μ_k - the cinematic friction coefficient, F_n - the normal load, s - the speed

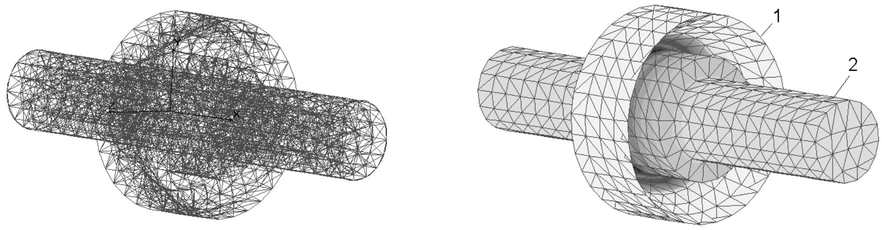
Taking into account that both the rubber lip and the polymeric rod are involved in the friction heat generation, the heat distribution is divided between these two elements according to the Charron-Vernotte law, Eq. 2 [6]:

$$Q_{rod} = Q \frac{\left(\sqrt{\lambda c \rho}\right)_{rod}}{\left(\sqrt{\lambda c \rho}\right)_{rod} + \left(\sqrt{\lambda c \rho}\right)_{lip}} \tag{2}$$

where: λ - the thermal transfer coefficient, c - the specific heat, ρ - the density, the index indicating the element for which the mechanical and thermal characteristics are given (the rod or the lip).

The finite element model (Fig. 7a), is targeted on the sealing; other system's elements are taken into account only as transferred heat flux. The other goal of the analysis is to investigate how the heat flux is distributed in the polymeric rod, thus, the model is subjected to a steady state analysis.

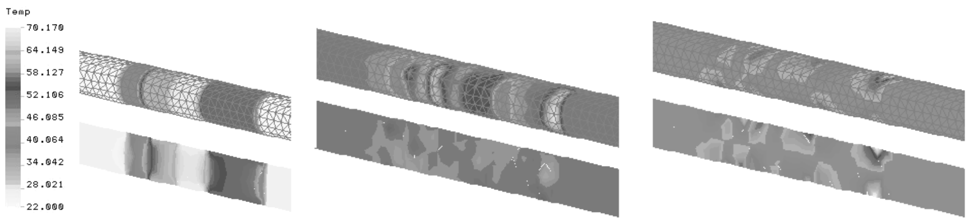
After setting of the material properties and the boundary conditions and running the program, the thermal distribution in the sealing system is obtained (Fig. 7b).



a) b)

Fig. 7. The rod-lip finite element model
a) the finite elements mesh; b) the thermal distribution between the rod and the lip seal: 1 - the rubber lip seal; 2 - the polymeric rod

In order to analyze the rod, this one is isolated and represented both in normal view and in a cross-section (Fig. 8a).



a) b) c)

Fig. 8. The rod thermal distribution
a) the rod thermal distribution; b) the thermal gradients in seal's rod Z direction
c) the thermal gradients in seal's rod Y direction

As one may see, the heat distribution is non-linear both along and across the rod, with higher values on the surface, and near the middle of the stroke. These results are in good concordance to the experimental measurements presented in Fig. 5.

The finite element model also allows for visualizing the thermal gradients in the rod. It can bee seen in Figure 9 that, in some areas, the temperature values are the highest, mainly at the ends of the stroke. This is not visible in Figure 5, where the stabilized values are plotted.

These peaks appear only in the transient regime, when the low thermal transfer coefficient of the rod material leads to local heat accumulations. During the functioning of the linear drive, the thermal regime becomes steady (at an equilibrium temperature), the all amount of heat generated in the rod by friction being dissipated in the environment.

Taking into account that the heat produces structural transformations in the lip's elastomeric material [7], the thermal distribution map of the rod can lead to an optimized design of the sealing system. Regarding the temperature evolution versus time, the presented model cannot provide information, since the analysis is done for a steady state. The behavior noticed in Figure 7 (the slow decrease of the temperature at the end of the test) can be explained by the cooling effect of the increasing air leakage, due to the wear of the lip-rod couple.

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4. CONCLUSIONS AND FUTURE WORK

Taking into account the above presented investigation and model, the following conclusions can be drawn:

- the functioning of the lip seals used in reciprocating motion have particular aspects, mainly due to the periodically change of the speed between zero and a maximum value;
- the dynamic behavior of the reciprocating seals can be improved using a non-metallic rod, the polymeric materials being preferred;
- in the tribology of reciprocating seals of pneumatic drives, both static and dynamic dry friction are involved;
- in the rods made of polymeric materials, some zones with heat peaks appear, existing the possibility of exceeding the admissible values;
- the finite element analysis can be used in order to establish the distribution of heat in the rod and the thermal gradients in cross directions, allowing for optimizing the design of the seals for a specific functioning regime;

The presented model, used for pneumatic drives rods analyze, can be improved by future developments:

- the dynamic modeling of the seal, introducing the speed variation during a stroke length;
- analyzing the seal in the transient regime, both at the beginning of the functioning and after the leakage rate is increasing due to the wear.

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