Vol. 41, No. 1 (2019) 14-22, DOI: 10.24874/ti.2019.41.01.02

Tribology in Industry

www.tribology.rs

RESEARCH

Application of Composite Electroless Nickel Coatings on Precision Parts of Hydraulics Aggregates

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Keywords:

Nanocomposite coatings
Chemical coatings
Nickel deposition
Nanosized materials
Micro-hardness
Wear resistance
Hardening
Durability
Hydraulic distributor

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A B S T R A C T

The article presents the results of the investigations on the development of new method of hardening and reconditioning of resource-determining parts of hydraulics aggregates of various purpose machinery by composite electroless nickel coatings. It is proved, that by obtaining the composite chemical coatings the most efficient are nanodispersed particles of aluminum oxide and potassium polytitanate. The tribological testing testified, that the wear of the samples which were deposited with the nickel based composite coating, is 1.4 times less than the wear of the samples with the base nickel coating. The bench testing determined that in spool and sleeves of the hydraulic distributors hardened by the composite electroless nickel deposition, leakage value is 1.4 times less than in commercial ones, and 1.3 times less compared with the pairs being reconditioned by ironing.

1. INTRODUCTION

Recently the durability requirements to new and repaired aggregates of different machinery at minimum production cost, repair, technical service and spare parts are increasing significantly. In this connection, great attention is paid to the development of the new methods of hardening and reconditioning of resource-determining parts [1-3].

At machines exploitation from 30 to 50 % of all breakdowns fall on hydraulic system because of precision parts wear, mainly spool and sleeves [4]. There are many reasons causing their wear and breakdown: alternate loads at high rates of flow and working fluid pressure, design features of parts, sticking, gripping, aggressive medium impact, etc. However, the main reason is abrasive wear because of mechanical particles intrusion into oil [5].

The applied today methods of hardening and reconditioning of spool and sleeves are high temperature and extensive by times [6]. To use them under industrial conditions complicated and expensive equipment is required. For hardening and performance restoration of slide valves the technological methods that allow minimizing subsequent machining are advanced. Furthermore, they should occur at the temperatures excluding parts buckling. In the first place, galvanic and chemical methods can be referred to hardening and reconditioning of the examined parts. Nevertheless, for all advantages the galvanic methods of reconditioning have such disadvantages as appearing of dendrids on parts edges, slight coating micro-hardness, etc. [7].

One of the advanced methods of machine parts hardening are composite electroless coatings, deposited by the galvanic method. Such coatings are obtained from electrolyte-suspensions, presenting electrolytes (solutions) with addition of high-dispersed powder, giving them specific properties: wear resistance, hardness, lubricant retentivety and improved corrosion resistance [8-11].

However, the main disadvantage of the technologies of obtaining of such coatings is high dispersion ability of the applied particles (from 200 nm and more), possessing low sedimentative resistance in (solutions) [12].

At the present times the technology of obtaining the nanometer range particles [13-15]. Widely known the unique properties of such particles – their high chemical activity, excessive sedimentative resistance in flow mediums, etc. While using such particles the coating deposition process will be carried out more stable, because Brownian motion and suspended condition without mixing in electrolyte (solutions) for a long time are typical for small-sized particles. Nanoparticles are easier “grew over” with cover because they possess high chemical activity.

Varying the compositions of electrolytes (solutions), components concentration, and changing the deposition modes it is possible to obtain the compositional chemical coatings with very various physical and mechanical properties.

As the base metal coating (matrix) it is the most advisable to use electroless nickel coating. Such coatings possess the variety of advantages in comparison with other coatings. The electroless nickel process runs on without electric current, it gives an opportunity of coating deposition on the parts with complicated configuration [16].

In this regard, the object of the carried out investigations is the development of the new method of hardening and reconditioning of resource-determining parts of hydraulics aggregates by composite electroless nickel coating.

2. MATERIALS AND METHODS

The analysis of the current technologies of obtaining nano- and ultra-sized materials allowed choosing the method of plasma Ostwald ripening, which allowed obtaining the nanosized powders of different metals. The method is based on evaporation of large-sized powder (raw material) in the plasma flow with the temperature of 4500-6000 °C and vapor condensation to the particles of the required size [1,8]. The obtained particles were characterized with the size of – 0.01-0.1 μm. This method allows obtaining various nanosized materials: pure, binary, alloy and composite.

When selecting material of nanosized additions for coatings deposition we considered the following:

- nanosized powders should possess high hardness to increase coating micro-hardness;
- particles in nickel coating solution should possess strong depletion effect;
- particles should provide increase of corrosion and wear resistance of coating.

On the ground of such requirements according to the scientific data [17-21] and the carried out preliminary investigations [1, 8] the following powder materials were selected: Al_2O_3; BN, TiC, AlN, SiC, B и K_2O $nTiO_2$.

Potassium polytitanate (K_2O $nTiO_2$) is a class of compounds presenting a layered crystal of a scaled form, with the thickness of 20-80 nm [15,22,23]. Potassium polytitanate has the layered structure, analogical to the structure of graphite and molybdenum disulfide. For that reason, the scaled potassium polytitanate can be applied to create high-strength composites, as an antifriction constituent. As a result, we suggested to introduce into the composition of nickeling solution the nanodispersed particles providing the increase of the coating micro-hardness (Al_2O_3; BN, TiC, AlN, SiC, B) and the potassium polytitanate particles to improve antifriction characteristics (K_2O $nTiO_2$).

For obtaining the nickel based coatings we selected the conventional acid solution of the following composition: nickel sulphate – 30 g/l, sodium acetate – 10 g/l, hypophosphite – 15 g/l. The preparation of the suspension solution consisted in the following. Primary, the distilled water was heated in the bath up to the temperature of 60 °C. Further, in a separate porcelain vessel it was mixed with a certain amount of nanosized material and by grinding during 10 min it was brought into homogeneous state. The obtained concentrated suspension was added to the main container (bath) with constant mixing. Further, the necessary quantity of nickel sulphate was added to the suspension. The obtained solution-suspension was heated up to the temperature of 80 °C and sodium hypophosphyte was added. After thorough mixing, the temperature was raised up to 92 °C.

In order to determine the most effective hardening material the preliminary experiments on determination of micro-hardness and thickness of the obtained coatings were carried out. The coatings were deposited on the samples in the form of plates manufactured from medium carbon steel 25 with the sizes of 100×15×2 mm. The powder concentration in the solution was 0.3 g/l and was selected empirically [1,8]. Coating micro-hardness was determined by the diamond pyramid pressing into the end face of metallographic specimen. After identification of the most effective hardening material, the further investigations of the physical and mechanical properties of the composite coatings were carried out with this powder only.

One of the most important properties of the composite coating is its micro-hardness as the main factor, influencing on its wear resistance. The coatings micro-hardness was determined at the ПМТ-3 device by the diamond pyramid pressing into the grinded end face of the plate under load of 20 g with five-fold repetition with bad values exception. The metallographic micro section of the plate must be strictly perpendicular to the coating. For the edge retention, the sample was covered with epoxide resin of the trademark ЭП-10, wherefore it was placed into the precast bed perpendicular to its base plate. The prepared samples were grinded with abrasive cloth with gradation from coarse-grained to finely grained (abrasive of the trademark 100, 180, 240, 320, 600, 1000, 2000). Grinding uptime on the cloth of each trademark did not exceed 30-40 s. At every cloth change the grinding direction was changed to 90°. Final polishing was carried out during 2-3 min on felt polishing disk, using paste ГОИ № 2 with grain sized 4-8 μm. For obtaining distinct boundary between metal layers after polishing, we carried out etching of micro-section during 2-3 s in the solution of the following composition: azotic acid – 5 sm^3; isopropyl alcohol – 95 sm^3.

Determination of the optimal conditions of coating deposition and concentration of the nanosized phase in the solution was done with application of the mathematic experimental design. As an optimization parameter, we used micro-hardness of the obtained coating as it considerably determines coating wear resistance. As factors producing the maximum influence on the optimization parameter, we selected the following: aluminum oxide concentration, potassium polytitanate concentration, post-heat treatment temperature of the coating.

The main factors having the impact on the coating deposition process, levels and their variation intervals are presented in Table 1.

Table 1. Characteristics of the experiment performance.

Factor	– 1	0	+ 1	Variation interval
Aluminum oxide concentration, g/l (x1)	0.1	0.3	0.5	0.2
Potassium polytitanate concentration, g/l (x2)	0.1	0.3	0.5	0.2
Heat treatment temperature, °C (x3)	200	350	500	200

One of the most important physical and mechanical coating characteristics is coating cohesive strength with the base metal. While in operation, the coating is subjected to the influence of temperature, mechanical loadings and other external and internal forces. The most stressed point in the coating is the boundary between it and the base metal. In this regard, for test purposes of the obtained coatings for mechanical strength of cohesion with the base, the bending deflection method and the temperature variation method were selected. The coating was deposited on the samples in the form of plates with the sizes of 100×20×2 mm, made of medium carbon steel 25. After coating deposition the samples were subjected to thermal treatment at temperature of 400 °C during 1 h. When applying the temperature variation method the sample with the coating was heated in the stove up to the temperature of 300 °C, it was held at this temperature during 15 min and then was cooled fast in the water with the temperature of 15-25 °C. Coating cohesive strength with the base was estimated by the presence of bubbles, fractures and stripping on the sample surface. The bending deflection method consisted in testing for plate like samples bending at an angle of 90° on either side up to the fracture. At high cohesive strength, the coating stripping should be absent.

One of the most important performance properties of machine parts operating in the intensive wear conditions is wear resistance. Wear process of the part surface layer depends on many factors and is connected with the complicated physical, mechanical, structural and chemical changes in the surface layers taking place at friction. In conjugation «slide valve-case» of the hydraulic distributor, the main friction type is sliding friction.

It can be reproduced more precisely at friction machine СМЦ-2 (Fig. 1) according to scheme «roller – block» (Fig. 2).

For this purpose, the blocks were manufactured from grey cast iron СЧ-20 full circle length – 20 mm, width – 10 mm. Roller was manufactured from medium carbon steel 40 with diameter 50 and width 12 mm. The experimental coatings were deposited on the roller. The samples with the deposited composite and base electroless nickel coating were subjected to study. To make the test conditions closer to the actual operating conditions, the tests were carried out on contaminated industrial oil И-20. As a contaminant we used quartz abrasive with the fraction of 8-12 μm at the concentration of 0.08 % in mass, which was fed to the friction zone through the separation funnel (Fig. 2) with the frequency of 10 drops per minute.

Fig. 1. Friction machine СМЦ-2 for coating testing for wear resistance.

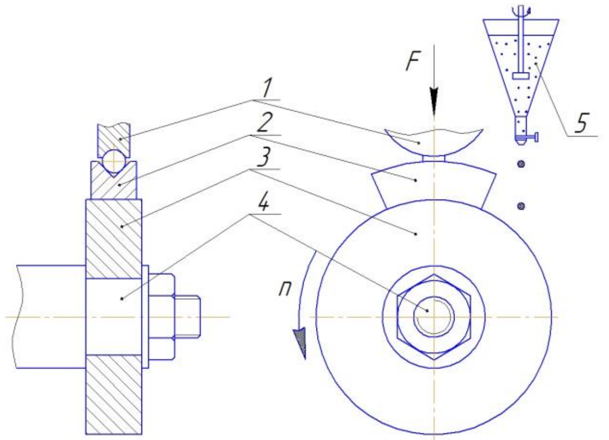

Fig. 2. Scheme of coating testing for wear resistance: 1 – roller, transmitting load; 2 – block; 3 – roller with coating; 4 – shaft of friction machine; 5 – separation funnel with contaminated lubricant.

The main load of the testing was 900 N, the shaft rotation frequency of the friction machine was 300 min^{-1}. Before testing, friction couple samples were run together during 3 h in the modes of the main testing. During the tests, each experiment was repeated 3 times. On test completing, the parts were washed in the solvent petroleum spirit, dried in the air during 24 h and were weighted on the analytical balance HR – 250 AZG within the accuracy of 0.1 mg. During the tests of the samples with experimental coatings for wear resistance, the following parameters were controlled: friction moment and wear.

To determine the suggested method efficiency the corresponding tests of the hydraulic distributors P80-3/1-222 were carried out. The hydraulic distributors were completed with the serial slide vale, the slide valve reconditioned by ironing (the existing reconditioning method), and the slide valve reconditioned by composite electroless nickel. Before test starting, the hydraulic distributors were adjusted and checked at bench КИ-4200 (Fig. 3). For the purpose we did micro-meterage of the slide valve operating surfaces with micrometer МК-25 kl. 1 in two faces and two measurements ranges. The accelerated testing of each distributor was carried out with the usage of contaminant at bench КИ-4200. As a contaminant of the power fluid we used quartz powder of the trademark 1К1О101 (the middle diameter of the fraction is 8-12 μm) at the concentration of 0.08 %.

Fig. 3. Bench for testing of hydraulic distributors КИ-4200.

To support the sedimentative stability of the abrasive the oil in the tank was mixed periodically with an arm mixer. For imitating the slide valves operation, the КИ-4200 bench was supplied with an extra self-engineered equipment (Fig. 4). The equipment permits to test each slide valve in the positions «Up», «Down», «Float» и «Neutral». The equipment consists of electric engine 1, flexible clutch 2, worm gear 3, piston rod 4 and extender 5, connected with the tested slide valve of the distributor. The frequency of the rotor shaft of the electro engine is 1800 min^{-1}. Rotation is transmitted via the flexible clutch to the driving shaft of the gearbox, which transmission ratio is 0.05.

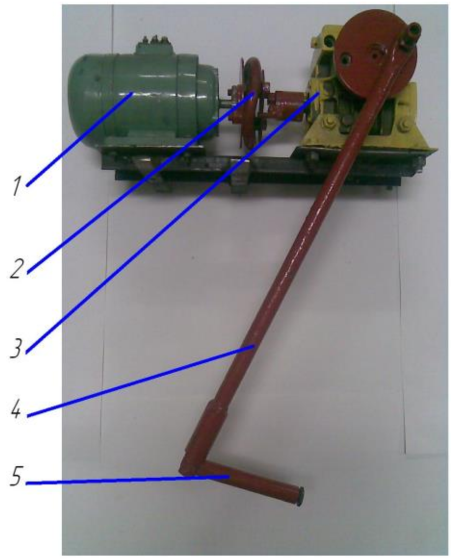

Fig. 4. Equipment to bench КИ-4200 for bench testing of hydraulic distributors: 1 – electric engine; 2 – flexible clutch; 3 – worm gear; 4 – piston rod; 5 – extender.

In such a way, the rotation frequency of the gearbox driven shaft was 90 min^{-1}. In one revolution of the driven shaft, the slide valve performs one full circle of operation. One full circle of slide valve operation is 1.5 s. The testing duration of each slide valve is 40 h.

Testing consisted of 5 stages. The first stage consisted in running-in of each slide valve (pressure 6-8 MPa, oil without contaminant, duration 8 h). The rest of four stages were carried out at the basic operation modes (pressure 16-18 MPa, oil contaminated with abrasive, duration 32 h).

For checking leakages in the conjugation «slide valve – case» on bench КИ-4200 is necessary to set the controlled slide valve to position «Up», using throttle create the pressure in the system 7-10 MPa.

The leakages in the regulator valve, spool and sleeves conjugations are collected at the bottom cover of the distributor and via the attachment flange flow into the tank. At determining the leakages in the spool and sleeves is necessary to separate them from the leakages in the valve mechanism. For this purpose, some changes were implemented into the distributor cover (Fig. 5). Between the compartments of the locking devices of the slide valve in cover 1 screens 2 were made to separate the leakages of each slide valve (Fig. 5a). To estimate the leakages we mounted into cover 1 special fittings 3. The leakages were recorded every 8 h of testing. The leak volume was measured by using a measuring vessel.

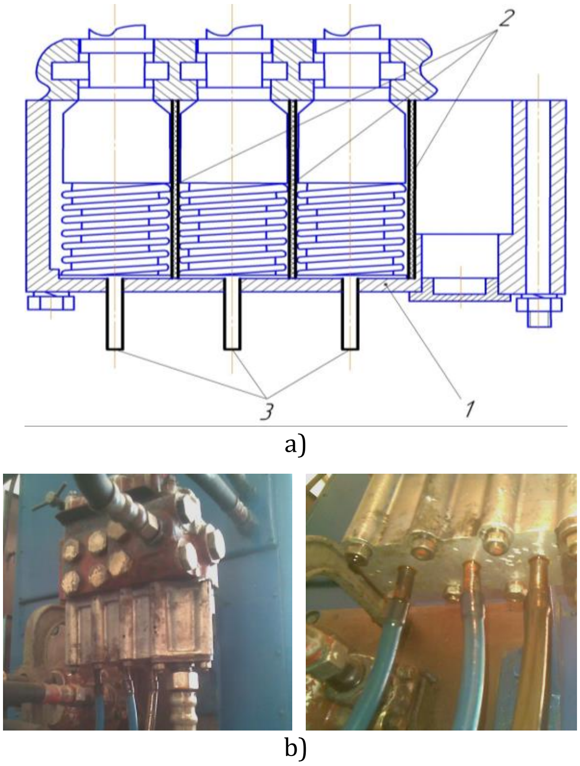

Fig. 5. Scheme a) and layout b) of improved distributor cover P80.

Comparative testing of hydraulic distributors P-80 with the hardened and serial slide valves was done in the conditions of common operation on tractors ДТ-75М, МТЗ-80, Т-150К, which perform various types of agricultural works. Comparison was done with new hydraulic distributors; the conditions of tractors operation were analogical. Before the beginning of testing, the hydraulic distributors were regulated and micro-meterage of the operating surfaces of the slide valves was performed. Test duration of every distributor in the average was 842 moto-h. In the process of the operational tests, we controlled service hours and after every 400 moto-h determined the technical state of the distributors and leakage value in the conjugation «slide valve – case». To estimate the leakages we used the versatile hydrotester КИ-28240 enabling any diagnostics of the hydraulic system of tractors and agricultural machinery.

3. RESULTS AND DISCUSSION

The results of the measurements of micro-hardness and thickness of the obtained coatings are presented in Table 2.

Table 2. Results of the measurements of micro-hardness and thickness of the composite nickel coatings.

Material of nanodispersed particles	Average value of coating micro-hardness, HV ±2%	Average thickness of coating, ±0.3 μm
Al_2O_3	910	18
$K_2O \cdot nTiO_2$	882	26
$Al_2O_3 + K_2O \cdot nTiO_2$	927	36
SiC	644	16
TiC	530	18
AlN	560	10
B	610	18
BN	680	17
Coating without nanodispersed particles (basic)	522	20

According to the experimental data presented in Table 2, the maximum hardness and thickness are typical for the coatings with addition of the nanodispersed particles of aluminum oxide and potassium polytitanate.

As a result of the experiments we determined the nanosized phase allowing to reach the maximum in comparison with the concerned powders, to increase the coating micro-hardness and thickness. Every other experiments were carried out only with the powders of aluminum oxide and potassium polytitanate.

The optimal concentrations of the nanosized phases and the temperature of the postheat treatment were determined with the application of the mathematic experimental design. As a result of the carrying out the corresponding experiments and mathematic calculations, the equation describing the coating deposition process was obtained:

$$y = 493.1 - 723.9x_1 - 2548.9x_2 - 2.9x_3 + 1287.5x_1x_2 + \\ +1.53x_1x_3 + 1.31x_2x_3 - 540x_1^2 - 5727.5x_2^2 - 0.0057x_3^2 \quad (1)$$

By the obtained equation, we plotted the response surface presented in Fig. 6.

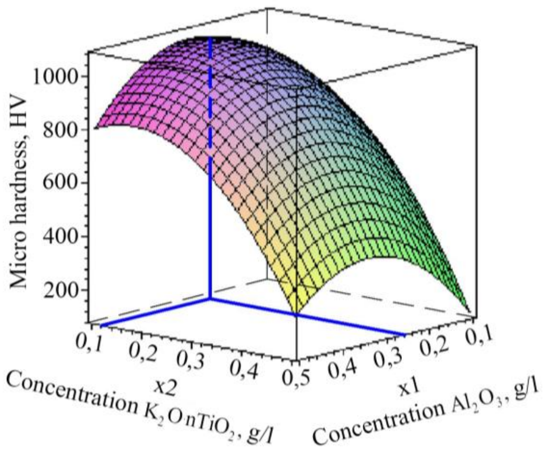

Fig. 6. Response surface.

From the submitted data it is apparent that, the maximum micro-hardness of the composition coating is reached at the aluminum oxide concentration of 0.25 g/l, potassium polytitanate of 0.12 g/l, the heat treatment of 400 °C, and corresponds to 1003 HV, what is 1.9 times higher than the base coating possesses.

Visual inspection of the coatings after the test performance for mechanical strength of cohesion with the base displayed the absence of bubbles, fractures and stripping on their surfaces. As a result, it is possible to conclude that, the strength of cohesion with the base metal exceeds the base coating durability for cracking.

The results of the friction samples testing for wear resistance are presented in Figs. 7 and 8.

Minimal wear by the mass is typical for the roller with the compositional electroless nickel coating, and corresponds to 2.7 mg, whereas the wear of the sample with the base coating is 3.8 mg. Therefore, the mass wear of the samples with the composite coating is by 1.4 times less than the wear of the samples with the base nickel coating. Besides, at the testing of the composite coating the decrease of the friction moment by 1.16 times in relation to the base coating was recorded. Further, we recorded the wear decrease of the block, contacting with the roller with the deposited composite coating. The wear of the block run together with the roller with the composite coating is by 2.6 times less than the wear of the block run together with the base nickel coating. This is explained with the implementation of the antifriction particles of potassium polytitanate into the coating. In such a way, the composite coating in comparison with the base coating possesses the increased wear resistance and good antifriction characteristics at the account of implementation of the particles with high hardness and antifriction properties.

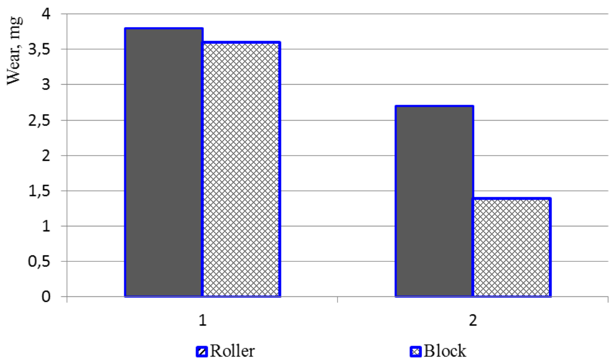

Fig. 7. Friction samples wear by the mass during the wear resistance testing process: 1 – with the base nickel coating; 2 – with the nickel based composite coating.

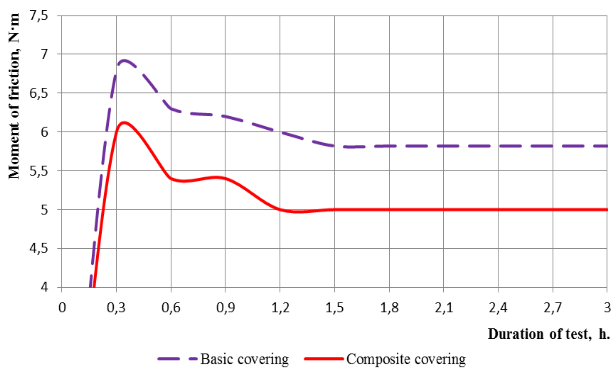

Fig. 8. Friction moment variation during the testing process.

Working capacity of the hydraulic distributors in the process of the accelerated bench tests was characterized with the leakage value in the spool and sleeve. The value in the maximum permissible leakage in the pair «spool and sleeve – case» at the operating pressure in the system must not exceed 25 sm^3/min. The bench tests results are presented in Fig. 9.

It is obvious from the experimental data, that at the end of testing, the leakages in the plant-manufactured spool and sleeve exceeded the acceptable value. In the spool and sleeve, hardened with the composite electroless nickel, the leakage value is by 1.4 times less than of the serial one, and by 1.3 times less that in the pair reconditioned with ironing. It is explained with the higher wear resistance and the increased antifriction characteristics of the composite electroless nickel coating.

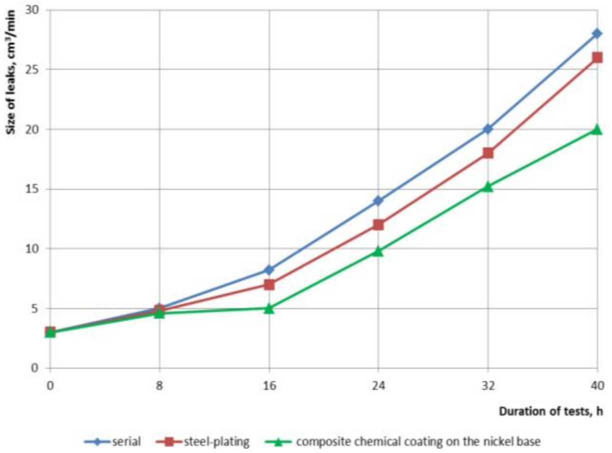

Fig. 9. Spool and sleeve leakage value according to the results of the bench testing.

According to the operational tests on the average the service hours of the hydraulic distributors was 842 h. Over the testing period, the breakdowns during the operation of the serial and experimental hydraulic distributors were not recorded. The leakage value was within the mark.

4. CONCLUSIONS

The investigation results showed that for increasing the wear resistance of the precision parts of the hydraulics it is reasonable to use the nickel based coatings with additions of the nanodispersed particles of aluminum oxide and potassium polytitanate. The optimal deposition modes of the composite electroless nickel coating and the solution-suspension composition determined with the mathematic experimental design permitted to obtain the coatings with the micro-hardness up to 1003 HV. Tribological tests proved, that the wear of the samples with the deposited composite electroless nickel, is 1.4 times less than the wear of the samples with the nickel base coating. The bench tests showed that in the spool and sleeves of the hydraulic distributors, hardened with the composite electroless nickel, the leakage value is 1.4 times less in comparison with the serial ones, and 1.3 times less in comparison with the pairs reconditioned according to the existing technology (ironing). At the service hours - 842 moto-hours in conditions of common service operation the breakdowns of the hydraulic distributors because of the spool and sleeves were not recorded. Therefore, the composite electroless nickel coatings should be reasonably used in manufacturing for hardening and reconditioning of the precision parts of hydraulics aggregates of various purpose machinery.

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