***Problems of Tribology**, V. 30, No 1/115-2025, 6-11*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2025-115-1-6-11

Lifetime improvement of contact brush units of automotive power machines. Part 1

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Received: 15 November 2024: Revised: 15 December 2024: Accept: 05 January 2025

Abstract

Lifetime improvement of contact brush units of automotive power machines is suggested. Particularities of mass transfer of aluminium electrode on copper substrate is researched. The structure of aluminium electrospark coating on copper substrate is investigated. The fine dispersed eutectic structure with copper-aluminium solid solutions of electrospark coating is detected. This structure is suitable for good coating conductance and well coating adhesion for high speed application under electric current like a contact brush unit of alternators or commutator unit of power starters.

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

Introduction and review of publications

The automotive electric equipment involves the electric machines (starter, alternator) incorporating the brush unit and hybrid drive vehicles as well. It has 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. Wear products of graphite and copper results in short-circuiting of the starter plated commutator or alternator slip ring thus reducing its performance during the ICE start procedure and battery recharge process. So the wear resistnce of these elements is of great importance for proper brush adlining and power power transfer through it as well.

Great interest rose in develpment and improvement of electric equipment parts made of copper and aluminium. These two metals are used in power equipment, and their chemical interaction is very interested for development of superficial strengthening technique.

Thus in the research [1] the paper presents a study of surface layers produced by electrospark deposition(ESD) using copper electrode on aluminium. The layers were investigated with metallographic methods. Microscopic examination was carried out to examine the structure of formed layers. Image analysis methods were used to observe the cross-section of the layer. For diffusion observations, ESD analyzes were performed on the cross-section of the produced layer. Scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) analysis was conducted to characterize the microstructure and composition of the coating. Also the tribological tests were made on the T-01 M type Ball-on-Disk testing machine. The research carried out for a sliding distance of 1000 m with load 10 N. The results of investigations showed that there is a possibility of obtaining the satisfying quality superficial layer on the aluminum using copper electrode. So these elements are siutable for electrospark coatings of good wear resistance.

The publicaion [2] is about good adhesion of copper to aluminium under electrospark alloying. So, there replacement of ferrous metals with lighter non-ferrous ones, in particular with aluminum and its alloys, is of great importance for reducing the specific material consumption of products. Modification of aluminum alloy D16 with combined electro spark coating VK8 + Cu is considered. Based on the method of finite element analysis of the Nastran software complex, an optimal coating continuity was determined at the level of 55-65%, which provides efficient workability of the coating via reducing the residual stresses in the base and tangent stresses in the plane of adhesive contact, optimization of the coating continuity, distribution of contact loads, and formation of optimal surface geometry. The results of modeling the stress-strain state of the coating-base at a coating continuity of 60% and a normal load of 600 N indicate a 30 MPa increase in equivalent stresses in a unit element of the coating and a decrease of this parameter by 100 MPa in the base as compared with an unmodified D16 surface, indicating the localization of normal stresses mainly in the combined coating. It was experimentally established that at a combined coating continuity of 60%, reduction of D16 wear by 2 times and decrease in the average power of acoustic emission by 1.33 times are provided, which testifies to the efficient structural adaptability of the coating-base under friction. The mechanisms of increasing the wear resistance of the VK8+Cu coating according to the rheological-kinetic model, which reflects the correlation between processes of fracture and deformation under friction, are considered. It is determined that the high wear resistance of the combined coating is due to the combination of rheological properties of hard alloy VK8 with a fracture toughness of 13.2 $MPa\cdot m^{1/2}$ and plastic copper material with a fracture toughness of 100 $MPa\cdot m^{1/2}$, which contributes to the efficient relaxation of stresses under friction. So, this research additionally proves good adhesion of discrete electrospark coating of copper to aluminium alloy.

Antifriction alloys are also friendly for coper structure as ststed in article [3]. The running-in coatings on the surface of tin bronze that was formed by electro spark alloying (ESA) applying the antifriction material of silver, copper, Babbitt B83 and graphene oxide (GO). The analysis of deposition on mass transfer, roughness, thickness and tribological properties of the running-in coatings were investigated by electronic scales, 3D optical profilometers, scanning electron microscopy (SEM), energy dispersion spectrum (EDS), metallographic microscopy and tribometer. The results show that the running-in coatings are dense, grains refined, uniformly distributed and metallurgical fusion with the substrate. The test results of different running-in coatings were summarized and analyzed, and the best industrial application scheme is determined. The base material, coating material, processing technology and coating technology of bearing bush which affect the product quality are analyzed. A new environmental protection technology of constructing running-in coatings of tin bronze bearing bush is put forward, and the technical design, manufacture, processing, installation and trial operation are described in detail. The industrial application adopts a new electro spark alloying of running-in coating technology on the tin bronze bearing Bush to realize the advantages of good surface comprehensive performance, excellent antifriction performance, strong fatigue resistance, high reliability, good durability. So, the running-in coating can be formed on the surface for better contact properties.

Good adhesion ability of copper bond to Ti and Mo during electrospark alloying is stated in work [4]. The article focuses on the laser treatment impact on strength of electric-spark deposited coatings. The coating microstructure, microhardness, and corrosion resistance are analyzed to evaluate the coating properties. Experiments have been carried out with Mo and Ti coatings deposited onto the substrate of steel 45 followed with a laser fusion treatment carried out in BLS 720 installation with neodymium (ND) glass. So, the electrospark copper coating can be easily mixed with different metal additives for structural improvement.

The structural phase content of copper electrospark coatings was comprehensively studied in research [5]. Antifriction materials, such as silver, copper, Babbitt B83, and graphene oxide (GO), were used to prepare running-in coatings on the surface of bronze QSn10-1 by electro-spark deposition (ESD). The analyses of mass transfer, roughness, thickness, morphology, composition, nanoindentation, and tribological properties of the coatings were investigated. The results showed that the running-in coatings were dense with refined grains that were uniformly distributed and in a metallurgical bond state with the tin bronze substrate. At optimum process parameters, the mass transfer was 244.2 mg, the surface roughness was 15.9 μm, and the thickness of the layers was 160 μm. The diffraction peaks clearly indicated the phases corresponding to α-Sn, SbSn, Cu_6Sn_5, and Cu, and a phase of Ag_3Sn appeared. The modulus and the hardness of the running-in coatings were 24.9% and 14.2% of the substrate, and the deformation ratio of the coatings was 10.2% higher than that of the substrate. The friction coefficient of the running-in coatings was about 0.210 after the running-in stage, which was 64.8% of that of the substrate (0.324). The main wear mechanism of the running-in coatings under optimal process parameters is plastic deformation, scratching, and slight polishing. The running-in coating deformation under the action of high specific loads provides the automatic adjustment of parts and compensation for manufacturing errors. So these coatings will work in the antifriction range.

Copper and aluminium electrospark interaction was comprehensively studied in paper [6]. There the layer-by-layer electrospark deposition of Cu, In, Pb, Cd, and Sn group metals and Ti, V, and W metals, as well as their carbides and hard metals of WC type, onto metallic surfaces is studied. This technique improves the quality and wear resistance of the surface layer compared to coatings without a sublayer. The sintered electrode materials containing 1030 wt.% of the (NiCrSiB)– WC6 alloy allow electrospark coatings with thickness up to 100 μm and microhardness 12.3–14.2 GPa to be formed. The wear resistance and service life of these coatings are substantially higher than of those made of standard hard metal WC6. Among the NiCrAl alloys, the best effectiveness in worn-part recovery is shown by the alloy from the ternary eutectic region (50.3 wt.% Ni, 40.2 wt.% Cr, 9.5 wt.% Al), which may provide coating thickness up to 1.0 mm. The novel coating technique and proposed electrode materials increase the resistance of cutting tools and life of equipment parts. So good electrospark adhesion of copper and aluminium additives can improve even hard loaded cutting tools.

The copper alloy electrospark coatings were investigated in reserch[7]. There was specified about that electro-spark deposition (ESD) technology is a new method for repairing and strengthening the surface of metal materials. This method has the advantages of simple equipment, convenient operation and wide application range. The alloyed coating has higher wear resistance, good corrosion resistance, excellent friction performance and other special properties, so it has better practical value and wide application prospect. The paper introduces the characteristics and principle of electro-spark deposition technology, analyzes the research status of this technology and points out the future development direction of this technology. And there the wear scars of the tin bronze substrate after tribological testing were investigated by scanning electronic microscopy.

Even small content of aluminium provides strong adhesion of electrospark copper coating to titanium, as stated in scientific work [8]. Nowadays, copper-titanium coatings have invited extensive attention of researchers in the surface modification of industrial and biomedical materials due to their excellent mechanical properties and biocompatibility. For the first time, the electrospark deposition technique was used for Cu-Ti coatings deposition on the Ti_6Al_4V alloy by processing in a mixture of copper and titanium granules at a copper concentration from 10 to 90 at.%. It is revealed that both cathode mass gain and coatings thickness rise with the copper concentration increase in the mixture of granules. According to EDS analysis, the copper concentration in the coating linearly grew with a growth of its content in the granule mixture. According to the data of X-ray analysis, intermetallic compounds were found in the structure of the coatings: $CuTi_3$, CuTi, Cu_4Ti_3, and Cu_3Ti. The detected phases provide the coating microhardness up to 6.7 GPa. Polarization tests in 3.5% NaCl solution showed corrosion resistance growth with a copper content decrease in Cu-Ti coatings. The oxidation resistance at a temperature of 900 °C grows with an increasing copper concentration in the coating structure. Cu-enriched sublayer is formed on upper layers of Ti_6Al_4V alloy after Cu-Ti coating oxidation at 900 °C. The wear rate of the coated samples as a function of copper concentration had the form of a parabola with a minimum for the coating made in an equimolar mixture of copper and titanium. The use of electrospark Cu-Ti coatings makes it possible to increase the wear resistance of the Ti_6Al_4V alloy surface up to 11 times.

Copper can be used as sublayer or additive for electrospark deposition of refractory compounds, as stated in paper [9]. In order to improve the lifespan of spot-welding electrodes used for welding zinc coated steel sheets, titanium diboride was deposited onto their surface after precoating nickel as an intermediate layer. The microstructures and phase compositions of TiB_2 and Ni coatings were characterized by SEM and XRD. The coating hardness was measured using a microhardness tester. The results indicate that a satisfactory TiB_2 coating is obtained as a result of the intermediate nickel layer acting as a good binder between the TiB_2 coating and the copper alloy substrate. Owing to its capacity of deforming, the precoated nickel layer is dense and crack free, while cracks and pores are observed in the TiB_2 coating. The hardness of the TiB_2/Ni coating decreases with the increase of voltage and capacitance because of the diffusion of copper and nickel and the oxidation of the coating materials. Because of the good thermal and electrical conductivities and high hardness properties of TiB_2, the deformation of the electrode with TiB_2/Ni coating is reduced and its spot-welding life is by far prolonged than that of the uncoated one. So the adhesion of electrospark copper additives is sufficient for different applications.

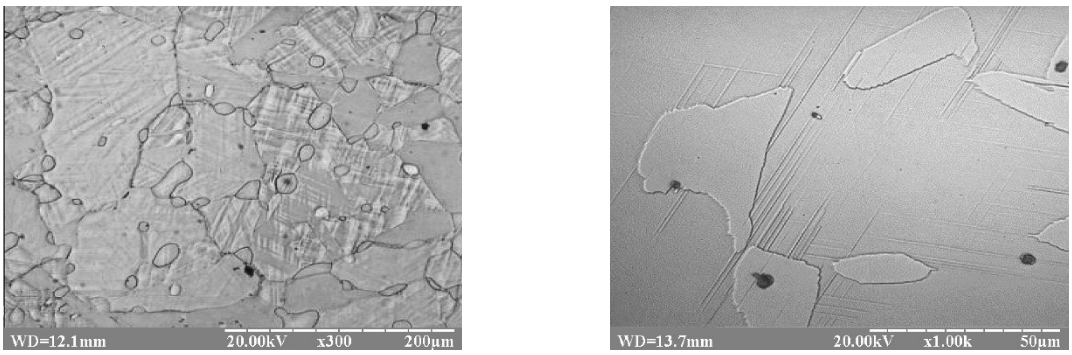
Formerly the electrospark coating on aluminium substrate were reserched [10]. The problems of resource extension and recovery of the piston–cylinder parts of internal combustion engines are considered. A method for modelling working conditions of pair ‘groove–ring’ of motors is developed, and durability of aluminium Al-25 alloy with electrospark coatings of different composition paired with a chromium alloyed steel under high-temperature fretting process is carried out. Optimum modes of hardening treatment for piston ring grooves of pistons of internal combustion engines are determined. But the mass transfer during electrospark alloying is about possibility of creation of aluminium coating on copper substrate.

Problem statement and objective

Thus present objective of this study is development of strengthening technique of friction joint of brush unit “copper-graphite” under working current flow and technique. Namely this paper is dedicated for research of coating structure.

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 – initial structure of which is indicated on fig. 1.) were fabricated in dimensions of hole disks 16×6×2,5 mm in order to provide the least friction contact area for experiment acceleration.



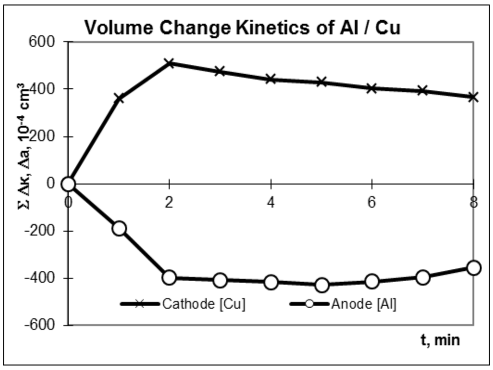
a b

Fig. 1. SEM images of initial structure of electric conductive copper M1E: a) under 300 electronic zoom; b) under 1000 electronic zoom

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. On the 7th mode the coating appears to be overburnt and dirty by soot and ash, and thus extremely porous. At that the electrode weight change Δa and cathode specimen of 1 cm^2 area weight change Δc were continuously monitored in a 1 minute period. According to aquired data the kinetic diagrams of electrode weight change was plotted. However the kinetic volume diagrams are more informative, so as the density of copper is twice bigger than aluminium one, so the kinetic volume diagrams were used for coating formation analysis (fig. 2. a). Mass transfer factor (Kt = (∑Δc / ∑Δa)·100%) was calculated as well (fig. 2. b).

Main results

The coating formation kinetics is on fig. 2. This diagram is about that the aluminium electrospark coating is deposited on the 6th mode of installation only in first two minutes (fig. 2., a) than tha mass transfer is changing into reverse direction - the copper is transferred on aluminium electrode, so the copper substrate errosion takes place. Mass transfer factor during this time is about 200% (fig. 2. b).



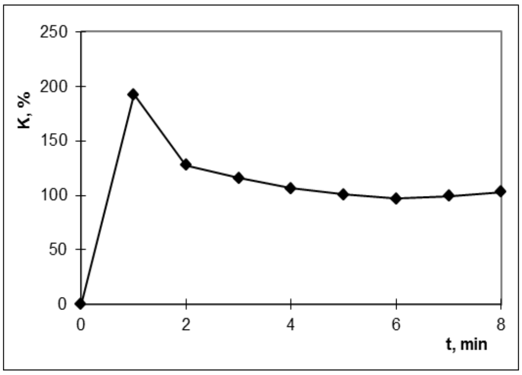


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Fig. 2. The volume change kinetics (a) and mass trenasfer factor (b) of aluminium electrospark coating on copper surface

On preliminary cleaned surface from oxides the electrospark coating has been deposited of thickness 150 micrometers per one cycle of electrospark alloying. Its total thickness is indicated on fig. 3. It is the modified superficial layer of 2-3 milimeters thick.

The coating structure is the matrix with black inclusions of copper oxide and aluminium oxide which will probably weaken the coating strength and worsen its electric conductivity (fig. 3.).

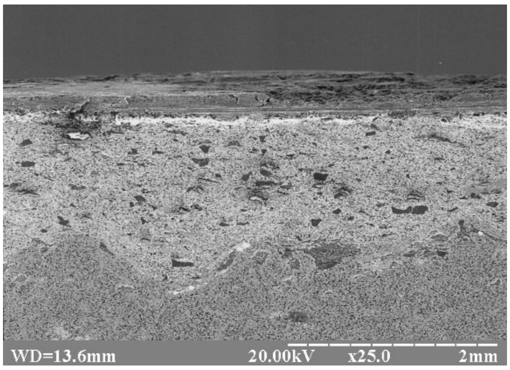

Fig. 3. SEM image of electrospark coating on the electric conductive copper by aluminium electrode under 25 zoom

The strengthening phase (matrix) in copper is the gamma-phase solid solution of aluminum in copper. It is well conductive for current and heat from the surface. Enriching the superficial content of aluminum the delta-phase solid solution of aluminum in copper, which hardness and melting temperature is less and bigger conductivity close to aluminum. Profound electronic microscopic research and X-ray phase research detected these two solid solutions (gamma – is dark grey and delta – is light grey) create the eutectic structure under electrospark fusion as indicated on fig. 4. The black dots on all structures (fig. 1., 3.-4.) are the carbon containing contaminations not relating to research procedure. It was only the lack of samples fabrication.

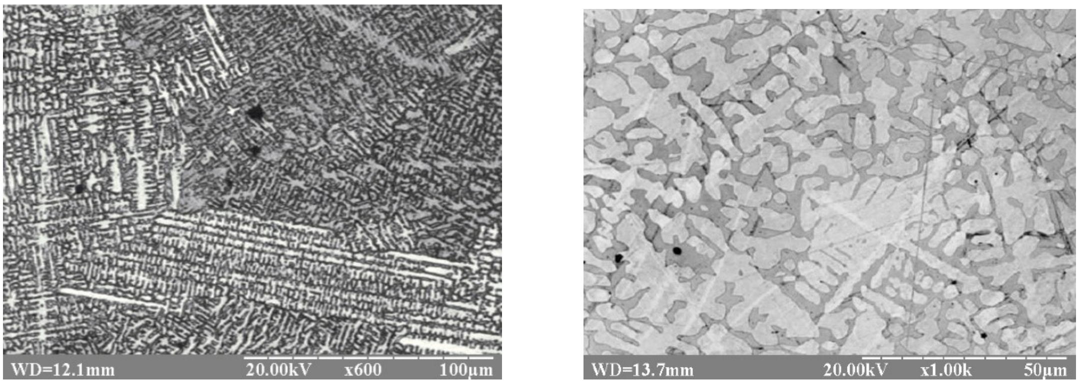

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Fig. 4. SEM electronic images of matrix structure of electrospark coating on copper substrate by aluminium electrode: a) under 600 zoom; b) under 1000 zoom

The coated and uncoated samples were tested on the friction test bench M-22ПВ under "pin-on-shaft" layout. Conventional vehicle alternator brush unit has been used in a friction test bench, so the load was equal to brush spring force. 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. Wear mechnism and friction surfaces will be investigated in following research.

Conclusions

So using electrospark alloying technique the wearproof coating has been acquired with good adhesion to substrate. The structure of this coating is eutectic of gamma-phase solid solution of aluminum in copper and delta-phase solid solution of aluminum in copper. This fine eutectic structure has satisfactory conductivity for power transfer purposes.

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 quadracopters as well.

References

1. S. Spadłoa, P. Młynarczyka Selected Properties of the Micro Electrical Discharge Alloying Process Using Copper Electrode on Aluminum, Transportation Research Procedia. 40 (2019) 96–101.

2. T.M.A. Al-Quraan, V.V. Tokaruk, O.A. Mikosianchyk, R.G. Mnatsakanov, N.M. Kichata, N.O. Kuzin Influence of Continuity of Electric Spark Coatings on Wear Resistance of Aluminum Alloy. Tribology in Industry Vol. 43, No. 4 (2021) 603-614.

3. Zhang Zhengchuan, Ie. Konoplianchenko, V. Tarelnyk, Liu Guanjun, Du Xin, Ju Yao, Song Zhaoyang Industry Application of the Coatings On the Bearing Bush By Electro Spark Alloying Technology. Науковий вісник ІФНТУНГ. No. 1(52) (2022) 15-23.

4. N. Radek, Ju. Shalapko, M. Kowalski Investigations of the Cu-Mo and Cu-Ti electrospark coatings after laser treatment. Vestnik Dvigatelestroyenia. 1 (2009) 143-149.

5. Zhengchuan Zhang, Ie. Konoplianchenko, V. Tarelnyk, Guanjun Liu, Xin Du, Hua Yu The Characterization of Running-In Coatings on the Surface of Tin Bronze by Electro-Spark Deposition Coatings 12. 930. (2022) 1-16.

6. V. B. Tarelnyk, A. V. Paustovskii, Yu. G. Tkachenko, E. V. Konoplianchenko, V. S. Martsynkovskyi, B. Antoszewski Electrode materials for composite and multilayer electrospark-deposited coatings from Ni–Cr and WC–Co alloys and metals Powder Metallurgy and Metal Ceramics, Vol. 55, Nos. 9-10, January, 2017. 585-595.

7. Zhang Zhengchuan, Liu Guanjun, Ie. Konoplianchenko, V. Tarelnyk, Ge Zhiqin, Du Xin A Review of the electro-spark deposition technology. Вісник Сумського національного аграрного університету. Серія «Механізація та автоматизація виробничих процесів», випуск 2 (44), (2021). 45-53.

8. Burkov A.A., Chigrin P.G., Dvornik M.I. Characteristics of Cu-Ti electrospark coatings on titanium alloy Ti6Al4V. Preprint research paper. Electronic copy available at: https://ssrn.com/abstract=4373155

9. LUO Cheng, XIONG Xiang, DONG Shi-jie TiB_2/Ni coatings on surface of copper alloy electrode prepared by electrospark deposition. Transaction of Nonferrous Metals Society of China. 21. (2011). 317-321.

10. M. F. Dmitrichenko, V. V. Varyuhno, A. V. Kulinich, A. G. Dovgal, and V. P. Koba, Extension of Resource of Power-Plants' Parts of Aviation Ground Equipment under Operating Conditions, Metallofiz. Noveishie Tekhnol., 39, No. 1: (2017) 69–81.

Довгаль А. Г., Білякович О. М., Приймак Л. Б. Поліпшення ресурсу контактно-щіткових вузлів автомобільних електромашин. Ч.1.

Запропоновано поліпшення ресурсу контактно-щіткових вузлів автомобільних електромашин. Досліджено особливості масопереносу алюмінієвого електроду на мідну підкладку. Досліджена структура електроіскрових покриттів на мідній підкладці. Виявлена дрібнодисперсна евтектична структура різних твердих розчинів алюмінію у міді електроіскрового покриття. Ця структура придатна для гарної провідності покриття а також хорошої адгезії покриття для високошвидкісного застосування під електричним струмом подібно до контактно-щіткового вузла генераторів та колекторних вузлів електричних стартерів.

Ключові слова: електрмашини змінного струму, генератор, автостартер, контактно-щітковий вузол.