im 2006
National Conference with International Participation
ENGINEERING MECHANICS 2006
Svratka, Czech Republic, May 15 – 18, 2006
paper no. 328

INCREASING IN LOADING CAPACITY OF HIGHLY LOADED SLIDING BEARINGS BY SURFACE MODIFICATION OF THEIR FRICTION SURFACES

E. Tesker, S. Tesker, N. Yakovlev, E. Dovgalenko, S. Litvinov, V. Treshev*

Summary: *The data of applied research aimed at new laser surface modification technologies development are presented in this paper. Both polymer and metal surface coatings formed on steel parts under laser radiation have been tested and their influence on the friction conditions, reliability, bearing capacity and durability the drive item as well as relationships between laser treatment modes, coatings composition and various exploitation parameters have been studied. It is shown that the worked out technologies, to be used in production, provide compressor's mechanical systems with increased reliability and operating properties.*

1. Introduction

Intensification of nature gas and oil production and refinery processes requires continuous improvement of compressor equipment reliability. Exploitation experience testifies to limitation of compressor lifetime and working capability caused by low wear resistance of highly-loaded parts. Manufacturers develop many innovations in design and special materials used for the compressor parts their efficiency could hardly meet the multi-factor operating requirements. Having much more complicated construction design the compressor equipment often loose their maintainability for a service staff at a place (refinery, pipes, etc.).

The working out of new task-oriented techniques providing various highly-loaded compressor parts with demanded properties for operation under multi-factor actions (aggressive medium, hard friction, cycled loads) was the main goal of the studies are being presented. For the purpose in view the complex investigation of laser surface alloying and treatment of steels and polymers as well as many life-like tests have been conducted.

It is well known that insufficient damage and wear resistance of friction parts surface is the main cause of equipment's failure. Traditionally using in production techniques of thermo- and chemical-thermohardening as well as many others are usually unable to provide items with demanded resistance especially under high dynamic loads and in aggressive medium. The process of surface wearing destruction caused by the number of mechanical and chemical phenomenon. The feature of contact interaction is the presence of considerable gradient fields of stress, temperature and deformation velocities. Without doubts that the surface layer's role in formation of operating properties of every particular item is rising significantly thanks to its

* Volgograd State Technical University, Lenin prospect, 400131 Volgograd, Russia

hardening but in this case the conditions for fragile or fatigue destruction could be sometimes induced. Thus the surface modification should ensure necessary mechanical strength and that is why the investigation of physical and chemical processes in surface layers, revealing determinant factors for loading capacity of working surfaces as well as development on its basis the techniques and coatings for surface modification appears rather complicated but very actual scientific problem.

Based all mentioned above, the alloying powders chemical composition as well as CO_2-laser alloying and modification techniques development was done using complex approach with concurrent consideration of following statements: items operating limits and changes in their surface layer's material properties at the final stage of lifetime; wear kinetic and failure mechanism; optimization of surface layer properties that influence on its bearing capacity, wear and failure resistance. The described approach allows to state necessary specific recommendations for a surface coating components choice and their ratio optimization as well as to make substantiated prediction of working capacity and lifetime range in the particular conditions.

Using laser advantages and features (such as highly concentrated and localized energy, huge heating and cooling rates and very short treatment times) we were forced to solve many experimental and research problems – alloys and polymer composition, treatment modes optimization, etc., that finally led us to elaboration of industry applicable technologies for laser hardening of steels, laser surface alloying on steels and irons, laser assisted formation of protective and solid-lubricating polymer films. Technologies features in detail and some examples of use will be given below.

2. Results and discussion

Nowadays, laser hardening of low-carbon corrosion-resistant steels which are utilized for cylinders, rods, crankshafts, plungers and crossheads production appears rather problematic. But we were capable of solving this task and had established that with specially developed and optimized laser treatment modes based on analysis of steel's chemical composition and phase conversions, that may well take place under highly concentrated energy beams, up to 1 mm (in thickness) surface layer with microhardness up to 7400 MPa can be formed. This layer has the homogeneous martensite structure with chrome-carbides distribution in its volume (see fig.1a). The indicated microhardeness value is significantly higher than it can be obtained after volume or induction heating. Besides, there is auspicious compressive stress field induced after the laser treatment which can also conduce to increasing in destruction and wear resistance. Proportional dependence between wearing intensity and microhardeness of local micro-volumes gives us grounds to suppose that wear resistance laser treated surface layer may grow up significantly. This supposition was approved by lifelike tests carried out on plungers of the opposite compressor "Créseau Luar" (France) where we obtained wear resistance rised up 2 times.

Other feature of lengthy surfaces laser treatment is the special laser track positioning, namely, with the track by track displacement value (S) less than beam's diameter (d_b). Study of laser treated samples wear kinetics with surface waviness recording equipment let us to find out that thanks to definite distribution of laser tracks and the surface micro-hardness the specific surface micro-geometry can be formed (fig.1b). That micro-geometry provides surface with a kind of "oil-traps", which in their turn, allow to obtain resistant lubricating oil film which separates friction surfaces and is favorable for their wear resistance.

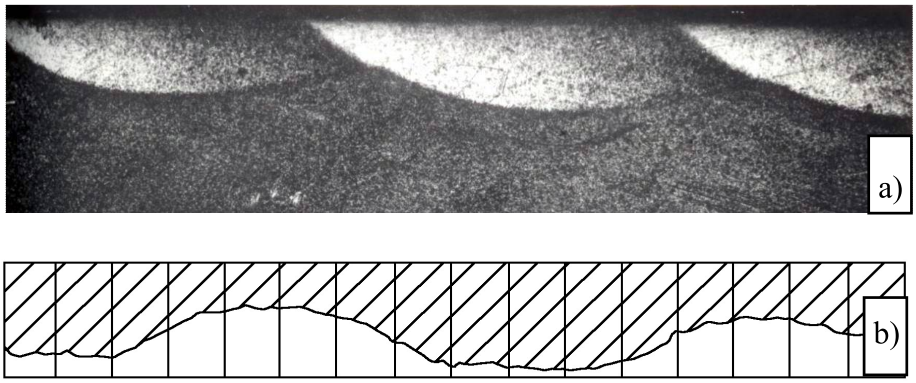

Fig.1. a - view of laser track traces in steel structure; b - surface micro-geometry after friction test

The approval of laser hardening positive influence on the samples mechanical strength was obtained from impact tests data. The increasing in impact elasticity (up to 1,5 times) was achieved thanks to increased crack nucleation work and its propagation through the hardened layer as well as crack arrest on the hardened layer-matrix steel interface (fig.2 a, b).

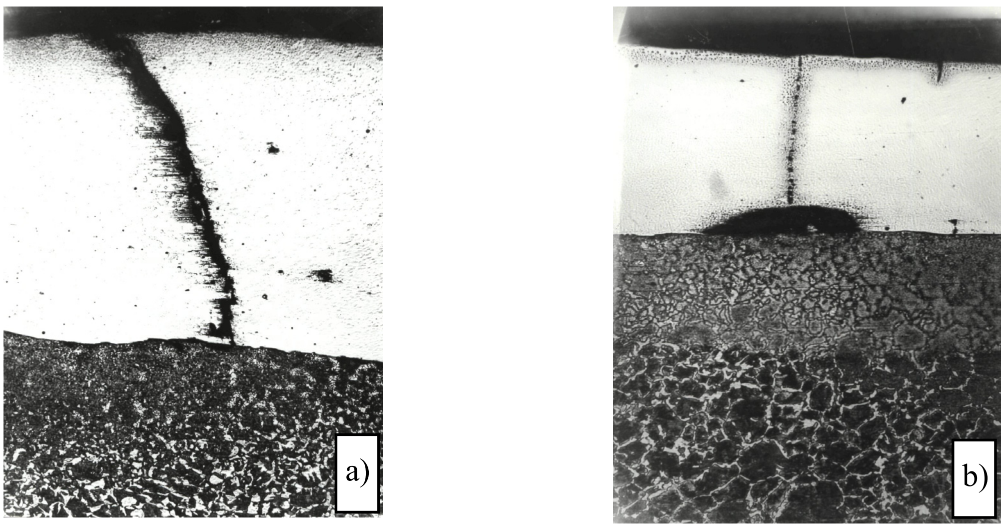

Fig.2. Crack arrest on the hardened layer-matrix steel interface.

The worked out laser technologies for multipurpose surface-alloyed coatings creation are highly effective in application for renovation and production of new compressors and spare parts. The microstructures of thermal sprayed coating and laser alloyed surface coating based on Ni-Cr-V powder system is shown on fig.3. It can be seen that there is no any structural defects (pores, microcracks, incontinuity etc.) in the alloyed layer. The highest adhesion is defined by the matrix-coating metallurgical bonding. The data at fig.4 - 6 prove high operating properties of laser alloyed surface layers based on Ni-Cr-V and Ni-Cr-B-Si powder systems. At these figures the results of adhesion, strike and wear tests are presented.

Another one worked out and successfully applying technology is laser formation of polymer protective, solid-lubricating films on the steel friction surfaces. The actuality of such surface modification for compressor aggregates is stated by very intricate operating conditions of sliding bearings which working ability limit the whole equipment's lifetime.

Bearings operate under high dynamic loads induced by vibration processes. Vibrations, in their turn, are mostly produced by the failures of lubricating layer followed with "jamming" and "setting" of friction surfaces. The known lubricating medium phenomenon such as "dry whirl", "oil whip" and "oil whirl" are accompanied with low-frequency vibrations, critical-frequency vibrations and dynamic misbalance with auto-vibrations. Besides, the listed damaging effects are always take place during self-accommodation of friction surfaces.

Presented below data of our research and test shows that using of worked out friction surfaces modification with solid-lubricating polymer films allow to avoid all of the damaging effects and rise up wear resistance and longevity of friction pairs.

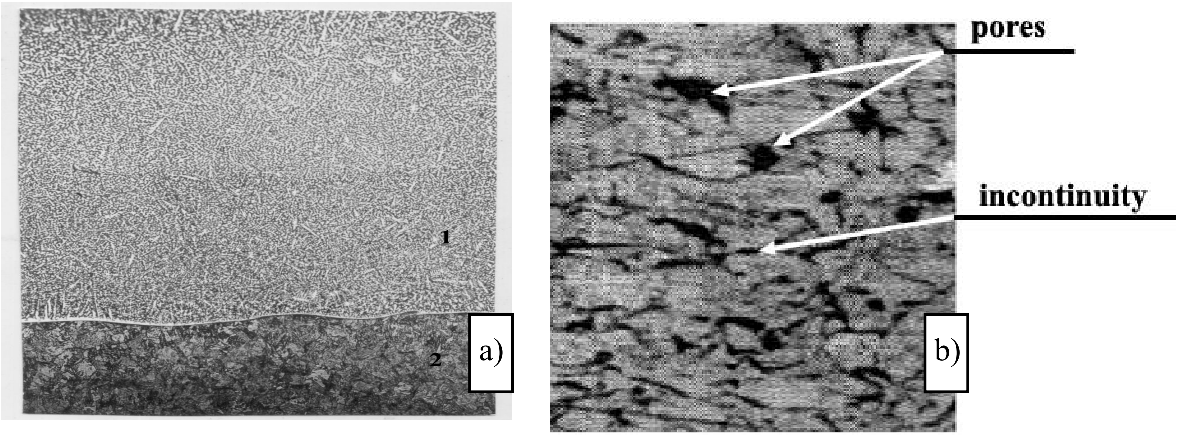

Fig.3. Microstructures of coatings ($100^{\times}$): a) - laser alloyed Ni-Cr-V based layer, where 1 - laser alloyed layer and 2 - matrix steel; b) - thermal spraying.

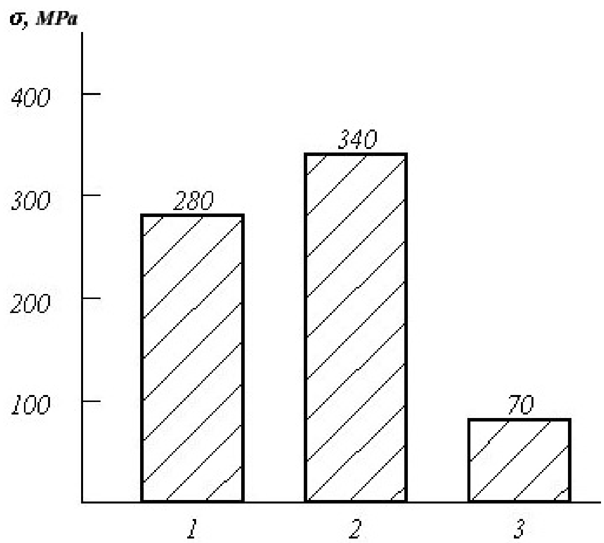

Fig.4. Adhesive strength tests results:
1 – laser alloying (composition Ni-Cr-V);
2 – laser alloying (composition Ni-Cr-B-Si);
3 – flame spraying.

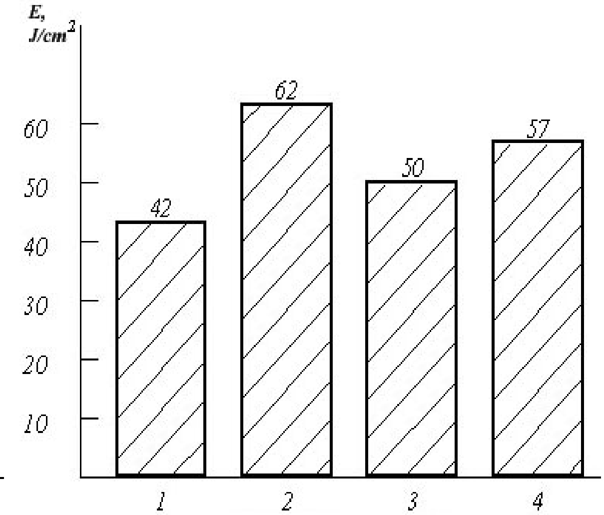

Fig.5. Impact elasticity tests results dependence from steel condition:
1 – steel in its regular condition;
2 – laser alloying (Ni-Cr-V);
3 – laser alloying (Ni-Cr-B-Si);
4 – laser thermo-hardening.

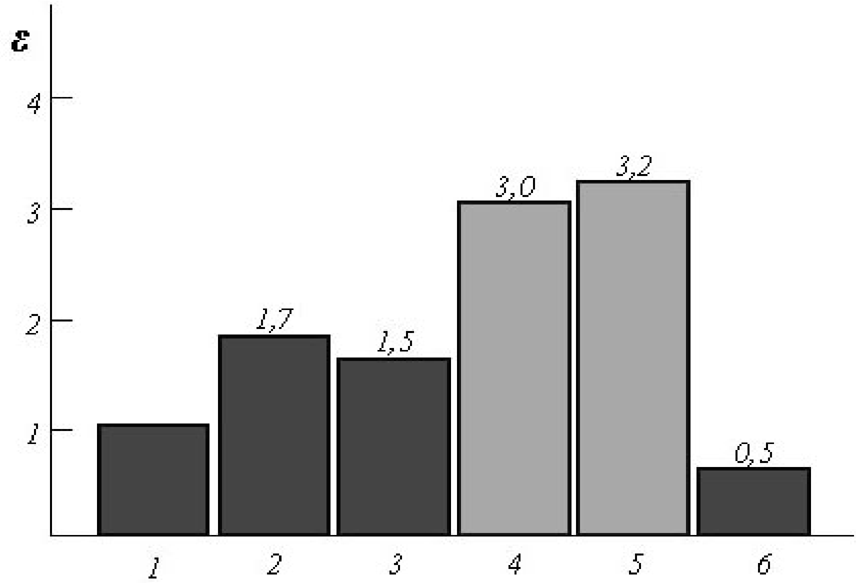

Fig.6. Wear resistance tests results: 1 – steel after volume thermo-hardening; 2 – steel after volume thermo-hardening and followed laser thermo-hardening; 3 – laser alloying (composition Ni-Cr-V); 4 – laser alloying (composition Ni-Cr-B-Si); 5 – laser alloying under argon protection (composition Ni-Cr-B-Si); 6 – thermal spraying.

The polymer composition was created using fluorine-containing elastomer solution in the special organic solvents mixture with following introduction of specific additives providing the polymer-steel surface chemical bonding. The airspraying of composition on the steel surface was chosen as coating method. CO_2-laser treatment was applied after 1 minute drying of obtained polymer layer. Laser treatment modes optimization was specially conducted.

The thickness of the polymer film was taken into consideration as a very important value for modified item operating properties and longevity of the film. Film thickness choice was made based on the statement that in order to obtain stable liquid friction using elasto-hydrodinamic lubricants the total thickness of lubricating films (oil, additives, solid lubricants) must be in limits $10⊕10^{-3}$ to $20⊕10^{-3}$ m. Specific thickness (λ) of lubricating film between friction surfaces can be found as total film thickness related to the sum of root-mean-square values of micro-geometrical heights (σ_1, σ_2) on these surfaces [1]. Direct microroughnesses contact is unable when $\lambda \geq 4$.

$$\lambda = h / \sqrt{\sigma_1^2 + \sigma_2^2} \quad (1)$$

Properties evaluation for the films has been done during tribotechnical tests on friction machine using oil lubricated sliding-friction between polymer coated disk and uncoated shoe. Test data presented at the fig.7. The load (F) was increased steppedly during the test. The loading "steps" showed as periods (I – VI) at the figures. The polymer coated disk samples tests were carried out in comparison with uncoated ones.

For uncoated samples the first initial testing period (I) was conducted under the load of 100 N/cm^2 and for the other periods (II – V) contact load was rased up from 200 to 800 N/cm^2 with the step of 200 N/cm^2. For the samples with polymer coatings the initial load equaled to 200 N/cm^2 and was stepped up to 1200 N/cm^2 with the same step.

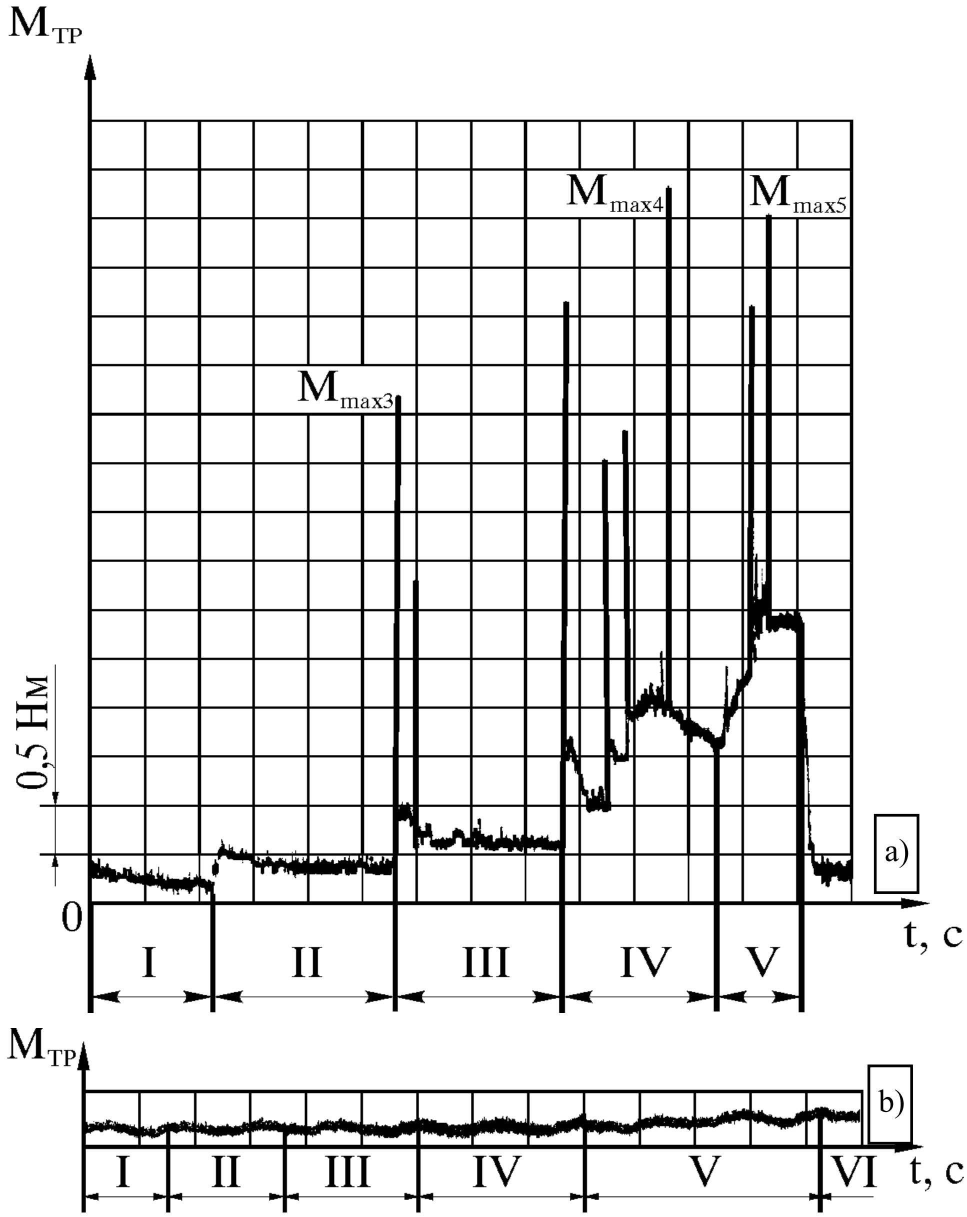

Fig.7. Friction test results: a) - uncoated steel sample; b) - steel sample with polymer film.

As shown at the fig.7a, increasing in contact load up to 400 N/cm^2 for uncoated sample led to sharp rising of friction torque and its following stabilization. These processes are associated with sudden oil film destruction at the moment of increasing in contact load. Further increasing in contact load accompanied with growth of instability in the friction process and after 800 N/cm^2 it was unable to keep on the test because of oil destruction. The test results for the coated samples are shown on the fig.7b. The process is stable during all testing modes (200 N/cm^2 $\leq$ F $\leq$ 1200 N/cm^2) and the breaking point was not reached even at 1200 N/cm^2 of contact load. Calculated average friction coefficient value was 0,006 what is equal to the coeffitient value of liquid friction. It can be concluded that applying of worked out film coating allow to increase bearing capacity up to three times and result into 9 fold decrease of average friction coefficient. Other positive effect of polymer films application is the significant decreasing in local contact temperature.

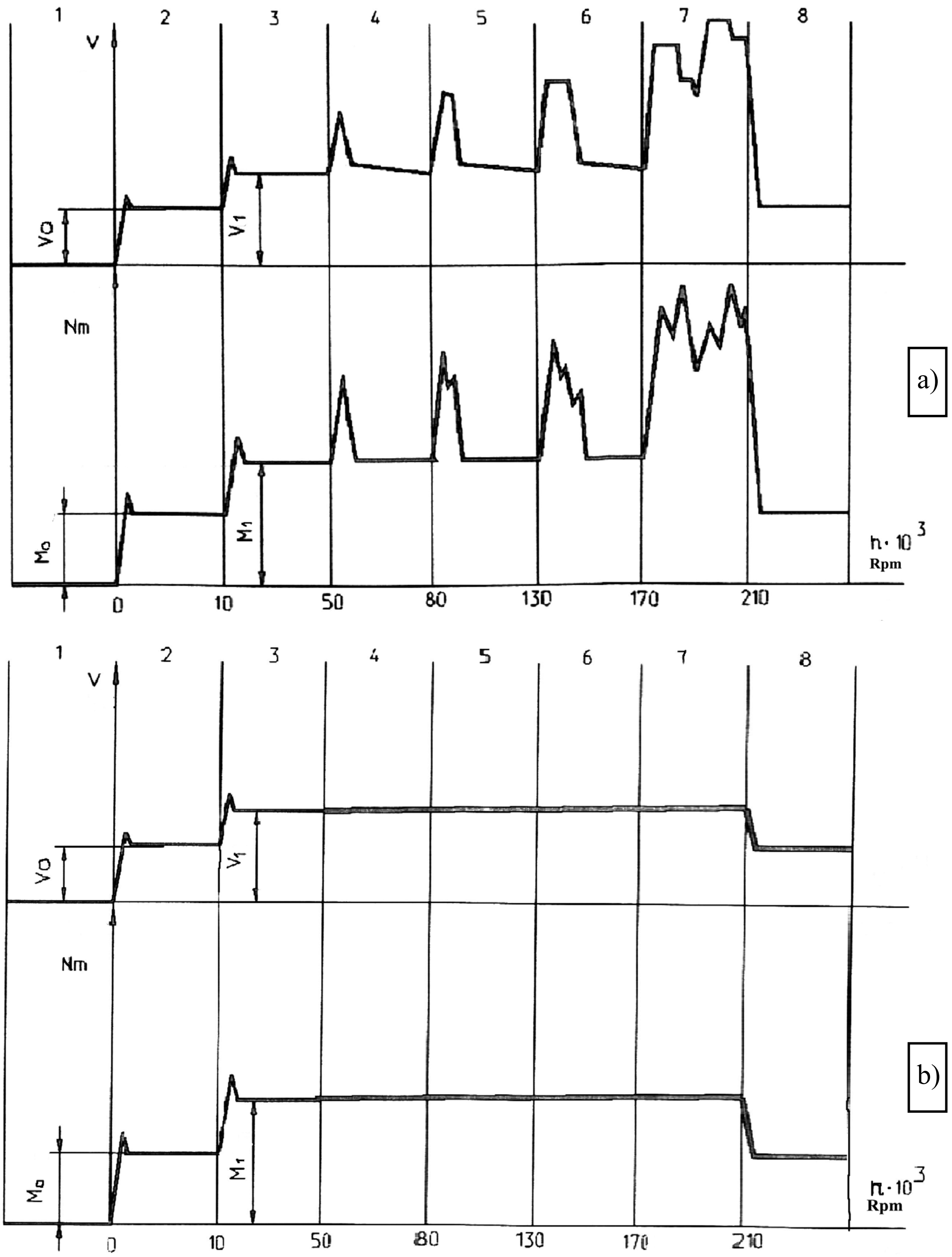

Fig.8.

Temperature range during the coated samples friction tests was 50 – 70°C. Absence of "temperature flashes" caused by surface "jamming" and unstable friction is also a favor for optimal lubricating. Besides, the effect of transferred polymer film on the counter body (shoe) was also revealed after the tests. The effectiveness of using worked out solid lubricating coating was proven by lifelike tests on the compressor plungers and crankshafts.

The other significant research stage were the friction tests conducted on the friction machine using vibro-measuring complex. During these tests we study vibration velocities acting on the friction item (disk-shoe). The results of the tests are presented at fig.8. The diagrams consist of eight periods. First period corresponds to the "zero-point" when neither friction machine nor vibro-measuring complex don't work. The second period characterizes the equipment's work without any load, i.e. disk spins with 600 Rpm, but the shoe is unloaded.

All vibrations and friction torque in this case produced by the friction machine drive and are equal to the testing machine characteristics (V_0, M_0). The third period describes that test conditions when the shoe is loaded with the tangential force equal to 600 N. The total friction torque has been increased at this period. The periods from 4 to 6 at the fig.8a shows that after number of cycles sharp increasing in friction torque has been registered and it was caused by the lubrication conditions change. At the seventh period the radical changes of lubrication were revealed. Oil destruction followed with its smoking became the evidence of dry friction with the highest vibration velocities and friction torque. The eighth period is equipment unloading. However, the measuring comlpex reading for the polymer coated sampe at the periods from 4 to 6 is absolutely opposite to the ones obtained for uncoated sample (see fig.8b). There is stable friction torque with no oscillations and as a result no damaging vibrations were fixed. Conducted vibration tests show that application of worked out polymer coating allow to create favorable friction conditions, exclude friction torque fluctuations and thanks to this improve operating properties of compressor drive bearings.

Considering that the compressor machine parts are often operate in aggresive mediums which can significantly damage their surfaces, limit the lifetime of the equipment as well as became a cause of expensive repairs we have carried out corrosion test of the samples with polymer coatings. As a samples for this test the real-life compressor plungers were chosen made of corrosion-resistant steel containing up to 13 percent of chrome in its composition. The corrosion medium for this test was prepared using NACE instructions and consisted of the acid mixture (H_2SO_4 + HCl) with inclusion of metallic copper as a positive ions donor for the process promotion. The samples were exposured in the solutoin for 72 hours. It was found that those samples which were covered by polymer coating had no any trace of corrosion damage but the uncoated samples at the same time became worthless.

3. Conclusion

The conclusion is that the worked out technologies allow to:

- provide highly-loaded parts with the unique mechnical and tribotechnical properties;
- restore weared out machine parts with no loses in their future longevity and durability;
- significantly decrease in friction coefficient, contact temperature, exclude vibrations;
- increase in parts wear resistance;
- protect surfaces against corrosion wearing.

The stated above investigation resuls serve as a basis for brand new resoursesaving technologies innovation at the oil and gas refinery plants. Industrial application of developed technologies confirms their high economic effectiveness and increased lifetime of compressor equipment.