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The use of the optical-mathematical method to describe the structure formation during friction

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Abstract

The paper describes the two-periodicity of the compression and tension zones of the serial piston rings surfaces and hardened with a TiN/CrN multilayer ion-plasma coating after bench tests at a sliding speed of 1.3 m/s. The assessment is made from photographs of the microstructure of the surfaces of the rings. The periods of average values of negative, zero, and positive Laplacians were estimated for the columns and rows of photographs. The periods were analyzed by the initial surface and the friction zone, as well as by the general photograph of both ring variants. The result of the evaluation of individual zones revealed a significant difference between the surfaces of the ring with a multilayer ion-plasma coating, both in columns and in rows, which is associated with the wear of the effective coating layer and is confirmed by a decrease in nanohardness. Assessment of the overall photograph revealed a 30 % difference corresponding to a hardened piston ring with nanocoating with the same nature of the compression and tension zones formation, which reflects a sufficiently high resistance to plastic deformation and wear.

Key words: multilayer nanocoating, piston ring, friction and wear, nanohardness, optical-mathematical analysis, structure formation, plastic deformation.

Introduction

The results of previous studies about evaluating the degree and nature of wear of serial oil scraper piston rings of the D100 diesel generator showed their insufficient wear resistance [1]. To increase their wear resistance, the authors studied the possibility of applying a hardening multilayer ion-plasma coating of the TiN/CrN system, which ensured a multiple increase in operational properties at different sliding speeds [2 - 4].

To assess the stress-strain state of various zones of serial rings during friction and hardened by an ion-plasma coating, it became necessary to use the optical-mathematical method for describing structural changes on their working surface [2, 4, 5]. This method allows to identify the relationship between the operating parameters and the formed structure in the contacting surfaces of the products, which can be estimated by approximating their digital images. Also, this method allows to assess the degree of generated stress and identify the zone of their maximum concentration [6 - 10].

After in these studies on the surfaces photographs after testing the piston rings for wear, two-periodicity of the compression and tension regions was revealed [2, 4, 5], it became necessary to describe these zones analytically.

The aim of the study is an analytical description of the two-periodicity of the compression and tension zones of the surfaces of serial piston rings and hardened by a TiN/CrN multilayer ion-plasma coating after bench tests at a sliding speed of 1.3 m/s from their electron-microscopic photographs of the friction surface.

Research Methodology

To carry out the calculations, energy parameters were used and periods of average values of negative, zero, and positive Laplacians were estimated from the columns and rows of photographs of the initial surface

and the friction zone of serial (Figs. 1, 3) and hardened rings (Figs. 2, 4), respectively. Additionally, we analyzed the general images of the serial and hardened ring variants after the tests, Fig. 5, 6, respectively.

The calculation algorithm is implemented as a subroutine. The program itself sends the corresponding values to the subroutine. In each photograph (Fig. 1 - 6), the subroutine searches for the values of the each periods of its pixels in columns and rows. The cycle for trial periods was calculated in the range from 2 to 200 pixels, according to the following source data:

s_{qj} – array of average values;

s_{1j} – average fraction of negative Laplacians by columns or rows;

s_{2j} – average fraction of zero Laplacians by columns or rows;

s_{3j} – average fraction of positive Laplacians by columns or rows.

Moreover, the indices in the algorithm have the following meaning:

q – the number of the sign (1 negative, 2 zero, 3 positive);

i – the group number of the same trial period;

j – the number inside the same group of the same trial period;

t – the trial period in pixels.

The number of periods was equal to the integer part of the number of pixels divided by the period. Then, the total algebraic deviation from the average value of the fractions of negative, zero, and positive Laplacians inside the trial period was calculated using formula (1).

$$a_q = \frac{\sum_{j'=1}^{t} s_{qj}}{t}. \tag{1}$$

The calculation of the average values of the shares of negative, zero, and positive Laplacians inside the trial period is carried out according to the formula (2).

$$b_q = \sum_{j=1}^{t} \left(s_{qj} - a_q \right). \tag{2}$$

After that, it was used the absolute value of the deviation from the average value according to the formula (3).

$$b_q = \left| b_q \right|. \tag{3}$$

The total value of the functional inside the trial period was found from formula (4), and from it the accumulation of functional according to formula (5).

$$c_i = b_1 + b_2 + b_3, \tag{4}$$

$$f = f + c_i. \tag{5}$$

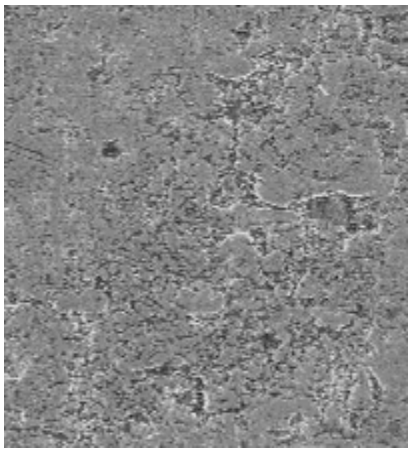

Fig. 1. Microstructure of the initial surface of the serial ring

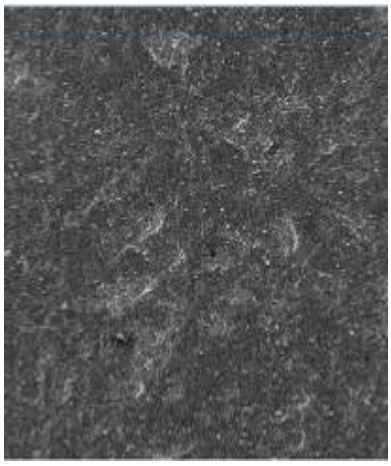

Fig. 2. Microstructure of the initial surface of the hardened ring

Fig. 3. The microstructure of the friction surface of the serial ring at a sliding speed of 1.3 m/s

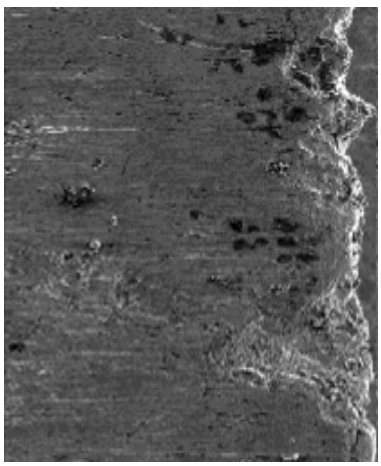

Fig. 4. The microstructure of the friction surface of the hardened ring at a sliding speed of 1.3 m/s

Based on the results of the cycle calculation, an array of trial periods functionals was created. The created array was sorted in descending of functionals to detect the most significant changes.

Table 1 - 4 presents the calculated periods, where the first column is the period in pixels, and the second is the corresponding functional.

As the table 1 - 4 show, the values of the functionals of both ring options differ in the results of counting in columns and in the rows of photographs of the initial and friction surfaces. However, if we compare

the functionals exclusively in rows or columns, then we can highlight a certain pattern. When counting by columns, the maximum functional of the initial surface of the serial ring is 13.7 % lower than its friction zone (see Tables 1, 3), and the hardened one is 32 % higher (see Tables 2, 4). However, a row calculation shows that the largest functional of the initial surface of a serial ring is 4 % higher than its friction zone (see Tables 1, 3), and hardened - 8.2 % lower, respectively. In both cases, both in columns and in rows, the largest difference between the surfaces is characteristic of a ring with a multilayer ion-plasma coating.

Table 1

Values of periods and corresponding functionals of the initial surface photograph of the serial ring

By columns		By rows	
period	functional	period	functional
2	0466	2	0883
3	0461	3	0866
154	0456	123	0855
5	0448	4	0813
114	0438	5	0807
59	0433	120	0791
17	0432	139	0779
53	0432	104	0771
158	0430	167	0765
21	0429	173	0764

Table 2

Values of periods and corresponding functionals o f the initial surface photograph of the hardened ring

By columns		By rows	
period	functional	period	functional
3	0559	2	0805
172	0514	3	0805
2	0502	127	0763
173	0500	200	0749
176	0497	89	0739
4	0489	157	0738
127	0486	5	0733
132	0483	4	0730
16	0481	18	0717
59	0478	65	0717

Table 3

Values of periods and corresponding functionals of the friction surface photograph of the serial ring

By columns		By rows	
period	functional	period	functional
2	0540	3	0848
3	0526	2	0837
176	0508	4	0795
170	0499	152	0752
131	0491	93	0733
166	0474	5	0731
75	0471	95	0725
130	0468	136	0725
12	0467	164	0721
4	0465	33	0718

Table 4

Values of periods and corresponding functionals of the friction surface photograph of the hardened ring

By columns		By rows	
period	functional	period	functional
3	0380	3	0877
193	0375	2	0831
5	0373	159	0767
94	0365	7	0764
47	0364	6	0760
2	0362	5	0742
177	0362	138	0740
125	0359	4	0728
185	0359	134	0722
178	0355	9	0718

This result, most likely, is associated with the wear of the effective coating layer, which is confirmed by a sharp decrease in the nanohardness of the hardened ring (initial microhardness of TiN/CrN was 53 – 59 GPa) after testing, the level of which approached the - starting material (4 - 4.7 GPa).

This is also indicated by the value of the maximum functional of the rings (calculated according to the rows of the friction zones, see Tables 2, 4).

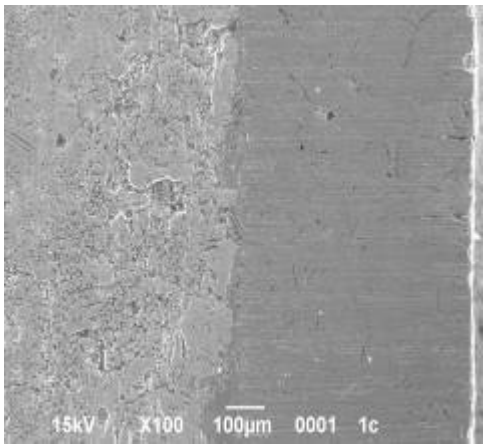

Fig. 5. General photo of the initial (left) structure and friction surface (right) of the serial ring

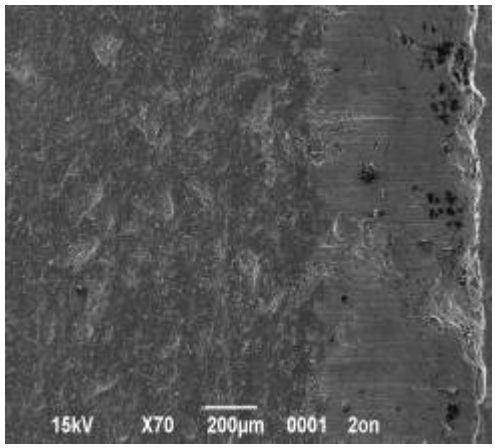

Fig. 6. General photo of the initial (left) structure and friction surface (right) of the hardened ring

So, on average, in columns the maximum functional of a serial ring is lower than the hardened one. The same indicator, that calculated in the rows, lower relative to the hardened ion-plasma multilayer coating of the working layer on average 30 %, which reflects its higher plastic deformation resistance in the considered directions. Moreover, the difference in columns and rows in both ring options is 26 %. This also indicates about the same distribution of compression and tension zones under identical operating conditions.

Table 5

Values of periods and corresponding functionals in the general photographof the serial ring after operation

By columns		By rows	
period	functional	period	functional
3	1311	2	0969
2	1256	159	0922
5	1152	3	0921
4	1138	5	0881
139	1131	4	0853
89	1122	105	0846
7	1108	6	0832
156	1097	128	0824
13	1093	7	0823
114	1087	115	0820

Table 6

Values of periods and corresponding functionals in the general photograph of the hardened ring after operation

By columns		By rows	
period	functional	period	functional
3	1323	3	0973
2	1232	2	0932
4	1177	188	0896
5	1172	4	0867
175	1172	119	0857
182	1166	22	0849
103	1155	87	0848
7	1110	111	0840
116	1109	180	0839
114	1107	135	0835

It is possible that a high spread in the functionalities of individual ring surfaces (see Tables 1 - 4) is directly related to the separation of the general image into individual fragments. Considering that the alternation of compression and tension zones was previously recorded over the entire volume of the material of the ring working surface [5], an additional assessment was made of the functionals calculated values (Tables 5, 6) of the general photograph of both considered options (Fig. 5, 6) after testing, which show a distinctive regularity, both in rows and in columns.

Conclusions

The studies of the nanostructured state showed the effectiveness of the proposed method for the analytical assessment of the compression and tension zones of the piston rings after friction and wear tests, namely:

- the greatest effect is achieved when calculating the functionals, the corresponding periods of the structure variability for the general picture of the working surface and the boundary in the ring;
- the revealed pattern during hardening by nanocoating reflects its rather high resistance to plastic deformation and wear;
- the difference corresponding to the variant of hardening by nanocoating of the piston ring reaches 30% with the same character of the formation process of compression and tension zones.

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Скобло Т.С., Сидашенко О.І., Мальцев Т.В. Застосування оптико-математичного методу для опису структуроутворення при терті.

В роботі виконано опис двухперіодічності зон стиснення і розтягування поверхонь серійних поршневих кілець і, зміцнених багатошаровим іоно-плазмовим покриттям TiN/CrN після стендових випробувань при швидкості ковзання 1,3 м/с. Оцінка виконана по фотографіях мікроструктури поверхонь кілець. Були оцінені періоди середніх значень негативних, нульових і позитивних лапласіанів по стовпцях і рядках фотографій. Аналіз періодів здійснювався по вихідній поверхні і зоні тертя, а також по загальній фотографії обох варіантів кілець. Результат оцінки окремих зон виявив істотну різницю між поверхнями кільця з багатошаровим іонно-плазмовим покриттям, як за стовпцями, так і по рядках, що пов'язано зі зносом ефективного шару покриття і підтверджується зниженням нанотвердості. Оцінка загальної фотографії виявила різницю 30%, що відповідає зміцненому поршневому кільцю нанопокриттям при однаковому характері формування зон стиснення і розтягування, що відображає досить високий опір пластичній деформації і зношуванню.

Ключові слова: багатошарове нанопокриття, поршневі кільця, тертя і зношування, нанотвердість, оптико-математичний аналіз, структуроутворення, пластична деформація.