639. Analysis of tribological properties of precise contact pairs

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Abstract. The aim of the presented research work is to investigate the possibilities of improving the tribological efficiency of different friction pairs by surface processing to obtain different roughness values and by modifying the friction surface with fluoroligomeric materials. Wear resistance and friction reduction abilities of precise friction pairs could be improved by the modification of their friction surfaces by surface processing to obtain a particular roughness level and by means of surface modification with fluoroligomeric materials. Tribological experiments of sealing friction pairs demonstrate that there is an optimal friction roughness magnitudes which results in the lowest friction coefficient and wear. The use of fluoroligomeric materials in such friction pairs could reduce the friction and wear of the shaft (up to 1,5 times). Fluoroligomeric materials can increase the serviceability of precise plunger pairs and the service life of the dies used for wire tensioning up to 4 - 6 times. These research results are the background to start the investigations aimed at improvement of the tribological properties of different high-precision friction pairs.

Keywords: precise friction pairs, surface modification, roughness, fluoroligomeric materials, wear resistance, friction coefficient.

Introduction

Processes in the tribo-system are influenced by all its elements: friction surfaces, its properties, lubricant and environment. Modification of the friction contact surface could help to reduce the friction losses and also to change the wear mode to a more convenient one. The efficient way for contact surface modification could be surface processing seeking the most efficient surface roughness and the use of special coatings which could change the contact conditions.

It is efficient to use anti-adhesive surface strengthening with fluoroligomeric materials (FOM), which are composed by fluorine oligomeric compound, oxygen and carbon. Gubanov and Troichanskaya investigated the tribological properties of fluoroligomeric material FOLEOX coatings [1]. They found that the film thickness is important using FOLEOX coatings, because at very thin films the tribological properties are changing dramatically. If the thickness is large enough then special structure called "sandwich structure" is formed. The chemosorbical bindings are creating between metal surface and the film. The research showed that thermal treatment of FOLEOX film strengthens the orientation effect of fluoroligomer molecules. The higher temperature promotes the forming of peroxidic groups in fluoroligomer and improves the bindings of polarized molecules. There are several advantages given by fluoroligomeric film on metal:

- the number of surface defects decrease because of fluoroligomer interaction with the surface;

- microhardness increases;
- oxidation energy and oxidation starting temperature increases;
- because of fluoroligomer the adhesive bindings between contact surfaces decreases and both surfaces are prevented from adhesion wearing. That is very important for starting and stopping moments.

Very important property of fluoroligomeric materials is the ability to strengthen the surface, thereby decreasing the number of surface cracks and self-renewal the fluoroligomeric layers during the friction process oil lubricated friction pairs [2].

Scratch tests were performed during the investigation of the wear resistance mechanism of the surfaces modified with the fluoroligomeric compounds [3]. Surface investigations with SEM micro-graphs after the scratch tests revealed a combination of very fine powders and patterns of compacted debris along the side of the scratch track. For both composites with and without fluoroligomeric coat, the wear path exhibited similar morphology with some regions along the wear track that are covered with a FOM film. The difference of surface conditions can be clearly observed.

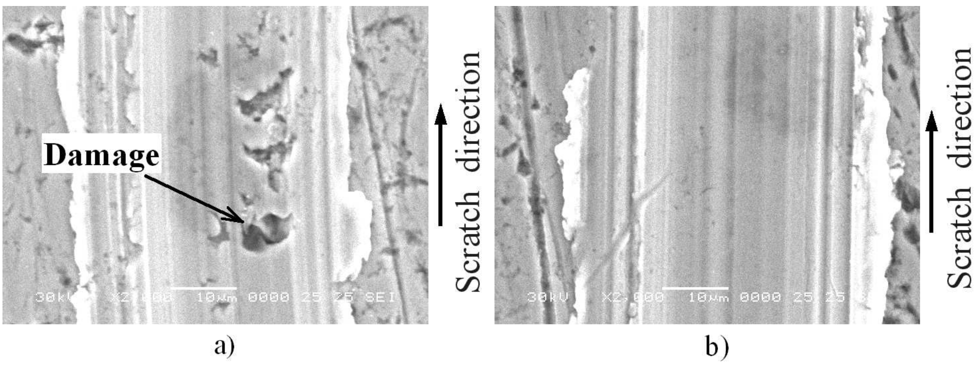

Fig. 1. SEM micrographs obtained from the scar surface of FOM/steel coating after wear testing at 10 N load showing (a) un-coated sample, (b) FOM-coated sample [3]

The worn surface of the scratch without FOM (Fig. 1a) clearly indicates flaking and delaminating of the surface. In the presence of FOM the wear particles, which are attached to the surface, are very thin. Fig. 1b displays that FOM layer formation is taking place at low FOLEOX intensity. The film is porous and adhesive to the worn surface. The FOM film modifies the contact rheology by reducing the shearing force at the contact, facilitating sliding and decreasing the damage due to plastic deformation. Results indicate that FOM film modifies the contact rheology by reducing the shearing force at the contact, facilitating sliding and decreasing the damage due to plastic deformation [3].

Research results approved that this material reduces the friction coefficient and increases the wear resistance. Our investigations demonstrate that the lubricating and strengthening anti-adhesive fluoroligomeric polymer material FOLEOX could be successfully used for the increase of wear resistance of the tension of wire, renovation of high-precision pairs in fuel pumps and for improving tribological properties of radial lip seals [4-6].

The aim of the investigations were to investigate the possibilities for enhancing the tribological efficiency of different friction pairs by the surface processing to obtain different roughness and by the modification of friction surface with fluoroligomeric materials.

Experimental procedure

The solutions of fluoroligomeric materials (0,5…10 % concentration) type FOLEOX were used for creating polymer coat on the metal surface. The specimen materials used are carbon steel utilized for machine structures. The mass of the FOM films in this study, depending of the thickness, was in the μg range. After the surface is coated with fluoroligomeric coat the chemosorbic bindings are created between metal surface and the film. The thickness of FOM layers was about 0,1…0,16 μm.

Tribological tests were performed with different equipment. The tightness of the plunger pairs (t_s) measured like the penetration time of the fuel through the gap between plunger and cylinder was determinate with the device KP-1640A according to standard methodology. The cyclic delivery of the fuel pump sections was tested using the testing and regulation stand of the fuel pumps KI-22205.

Experiments with the friction pair „shaft - radial lip seal (RLS)“ were accomplished on the special stands for seals created in Hamburg-Harburg TU (Fig. 2).

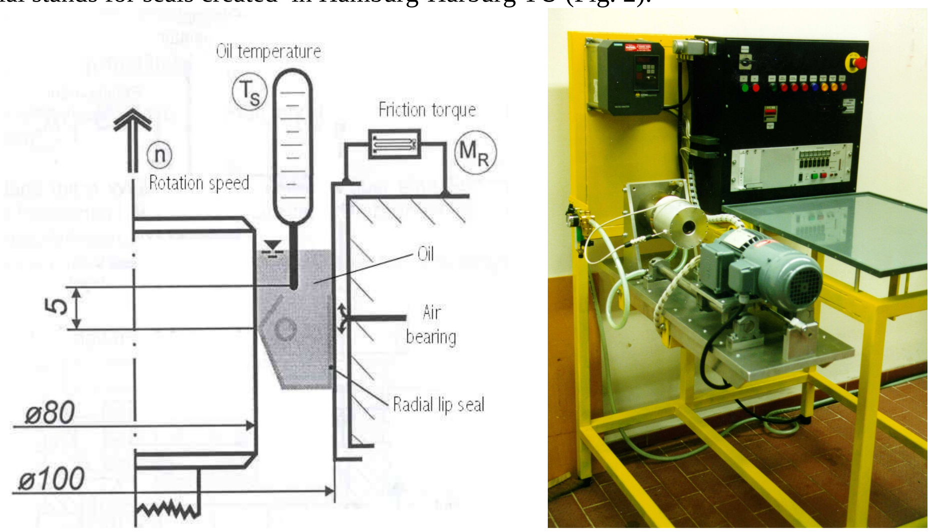

Fig. 2. General scheme and picture of vertical test rig

Friction torque was measured with method of air compression and temperature on the seal - with special sensor. After wear tests of the mentioned friction pairs the depth of the wear pit on the shaft adapter was registered in a special wear stand.

The influence of FOM to the change of the friction force of die for tension of wire was studied by experimental tests using tension machine FT10/1. The wire was pulled through the dies which were covered with FOM and the ones that were not.

Results and discussion

Surface modification by FOM coating indicates good elasticity in rough contacts but with a higher hardness may be more suitable for abrasive applications i.e. reduced plasticity in a given tribo-contact.

Research results for the tightness in fuel pump precision pairs.

64 precise pairs were analyzed from the fuel pumps delivered in the factory for repair. The research outcomes are presented in Table 1.

We can observe that approximately 20 % of precise pairs are unusable because of insuficient tightness (t_s < 5 sec.) and ~ 23 % could been restored for further operation. The rest could been used without the restoration.

Precise pairs from group 1a was treated with fluoroligomeric material FOLEOX and tightness was measured again. It was estimated that the tightness of all plungers increased over 5 sec. ($t_s \geq$ 5 sec.).

After experiments it was ascertained that the serviceability of the most plunger pairs, which failed because of insufficient tightness, could be restored using tribological material FOLEOX.

Table 1. Statistical row of the precise pairs tightness

N° of interval, i		Borders of interval, sec.		Frequency, m_i		Statistical probability, p_i	
1	1a	0...20	0...5	24	13	0,375	0,203
	1b		5...20		11		0,172
2		20 ... 40		15		0,234	
3		40 ... 60		12		0,188	
4		60 ... 80		5		0,078	
5		80 ... 100		3		0,047	
6		> 100		5		0,078	

The research findings of the friction pair „shaft - radial lip seal“.

In tribological research of radial lip seals the influence of two factors were investigated: influence of shaft surface roughness and influence of surface modification with FOM.

Testing of RLS with the shaft of different surface roughness indicates that there is a dependence of initial shaft surface roughness on the friction torque values (Fig. 3). Optimal value of surface roughness lies at Ra of 0,033 … 0,034 µm. Overly smooth surfaces are not efficient because of bad conditions for oil film preservation at the surface. Excessive surface roughness is the reason for high friction coefficient because of mechanical component of friction force.

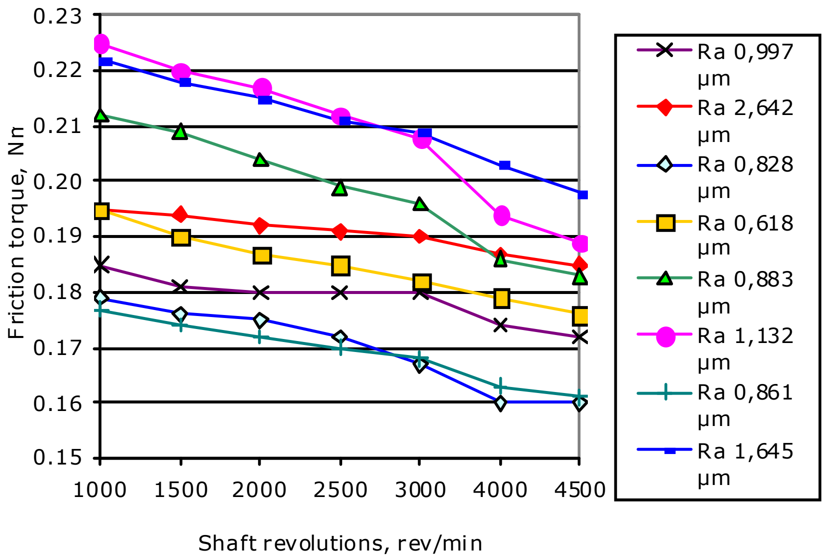

Fig. 3. Results of friction torque measurement for RLS/shaft tests for the shafts with different surface roughness

In the graph of wear results of RLS/shaft friction pair according to the width of wear path on the RLS (Fig. 4) the dependence between initial roughness of shaft surface and wear of RLS is presented. Mathematical approximation of roughness and wear results (Fig. 5) clearly indicates that there is an optimal roughness which correlates with the lowest wear and the highest service life of the friction pairs.

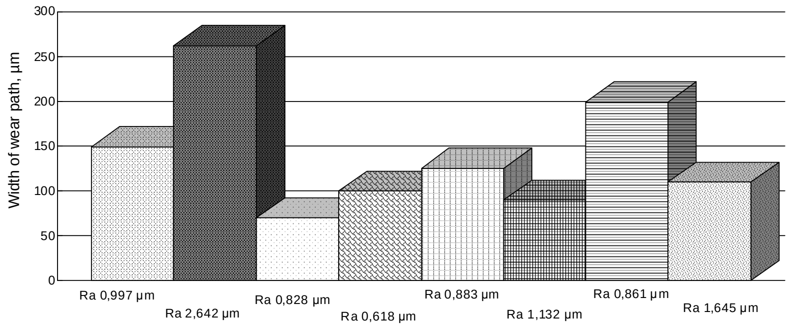

Fig. 4. Wear results of RLS/shaft friction pair with different surface roughness according to the width of wear path on the RLS

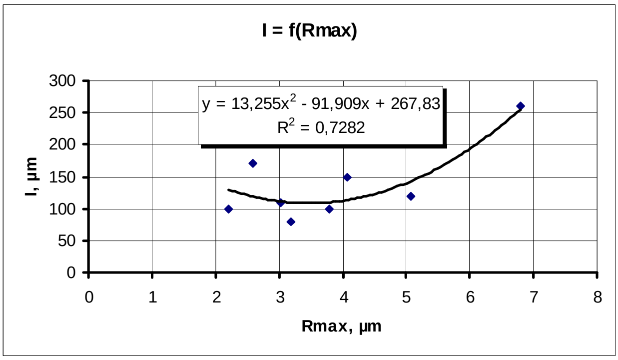

Fig. 5. Correlation between shaft roughness (R_{max}) and wear of RLS

The modification of shaft surface with FOM increases the tribological efficiency of friction pairs. Fig. 6 presents the dependence of the friction torque on the rotating speed. Friction pair with FOM coated shaft adapter (W_F-Rc) demonstrates lower friction coefficient than control version of shaft adapter (W_C-Rc). Increasing temperature in contact zone reduces inside friction force of the oil and as an outcome – tendency of lower friction torque.

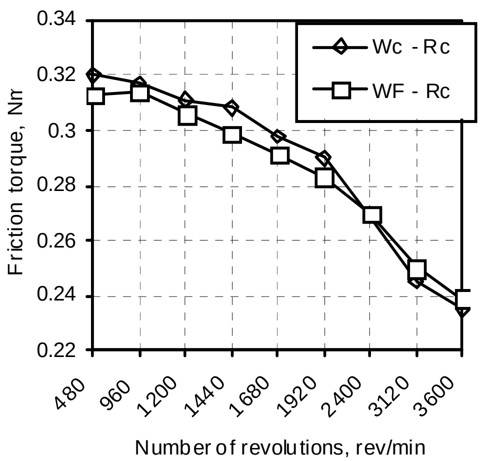

Fig. 6. Friction torque as a function of rotation speed of control specimen (W_C-Rc) and shaft with fluoroligomeric coat. (W_F-Rc)

The outcomes of wear tests are very important (Fig. 7). The use of FOLEOX leads to reduced wear in comparison to the control version (for higher speed - even 1,5 times). This confirms tribological efficiency of the FOM and conforms to friction coefficient measurements.

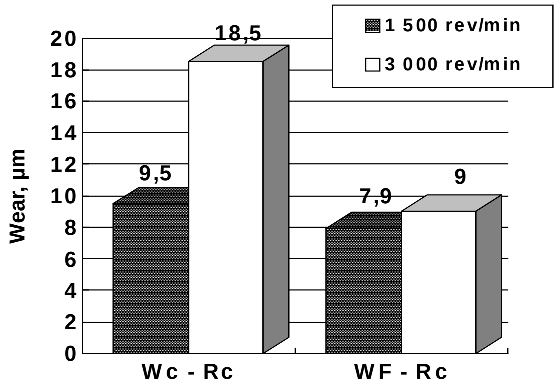

Fig. 7. Wear of control specimen (W_C-Rc) and shaft with fluoroligomeric coat. (W_F-Rc) against the radial lip seal

<u>Research results on the longevity of the dies for wire tensioning.</u>

The performed research works demonstrate that the following factors have the largest influence on the die: 1) chemical composition of the blank of the wire; 2) the geometrical parameters of the blank; 3) the quality of blank improvement; 4) die defects.

The results of tribological research of pulling force (average mean of force) are presented in Fig. 8.

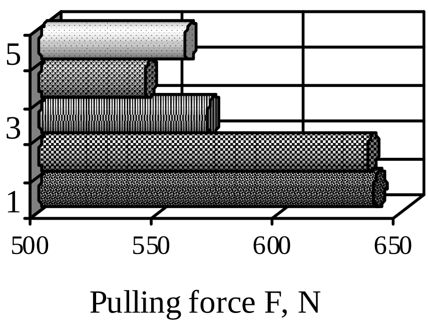

Fig. 8. The results of measurement of pulling force: 1 - the die without cover of “FOLEOX” and without lubrication, 2 - without cover and with the lubrication (lubrication 75 % powder of soap, 25 % MoS_2), 3 - the die with cover of “FOLEOX”, without lubrication, 4 - the die covered with “FOLEOX” and lubrication (lubricant - 75% powder of soap, 25% powder of MoS_2), 5 - the die with coating and lubrication (lubricant - powder MoS_2)

Tribological experiments reveal the efficiency of fluoroligomeric materials at friction pairs of different type. Presented results are the background to start the investigations of improvement the tribological properties of different precise friction pairs [7].

Conclusions

- Wear resistance and friction-reducing capacity of precise friction pairs could be improved by modification of friction surfaces by means of surface processing for intentional roughness and by applying surface modification with fluoroligomeric materials.

- Tribological experiments of sealing friction pairs indicate that there is optimal friction roughness which correlates with the lowest friction coefficient and wear values. The use of fluoroligomeric materials in such friction pairs could reduce the friction and wear of the shaft (up to 1,5 times).
- Fluoroligomeric materials can increase the serviceability of precise plunger pairs and the service life of the wire-tensioning dies up to 4 - 6 times.
- Presented results are the background to initiate the investigations for improvement of the tribological properties of different precision friction pairs.

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