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RESEARCH

Tribological Processes in Contact Zone of Oil Seal and Speedi-Sleeve

The wear of contact elements consisting of oil seal and shaft sleeve brings to the appearance of graduate defect. The most common way of its manifestation is the oil loss (leakage) or the working pressure lowering. These problems today are usually present at the internal combustion engines.

In exploitation processes, the wear of both contact elements, which have a sealing function, are present. At the internal combustion engines, the price of an oil seal is significantly lower compared to the price of the crankshaft. Replacement of only oil seal without the shaft sleeve regeneration gives no significant effects. New oil seal, that is, its seal lip, realize the contact onto the already worn off surface of shaft sleeve. This way of contact geometry realization the most often brings to the repeated defect. On the other hand, the process of shaft sleeve regeneration (plasma spray, plasma arc surfacing, etc.) and its finishing processing are relatively expensive.

One of the ways to overcome these problems is to build-in the sealing ring (Speedi-Sleeve) onto the worn off shaft sleeve. Due to the very extensive tribological investigations, a part of which is presented in this paper, the regeneration of worn off shaft sleeve by the application of the sealing ring is a very rational and effective method.

Keywords: *oil seal, speedi-sleeve, wear, temperature*

1. INTRODUCTION

Until recently, the main attention in industrially developed countries has been aimed at the process of new technical systems creation. However, activities today have been moved toward optimal and rational maintenance of technical systems already in use. New and economically justified methods for working life prolonging have been founded. One such approach is application of new solution for regeneration of worn off shaft sleeves by sealing rings method.

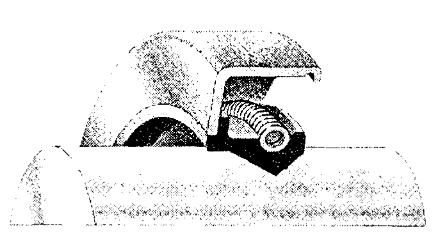

Figure 1. Sealing done by oil seal

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The most often way of sealing in engineering practice is with oil seal, as shown in Figure 1. Sealing is done by creating a zero or a very small clearance between moving elements.

The wearing process in the zone of contact between oil seal and a shaft sleeve is always present. By applying certain constructive solutions the wearing process can be slowed but it cannot be eliminated totally. During the work, wearing debris or abrasive particles from external environment are embossing into the seal lip of oil seal (being in contact with the shaft sleeve surface). This causes the development of the wearing process of shaft sleeve surface at the point of its contact with the oil seal. Thus, in a certain period of time the collapse of the basic sealing function happens, even if the oils seal is replaced with the new one. Such failure is manifested by the oil loss (leakage) or by the working pressure lowering. One way to overcome these problems is to build in the sealing ring (Speedi-Sleeve) onto the worn off shaft - Figure 2.

The group of technical systems suitable for application of sealing rings is engines, that is their crankshafts.

Through very extensive tribological investigations we performed, it have been determined that application of sealing ring for engine's crankshaft sleeve regeneration is a very rational and effective method.

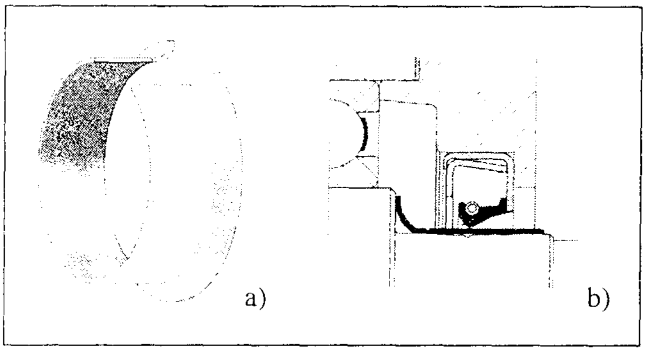


Figure 2. Sealing ring look (a) and the place of its installing (b)

2. CHARACTERISTICS OF INVESTIGATION

2.1. Contact pairs

In order to determine valid conclusions parallel investigations of wearing process have been conducted with following contact pairs:

- oil seal / shaft sleeve and
- oil seal / shaft sleeve + sealing ring.

In both cases unworn crankshaft sleeve was used, from engine of 1100 cm^3, which is build in YUGO 55, ZASTAVA 101 and ZASTAVA 128 cars. Investigated shaft sleeve is (according to the constructive documentation from Engine Factory DMB - Beograd) with diameter in range 63,970 - 63,995 mm. Shaft sleeve is made by cutting from the original crankshaft.

Oil seals are of dimensions (64x80x8), which suit to the chosen shaft sleeve and are of reputable European manufacturer.

Sealing rings were manufactured by private company from Former Republic of Yugoslavia. For manufacturing of investigated sealing rings the stainless steel according to the American standard AISI 304 stainless steel, was used. Mechanical properties according to the Inspection Certificate of manufacturers are given in the Table 1.

Table 1.

strength			*hardness*
Rp 0.2%, MPa	Rp 1%, MPa	Rm, MPa	HRB
250	*280*	*625*	*78*

Sealing ring wall thickness is 0,25 mm.

2.2. Sliding velocity

Sliding velocity is obtained according to the shaft sleeve geometry and according to the data obtained from statistical analysis of engine working in city driving conditions and open road conditions. Frequency of particular number of revolutions, in city driving conditions, is given in Table 2.

Table 2.

n, rpm	*frequency, %*
1000	30
1500	20
2000	10
2500	20
3000	20

According to the data from Table 2. average number of revolutions for engine in city driving conditions is:

$$n_{sr} = 1900 \text{ rpm}$$

Maximum engine's number of revolutions is:

$$n_{max} = 6000 \text{ rpm}$$

Average number of revolutions for open road conditions is n = 4000 rpm. It was determined that 2/3 from total driving is in city driving conditions and remaining 1/3 is in open road conditions. According to these data the number of revolutions used for investigation is determined as:

$$n = 2600 \text{ rpm}$$

For selected diameter of crankshaft sleeve (d≈64 mm), the sliding velocity is:

$$v_{kl} = \frac{d \cdot \pi \cdot n}{60 \cdot 1000} = \frac{64 \cdot \pi \cdot 2600}{60 \cdot 1000} = 8{,}71 \frac{m}{s}$$

2.3. Lubrication system

System with continuous lubrication is presented in Figure 3. Lubrication is done by the piston pump with a flow rate of $\dot{V} = 0{,}1$ *l/min*. Piston pump forces the fresh motor oil into the main system with contact elements. Fresh oil, which is brought into the contact zone, provides the real lubrication conditions. Beside it, the oil, which circulates, takes away part of the heat generated in the contact zone. After passing through the main system with contact elements, the oil goes to the auxiliary reservoir, from where it has a free fall to the main reservoir. Inside the main reservoir the oil cooling is done in natural way, so that "fresh oil" is forced again to the main system with contact elements with what the circle of lubrication is closed. There is no loss, that is, an oil leakage in lubrication system.

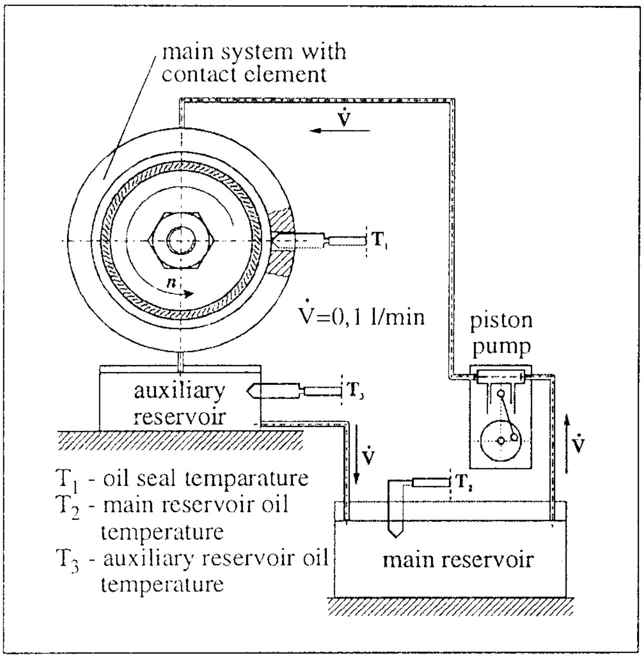


Figure 3. System with continuous lubrication and with thermocouples layout

The main system construction provides an easy system assembling and disassembling with a very good repeatability of contact elements positioning. This is necessary because of the fact that at every 5 hours of continuous device working, the measurement of selected wear parameters on contact elements is done.

In Figure 3., positions of thermocouples for oil seal temperature measurement and for oil temperature measurement in main and auxiliary reservoir are shown.

3. RESULTS

3.1. Temperature change measurement results

For monitoring of temperature change the measuring chain, shown in Figure 4., have been formed. Thermocouples TP1 - TP3 (of type J - OMEGA Engineering, Inc., USA) converts a temperature signal into the voltage signal. Thermocouples are attached to the scanner UPM60 (Hottinger Baldwin Messtechnik) that converts a voltage signal generated in thermocouples to temperature signal of Celsius scale. PC computer, with application of adequate data acquisition software, controls the scanner UPM60 and does the data storage at computer's hard disc.

Each separate experiment lasted for 5 hours and total contact pairs behavior investigation time was 150 hours for each pair. On diagrams, the highest temperature stands for metal part of oil seal temperature (label T_1). Two lines, representing temperature changes of oil in main and auxiliary reservoir, are in most parts overlapped (temperatures labeled T_2 and T_3). It should be noticed that oil temperature in auxiliary reservoir, T_3, is always a bit higher than the oil temperature in main reservoir, T_2. Results are shown in Figure 4., only as comparative representation of temperature for both contact pairs in same investigation period (105 - 110 hours).

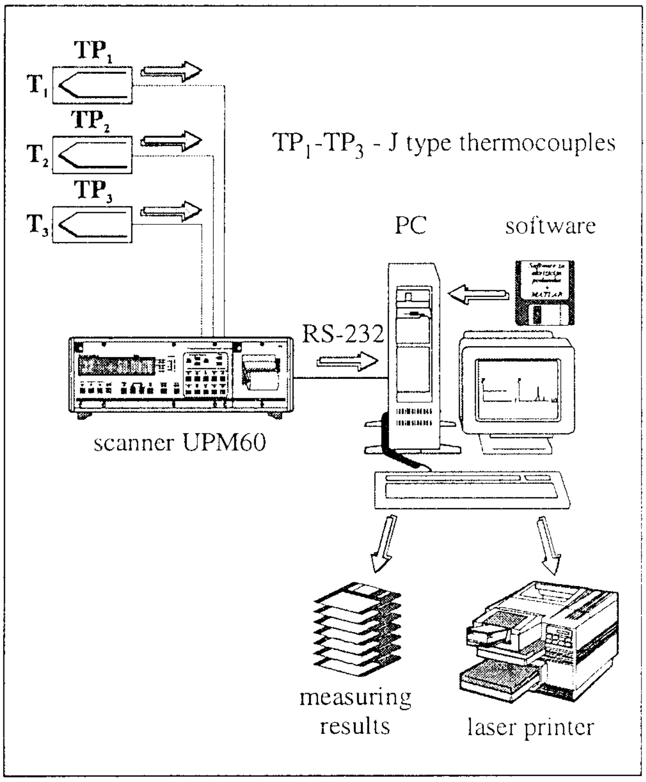


Figure 4. Measuring chain for temperature change monitoring

According to all processed results, the conclusion have been made that average value of maximum temperatures for oil seal / sleeve contact pair (55,90 °C) is for about 2 °C lower from average value of maximum temperatures for oil seal / sleeve contact pair +sealing ring (57,72 °C). Since the environment temperature was not the same one during the experiment, temperature of oil in main reservoir was subtracted from oil seal temperature, in order to eliminate influence of temperature deviation. Diagrams in Figures 6. and 7. was made due to the previous. Average value of oil seal temperature lowered for the value of oil temperature in main reservoir, for oil seal / sleeve contact pair (10,15 °C) is about 2 °C lower than average value of oil seal temperature lowered for the value of oil temperature in main reservoir, for oil seal / sleeve + sealing ring contact pair (12,10 °C).

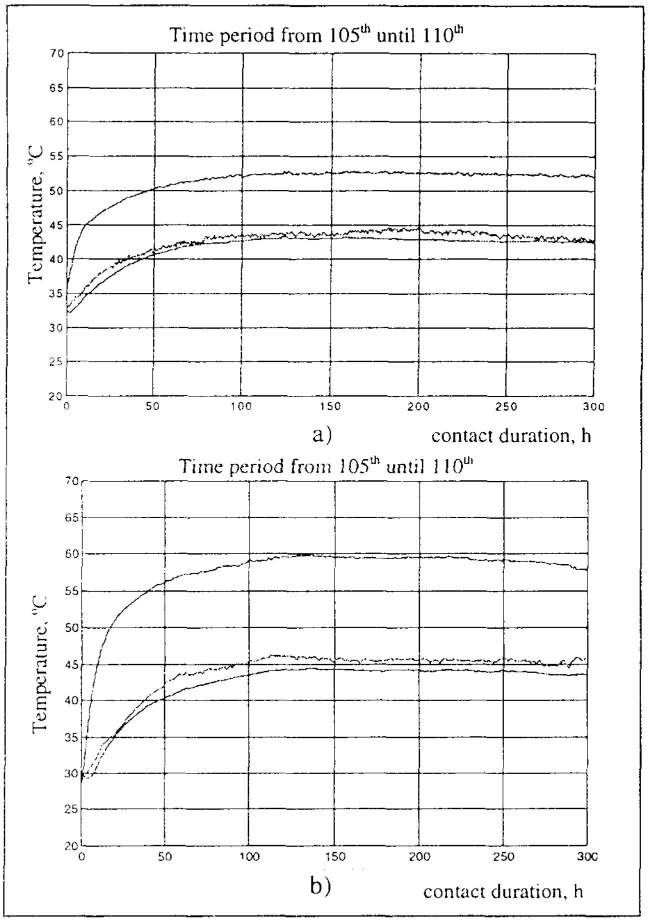


Figure 5. Characteristic temperatures for oil seal / sleeve contact pair (a) and oil seal / sleeve + sealing ring (b)

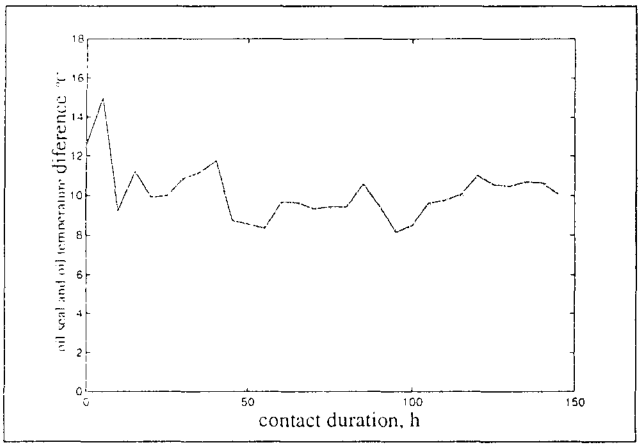


Figure 6. Oil seal temperature lowered for the value of oil temperature in main reservoir for oil seal / sleeve contact pair

By monitoring of thermal behavior it can be determined that average value of oil seal temperature, thus of contact zone itself, is insignificantly higher for the case of oil seal / sleeve + sealing ring contact pair than for the case of oil seal / sleeve contact pair. The reason for this lies in the fact that the diameter of seal lip resting at oil seal is bigger because of the sealing ring built in. Under these conditions a contact zone pressure increase occurs.

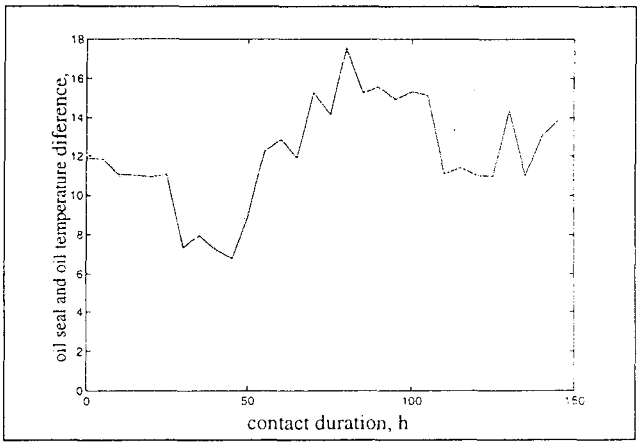


Figure 7. Oil seal temperature lowered for the value of oil temperature in main reservoir for oil seal / sleeve + sealing ring contact pair

3.2. Wear investigation results and oil seal deformation

In order to define the intensity of wear processes and oil seal deformation during its contact with shaft sleeve, the monitoring of linear (one-dimensional) wear parameters was done, that is, in accordance with contact geometry the oil seal diameter, Ds, was monitored. Measuring of the diameter was done in determined time intervals (for every 5 hours of working), by using universal tool microscope UIM 21, whose precision of reading is of 1 μm level. In Figure 8., positions of measuring directions at the oil seal with aluminum case are shown. Oil seal diameter is determined by applying the following equation:

$$Ds = \frac{1}{4}\sum_{i=1}^{4} Ds_i$$

where D_{Si} are diameters in directions 1-1, 2-2, 3-3 and 4-4. In Table 3. results of oil seal diameter measuring for oil seal / sleeve contact pair, are presented, where h stands for oil seal diameter increase compared to its initial value. Results of oil seal diameter measuring for oil seal / sleeve + sealing ring contact pair are given in Table 4.

Table 3.

Contact duration [h]	Ds_1 [mm]	Ds_2 [mm]	Ds_3 [mm]	Ds_4 [mm]	Ds [mm]	h [mm]
0	61. 5180	61. 5090	61. 6590	61. 5390	**61. 5562**	0
10	61. 9630	62. 0130	61. 7510	61. 9050	**61. 9080**	0. 3517
20	62. 1040	62. 0990	61. 9100	62. 0510	**62. 0410**	0. 4847
30	62. 1130	62. 1260	61. 9540	62. 0810	**62. 0685**	0. 5122
45	62. 2430	62. 1570	61. 9620	62. 0610	**62. 1058**	0. 5495
60	62. 2860	62. 2320	62. 0210	62. 1230	**62. 1655**	0. 6092
85	62. 3360	62. 2540	62. 0200	62. 1290	**62. 1848**	0. 6285
125	62. 3530	62. 2680	62. 1680	62. 0740	**62. 2158**	0. 6595
150	62. 3010	62. 1610	62. 1880	62. 2370	**62. 2217**	0. 6655

Table 4.

Contact duration [h]	Ds_1 [mm]	Ds_2 [mm]	Ds_3 [mm]	Ds_4 [mm]	Ds [mm]	h [mm]
0	61. 5530	61. 6670	61. 5660	61. 4660	**61. 5630**	0
10	62. 0770	62. 1880	62. 0830	61. 9670	**62. 0788**	0. 5157
20	62. 0960	62. 2030	62. 1240	62. 0210	**62. 1110**	0. 5480
40	62. 2110	62. 2210	62. 2130	62. 2130	**62. 2145**	0. 6515
70	62. 2960	62. 4200	62. 3090	62. 2640	**62. 3222**	0. 7592
100	62. 4060	62. 5330	62. 4000	62. 3300	**62. 4172**	0. 8543
130	62. 4040	62. 5410	62. 4180	62. 3860	**62. 4372**	0. 8742
150	62. 5190	62. 5950	62. 5100	62. 4290	**62. 5132**	0. 9502

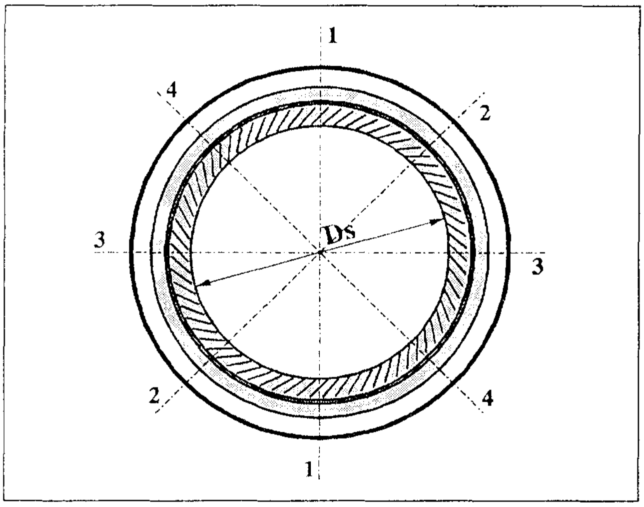


Figure 8. Oil seal with positions of measuring directions

Diagrams of changes (increase) of oil seal internal diameter for both contact pairs are presented in Figure 9. and in Figure 10. It is obvious that in the second case (oil seal / sleeve + sealing ring contact pair) more intensive wear and deformation process of the oil seal occurs, that is, its internal diameter increases. This can be better noticed in Figure 11., where the changes of oil seal internal diameter, for both cases, are comparatively presented. Results obtained are absolutely in accordance with investigation results for temperature changes. Increase of wear and deformation of oil seal for oil seal / sleeve + sealing ring contact pair occurs due to increase of seal lip resting diameter at oil seal. Under these conditions increase of contact zone pressure occurs. Increase of resting diameter (0,5 mm) is equal to the doubled value of wall thickness of sealing ring (0,25 mm). After 150 hours, wear and deformation of oil seal for oil seal / sleeve + sealing ring contact pair is for 0,23 mm bigger compared to the reference oil seal / sleeve contact pair. This means that increased wear and deformation of oil seal are absolutely compensated with the wall thickness of sealing ring.

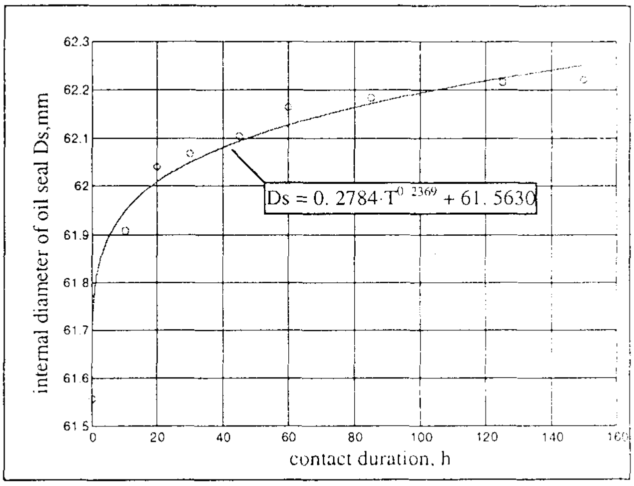


Figure 9. Wear and deformation of oil seal for oil seal / sleeve contact pair

Table 5.

Contact surface	Number of measu-rements	Ra [μm]	Rq [μm]	Rt [μm]	Rv [μm]	Rp [μm]	Sm [μm]	S [μm]	Rz [μm]	Δq [°]	Rsk [-]	Rku [-]
Shaft sleeve	1	0.32	0.43	3.2	2.6	0.7	54	19	2.7	4.2	-1.6	8.2
	2	0.37	0.52	3.6	2.9	0.7	62	19	3.1	4.4	-1.9	8.8
Speedi-Sleeve	1	0.25	0.31	1.6	0.8	0.7	66	13	1.2	1.7	-0.1	2.5
	2	0.31	0.36	1.7	1.0	0.7	60	13	1.4	1.6	-0.5	2.8

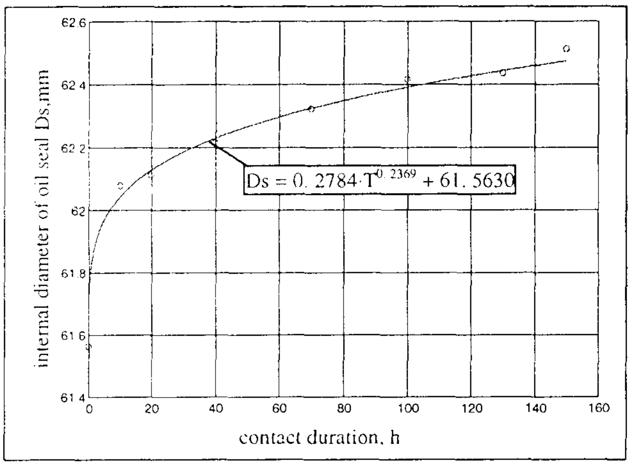


Figure 10. Wear and deformation of oil seal for oil seal / sleeve + sealing ring contact pair

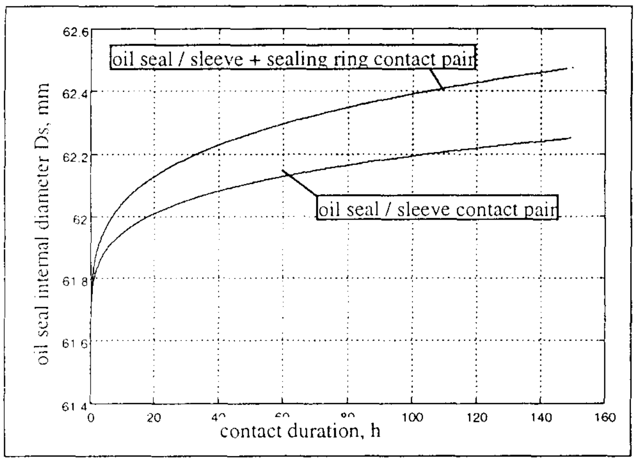


Figure 11. Oil seal internal diameter changes

3.3. Crankshaft sleeve and sealing ring wear investigation results

At the beginning of investigation, the review of contact surfaces topography for crankshaft sleeve and for sealing ring was performed. Measurement was conducted at computerized device TALYSURF 6. Measuring results is given in Table 5.

Due to parameters given in Table 5., both contact surfaces belong into the fifth class of roughness in accordance with Yugoslav standards.

Quantification of wear process for sleeve and sealing ring was very hard to perform because of two main reasons, as following:

1. Sleeve wear and especially sealing ring wear was of a very small level (wear track depth was maximum up to 1 μm) which caused that changes had been developed at microgeometry level of contact surface.

2. Contact surface corrugation at the sealing ring area, (of several μm level), is caused by the manufacturing process itself and had significantly lowered visibility of the contact zone. Illustration of this phenomenon is given in Figure 12. A part of sealing ring contact surface, the same reference line filmed, after the 10th and after the 150th hour of contact.

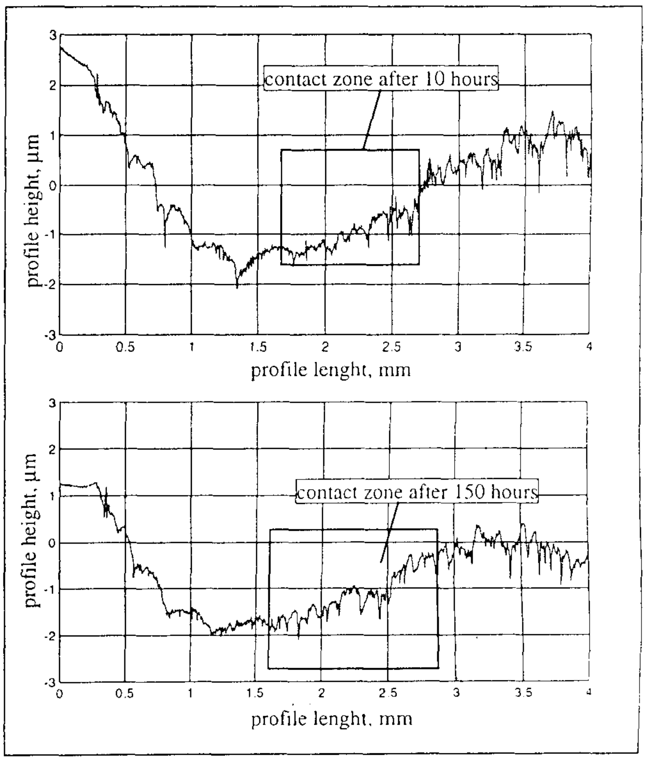


Figure 12. Contact surface profile at sealing ring area

Because of problems stated above, a statistical analysis of saved signals was done. During this process, in area around contact zone, elimination of corrugation influence was done.

Due to the profile filming in a contact zone and results analysis, the wear curve for sleeve was obtained as in Figure 13.

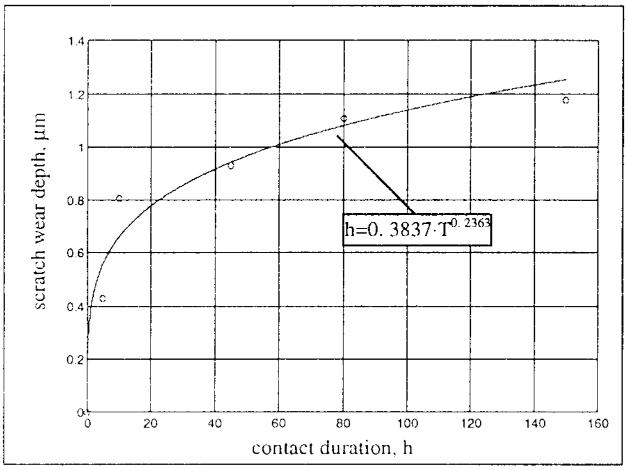
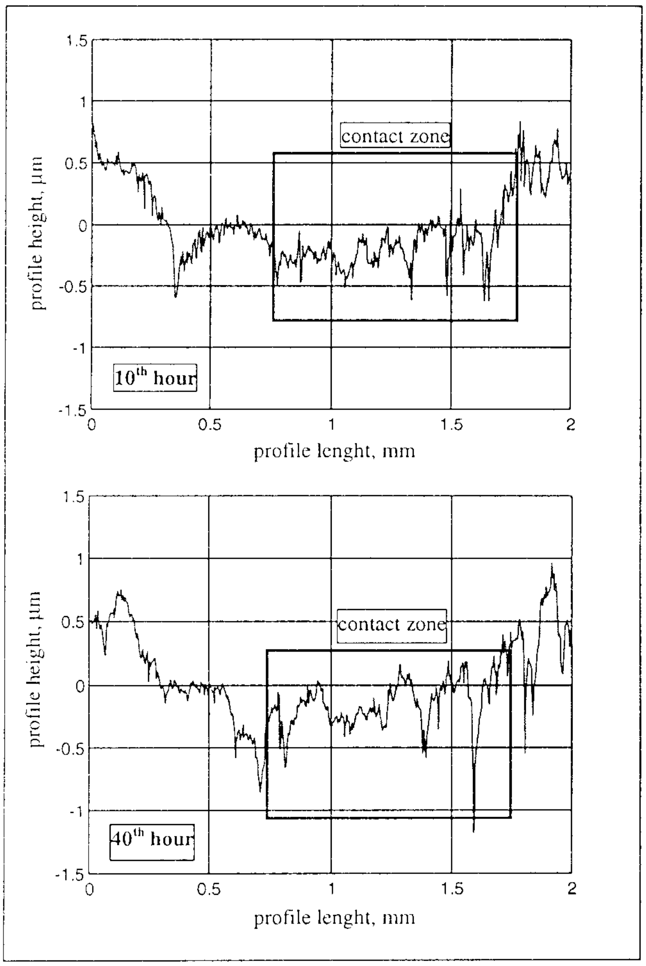


Figure 13. Wear curve for crankshaft sleeve (oil seal / sleeve contact pair)



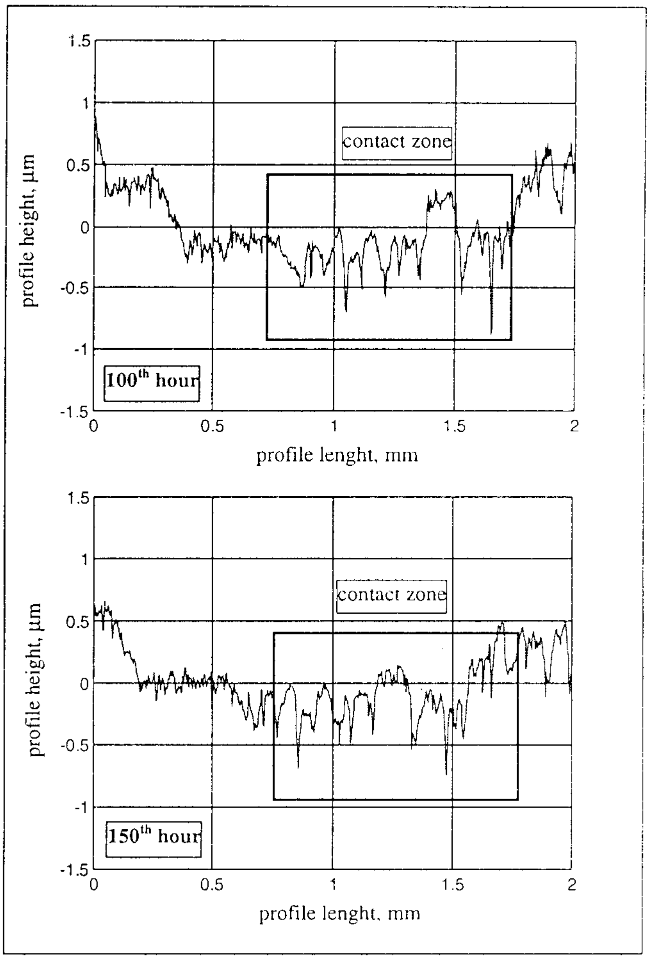


Figure 14. Development of sealing ring wear (oil seal / sleeve + sealing ring contact pair)

Development of sealing ring wear (oil seal / sleeve + sealing ring contact pair) was negligible during 150 hours of working. This is shown in Figure 14., where the changes in sealing ring contact surface microgeometry can be hardly seen, though it has very large magnification level.

One conclusion can be drawn from the analysis of presented results, that sealing ring wear (oil seal / sleeve + sealing ring contact pair) is not the limiting factor in its application for regeneration of sliding surfaces in contact with oil seal. Though the bearing curve for sealing ring profile is a bit worse than the one for crankshaft sleeve, experimental investigation determined that sealing ring contact zone wear is lower than crankshaft sleeve contact zone wear with same investigation conditions for both cases. Sealing ring wear intensity (oil seal / sleeve + sealing ring contact pair) is very slow. This enables long time sealing and its reliable application for regeneration of worn off sleeve.

4. CONCLUSION

There are certain differences in intensity of tribological process development for oil seal / sleeve + sealing ring contact pair and oil seal / sleeve contact pair. These differences are caused by changes in contact conditions and in contact elements' materials.

Average value of maximum temperatures in contact zone for oil seal / sleeve + sealing ring contact pair is a bit higher than the one for the reference contact pair (oil seal / sleeve). The reason for this lies in the fact that, for oil seal / sleeve + sealing ring contact pair, the diameter of seal lip resting at oil seal is bigger because of the sealing ring built in.

For oil seal / sleeve + sealing ring contact pair, the development of wear process and deformation of oil seal is intensive (increase of oil seal internal diameter). This is due to the pressure increase in contact zone, that is, because of seal lip resting diameter at oil seal increase (because sealing ring was built in). More intense development of wear process and deformation of oil seal process are absolutely compensated by oil seal wall thickness.

Oil seal contact zone wear is significantly lower than crankshaft sleeve contact zone wear under the same investigation conditions. This means that sealing ring wear, (oil seal / sleeve + sealing ring contact pair), is not a limiting factor in its application for regeneration of sliding surfaces in contact with oil seal.

All results obtained show that regeneration of worn off sleeve by sealing ring application is a very effective and rational method.

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