Hydrogen Wear on Working Surfaces of Metal Components of Friction Brake

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Abstract

The article examines the interaction between the periods of amplitudes of longitudinal waves of the surface micro-protrusions of rim and the crystal lattice of its material, which contributes to the growth of local gradients of pulsed specific stresses and flash temperatures during electro-thermo-mechanical friction. The interaction of external hydrogen with internal hydrogen located in the subsurface layer of the metal friction element is illustrated. As part of the study of hydrogen wear of the working surface of the pulley rim, the following were considered: adhesion, adsorption, diffusion in electric and thermal fields, and the stress-strain state of the pulley rim was also assessed. Means are proposed that prevent the release of hydrogen from the steel surface of the pulley rim by limiting the movement of its ions.

Keywords: braking devices, friction vapours, metallic friction element, crystal lattice, longitudinal and transverse waves.

DOI: 10.52171/2076-0515_2021_13_03_27_37

For citation:
Janahmadov A.Kh., Skrypnyk V.S., Volchenko N.A., Zhuravlyev D.Y., Vudvud A.N.
[Hydrogen Wear on Working Surfaces of Metal Components of Friction Brake]
Herald of the Azerbaijan Engineering Academy
2021, vol. 13, no. 3, Pp. 27–37. *(in English)*

Herald of the Azerbaijan Engineering Academy
2021, Vol. 13, №. 3, Pp. 27 – 37
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Əyləclərin metal friksion elemetlərinin işçi səthlərinin hidrogen yeyilməsi

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Xülasə

Məqalədə elektrotermomexaniki sürtünmə zamanı impulslu nisbi yüklərin lokal qradientlərinin və temperatur işıltısının artmasına kömək edən səthi mikroçıxıntıların və onun materialındakı kristal torun uzununa dalğalarının amplitud dövrlərinin qarşılıqlı əlaqəsi vurğulanıb. Metal sürtünmə elementinin səthaltı təbəqəsində olan xarici hidrogenlə daxili hidrogenin qarşılıqlı əlaqəsi təsvir olunub. Qasnağın işçi səthinin hidrogen yeyilməsinin tədqiqi zamanı adgeziya, adsorbsiya, elektrik və istilik sahələrində diffuziya məsələlərinə baxılıb, həmçinin qasnağın gərginlik-deformasiya vəziyyətinin qiymətləndirilməsi aparılıb. Onun ionlarının hərəkətini məhdudlaşdırmaqla, qasnağın polad səthindən hidrogenin ayrılmasının qarşısını almaq üçün vasitələr təklif edilib.

Açar sözlər: əyləc qurğusu, sürtünmə cütü, metal friksion elementi, kristal tor, uzununa və eninə dalğa

DOI: 10.52171/2076-0515_2021_13_03_27_37

УДК: 629.113:621.7.082.18

Водородный износ рабочих поверхностей металлических фрикционных элементов тормозов

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Аннотация

В статье рассматривается взаимодействие периодов амплитуд продольных волн поверхностных микровыступов обода и кристаллической решетки в ее материале, способствующее росту локальных градиентов импульсных удельных нагрузок и температур вспышки при электротермомеханическом трении. Проиллюстрировано взаимодействие внешнего водорода с внутренним водородом, находящимся в подповерхностном слое металлического фрикционного элемента. При исследовании водородного изнашивания рабочей поверхности обода шкива рассмотрены: адгезия, адсорбция, диффузия в электрическом и тепловом полях, а также произведена оценка напряженно-деформируемого состояния обода шкива. Предложены средства, предотвращающие выделение водорода из стальной поверхности обода шкива за счет ограничения движения его ионов.

Ключевые слова: тормозные устройства, пары трения, металлический фрикционный элемент, кристаллическая решетка, продольные и поперечные волны.

Introduction

Hydrogen wear as one of the processes of destruction of metal friction surfaces under electrothermomechanic friction is caused by the decomposition of hydrocarbon steels and steels with the release of hydrogen, which diffuses into the surface layer of alloyed cast iron, causing them to brittle. In particular, it has been established that the sizes of the products of wear at rubbing after the slurry of steel samples are significantly larger than those of manure (the linear dimensions differ by a factor of 5-6) [1-6].

At the same time, on a steel-washing surface, significant setting and damagecentres are formed. The literature lacks detailed data and results of studies on the influence of external and internal hydrogen on the processes of electrothermomechanic friction and the wear of the friction pairs of disc-drum type and strip-block type of brakes. In addition, the interaction between the amplitude periods of the longitudinal waves of surface microasperitiesand the crystal lattice of the material was not considered.

The state of the problem

The diversity of the structure of carbon and alloyed steels results in different steels reacting to friction differently and having different durability characteristics with the same type of crystal lattice. In addition, chemicothermal and thermomechanic processing also has a significant influence on the structure and tribotechnical properties of the surface and subsurface layers that are the hydrogen accumulator in their volume.

The wear of the subroughness of friction surfaces in the hydrogen-containing environment is the subject of the study [1]. In the latter, hydrogen is injected into the subsurface layer of a metal body and interacts with its crystal lattice. It is noted that the driving force in hydrogen degradation processes is temperature, pressure, deformation, structure and defects of the crystal grid.

The studies [2 - 5] consider the interaction of hydrogen with metals and non-metallic elements. The influence of hydrogen on the different properties of metals and alloys and on their specific defects is illustrated. The information about hydrogen fragility and the influence of hydrogen on mechanical characteristics in the pair «hydrogen - metal» in the groups of the

D. Mendeleev's periodic system is extended.

The study [6] establishes the relationship between metal friction capture in the crystalline structure of metals. It is shown that metal vapours having a body- and face-centered cubic (BCC and FCC) lattice are intensively worn out due to capture. Friction vapours from metals with close-packed hexagonal (CPH) lattice are worn out significantly less than with BCC or FCC lattices. The large difference in the wear rate of metals with different lattice types is due to the potential for hydrogen wear and development.

The studies [7-10] have determined that under heavy friction conditions the maximum temperature is formed at some depth from the friction surface. This creates the conditions under which hydrogen, if adsorbed to the surface of the component at a temperature gradient, diffuses into the interior of the surface, concentrates there, causes the brittle of the surface layers and increases wear. Though it was not specified what was happening in the subsurface layer of the metal element with the structures of its crystal lattices.

Problem statement

The main issues of the article are: design, operation and energy load of friction pairs of braking devices; hydrogen - accelerator of wear and destruction of working surfaces of metal brake friction elements.

The objective of the work is to investigate the influence of hydrogen wear on the destruction of the metallic friction element in electrothermomechanic friction, with the help of gradient theory and the interaction of periods of amplitude of the longitudinal waves of surface microasperities and the pulley rim crystal lattice material of drill winch strip-block type brake.

Design, operation and energy load of brake friction pairs. The design of the metallic element and its metal content influence the hydrogen wear rate of the working surface significantly. Figures 1 *a*, *b*, *c* show the friction pairs of different types of brake devices.

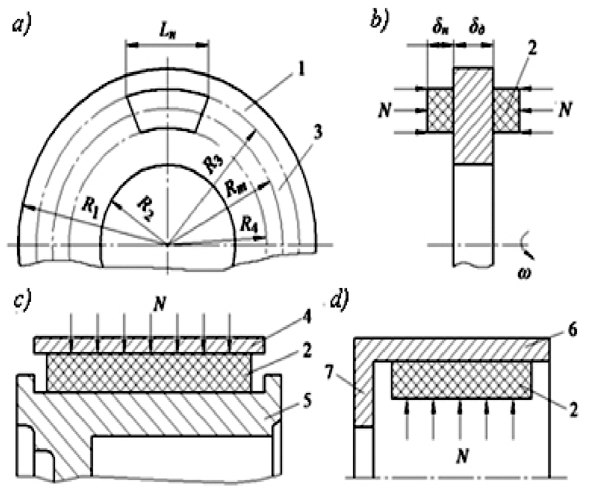

Figure 1 *a*, *b*, *c*, *d* – Layouts of different types of brake friction units: *a*, *b* – disc-block(longitudinal and transverse) *c* –strip-block (transverse); *d* - drum-block (cross section); 1, 3 - brake disc with friction track, 2 - friction linings; 4 - brake tape; 5, 8 - the rim of the pulley with the supporting protrusion; 6, 7 - flange drum

The different arrangement of the metal friction elements of the braking devices in relation to the air flows of the surrounding surfaces makes it possible to operate in terms of the longitudinal and transverse flow. Thus, the friction pairs of the strip- and drum-block brakes are exposed to two streams of air, while the disc-block brakes are only exposed to the transverse air flow.

The results of calculations of the dependency presented in work [7] are shown in figure 2 *a*, *b* in terms of the variation in the second-by-second air flow, longitudinally and transversely of the strip brake element of the drill winch, depending on the degree of their heating.

Dependency analysis in figures 2 *a*, and 2 *b* show that the amount of air transecting the working elements of the strip brake in a temperature range from 100 to 1000 ºC is, on average, 568 times less, than the gaps between the internal surface and the inoperable surface of the friction linings and their side surfaces. The speed of the air at the transverse change between the above-mentioned brake friction pair temperatures is 5.1 times higher during braking than when the brake is opened. The air-shift time is 4.96 times slower for open brake than for the strip brake during braking. When comparing heat transfer coefficients presented as graphics in fig. 2*a* and 2*b* from the heated parts of the strip-block brake, when there is a transverse change of the surrounding air, we see that their values are 14.95 times higher when the brake is opened than when it is in operation. A comparison of the rate, speed and time of the air shift with the transverse and longitudinal air scrubbing of the open brake components (see fig. 2*b* and 2 *c*) shows that the transverse airflow is 7.6 times higher than the longitudinal airflow. This circumstance leads to an air speed and changeover time of respectively 852 and 2.37 times higher longitudinal than transverse diagramair scrubbing of the strip brakes.

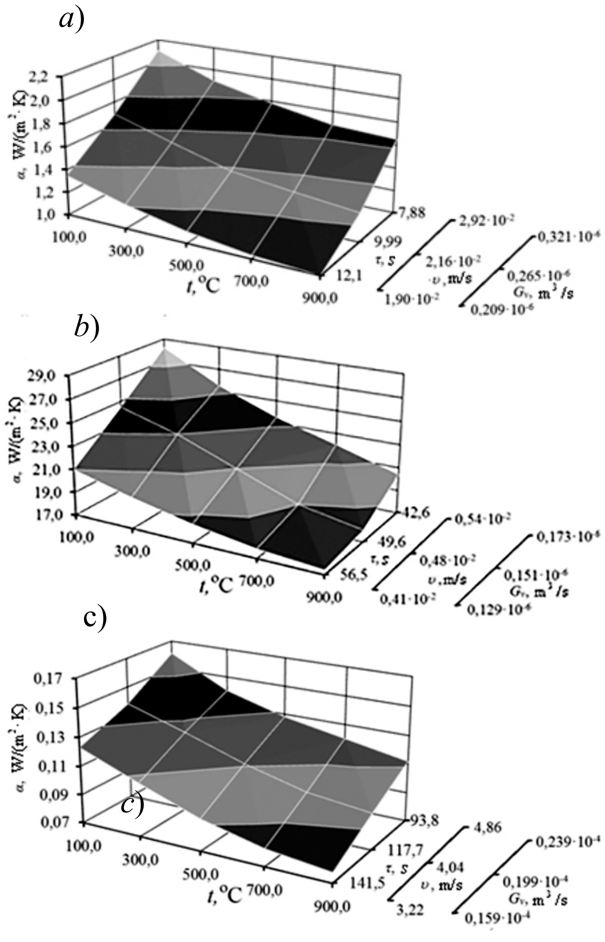

Figure 2 *a*, *b*, *c* – Pattern of heat transfer coefficient (*α*) from heated strip-block brake components while air scrubbing as follows: transverse (*α*)during braking; transverse (*b*) and longitudinal (*c*) in the case of open braking; at different temperatures (t) of the working surfaces of the friction elements of the ribbon-cam brake and from the time of change (τ), the speed (*V*) and the flow (*G*v) of the air washing the working surfaces of the brake

The following are the values of the heat-recovery coefficients of convection from the non-closable part of the bandage during braking, depending on the angular speed of the friction pairs: at an angular speed of rotation of the bandage equal to 3, 6, 9, 12 and 15 c^{-1}, the values of the heat-recovery coefficients of convection are respectively 3.64; 1.81; 1.21 0.905 and 0.725 W/(m^2 K). As can be seen, as the angular speed of the friction pairs of the strip-block brake increases, the heat-transfer coefficient of the convection from the bandage is reduced due to the reduction in the time of interaction of its working surface with the surrounding air. Calculate the total heat recovery coefficients of heated band brake elements over the braking process (63 plugs) when lowering it into a well and before the start of braking (64 plugs).

I. During braking. Initial data: temperature of friction pairs of the strip-block braking system before the start of braking t_1 = 575°C, at the end of braking t_2=590°C, time of braking $\tau_т$=2,1 s, angular speed of friction pairs ω = 8,95 s^{-1}. By graphical dependence (see fig. 2 a) at t = (575+590) / 2 = 582.5°C air flow G_V = 0.267 10^{-6} m^3/s, its speed and time of change are respectively υ = 2,34 10^{-2} m/s, τ = 9.8 s and heat-transfer convection coefficient of heated strip brake elements α_1=1.345 W/(m^2 K). The heat-return coefficient of the convection air of the brake strip that is not covered is $\alpha_л$ = 1,205 W/(m^2 K). The heat transfer coefficient of the friction pairs of the brake at t=582.5°C is the graphical relationship $\alpha_л$ = 48,6 W/(m^2 K). The total heat transfer coefficient is

$$\sum\alpha = 1,345+1,205+48,6= 51,15 W/(m^2 K).$$

II. The brake is open. Option A. Cross-air scrubbing of heated strip brake elements. Initial data: temperature of lateral surface of friction linings $t_н$=440°C, temperature of inner surface of tape $t_л$ = 75°C, time of forced cooling $\tau_о$= 2.0 min. By graphical dependence (see fig. 2 *b*) at $t_ф$=440°C air flow $G_V = 0,1461\cdot10^{-3}$m^3/s, air speed and time υ = 0.523 10^{-2} m/s,

τ = 42,28 s and heat return convection is α_1 = 26.0 W/(m^2 K).

The radiant heat transfer coefficient at $t_ф$ = 440 ºC is $\alpha_л$ = 42,6W/(m^2 K).

The total heat transfer coefficient is obtained

$\Sigma\alpha$ = 26,0+42,6 = 68,6W/(m^2 K).

Option B. Longitudinal air scrubbing of strip brake friction surfaces. Initial data: temperature of working surface of bandage $t_б$ = 390ºC, temperature of working surface of friction linings $t_н$ = 590ºC, time of natural cooling τ_o = 2.0 min.

For t = (390+590)/2 = 490ºC, derived from the graphic dependency (see fig. 2 *c*); G_V = 0,201·10^{-4}m3/s, υ = 4,05·10^{-2}m/s; τ = 111.86 s, α_1 = 0.1125 W/(m^2 K). In this case $\alpha_л$= 39.0 W/(m^2 K).

Thus the total heat transfer factor is $\Sigma\alpha$ = 39.112 W/(m^2 K).

According to the developed methodology, heat transfer coefficients from heat-loaded brake service elements are determined in a range of temperatures from 100 to 1000ºC, which vary with longitudinal (0.77...0.161) W/(m^2 K) and transverse (17.4...28.2) W/(m^2 K) change in the air scrubbing in case of an open condition and in the case of a transverse change - from 0.95 to 2.1 W/(m^2 K). The heat transfer by the radiation of the braking surfaces in the temperature range from 100 to 1000ºC changes the heat transfer coefficient by descending from 5.0 to 138.5 W/(m^2 K).

Thus, from the analysis of the values of the heat transfer coefficients, it follows that with the brakes switched on and off, most of the heat is allocated by radiation and the smaller by convection. In addition, the insufficient efficiency of forced air cooling contributes to the intensification of hydrogen wear on the working surface of the brake pulley rim.

Hydrogen is an accelerator of wear and tear on the working surfaces of metal brake friction elements

The presence of microasperities of interacting surfaces of different heights in a pair of «metal-polymer» results in the concentration of specific loads and, consequently, in the generation of electrical and thermal currents at individual areas of contact surfaces, which increases local temperatures (flares and surface temperatures). This process is referred to by Burton as the «thermoelasticinstability». As the microasperitiescontinue to interact, the elevation of the sections where the specific loads develop will decrease due to wear and tear until contact occurs everywhere. At the same time, the new contact areas are starting to heat up, expand and absorb the load; the old ones decrease the load, cool down. The scale of heated areas is large compared to the scale of surface roughness, and the time of the described cycle is large compared to the time of interaction of roughness.

The variation of the wave geometry during the thermoelastic instability, as well as the regularities of the variation of its wear-friction properties during the contact-pulse interaction, leads to the following. The electrothermomechanic resistance of discontinuous contacts with different energy activity of microcapacitors and thermobataries [6, 7] with instantaneous switching thereof at the change of spots of contacts of microasperities and gradients of mechanical properties, as well as the rate of penetration of pulses of electric and thermal currents interacting with one another causes «destruction» of the more heated boundary of the wave and is compensated by the process of its continuous restoration when the materials are pumped on the less heated boundary of the wave. Furthermore, the penetration of pulses of electrical and thermal currents affects the wear rate of the areas of the microasperitiesduring re-polarization, which leads to the destabilization of the dynamic friction factor.

Fig. 3 *a*, *b*, *c*, *d* show the regularity of the variation of the thermoelastic instability of the stains of the metal-polymer friction pair contacts at V = *f(p),* where *p* is the specific loads; *V* is the speed of slipping. In order to avoid transient phenomena, one of the surfaces is represented as perfectly smooth and electro the rmally nonconductive. The fixed microasperitiesof the polymer lining have a slip coefficient *c* and their surfaces contain a small initial wavelength amplitude Δ with a wavelength λ.

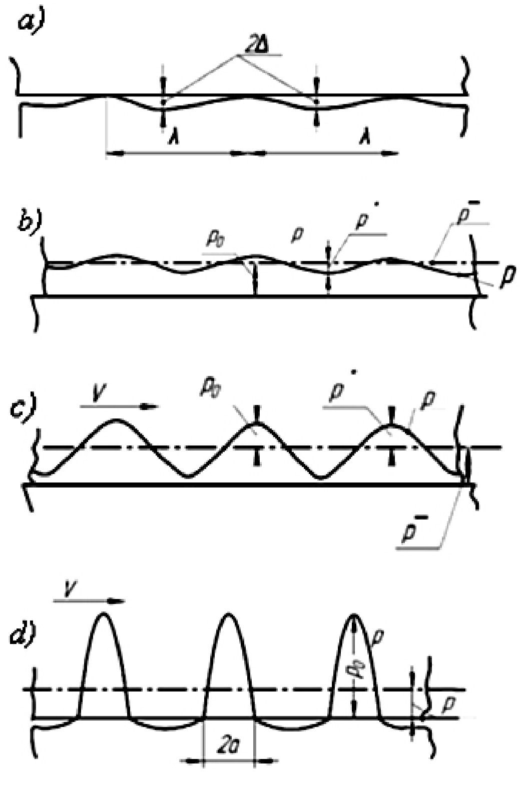

Figure 3 *a*, *b*, *c*, *d* – Regularity of thermoelastic spot instability variation of metal-polymer friction pair contacts $V = f(p)$:*a* - unloading; *b*, *c*, *d* - when loaded, when V=0; $V \le V_c$; $V_c > V$

From fig.3 follows that the initial sinusoidal waviness of the wavelength λ gives a fluctuation in the specific load of the same length as the formula [8].

$$p(x) = \overline{p} + p^* \cos(2\pi / \lambda) \tag{1}$$

A review of the fluctuating components of specific loads and electrical and thermal currents made it possible to estimate the thermal distortion of the friction surface of the lining.

In order to compress the wave to a quasi-flat surface, the thermally specific loads *p(x)* need to be reinforced by insulated specific loads (fig. 3 *b*). Subsequently, as the speed of sliding *(V)* increases to a tolerable value *(V_c)*, the fluctuation of specific loads increases rapidly in magnitude (Fig. 3*c*).

When the fluctuation of the specific loads p^* reaches their average value $\overline{p}$ the surfaces will be divided on initial wavy valleys and the contact spot will be concentrated in the ridges (fig. 3 *d*). Suppose that the specific loads on the contact sections are $-a \le x \le a$ Hertz, i.e.

$$p(x) = p_0 \left[1 - \left(\frac{x}{a} \right)^2 \right]^{0,5},$$

where $p_0 = aE^* / 2R$; E^* isthe Jung module of friction materials at p^*

The curvature ρ of the distorted surface at x=0 is determined from the expression

$$\rho = cfVp_0, \tag{2}$$

where *f* is the dynamic coefficient of friction.

The dependence (2) is fair when the initial waviness is low compared to the subsequent thermal distortion.

Thus, from the dependency (2) it follows that

$$a = 2/(cfVE^*). \tag{3}$$

Continuous contact is intermittent when $V \rightarrow V_c$, which allows the permissibledimension of the contact area $\alpha_c = \lambda/(2\pi)$ to be determined after a series of transformations.

The uneven distribution of specific loads on contact spots directly results in the uneven distribution of electrical and thermal currents and consequently in the uneven distribution of surface temperatures. At speeds of sliding less than permissible when microcontacts are in continuous interaction, the fluctuation of specific loads aresinusoidal with amplitude p^* (see fig. 3 *b*). It follows that electrical and thermal currents are also sinusoidal, confirming their wave nature [6].

Let's stop on fluctuation of crystalline lattice of metal element of friction under influence of dynamic and heat load of the brake. The laws of elasticity which take place in the friction pair «metal - polymer» at their friction interaction, at longitudinal and transverse deformations reflect the mutual categorical relationships between (current) instantaneous deformations and fluctuations of the crystal lattice of the subsurface metal friction element [9].

The energy quanta of elastic fluctuations are called phonons. Sound waves in crystals are seen as the spread of phonon quasiparticle, and thermal fluctuations of crystal lattice are seen as the thermal excitation of phonons.

The dispersion of waves depends on the phase speed $\upsilon_ф$of the harmonic wave and its frequency ω. The latter depends on the wave number k of the flat harmonic wave $\omega = \omega(k)$. The dispersion equation can have several branches that correspond to different types of waves (modes), i.e. longitudinal and transverse.

In most cases, the dispersion of longitudinal and transverse waves is caused by the micro-nano-scale properties of the subsurface layers of the metallic friction element (fluctuations of atoms and molecules, their thermal movement, and the structure of the crystal lattice). In dispersing medium a distinction is made between the temporal (private) and spatial dispersion depending on the braking mode. The time dispersion is characteristic for the emergency and single brakes of the cyclic loading mode. It is determined by the delay (inertia) of a physical response (for example, electrical or thermal polarization) to mechanical displacement.

The spatial dispersion of longitudinal and transverse waves occurs during prolonged braking, when the behaviour of the subsurface layer of the metallic friction element depends on the dynamic and thermal loading not only of the discrete microasperities of the friction surfaces, but also neighbouring microasperities, i.e. there is a non-localized response of surface microasperitiesto the external impact.

The character of the fluctuationof the crystalline lattice of the surface layer of the metal element of friction is affected by its defects and heat load. If there are many defects in the crystal, the local fluctuationaroused by one defect can move to the other. In this case the local fluctuation have a narrow frequency band, i.e., they form an imputed zone of fluctuation frequencies. The fluctuationamplitude is greater the higher the temperature of the surface layer of the metal friction element is, but it is always significantly smaller than the permanent crystalline lattice. The heat fluctuations (background) may be subjected to sonic fluctuations caused by the diffusion of elastic waves in the crystal. They are produced by external action in the form of a normal force acting non-periodically and forming part of the dynamic friction coefficient.

Fig. 4*a*, *b* show the longitudinal (*a*) and transverse (*b*) waves when the crystal lattice is fluctuating and distorted (*c*, *d*) when the normal force (N) is applied to them under electrothermomechanic friction. A significant change in the amplitude (A) during time (τ) of action of the normal forces (N) is described. In the first case (fig. 4 *c*), the wave lengthens and in the second (fig. 4 *d*) it flattens, but the wave amplitude remains the same. The amplitude of the transverse wave of fluctuations is increased by the longitudinal wave of fluctuations.

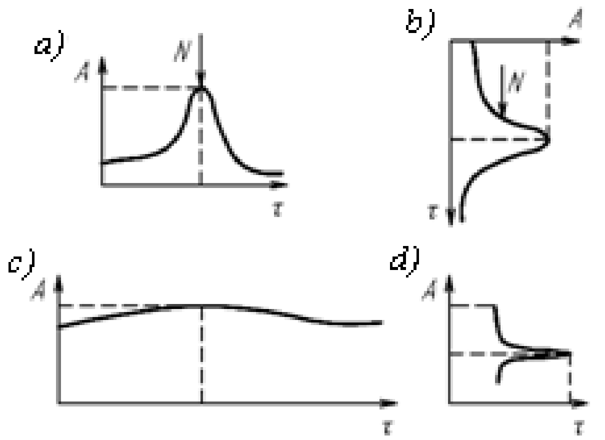

Figure 4 *a*, *b*, *c*, *d* – Longitudinal (*a*) and transverse (*b*) waves when the crystal lattice is fluctuating and distorted (*c*, *d*) by normal forces

Hydrogen formation is largely determined by the temperature factor of the medium. Accordingly, the intense wear on the working surface of the water-soaked pulley that interacts with CO in a high-temperature state leads to the formation of hydrogen, for example by reaction:

$CO + H_2O \rightarrow CO_2 + H_2$.

The increase in temperature on the metal-polymer tripod-contact initiates the thermal decomposition of polymers to form intermediate compounds, the dehydrogenation of which hydrogen produces [10].

In the surface layer of the pulley rim atelectrothermomechanic friction, mechanical action results in breakdowns of the chemical bonds of the crystal lattice, microfractures appear, and the destruction of the material integrity of the pulley rim occurs. The resulting fresh fracture surfaces of the solid material of the working surface of the rim have free, uncorrelated chemical bonds with the active centres, are disequilibrium and have very different properties from the normal surface. The metals of transition groups (Cr, Ni, Mn, etc.) contained in cast steel 35ChNL are capable of catalyzing dissociation processes of water molecules.

The distribution of hydrogen in the material is highly dependent on imperfect crystal structure. By penetrating structural defects that are point, linear, surface, volumetric and energetic, such as incipient cracks, hydrogen atoms collide to form molecular hydrogen that is much larger than atomic hydrogen in diameter.The reaction of the formation of atomic hydrogen is accompanied by the release of a significant amount of heat which stimulates other chemical processes with the creation of new hydrogen phases in the crystal lattice (for example, hydrogen reacts with residual metal elements to form hydrides). As a result of these processes, considerable tensile stresses arise, and the increased internal pressure in the defects destroys the material through all developed and connected cracks. Multiple cracks, fusing may immediately turn a surface layer of an element into a powder [11-14].

The degree of hydrogen absorption of surfaces in electrothermomechanic friction is altered by medium factors. The influence of hydrogen, as an accelerator of wear and destruction of the working surface of the pulley rim when in contact with water in hydrocarbon medium, when changes in humidity and temperature of the medium are given in [15].

The process of hydrogen wear is intensified in wet and cold climates. One of the reasons for the rapid wear of the friction pairs of the strip-block brakes of the drill winches operated in Siberia in the northern regions of the country, where in the process of working the technique has been in contact with snow for a long time, is intensive tribohydrogenabsorbtion. Due to the large temperature difference, hydrogen is not dissipated at low temperatures in surface layers, but is concentrated between the friction zone and the volume of the rubbing part material.

At low temperatures, the manure exceeds several times the value fixed at ambient temperatures.

Key steps in the hydrogen wear of tribocoupling complement the above mentioned (see fig. 5).

The main directions of reducing the hydrogen absorption of the working surface of the metal friction element of braking devices are:

- «Scaring off» the external hydrogen containing in wet air, rain water and snow, by sealing the working surfaces of the rims of pulleys and drums, as well as treadmills of friction of discs;

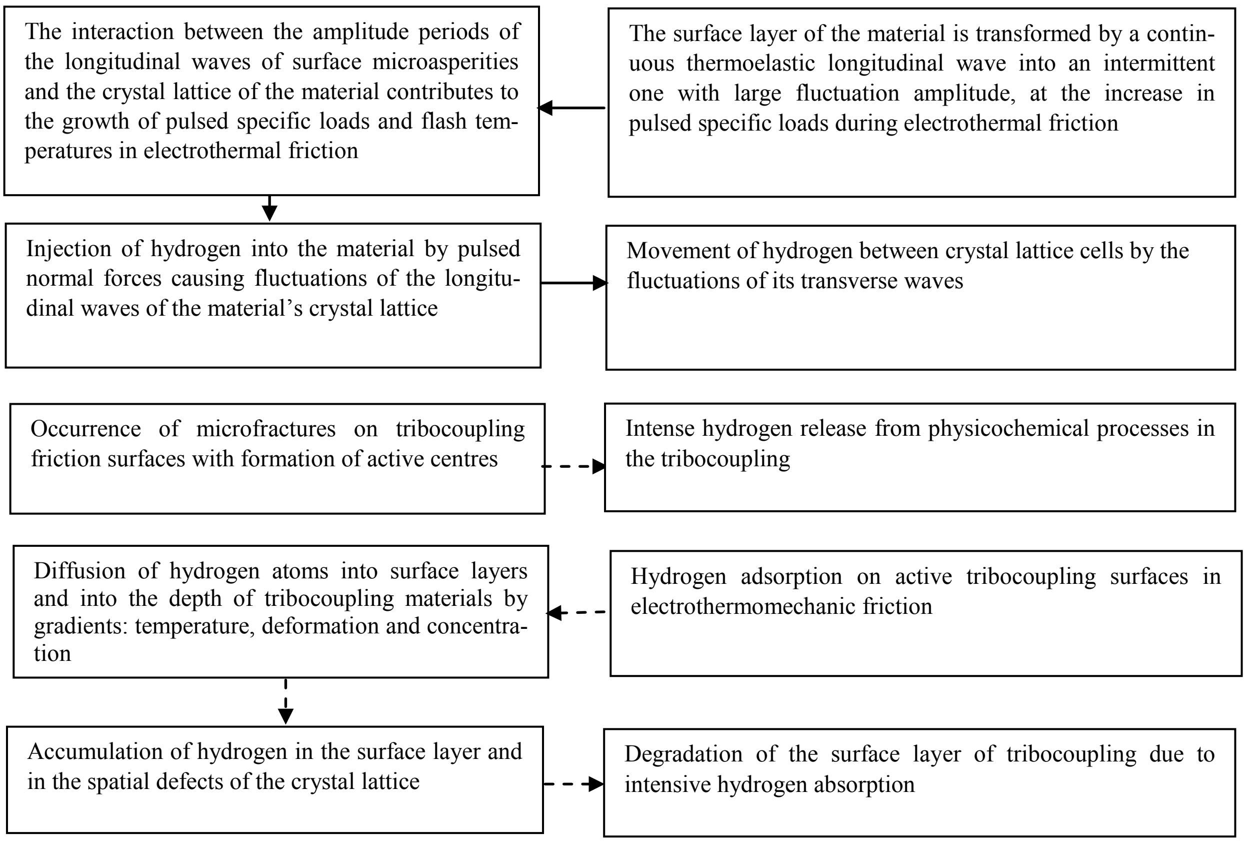

Figure 5 – Main steps in the hydrogen wear of tribocoupling

- creation of electric and electromagnetic fields charged positively «repulsive» external hydrogen from internal hydrogen;

-introduction into the crystalline lattice of the metal of chemical components which «deter» external hydrogen;

- limiting the interaction of the external longitudinal and transverse material with similar waves of the crystal lattice by controlling specific loads in friction pairs.

Conclusion

The main stages of hydrogen wear and destruction of the metallic friction element during electrothermomechanic friction with the aid of gradient theory and the interaction of periods of amplitude of the longitudinal waves of surface microasperities and the crystal lattice of the rim pulley material of strip-block drill winch brake are described.

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Received: *21.11.2020*
Revised: *14.09.2021*
Accepted: *21.09.2021*