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THE PROBLEM OF PROBABLE DISTRIBUTION PATTERNS OF THE MAIN OPERATIONAL FRICTION PAIR PARAMETERS OF BRAKES

A.Kh. JANAHMADOV[1+], N.A. VOLCHENKO[2], M.Y.JAVADOV[3],
P.S. KRASIN, V.S. SKRIPNIK[4], I.O. BEKISH[4]

Prediction of the reliability of designed friction units of brake devices is possible only if there are patterns of the probable distribution of their main operational parameters. The latter include the dynamic friction coefficient of friction units and wear of the working surfaces of the pads.

The presence of numerous data from domestic and foreign researchers made it possible to describe the values of the probable distribution of friction materials and operational parameters of friction pairs in curves with different frequencies and amplitudes, which made it possible to establish the suitability of the use of materials, fluctuations in operational parameters and uneven wear of the working surface of each friction overlays

Key words: *braking device, friction pairs, patterns of the probable distribution of their main operational parameters.*

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Introduction. The main operational parameters of vehicles disc brakes are the dynamic coefficient of friction and wear of their friction pairs. In contrast to brake discs, the base material components for friction pads produced by various companies, i.e. the amount of different types of additives, determined by a huge number of of friction pad types. Moreover, manufacturers, as a rule, develop them according to the materials of brake discs, which are heating energy storage devices, undergo a stress-strain state depending on temperature conditions and the nature of braking. At the same time, there should be minimal wear of the friction pair, durability of operation, minimal dependence on weather conditions, environmental friendliness and economy of production and operation, comfort of driving a car and its maintenance, etc. Among the largest world manufacturers of the braking pads, the following may be noted: “Federal Mogul”, “Honeywell”, “TMD Friction”, TRW, “Allied Signal”, “Ferodo” (establishment – Great Britain), “Otto Zimmermann” (establishment – Germany), “Masuma” (Japan), “Hankook FRIXA” (South Korea), EBC, “Brembo Group” (main office in Itali, braking systems for Porshe and Ferrari Vehicles), ATE, “Akenobo” (Japan), “Kashiyama”, LPR, etc. In the CIS countries – АТИ, ТИИР, «МарКон» (Jaroslavl, Russia), “АККОР” factory (Naberezhnye Chelny), Nizhegorod braking pads factory “ЮККА” (Russia); “Dafmi”, “Best” (Ukraine), GNU IPM, PRUM “Molodechny powder metallurgy plant” (Belarus) and etc.

Literature analysis and problem statement. The work [1] shows diagrams and graphical dependencies for the main types of friction materials used in friction pairs of vehicles and their ranges of change in operational parameters: sliding speeds, specific loads, dynamic coefficients of friction, sur-

[1] National Aviation Academy (Baku, Azerbaijan)
[2] Kuban State Technological University (Krasnodar, Russia)
[3] Azerbaijan Engineering Academy
[4] Ivano-Frankovskiy National Technical University of Oil and Gas (Ivano-Frankovsk, Ukraine)
+ Janahmadov Ahad, E-mail: dzhanakhmedov@yahoo.com

face temperatures, linear and volumetric wear. However, the given data were not summarized and the exact ranges of their variation, as well as the laws of distribution, were not indicated.

The longevity distribution of polymer brake linings is characterized by position, scale and shape parameters. In turn, the durability depends on the main operational parameters (temperatures: flash, surface and volumetric; dynamic coefficient of friction) friction. A number of distribution laws are known [2] normal, Gumbel, type I, exponential and Rayleigh, have a fixed form and do not require an explicit form parameter. Other distribution laws: logarithmic, normal, Weibull, gamma distribution, Student's, F - distribution and beta distribution, have one or more shape parameters, which allows you to select more accurately the type of distribution to describe the sample data. Regardless of whether the distribution has a shape parameter, sample data can be described with sufficient accuracy by selecting suitable values for the position and scale parameters.

However, in this work, there were no attention paid to the distributions of the operating parameters of the brakes according to the function of sines and cosines. Besides, there are no "pure distributions", but there are hybrid combinations of distributions.

Electrodynamically established patterns of change in operational parameters (specific loads, dynamic coefficient of friction, surface temperatures during heating and forced cooling and wear of the working surface of the lining) metal-polymer friction pairs of band-block brakes of drawworks [3]. At the same time, attention was not paid to the generalized pattern of changing the operational parameters of several friction materials and brake linings.

Kragelski have presented as a group diagram wear distribution of a friction units. The first group included disc and disc brakes, and the second - drum and shoe brakes. The groups were fixed depending on the load patterns in friction pairs.

The purpose of the work is to substantiate the probabilistic distribution of the main operational parameters of brake friction pairs.

Hypotheses for the distribution of density probabilities of parameters. Lets examine the statistical hypothesis, which is some statements about the complex distributions, for example, the statement that the time of failure-free operation of the brake friction pads when drilling at a depth of 4000 m is 50-60 hours, or that a random variable obeys this distribution.

Definition. Hypotheses stating that there is no difference between the compared values of the parameters, and the observed deviations are explained only by random fluctuations in the samples, are called null hypotheses and are designated as H0. All other hypotheses that differ from zero are called alternative and are designated as H1.

Let's consider errors of the first and second kind. *The error of the first kind*, denoted by α, is called the error of rejecting a correct hypothesis. The value 100 α% serves as a level of significance.

An error of the second kind, denoted by β, is an error of accepting a false hypothesis. The value 1 - β is called the power of the criterion. By expressing this value in terms of a certain parameter, a *power function* is obtained. Obviously, the choice of the values of α and β should depend on the consequences of committing errors of the first and second kind, respectively. The only way to simultaneously reduce errors of both kinds is to increase the sample size of parameters [3]. The sample space for all possible values of the statistics underlying the criterion for testing the hypothesis is divided into two parts: the region of admissible values and the critical region in which the hypothesis is rejected (Fig. 1).

Hypothesis verification order

1. Hypotheses H0 and H are formulated
2. α and β are chosen. (In some cases, instead of β, n is chosen - the distribution law of the smallest ordinal statistics of the sample size).
3. Selective statistics (criterion) is selected.
4. The critical area is determined.
5. Statistic is calculated based on the sample.
6. Hypothesis H0 is accepted or rejected.

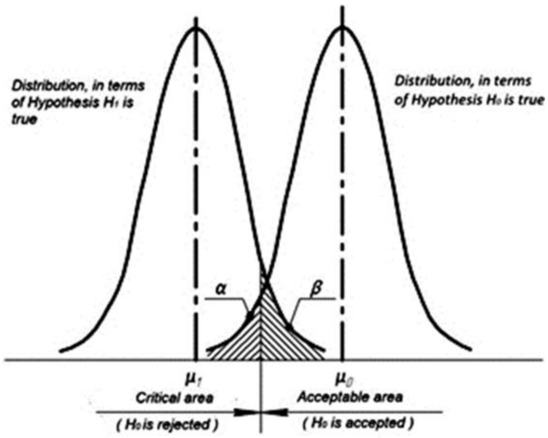

Fig. 1 *- The range of acceptable values and the critical area of the selection of parameters*

This is how the classical approach of the distribution of the density probabilities of the parameters are implemented.

Fig. 2 illustrates the distribution of basic and sample functions, discrete density probabilities and their analysis for the operational parameters of braking devices. Distribution of density probabilities of operating parameters of braking devices. Let's examine the approximate composition of the materials used for the manufacture of friction linings (Fig. 3). As a rule, rubbers (up to 200° C) and phenolic resins or their modifications are used as a polymer bond [5, 6], which withstand temperatures on the friction surface up to 400 - 450° C. A slight increase in operating temperatures can be achieved through the use of polyamide resins of the API-2 type, but they are much less technologically advanced [8].

The main types of abrasive additives include powders of the following materials: SiO_2, Al_2O_3, SiC, B_4C, TiC, WC, Fe_2O_3, Fe_3O_4, Cr_2O_3, MgO, $ZnSiO_4$, etc. [7, 8, 9]. Typically, abrasives with a Mohs hardness of 7 to 9 are used.

The introduction of *modified additives* is aimed to solve a wide range of problems - the formation of a friction membrane and stabilization of the friction process (lubricants), a decrease in wear, an increase in the dynamic coefficient of friction, heat resistance and thermal conductivity. Among the most used modifying additives, the following may be highlighted $CaSiO_3$, $Ca(OH)_2$, $CaCO_3$, $BaSO_4$, MoO_3 and lubricants - MoS_2, graphite, coke, Sb_2S_3, PbS, Cu_2S [7, 8, 10]. Metal powders - Fe, Cu, Al, Sb, etc., can also be used as modifying additives, which, in addition to increasing thermal conductivity, creates oxidation-reduction membrane to reduce wear and can play the role of abrasive additives.

As *reinforcing materials*, the following are used: metal (for example, Fe, Cu, steel) and organic (aramid and carbon) fibers, ceramic fibrous materials (microfiber made of K_2TiO_3, $Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O$ (sepiolite), Al_2O_3, glass and basalt fibers) [7, 8, 10]. Fibrous fillers, in addition to increasing the strength and rigidity of the brake pad material, like metal powders, improve the tribotechnical and tribophysical characteristics of friction materials.

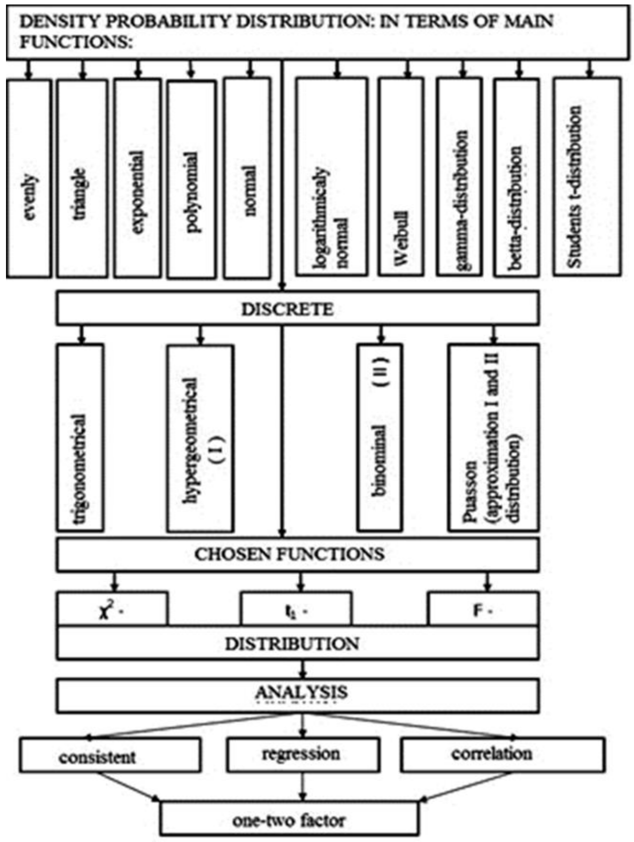

Fig. 2 *- Distribution by basic and sample functions, discrete densities probability and their analysis for the performance parameters of braking devices*

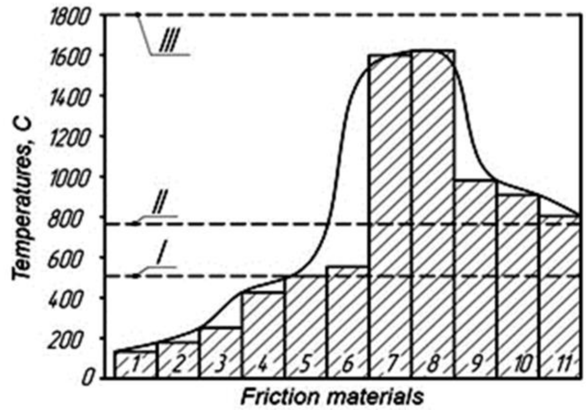

Fig. 3 *- The main types of friction materials used in friction pairs of vehicles and their operating temperature ranges: volumetric (I), surface (II) and flash (III): 1 - leather, nylon, cork; 2 - wood; 3, 5, 6 and 11 - rubber-based polymer, aluminum-based sintered powder materials; combined binder; resin binder and resin binder after heat treatment; 4, 9 - sintered powder based on: copper, iron; 7, 8 - composite with a matrix: carbon, ceramic; 10 - cast iron*

Fig. 3 shows that the bulk temperature of 500 ºC can withstand the materials numbered 5-11, and the surface temperature, which exceeds the permissible for many friction materials, only numbered 7 ... 11.

Tab.

Main compound compositions of materials of friction linings based on a polymer matrix

Friction pads materials			According to the patent US 6080230	
			“Ferodo”	
I	II	III	IV	V
Binding materials, 20/40=0,5	Abrasive materials,% 9/6=1,5	Lubricants,% 10/29=0,345	Reinforcing fibers,% 27/10=2,7	Modifying additives,% 34/15=2,26

Comparing the typical compositions of the compositions of the materials of the friction pads, according to US patent 6080230 (I-th) and Ferodo's firm (II-th) based on a polymer matrix, the following is true according to table: according to the first component - the II material is softer than the I; for the second component - the I material will wear out faster than the II; for the third component - in the I material, the wear-friction properties will be lower than in the second; for the fourth component - the I material is stronger than the II; for the fifth component - the I material has better operating materials than the II.

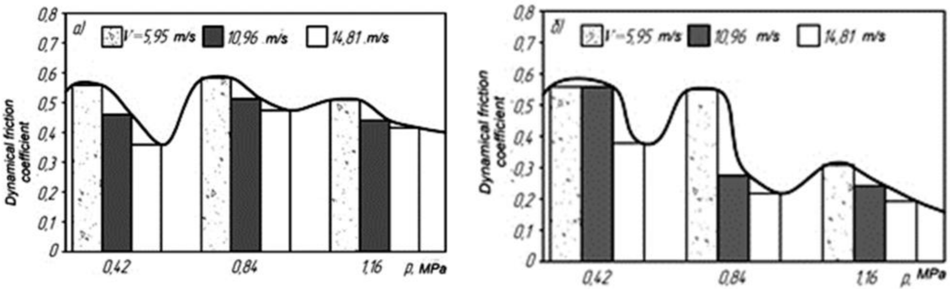

Fig. 4 a, b *- Average values of the dynamic coefficient of friction f depending on the specific loads p and the sliding speed V for friction pairs: a - "ceramic-matrix composites - cermets"; b - "gray cast iron – cermets"*

Thus, the I material can be used in the brakes of medium-duty trucks, and the II- in road vehicles.

Proceeding to the pattern analysis of changes in the average values of the dynamic coefficients of friction f depending on the specific loads p and the sliding speed V for friction pairs (Fig. 4): a - "ceramic-matrix composites - cermets" (I); b - "gray cast iron - cermets" (II). The analysis showed the following: the first friction pair worked in the range of f from 0.58 to 0.35, and the second - from 0.58 to 0.15; in the first pair of friction, the maximum jump f from 0.55 to 0.35 occurred at a specific load of 0.55 MPa, and in the second - from 0.55 to 0.2 at a specific load of 1.0 MPa; the sliding speeds were the same and amounted to 14.81 m/s.

Thus, the first friction pair is hard and has a high allowable temperature for materials, and the second friction pair is soft with a low allowable temperature for materials.

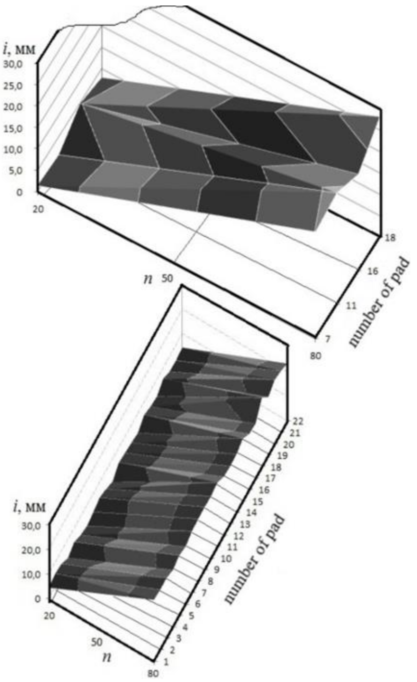

Fig. 5 a, b *- Regularities of linear wear of friction linings on the arc of the belt covering the brake pulley, depending on the number of descents of the drilling tool during six round trips for: a - 7, 11, 16, 18th linings; b - twenty-two belt blocks*

Distribution of the density probabilities for the wear of the band-block brake linings of the drawworks. Along with the dynamic coefficient of friction, one of the main operational parameters is the wear of the working surfaces of the friction linings [11]. Based on the processing of experimental data from the wear of the working surfaces of the brake friction linings of the drawworks model U2-5-5, analytical dependences were obtained to determine the wear of the linings along the width, the correlation coefficient corresponding to each of the linings, the root-mean-square error. For friction linings of a brake band, the correlation coefficient varies within the following limits: from r = 0.714 to r = 0.995, respectively, for the 21st and 12th linings. The values of the correlation coefficients r are close to 1.0, which indicates a stable relationship between the number of runs of the drilling tool and the wear of the linings along the width. The maximum and minimum wear deviation for the above linings is 1.98 and 13.85%.

From the above-obtained analytical dependencies, graphs were built to show the relationship between the linear wear of the working surfaces of the friction linings and the number of runs of the drilling tool during six round trips for: 7, 11, 16 and 18th linings (Fig. 5 a); twenty two belt blocks (Fig. 5 b). It has been established that the linings can work out to permissible wear, that is, to a thickness of 26.0 mm, respectively, 82, 78, 92 and 75 runs of the tool when drilling a well with a depth of 4108 m, the average value is 82 runs. The deviation of other obtained values of the descents from the average are, respectively, 12.2; 8.53; 4.88%. Consequently, the number of descents does not differ significantly, which indicates some leveling of the specific loads of the above pads.

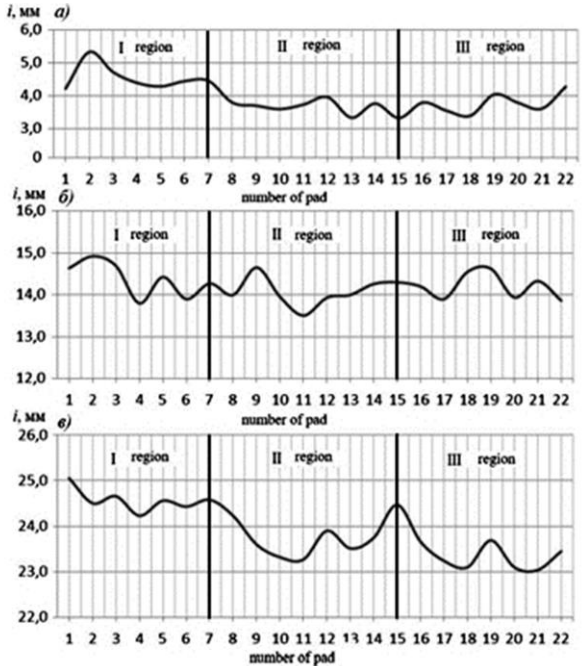

Fig. 6 a, b, c *– Linear wear patterns of the friction linings working surfaces (n = 22 pcs) on the arc of the belt covering the brake pulley after running the drilling tool: a - twenty; b - fifty; c - eighty*

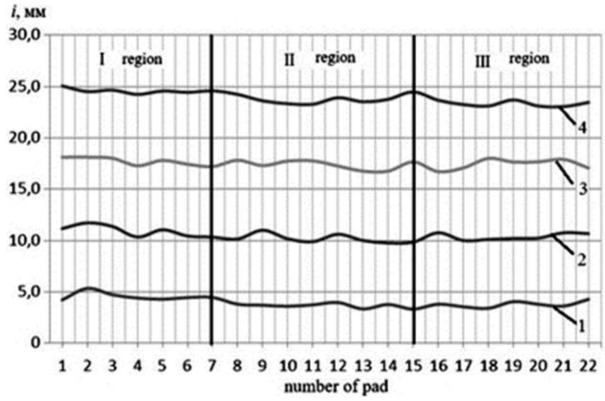

Fig. 7 *- Graphical dependencies of linear wear of friction linings (i) along the length of the band-block brake on the number of runs n of the drilling tool (curve 1 - n = 20; curve 2 - n = 40; curve 3 - n = 60; curve 4 - n = 80)*

Fig. 6 a, b, c and 7 show the regularities of linear wear of the working surfaces of the pads when running the drilling tool. The obtained dependencies confirm the wave nature of wear at the center point of each belt block lining.

Fig. 8 and 9 a, b, c, d shows the histograms of the wear distribution over the width of the friction linings of the band-block brake of the U2-5-5 drawworks. Histograms were built according to the following relationship:

$$P' = \sum m_i / \sum m_i$$

where m_i - the total number of friction linings with uneven wear in the intervals: 0 ... 1, 1 ... 2, 2 ... 3, 3 ... 4, 4 ... 5, 5 ... 6 mm; $m_н$ - the total number of the investigated friction linings (33 pcs).

The histograms shown in Fig. 8 a, b, c, d are analyzed. For comparison, consider the 7th, 11th, 16th, 18th brake band lining of serial friction units, with the uneven wear ranges from 3.0 to 4.5 mm. This corresponds to the following percentages, respectively, 10, 9, 10 and 4%. It may be observed from other histograms that the linings of the incoming belt part have a smaller amount of uneven wear than the outgoing This is due to the higher vibration amplitude of the outgoing belt part, which leads to skewing of the friction linings and an increase in shock loads.

In the improved frictional units from the redistribution of specific loads (Fig. 9 a, b, c, d), there is no uneven wear of the linings in the range of 3.0 ... 4.5 mm. If the wear is uneven from 1.5 to 3.0 mm, the linings (7 and 11) located on the incoming belt part have such percentages, respectively, 36 and 42%. For the blocks (16th and 18th) of the incoming belt part, they are 17 and 53%, respectively. Therefore, the frictional linings of the oncoming strand of the belt have a smaller amount of uneven wear than the outgoing one. As follows from the histograms, the unevenness of the wear of the linings along the width in the improved friction units has significantly decreased in comparison with the values of the uneven wear of the serial friction units. This is explained by a noticeable decrease in specific loads and, as a consequence, surface temperatures and the formation of a steam cushion between the brake friction pairs, which contribute to a decrease in the vibration amplitude of the brake band and shock loads. The surface temperatures of the linings of the incoming part of the belt are reduced to the temperature of the runaway, which causes some leveling of their wear. This leads to possible performance of the friction linings simultaneous replacement of the incoming and runaway branches of the brake bands.

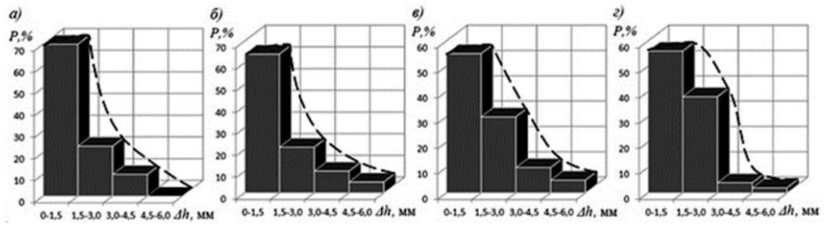

Fig. 8 a,b,c,d *- Histograms of uneven wear distribution in serial linings (in width) of a band-block brake: a - 7th; b - 11th; c - 16th; d - 18th*

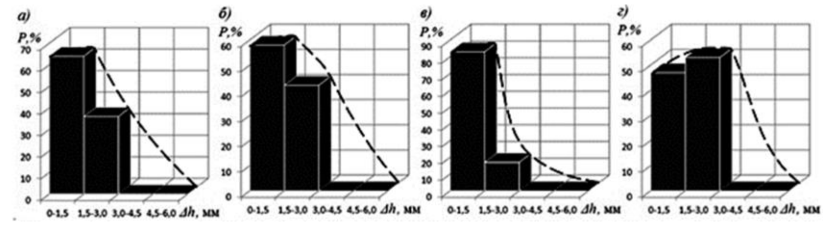

Fig. 9 a,b,c,d *- Histograms of the uneven wear distribution in serial linings (in width) of the improved frictional brake units: a - 7th; b - 11th; c - 16th.*

Conclusion. Theoretical and experimental studies of the main operational parameters probability distribution of friction pair patterns in brakes, using various types of analysis showed the following results.

The analysis was carried out sequential and correlation with the involvement of a one-, two- and three-factor approach to assess the operational parameters of friction pairs; the factors were: friction materials; number and amount of pads, number of runs of the drilling tool; operational parameters were: specific loads, sliding speed, dynamic coefficient of friction, surface, volumetric and flash temperatures, as well as wear of the working surfaces of the linings.

The description of the probability values of the friction materials distribution and the friction pairs operational parameters by curves with different frequency and amplitude, made it possible to establish the suitability of the use of materials, fluctuations in operational parameters and uneven wear of the working surface of each friction pad.

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ƏYLƏCLƏRİN SÜRTÜNMƏ CÜTÜNÜN ƏSAS İSTİSMAR PARAMETRLƏRİNİN EHTİMAL PAYLANMA QANUNAUYĞUNLUĞU PROBLEMLƏRİ

Ə.X. CANƏHMƏDOV, N.A. VOLÇENKO, M.Y.CAVADOV,
P.S. KRASİN, V.S. SKRIPNIK, İ.O. BƏKİŞ

Əyləc qurğularının layihələndirilmiş sürtünmə düyünlərinin etibarlılığının proqnozlaşdırılmasının yalnız onların əsas istismar parametrlərinin ehtimal paylanması qanunauyğunluğu olduqda mümkünlüyü göstərilmişdir. Sonuncuya friksion düyünlərin dinamik sürtünmə əmsalı və onların örtüklərinin işçi səthlərinin yeyilməsi aiddir.

Məqalədə yerli və xarici tədqiqatçılardan əldə olunmuş çoxsaylı məlumatlar əsasında friksion materialların ehtimal paylanması və fərqli tezlik, eləcə də, amplituda ilə sürtünmə cütü əyrilərinin istismar parametrlərinin təsviri göstərilmişdir. Bu da öz növbəsində, materialların istifadəyə uyğunluğunu, istismar parametrlərinin vibrasiyası və hər bir friksion kündənin işçi səthinin qeyri-bərabər yeyilməsini müəyyənləşdirməyə imkan verir.

Açar sözlər: *əyləc qurğusu, sürtünmə cütü, friksion materialın və istismar parametrlərinin ehtimal paylanması qanunauyğunluğu.*

К ПРОБЛЕМЕ ЗАКОНОМЕРНОСТЕЙ ВЕРОЯТНОГО РАСПРЕДЕЛЕНИЯ ОСНОВНЫХ ЭКСПЛУАТАЦИОННЫХ ПАРАМЕТРОВ ПАР ТРЕНИЯ ТОРМОЗОВ

А.Х. ДЖАНАХМЕДОВ, Н.А. ВОЛЬЧЕНКО, М.Я. ДЖАВАДОВ,
П.С. КРАСИН, В.С. СКРЫПНЫК, И.О. БЕКИШ

Показано, что прогнозирование надежности спроектированных узлов трения тормозных устройств возможно лишь в том случае, если имеются закономерности вероятного распределения их основных эксплуатационных параметров. Установлено, что к последним относятся динамический коэффициент трения фрикционных узлов и износ рабочих поверхностей их накладок.

В работе на основе многочисленных данных отечественных и зарубежных исследователей приводится описание величин вероятного распределения фрикционных материалов и эксплуатационных параметров пар трения кривых с различной частотой и амплитудой, что позволило установить пригодность применения тех или иных материалов, колебания эксплуатационных параметров и неравномерность износа рабочей поверхности каждой фрикционной накладки.

Ключевые слова: *тормозное устройство, пары трения, закономерности вероятного распределения фрикционных материалов и эксплуатационных параметров.*

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