1. INTRODUCTION

It is known that the service life of machinery directly depends on the reliability and wear resistance of the friction units, primarily on the surface loading capacity of the parts, which is determined by the quality of the surface layer.

The parts of machines and mechanisms that are in contact with the food stuff during operation at food industry enterprises are made of stainless steel alloys, in particular austenitic steels Cr18N9T, 12Cr18N10T, etc. However, the tribological properties of these steels are extremely low [1]; therefore, they cannot operate in friction units without additional surface hardening. In this regard, the formation of surface layers with high tribological properties on these steels is an urgent problem.

One of the promising methods for surface hardening of metals is electrosparl alloying (ESA) [2], which has a number of advantages over the conventional methods of hardening: metal plating, welding deposition, plasma spraying, etc. These advantages include a high adhesion of the deposited material to the base, the absence of heating of the parts during machining, and the simplicity of equipment and process implementation. Based on this, the problem was formulated as follows: to develop a technology for the formation of surface layers with high tribological properties on friction units of stainless steel Cr18N9T using ESA. To this end, we selected materials for the machining electrodes and optimized the energy (energy of electric pulses and their repetition frequency) and process parameters (geometrical shape, sizes, and type of motion of the machining electrode (vibration or rotation)).

2. EXPERIMENTAL RESEARCH

The electrodes for ESA were rods of T15K6 and VK8 hard alloys and BrOF6,5-0,15 bronze with a length of 40 mm and a diameter of 4 mm.

The preliminary results have shown that high-quality layers with a thickness of about 0.1 mm and a continuity of about 98% are obtained at an electric-pulses energy of 0,6–1,0 J and a pulse repetition frequency of 250 Hz with a complex movement of the machining electrode (rotation + vibration).

To estimate the wear resistance of the coatings formed on steel Cr18N9T by ESA using the above materials, the samples were subjected to tests on a reciprocating friction machine at an average sliding velocity of the mobile sample of 0,0675 m/s [3]. The coatings were deposited on samples of a special shape with a working width of 3 mm and a length of 48 mm. The counterbody was 3-mm-thick plates of hardened steel 45 (HRC 58).

The tests have shown that uncoated stainless steel Cr18N9T underwent the highest wear; first signs of scoring were observed under a load of 78,4 N.
In this case, the coefficient of friction had a value of about 0.65. The lowest coefficient of friction of 0.11 was exhibited by the BrOF6,5-0,15 bronze coatings until a load of 220.5 N. In some case, to reduce the running-in time, the preliminarily formed coating of a T15K6 hard alloy was additionally coated with bronze; owing to higher plasticity, the bronze filled the discontinuous regions and generally contributed to a decrease in the surface roughness. It is evident from the figure that these coatings (T15K6 + BrOF6,5-0,15) exhibit the highest wear resistance.

On the basis of the wear-test results, this technology was used for hardening the friction units of steel Cr18N9T stirrer shafts of an AII-250-SR-150 machine (Italy) for canning fruit puree at the Orhei cannery „ORHEI-VIT“ (Republic of Moldova).

To decrease the roughness of the coated friction surfaces, prior to installing into the canning machine, they were subjected to a finish machining, i.e., surface plastic deformation (SPD) using a steel ball and the subsequent lapped finishing, which provided the surface smoothness with parameter $Ra$ of 0.32 μm.

The operation of the shafts with a T15K6 + BrOF6,5-0,15 coating for 18 months has confirmed its high reliability; this fact suggests that ESA is a high-efficiency method for improving the wear resistance of friction units of food stainless steels, such as Cr18N9T.

Interesting results were also obtained by doping of the 45 steel with electrodes of molybdenum, chromium, bronze BrOF6,5-0,15 and hard alloy T15K6 + bronze BrOF6,5-0,15 (composite coating). Samples of steel 45 were subjected to electrospark alloying (ESA) on an EFI-10M commercial plant at electric discharge energy of 0.3–1.0 J. Friction and wear tests were conducted using an upgraded SMT-2 friction and wear machine. The test samples were special segments of steel 45 coated with the above materials. The coated segment (with a flat working surface) was paired with a disc of steel 45 (HRC 40-43). All the tests were conducted in MGE-46V hydraulic oil under loads of 400, 600, 800, and 1000 N for 15 min at each of the loads and under a load of 1200 N for 3 h.

The rotation frequency of the discs (counterbody) was 540 rpm. Wear $U$ of the samples was determined by weighing the samples on an electronic balance with an accuracy of 0.1 mg before and after the tests. The wear of the discs was determined in a similar manner. During the tests, all parameters (friction force, friction torque, coefficient of friction, temperature in the friction zone, and sliding distance) were automatically recorded in a computer every 0.5 s.

The tribological tests revealed that, the chromium coating is the most wear-resistant under these conditions (Fig. 2).
It is of interest that, under these friction conditions, the degree of wear of the molybdenum coating was twice as much as that of the chromium coating. Uncoated steel 45 exhibited a 34 times higher degree of wear than the chromium coating; however, it slightly wore out discs from its friction pair. Thus, the amount of wear of the discs was the lowest: 5.8 mg. The highest degree of wear was observed for the discs paired with the T15K6 + BrOF6,5-0,15 composite coating. Under these conditions, BrOF6,5-0,15 bronze exhibited the highest degree of wear of all the coatings. For example, it was 12.25 times greater than the wear of the chromium coating. Meanwhile, the bronze coating wore out the counterbody seven times less intensively than the T15K6 + BrOF6,5-0,15 composite coating.

Figure 3 shows plots of variation in the coefficient of friction versus load and composition of the deposited coating during the running-in to a working load of 1200 N (second-pattern tests). It is evident from this figure that the highest and lowest coefficients of friction are exhibited by the bronze coatings (curve 5) and uncoated steel 45 segments (curve 1), respectively. As noted above, uncoated steel 45 underwent the greatest wear during the tribological test. In addition, it was found that its coefficients of friction were the lowest.

This is probably attributed to the fact that steel 45 as received is a soft material with respect to the counterbody, i.e., a disc of hardened steel 45. Although wear occurs at a low coefficient of friction, it is a continuous process that involves more and more layers of the friction surface. Furthermore, it should be noted that, during running-in, the coefficients of friction for steel 45 and the chromium and molybdenum coatings continuously increase. However, all the time, they remain lower than the coefficients of friction for bronze and the T15K6 + BrOF6,5-0,15 composite coating, although the coefficients of friction of the last-mentioned coatings decrease.

It has been found that the surface layers of the chromium and T15K6 + BrOF6,5-0,15 coatings undergo hardening during friction. Steel 45 also undergoes hardening. However, the hardening process occurs in different ways. At a minimum wear, the chromium coatings subjected to high loads are significantly hardened: from 861 to 1697 MPa with respect to the initial state. During the wear of the T15K6 + BrOF6,5-0,15 composite coating, over time, increasingly harder layers of the T15K6 coating become open and strongly resist the wear. Steel 45 is hardened at 236–295 MPa; after that, it wears out, and this process is repeated several times. The behavior of the molybdenum and BrOF6,5-0,15 bronze coatings is different: they soften during friction. First, it should be noted that, in the initial state, the molybdenum coating is the hardest (8132 MPa). It is obvious that this coating has this high hardness because, during alloying, molybdenum is bound to atmospheric nitrogen to form a molybdenum nitride (MoN).

Coatings of chromium, molybdenum and bronze were tested also in a cutting fluid, which was prepared by the addition of 260 ml of the MR-7 oil to 3 l of distilled water, under loads of 200, 400, 600, 800, and 1000 N for 15 min at each load (Fig. 4).
Examining Figure 4, it should be noted that as a result of the tribological tests electrospark coatings showed higher antiwear properties chromium ($U = 0.7$ mg) and molybdenum ($U = 1$ mg) coatings. Steel segments covered with bronze BrOF6,5-0,15 wore the most ($U = 4.7$ mg). As can be clearly seen from Figure 4, hardened alloy steel 45 are worn much more than the segments. Even discs that have worked with segments covered with bronze, worn out 2.85 times larger than the segments. Discs that have worked with coatings of chromium, had the largest wear ($U = 109$ mg). Apparently this is due to the high hardness of these coatings.

Figure 5 shows curves of variation in the coefficient of friction versus load and coating composition. It is evident that the coefficients of friction varied in different ways. For example, they constantly decreased for BrOF6,5-0,15 bronze (curve 3) and, conversely, increased for molybdenum (curve 2). For the chromium coating, the coefficient of friction varied only slightly with increasing load (curve 1).

The bronze coating underwent the greatest wear and the friction surface roughness parameters significantly decreased with increasing load; hence, the contact area increased over time, which apparently resulted in a change (decrease) in the coefficient of friction.

3. CONCLUSIONS

This way, by electrospark alloying may significantly increase the durability of the working surfaces of friction pairs of different materials, and therefore improve the reliability of machines.

Fig. 5. Variation in coefficient of friction versus load and composition of the deposited coating: (1) the chromium, (2) molybdenum, and (3) BrOF6,5-0,15 bronze coatings.

REFERENCES

