Pulse-contact frictional interaction of microprotrusions of friction pairs of brake devices

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Abstract. The article materials disclose contact-impulse frictional interaction of microprotrusions of friction pairs of strip-block brakes, based on the principles of the gradient theory of electric and thermal fields. The effect of “transistor” was applied by selecting friction pairs of the brake to reduce their energy loading, and as a result, wear resistance increase.

1. Introduction

The friction and wear properties of friction pairs of brake devices are determined by the structure and properties of the contacting materials, as well as their operating conditions. Intensive heat generation during the operation of heavy duty friction pairs of brake devices has a significant impact on the types of contacts and their performance due to changes in the chemical composition, mechanical and thermal properties of materials, activation of physical and chemical processes in the surface layers, thermal deformation of friction elements, etc. The combination of these processes, phenomena, and effects often leads to deterioration of performance, the appearance of failures and premature failure of friction pairs of brakes.

Based on the foregoing, the creation of a generalized electromechanical theory of friction and wear of metal-polymer friction pairs of brake devices will allow forecasting, adjustment and purposefully change their internal and external operating parameters in order to increase the efficiency and service life of friction units. At the same time, it is necessary to establish the interrelation of processes, phenomena, and effects occurring at the macro-, micro- and nano-levels during contact-impulse frictional interaction. The main parameters that need to be paid attention to are: electric ion currents in the surface layers of the polymer lining, permissible electric potential gradients and temperature differences in metal-polymer friction pairs.

In the study of the working conditions [1-3] of metal-polymer friction pairs and wear intensity [4, 5] of their working surfaces, the energy levels of the microprotrusions of the friction surfaces were not taken into account when they were in contact. To date, the possibility of the formation of friction pairs of a new generation by modifying polymer materials of linings with semiconductor materials has not been studied.

The work aim is to reduce the energy load of friction pairs of a strip-block brake by forming friction pairs with a transistor effect.
2. Evaluation of the energy level of a single microprotrusion of a metal friction element

The values of the energy levels of the microprotrusions of the contacting friction surface significantly affect their wear and friction properties.

Figure 1 shows the multilayer structure of the microprotrusion of the friction surface of the pulley and its energy levels (Table 1).

![Figure 1. The multilayer structure of the microelevation and its energy levels.](image)

| Electric potential | Temperature gradient |
|--------------------|----------------------|
| $\varphi$          | $v$                  |
| $\varphi + d\varphi$| $v + dv$             |
| $U/2$              | $v' + dv'$           |
|                    | $\theta$             |
|                    | $dT$                 |
|                    | $dT'$                |

Contacting microprotrusion $K$ is represented in the form of a multilayer structure bounded by surface $\varphi$ and $v$ and another surface $\varphi + d\varphi$ and $v + dv$. The electrical and thermal resistance of this layer is $dR$ and $dW$. All layers carry a different current $I$ and their electrical resistances are not equal to each other and are determined by the formula (1):

$$dR = \frac{d\varphi}{I}.$$  \hspace{1cm} (1)

The electrical resistance is non-constant since the values of $n$ and $k$ depend on $v$ differently. Thermal resistances $dW$ are not equal to each other and change from layer to layer. Heat flux causes a temperature gradient on the surfaces of the microprotrusion layers $-\frac{dv}{dn}$. As it passes through the bottom surface of the first layer, a temperature gradient appears in it $-\frac{d(v + dv)}{dn}$. Joule heat released in the first layer of microprotrusion is equal to $\left(\frac{d\varphi}{dR}\right)^2$. Since the heat released in the first layer of the microprotrusion must be equal to the difference between the incoming and outgoing heat in the second layer of the microprotrusion, in the instantaneous steady state with polarization reversal along gradients

$$\frac{dv}{dW} - \frac{dv + d^2v}{dn + d^2n} = \left(\frac{d\varphi}{dR}\right)^2.$$  \hspace{1cm} (2)

Since $d^3W << dW$, and instead of $\left(\frac{dn + d^2W}{dn}\right)^{-1}$ we write $1 - \frac{d^3W}{dn}$, we define

$$\frac{(d\varphi)^2}{dR} = \frac{d^2v - dv}{dn} \frac{d^2W}{dn}.$$  \hspace{1cm} (3)

If $dR = \text{const}$ due to the insignificant thickness of the first layer of the microprotrusion, then $\frac{dW}{dR} = n/k$ and, therefore
Substituting this expression into (3), we obtain
\[
\left(\frac{k}{n}\right)\frac{d^2W}{d\alpha} + d\left(\frac{d\theta}{d\varphi}\right) = d\left(\frac{kd\theta}{nd\varphi}\right) = -d\varphi.
\]  
The first integration between the surfaces \(A_0\) and \(A_1\), the last of which is read by the lower limit with the potential \(\varphi\) and temperature \(v\), leads to the expression:
\[
\frac{k}{n}d\theta = -\varphi.
\]  
Reintegration gives
\[
\int_0^\theta \frac{k}{n}d\theta = \int_0^0 \rho xd\theta = \frac{1}{2} \varphi^2.
\]  
Equation (7) is a general expression for the case when the contact surface is heated by the electric and accumulated thermal currents generated by it, it is an area of contraction. If this area is of sufficient length and the total voltage on the contact \(U\), then potentials \(\pm U/2\) arise on the surfaces of the layer.

Knowledge of the law of temperature potential distribution over the height of the microprotrusion of the working surface of a metal friction element allows selecting the components of the structure of its material and purposefully controlling the energy load of metal-polymer tri-shells, while at the same time reducing the surface temperature stresses.

The application of the gradient theory of solids and at the boundaries of the interfacial layers in the range of surface temperatures below and above the allowable for a polymer lining material will provide a positive gradient of mechanical properties in the surface layers of metal-polymer friction pairs of braking devices. However, the electric potential and temperature gradients, which appear on the contact spots of the microprotrusions of the polymer-metal friction surfaces and over their depth, have a significant effect.

Table 2 shows four cases of contact-impulse interaction of microprotrusions of friction surfaces with different gradients of electric potential and temperature under given boundary conditions. Briefly analyze each of these cases.

In the first case, the asymmetry is observed in separate zones where the distance \(r\) from the contact exceeds the radius \(a_n\) of the contact spot \(A_k\) of the microprotrusion, which has the shape of a circle. It is established that the potential gradient in the area of contraction decreases with increasing distance from the contact patch. At the same time, the total space charge in certain areas of tightness is almost the same as the charges in the immediate vicinity of the contact patch. Consequently, the effect of specific charges on the electric field in the area of contraction is negligible. Similar reasoning is true for the thermal field.

It is established that the asymmetry does not violate the law of dependence of the form \(\varphi_e - v\) in the narrowest places in the area of contraction, since the temperature gradients and stresses in them are large, and the asymmetry in certain zones does not affect the overall voltage \(U\) of the contact spot \(\theta\).

The second case is characteristic of metal-polymer friction pairs. When the microprotrusions of the contact surface are heated, the conditions \((d\varphi / dn) = 0\) and \((dt / dn) = 0\) are not met, since there is a temperature difference between the interacting contact spots. In this case, the heat flux is divided into the longitudinal (part \(X\)) and transverse (part \(Y\)) parts. The effect of heat flux along \(Y\) is the reason for the deviation of the calculation results according to (10) by approximately the value of \(W_x / W_y\). The components of equation (10) are determined by formulas (8) and (9).

The transverse electric field affects the conductivity of films of primary and secondary structures of metallic friction elements. This phenomenon is called the field effect, which is important in
electrochemical conditions when it becomes possible to vary the transverse electric field by changing the electric potential of the film, the magnitude and sign of the surface charge of the metal (when passing through the potential of zero charges).

The third case is characterized by intense mass transfer from microprotrusions of the contacting surfaces according to the polymer-metal scheme and vice versa. Mass transfer determines the energy levels of friction surfaces in the interaction of their microprotrusions (dependences (11) and (12)).

The fourth case differs from the third one in the values of the gradients \((\text{grad}\varphi)_{A1}\) and \((\text{grad}\varphi)_{A2}\) since the energy levels of the semiconductors in the friction pair are different.

| Table 2. Contact-impulse interaction of microprotrusions of friction surfaces with different electric potential gradients and temperature |
|---|---|---|
| No. | Cases of contact patch interaction | Dependence for the evaluation of electric and thermal fields |
|---|---|---|
| 1 | The asymmetric position of the electric field on the contact patch | \(\frac{d\varphi}{dn}\) decreases as \(1/r^2\); each \(q_n\) affects how \(q_n/r\) does not violate the dependence \(\varphi_0 - \nu\) |
| 2 | Symmetric with significantly different conductivities (metal-polymer pair) | \((d\varphi/dn)_{A1} = 0\) and \((dt/dn)_{A1} = 0\) |
| | | \(\int r \rho dt = 0.5\varphi_0^2\) |
| | | \(W_r = 0.125a_n\lambda_n\) |
| | | \(W_r = \frac{S}{1.7a_n\lambda_n} + \frac{1}{2\pi a_n\lambda_n}\) |
| 3 | Symmetric with conductivities that are slightly different (metal-to-metal, polymer-to-polymer pairs) | \(\left(\frac{d\varphi}{dn}\right)_A = 0; \left(\frac{dt}{dn}\right)_A = 0\) |
| | | \(\int \rho \lambda_n dt = 0.5\varphi_0^2\) |
| | | \(\int \rho \lambda_n dt = 0.125u^2\) |
| 4 | Symmetric with conductivities that differ slightly (pair “semiconductor-semiconductor”) | \((\text{grad}\varphi)_{A1}\) differs from \((\text{grad}\varphi)_{A2}\) |

It has been established that the longitudinal thermal field arising in friction pairs of the brake during their pulsed frictional interaction destroys the charges of the transverse electric field.

3. The design and operation of the friction nodes of the strip-block brake in transistor mode

Semiconductor elements operating in the transistor mode are installed in the body of the polymer linings of the friction brake nodes.

According to the kinematic schemes of the strip-block brake (Figure 2), the improved linings 3 are mounted on brake bands 2, which are attached to the balancer at one end (on the side of the leaving branch of the band), and to the crank necks of the crankshaft at the other end (on the side of the entering branch).

The figure 2, the following conventions are used: \(S_e, S_l\) — tension of the entering and leaving branches of the band; \(F_w\) — worker’s effort; \(R_p, r\) — radii: the working surface of the rim of the pulley; crankshaft; \(\omega\) is the angular velocity of the brake pulley.
Serial strip-block brakes drawworks work as follows. By moving the crank, the crankshaft is rotated, as a result of which the driller tightens the brake bands 2 with advanced friction linings, 3 and they sit on the brake pulleys 1. The braking process of the strip-block brake is characterized by the following stages: initial, intermediate and final.

Figure 2. Kinematic diagram of the strip-block brake: 1 – brake pulley, 2 – brake band, 3 – improved linings.

In the initial stage of braking, the improved friction linings 3 located in the middle part of the brake band 2 interact with the working surface of the pulley 1. The front of interaction extends towards the improved friction linings 3 of the incoming (I) branch of the brake band 2.

The intermediate stage of braking is characterized by the further spread of the front of the interaction of the improved friction linings 3 towards the escaping (II) branch of the brake band 2.

The final stage of braking is characterized by the fact that almost all the fixed linings 3 of the brake band 2 interact with the working surface of the rotating pulley 1. In the process of braking, the sequence of occurrence of the friction linings in contact with the working surface of the pulley repeats. A complete braking cycle is completed by stopping the brake pulleys 1 with a drum. The drawworks brake is also controlled by supplying compressed air through the crane of the driller to the pneumatic cylinder, the rod of which is connected to one of the crank necks of the brake crankshaft.

In case of uneven wear, the improved friction linings 3 mounted on the belts 2, the balancer at the time of braking deviates somewhat from the horizontal position and equalizes the loads on the running branches of the brake bands 2, while ensuring uniform and simultaneous girth of the brake pulleys 1. Due to ball joints, the realization of loads this does not change from brake tapes 2 to balancer 11.

Consider the design of improved friction lining 3 and features of the work of its cooling units (Figure 3).

Figure 3. Longitudinal section of an improved friction assembly: 1 – brake pulley, 2 – advanced friction lining, 3 – brake band, 4 – reinforcing wire, 5 – metal strip, 6 – vertical holes, 7 – semiconductor substances that form a U–shape cross–sections of transistors, 8 – semiconductor substances forming a T–shaped cross–section of transistors.

Figure 4 a, b, the following conventions are used: $E_K$, $E_A$ and $E_D$; $E_v$ – energy: contact electric field; donor levels of p- and n-conduction types; space charge ($e_s$); $E_{Fp}$, $E_{Fn}$ – Fermi energy levels; $\phi = E_{Fp} – E_{Fn}$ – potential barrier height; $e$ – electron charge; $\phi$ – contact potential difference; $U$ – external field voltage; $G$ – Gibbs energy; $R$ – contact electrical resistance; electric currents: diffusion ($I = I_p + I_n$); drift ($I_d = I_{d_d} + I_{d_p}$); $I_n$, $I_p$ – diffusion current: electrons; of ions; $I_{d_d}$, $I_{d_p}$ – Drift current: electron carriers, which are minor for the p-region, are returned to n-region by the contact electric field; nonbasic
carriers for the n-region — holes returned to the p-region; $d_p$, $d_n$, $d$ — coverage: common, $p$- and $n$- conduction types; $L_1$, $L_2$ — lengths of regions of $p$- and $n$-type conductivity.

![Figure 4](image)

**Figure 4.** Energy regions in case of disturbance by an external electric field in the pn junction in their own semiconductor substances when the reverse (a) and direct (b) current directions occur.

Improved friction lining 3 on its non-working surface has a strap 5 with fastening tendrils. Metal strap 5 is reinforced to the body lining 3 with wire 4. The antennae lining 3 are attached to the brake tape 2.

In the body of the lining 3, vertical slots 6 of the same diameter are made in its cross-section to the depth of allowable wear of the lining 3. On the side of the non-working surface of the lining 3, also to the depth of its allowable wear, cross-section grooves of the square section are made (Figure 3). In the indicated voids of the patch 3, transistors of the $P$- and $T$-shaped cross sections with transitions, respectively, $npn$ and $pnp$ of own semiconductor substances 7 and 8, alternating according to figure 3, are installed on its incident and escaping parts of the surface. $P$-and $T$-shaped transitions of multi-row transistors by the outer surfaces of the shelves are interconnected by a jumper that is below the non-working surface of the lining 3. The end surfaces of the intrinsic semiconductor substances with $n$- and $p$-types of transition are friction surfaces.

When choosing your own semiconductor substances 7, providing transitions $n$-$p$-$n$ and $8$ — $p$-$n$-$p$, you must observe the inequality:

$$E_{12} > E_{23},$$

where $E_{12}$ is the interaction energy of the contact spots of microprotrusions of the friction surfaces of the polymer-metal pair; $E_{23}$ is the interaction energy of contact spots of microprotrusions of friction surfaces of the “metal – own semiconductors” pair.

The choice of own semiconductor substances for strip linings should be made taking into account:

- structural components of the material of the metal friction element;
- in mixed rows of $P$- and $T$-shaped structures with $n$- and $p$-types of electrical conductivity, semiconductors work constantly in friction pairs during electrothermal-mechanical friction interaction, acquiring the properties of impurity semiconductor substances [6].

In the mixed series of $P$- and $T$-shaped structures of intrinsic semiconductor substances, a ($p$) - electron ($n$) transition dominates the hole. It is the contact of two inherent semiconductors with different types of conductivity ($n$- and $p$-types). To obtain contact with well-controlled and constant properties, it is necessary to create it in the form of an internal interface at which a semiconductor of one type would pass continuously into a semiconductor of another type. This is achieved by doping (introducing) the impurity to the appropriate places during the growth of the crystal by diffusion or implantation of the impurity into the ready-made crystal.

Requirements for own semiconductor substances, which act as energy-absorbing elements in transistors of the $P$- and $T$-structural forms, are formulated taking into account the possibility of
controlling and controlling the internal electric field excited by pulsed specific loads and flash temperatures on contact spots of micro projections of friction surfaces. During their frictional interaction, an external electric field is generated, which effectively interacts with the internal electric field.

Let us consider the kinetics of pn junctions in intrinsic semiconductor substances in case of an imbalance in the external electric field caused by the frictional interaction of the microprotrusions of the friction surfaces.

At the beginning of electrothermal friction, the contact layer formed at the ends of intrinsic semiconductor materials with n- and p-types of electrical heat conduction is blocking. The resistance of the barrier layer can be changed using an external electric field. If semiconductors with a pn-junction, which are components of multi-row transistors, are connected to a current source so that the positive pole of the source is connected to the p-region and the negative pole is connected to the p-region, the resulting field will coincide in direction with the contact electric field. Since the transition zone has a large electrical resistance compared with the rest of the multi-row transistors, the applied external potential difference almost all falls on the barrier layer. The voltage drop on the remaining areas of semiconductor substances indicates that they reduce the energy load of friction pairs of the brake.

The external voltage \( U \) shifts the energy levels in the contacting zones by an amount equal to \( eU \). Fermi levels are also shifted due to an imbalance. The height of the potential barrier increases and becomes equal to \( e(\rho + U) \). The applied voltage prevents diffusion movement of the main charge carriers, which “retreat”, as it were, from the pn-junctions. This leads to an increase in the contact patch (d) of microprotrusions and an increase in the resistance of the contact layer. However, a small amount of minority charge carriers from the p-region and p-region can flow through the pn-junction, and a small current, called reverse current, arises in the circuit. The voltage applied to the pn-junction, in this case, is called reverse and is considered to be negative.

If pn-junctions in multi-row transistors are connected to the source so that the positive pole of the source is connected to the p-junction and the negative pole is connected to n-junction, then the height of the potential barrier decreases by the value of the applied voltage and becomes equal \( e(\rho - U) \).

A decrease in the potential barrier leads to an increase in the number of n-region electrons with the energy necessary to overcome it, which causes a rapid increase in the diffusion current. In this case, the external and contact fields in the transition region have opposite directions. Therefore, the resulting field is weakened, as a result of which the contact zone (d) and its resistance decrease, which also contributes to the growth of the diffusion current. Since the strength of the drift current is small, the current flowing through the pn-n junction is entirely due to the main carrier flows (this is a direct current). The current strength, in this case, will increase with increasing voltage of the current source. The voltage applied to the pn-junction, in this case, is direct and is considered positive. Thus, the pn-junction has one-way conductivity.

The effect of direct and reverse current circulating in multi-row transistors allows to equalize the energy load of the oncoming (III) and escaping (IV) parts of the working surface of the lining 3, as well as along the brake band 2.

4. Conclusion
During the frictional interaction of microprotrusions of friction pairs of the band-brake brake, in the mode of high sliding speeds and specific loads, electric currents are generated and considerable thermal currents accumulate, which leads to an increase in surface temperatures and their gradients. At temperatures above 400 °C, the binder component – phenol-formaldehyde resin – burns out of the surface layers of the friction lining. As a result, a corrosive hydrogen-containing medium arises, which creates conditions for tribocracking and is accompanied by the release of free hydrogen. Hydrogen, interacting with chemical elements (silicon, sulfur, white phosphorus, titanium, and iron) of the material of the surface and subsurface layers of friction pairs, forms unstable hydrides. The surface layers of microprotrusions are subjected to electron-ion polarization by longitudinal heat fluxes, accompanied by a sharp jump in the temperature gradient across the thickness of the surface layer. In this case, the films
of the primary and secondary structures of the metal are “stitched” by the electric current of the same transverse field, contributing to the intensification of their wear. In this regard, the effect of hydrogen embrittlement of the surface layer of the steel rim of the pulley is enhanced.

At a temperature exceeding the allowable for the material of the patch on its working in the process of tribodestruction, the centers of polymer radical molecules are formed that can capture charge carriers at times of tribocontact with a metal friction element. The influence of surface temperature, sliding speed, unit loads and time of contact of microprotrusions of friction surfaces on the magnitude and sign of triboEMF was established. It is noted that the contact potential difference with increasing temperature for electropositive polymers increases and for electronegative decreases. The time of contact of polymeric materials (polycaproamide, tetrafluoroethylene, ethylene, fluoropolymer, epoxy resin ER-20) with a metal affects the sign of the charge (until the permissible temperature of the above materials is reached).

An increase in sliding speed at low specific loads on the contact spots of microprotrusions of friction surfaces leads to an increase in triboEMF for all polymeric materials due to the intensive removal of ions of opposite sign adsorbed from the environment from the surface of the polymer.

It has been established that the direction and magnitude of the electric current affect the wear process of metal-polymer tribosystems. When applying the potential difference to the polymer of the friction pair with the “+” sign, the wear rate of the metal friction element is two times higher than when the negative is applied. This is due to the strengthening of the process of hydrogenation of its steel working surface with an electric field. The increase in wear of polymer linings when applying a positive charge sign to working surfaces occurs due to more intense oxidation, which leads to destructive polymer processes.

The obtained results are explained by the presence of double electric layers formed by each friction element of a friction pair. Electromechanical friction excites the process of transferring iron cations from a steel element to the friction of the working surface of the polymer lining, as well as metal inclusions of the lining material and its wear products to the working surface of the pulley. Depending on the nature of the functional groups formed, the polymer is the center of the capture of electrons or ions from the metal surface, which causes the sign of triboEMF.

Analysis of the results on the study of the mechanism of formation of a friction element of a polymer film on a steel surface due to frictional transfer and wear products showed the following. The basis of the kinetic condition of the unstable state of a frictional transfer film is the inconsistent formation of electrical double layers of the transfer film and its destruction at different rates over time. We single out several stages of the formation of a frictional transfer film at different temperatures (below and above the allowable value for a polymer patch material).

The first stage refers to the period when the dynamic coefficient of friction in the friction pair decreases, and the content of friction transfer products charged negatively on the surface of the metal friction element (surface temperatures do not exceed 175 °C). They are able to form an oriented film.

At the second stage, the dynamic coefficient of friction increases due to an increase in the amount of binder in the total mass of wear products, which are positively charged (surface temperature range 175-350°C).

The third stage is characterized by an increase in the amount of binder in the frictional transfer film since there is a tribocracking, accompanied by a catastrophic decrease in the filler. This leads to a drop in the dynamic coefficient of friction. The film particles are negatively charged, the surface temperatures exceed the permissible (350°C). As a result of studies (Table 3), the energy intensity of wear of the improved linings was revealed 1.3 times lower.
Table 3. Triboelectric and performance parameters of an improved strip-bloke brake of a U2-5-5 draw works

| Friction pair | Charge sign | Performance parameters |
|---------------|-------------|------------------------|
|               | +            | -                      |
| Element density | Friction force $F_f=(S_i-S_d)$, kN | Dynamic coefficient, $f$ | temperature gradients | brake torque $M_t$, kNm | Energy intensity of wear rate $I_w$, mg/J |
| high         | low         |                         |                     |                         |                                |
| FC-24A-steel 35HNL | Polymer Metal | 259.6 | 0.38 | 40…60 | 6…15 | 188.2 | 2.5 |
| Semiconductors (p-r-p) – steel 35HNL | Generated currents direct | 220.5 | 0.42 | 20…30 | 10…15 | 195 | 2.3 |
| Semiconductors (r-p-r) – steel 35HNL | Generated currents back | 240.8 | 0.45 | 10…20 | 5…10 | 200.5 | 2.45 |
| The results of experimental studies of friction pairs | | 260 | 0.43 | 10…35 | 5…13 | 198 | 2.35 |

This is explained by the magnitude of the potential difference between the microprotrusions of the rubbing surfaces (Table 4).

The greatest potential difference has a pair of friction semiconductors with an npn junction - steel 35KhNL, while the working area of the transistors of the $P$- and $T$-shaped cross-section is 21.5% of the surface friction of the polymer lining. Transistors have almost no effect on the dielectric constant of the material of the plates. In a friction pair, positive charges are generated, and a positive transverse electric field arises, preventing the adsorption of hydrogen ions to the surface layers of the friction surfaces. This circumstance plays a crucial role in reducing the hydrogen wear of friction pairs of the brake.

The area of the transistor inserts embedded in the body of the friction lining of the polymer material FK-24A depends on the diameter and width of the rim of the treadmill pulley.

Table 4. The potential difference between the microelevations of friction pairs of the strip-bloke brake of the U2-5-5 draw works

| Friction pairs | FC-24A-steel 35HNL | Semiconductors (p-r-p) – steel 35HNL | Semiconductors (r-p-r) – steel 35HNL |
|---------------|--------------------|--------------------------------|--------------------------------|----------------|
| Potential difference $\Delta V$, mV | 0.47 | 0.64 | 0.55 |

It has been established that friction linings modified by intrinsic and impurity semiconductors form a mixed series of $P$- and $T$-shaped structure with hole-electronic transitions. During friction, new pairs are formed with single and dissimilar double and triple conductive junctions. New friction pairs have the ability to instantly switch to the transistor mode.
The results of experimental studies of improved friction pairs of band-brake brakes containing friction linings modified with semiconductors showed that friction pairs of the new generation are characterized by stable friction forces and a dynamic friction coefficient, a decrease in the surface and volume temperature gradients of the pulley rim, a decrease in energy loading to 15.0% and wear lining working surfaces up to 11.5%.

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