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Superconductivity Effect in Brake Friction Pairs

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Abstract

The article addresses the following issues: general principles of the state of superconductivity in brake friction pairs; isotropic and Josephson effects; paired electron and its role in superconductivity; vibrations of the crystal lattice and vortices in the metal friction element; the discussion of the results. The exciting factor for particles of various kinds in metal friction elements is pulsed normal forces in the mating of friction pairs. Conduction electrons in a metal at a low ambient temperature and its thermally stabilized state are capable of forming pairs that unite particles with equal, oppositely directed impulses. For this to happen, there must be an attraction between the electrons. Behavior and connections of pairs of electrons and the interaction of their energy levels with the nodes of the crystal lattice of a metal friction element. The presence of positive ions in the crystal lattice ensures that a moving electron attracts nearby ions, they shift towards it and create a local excess of positive charge. A locally polarized region attracts another electron, which moves towards the first one. Elastic vibrations of the crystal lattice are the movement of phonons-quanta of sound waves. In this case, electrons are attracted, emitting and absorbing phonons. Between electrons and vibrations of the crystal lattice occurring directly by the attraction of the lattice of electrons prevailing over the Coulomb collision. The emergence of mechanical and magnetic vortices, when the transport current fields exceed the minimum limit of its intensity, magnetic vortices are born near the surface and migrate deep into the metal friction element.

Keywords: braking device, friction pairs, metal friction element, superconductivity, electric, magnetic field.

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Əyləc sürtünmə cütlərində ifratkeçiricilik effekti

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Xülasə

Məqalədə aşağıdakı məsələlərə toxunulur: əyləcin sürtünmə cütlərində ifratkeçiriciliyin vəziyyətinin ümumi prinsipləri; izotrop və Cozefson effektləri; cütləşmiş elektron və onun ifratkeçiricilikdəki rolu; kristal qəfəs titrəmələri və metal friksion elementində rəqslər. Metal friksion elementlərində müxtəlif növ hissəciklər üçün həyəcan verici amil sürtünmə cütlərinin cütləşməsində impulslu normal qüvvələrdir. Ətraf mühitin aşağı temperaturunda metalda keçirici elektronlar və onun termal sabitləşmiş vəziyyətində bərabər, əks istiqamətli impulslarla hissəcikləri birləşdirən cütlər əmələ gətirməyə qadirdirlər. Bunun baş verməsi üçün elektronlar arasında cazibə olmalıdır. Kristal qəfəsdə müsbət ionların olması hərəkət edən elektronun yaxınlıqdakı ionları cəlb etməsini, ona doğru yerdəyişməsini və lokal izafi müsbət yükün yaratmasını təmin edir. Lokal qütbləşmiş bölgə birinciyə doğru hərəkət edən başqa bir elektronu cəzb edir. Kristal qəfəsin elastik rəqsləri səs dalğalarının fononlarının-kvantlarının hərəkətidir. Belə olan halda, elektronlar fononları buraxmaqla və udmaqla cəlb olunur. Səthdə yaranan maqnit rəqsləri metal friksion elementinin dərinliyinə doğru yerdəyişmə edir.

Açar sözlər: əyləc qurğusu, sürtünmə cütləri, metal friksion element, ifratkeçiricilik, elektrik sahəsi, maqnit sahəsi.

Эффект сверхпроводимости в парах трения тормозов

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Аннотация

В статье затронуты вопросы: общие принципы состояния сверхпроводимости в парах трения тормозов; эффекты изотропический и Джозефсона; спаренный электрон и его роль в сверхпроводимости; колебания кристаллической решетки и вихри в металлическом фрикционном элементе. Возбуждающим фактором для частиц различного рода в металлических фрикционных элементах являются импульсные нормальные усилия в сопряжении пар трения. Электроны проводимости в металле при низкой температуре окружающей среды и его термостабилизационном состоянии способны формировать пары, объединяющие частицы с равными противоположно направленными импульсами. Для этого необходимо, чтобы между электронами существовало притяжение. Наличие в кристаллической решетке положительных ионов способствует тому, что движущейся электрон притягивает близлежащие ионы, они смещаются в его сторону и создают локальный избыток положительного заряда. Локально поляризованный участок притягивает другой электрон, который сдвигается по направлению к первому. Упругие колебания кристаллической решетки являются движением фононов-квантов звуковых волн. При этом электроны притягиваются, испуская и поглощая фононы. Возникающие при этом у поверхности магнитные вихри мигрируют вглубь металлического фрикционного элемента.

Ключевые слова: тормозное устройство, пары трения, металлический фрикционный элемент, сверхпроводимость, электрическое поле, магнитное поле.

Introduction

The presence of the triboelectric effect in metal-polymer friction pairs worsens the antifriction properties of materials, increasing the friction force by 15–50% and wear several times [1]. A valuable recommendation is to suppress triboelectric effects by using bipolar materials (i.e., materials that generate charges of opposite sign). An increase in the number of electrons in the triboconjugation helps to intensify the superconductivity of the metal friction element of the braking device. Superconductivity in friction pairs is local in nature.

Analysis of literary sources and the state of the problem

The influence of wear products on friction and wear has long been established. In the works of I.V. Kragelsky and A.V. Chichinadze [2, 3] it is noted that the presence of wear particles contributes to a slight increase in the dynamic coefficient of friction, in some cases it is almost independent of the presence or absence of such particles, and sometimes they, acting like balls, they reduce electrothermomechanical friction. Factors influencing the retention of wear particles in the friction zone may be the size of the area of friction microprotrusions, the presence of grooves or grooves on the surface, and the mutual overlap coefficient. In the mentioned works nothing was said about the magnetic properties of wear products of brake friction pairs. In [4] it is indicated that the volume of the material under study has time to warm up and the temperature differences do not exceed 150 ºC, then, for example, during the braking process of a real brake, such a large amount of heat is released on the generating surface in a short time (10÷20) s that it occurs thermal shock directed deep into the elements of the friction pair. Temperature differences along the depth of the elements reach 700 ºC or more. This is due to the superconductivity of microprotrusions of the metal sample. In [5], a method was proposed for determining the contact electrothermal resistance in tribo-couplings of metal-polymer friction pairs of braking devices. However, this method did not say anything about the superconductivity of the metal friction element. In [6] it is indicated that a superconducting metal friction element is very sensitive to heat transfer processes and is capable of weak forced cooling with fairly small heat losses due to a decrease in the thermal resistance of thermal conductivity.

When assessing the thermal stabilization state of a metal friction element, it is based on equalizing the temperature gradient across its thickness [7]. However, this is only possible in the superconducting state of the metal friction element.

The article addresses the following issues: general principles of the state of superconductivity in brake friction pairs; isotropic and Josephson effects; paired electron and its role in superconductivity; vibrations of the crystal lattice and vortices in the metal friction element; the discussion of the results.

Goal of the work – substantiation of the effect of superconductivity in metal friction elements of brakes.

General principles of the state of superconductivity in brake friction pairs. During the electrothermo-mechanical friction interaction of brake friction pairs, an electric current is generated at their interfaces, promoting the appearance of magnetic ring lines around a cylindrical metal ring (Fig. 1). The latter are the rims of drums and pulleys.

In drum and band brakes, the mutual overlap coefficient is less than unity and therefore high-speed switching will occur, i.e., the closure of sections of current circuits depending on the braking time. Large currents will contribute to the emergence of a local superconducting state of the metal friction element. The last is the pulley rim, which uses magnetic insulation for its inner surface. This circumstance allows one to consider local superconductivity from the side of electrothermomechanical friction.

Other factors influencing superconductivity are shown in Fig. 2.

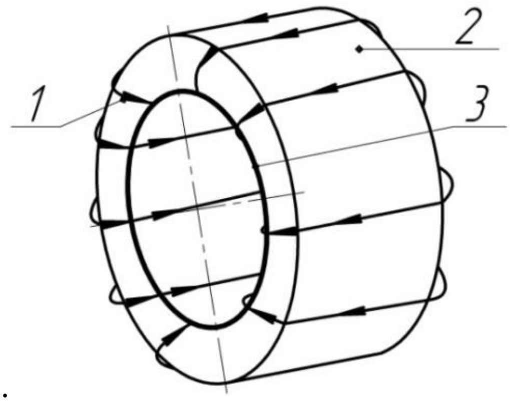

Figure 1 – Magnetic ring lines (1) around a cylindrical metal ring (2) with magnetic insulation (3)

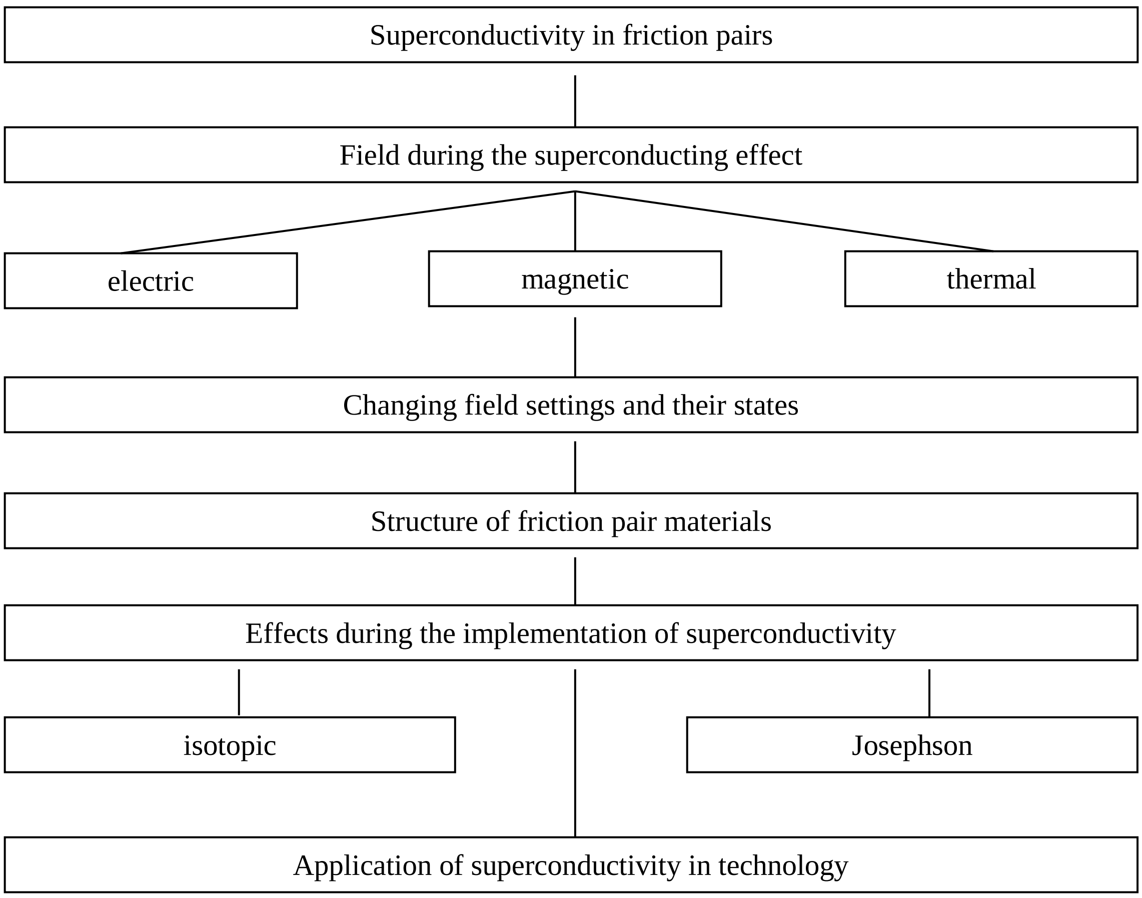

Figure 2 – Components of the superconductivity effect in brake friction pairs

In this case, a first-order phase transition occurs – the total destruction of superconductivity by a magnetic field. Phase transition of the second kind is the transformation of a paramagnet into a ferromagnet or into an antiferromagnet. In these cases, the density changes continuously, heat is not released or absorbed, and the heat capacity changes abruptly, but does not go to infinity. The appearance of a mixed phase determines the reaction of a type II superconductor to the passage of electric current from a created external source.

Let us dwell on the physical processes that contribute to superconductivity in metal friction elements of brakes. Conduction electrons in a metal at low ambient temperatures are capable of forming pairs that unite particles with equal and oppositely directed impulses. For this to happen, there must be attraction between the electrons.

Behavior and connections of electron pairs and the interaction of their state with the nodes of the crystal lattice of a metal friction element.

The presence of positive ions in the crystal lattice ensures that a moving electron attracts nearby ions, they shift towards it and create a local excess of positive charge. A locally polarized region attracts another electron, which will move towards the first one [8]. Elastic vibrations of the crystal lattice are the movement of phonons - quanta of sound waves. In this case, electrons are attracted, emitting and absorbing phonons. Between electrons and vibrations of the crystal lattice, the direct attraction of electrons by the lattice prevails over the Coulomb repulsion.

The appearance of mechanical and magnetic vortices when the transport current field exceeds the minimum limit of its strength. Magnetic vortices are born near the surface and migrate deep into the metal friction element.

Normal electrical resistance arises due to the dissipation of current carriers by thermal vibrations of the lattice (in other words, phonons), as well as by impurity atoms and other inhomogeneities. If the current is carried by individual electrons, then the resistance cannot be zero [9].

Isotopic and Josephson effects

The isotope effect plays a decisive role in constructing the theory of superconductivity. Maxwell and Reynolds established connections between the critical temperature and the mass of isotopes. In the latter, the nuclei of atoms have the same number of protons (same charge), but different numbers of neutrons (different masses). The mass of an isotope is a characteristic of the crystal lattice and can affect its properties. For example, the frequency of lattice vibrations is known to be related to the mass of ions by the relation $\omega \sim M^{-½}$. Superconductivity, which is a property of the electronic system of a metal, turns out to be related due to the discovery of the isotopic effect with the state of the crystal lattice. Consequently, the occurrence of the superconductivity effect is due to the interaction of electrons with the crystal lattice. Interestingly, it is this interaction that is responsible for the appearance of electrical resistance. Under certain conditions, it should lead to its absence, i.e. to the effect of superconductivity.

There are stationary and non-stationary Josephson effects. The first of them is the possibility of flow through a tunnel contact formed by two superconductors separated by a thin layer (≈ 10^{-7} cm) dielectric, direct current.

It is essential that this superconducting current flows through a barrier characterized by a zero potential difference.

The magnitude of the Josephson current is described by the formula $j = j_0 \sin\varphi$, where φ – phase difference on both sides of the tunnel passage. The wave function is a complex quantity and as such is characterized by amplitude and phase. It turns out that superconductors separated by a fairly thin ($d \ll \xi_0$) dielectric layer, are characterized by a stable value of their phase difference. The magnitude of this difference can be controlled by an external magnetic field. The experiment showed that such a macroscopic phenomenon as electric current is directly determined by the phase of the wave function.

If the current flowing through the contact reaches its maximum value, then a potential difference appears at the junction V. Its appearance does not exclude the possibility of the flow of superconducting current. However, this current becomes alternating (its frequency $\omega = \frac{2eV}{h}$). Thus, it becomes possible to generate alternating current using a constant potential difference. The described phenomenon is called the non-stationary Josephson effect. The flow of a superconducting current, which does not require energy expenditure, in the presence of V is accompanied by the emission or absorption (in the reverse transition) of a photon with energy $h\omega = 2eV$.

Paired electron and its role in superconductivity

Electrons carry the same charge and therefore cannot be attracted to each other directly. However, when moving, the first electron (Fig. 3 solid trajectory) attracts positively charged ions at the nodes of the crystal lattice, displacing them and forming a local excess of positive charge (and causing elastic vibrations of the lattice - phonons). This charge attracts another electron (dashed line), binding the two particles into a virtual pair. Cooper pairs of electrons are connected by "invisible knots" and can only move in concert. If one of the electrons "bumps" into a defect in the crystal lattice (Fig. 4 black circle), it cannot scatter because it is held by a second electron from a given distance. And the absence of dissipation means the absence of electrical resistance [5].

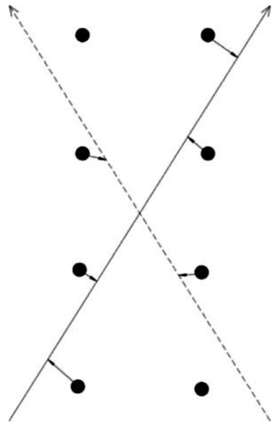

Figure 3 – Behavior and state of electrons when interacting with a crystal lattice site

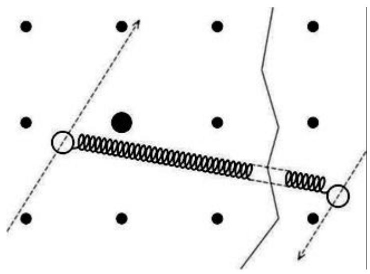

Figure 4 – Behavior and connections of electron pairs (according to Cooper)

A paired electron can undergo scattering only by breaking its bond with its partner. Therefore, to destroy superconductivity, the average speed chosen by electrons in an external electric field must exceed a certain limit proportional to the binding energy of electron pairs. This limiting speed corresponds to the critical current density. Pair bonds should also be broken upon interaction with phonons of sufficiently high energies, which occurs when the temperature rises above the critical one. Below this limit, when Cooper pairs encounter phonons, they most often do not break, but simply transform into new states.

Since paired electrons move with opposite impulses, in a magnetic field they are acted upon by forces directed in different directions and therefore work to break the pair. If the field strength is low, it is more profitable for the superconductor to push it to the surface and keep the Cooper pairs in a bound state. Although such ejection requires energy consumption, it is more than compensated by its savings while maintaining Cooper pairs. The theory also allows us to understand the physical meaning of the coherence length, which corresponds to the average distance between paired electrons. This length is approximately equal to 10^{-5} cm and is therefore a thousand times greater than interatomic distances [6].

The superconducting state occurs at the junction between atoms and electrons. For example, it was found that for mercury isotopes, the critical transition temperature to the superconducting state varies in inverse proportion to the square root of the atomic weight. This directly indicated that superconductivity occurs with the participation of vibrations of the crystal lattice, the frequency of which obeys the same dependence. Shortly before this, Herbert Fröhlich, a professor of theoretical physics at the University of Liverpool, came to the same conclusion. Fröhlich's model did not explain the Meissner–Ochsenfeld effect, but it supported suspicions that a superconducting state was possible.

Vibrations of the crystal lattice of a metal friction element under the influence of loading in friction pairs. The laws of elasticity that take place in the metal-polymer friction pair during their frictional interaction, at least with longitudinal and transverse (and sometimes large) deformations, reflect one-to-one relationships between the (current) instantaneous values of deformations and vibrations of the crystal lattice of the surface layer of the metal friction element.

Energy quanta of elastic vibrations are called phonons. Sound waves in crystals are considered as the propagation of phonon quasiparticles, and thermal vibrations of the crystal lattice are considered as thermal excitation of phonons.

Wave dispersion – dependence of the phase velocity υph of a harmonic wave on its frequency ω. The latter depends on the wave number of the plane k harmonic wave $\omega = \omega(k)$. The dispersion equation can have several branches, which correspond to different types of waves (modes), i.e. longitudinal and transverse.

In most cases, the dispersion of longitudinal and transverse waves is caused by the micro-nanoscale properties of the near-surface layers of the metal friction element (vibrations of atoms and molecules, their thermal motion, structure of the crystal lattice). In dispersive media, temporary (partial) and spatial dispersion are distinguished depending on the braking mode. Temporary is characteristic of emergency and single braking of a cyclic loading mode and is determined by the delay (inertia) of the response of some physical quantity (for

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example, electrical or thermal polarization, mechanical displacement).

Spatial dispersion of longitudinal and transverse waves occurs during a long-term braking mode, when the behavior of the near-surface layer of a metal friction element depends on the dynamic and thermal loading of discrete protrusions of microprotrusions of friction pairs not only on them, but also on neighboring low microprotrusions, i.e. there is a non-local response microprotrusions of the surface to external influence.

The nature of vibrations of the crystal lattice of the surface layer of a metal friction element is influenced by its defects, but also by its heat load.

If there are a lot of defects in the crystal, then a local vibration excited at one can transfer to another. In this case, local vibrations have a narrow frequency band, i.e., they form an impurity zone of vibration frequencies [7].

The higher the temperature of the surface layer of the metal friction element, the greater the amplitude of oscillations, but it is always significantly less than the lattice constant. Thermal vibrations (background) can be superimposed by sound vibrations caused by the propagation of elastic waves in the crystal generated by external influences in the form of a pulsed normal force, which is a component of the dynamic friction coefficient acting aperiodically.

In Fig. 5 *a*, *b*, *c*, *d* show longitudinal (*a*) and transverse (*b*) waves during vibration of the crystal lattice and their distortion (*c*, *d*) under the action of normal forces (*N*) upon them during electrothermomechanical friction.

In this case, a significant change in the amplitude body (*A*) occurs (τ) during the action of normal forces (*N*). In the first case (Fig. 5 *c*) the wave lengthens, and in the second (Fig. 5 *d*) it is flattened, but the amplitude of the wave remains the same.

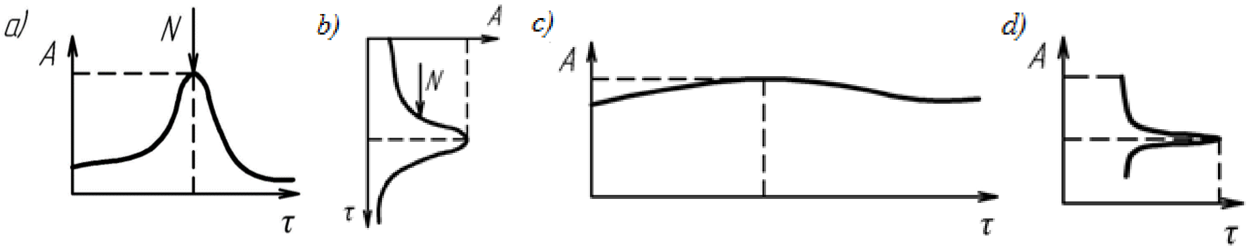

Figure 5 a, b, c, d – Longitudinal (*a*) and transverse (*b*) waves during vibration of a crystal lattice and their distortion (*c*, *d*) under the action of pulsed normal forces on them during electrothermomechanical friction

The transverse vibration wave is amplified by the longitudinal vibration wave.

Let us move on to consider the influence of the Debye temperature (T_D) on the vibration frequency of particles in the crystal lattice of a metal friction element. The Debye temperature is a physical constant of metals, characterizing their many properties - heat capacity, thermal conductivity, electrical conductivity, line broadening of X-ray spectra, elastic properties, etc. [10]. The maximum frequency (ν_D) of metal atoms was determined by the following formula:

$$\nu_D = \frac{T_D - k_в}{h}, \quad (1)$$

where $k_в$ – Boltzmann constant; h – Planck's constant.

Table 1 – The value of the Debye temperature for metals and the vibration frequency of their particles

№ п/п	Metal	Temperature Debye, T_D, ºK	Oscillation frequency particles, $\nu_D \cdot 10^{11}$, s^{-1}
1	Pb	295,0	60,76
2	Zn	300,0	62,44
3	Cu	344,5	71,71
4	Ni	375,0	78,05
5	Mo	380,0	79,1
6	Ti	420,0	87,42
7	Al	429,0	89,29
8	Fe	464,0	96,58

In table 1 presents the results of calculations using formula (1) with the following initial data: $k_в = 1,38 \cdot 10^{-23}$ J/K; $h = 6,63 \cdot 10^{34}$ J·s. The ratio of these constants was $k_в / h = 0,208 \cdot 10^{11} \cdot K^{-1} \cdot s^{-1}$.

An analysis of the vibration frequencies of particles in metal structural elements showed the following: the maximum ratio is the eighth and the first element and is equal to 1.59, and the minimum is the eighth and seventh element, which is 1.08; being nearby, structural elements with a large ratio number create a local oscillatory overload in the near-surface layer of the metal friction element, which significantly affects its local deformation. Using the example of a band-and-block brake on a drill drawworks, in which the pulley weighs 0.5 tons, let us consider the occurrence of a negative temperature gradient in its body without taking into account the gradient of the mechanical properties of the pulley material.

When braking with a brake, currents are generated and heat is accumulated in the surface layers of the working parts of the friction unit. These processes cause the greatest changes in the near-surface layers of friction linings. During the process of plastic deformation, a change in structure and properties occurs in their materials. At the same time, mechanical, potential and temperature gradients in the surface layers of metal-polymer friction pairs continuously change, the level of which depends on the braking modes. The value of the surface temperature depends not only on the number of hoisting operations performed by the band-shoe brake of the drilling drawworks, but also on the physicochemical properties of the near-surface layers of their metal-polymer friction pairs. It has been established that at the beginning of lowering a 6-level tool, the generated electrical and thermal energy is spent on heating the pulley rim. In this case, the temperature increase in the pulley rim is minimal, but in the future it increases due to an increase in braking time and weak forced convective and radiation heat transfer from the matte surfaces of the pulley, washed by high-speed air currents. All processes are local in nature.

In the crystal lattice of a metal friction element

Of particular interest is the study and application of the theory of highly excited states in crystals of a metal friction element of the plasticity and strength of its surface and

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subsurface layers. In this case, plastic deformation (stresses) must be considered in compliance with the laws of behavior of inhomogeneous, highly nonequilibrium systems that undergo local structural transformations and move towards equilibrium through the movement of the components of new structures along the crystal under the influence of gradient stresses. In this case, a deformable crystal is capable of carrying out plastic flow in local volumes, proceeding as a dissipative process due to relay reorganization between two adjacent structures.

The generation of entropy in the considered zone of the crystal is a local kinetic structural transition that promotes the onset of plastic shear.

The noted structural transformation differs from the thermodynamic structural transition and must correspond to nonequilibrium thermodynamics, which is a component of nonequilibrium tribology during the frictional interaction of friction pairs of brake devices. In this case, at each point of the deformable contact spots of the microprotrusions at a given moment in time there is only one system of slip planes in which a loss of shear stability occurs.

Shear information, which is anisotropic in nature, is always accompanied by a material rotation within the structural element of deformation (block grains, dislocation structure cells, etc.). In this case, the material rotation, unlike the crystallographic one, does not affect the spatial orientation of the crystal lattice [6]. This, in turn, causes a turning moment on the part of the surrounding material at the boundary of the structural element of deformation. Rotational modes (one of the numerical characteristics of the probability distribution of a random variable, estimated by their density) of deformation sets in motion the entire hierarchical structure of the levels of deformable contact spots of microprotrusions. Structural elements begin to move as a whole, experiencing translation (transmission) and crystallographic rotation. Rotational modes of deformation form a field of turning moments and provide, inside the structural element of deformation, the release of dislocations from their slip planes, which causes misorientation of the cellular dislocation substructure with the sequential involvement of multiple sliding of contact spots of microprotrusions as a vortex of material rotations of crystallographic shifts on a cylindrical surface.

The relationship between shears and rotations shows that the elementary act of plastic deformation is not a shear, but a translational-rotational vortex. The latter in scale can be at the meso, micro and macro levels. The hierarchy of vortices arises due to the formed hierarchy of different structural levels of deformations. The movement of the entire hierarchy of structural levels of deformation causes its vortex character, contributing to the emergence of new channels of energy dissipation, more effective than from the movement of individual dislocations.

The rotational modes of deformation at different scale levels differ from each other. Their evolution with increasing degree of deformation is naturally reflected in a change in the fractal dimension in places where mechanical stress concentrators are present on the surface of the metal friction element.

The hypothesis of a translational-rotational vortex in relation to the structural levels of deformable materials of microprotrusion contact spots is associated with the energy levels of its core itself, in which temperature gradients increase across the cross section of the core to the peripheral layers, and, consequently, temperature stresses. As for mechanical deformations, they decrease towards the center of the core, and consequently, the turning moments that arise. The change in the gradients listed above is the driving factor of translational-rotational vortices that arise at the structural levels of the deformable materials of the contact spots of the microprotrusions of the metal friction element.

If the current strength is small and the magnetic field created by it is less than H_d, (minimum intensity) Abrikosov vortices do not arise. When the transport current field exceeds this boundary, vortices are born near the surface and migrate deeper (Fig. 6).

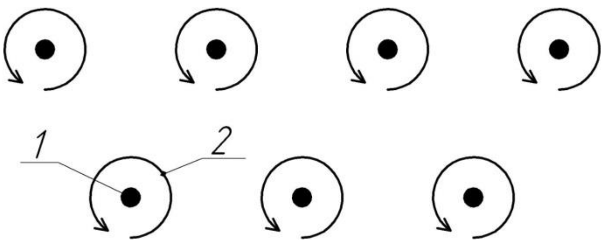

Figure 6 – Formation of magnetic vortices: 1 – core; 2 – vortex

If electrons are scattered by vortices normal behind the nuclear cross sections, the sample acquires electrical resistance. To prevent this from happening, the vortices must be stopped, i.e. pin, clinging them to specially created inhomogeneities of the crystal lattice. Thanks to this, through type II supercon-ductors (wear products between micro-protrusions), it is possible to pass currents whose density reaches hundreds of amperes per 1 cm^2. The rotating rims of the pulley and drum are the core of the solenoid, which is surrounded by magnetic ring lines [8]. Vortexes in a type II superconductor can be represented as “virtual” solenoids formed by superconducting circular currents, the axis of which is parallel to the external magnetic field. Outside the vortices, the magnetic field is zero [6].

The density of vortices increases as the magnetic field increases. If it only slightly exceeds Hc1, the vortices line up far from each other and almost do not interact with each other. As the field increases, the currents of neighboring vortices overlap, and repulsive forces arise between the vortices. Because of this, the vortices form something like a crystal lattice, which in homogeneous superconductors consists of triangular cells. As the field increases, the cells contract, and upon reaching Hc2, the normal cores of neighboring vortices merge with each other. Bulk superconductivity is destroyed, and the external magnetic field completely penetrates into the sample. Thus, Abrikosov’s theory explained the experimental results of the Kharkov physicists. And the mixed state of a type II superconductor is often called the Shubnikov phase.

The discussion of the results

The results of theoretical and experimental studies of the state of superconductivity at low and high temperatures of metal friction elements of brake devices made it possible to establish the following:

- the exciting factor for particles of various kinds in metal friction elements is the pulsed normal forces acting in the interface of friction pairs;
- conduction electrons in a metal at a low ambient temperature and its thermally stabilized state are capable of forming pairs

that unite particles with equal and oppositely directed impulses. For this to happen, there must be an attraction between the electrons;

- behavior and connections of pairs of electrons and the interaction of their energy levels with the nodes of the crystal lattice of the metal friction element;

- the presence of positive ions in the crystal lattice ensures that a moving electron attracts nearby ions, they shift towards it and create a local excess of positive charge. A locally polarized region attracts another electron, which moves towards the first;

- elastic vibrations of the crystal lattice are the movement of phonons - quanta of sound waves. In this case, electrons are attracted, emitting and absorbing phonons;

- between electrons and vibrations of the crystal lattice, there is a direct attraction of electrons by the lattice, which prevails over the Coulomb collision;

- the emergence of mechanical and magnetic vortices, when the transport current field exceeds the minimum limit of its intensity, magnetic vortices are born near the surface and migrate deep into the metal friction element.

Conclusions

Thus, an assessment of the state of superconductivity of metal friction elements of brake devices is given.

Conflict of Interests

The authors declare there is no conflict of interests related to the publication of this article.

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