Increasing the Wear Resistance of Materials in Friction Vapors of Top-Mose Devices Taking into Account Hydrogen Wear

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Abstract

In the article, the value of external and internal hydrogen in the contact zones of microprotrusions of brake friction pairs is highlighted. The interaction of external hydrogen with internal hydrogen located in the subsurface layer of the metal friction element is illustrated. In friction pairs with electrothermomechanical frictional interaction, the source of hydrogen is the surface layer of the polymer lining during the cracking process. In the study of hydrogen wear, the following were considered: adhesion, adsorption, diffusion in electric and thermal fields, as well as an assessment of the stress-strain state of brake friction pairs. A method for industrial research of friction pairs of band-shoe brakes of drawworks is described, which prevents the release of hydrogen from the steel surface of the pulley rim by an electric field with the same charges, which restrict the movement of hydrogen ions.

Keywords: band-shoe brake, improved friction pairs, materials of friction elements, hydrogen wear, wear resistance of materials, operational parameters, energy levels.

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Hidrogen yeyilməsi nəzərə alınmaqla, əyləc qurğularının sürtünmə cütündə materialların yeyilməyə davamlılığının artırılması

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Xülasə

Məqalədə, əyləclərin sürtünmə cütlərinin mikroçıxıntılarının kontakt zonalarında xarici və daxili hidrogenin əhəmiyyəti qeyd olunub. Metal sürtünmə elementinin səthaltı təbəqəsində olan xarici hidrogenlə daxili hidrogenin qarşılıqlı əlaqəsi qeyd olunur. Elektrotermomexaniki friksion qarşılıqlı təsir zamanı sürtünmə cütlərində hidrogen mənbəyi krekinq prosesi zamanı polimer kündənin səth təbəqəsidir. Hidrogen yeyilməsinin tədqiqi zamanı elektrik və istilik sahələrində diffuziya, adgeziya, adsorbsiya nəzərə alınmaqla, həmçinin əyləcin sürtünmə cütlərinin gərginlik-deformasiya vəziyyətinin qiymətləndirilməsi aparılıb. Qasnağın polad səthindən ayrılmış hidrogen, eyni yüklərə malik elektrik sahəsi ilə hidrogen ionlarının hərəkətini məhdudlaşdırır. Qazıma bucurqadının lentli-kündəli əyləclərinin sürtünmə cütünün sənaye tədqiqat üsulu təsvir edilib.

Açar sözlər: lentli-kündəli əyləc, qabaqcıl sürtünmə cütü, sürtünmə elementləri materialları, hidrogen yeyilməsi, materialların yeyilməyə dayanıqlığı, istismar parametrləri, enerji səviyyələri.

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Повышение износостойкости материалов в парах трения тормозных устройств с учетом водородного износа

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Аннотация

В статье отмечено значение внешнего и внутреннего водорода в зонах контакта микровыступов пар трения тормозов. Проиллюстрировано взаимодействие внешнего водорода с внутренним водородом, находящимся в подповерхностном слое металлического фрикционного элемента. В парах трения при электротермомеханическом фрикционном взаимодействии источником водорода является поверхностный слой полимерной накладки при крекинг-процессе. При исследовании водородного изнашивания рассмотрены: адгезия, адсорбция, диффузия в электрическом и тепловом полях, а также произведена оценка напряженно-деформируемого состояния пар трения тормоза. Описан метод промышленных исследований пар трения ленточно-колодочных тормозов буровых лебедок, предотвращающий выделение водорода из стальной поверхности обода шкива электрическим полем с одноименными зарядами, которые ограничивают движение ионов водорода.

Ключевые слова: ленточно-колодочный тормоз, усовершенствованные пары трения, материалы фрикционных элементов, водородный износ, износостойкость материалов, эксплуатационные параметры, энергетические уровни.

Introduction

Hydrogen wear as one of the processes of destruction of the surfaces of metal friction elements under conditions of electro-thermomechanical friction is caused by the decomposition of hydrocarbon steels with the release of hydrogen, which diffuses into the surface layer of steel, causing their embrittlement. In particular, it was found that the size of the wear products after the hydrogenation of the samples is significantly larger than before (the linear dimensions differ by a factor of 5–6) [1–4].

In addition, those that are detached under rol ling and sliding friction have significant seizure and damage sites, rather than spalling from non-hydrogenated samples. However, the literature does not describe their effect on electrothermomechanical friction and wear of friction pairs.

Analysis of literary sources and the state of the problem

In works [1–3] physical and mechanical processes on the friction surface of hydrogen wear of parts of machinery and equipment are investigated.

The reasons for the release of hydrogen, hydrogenation of rubbing surfaces and their destruction have been established. A complex picture of the behavior of hydrogen in the surface layers in the process of friction under the influence of various factors is shown, and the influence of "biographical" hydrogen on the wear of parts is determined.

The reasons for the transfer during friction of a harder material to a soft material: steel to bronze, cast iron - to plastic are stated [5]. Practical recommendations are given for suppressing hydrogen wear and increasing the durability and reliability of machine and equipment parts. In this case, the following was not considered: the effect of external hydrogen on the surface layer of the metal friction element and its entry into the subsurface layer by injection; the phenomenon of adhesion and the types of contacts of friction pairs during their frictional interaction was not taken into account, as well as the combination of adsorption - diffusion phenomena observed in the surface and subsurface layers of friction pairs. And most importantly, there was no approach to external and internal hydrogen and their role in tribochemical reactions.

The discovery of the phenomenon of formation of a hydrogen-saturated zone in the subsurface metal layer during friction is proposed, which consists in the fact that when it is rubbed against a water-containing material or metal in a water-containing medium, hydrogen is released and localized in the subsurface metal layer, due to tribochemical processes and temperature gradients, leading to the dispersion of the surface, and when the metal is supersaturated with hydrogen - to its liquefaction and subsequent transfer to a less durable counterbody (the phenomenon of "hydrogen wear of metals") [6].

However, the hydrogen phenomenon is not extended to friction pairs "metal-polymer" and does not take into account cracking – a process in the surface layers of the lining.

In [7, 8] tribocracking of contact spots of microprotrusions of metal-polymer friction pairs was investigated, their energy loading was estimated taking into account the redox processes occurring on the working surfaces.

The regularities of changes in the dynamic coefficient of friction are established depending on the energy loading of metal-polymer friction pairs exposed to electric, thermal and chemical fields. It is shown that tribocracking is of a complex tribochemical nature with burnout from the surface layer of a polymer lining of formaldehyde resin. This process is accompanied by the release of water, hydrogen, oxygen and other gas mixtures.

In studies [8] it was shown that during the cracking process of the surface layer of the lining (material FK-24A) in the surface temperature range of 300-730° C, hydrogen was released from 17.1% and was a significant addition to the internal hydrogen in the metal.

Formulation of the problem

The main issues of the article: design, operation and energy loading of friction pairs of brake devices, hydrogen wear of working surfaces of frictional units of brakes during electrothermomechanical friction; methods and means of protecting friction pairs of brake devices from hydrogen wear.

The purpose of this work is to study the effect of hydrogen on wear in friction units of brake devices used in mechanical engineering, as well as to reduce hydrogen wear in the friction interaction zone with open friction pairs, while creating the main and residual positive electric fields between their working surfaces.

Design, operation and energy loading of friction pairs of braking devices

In fig. 1 *a, b* shows the friction pairs of a disc-shoe brake. Friction pairs consist of friction linings 2, which are located on stationary brake pads. With the frictional interaction of the working surfaces of the linings 2 with the rotating brake disc 1 under the action of the normal clamping force N, a friction treadmill 3 is formed.

In fig. 1 *c* illustrates the friction assembly of a drawworks band brake. When tightening the brake band 4 under the action of a normal clamping force N, the working surface of the friction pad 2 interacts with the friction track of the pulley rim 5.

The latter is connected to the drum flange with the rope by means of the fastening protrusion 8. Thus, the frictional interaction of the friction pairs of the band-shoe brake is realized [9].

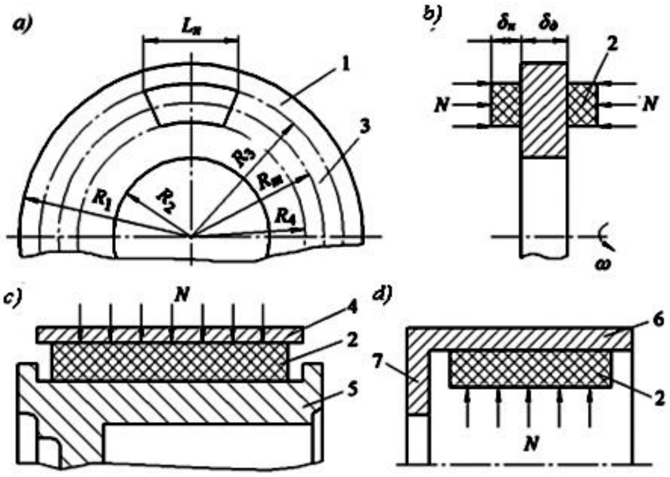

Figure 1 a, b, c, d – Diagrams of various types of frictional units of braking devices: a, b - disc-shoe (longitudinal and transverse section); c - tape-shoe (cross section); d - drum-shoe (cross section)

The frictional unit of the car drum-shoe brake is shown in fig. 1 *c*. The unit contains a rim of a brake drum 6 with a flange 7, as well as friction linings 2 located on the brake pads.

When expanding the latter in their toe and heel parts, the working surfaces of the linings 2 frictionally interact with the inner (working) surface of the brake drum 6 rim.

According to the molecular-mechanical model of electrothermomechanical friction, the interaction of the surface irregularities of bodies can be represented in the form of viscous sliding of the actual contact areas (adhesive component), deformation of irregularities (deformation component), etc. causing them to be stressed.

Therefore, heat generation during friction is due, on the one hand, to the destruction of adhesive bonds in the actual contact zones, and, on the other hand, to the stress-strain state of roughness irregularities.

The stress-strain state of microprotrusions of friction pairs with different types of contacts (ohmic, neutral, blocking) leads to volumetric heat release in the surface and subsurface layers of frictionally interacting materials.

In this case, the power of the latter makes up a significant part of the total (taking into account the adhesive component) power of heat release and, accordingly, significantly affects the fields of surface and bulk temperatures, mechanical-thermal stresses and their gradients.

Let us assume that the distribution p1 and p2 of the volumetric power density of heat release in the contacting microprotrusions of the metal-polymer friction pairs obey the exponential law (fig. 2).

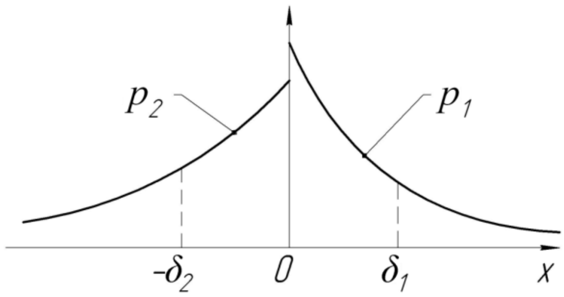

Figure 2 – Regularities of changes in the distribution (p1, p2) of the volumetric power density of heat release in the "metal - polymer" friction pair

$$p_1(x,t) = \frac{\alpha_1}{\delta_1} e^{-\frac{x}{\delta_1}} q(t),\ x > 0; \qquad (1)$$

$$p_2(x,t) = \frac{1-\alpha_1}{\delta_2} e^{x/\delta_2} q(t),\ x < 0, \qquad (2)$$

where α_1 is the coefficient of distribution of the heat flux (q) into the metal friction element; δ_1 and δ_2 are the thickness of the surface layers of heat release.

At each moment of time t > 0, distributions (2) satisfy the heat balance law

$$\int_0^{+\infty} p_1(x,t)dx + \int_{-\infty}^{0} p_2(x,t)dx \equiv q(t) \qquad (3)$$

For a complete analytical description of convective and radiative heat transfer of the surfaces of metal friction elements of brakes, it is necessary to specify systems of equations and unambiguity conditions.

Listed in table 1, four boundary conditions (classical) constitute the uniqueness conditions, and the set of initial and boundary conditions is called boundary conditions. It should be noted that thermoelectric power. etc. with. is only one (first) component of the total integral emf, which also includes: caused by the entrainment of carriers of electric charges by waves of mechanical and temperature stresses (the so-called acousto-electric effect),

Table 1 – Classic list of boundary conditions

Kind of boundary condition		Dependencies
	I-st	The body surface temperature (t_p) is known
	II-nd	The intensity of the heat flux from the outside into the body is given (q_v) $$-\lambda \frac{\partial t_p}{\partial x}\Big|_{x=+0} = q_v. \quad (4)$$
	III - rd	The heat flux coming from the washing medium is directly proportional to the temperature difference between the medium and the body surface $$-\lambda \frac{\partial t_p}{\partial x}\Big|_{x=+0} = \alpha\left(t_p - t_{x=+0}\right). \quad (5)$$
	IV-th	The body is in contact with another body that has different thermophysical characteristics $$t_{p1}\Big|_{x=+0} = t_{p2}\Big|_{x=-0}. \quad (6)$$

Legend: λ, α - coefficients: thermal conductivity, heat transfer; q_v - specific heat flux; indices x = + 0 and x = -0 - external and internal surfaces; $\partial t_p / \partial x$ is the temperature gradient over the thickness of the body; t_p - heating temperature.

the interaction of metals of the friction pair in the presence of an electrically conductive electrolytic liquid (e.d. of a galvanic microelement) and e. etc., arising from the interaction of a friction pair in an electromagnetic field or when at least one of its elements is in a magnetized state.

The value and direction of the integral e. etc. with depends on the physical and mechanical properties of the metals of the friction pair, on the speed and load modes of friction, on the state of the rubbing surfaces and many other factors that cause significant fluctuations and even the inversion of this parameter.

Moreover, pulsed high-frequency mechanical vibrations in the friction zone are inseparable from thermoelectric relaxation processes, and both of these factors always jointly affect the scatter of the experimental values of wear resistance of parts of friction pairs of brakes.

The effect of the thermal current on the wear resistance of parts is associated with the peculiarities of the course of relaxation, oxidative, diffusion and other processes affecting each other.

Suffice it to note that oxide films on the surface of contacting metals have semiconducting properties and high resistivity and can play the role of amplifiers of thermoelectric effects, which can cause the appearance of rather significant eddy currents in the places of the closest approach of the contact points and due to the low thermal conductivity of the oxides, promote localized heat release. The conductivity of the contact also depends on the combination of materials of the friction pair (for example, copper-copper, steel-copper, etc.) and the state of the rubbing surfaces.

In the study of the conductivity of the contact, its hysteresis is noted: if with increasing pressure the electrical conductivity of the contact increases relatively quickly, then with a smooth load shedding it decreases much more slowly and does not coincide with the initial values. In addition, when unloading pairs of contaminated surfaces that have boundary la-yers of products of cracking processes occurring in the surface layers of the polymer lining, the conductivity hysteresis curves show not a monotonic decrease in the contact conductivity, but a paradoxical "swelling" of the curves, the reason for which remains unclear. One of the energy parameters of the friction units of the drawworks band-shoe brake is the dynamic coefficient of friction for FK-24A materials - steel 35HNL (fig.3).

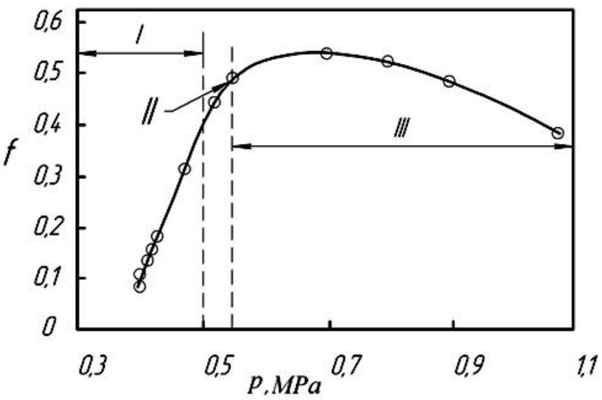

Figure 3 – Regularities of change in the dynamic coefficient of friction from the pulsed specific load:
1 - area of weak wear, II - transition area, III - area of intense wear

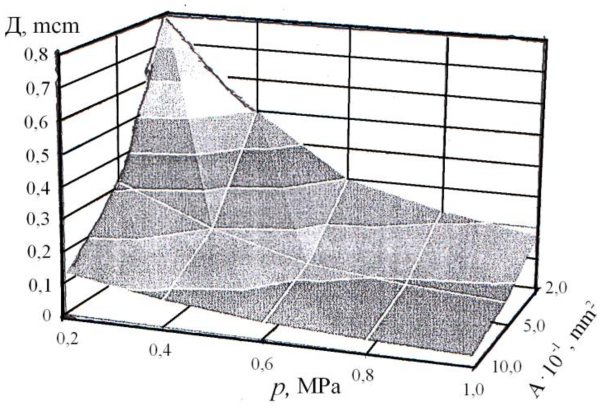

Figure 4 – Regularities of changes in deformations of microprotrusions of friction pairs of a tape-shoe brake of a drawworks from impulse specific loads at different areas of the surfaces of their contacting spots

From the latter, it follows that with an increase in impulse specific loads, a drop in the dynamic coefficient of friction of the frictional unit of the brake is observed.

According to fig. 4, with an increase in the area of contact spots of micro-protrusions of friction pairs at low impulse specific loads, a noticeable increase in deformations of micro-protrusions of the friction pairs of a drawworks brake was observed. Of particular interest is the study and application of the theory of highly excited states in crystals of a metallic friction element of plasticity and strength of its surface and subsurface layers. In this case, plastic deformation (stresses) should be considered in compliance with the laws of behavior of inhomogeneous, strongly nonequilibrium systems undergoing local structural transformations and following to equilibrium by the movement of the constituent new structures over the crystal under the action of gradient stresses. In this case, the deformed crystal is capable of carrying out plastic flow in local volumes, which proceeds as a dissipative process, due to the relay-race rearrangement between two adjacent structures.

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

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

Shear information, which is anisotropic, is always accompanied by material rotation within the structural element of deformation (block grains, cells of the dislocation structure, etc.). In this case, the material rotation, in contrast to the crystallographic one, does not affect the spatial orientation of the crystal lattice [10]. This, in turn, on the side of the surrounding material at the boundary of the structural element of the deformation causes a turning moment. 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 deformation modes form a field of turning moments and provide inside the structural element of deformation the exit of dislocations from their slip planes, which causes misorientation of the cellular dislocation substructure with the successive involvement of multiple slip of contact spots of microprotrusions as a vortex of material rotations of crystallographic shears on a cylindrical surface.

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

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

The hypothesis of a translational-rotational vortex as applied to the structural levels of deformable materials of contact spots of microprotrusions is associated with the energy levels of its core itself, in which the temperature gradients increase along the core section towards the peripheral layers, and, consequently, the temperature stresses. As for the mechanical deformations, they decrease towards the center of the nucleus, and, consequently, the arising turning moments. The change in the above gradients is the driving factor of the 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.

There are a number of features of the interaction of hydrogen with steel, associated with the nature of the external influence and the two forms of the element of the ingress of hydrogen into the surface layer of the metal friction element.

The first diffusion-active form - hydrogen in the form of an ion is dissolved in the crystal lattice of the metal, and the second - hydrogen in the form of an ion is in a molecular state in crystal lattice defects.

The diffusion-active form, upon dissolution, reaches an equilibrium concentration value for the given temperature and voltage gradients, electric and thermal fields. This shape is reversible and does not affect the brittleness of the steel.

The molecular form has an embrittling effect on steel and some other metals. The transition from the dissolved form to the molecular form depends on the defectiveness of the steel, temperature and, especially strongly, on the stress-strain state.

The concentration of the molecular form depends on the defectiveness of the metal and can reach a threshold concentration that causes destruction.

Depending on the effect of specific loads in the friction pair, a particular relationship arises between the two forms of the state of hydrogen: in the first case, under corrosive action, there is a gradual, irreversible transition of hydrogen dissolved in equilibrium concentration into a segregated (molecular) form; in the second case, when there is a mechanical effect on the friction pair, hydrogen under the action of a stress gradient in the metal is concentrated in the zone of maximum stresses, where it transforms into a molecular form and causes destruction; in the third case, when there is friction and temperature and stress gradients, electric and thermal fields appear on the surface, a super-equilibrium concentration of hydrogen is formed in the surface layer, released (during friction) from the adsorbed water and the working surface of the polymer pad.

Hydrogen wear of working surfaces of frictional units of brakes during electrothermomechanical friction

Hydrogen wear arises as a result of cooperative (synergistic) interaction of surface processes, phenomena and effects: exoemission, adhesion, adsorption and tribodestruction, which lead to the release of hydrogen. The source for hydrogen is moist air, which washes the friction pairs of the brakes when vehicles are moving, and water gets on the working surfaces of their friction units.

The amount of external hydrogen increases due to the cracking process of the surface layer of the polymer liner.

Together with non-equilibrium processes occurring during deformation, which has the character of translational-rotational vortices of contact spots of microprotrusions of a metal friction element.

On the surface layer of the metal, temperature gradients, electric and stress-strain fields appear. This leads to the diffusion of hydrogen into the metal, its concentration in the subsurface layer and accelerated wear or destruction of this layer.

During friction, exoelectron emission arises on the surface, supplying electrons capable of solvating on water molecules and decomposing them into oxygen and hydrogen.

Hydrogen evolution is possible as a result of secondary reactions of tribodegradation of hydrocarbons (for example, the surface la-yer of a polymer patch). Inside the surface layer, a hydrogen injection system is formed to a superequilibrium concentration due to a gradient of hydrogen pressure on the surface and in the vortex core.

The mass formation of defects distributed unevenly in the deformed layer also contributes to an increase in the concentration of hydrogen, its molization, followed by destruction of the metal. The stages of hydrogen wear and the effect of hydrogen on the friction process are given in table 2.

Table 2 – Stages of hydrogen wear of the working surfaces of brake friction pairs during electrothermomechanical friction

Stages	Processes, phenomena and effects arising from action	
	impulse specific loads in brake friction pairs	and their consequences
1	Intensive release of hydrogen in the friction zone from moisture and polymer material of the rubbing pair	tribochemical reactions are intensified
2	Desorption of water from the surface of the metal rim	the temperature of the friction surface rises
3	Hydrogen adsorption by the working surface of the metal rim	the introduction of external hydrogen is intensified
4	Diffusion of hydrogen into the surface layers of the metal rim, its intensity is determined by the gradients of temperatures and equivalent stresses	temperature gradients and mechanical-temperature stresses increase
5	Hydrogen concentration in the subsurface layer in the zone of its maximum temperature	temperature gradients appear in the near-surface layer
6	A. Low-temperature brittle fracture of the surface layer of a metal friction element saturated with hydrogen as a result of the formation of a large number of microcracks in the contact zone	equivalent stresses increase, hydrogen molization occurs;
	B. Burnout of binding components from the surface and subsurface layers of the polymer lining	electrolyte islands appear
	C. High-temperature viscous destruction of a rubbing metal layer in the form of spreading it on a counterbody as a result of liquefaction	At surface temperatures of about 800…1000º C, the metal friction surface is supersaturated with hydrogen

There are several types of hydrogen embrittlement: the first and second kind. The first kind of embrittlement is due to the sources contained in the parent metal, due to the increased content of internal hydrogen. Embrittlement of the second kind is caused by sources that accumulate external hydrogen in the surface layer of the metal. It was found that the first kind of embrittlement is reversible and intensifies with an increase in the deformation rate. Embrittlement of the second kind occurs at low strain rates and can be both reversible and irreversible.

The theory of hydrogen embrittlement can be divided into four groups.

1. Adsorption hypotheses explaining the decrease in the breaking stress due to the decrease in the surface energy inside the cracks during the adsorption of hydrogen (hydrogen acts as a surfactant).

2. Diffusion hypotheses: anomalous diffusion occurs on the working surfaces of the metal-polymer friction pair - a class of phenomena in which the mean square of displacements is not a linear function of time, but is described by a power law. Such diffusion can be of two types - superdiffusion (accelerated walk) and subdiffusion (slow walk). A computer model of diffusion-limited aggregation is a field filled with particles in chaotic Brownian motion. The center of aggregation is introduced into the field, to which any accidentally touched particle "sticks"; the growth of a conglomerate of

particles - a fractal cluster - begins. Often only one propelling particle is used in simulations.

3. The theory of molecular hydrogen pressure, according to which embrittlement is the result of the pressure gradient of molecular hydrogen in macro- and microvoids, as well as in cracks inside the metal. The pressure arises from the molization of atomic hydrogen.

4. The theory of interaction of internal hydrogen with the crystal lattice of the metal; hydrogen is a type of defect that lowers the strength of a cohesive metallic bond.

5. Theories based on the interaction of hydrogen with dislocations; hydrogen produces a blocking effect on dislocations, contributing to the formation of blocking contacts in friction pairs.

Methods of protecting friction pairs of brake devices from hydrogen wear

Let us consider the design features and operation of the improved friction pairs of the tape-shoe brake of the drawworks (fig. 5 *a*, *b*). Friction linings 3 were installed on brake bands 2, attaching one end (from the running down strand of the strap) to the balancer 11, and the other (from the incoming strand) to the cracxbcv nk journals 6 and 9 of the crankshaft 10. Serial band-shoe brakes of a drawworks work as follows: by moving the handle, the crankshaft turns, as a result of which the driller tightens the brake bands 2 with friction linings 3 and they sit on the rims of the brake pulleys 4. The brake pulley 4 has longitudinal grooves 12 of the "dovetail" type, in which additional friction elements 13 made of retinax FK-24A are installed along the perimeter of the rim from its free edge with a constant pitch.

Along their length, there are 14 fluoroplastic-4 tablets. The friction elements are se-parated from the pulley rim 4 and the tablets by thermal insulation 15. In this case, the right flange 9 is removable and is attached along the perimeter of the pulley rim end with 4 bolts 1. Friction linings 3 are attached to the brake band 2 using tendrils 18.

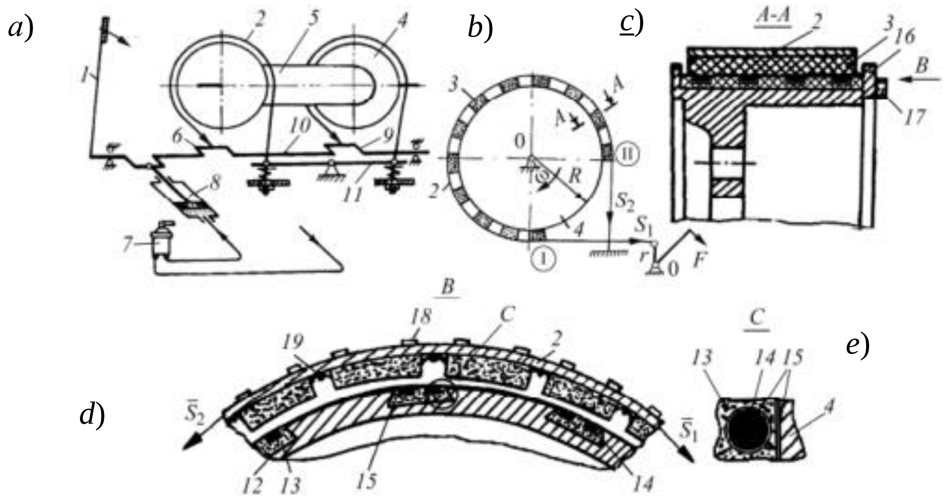

Figure 5 a, b, c, d, e – Kinematic diagrams of a tape-block brake of a drawworks winch (a, b); cross-section and longitudinal section of the brake friction assembly (c, d); thermal insulation of the friction element, tablets – inserts (e): 1 - brake control lever; 2, 3 - brake bands with linings; 4, 16 - brake pulley with removable flange; 5 - winch drum; 6, 9, 10 - crank journals of the crankshaft; 7, 8 - pneumatic cylinder valve; 11 - balancer; 12 - dovetail longitudinal grooves; 13 - additional friction elements with FK-24A material; 14 - tablets - fluoroplastic inserts - 4; 15 - thermal insulation; 17 - mounting bolts; 18, 19 - fastening and spacer strips

Between the linings along the perimeter of the brake band 12 are installed spacer bars 19. Here used the following designations: *R* - radius of the working surface of the brake pulley; *r* is the radius of the crank of the crankshaft; ω - angular speed of rotation of the pulley; $\overline{S}_1$ and $\overline{S}_2$ - tension of the incoming and outgoing branches of the brake band; *F* - working force on the brake control lever; q^+ and q^- are positive and negative charges of the electric field.

With the frictional interaction of the microprotrusions of the friction pairs of the band-shoe brake in the mode of high sliding speeds and specific loads, electric currents are generated and thermal ones accumulate, and, consequently, surface temperatures and their gradients increase.

At temperatures above 400° C, the binder component, formaldehyde resin, burns out from the surface layers of the friction lining, as a result of which a corrosive water-containing environment arises, creating conditions for tribocracking, accompanied by the release of free hydrogen. The latter, interacting with the surface and subsurface layers of materials (silicon, gray, white phosphorus, titanium, iron, etc.) of friction pairs, forms unstable hydrides. In addition, the surface layers of microprotrusions undergo electron-ion thermal polarization, at which a sharp jump in temperature is observed.

Gradient across the thickness of the surface layer. As a result, the hydrogen wear of the surface layers of the friction materials of the friction pairs of the band-shoe brake of the drawworks is significantly increased, which is due to the active release of hydrogen from the polymer lining in the friction zone due to tribocracking, which ensures its continuous flow into the surface layer of the steel rim of the pulley; its adsorption on the surfaces of metal-polymer friction pairs; diffusion into the deformed surface layer of the pulley rim, depending on the stress gradients; a special type of surface destruction due to the simultaneous development of a large number of microcrack nuclei throughout the contact zone.

The property of FK-24A polymeric materials and fluoroplastic-4 tablets-inserts in FK-24A material to "select" a charge is probably related to the ability to attach ions and electrons to their surfaces, saturating the double electric surface layers of the polymer. After the frictional interaction of friction pairs FK-24A and FK-24A - a tablet-insert made of phtroplast-4, the first material will be positively charged and play the role of an electron donor due to the higher dielectric constant compared to the second, which is negatively charged and plays the role of an electron acceptor.

A completely different picture is when the binder components burn out from the surface layers of these materials, from which water with a high dielectric constant is released. In this case, the friction elements FK-24A with tablets-inserts made of fluoroplastic-4, due to the lower allowable temperature for their components, become electron donors, saturating the double electric surface layer of the brake pulley rim, and therefore, increasing the potential difference between its sections steel 35HNL-FK-24A with tablets-inserts. Surface temperature gradients significantly exceed the depth gradients in the near-surface layer of the pulley rim.

In addition, the lines of a positive electric field will block hydrogen ions (H^+), preventing them from penetrating into the subsurface layer.

A similar situation is in the surface and near-surface layers of the FK-24A friction material, the permissible temperature of the components of which is higher. Here, the FK-24A material becomes an electron donor for the components, saturating the double electric layers (liquid (one layer) and the surface layer of the pad (the second)), between which a potential difference arises, as a result of which the positive electric field of the surface layers of the pads on the brake band is enhanced.

The energy levels formed on the working surfaces of the improved friction pairs of the brake are due to the contact electrothermomechanical process from the collision of microprotrusions of metal-polymer pairs of the tribosystem.

As a result of plastic deformation at the contact points, electric currents are generated as long as their discreteness remains and the actual contact area is small compared to the nominal one ($A_r \le A_0$).

Thus, as a result of the summation of the components of the generated currents, an electric field arises at the spots of the friction contact, and at $A_r \ge A_0$, an unsteady heat flux is subsequently accumulated, causing an uneven temperature field.

During friction between the polymer and the metal (Fig. 6), in contrast to the breaking of the contact between metals or their friction, the surface charging occurs gradually when the contact spots of the microprotrusions are worn out as a result of the increase and rupture of contacts between the "charging spots"; while accumulating charge.

When the microprotrusions of the metal-polymer tribo-conjugation interact, when the work function (W) of electrons and ions from the metal and polymer will be equal, the surface may not be charged.

Then the polymer is called electrophobic, in contrast to electrophilic, which is electrified at $W_M > W_P$ and $W_M < W_P$. A thin layer of moisture forms on the surface of electrophilic materials (when their binders burn out from the surface layers of tablets-inserts, as well as polymer elements and linings), which facilitates charging.

When two polymer films of materials (P_1) + (P_2) come into contact (fig. 7) without friction, a charge density appears on their surface

$$\sigma_S = \frac{e\left(W_{p_1} - W_{p_2}\right)}{1/\rho_{s_1} + 1/\rho_{s_2}},$$

where Wp_1, Wp_2 are the Fermi levels of the surfaces of the first and second polymer pads; $\rho_{s|}$ and ρ_{s2} are the densities of surface states of polymer linings and friction elements with insert tablets.

If $W_{p1} > W_{p2}$, then the first pad will be charged positively, if $W_{p1} < W_{p2}$ then negatively.

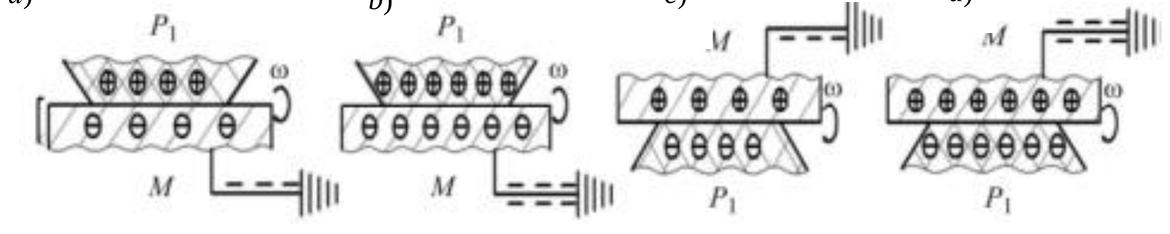

Figure 6 *a, b, c, d* – Accumulation of electric charges in friction pairs polymer (P_1) - metal (M) (a, b) (straight) and metal (M) - polymer (P_1) (c, d) (reverse) during their frictional interaction

A number of polymers arranged in such a way that each subsequent one is charged negatively with respect to the previous one upon contact with it is called triboelectric. The position of the polymer in the tribological series characterizes its tendency to be charged with positive or negative charges.

When the contact is instantaneously broken between two spots of microprotrusions with charges + q and – q, a large potential difference arises. The physical and mechanical properties of the materials of the friction pairs of brake devices are shown in table 3. The hydrides SiH_4, PH_3 and H_2S indicate the number of hydrogen atoms per element atom in their molecule. Starting with silicon, the formation of molecular compounds indicates that the elements take on the electronic configuration of the subsequent inert gas (argon, which is the last element of the third period of the periodic table), forming generalized electron pairs with hydrogen atoms.

Based on the results of studying the influence of the mechanism of electronic and ionic thermal polarization during electrothermomechanical friction on the transfer processes in metal-polymer metal-polymer vapors, it is possible to explain the hydrogenation of the metal, which causes embrittlement and dispersion of the layer deformed by friction.

Hydrogen is released upon activation by electrothermomechanical friction of the hydrocarbon dehydrogenation reaction of the surface layer of the polymer pad. Its suppliers are products of thermal destruction of an organic binder (for example, various resins), as well as moisture that gets on the working surface of a metal friction element in a tribological system. The diffusion flow of hydrogen formed on the working surface of the steel friction element is directed to the zone with the maximum local temperature located at a certain depth from the friction surface (displacement of the zone with the maximum temperature), where it dissolves. Thus, the hydrogen absorbed by the metal is capable of dissociating, and it is the uniquely small size of the proton (1 · 10-13 cm) and its opposite charge with respect to the metal that help it to penetrate into the lattice quite easily.

The improved friction couples were tested in band-shoe brakes of U2-5-5 drawworks with natural and forced cooling during lowering of the drill string into the well to a depth of 4108,0 m.

The column was recruited from 102 candles, of which six drill collars (heavy drill coars), and the rest - LBT (light) with a total weight of 962,23 kN. In this case, the ambient temperature is 20,2 °C, and the pressure is 0,0942 MPa.

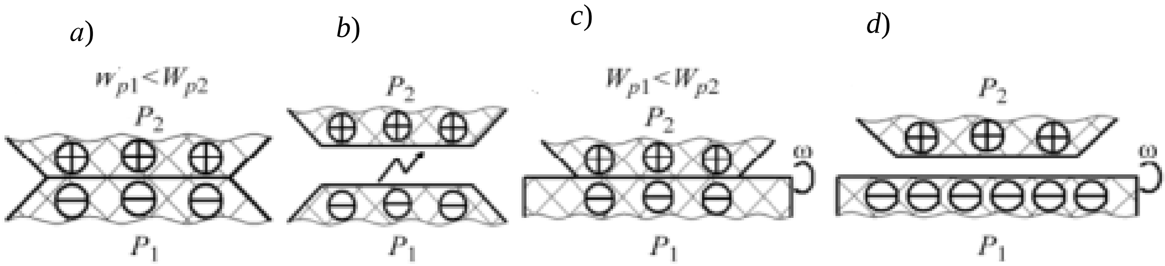

Figure 7 *a, b, c, d* – Accumulation of electric charges in friction pairs polymer (P_1) - polymer (P_2) at static (*a*), frictional (*c*) interaction and open state (*b*, *d*)

Table 3 – Characteristics of brake pulley steels

Steel content, mass%		Valence		The predominant type of own conductivity		Hydrides
35KhNL (I)	35KhNL (II)	I	II	I	II	
2,20…0,42 Si	0,2…0,4 Si	4		Semiconductor		SiH_4
Up to 0,3 Cu	-	1, 2	-	*n*	-	-
0,4…0,9Mn	0,4…0,9Mn	2, 3, 4, 5, 6, 7		*n*		-
0,7…0,9 Ni	-	2	-	*n*	-	-
Up to 0,04 P	Up to 0,04 P	3		*n*		PH_3
0,5…0,8 Cr	0,8…1,1 Cr	3, 6		*p*		-
Up to 0,04 S	Up to 0,04 S	2, 4, 6		Dielectric		H_2S
-	0,3…0,4 C	-	2,4	-	Dielectric	-
-	0,2…0,3 Mo	-	6	-	*p*	-
36,62…97,82 Fe	97,82…98,02 Fe	1, 3		*n*		FeH, FeH_3

It was found (table 4) that while maintaining a number of basic technical characteristics of the analogue, the proposed friction pairs reduce the energy intensity of wear of the linings by 1.3 times under the given loading conditions, which affect the potential difference between the microprotrusions (table 5).

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The FK-24A-FK-24A + fluoroplast-4 friction pair has the greatest potential difference, since the area share of the tablets-inserts in the FK-24A friction element is only 14%.

In addition, they practically do not affect the dielectric constant of the material of the friction element, which contributes to the generation of positive charges in this friction pair and, as a consequence, the appearance of a positive electric floor, which prevents the adsorption of hydrogen ions into the near-surface layers of friction pairs in their closed and open states.

This circumstance plays a decisive role in reducing the hydrogen wear of the brake friction pairs.

Table 4 – Tribo-electric and operational parameters of an improved band-brake brake of a U2-5-5 drawworks

Friction pair	Charge sign		Performance parameters					
	+	-	strength friction $F_f=(S_1-S_2)$, кH	dynamic friction coefficien, f	temperature gradients Super-ficial t, °C/mm	temperature gradients bulk t_v, °C/mm	Braking moment M_f, кNm	Energy intensity of wear lining I, mg/J
Two chemically identical elements	Density element							
	Large	Small						
FC-24A-steel 35HNL	Polymer	Metal	259,6	0,38	40,0… 60,0	6,0… 15,0	188,2	2,5
Semiconductors ("n-p-n") - steel 35KhNL	Generated currents	Straight	220,5	0,42	20,0… 30,0	10,0…15,0	195,0	2,30
Semiconductors ("p-n-p") - steel 35KhNL		Back	240,8	0,45	10,0… 20,0	5,0… 10,0	200,5	2,45
The results of experimental studies advanced friction pairs			260,0	0,43	10,0… 35,0	5,0… 13,0	198,0	2,35

***Note:** the surface area of the tablets of the inserts with friction elements is (45 ... 75) ° from the arc of a circle around the tape with the lining of the pulley rim

Table 5 – The potential difference between the microprotrusions of friction pairs flax exactly-block brake drawworks U2-5-5

Friction pairs	FC-24A-steel 35KhNL	Semiconductors	
		("n-p-n")- steel 35KhNL	("p-n-p")- steel 35KhNL
Potential difference ΔV, mV	0,47	0,64	0,55

Depending on the diameter and width of the pulley treadmill rim, the area of tablets-inserts and fluoroplastic-4 embedded in friction elements made of FK-24A polymer material, located along the perimeter of the pulley rim, is set.

In order to "suppress" hydrogen during its formation in the zone of frictional contact when creating new friction materials for vehicles, copper oxide or other additives were introduced into the friction lining, which chemically bonded with hydrogen.

In this case, the wear resistance of the friction material and the associated counterbody increases several times. And, most importantly, one of the main defects of the friction material disappears - the smearing of steel on it.

To protect metals from the effects of hydrogen at elevated temperatures and pressures, the following methods are recommended: introducing strong carbide-forming elements (chromium, molybdenum, vanadium, niobium and titanium) into steel to stabilize the carbide component and prevent steel from decarburization with the formation of methane and a kind of corrosion of steel; cladding or lining of steel with metals having a lower hydrogen permeability (for example, copper, silver, aluminum, steel 08X13, 12X18111OT, etc.).

It should be noted that the phenomena, effects and the complexity of the processes during hydrogen wear of the working surfaces of the metal friction elements of the brakes should be noted.

The structure of their metal, under the influence of hydrogen released during electrothermomechanical friction, turns into a dynamically changing system, which turns into a state of chaos (catastrophically intense wear and emergency destruction) or self-organization, providing long-term, trouble-free operation of tribo-couplings.

Conclusion

Based on the foregoing, the following discovery formula is proposed:

A previously unknown phenomenon of the formation of a hydrogen-saturated zone in the subsurface layer of a metal friction element (rim, disc) of a brake device containing an "internal" hydrogen in its body was established, which consists in the fact that during electrothermomechanical friction in a hydrogen-containing medium there is a release of "external" "Internal" hydrogen in the subsurface layer of a metal friction surface due to its uneven heating caused by tribochemical processes, phenomena and effects, followed by dispersion of "external" hydrogen on the surface of microprotrusions subject to plastic shear deformations with the appearance of a translational-rotational vortex, which promotes injection into the subsurface layer of "external" hydrogen through microdefects and its mixing with "internal" hydrogen due to pressure, temperature and stress gradients, which, when the metal friction surface is saturated with hydrogen, leads to its liquefaction with

The next transfer to a less durable working surface of the polymer pad, i.e. there is a phenomenon of hydrogen wear of metals.

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