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TRANSFERRED MATERIAL INFLUENCE ON ELASTOMER-PLASTOMER COUPLE BEHAVIOR IN DRY SLIDING

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Abstract: *The pneumatic drives' rods are subjected to specific inertia forces generated by speed and acceleration evolution during a working cycle. The sealing friction can be used to balance these forces effect. The polymeric materials, used as replacement for metals, offer lower weigth of the rod, leading to lower ineria forces. If a rubber lip-polymeric rod sealing system works in dry conditions, a transferred lip material film to the rod occur. The paper investigate the influence of this film on the tribological behavior and efficiency of the seal. The transferred material can improve the over-all drive's performances, especially in actuators case.*

Keywords: *pneumatic sealing, polymeric rods, rubber lip, dry sliding*

1. INTRODUCTION

During the pneumatic drives functioning, in reciprocating motion regime, the rod acceleration get high values at the ends of the strokes, Figure 1.

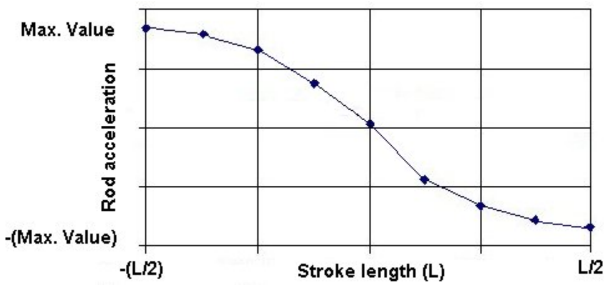


Figure 1. Rod acceleration values evolution during a stroke

Due to the rod weight, at the ends of the stroke the inertia forces can reach high values, leading to difficulties in precise positioning of the rod, especially in pneumatic actuators case. Different methods are used for inertia forces effects balancing, mainly based on the controlling of friction force values in the sealing system [1]. The drawback of the method is that the wear of the lip is accelerated, especially when the absence of the lubricant is required by environmental prescriptions.

A new approach of pneumatic drives' design is the use of polymeric materials [2]. These ones offer mechanical resistances comparable with metals, at much lower weight. Thus, the rod mass is lower, the inertia forces values being lower too.

The rod sealing systems used in pneumatic drives are rubber lip based and, if the rod is made by polymeric materials and the absence of lubricant is required, there are accomplished the conditions for the "third body" [3,4] appearance, as a transferred lip-to-rod material film.

The authors performed several investigations on the appearance and evolution of the transferred material film [5,6], the present paper being focused on the general evolution and influence of this "third body" on tribology and efficiency of the pneumatic drives' sealing system.

2. EXPERIMENTAL INVESTIGATIONS BASIS

In order to investigate the influence of transferred material film on seal's behaviour and performance a test rig was designed, as a pressurised enclosure where a polymeric rod is externally moved in reciprocating sliding. The sealing system is rubber lip based. The rig stands as a real pneumatic drive simulator, Figure 2.

The main functioning parameters, specific to pneumatic drives, can be monitored and recorded. Also, some of them are adjustable in a range of values, Table 1.

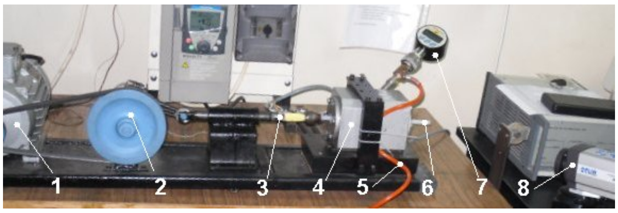


Figure 2. Pneumatic drives test rig: 1-electric drive; 2-eccentric; 3-stress gauge; 4-pressurised enclosure; 5-compressed air pipe; 6-polymeric rod; 7-pressure gauge; 8-thermographic & optical vision camera.

Table 1. Testing parameters

Parameter	Status	Range
Air pressure	Adjustable, recorded	6-8 bar
Sliding speed	Adjustable, recorded	105-472 strokes/min
Lip-rod tightening	Fixed	0.15 mm
Stroke length	Fixed	50 mm
Sealing friction force	Recorded	-
Sealing temperature	Recorded	-

As tested materials, were chosen silicone rubber for lip and polyetheretherketone (known under commercial name PEEK) for the rod.

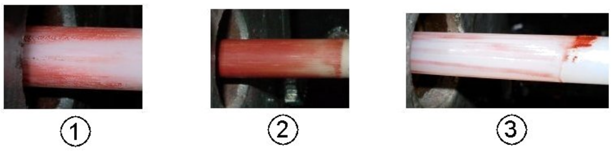
Previous authors' research shows that the appearance and maintenance of transferred material film is possible only in a temperature domain, directly influenced by the rod material [6]. As consequence, a corresponding testing regime was chosen, in order to obtain the transferred material layer for the PEEK.

During the tests, the evolution of layer was optically monitored. The friction force and air pressure loss time evolutions were also recorded, Figure 3.

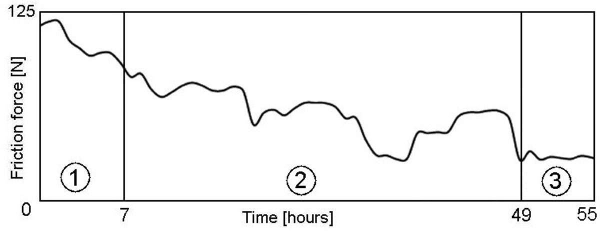
3. SEALING SYSTEM TRIBOLOGY IN PRESENCE OF TRANSFERRED FILM

Tribological analysis of a couple of materials covers two main aspects: friction evolution – as force or as coefficient and wear – as type or rate. Further, in this paper, the friction force and wear type is considered.

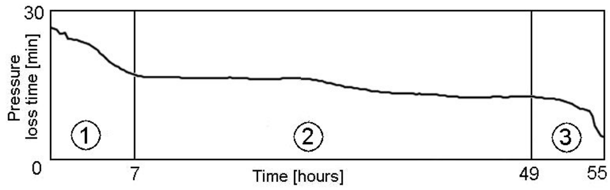
In dry sliding of polymers, especially when rubber is involved [7,8], stick-slip and adhesion phenomenon occur leading to the "third body" appearance, as a transferred material film.



a)



b)



c)

Figure 3. Friction force value evolution for PEEK rod, 7 bar air pressure, 210 stokes/min sliding speed (1-initial stage, transferred film formation; 2-stabilized stage, continuous transferred layer; 3-final stage, transferred layer discontinuity and sealing system failure): a) - layer evolution; b) – friction force evolution; c) – pressure loss time evolution.

The performed experiments shown that, in the beginning of the movement when the transferred film is not yet formed, the friction force value is high (area 1 in Figure 3b), leading to high contact temperatures. In this stage, the adhesion phenomenon leads to local transfer of the lip's material on the rod and it can be seen, in the corresponding optical image 1 in Figure 3a, that the layer is un-continuous, the initial deposits following a typical stick-slip pattern.

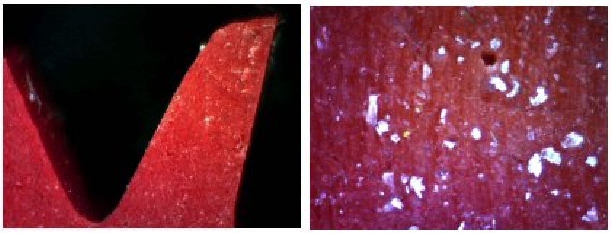
The transferred material layer, soon as it is full formed – optical image 2 in Figure 3a, acts as a lubricant leading to a decrease of friction force. This observation is in very well concordance with the literature [9]. A stabilized working regime of the sealing system is now reached, the transferred material layer compensating the wear of the lip-rod couple, area 2 in Figure 3b. Some variations of friction force value can be observed, caused by occasionally appearance of abrasive wear (due to hard debris detached – high values), but compensated by the transferred layer – low values.

Eventually, the quantity of material detached from the lip cannot be compensated, the transferred layer is expulsed by the pressure and the sealing fails – optical image 3 in Figure 3a and area 3 in Figure 3b.

In order to establish the dynamics of transferred layer evolution after its forming and the failure causes, some optical investigations were performed.

3.1 Rubber lip optical investigation

Taking into account that the main material source for the transferred layer is the lip [8,9], a closer look to this one is necesary, Figure 4.

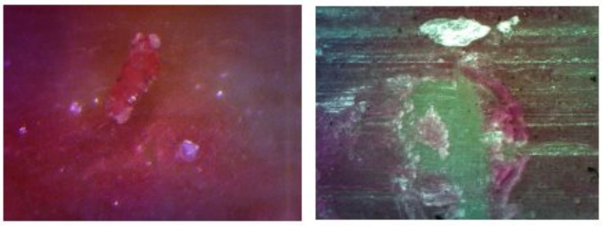


a) b)

Figure 4. Silicone rubber lip cross-section optical image: a) 30x magnification; b) 200x magnification

In Figure 4 can be identified the ingredients of the lip: the silicone rubber – as bulk base and silica particles, used as filler. Consequently, in the transferred layer both substances will be found.

Due to its physical properties, the rubber will act as a very viscous fluid, incorporating the hard silica particle. If the thickness of the transferred layer is higher than silica particles dimension, the contact between these ones and rod, respectively lip, is avoided, the abrasive wear of the system being avoided, Figure 5a.



a) b)

Figure 5. Transferred material layer optical image: a) incorporated hard particles; b) hard debris generating layer rupture

During the seal functioning, due to high local temperatures, the transferred rubber material is subjected to a thermal hardening, becoming less fluid. At this time the enclosed hard particles acts as a sort of “crystallisation centres”, leading to layer ruptures and hard debris production, Figure 5b. These ones cannot anymore be incorporated into the material, generating ruptures into the layer.

The hard debris affects not only the transferred layer but also the lip, generating a massive detach of the material, Figure 6.

Eventually, due to thermal hardening and the action of hard debris, the transferred material layer cannot anymore compensate the wear of the lip. In this situation, the air pressure pushes out the layer material.

Figure 6. Abrasive wear of the lip due to hard debris

This elimination of the transferred material leads to quickly failure of the sealing system.

3.2 Polymeric rod optical investigation

During the seal’s working there are hard particles, detached from the lip or generated by hardening of the layer, which cannot be “isolated” into the layer material and reach to the rod surface, generating here abrasive wear tracks. In the early stabilized stage, when the transferred material has a viscous behaviour, the tracks on the rod’s surface are filled and covered, balancing this way the abrasive wear effects, Figure 7.

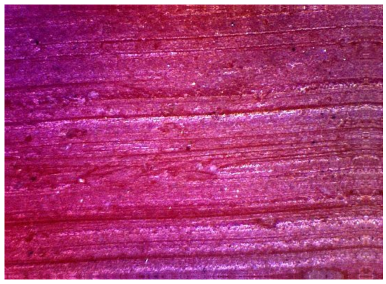
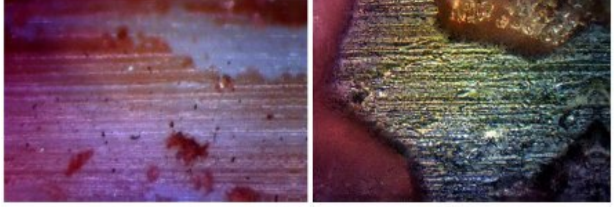


Figure 7. Abrasive wear tracks on the rod’s surface covered by transferred material

In the late stabilized stage, due to thermal hardening, the transferred material loses the capacity to compensate the abrasive wear, becoming fragile and developing large ruptures, Figure 8a. This way the rod surface is exposed to abrasive action of hard debris, either detached from the lip, either generated into the material layer, Figure 8b.



a) b)

Figure 8. Abrasive wear on the rod: a) layer rupture; b) wear tracks on the rod

The generated abrasive scars modify the rod's surface roughness, allowing the manifestation of internal friction phenomenon into the rubber [10], leading this way to rapidly degradation of the lip.

Taking into account all above presented, can be observed that, during the pneumatic drives' seals functioning in dry reciprocating sliding, the wear is both adhesive and abrasive.

In the beginning, before and in the early stage of transferred layer formation, the adhesive aspect of the wear is preponderant. After layer formation, due to hard debris (either filler particles detached from lip, either thermal hardened particles detached from the layer) the abrasive aspect of the wear become preponderant.

4. SEALING SYSTEM EFFICIENCY IN PRESENCE OF TRANSFERRED FILM

In order to investigate de effect of transferred material layer on seal's efficiency, the monitoring and recording of air pressure loses method was chosen [11]. During the tests was observed that time necessary for the air pressure to drop from nominal service value to minimum accepted value shows a continuous decrease, caused by sealing system wearing.

In the beginning, area 1 in Figure 3c, when the transferred layer is not yet formed, the pressure loss time have a high decrease rate. As soon the layer insulates the lip from the rod, the pressure loss time shows a constant, low decrease rate, area 2 in Figure 3c. Now all the modification occurred into the rod-lip couple tribology are compensate by the transferred material layer.

In the last working stage, area 3 in Figure 3c, the wear losses are too big, the layer cannot anymore compensate these and the system failure occur.

5. CONCLUSIONS

The influence of transferred material film on tribology and efficiency of pneumatic drives' sealing, based on polymeric rod-rubber lip couple working in dry sliding, was investigated.

Following the tests results, some conclusions can be drawn:

- the polymeric rod-rubber lip seal couple is a desirable designing solution for pneumatic drives;
- the transferred material layer have a considerable influence on tribology behaviour, of elastomer-plastomer couple in dry sliding contact, balancing the abrasive wear effects;
- the presence of transferred material layer leads to an improvement of the sealing system efficiency;
- the main influencing parameter of transferred material layer formation in dry sliding is the contact temperature;
- the elastomer-plastomer seal in dry sliding can be optimized by accurate controlling of the contact temperature, in order to avoid the thermal hardening of the transferred material.

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