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Friction and wear of current-transmitting contact elements of electric transport with the use of metal-graphite composite materials

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Abstract

The work provides an analysis of research devoted to the problem of manufacturing and operation of current-transmitting elements of electric transport, namely, the durability of contact parts according to operational and tribological characteristics. The work of current-transmitting elements of electric transport consists in the continuous sliding of one element on the surface of another and is accompanied by wear. At the same time, two types of wear are distinguished: mechanical and electrical. It has been established that the correct choice of materials has the greatest impact on reducing friction and wear of electrical contact elements. The basis for this is graphite material, which has the best current-conducting characteristics, but has insufficient strength and wear resistance. Approaches to the creation of materials for electrical contact elements using composite metallographite materials based on copper, aluminum, lead and other materials are analyzed.

Key words: electric transport, metal-graphite inserts, friction, wear, composite materials.

Introduction

The work of current-transmitting elements of electric transport consists in the continuous sliding of one element on the surface of another and is accompanied by wear. At the same time, two types of wear are distinguished: mechanical and electrical. Electric current accelerates wear, especially during sparking and arcing. The ratio between electrical and mechanical wear depends on the contact pressure between the transmission contact element and the copper wire.

The main foreign manufacturer of electrical contact elements is the company "Electrokarbon". Electric contact brushes are produced for various international companies, such as BOSCH, Makita, Hitachi, Hilti, etc. Most of these brushes are standardized and differ only slightly in geometric dimensions.

Contact inserts of various designs are used in the trolley bus collector: profile shape, flange, cross-sectional configuration along the length and shape in plan, as well as material: carbon graphite, metal and metal-ceramic. The applicability of one or another type of inserts is determined by their technical characteristics: resistance to abrasion, mechanical strength, electrical conductivity, spark intensity when ensuring the durability of contact wires of trolleybus lines, as well as their cost, which is often decisive. for the consumer. However, despite these structural differences, as well as differences in the use of materials (compositions) in the manufacture of contact inserts, it is possible to single out a common design feature of the inserts.

A carbon brush that slides over an electrical contact carries current from or to the moving surface. The brush performs this function within a limited mechanical system. Unlike most other electrical contacts, brushes require more frequent replacement, resulting in longer brush wear, which is a key issue. Brush wear is caused by a combination of mechanical wear from friction and electrical wear due to excessive surface contact resistance (arcing). For quantification, this leads to frictional breakdown and causes mechanical wear of the brushes and voltage drop is the main indicator of electrical wear. At any time during operation, the carbon brushes wear both mechanically and electrically at the same time. Thus, total wear is the sum of mechanical and electrical wear. It is also important to note that there is often a slower rate of wear with the highest allowable brush pressure.

However, insufficient attention is paid to electric contact elements of trolleybuses in modern literature due to their limited use. At the same time, current-carrying elements of railway transport have a lot in common with trolleybus collectors. At the same time, such constructions are more widely used in the world.

Main material

Among the problems related to the manufacture and operation of current-transmitting elements of electric transport, the main one is the durability of contact parts in terms of operational and tribological characteristics. The study of the wear resistance of electrical contact inserts is carried out by theoretical and experimental methods. Bench and operational tests are necessary to verify the effectiveness of the proposed technological and design recommendations. At the same time, the bench tests should be close to the operating conditions of the friction unit.

In studies [1-2], the authors proposed a device for testing the elements of the contact electrical network of transport for friction and wear (Fig. 1). The device had the following parameters: the maximum speed of rotation of the disk with a contact wire was 1200 rpm; the length of the contact wire, which is installed on the disc, 1 m; pressure 1.5... 8.5N; the current through the sliding contact was 500 A; humidity in the contact zone varied in a controlled manner.

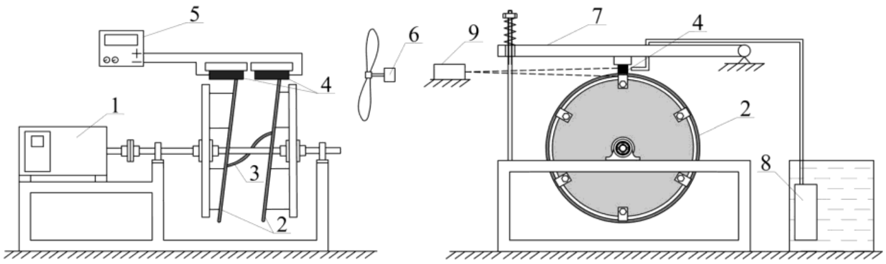

**Fig. 1. Device for the study of electric contact pairs of friction [1]:
1) converter, 2) contact wires, 3) connecting conductor, 4) contact bars, 5) power source, 6) cooling system, 7) clamping mechanism, 8) pump, 9) thermometer**

To obtain qualitative results of wear of friction pairs, tests were carried out for different types of contact strip materials: graphite, carbonite, copper.

The wear of the contact wire and contact strips was assessedafter 10,000 passes of the contact bars with the contact wire. Each test was performed 6 times. To ensure constant friction and maintain a constant temperature in contact, the device was equipped with an air cooling system with a non-contact temperature gauge.

The resulting test electromechanical wear of the sliding contact had a clearly defined U-shaped character, which is due to the simulation of real operating conditions. The appearance of condensation on the contact wire was caused by increased sparking, and the separation caused a short-term appearance of an electric arc.

The analysis of the obtained dependences showed that for the contact wire and all types of contact strip materials, an increase in wear was observed with an increase in the clamping force and current strength in the contact. It was established that wear in the friction pair increases with increasing humidity and current regardless of pressure. This is due to the appearance of a low-conductivity film in the contact zone, which dramatically changes the nature of the interaction of the friction pair and significantly increases the contact resistance between the contacting surfaces. Thus, the appearance of moisture in the contact negatively affects the degree of wear of the contact bars. This is especially noticeable for direct current. It was also established that when the pressing force was reduced, electrical wear of components prevailed over mechanical wear. This conclusion applies to both the wear of the contact wire and the contact strips.

In the article [3], the classification and causes of the most common carbon damages of the contact surfaces of pantographs operated on the railways of Poland are given. It is noted that in Poland it is possible to use carbon composite impregnated with metal impurities, the metal content of which in carbon contact pads cannot exceed 40% by weight.

The requirement to comply with the main technological characteristics of the material for carbon contact elements is noted. On the other hand, such limitations do not allow the efficient use of such graphite elements at high voltages (more than 10 kV) and alternating current. In this case, increased heating of the contact elements is possible.

To ensure reliable operation, it is necessary to evenly distribute the copper in the volume of the carbon overlay and firmly connect it to the carbon composite. Failure to comply with this technological requirement leads, in addition to overheating, to delamination, as shown in fig. 2. Exfoliation of the material, in this case copper, is visible in the lower part of the cavity of the depicted defect. In this case, a catenary-related cause can be clearly ruled out due to minor mechanical loads on this part of the catenary strip.

Fig. 2. Exfoliation of the material of the contact element [3]

The most common damage to coal contact strips and the identified causes of their occurrence, listed and classified in the article, testify to the need to observe the appropriate parameters of the material and construction at the stage of design, production and proper technical operation. The causes of damage also indicate the need for constant diagnostics of the state of the catenary network using devices for measuring forces and the location of the catenary network relative to the vehicle.

In work [4], a metal-saturated carbon fiber carbon composite (C/C composite) is recommended for the manufacture of contact strips of the pantograph of high-speed electric railway vehicles, as its mechanical bending and impact strength is much higher than that of ordinary graphite impregnated with metal. The authors investigated the wear properties of a C/C composite impregnated with a copper-titanium alloy sliding on a copper disk under the action of an electric current under the action of arc discharges. The tested C/C composite was produced by pressing and sintering laminated carbon fiber sheets. A certain anisotropy in the physical properties of the material, which arises due to the orientation of the lamination of carbon fiber sheets, has been established. The C/C composite was tested for friction in two directions, parallel or perpendicular to the sheet layer. Test results show that the wear rate when sliding in the parallel direction exceeds the rate in the perpendicular direction. This is especially evident in cases where the material is exposed to higher current density and more frequent arc discharges.

In [5], the authors investigated the effects of friction and electrical phenomena, such as arcing and sparking, which regulate the rate of wear of the sliding contact between the contact wire and the collector strip. These two effects are interrelated in a complex way. Conducted research on the wear of collector tape and contact wire using laboratory tests, conducted comparative tests between different combinations of materials. Dependences on basic parameters such as sliding speed, contact force and current strength are established. A procedure is proposed that combines a wear model for the contact between the collector strip and the contact wire with the simulation of the dynamic interaction between the pantograph and the catenary. The adopted wear model is based on the results of the wear pattern and takes into account the effect of electric current based on the results obtained on the laboratory test bench.

The dependence of the electric contact resistance on the contact force between each contact strip of the pantograph and the contact wire of the overhead line was considered, and the corresponding electric current on each of the two collectors of the pantograph was estimated. The values of contact forces and electric current were entered into the wear model and the degree of wear of collector strips and contact wire along the overhead line was calculated, creating an irregular profile of the contact wire.

The proposed procedure is applied to two cases: the first one compares contact wire wear using copper collector strips and graphite collector strips for a DC line. In the second, the consequences of changing the mechanical tension of the contact wire according to the levels of wear are provided.

Composite electrically conductive graphite-filled materials with increased tribological properties are also of interest. In [6], the tribological behavior of metal matrix composites containing graphite particles is considered. A theoretical hypothesis regarding friction and wear is presented; composites in the presence of a thin lubricating film. Experimental results showed that friction and wear rate in metal matrix-graphite particle composites are significantly reduced compared to those in matrix alloys as a result of the introduction of graphite particles. When the graphite content in metal matrix composites exceeds about 20%, the coefficient of friction approaches that of pure graphite and becomes independent of the matrix alloy. Initially, during the sliding of the film, there is no graphite, but it is formed as a result of surface and subsurface deformation, which leads to the transfer of graphite to the tribosurface. A dynamic steady state of the film is established, which is characterized by its friction and rate of wear. The effects of variables such as normal pressure, sliding speed, and composition on steady-state friction and wear rate are discussed. It was established that the presence of graphite particles in the matrix of aluminum alloys increases their resistance to burrs and allows them to work under extreme lubrication without burrs. Copper-graphite and silver-graphite compositions are used in electric brushes and contact strips.

In the article [7], the effect of alloying aluminum with copper (2–4%), silicon (2–4.5%), tin (10–15%), and lead (10–15%) on its wear resistance under steam friction conditions was investigated with copper contact wire.

In practice, it is customary to use cheap electrographic inserts that work without lubricating the contact wire. According to some parameters, these inserts are superior to metal counterparts, but due to fragility and low strength, they fail as a result of impacts. Their service life is limited, and high humidity and sticking wet snow reduce it by one or two orders of magnitude. Metal-ceramic copper-lead-graphite inserts made of 87% copper powder, 9% lead, 4% graphite are more effective: they do not damage the contact wire and are suitable for use due to their wear resistance, but in the case of atmospheric precipitation, the wear of these inserts is 2.2 times greater than that of electrographite . In addition, their use is limited by the high cost of components and manufacturing. The latter is also characteristic of metal inserts made of aluminum-tin alloys with electrographite bushings placed in the middle part of the working track in fig. 3.

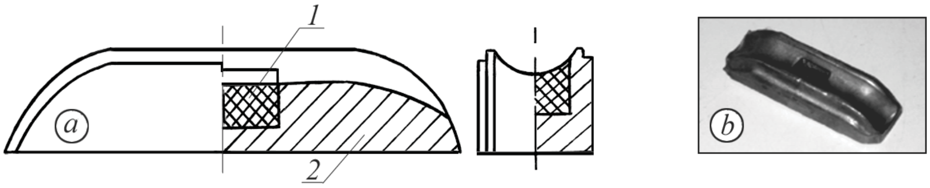

Fig. 3. Combined metal-electrographic current collector insert [7]: (a) structural features, (b) general appearance, (1) electrographite, (2) metal base

With the help of casting, it is possible to achieve high electrical conductivity and lower hardness compared to the contact wire (to prevent its mechanical damage), high wear resistance and low cost of trolley inserts. A comparison of the properties of metallic electrical contact materials shows that aluminum is preferred.

However, even with minor plastic deformations, pure aluminum, compared to other soft metals, tends to stick with copper during dry friction. Under certain conditions, aluminum-based materials capable of self-lubrication (that is, such materials that contain soft but impact-resistant components and a hard matrix).

It has been established that alloying increases the wear resistance of metals and reduces the wear of contact wires. The use of an electrographite sleeve reduces the wear of the metal insert. Field studies of metal trolley current-carrying inserts with electrographite bushings showed that their durability in dry weather is 5-8 times longer, and in rainy weather - 2-3 times longer than that of conventional products.

In [8], the tribotechnical and operational properties of composite materials based on dispersion-strengthened copper were investigated in comparison with the known ones when they are used as current collectors of moving urban transport. The impact on the coefficient of friction and material wear of the method of its compaction - pressing followed by sintering and hot stamping - was studied. It has been established that the highest operational properties have the inserts of tram rails, which are made of material based on dispersion-strengthened copper by the method of hot stamping, which is due to its low coefficient of friction and low intensity of wear of both the material and the counterbody.

High-speed electric sliding was studied in [9] because of its many important industrial applications. In the paper, a friction testing machine with a sliding speed of up to 75 m/s and a current of 100 A was constructed, and the friction and wear resistance of carbon graphite material during high-speed sliding with and without current was investigated. The influence of load, sliding speed and electric current on the tribological behavior of the tested material was investigated. The wear debris was examined by SEM. The test results showed different indicators of friction and wear of the tested material with and without current.

A series of tests on the friction and wear behavior of pure carbon strip/copper AC contact wire was carried out in [10] on a high-speed block slip ring tester. Electric current, normal force, and sliding speed had distinct effects on the test results. The worn spot has the smallest size without an electric current. The worn area increases with increasing electric current. Arc ablation pits, dark arc ablation current lines, skid marks, chips and a copper layer are found on the worn surfaces. The main wear mechanisms are arc erosion, abrasive and adhesive wear.

The service life of the pantograph/contact network system directly affects the stable operation and stable current intake of electric locomotives. In [11], a series of tests was conducted to study the friction and wear behavior of carbon strips and copper contact line using a high-speed line-on-block tester. The friction and wear behavior of carbon strips/copper contact line is significantly affected by normal load, electric currents and sliding speed. By comparing different worn microscopes of carbon strips, it can be found that abrasive wear, adhesive wear and arc ablation are the main wear mechanisms.

In a number of works, the authors focus on the design features of contact electrical systems of transport, both in terms of material composition and the structure of current collector systems.

In [12], the effect of electric current on internal deformation processes in materials is studied. Manufacturing processes (such as forging, rolling, extrusion, and forming) use heat to reduce the forces involved in making parts. However, due to the negative consequences associated with hot processing, it is desirable to use another, more efficient way of applying energy. This article investigates changes in material properties of various metals (aluminum, copper, iron, and titanium-based alloys) in response to the flow of electricity. The theory of electromigration and electroplasticity is reviewed and implications are analyzed. It is shown that with the help of an electric current, the voltages of the currents are reduced, which leads to a lower specific strain energy. The approaches proposed in the work can be used to explain the mechanism of the effect of electric current on materials used in contact transport electrical networks.

The article [13] describes the technology for obtaining a carbon-aluminum alloy of the composite type using a non-autoclaved (gasless) method of impregnating a carbographite base from a matrix aluminum alloy. The use of aluminum alloy as a matrix alloy and carbon graphite or ceramics as a porous blank allows to obtain composite materials that are widely used in mechanical engineering for the manufacture of current receivers, pantograph inserts, electric brushes, sealants, and bearing liners. There are several types of brushes, such as: metal graphite, electro graphite, graphite, connected with resin, carbon graphite. Metal graphite (with impregnation) brushes are used in more responsible nodes and various mechanisms. From this it follows that the use of brushes made of a composite carbon-aluminum alloy will be appropriate and appropriate.

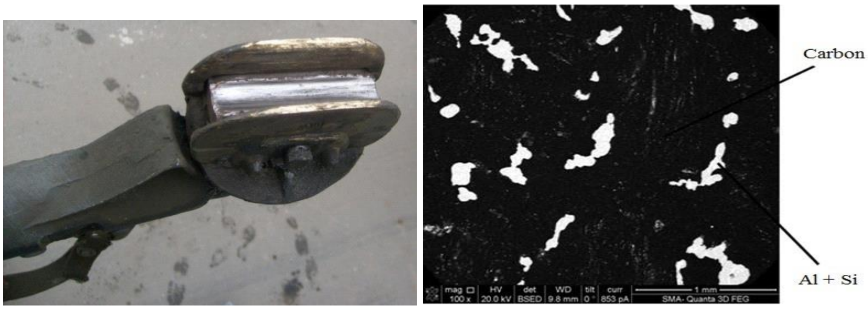

Fig. 4. Carbon graphite inserts of a trolleybus pantograph impregnated with an aluminum alloy [13]

It is advisable to improve the design of contact brushes by impregnating the working layer with an aluminum alloy to increase strength, electrical conductivity and anti-friction properties. In terms of electrical properties, aluminum is not significantly inferior to copper, since its share in the composition of the composite is only 15%, and therefore it has better casting properties (fig. 4). In addition, the use of the gasless impregnation method allows to significantly reduce the cost of composite materials due to the use of conventional structural materials in the equipment. Due to the low cost of equipment, it is possible to manufacture a large number of impregnation tanks for the organization of series or mass production of composites.

The paper [14] considers the problems of extending the life of contact bars for pantographs of electric traction vehicles by choosing the elemental composition of the inserts. In particular, the use of nanostructured crystals of partially stabilized zirconium dioxide for the modification of inserts is proposed. The effect of doping zirconium dioxide crystals with rare earth elements on tribological properties was experimentally investigated. Sample hardness and crack resistance were assessed by the kinetic microindentation method. It has been established that alloying zirconium dioxide crystals is an effective method of increasing strength properties. Samples of crystals that showed the highest characteristics of crack resistance and hardness were selected. Tribological tests of the selected samples under dry sliding conditions were carried out on laboratory friction machines. It was established that the rate of wear of surfaces for constant friction is directly proportional to the nominal pressure. The morphology and mechanism of wear of the friction surfaces were studied, the appearance of unevenly distributed films of secondary structures on the friction surface was shown. The use of zirconium inserts in the contact strips increases the wear resistance and permissible load on the assembled pantograph, which reduces the potential of arc discharge.

The study [15] describes the designs of current collectors, which ensure the prevention of rebound and premature wear of the contact wire on the supports by reducing the lifting resistance of the current collectors. Suspended contact systems for electric vehicles use a catenary or single-contact wire suspended from consoles, brackets, or running wires. For a single contact wire, the inclined pendulum suspension provides optimum performance for pantograph or trolley pantographs, although it is underused in the United States. A typical suspension for a single contact wire consists of straight suspension suspensions with stable arms. A rigid mount has been shown to result in a heavy, stiff suspension, resulting in pantograph bounce, arcing, and premature contact wire wear. Inclined pendulums can be used in constant tension systems or variable tension systems where they provide semi-constant line tension and keep the wire tension relatively constant over a range of temperatures. Such suspensions provide less resistance to the lifting of current collectors at the suspension point, so that the lifting of the contact wire occurs as the collector approaches and passes under it. The energy wave created in the wire by the moving collector allows the collector to pass smoothly without rebound or loss of continuous contact.

The article [16] provides data on particle shape, component and granular composition, for information on the relationship between compact density and pressing pressure for powder materials with special properties based on tungsten and carbon suspensions.

It was shown in [17] that in the manufacture of electrodes and current receivers based on graphite, there is a significant simplification when using a flexible graphite sheet. The incorporation of the flexible graphite sheet Grafoil and its powder into lithium was evaluated using an electrochemical charge-discharge cycle in a configuration with a lithium anode and a graphite cathode. A sheet form with and without a copper current collector was used. It is noted that the relatively low capacity of the Grafoil sheet is explained by the limitation of diffusion of the structure, especially for the high capacity of its powder form. The highly irreversible ability of the powder material may be due to non-functional graphite structures or impurities present in the powder. The presence of the second impedance arc indicates that a structural modification occurs in the graphite anode due to the formation of a porous structure as a result of graphite expansion.

The purpose of the work [18] is to determine the main ways of increasing the resource of inserts of coal current receivers of high-speed electric rolling stock. The existing approaches to the production of surface inserts of current collectors in Europe and Ukraine are considered. The most effective ways of increasing the current-conducting capacity and wear resistance of the elements of the current receiver have been determined. It has been established that the existing system for determining the quality of manufacturing of current-carrying elements has a number of shortcomings that complicate the control of receipt and make it impossible to diagnose current-carrying elements in operation. Based on the facts, we offer a new stand for the needs of the locomotive depot, which will avoid the existing difficulties with the diagnosis of the current collector elements. According to the results of the operational studies conducted on the basis of the locomotive depot, it is proposed to introduce a system of operational diagnostics of the state of the current collector elements during operation. In the course of a comparative analysis of existing and prospective directions of development of current-receiving elements with high load current-conducting capacity and durability, the design conditions for the optimal ratio of inserts were determined. It has been established that a significant part of failures occurs due to an imperfect maintenance system. The obtained results of the analysis of the sources of information determine the need to introduce a copper component to the coal inserts, which will increase the load capacity of the current receivers. Deficiencies of the existing diagnostic systems of carbon current-carrying inserts of pantograph runners have been established, the solution of which should be the basis for the development of new diagnostic tools and systems of current-carrying elements.

In the article [19], a simulation model of the dynamic interaction between the contact network and the pantograph was developed using flexible multibody methods of dynamic analysis. In the analysis model, the pantograph is modeled as a rigid body, and the catenary wire is designed using the formulation of absolute nodal coordinates, which allows efficient analysis of large deformable parts. Furthermore, to represent the dynamic interaction between these parts, their relative motions are constrained by a sliding joint. Using this model, data on contact force and contact loss for a given speed of movement are obtained. The results are evaluated according to the international standard EN 50318.

The purpose of the work [20] is to manufacture hybrid metal matrix composites for dry sliding and to study the effect of sliding speed, load and reinforcement (aluminum oxide and graphite) on wear properties, as well as its contact friction. The behavior of dry sliding during wear of the Al-Si10Mg alloy reinforced with 3, 6, and 9 wt% was considered. of aluminum oxide together with 3% by mass. graphite The method of casting with mixing was used for the manufacture of composites. Mechanical properties such as hardness and tensile strength were evaluated. A disc wear test device was used to evaluate the wear rate and the friction coefficient by changing the loads of 20, 30 and 40 N, sliding speeds of 1.5 m/s, 2.5 m/s and 3.5 m/s. It was found that the mechanical properties of the hybrid metal matrix composites showed significant improvement. The wear rate and coefficient of friction for the alloy and composites decreased with increasing sliding speed and increased with increasing applied load.

In [21], a study of the interaction of contact elements of pantographs of electric transport operated on direct and alternating current sections of railways was carried out. In contrast to the known methods of bench tests, the mechanism of current collection and wear resistance was investigated on a new test setup in a minimally narrow zone of sliding contact. Experimental studies have confirmed that the intensity of wear of contact elements of current collectors depends on the current load of the contact zone, the amount of contact pressure, the area of the contacting surface and the speed of movement. The possibility of maintaining a reliable contact connection in a sliding contact in extreme operating modes in the case of using a reliable contact material of the current collector pads has been practically proven. It is proposed to use a composition of powders based on bronze, iron and graphite for the manufacture of contact elements of current collectors, which can provide reliable contact through interaction with the contact wire.

Conclusions

1. The main problem related to the manufacture and operation of current-transmitting elements of electric transport is the durability of contact parts according to operational and tribological characteristics. The study of the wear resistance of electrical contact inserts is carried out by theoretical and experimental methods. The work of current-transmitting elements of electric transport consists in the continuous sliding of one element on the surface of another and is accompanied by wear. At the same time, two types of wear are distinguished: mechanical and electrical.

2. The correct choice of materials has the greatest impact on reducing friction and wear of electrical contact elements. The basis for this is graphite material, which has the best current-conducting characteristics, but has insufficient strength and wear resistance.

3. The basic approach in the creation of materials for electrical contact elements is the use of composite metallographite materials in a certain ratio of components. Copper, aluminum, lead and other materials with good electrical conductivity and anti-friction properties are used as metal components.

4. It is possible to improve the operational and tribological properties by reducing the contact pressure or its uniform distribution over the contact zone by using the appropriate modernized designs of electric transport current receivers and using computer modeling methods.

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Ковтун О.С., Диха О.В. Тертя та зношування струмопередавальних елементів електротранспорту із застосуванням металографітових композиційних матеріалів

В роботі наведений аналіз досліджень, присвячних проблемі, що стосуються виготовлення та експлуатації струмопередавальних елементів електротранспорту, а саме довговічності контактних деталей за експлуатаційними і трибологічними характеристиками. Робота струмопередавальних елементів електротранспорту полягає в безперервному ковзанні одного елемента по поверхні іншого і супроводжується зносом. При цьому розрізняють два види зносу: механічний і електричний. Встановлено, що на зниження тертя і зносу електроконтактних елементів найбільший вплив має правильний вибір матеріалів. За основу при цьому приймається графітовий матеріал, який має найкращі струмопровідні характеристики, але має недостатню міцність і зносотійкість. Проаналізовано підходи щодо створення матеріалів електроконтактних елементів із застосування композиційних металографітних матеріалів на основі міді, алюмінію, свинцю та інших матеріалів.

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Ключові слова: електротранспорт, метало-графітні вставки, тертя, зношування, композиційні матеріали