On the Efficiency of Forced Air Cooling of Frictional Connections of Brake Devices

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Abstract

The materials of the article are devoted to the features of forced, direct cooling with moist compressed air of the working surfaces of friction pairs of brake devices. The results of a computational experiment concerning the design parameters of the cooling system and its operational parameters are presented. The efficiency of air cooling of the drum-shoe brake friction pairs is estimated. Attention is paid to the peculiarities of forced cooling with moist compressed air of brake tribo couplings. Compressed air pressures have been established, at which it is possible to forcibly cool the friction pairs of drum-shoe and band-shoe braking devices.

Keywords: brake, microprotrusions of friction pairs, direct forced cooling, moist compressed air, “Box Hunter” method, cooling efficiency.

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Əyləc qurğularının friksion qovşaqlarının məcburi hava soyudulmasının effektivliyi

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Xülasə

Məqalə, əyləc qurğularının sürtünmə cütünün işçi səthlərinin nəm sıxılmış hava ilə məcburi, birbaşa soyudulması xüsusiyyətlərinə həsr edilib. Soyutma sisteminin struktur parametrləri və onun istismar parametrləri ilə bağlı hesablama təcrübəsinin nəticələri təqdim olunub. Baraban-kündəli əyləcin sürtünmə cütünün hava ilə soyudulmasının effektivliyi qiymətləndirilib. Əyləc triboqovşaqlarının nəm sıxılmış hava ilə məcburi soyudulması xüsusiyyətlərinə diqqət yetirilib. Sıxılmış havanın təzyiqi müəyyən edilmişdir ki, bu zaman, baraban-kündəli və lent-kündəli əyləc qurğularının sürtünmə cütünün birləşmələrinin məcburi soyudulması mümkündür.

Açar sözlər: əyləc, sürtünmə cütünün mikro-çıxıntıları, birbaşa məcburi soyudulma, nəm sıxılmış hava, “Boks-Xanter” metodu, soyudulma effektivliyi.

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Об эффективности принудительного воздушного охлаждения фрикционных сопряжений тормозных устройств

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Аннотация

Статья посвящена особенностям принудительного, непосредственного охлаждения влажным сжатым воздухом рабочих поверхностей пар трения тормозных устройств. Приведены результаты вычислительного эксперимента, касающиеся конструктивных параметров системы охлаждения, и его эксплуатационные параметры. Оценена эффективность воздушного охлаждения пар трения барабанно-колодочного тормоза. Уделено внимание особенностям принудительного охлаждения влажным сжатым воздухом трибосопряжений тормозов. Установлены давления сжатого воздуха, при которых можно принудительно охлаждать сопряжения пар трения барабанно-колодочных и ленточно-колодочных тормозных устройств.

Ключевые слова: тормоз, микровыступы пар трения, непосредственное принудительное охлаждение, влажный сжатый воздух, метод «Бокса Хантера», эффективность охлаждения.

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Introduction

When choosing friction pairs of a braking device, the main characteristics are the durability and performance of their materials. The durability of a friction pair is primarily determined by the wear of the friction lining, and its performance is determined by the stability of the dynamic coefficient of friction and, as a consequence, the braking torque. During the operation of the braking device, the friction pair heats up in different ways, which leads to a change in the indicated characteristics - the wear rate increases, and the stability of the braking torque decreases. Thus, when assessing the durability and performance of the braking device and their improvement, it is necessary to investigate the direct and indirect forced cooling of its friction pair.

Problem state

Known works [1-3], in which in conjunction of pairs of friction drum, disc and tape-shoe brakes, compressed air was supplied using devices and systems. The latter provided the supply of compressed air through the fixed friction units "tape-patch"; "Block-pad". The efficiency of reducing the energy load of friction pairs of brake devices was on average 10-14%. However, this did not take into account the changes in the micro-profile of the frictional interaction of friction pairs and the processes occurring in the coupling.

The processes accompanying electrothermomechanical friction also significantly affect the properties of surface layers. Due to the introduction of contacting protrusions during tangential displacement, there is an elastoplastic deformation of the surface layers. The thickness of the deformed layer depends on the sliding speed; it decreases with increasing speed. Multiple elastic surface deformations lead to fatigue. Plastic and elastic deformations of the surface layer in the process of electrothermomechanical friction lead not only to a change in its properties, but also to the formation of a new microrelief, typical for the given friction conditions.

The high temperature that develops during friction leads to annealing and softening of the surface layer and smoothing of microroughnesses, to structural changes in the material, as well as to the occurrence of diffusion processes.

The temperature gradient along the depth has a significant effect on the properties of the friction surface, leading to a gradient of mechanical properties. Changing the structure of the surface layer significantly changes its mechanical properties. The mechanical properties of the surface layer can be estimated from the results of measuring its microhardness. Usually the surface layer of metals has a high hardness, which is explained by its work hardening. This cold-worked layer can be detected by X-ray diffraction analysis [3].

The supply of compressed air to the interface of friction pairs helps to reduce their energy load, but it will harm the following: transformation of the elastoplastic deformation of the surface layers into their elastic state; decrease in specific loads and increase in sliding speed; delayed formation of a new microrelief; lack of diffusion phenomena; a decrease in the depth temperature gradient that does not affect the mechanical gradient of the material properties; the surface layer has a lower hardness, which is explained by its weak work hardening; oxidative processes are accelerated and reduction processes are slowed down, destruction of adsorption and double electrical layers, etc.

Formulation of the problem

This publication addresses the following issues in relation to the problem being solved:

- design and operation of the system for forced cooling with moist compressed air of friction pairs of brakes;
- the results of a computational experiment according to the "Box Hunter" method;
- efficiency of forced air cooling of friction pairs of drum-shoe brakes;
- about the features of forced cooling with moist compressed air of brake tribo couplings.

The purpose of the work – is to substantiate direct forced cooling with moist compressed air by a micro-protrusion of friction pairs of brake devices.

Design and operation of the system for forced cooling with moist compressed air of brake friction pairs

The pressure of compressed air supplied for forced cooling of friction pairs of brake devices depends directly on the specific loads developed between their friction pairs. Specific loads in the band-shoe brakes of the drawworks reach 1.5 MPa, and in the drum-shoe brakes of vehicles it is only 0.7 MPa.

The system of forced cooling with moist compressed air of the friction pairs of the rear drum-shoe brakes of a cargo vehicle works as follows [1]. According to fig. 1 compressed air from compressor 1 enters the receiver 2 of the pneumatic system of the vehicle, and then into the controlled gearbox 3 (type valve 122-16 UHL 4 GOST 18468-79). The reducer 3 has a built-in pressure gauge 7, which controls the pressure of the supplied air. From the reducer 3 it enters the solenoid valve 4 (gas valve SPB PG-24 PV-16), and then through the system of tees 6 and pipelines it goes to the fittings of 8 brake pads with friction linings 9 (4 fittings on one shoe) into the gap between the working surface drum 10 and linings.

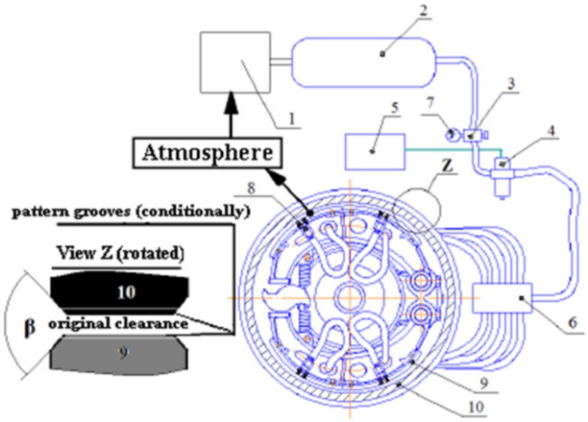
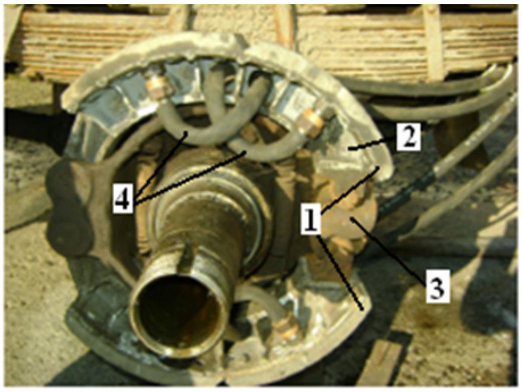


Figure 1 – System for forced cooling with moist compressed air of the working surfaces of the friction pairs of the drum-shoe brake of the vehicle:
1 - compressor; 2 - receiver; 3 - reducer; 4 - electromagnetic valve; 5 - brake valve; 6 - tee systems; 7 - manometer; 8 - hose with fitting; 9 - brake shoe with friction linings; 10 - brake drum

The solenoid valve 4 is designed to supply air to friction couples interacting frictionally and to stop supplying it after the braking process is completed. For this, the solenoid valve 4 is electrically connected to the limit switch of the brake valve 5, which also includes the rear brake lights. When the driver presses the brake pedal, the limit switch is first triggered, which activates the brake lights and the solenoid valve 4. The latter will begin to supply compressed air from the gearbox 3 to the brake friction couples.

At the same time, compressed air enters the pneumatic chambers and the expanding fist 3 (Fig. 2 a) enters into operation, expanding the brake pads 1. After the driver stops acting on the brake pedal, the supply of compressed air to the brake chambers will stop, and after a while the limit switch will turn off the solenoid valve 4 and brake lights.

a)



b)

Figure 2 a, b – Brake without a drum with elements of the cooling system (a) and measuring the compressed air consumption in it (b) 1 - brake pads; 2 - friction linings; 3 - expanding fist; 4 - hoses with fittings; 5 - air flow measurement with a mass flow meter MV-306

Thus, the air will still flow into the friction zone for some time after the end of the braking process.

The compressed air consumption was measured with an MV-306 5 mass flow meter (Fig. 2 b). The supply of compressed air at a pressure of 2,0-3,0 MPa between the brake friction pairs is possible only when the vehicle is braked. The design of the system for cooling with compressed air of the friction pairs of the band-shoe brakes of the drawworks is simpler. In it, the compressed air is supplied through the brake band and friction linings. About the air cushion between the friction pairs of the band-shoe brakes, since the cushion "breaks" in the gaps between the linings and the compressed air pressure can reach up to 0,7 MPa. Table 1 illustrates the design parameters of the friction unit of a given brake vehicle model ZIL and the parameters of the forced cooling system of the tribo interface.

The stability and reliability of the braking device is largely determined by the thermal state of its main working elements. In drum-shoe brakes, these are friction pairs.

Table 1 – Design parameters of the friction unit of the brake and parameters of the system of its forced cooling

Rim working surface radius R, mm		210,0
Rim width B, mm		140,0
Reduced rim thickness δ, mm		18,0
Drum weight G, kg		45,0
Material		SCh-15
Working	length l, mm	210,0
	width b, mm	140,0
Area	pad A, cm^2	1176,0
	hole (32 with a diameter of 13,0 mm) in the escutcheon for the installation of rivets, A, cm^2	42,45
Pad thickness δ_p, mm		20,0
Pad weight G_p, kg		1,5
Material		FK-24A
Average maximum clearance between the working surfaces of the brake friction pairs h_3, mm		1,2
Intervals changes	compressed air pressure P_a	0,0 – 0,8
	bore diameters	2,1 – 8,0
	air velocities υ, m/s	1,0 – 70,0
	air flow rate entering the gap between brake friction pairs $G_a \cdot 10^2$, cm^3 / s	1,0 – 20,0

The main factors that determine the thermal state of friction pairs of brakes operating in compressed air are: specific loads in contact on the working surfaces of the friction pair; surface temperatures of brake friction pairs; the sizes of the diameters of the holes through which the compressed air flows; the amount of cooling compressed air involved in heat removal, depending on its pressure and speed; operating mode of the cooling system (switching frequency and duration).

Results of a computational experiment according to the "Box Hunter" method

At present, along with other calculation methods, the mathematical theory of experiment planning, which refers to a computational experiment, has become increasingly widespread [4]. Tasks with the help of the latter are solved as follows. Initially, it is established to what extent each of the factors (design and operational parameters) affects the output parameter.

A quantitative measure is the value of the model coefficient corresponding to a given factor. In this case, the plus sign indicates an increase in the value of the parameter, and the minus sign indicates its decrease, that is, indicate the nature of the influence.

Then the location of the set of factors is established according to the strength of their influence. After that, decisions are made based on possible situations, which are distinguished by the adequacy of the model, the significance and insignificance of the coefficients. When constructing a regressive formula, obtaining an adequate model means the completion of the task. The modified method for the computational experiment is the “Box Hunter” method [5]. As the response functions, it is required to determine the indicator of direct measurement - the maximum value of the braking force F_B and the calculated braking torque of the right rear wheel of the vehicle model ZIL. The following are selected as variable functional parameters of the brake mechanism: the pressure of the supplied air P_a and the diameter of the supply holes in the friction lining d_h.

The experimental technique included the following stages: determination of the levels of the considered parameters (pressure of the supplied) air through the nozzle P_a and the diameter of the supply holes in it (d_h), and the intervals of their variation; build an experiment plan (experiment planning matrix).

The upper levels of the considered parameters are determined by the lower maximum pressure of the supplied air P_{amax}=0,77 MPa, the maximum diameter of the inlet opening in the fitting installed in the friction pad, taking into account its strength d_{hmax}=8,0 mm. When the diameter of the outlet in the choke is more than 8,0 mm, the air flow from the receiver increases, the compressor performance decreases, the speed of the brake friction pairs decreases due to the creation of a powerful air cushion between the working surfaces.

The lower levels of the considered parameters are selected as follows: the minimum pressure of the supplied air P_{amin}=0,1 MPa. The minimum diameter of the inlet hole in the fitting installed in the friction lining d_{hmax}=2,0 mm. When installing a smaller diameter of the supply hole in the fitting, this will lead to the creation of turbulences of the supplied air into the friction zone, which increase its efficiency as a cooling heat carrier, but the air whistle is heard.

Let us determine the intervals of variation of the considered parameters according to the plan of the "Box-Hunter" experiment [5] according to:

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- pressure of the supplied air P_a:

$P_{amin} \leq P \leq P_{amax}$, $0{,}1 \leq P \leq 0{,}77$ MPa
$P_0 \approx 0{,}49$ MPa
$-\alpha = 0{,}1$ $\quad +\alpha = 0{,}77$ MPa

$$-1 = \frac{0{,}1 + 0{,}44(1 - 1{,}41)}{1{,}41} \cong 0{,}2\ MPa,$$

$$+1 = \frac{0{,}77 + 0{,}44(1 - 1{,}41)}{1{,}41} \cong 0{,}67\ MPa,$$

$$\Delta P = (0{,}67 - 0{,}2)/2 = 0{,}24\ MPa.$$

The diameter of the inlet holes in the fittings d_h:

$d_{hmin} \leq d \leq d_{hmax}$ $\quad 2{,}0 \leq d \leq 8{,}0$ mm
$d_0 \approx 5{,}0$ mm
$\alpha = 2{,}0$ mm, $\quad +\alpha = 8{,}0$ mm

$$-1 = \frac{2 - 5(1 - 1{,}41)}{1{,}41} \cong 2{,}9\ mm, \quad +1 = \frac{8 - 5(1 - 1{,}41)}{1{,}41} \cong 7{,}1\ mm,$$

$$\Delta d = (7{,}1 - 2{,}9)/2 = 2{,}1\ mm.$$

where -1.41 and +1.41 - the minimum and maximum coefficients are borrowed from the factorial experiment matrix [1].

The characteristic of the experimental design is shown in table 2. Table 2 shows - α and + α - respectively, negative and positive magnitudes of the stellar arms; - 1 and + 1 - lower and upper levels of variation; 0 - center of the experiment; ΔXj - interval of variation of parameters.

The factorial experiment matrix (Box-Hunter design, core 22) is shown in table. 3.

Table 2. Characteristics of the experimental design for parameters P_a and d_h

Parameters	Variation levels					
	$-\alpha$	-1	0	+1	$+\alpha$	ΔX_j j=1.2
X_1, MPa	0,1	0,2	0,44	0,67	0,77	0,23
X_2, mm	2,0	2,9	5,0	7,1	8,0	2,1

Table 3. Matrix of factorial experiment in natural values of parameters F_B and M_B

№ experience	P_A, MPa	d_h, mm	On the right rear wheel	
			Braking force F_B, N	Braking torque M_B, N·m
1	0,12	2,9	7320	3294,0
2	0,66	2,9	8520	3834,0
3	0,12	7,1	7580	3411,0
4	0,66	7,1	8310	3739,5
5	0	5,0	7920	3564,0
6	0,77	5,0	8050	3622,5
7	0,39	2,0	8090	3640,5
8	0,39	8,0	7600	3420,0
9	0,39	5,0	8230	3703,5
10	0,39	5,0	8450	3802,5

The matrix of the factorial experiment in the full-scale values of the parameters of the braking force F_B and the braking torque M_B, developed by the right rear brake of the vehicle of the ZIL model, will be used in the future to obtain regressive dependencies for their determination.

For this, it is necessary to carry out experimental studies and establish the regularities of changing the parameters according to the dependences of the form $G_V = f(P_h)$, $G_V = f(d_h)$ and $G_V = f(V)$ (Fig. 3 a, b, c) and $V = f(P_a)$ and $V(d_h)$ (Fig. 4 a, b).

Analysis of the graphical dependencies listed above made it possible to state the following.

Compressed air consumption G_V depending on:

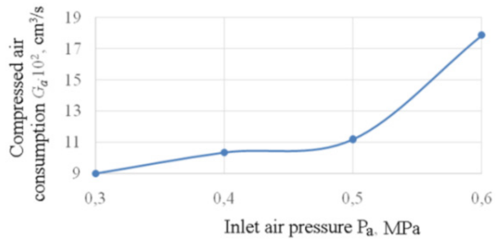
- pressure P_a at the inlet to the pipeline choke (Fig. 3 a) has a quasi-linear character, and after 0,5 MPa it sharply increases, which significantly affects the compressor performance;

- diameters d_h of the supply holes in the cooling system of the brake friction pairs (Fig.

3 b) it follows that at d_h = 7,5 mm the compressed air consumption becomes constant and there is no point in increasing it;

- the average velocity V of air outflow from the pipeline choke (Fig. 3 c), depending on their hydraulic resistance;

a)



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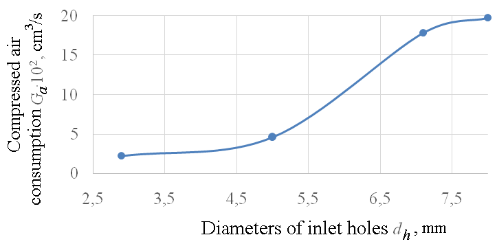


c)

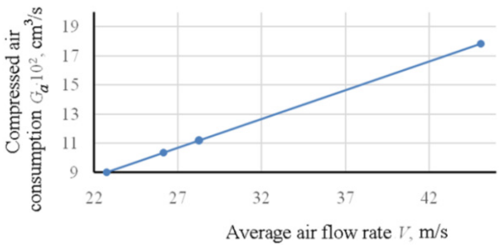


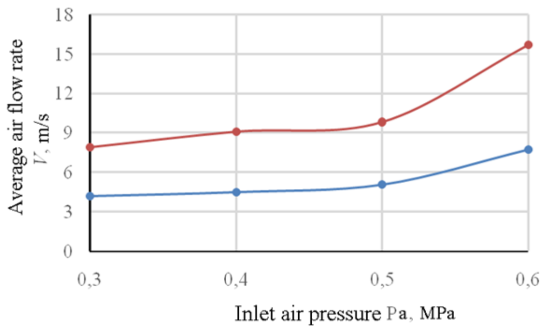
Figure 3 a, b, c – Dependence of compressed air consumption $G_a \cdot 10^2$ in the system of forced cooling of friction pairs of drum-shoe brakes of a vehicle model ZIL: *a* - air pressure at the inlet at d_h = 7,1 mm of the opening of the pipeline fitting; *b* - the diameters of the supply holes at P_a = 0.6 MPa; *c* - average air flow rate υ at d_h = 6,0 mm

The dependence of the average speed V of air outflow into the forced cooling system of the brake friction pairs on:

- pressure P_a at the inlet to the pipeline choke (Fig. 4 *a*) indicates that the velocity gradient is greater at high air pressures than at low ones:

- diameters do of the inlet holes of the cooling system of the brake friction pairs (Fig. 4 *b*) indicates that the point O of the intersection of the two curves is the rational hole diameter and is equal to 4,5 mm.

a)



b)

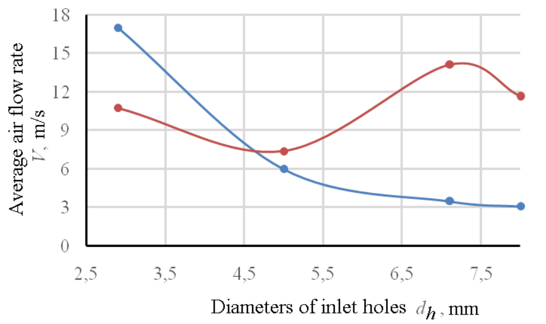


Figure 4 a, b – Dependence of the average air flow velocity V in the forced cooling system on: *a* - inlet pressure with a hole diameter d_h = 7,1 mm; *b* - diameters of the inlet openings of the pipeline fittings at an air pressure of P_a = 0,6 MPa; 1 - before and 2 - after the pipe union

Efficiency of forced air cooling of drum-shoe brake friction pairs

The purpose of forced air cooling of friction pairs of braking devices is to limit the energy loading of the surface layers of the tribo interface. With an increase in the permissible temperature for the surface layers of the friction lining, the binder component, i.e. formaldehyde resin, burns out.

Everything that happens is subject to the cracking process [6, 7]. Table 4 shows an assessment of the efficiency of forced air cooling of the friction pairs of the rear brake of a vehicle model ZIL.

Table 4 – The efficiency of forced air cooling of the friction pairs of the rear brake of the vehicle model ZIL

Surface temperatures t_p from which forced cooling of brake friction pairs was made						
100	150	200	250	300	350	400
Compressed air consumption $G_a \cdot 10^2$, cm^3 / s at d_h = 4.5 mm and its P_a = (0,3 – 0,6) MPa						
10,5	12,0	13,5	15,0	17,0	18,5	20,0
Reduction of t_p of brake friction pairs by (ºC):						
5,0	10,0	15,0	20,0	30,0	35,0	50,0

Surface temperatures from 100 to 200°C of brake friction pairs characterize their steady state, the amount of heat generated by the coupling is equal to the amount of heat removed into the environment. In this case, the cooling system will rarely turn on. In the range of surface temperatures from 250 to 350°C, the cooling system is switched on more often after the completion of the next braking by the vehicle. As for the surface temperatures up to 400°C and above, an edothermal reaction associated with the cracking process takes place in the surface layer of the polymer lining, which reduces the heat load of the tribo conjugation. In general, the efficiency of air cooling of friction pairs of drum-shoe brakes of a vehicle in the temperature range from 100 to 200°C, from 250 to 350°C and up to 400° C and above is, respectively, 7.0; 9.0; and 12.5% excluding free and forced convective heat transfer.

Further, using the experimental data from the established patterns of change in the parameters $G_V = f(P_a)$, $G_V = f(d_h)$ and $G_V = f(V)$ (Fig. 3 *a*, *b*, *c*) and $V = f(P_a)$ and $V(d_h)$ regression dependencies were obtained to determine:

braking force

$$F_B = 6008{,}5 + 3833{,}4P_a - 2356{,}1P_a^2 + \\ + 600{,}6d_h - 55{,}8d_h^2 - 207{,}2P_a d_h \tag{1}$$

braking torque

$$M_B = 2703{,}8 + 1725P_a - 1060{,}2P_a^2 + \\ + 270{,}3d_h - 25{,}1d_h^2 - 93{,}3P_a d_h \tag{2}$$

The critical values of the parameters of the cooling system are P_a = 0,63 MPa and d_h = 4,2 mm. The regression dependences (1 and 2) were used for calculations, which formed the basis for the graphical dependences shown in Fig. 5 a, b and made in 3D format.

a)

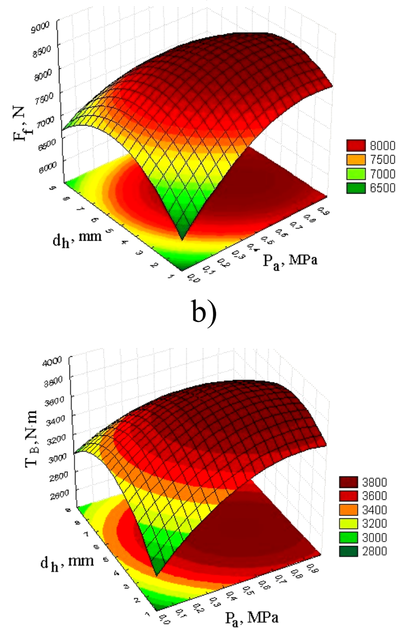


Figure 5 *a*, *b* – Dependences of the braking force (*a*) and the moment (*b*) on the pressure of compressed air at the inlet to the cooling system and the diameters of the inlet pipe fittings

The analysis of the latter made it possible to state the following:

- the compressed air pressure Pw = 0,63 MPa in the cooling system is critical when the hole diameter is d_h = 4.2 mm;

- the minimum gradient of the friction force F_B was achieved at d_h=2,0 mm and P_a

=0,05 MPa, and the maximum - at d_h =4,2 mm and P_a =0,63MPa (Fig. 5 a);

- the maximum gradient of the braking torque T_B was achieved at d_h =4,2 mm and P_a=0,63 MPa, and the minimum - at d_h =2,0 mm and P_a = 0,05 MPa (Fig. 5 b).

Features of direct forced cooling with moist compressed air of brake tribo couplings

The increasing requirements for reliability and the occurrence of transient processes in friction pairs under the influence of small specific loads (2,0-3,5 MPa) and cooled by compressed air have led to the problem of combining microprotrusions of materials with opposite properties - electrical conductivity and wear resistance - in the contacts. So, under conditions of normal oxidative wear, an increase in the contact force of the RK leads to an increase not only in wear, but also in the level of jumps in the contact resistance RK up to the complete absence of contact and the occurrence of frictional non-conductivity.

Upon reaching the permissible value of the RK, at which the seizure of the contact surfaces occurs, the conductivity increases to the conductivity of the pure metal, but at the same time the wear rate increases dramatically [8]. The main type of wear for the friction pairs under consideration is selective frictional oxidation of alloying elements in the metal rim.

With a low content of the latter, their oxides are formed locally (a continuous film is not formed), and the resulting jumps in the contact resistance RK can be limited, and their growth with the accumulation of wear-friction oxidation products (Fig. 6) can be eliminated (limited) by such measures, as the use of devices for cleaning surfaces from wear products.

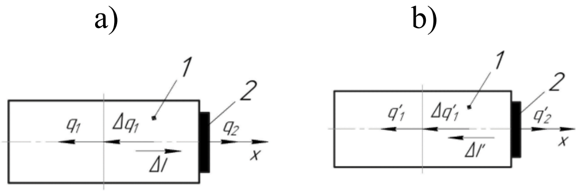


Figure 6 a, b - Schemes of distribution of heat fluxes between friction pairs "metal (1) - polymer (2)" (*a*) and polymer (2) - metal (1) (*b*)

The presented friction pairs (Fig. 6 a, b) in the form of an electric thermal generator and a refrigerator with heat fluxes q_1 towards the metal friction element and towards q_2 of the polymer lining. The values of q_1 and q_2 in the steady state are determined by its parameters R_k, v_C, as well as by the electrothermal resistances r_1 and r_2. Since $r_1 << r_2$ and $r_1 >> r_2$, and $q_1 >> q_2$ and $q_1 << q_2$ temperature gradients

$$\frac{dT_1}{dx} = \frac{dT_2}{dx}; \qquad \frac{dT_1}{dx} \neq \frac{dT_2}{dx};$$

$$\frac{\partial \Delta T}{dx} = \frac{dT_1}{dx} = \frac{dT_2}{dx}; \tag{3}$$

$$\frac{\partial \Delta T}{dx} \neq \frac{dT_1}{dx} \neq \frac{dT_2}{dx}. \tag{4}$$

The resulting thermal diffusion flow of matter (soft and hard phases) is directed towards and against the temporarily differential flow Δq towards “metal-polymer” and “polymer-metal”.

In this case, the ratios of the sizes of the contact areas A_1 and A_2 of the microprotrusions are such that the deformation components of the diffusion transfer are also directed to the side ($A_1 \neq A_2$), therefore, the A_1 platform periodically rests, and A_2 is in contact all the time. The surface layer of a polymer liner is always more energetic due to its thermal insulation properties and has a higher temperature.

Resultant transfer of matter towards the hot contact of the metal friction element

$$\Delta l_{\sum} = D_T 0 \frac{\partial \Delta T}{dx} + D_\varepsilon \frac{\partial \Delta \varepsilon}{dx}, \qquad (5)$$

where D_T, D_ε are the coefficients of thermal diffusion and deformation, respectively; $\frac{\partial \Delta T}{dx}$, $\frac{\partial \Delta \varepsilon}{dx}$ - change in temperature and deformation gradients.

According to expression (5)

$$\Delta l_{\sum} = 0 \text{ at } \frac{\partial \Delta T}{dx} = 0, \quad \frac{\partial \Delta \varepsilon}{dx} = 0. \qquad (6)$$

To fulfill conditions (9) it is necessary: creation of a physically homogeneous contact pair with equal temperature and deformation gradients in the surface layer (“metal-metal” pair); suppression of diffusion processes by temperature gradients of the opposite sign (materials with different signs of thermoEMF) [8-11].

The intensity of selective frictional oxidation processes, which was estimated from the results of measuring and summing the levels (number, amplitude and duration) of jumps in the contact resistance RK, depends on the size and number of oxide particles between the contact surfaces. To improve the conductivity and reduce the wear rate, constructive and technological methods can also be used: optimization of the contact force, an increase in which in the normal oxidative wear mode leads to an improvement in conductivity; reducing the activation of the metal surface by using materials prone to softening; reducing the activation of the surface of the friction material of the lining by using various kinds of modifiers in the form of inserts; reducing the concentration of alloying components to the limits in the metal friction element sufficient to eliminate seizure.

Self-regulation of the equilibrium of microtransference and redox processes, accompanied by an abnormal decrease in the intensity of wear and friction losses, occurs during selective transfer, in which the contact pair becomes an electric thermal generator and an electric thermal refrigerator and converts part of the friction work into useful forms of activation. For weakly loaded sliding contacts of friction pairs, this effect is of interest in that it not only does not require the supply of energy from the outside, but also establishes a regime of equilibrium non-oxidative friction - an important condition for reliable contact [12].

The stability of selective transfer in weakly loaded sliding contacts of friction pairs is impeded by the formation of oxides of alloying elements, which do not dissociate when heated as a result of friction, as well as surface contamination by polymerization products and negatively charged wear particles.

The concentration of contaminants, their composition and properties are random and not amenable to regulation and control. Thus, in real working environments with random composition and properties, the likelihood of self-regulation of the equilibrium of processes is very small. Nevertheless, practical cases are known when, in the mode of selective frictional oxidation of microtransport, weakly loaded sliding contacts of friction pairs operate for a long time without noticeable wear while maintaining reliable contact, i.e. in equilibrium mode. Consequently, the selective transfer mechanism is free of oxidative processes, and an obstacle arises in the way of its implementation - the phenomenon of frictional non-conductivity of the polymer pad in weakly loaded sliding contacts of the selective transfer effect and its solution to the problem of combining opposite properties in contact materials (high wear resistance and ideal electrical conductivity) gets a new, more real basis. The results of many years of research on the processes of contact interaction in a weakly loaded sliding contact show that, in addition to selective transfer on the surface of contacts under similar conditions, other competing processes can arise: frictional oxidation, frictional polymerization of organic vapors, formation of organometallic compounds (metal soap), destruction of wet compressed air in an electric discharge. All these processes, as well as selective transfer, are a consequence of the activation of the surface of the metal and the medium during plastic deformation and friction. The result depends on the intensity of each of these processes in the given conditions.

When vapors are formed from moist compressed air during a pause (on the juvenile surface), the resulting polymer film suppresses oxidative processes, and surges are not renewed even by additional activation of oxidation by evaporation of condensed moisture. The resource of traditional friction pairs operating under friction conditions without compressed moist air in their conjugation cannot be significantly increased. The presence of controlled moist compressed air automatically solves the problem of cleaning the surface from wear products. Finally, the working coolant is the medium with which the system exchanges matter and energy, due to which self-regulation of competing processes can be achieved.

Conclusion

The forced cooling with moist compressed air of friction pairs of drum and band-shoe brakes is illustrated and how it affects the processes, phenomena and effects in their conjugation.

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