



Lifetime Improvement of Contact Brush Units of Automotive Power Machines. Part 2

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Abstract

Lifetime testing of contact brush units of automotive power machines is held. Friction contact of copper and graphite under working voltage and current within ordinary atmosphere environment was simulated on the friction test bench. Wear resistance and friction losses have been detected. Wear mechanisms and friction surfaces were investigated using the scanning electronic microscopy. This study allows recommendation the optimal surface treatment of copper elements of contact brush unit of alternators or commutator unit of power starters.

Keywords: AC power machines, alternator, vehicle starter, contact brush unit, friction in power contact

Introduction and review of publications

Formerly the optimal technological modes of electrospark coating of aluminium on copper substrate were detected. Kinetics of mass transfer and coating thickness were researched. Using the scanning electronic microscopy the structure of acquired coating was thoroughly investigated. Presumption of good electric conductivity together with good adhesion to copper substrate under moderate heating was made and as well. The last issue can be checked only during the benchmark friction testing with research of friction surfaces. Considerations of the latest investigations in this area are the following.

So in the research [1] sliding wear behavior of copper-graphite composite for maglev vehicles and high-speed railway train was investigated. The samples were formed by cold pressing at 300 MPa and by hot sintering (950°C × 3 h) in a hydrogen atmosphere. After specimens were cooled to room temperature with the furnace, further pressing at 300 MPa was performed. Wear tests were conducted with a specially designed sliding apparatus to simulate the tribological condition of sliding current collectors in a maglev system. The material was slid against a stainless steel band under unlubricated condition. Worn surfaces of the material were analyzed by SEM and field-emission-gun environment SEM equipped with an energy dispersive X-ray spectroscopy. Within the studied range of normal pressure and electrical current, wear loss increased with increasing normal pressure and electrical current. Adhesive wear, abrasive wear and arc erosion were the dominant mechanisms during electrical sliding. It provides principle for designing suitable sliding counter parts for the current collection device in maglev system.

The publication [2] is about that copper-graphite is an important tribological material used in the applications of electrical sliding contact like generators and electrical brushes. A series of experimental tests were conducted on a pin-disc tribometer in air and dry sliding condition. The pair of material was subjected to electric current ranging from 0 to 10A, normal loads of 5 to 30N and sliding speed of 0.5 m/s. The duration of each test was 30 minutes. Experimental results indicated that the friction coefficient decreases and wear rate increases with increasing load with and without applied electric current. The changes in surface chemistry and topography of the tribo-surfaces were characterized using Raman spectroscopy, scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS). This later technique was used to analyze the transfer of pin materials to the counterface, and also to understand how copper and graphite influence the tribological properties. Results indicated that, electric current and normal load have more or less significant influence on the tribological behavior of the pair of materials and the effect of oxide layer created at interface of the pairs in contact.

As stated in article [3] the copper matrix composites were prepared by spark plasma sintering (SPS). The current-carrying friction and wear tests were carried out on a self-made HST-100 high-speed current-carrying



friction and wear tester, and the effect of the graphite content on the current-carrying friction and wear properties of the composite material was studied. The results show that with an increase in graphite content, the average friction coefficient and wear rate of the two materials decreased significantly, the fluctuation amplitude of the friction coefficient was also significantly reduced, and the average friction coefficient of copper-coated graphite composite with graphite content of 10 wt.% was 0.100; when the graphite content was the same and more than 5.0 wt.%, the average friction coefficient and wear rate of copper-graphite composites were slightly higher than copper-copper-coated graphite composites; the current-carrying efficiency and current-carrying stability of the copper matrix composite were obviously higher than that of copper material; there was a mechanical wear area and arc erosion area on the wear surface of the composites, with the increase in graphite content, the adherence and the tear of the mechanical wear area weakened, the rolling, plastic deformation increased, and the surface roughness decreased obviously. The surface roughness of the wear surface of copper-copper-coated graphite composites with graphite content of 10 wt.% was 3.17 μm . The forms of arc erosion included melting and splashing, and were mainly distributed in the friction exit area.

Good influence of organosilicon dopant to the brush materials is stated in work [4]. The brush materials modified with organosilicon were prepared by the powder metallurgy method, and their current-carrying friction and wear properties were compared with those of brush materials modified with SiO_2 . The materials were characterized by SEM, XRD, XPS, deep etching, and roughness. The results showed that, compared with the SiO_2 , organosilicon can significantly reduce the wear rate of brush materials by 67–88%, because the SiOC fiber produced by pyrolysis of organosilicon could control the graphite content on the friction surface by reducing abrasive wear. In the aspect of wear mechanism, organosilicon could greatly reduce the abrasive wear of the materials and the mated materials, but aggravated the adhesive wear of the materials.

In research [5] copper-graphite sintered materials were prepared by powder metallurgy technology. The relationship of the graphite content to the third body topography and the impact of the graphite content on frictional properties of the materials were investigated on a constant speed friction test machine. The results showed that, when less than 15%, the graphite had a significant influence to the material porosity and the friction temperature. The results demonstrated clearly the friction and wear property of the material was closely related to the graphite content and this was due to the effect of the third body containing graphite particles formed on the frictional surface under dry friction condition. The third body derived from low graphite content sintered materials had a high level of metal composition. Plowing effect of the hard metal led to higher friction coefficient and wear rate. With the increase of graphite content, the density and adhesion of the third body reduced because of the increase level of graphite in the third body. The low compactness and easy flow of the third body alleviated the surface plowing, lowered and stabilized the friction coefficient and, therefore, reduced wear rate.

The following was comprehensively studied in paper [6]. Resin-coated graphite/copper composites and copper-plated graphite/copper composites were prepared by cold pressing-pressure sintering process using phenolic resin powder, graphite powder, copper-plated graphite powder and electrolytic copper powder as raw materials, respectively, the friction and wear properties of two kinds of graphite/copper composites at room temperature, high temperature and current-carrying were studied, and compared with overseas Roland grounding brush; the effects of resin decomposition on the conductivity, mechanical and friction and wear properties of the composites were analyzed based on the crystal structure of copper matrix and the variation of composite conductivity and mechanical properties at high temperature (200–600 $^{\circ}\text{C}$). The results show that the mechanical properties of resin-coated graphite/copper composites at high temperature are better than that of copper-plated graphite/copper composites. When the ambient temperature reaches 600 $^{\circ}\text{C}$, the shear strength of resin-coated graphite/copper composites decreases by only 6%, while that of copper-plated graphite/copper composites decreases by 24%. The high temperature (250 $^{\circ}\text{C}$) wear resistance and friction stability of resin-coated graphite/copper composites are much better than those of copper-plated graphite/copper composites and Roland brush, the current-carrying friction factor of the resin-coated graphite/copper composites is lower than that of Roland brush. The resin coating of graphite can improve the friction and wear properties of copper matrix composites at high temperature and current-carrying, due to the protection of the resin layer, a continuous and stable graphite lubricating film can be formed even under the conditions of high temperature oxygen and current-carrying, thus reducing the friction contact micro-gap; the carbonized resin breaks into fine hard particles during the friction, which hinder the adhesion and wear between composite and disc; the Cu matrix softening at high temperature is not obvious, so the occurrence of arc decreases.

Copper-graphite composites were investigated in research [7]. Copper-graphite composites were prepared by spark plasma sintering (SPS) with copper powder and copper-coated graphite powder. The effect of particle size of raw material powder on the current-carrying friction properties of copper-graphite composites was studied. The results show that the friction coefficient of the composites decreased with the decrease of the particle size of copper-coated graphite powder, the friction coefficient of the composites increased with the decrease of the particle size of the copper powder, the wear rate of the composites increased with the decrease of the particle size of the copper-coated graphite powder, and the wear rate of the composites increased significantly with the decrease of the particle size of the copper-coated graphite powder. The current carrying properties of composites with different particle size ratios and QCr0.5 pairs are good and fluctuate little. The current-carrying friction properties of 150 μm copper powder and 75 μm copper-coated graphite powder were found to be the best. The wear surface could be divided into mechanical wear area and arc erosion area. The main area of arc erosion was less than 15% of the

total area, and it was mainly distributed in the friction outlet area. The main forms of mechanical wear included furrow, rolling deformation, cold welding, and tearing, among other forms. Graphite film was formed on the surface. The surface quality of the composite prepared by 150 μm copper powder and 75 μm copper-coated graphite powder was the best, the Sa was 3.22 μm , rolling deformation was the most adequate, no large tear pit and furrow appeared, and the carbon content on the worn surface was much higher than that in the composite. The behavior of arc erosion was mainly melting and splashing, and the particle size of the original powder had little effect on it.

As stated in scientific work [8], during the train operation, the pantograph/catenary system is subjected to an extremely harsh service environment. Relative humidity has a great influence on the current-carrying tribological behaviors of carbon strips. The identification and understanding of the wear mechanism are extremely important in wet and dry conditions. This study was carried out to investigate the humidity effect on the service properties of carbon sample rubbing against copper (Cu) with and without electric current using a home-made wear tester, and the humidity ranging from 10% RH to 80% RH. The results indicate that the sliding wear behavior of the friction interface is drastically affected by the intervention of water vapor and electric current. The coefficient of friction (COF) without current is obviously lower than current-carrying sliding when the humidity is constant. However, the increased humidity led to a decreasing trend. After the current increases to 10 A, all the COF values are closed to each other ultimately. These phenomena mainly result from the formation and destruction of water lubrication film. Furthermore, the tribo-pairs worn surface appears the most sensitive to the current effect under dry conditions. The reverse transfer of Cu and carbon is greater on account of the current agglomeration effect, and the oxidation degree is more severe. The wear mechanisms of carbon are mainly material transfer accompanying with oxidation erosion. However, the wear degradation is weakened under water lubrication and uniform current distribution which improves the conductive quality. This is the coupling effect of humidity environment, current and heat concentration. This experiment provides technical support for the operation of an electric locomotive under an extremely harsh service environment.

The purpose of thesis [9] is to propose a technique to improve electric brush properties in an effort to produce a more proficient electric motor by creating a new brush material with improved properties and performance. There are many applications for electric motors and each application would benefit from overall, increased proficiency. Understanding the role an electric brush plays within an electric motor is crucial to improving functionality. The proposed technique to create a novel graphite-copper material involves a two-step procedure that will intercalate CuCl_2 into the graphite structure, and then by chemical reduction, will reduce the CuCl_2 and result in the final products of copper and graphite. The proposed technique seeks to successfully increase the conductivity and wear properties of an electric brush by incorporating copper into graphite which will also enhance the properties of an electric motor. This thesis will detail the procedures of data collection and how to analyze results of the proposed technique. Expected results will also be discussed utilizing preliminary data collected utilizing XRD, SEM, TGA, and BET equipment. Finally, struggles and challenges of such a technique will also be discussed as well as plans for future work on the proposed technique.

Formerly some properties of aluminium electrospark coatings on copper substrate were researched in work [10]. The automotive electric equipment involves the electric machines (starter, alternator) incorporating the brush unit and hybrid drive vehicles as well. It is the friction joint of conducting copper and graphite brush. Work efficiency and lifetime of these machines strongly depend on the contact quality and general state of this friction joint. Thus preset objective of this study is research of friction joint of brush unit "copper-graphite" under working current flow and technique of its superficial improvement. For experimental purposes the samples of M1E electric conductive copper ГОСТ 859-2001 complying with ТУ 1276-003-38279335-2013 were fabricated in dimensions of hole disks 16 \times 6 \times 2,5 mm in order to provide the least friction contact area for experiment acceleration. As the friction counterbody the conventional alternator brush made of graphite ГЭ-1, ГОСТ 7478-75 was used. Copper samples were strengthened by electro-spark alloying on unit ALIER-52 on 6-7 modes by aluminum electrode made of rod aluminum ГОСТ 15176-89. The coated and uncoated samples were tested on the friction test bench M-22IIB under "pin-on-shaft" layout. Friction speed was about 1,5-2 m/s that complies the test bench shaft rotation speed about 2000-2400 rpm. In order to simulate the brush unit work the 24 V DC voltage was applied to friction contact and linear wear rate was detected. So uncoated samples have demonstrated the wear rate of 345,5 micrometers per kilometer, unlike coated samples that have the wear rate 81,8 micrometers per kilometer what is about 4,26 times improvement of electro erosive wear resistance. Thus the technique researched is suitable and can be recommended for improvement of brush units of vehicle alternators and starters, DC engines collectors for electric power vehicles, hybrid vehicles and quadcopters as well.

This paper is devoted to investigation of wear results and friction surfaces of copper samples in ordinary atmosphere environment and in low vacuum condition modelling the the friction of contact unit of alternators and vehicle power starters.

Problem statement and objective

The objective of this study is friction testing of "ESA coated copper-graphite" under working current flow in atmosphere pressure. Namely this paper is dedicated to research of coating wear resistance and wear mechanisms.

Methods

For experimental purposes the samples of M1E electric conductive copper (content: 99,96% Cu, 0,002 Ni, 0,005 Fe, 0,004 S, 0,002 Sn, 0,005 Pb, 0,004 Zn, 0,002 Sb) were fabricated in dimensions of hole disks 16×6×2,5 mm in order to provide the least friction contact area for experiment acceleration.

As the friction counterbody the conventional alternator brush made of graphite ГЭ-1, (contains 0.05% Cu, ash content 10-14 %) was used. Copper samples were strengthened by electro-spark alloying on unit ALIER-52 on 6-7 modes by aluminum electrode made of rod aluminum (АД31Е (1310Е, 6101) containing 97.68% Al, 0,5 % Fe, 0,7% Si, 0,03% Mn, 0,03% Cr, 0,1% Cu, 0,06% B, 0,8% Mg, 0,1% Zn. The 6 mode of ALIER-52 installation provides the following electrospark alloying descriptions: impulse duration was 700 microseconds, amplitude value of current impulse was 200 A; the impulse energy was 2,52 Joiles; coating thickness was 0,3 mm.

The coated and uncoated samples were tested on the friction test bench M-22ПВ under "pin-on-shaft" layout. Friction speed was about 1,5-2 m/s that complies the test bench shaft rotation speed about 2000-2400 rpm. In order to simulate the brush unit work the 24 V DC voltage was applied to friction contact and linear wear rate was detected. Using the rheostat the current strength has been changed from 1 to 5 A (fig. 1.).

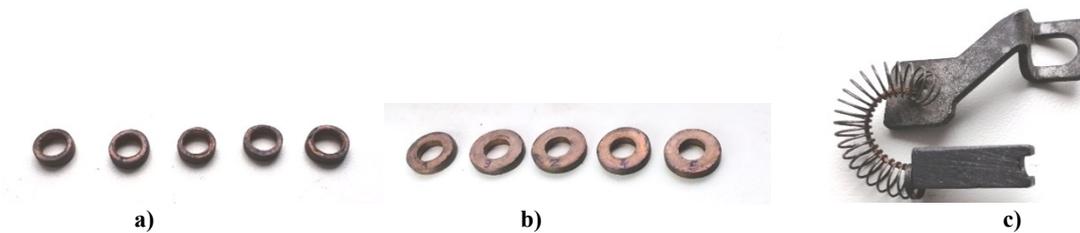


Fig. 1. Samples for wear testing: a) uncoated (deeply worn) copper samples; b) coated copper samples; c) real alternator graphite brush (counterbody) with the worn place shown.

So uncoated samples have demonstrated the wear rate of 345,5 micrometers per kilometer, unlike coated samples that have the wear rate 81,8 micrometers per kilometer what is about 4,26 times improvement of electro erosive wear resistance.

In order to detect the wear mechanisms for improvement the strengthening technique the wear surfaces were investigated instantly after testing on the electronic microscope РЭМ-106И and specific areas were additionally analyzed by X-ray element analyzer. SEM images and analysis results are on fig. 3.

Main research results

The wear testing results are represented on fig. 2.

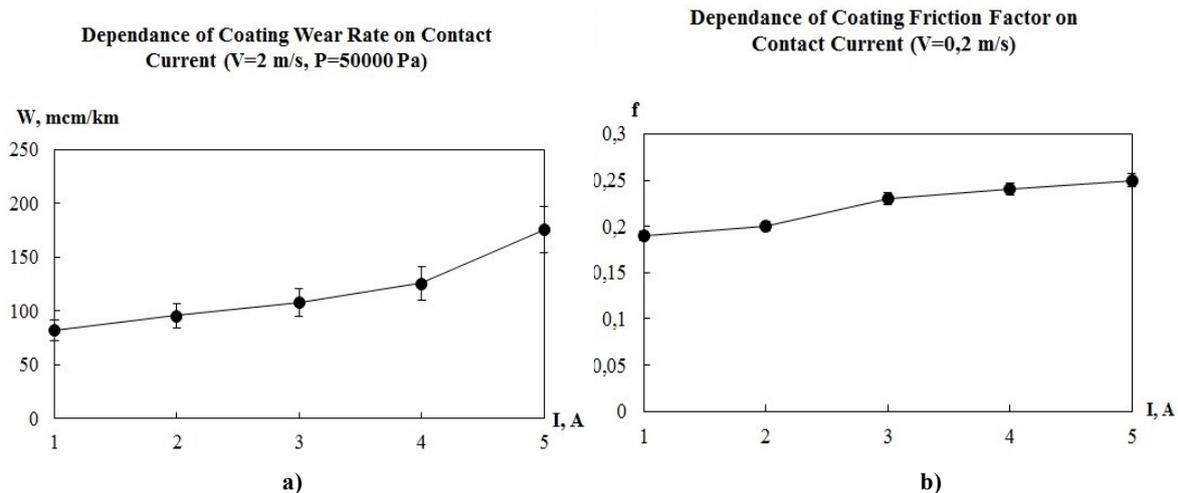


Fig. 2. Dependence of wear rate and friction factor of aluminium electrospark coating on (a,b) current strength

The coating friction properties depending on current strength and atmospheric pressure are on fig. 3. So, the coating wear rate depending on the current strength increase (from 1 to 5 A) allowing prediction the brush unit lifetime on boosted modes is about increasing from 81,8 to 175,6 μm per km (fig. 2., a) and friction factor was kept in the antifriction limits 0,19-0,25 (fig. 2., b) that means it will not create the big resistance to alternator rotor rotation.

In order to explain the acquired results the friction surfaces (right after experiment for better elements storage covered by clean vacuum film while delivering to microscope) were investigated on scanning electronic microscope REM-106I. Acquired results are on fig. 3.

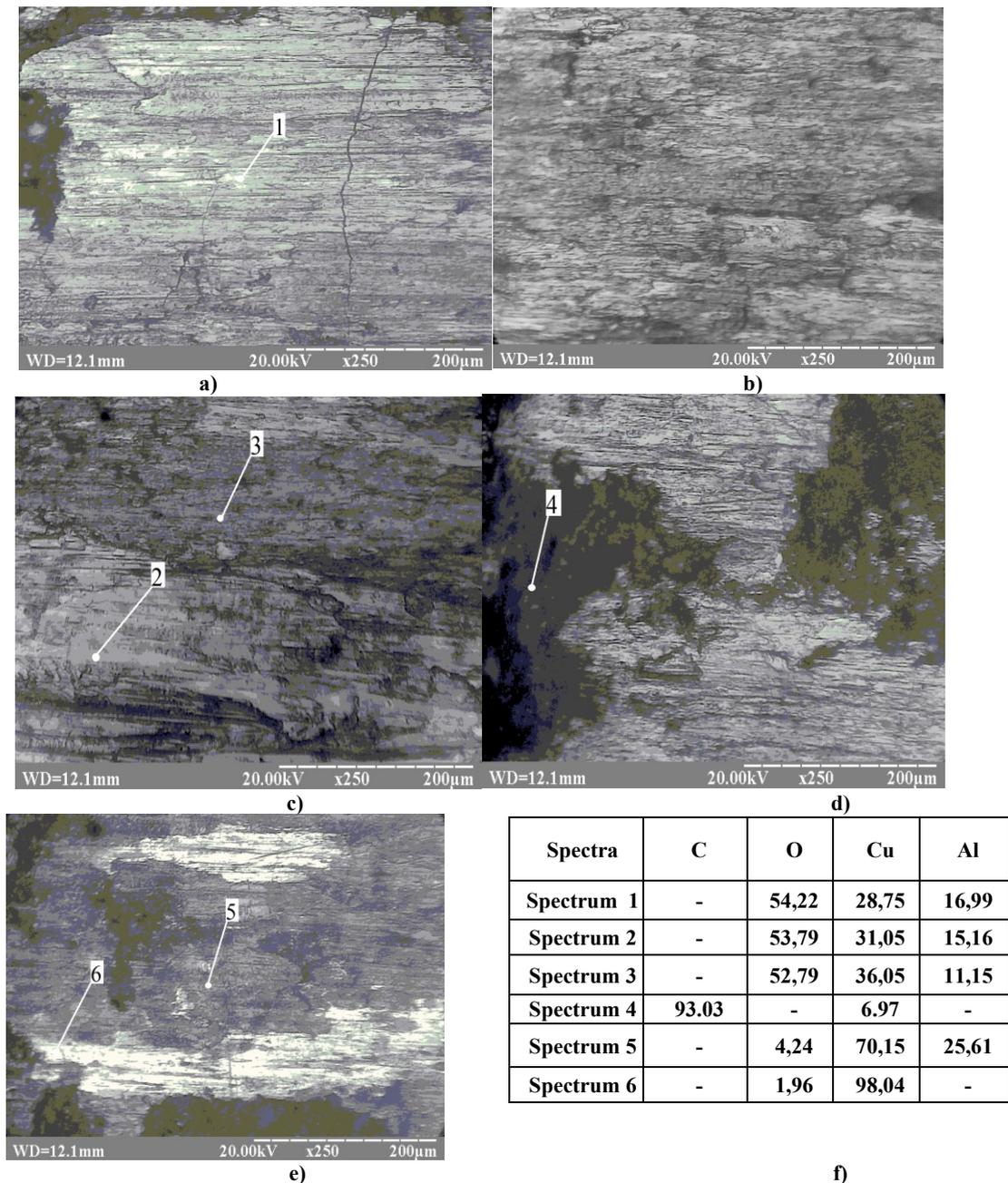


Fig. 3. SEM images of friction surfaces of ESA coating of aluminium on copper M1E in 250 electronic zoom under 12 V conducting different DC in coated copper-graphite contact under atmospheric pressure (101 325 Pa): a) 1 A; b) 2 A; c) 3 A; d) 4 A; e) 5 A; f) elements content in specified areas

As it can be seen from fig. 3. a, under low current strength surface is covered by oxides of copper and aluminium and pure areas of hard solution of aluminium in copper. It can be stated according to spectra 1, 2, 3 and 5 elements content. Thin films of oxides and pure hard solution have good conductivity for power transfer purposes. Overheating of surfaces causes the superficial coating cracks. However increasing the current strength burns through spots appear in coating surfaces and they are immediately covered by graphite particles spectrum 4 fig. 3. d. Overloading the coating by big current strength leads to coating destruction by burn out and naked substrate of pure copper comes to friction surface (see spectrum 6 fig. 3. e).

Natural testing of simple copper-graphite contact brush unit of vehicle alternator (under 14,5 V DC voltage and no more than 5 A load current) has demonstrated the two and half longer unit lifetime comparing with uncoated copper rings of this unit. But more intensive wear rate of graphite brushes (double times bigger) was detected. But, it is obviously, replacement of graphite brushes (with new better voltage regulator built in) is much easier in operational conditions of vehicles during the next maintenance check procedure, than replacement of

copper rings of alternator (or starter commutator). That's why the findings of this paper can be considered as satisfactory and feasible in vehicles operation and maintenance process.

Conclusions

So the electrospark alloying coating of aluminium on copper has demonstrated satisfactory wear resistance in power transferring contact under 24 V and current strength from 1 to 5 A. Wear mechanism with in atmospheric pressure is oxidative with sparking burn out. It is the area for future research. Thus alluminium electrospark coating can be applied for superficial strengthening of copper element of copper-graphite contact brush unit, which works under voltage up to 24 V and current load up to 5 A with satisfactory wear rate and friction factor.

Thus the ESA coating researched is suitable and can be recommended for improvement of brush units of vehicle alternators and starters, DC engines collectors for electric power vehicles, hybrid vehicles.

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Довгаль А.Г., Білякович О.М., Приймак Л.Б. Поліпшення ресурсу контактнo-щіткових вузлів автомобільних електромашин. Ч. 2.

Проведено випробування довговічності контактнo-щіткового вузла автомобільних електромашин. Було модельовано фрикційний контакт міді та графіту на машині тертя за робочої напруги та струму у звичайному середовищі атмосфери. Було визначено зносостійкість та фрикційні втрати такого вузла. Було досліджено поверхні тертя та механізми зношування за допомогою скануючого електронного мікроскопу. Це дослідження дозволяє рекомендувати оптимальну поверхневу обробку мідних деталей контактнo-щіткового вузла генераторів та колекторних вузлів електричних стратерів.

Ключові слова: електромашини змінного струму, автомобільний генератор, автостартер, контактнo-щітковий вузол.