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THE ANTIFRICTIONAL COATINGS ON THE MOLYBDENUM BASE.

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Abstract: Friction and wear of the antifrictional complex coatings on the molybdenum base were under investigation. Coatings were obtained using complex vacuum-plasma technologies under reactive coatings deposition utilizing vacuum arc deposition of Mo-N coating and RF-magnetron deposition of MoS_2. Total coating thickness is 10 mkm.

It was shown by means wear track profilography and acoustic emission investigation that such coatings are very effective working in pairs with hard coatings Ti-Al-N. During run-in period of exploitation such coatings shows low friction coefficient close to MoS_2, but they have much more resistance to wear in many times greater than MoS_2, and significantly more stable friction coefficients.

Keywords: *vacuum-plasma technologies, tribology, reactive coatings deposition.*

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1. Introduction.

Scientific technological Corporation "FED" conduct extensive work in the area of development and practical utilization of novel nanomaterials and technologies of obtaining such materials (multicomponent, mono and multilayer, nanostructured, gradient) of different functional application (antifrictional, hardening and others) for improvement performance of materials, units and samples of aircraft aggregates, as well as in the field of development of technological processes for the application of such coatings and equipment for their implementation.

The basis of technology is the processes of atomic-ion surface modification and the formation of nanolayer coatings from various elements and chemical compounds under the influence of a nonequilibrium low-temperature plasma.

The peculiarity of the developed coating processes lies in their complexity: different coating methods (plasma CVD, vacuum-plasma PVD (vacuum arc, magnetron), ion saturation and ion surface treatment) are combined in a single technological cycle.

For the application of functional multilayer composite coatings, experimental and technological equipment was developed and developed - the automated system Avinit [1], which allows the implementation of complex coating methods.

Avinit coatings are deposited on high-grade precision surfaces roughness (up to V = 11-12) without reducing the surface cleanliness class. Precipitation is carried out at low temperatures that do not exceed the tempering temperatures of the base material, which ensures the preservation of mechanical characteristics and the absence of warpage of the articles to be coated.

Correct choice of individual layers materials, deposition methods and optimization of technological parameters create prerequisites for the synthesis of materials with a complex of unique properties, including with exceptionally high hardness, strength, chemical stability, low coefficient of friction and increased wear resistance.

When developing new design solutions, the development of advanced technologies and materials with enhanced technical characteristics are of primary importance. One of the important areas of work in this regard is to increase the reliability and service life of friction units.

In connection with the sharp difference in the requirements for the properties of friction components in the volume and in the thin near-surface layer that determines the parameters of friction and wear, it is increasingly important to use new technologies for the application of protective, wear-resistant, antifriction and run-in coatings that enhance the possibilities of forming working layers.

MoS_2 (molybdenum disulphide) is the most widely used solid lubricant. Molybdenum disulphide has an extremely low coefficient of friction, lower than that of Teflon and graphite. The achievable friction coefficient is less than 0.05, varying depending on humidity and friction conditions.

Various low-temperature processes of deposition of MoS_2 coatings by magnetron sputtering are worked out.

The thickness of the coatings can vary, usually ranging from 1 to 10 microns. Coatings can be extremely thin and ultra-thin (0.1 micron or less), which is extremely important when coating the precision components.

The most significant drawback of such coatings is their very low wear resistance.

To increase their practical use, it is highly desirable that coatings, while maintaining a low friction coefficient at the level of pure molybdenum disulphide, have a significantly higher wear resistance.

It was shown in [2-4] that tribosystems based on superhard coatings (based on MoN TiAlN) have low friction coefficients at a level of less than 0.07-0.09. After testing such friction pairs for wear no signs of increased wear, the working planes of samples covered with ▼ 10 ***Avinit*** C320 (310) and ▼ 10 ***Avinit*** C220 were not detected.

Such tribosystems have already found practical applications [5, 6].

Further improvements are associated with the creation of tribocouple designs with even lower coefficients of friction and increased wear resistance.

The technological capabilities of the ***Avinit*** installation allow us to proceed with the development of antifriction coatings based on the strengthened molybdenum disulphide of the following type:

- strengthened nanostructured coatings;
- strengthened nanolayer coatings;
- strengthened composite coatings (based on molybdenum disulphide == molybdenum nitride on surfaces with low roughness followed by mechanical run-in during operation).

In this paper, the results of studies of reinforced composite coatings of ***Avinit*** on the basis of molybdenum and a study of their tribological characteristics are presented.

Research Methodology.

For the coatings deposition, the ***Avinit M*** and ***Avinit C*** units of the ***Avinit*** installation were used. The coatings were applied on the samples used in the tests on the friction machine, according to a specified program, in which the time, sequence and operating conditions of the evaporators, the reaction gas supply system were set.

Metallographic studies of samples with coatings (microsections, hardness of coating, determination of surface geometry after coating) were carried out using metallographic, chemical, X-ray and micro-X-ray spectroscopy, microhardness and roughness measurements of friction surfaces. The surface roughness of the samples before and after the coating was measured on a profilometer - profilograph.

Metallophysical studies of the obtained coatings were performed with a scanning electron microscope JSM T-300.

Tribological studies on friction and wear were carried out using an improved serial friction machine 2070 SMT-1 in the "ring-ring" scheme.

Before the tests, the samples were washed with gasoline, dried at a temperature of 70°C. Before and after the tests, the samples were weighed on analytical scales VLR-200 with an accuracy of 10^{-5} g to assess the wear resistance of coatings.

Friction mode - boundary lubrication conditions (working fluid consumption - 2 liters / hour).

Working fluid - aircraft fuel TS-1 with a class of purity 6 ... 8.

Friction conditions:

- speed of rotation of a driving shaft 500 min^{-1};
- a stepwise increase in the load until the scoring is formed or to the maximum possible value;
- dwell time at each load stage 15 ... 20 min.

Working fluid for lubrication was supplied through the internal openings of the samples.

In the course of experiments, we recorded:

- the friction moment (recalculated in the coefficient of friction), the magnitude of which was judged on the mechanical losses in tribosystems;
- The temperature of the elements was continuously recorded in real-time tests in close proximity (1 mm) from the friction zone, using a sliding thermocouple.

To determine the scuffing of the surface layers of materials of friction pairs, the load was carried from P_{min} to the critical value P_{cr} at which the scuffing takes place.

In addition, we measured the rate of wear by the acoustic emission method. The wear rate was recorded for a time of 20 msec in relative wear units.

To reproduce the test results for wear, the surface of the end surfaces was controlled by the contact area: not less than 90% of the working surface of each sample.

3. Experimental part.

The essence of the design.

The tribocouple (the main sample A and the counterpart sample B) is similar to that tested in [2-5] - a sample A with a coating of ▼10 ***Avinit*** C320 (310) (based on TiAlN) 1.5-2 µm thick and sample B with a coating ▼10 ***Avinit*** C220 (based on MoN) with a thickness of 1.5-2 µm.

However, the counter sample B has a working surface grindedwith a roughness class ▼ 7 ... 8, on which is deposited an unseparated MoN coating with a thickness of ≈ 10 µm with a roughness class of ▼ 7 ... 8. Then MoN coating is applied to the MoS_2 coating with a thickness of ≈ 5 ... 10 µm RF magnetron sputtering. Finally, the working surface has a roughness across the topography: - Ra 1.9 (▼ 6b). It is assumed that the MoS_2 coating fills the submicroscopic irregularities of the MoN rough microrelief. During operation, as the MoS_2 coating wears out on the working surface, an dispersed structure is formed on the basis of MoN- MoS_2 remaining in the unevenness of the microrelief, providing higher antifriction values in the operating loading range

1. Preparation of samples A (steel 30X3VA, 30 ... 35 HRC) under Ti-Al-N deposition.

The working surface is machined to: - non-flatness ≤ 0.002 mm, roughness -Ra 0.104 (▼ 10). Samples A are nitrided ***Avinit N*** [7] h = 0.2 ... 0.3 mm, H> 700 HV. After nitriding, the working surface has a roughness: - Ra 0,397 (▼ 8). To reduce roughness, the working surface of samples A is lapped manually on a cast iron plate without the use of abrasive. Lapping time - 2 ... 3 min. Before obtaining on the entire working surface a new lapping relief with a roughness: Ra 0.020 (▼ 12). The surface of samples A is coated with Ti-Al-N (***Avinit*** C310). Finally, the working surface has a roughness: - Ra 0.060 (▼ 10в ... 11б).

2. Preparation of samples B (30X3VA, 28 ... 33 HRC) under (MoN + MoS_2)

The working surface of the samples is grinded with a cleanliness class of ▼ 7 ... 8. On the working surface, an unseparated MoN coating with a thickness of ≈ 10 μm is deposited. MoN coating is coated with MoS_2 coating with a thickness of ≈ 5 ... 10 μm RF magnetron sputtering. Finally, the working surface has a roughness across the topography: - Ra 1.9 (▼ 6b).

Stage 1. Conducting tests to determine the coefficient of friction and wear resistance of the tribosystems Avinit C310 (TiAlN) - MoN = 10 μm + MoS_2 = 5 ... 10 μm (operating time 0 ... 8 hours).

Tribopair No. 1 for testing in phase 1

- Sample A - Avinit C310 coating (TiAlN);
- sample B - coating MoN = 10 μm + MoS2 = 5 ... 10 μm

Changes in the friction coefficient and temperature in the contact zone along the test time are shown in Fig. 1.

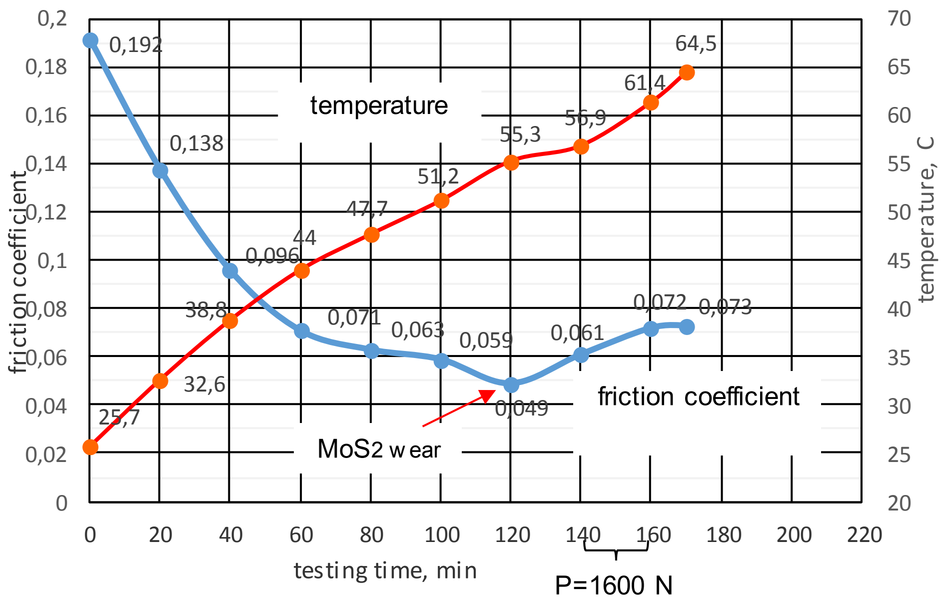

Fig. 1.

The level of acoustic emission by time of testing is shown in Fig.2

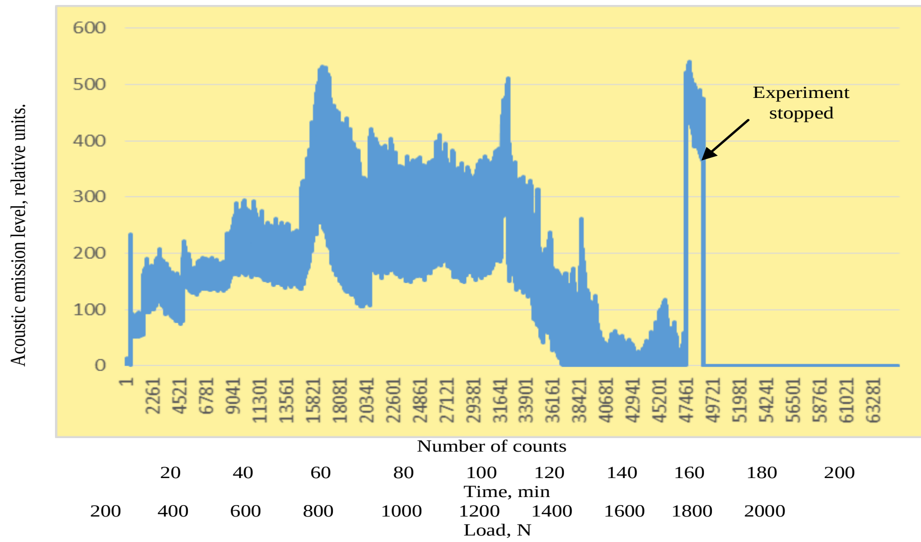

Fig. 2.

The best level of antifriction the tribosystem shows in the load range from 1000 to 1200 N, which is apparently explained by the operation of the MoS_2 coating, which fills submicroscopic irregularities in the microrelief providing high antifriction rates in the operating loading range. Tribosystem has a high level of bullying (more than 2000 N).

The change in the level of acoustic emission (based on the results of three experiments) indicates an almost complete run-in of the tribosystem in the range of loads 1200 ... 1600 N.

Above the loads of 1000 - 1200 N, the level of tribotechnical characteristics and acoustic emission is unsatisfactory. The level of the acoustic emission signal increased sharply and persisted for 5 minutes. At a load of more than 1000 N there is a transition from normal wear to microcutting.

At the end of the tests for bullying, on the working surface of sample A local crescent wear of the Ti-Al-N coating was revealed up to the main material, adjacent to the inner cylinder of the sample. Scraps of coatin on the boundaries of the worn zone are not available. The weight wear of sample A was 1 mg, the weight wear of sample B was 0.0000 mg.

The working surface of sample B is in a satisfactory state

This behavior of the tribosystem is not typical for fatigue wear (by the nature of acoustic emission and the change in the friction moment). A possible cause is the presence of "grinding" of the surface of sample A by the surface of sample B.

At the same time, the profilogram of the sample surface shows that during the test, some running-in of the sharp cutting edges of the MoN coating occurred.

Since the working surface of sample A was worn out and the surface of specimen B was in satisfactory condition with improved profilographic characteristics and allowed to be used for subsequent tribological tests, it was decided in the second stage to test the tribocouple with a new sample A and sample B tested in the first stage.

Stage 2. Conducting tests to determine the coefficient of friction and wear resistance of the tribosystems Avinit C310 (TiAlN) - MoN = 10 μm + MoS2 = 5 ... 10 μm (operating time 8 ... 16 hours).

Tribopair No. 2 for testing in phase 2

- Sample A - Avinit C310 (TiAlN) coating, manufactured for both Stage 1;
- Sample B - Sample B after the first stage.

The coefficient of friction and temperature in the contact zone in time for wear resistance tests are shown in Fig. 3.

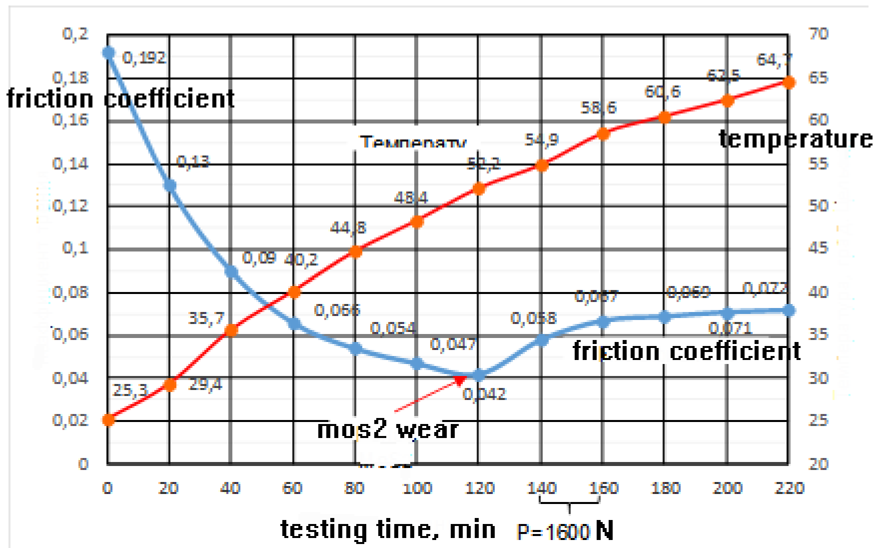

Fig. 3.

The level of acoustic emission by the time of the test is shown in Fig. 4.

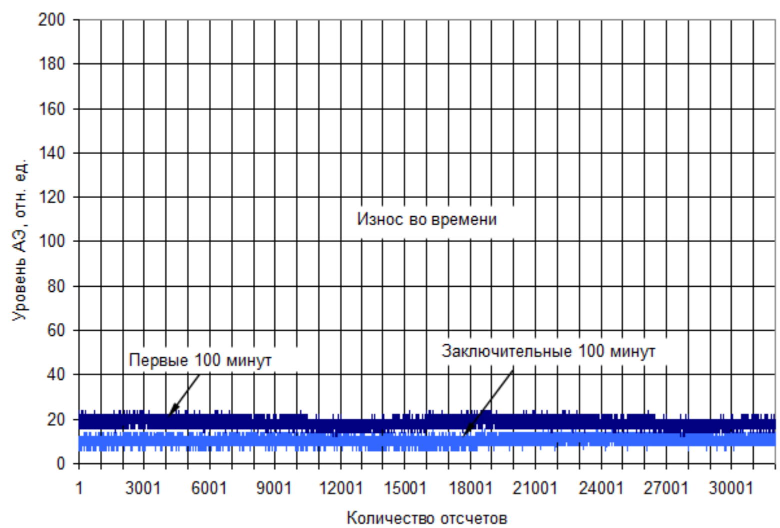

Fig. 4.

The change in acoustic emission signals is not typical for fatigue wear (continuous emission), and the level of acoustic emissions signals practically does not change during the test, being approximately 10 rel. Units. It can be assumed that there is a mutual process of "grinding" of the working surfaces of samples A and B during the testing.

The analysis of the profilograms shows that the surface roughness of sample A remains practically unchanged (the surface roughness of sample A after the tests is Ra 0.046); the surface roughness of specimen B is substantially improved (the surface roughness of sample B after the tests is Ra 0.705).

At the same time, the wear rate is significantly lower than that of pair No. 1, both in terms of acoustic emission indexes and in terms of weight wear. The weight wear of sample A is 0.0001 g; Sample B 0.0002 gr.

According to the level of tribotechnical characteristics and acoustic emission, Tribopar No. 2 has fairly good indicators.

Taking into account the good condition of the tribo-pair No. 2 after the tests, which allows its use for subsequent tribological tests, it was decided to continue the trial of tribo-pair No. 2 at the third stage.

Stage 3. Conducting tests to determine the coefficient of friction and wear resistance of the tribosystems Avinit C310 (TiAlN) - MoN = 10 μm + MoS2 = 5 ... 10 μm (operating time 16 ... 24 hours).

Tribopair No. 3 for testing in Phase 3

- continuation of tribopair test No. 2.

Исходное состояние профиля рабочей поверхности образца А покрытие **Avinit** C310 (TiAlN**)** представлено на рис. 5 (шероховатость Ra 0,04)

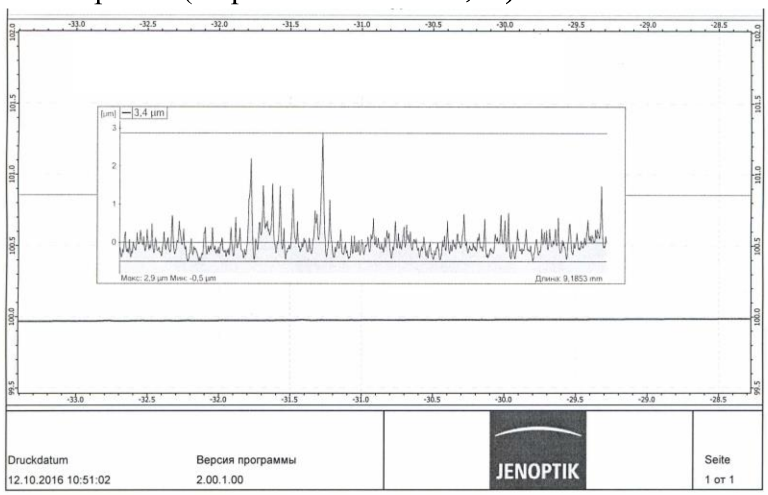

Fig. 5/

Исходное состояние профиля рабочей поверхности образца В покрытие MoN=10 мкм $+MoS_2$=5…10 мкм (наработка 8…16 час.) представлено на рис. 6

Fig. 6/

The coefficient of friction and temperature in the contact zone in time are shown in Fig. 7/

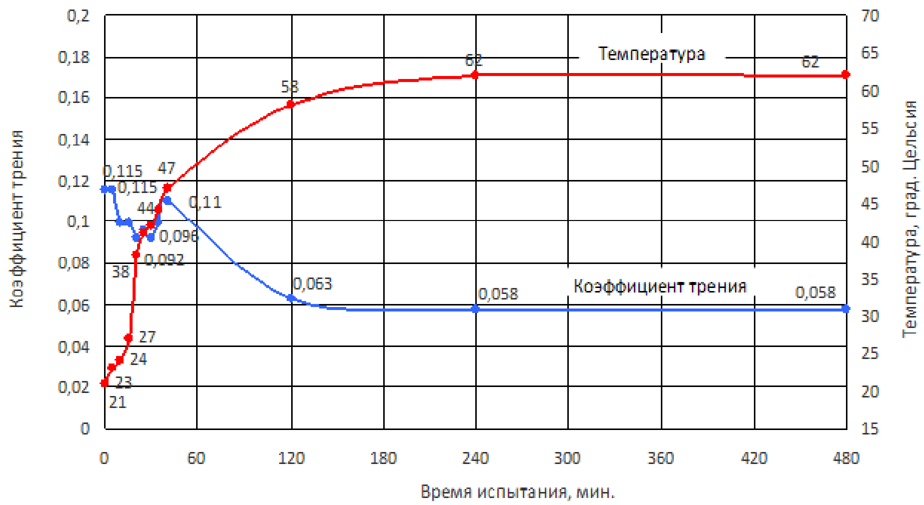

Fig. 7.

The level of acoustic emission by the time of the test is shown in Fig. 8/

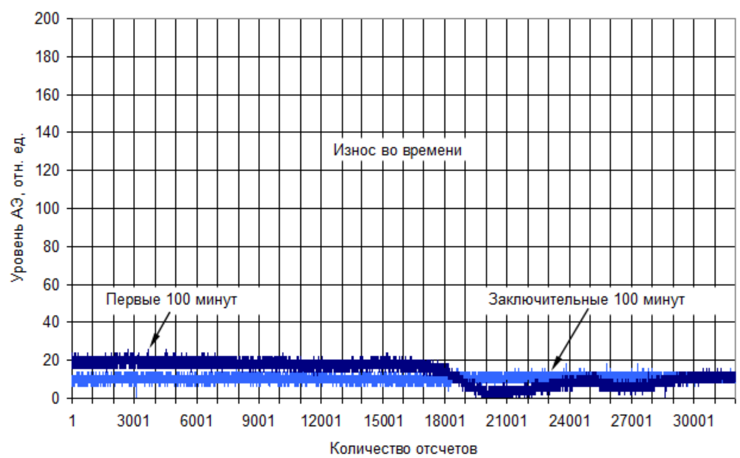

Fig. 8.

It is noted that the area of the working surface of sample B, which has a sheen (run-in visually), increased in comparison with the state after the first 16 hours of wear testing. The surface roughness of sample A after the tests R a 0.025. The roughness of the surface of sample B after the wear tests is Ra 0.108. Weight wear of sample A - 0.0001 gr, sample B - 0.0001 gr.

The tribosystem has an abnormally low rate of wear rate.

On the level of tribotechnical characteristics and AE, tribopar No. 3 has high indexes, better than pairs No. 1 and No. 2.

Состояние профиля рабочей поверхности образца А – покрытие ***Avinit*** С310 (TiAlN) представлено на рис. 9 (шероховатость Ra 0,02)

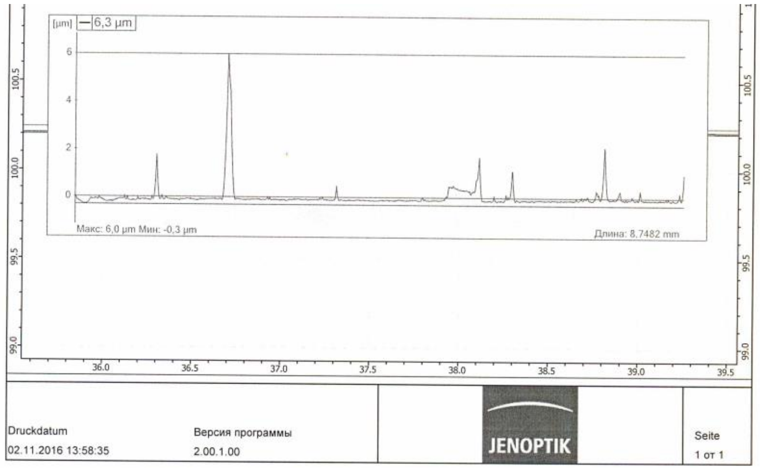

Fig. 9.

Состояние профиля рабочей поверхности образца В покрытие MoN=10 мкм +MoS_2=5…10 мкм (наработка 16…24 час.) представлено на рис. 10.

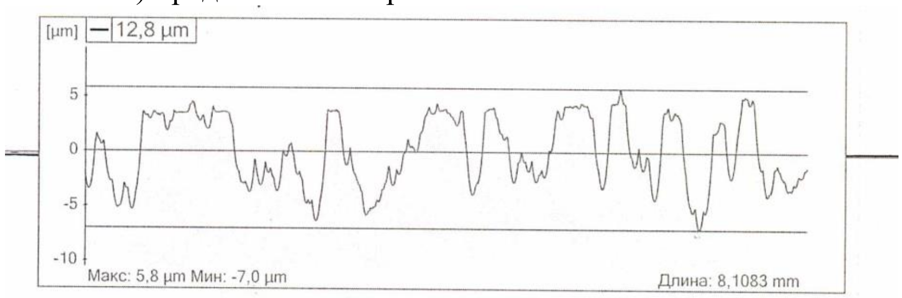

Fig. 10.

Conclusions

Tribological tests using the method of acoustic emission and profilographic measurements have shown that the improved antifriction hardened composite coatings of ***Avinit*** MoN-MoS_2 have high tribological characteristics when operating in pairs with superhard coatings based on Ti-Al-N. During the run-in during operation, keeping low values of friction coefficients close to MoS_2, they have a much higher resistance to wear, many times higher than the resistance of MoS_2, and much more stable friction coefficients, which is explained by the MoS_2 coating that fills submicroscopic irregularities of the microrelief providing High rates of antifriction in the operating load range..

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