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WORKING CAPACITY OF ROLLING PILLOWS AND RELIABILITY INVESTIGATION

The article is devoted to a comprehensive study of the performance and reliability of roller bearings. Based on the analysis of the longevity of the pillows and the generalization of the research results, the method of assessing the impact of key factors on the longevity of roller bearings has been clarified. A mathematical model was obtained to express the longevity of rolling pads as a function of a random argument based on a known law of distribution of conductivity. It has been confirmed that the longevity of roller bearings is distributed by the law of normal logarithmic distribution. Probability-statistical models for estimating the continuous operation of roller bearings as a result of the composition of the distribution function of the dynamic load, taking into account the typical variable loading modes and real operating conditions, have been clarified. Given the need to substantiate the adequacy of probabilistic-statistical mathematical models and to obtain more accurate results, the probability of continuous operation of roller bearings with a high level of reliability was assessed. An analytical model of pillow conductivity has been developed. The probability of uninterrupted operation of the pads was assessed, taking into account the operating modes. Probabilistic-statistical models of longevity of pillows have been clarified. The system of equations obtained as a result of analytical studies represents mathematical models of the continuous operation of roller bearings, taking into account the typical variable loading modes. In order to ensure a high level of reliability and to more accurately determine the effect of the equivalent load, the relative error of the reliability index was 0.05 and the significance level was 0.01. These conditions meet the requirements of methods for assessing the reliability of experimental data.

Key words: *rolling pads, performance, reliability, longevity, operating modes, uninterrupted operation, probabilistic and statistical models.*

Гулієв С.С. Дослідження працездатності та надійності роликових підшипників. *Стаття присвячена комплексному дослідженню експлуатаційних характеристик і надійності роликових підшипників. На основі аналізу довговічності подушок та*

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узагальнення результатів досліджень уточнено методику оцінки впливу ключових факторів на довговічність роликових підшипників. Отримано математичну модель для вираження довговічності прокатних колодок як функції випадкового аргументу на основі відомого закону розподілу провідності. Підтверджено, що довговічність роликових підшипників розподіляється за законом нормального логарифмічного розподілу. З'ясовано ймовірнісно-статистичні моделі для оцінки безперервної роботи роликових підшипників як результату складу функції розподілу динамічного навантаження з урахуванням типових змінних режимів навантаження та реальних умов експлуатації. Враховуючи необхідність обґрунтування адекватності ймовірнісно-статистичних математичних моделей та отримання більш точних результатів, була оцінена ймовірність безперервної роботи роликових підшипників з високим рівнем надійності. Розроблено аналітичну модель провідності подушки. Оцінювалася ймовірність безперебійної роботи колодок з урахуванням режимів роботи. З'ясовано ймовірнісно-статистичні моделі довговічності подушок. Отримана в результаті аналітичних досліджень система рівнянь являє собою математичну модель безперервної роботи роликових підшипників з урахуванням типових змінних режимів навантаження. Для забезпечення високого рівня надійності та більш точного визначення впливу еквівалентного навантаження відносна похибка індексу надійності становила 0,05, а рівень значущості – 0,01. Ці умови відповідають вимогам методів оцінки достовірності експериментальних даних.

Ключові слова: *прокатні колодки, продуктивність, надійність, довговічність, режими роботи, безперебійна робота, ймовірнісно-статистичні моделі.*

Description of the problem. Different types of machines and mechanisms are widely used in most industries. Machines facilitate heavy manual labor, increase productivity and reduce the cost of production [1, 2].

Machines and mechanisms consist of separate knots, junctions and details, the most responsible of which are knotted pads. The pads support the shafts and the details on the shafts. The details of the pillows must have quality indicators such as strength and rigidity, resistance to wear, heat, vibration and reliability [3, 4].

Pillow-block parts must be functional - be able to perform maintenance in the required time, meet the requirements of minimal preparation and maintenance costs. Therefore, it is important to design pillow-block joints and evaluate their performance and reliability in engineering calculations [5, 6].

At present, the main focus in the design of machines is on the reduction of dynamic loads and mechanical external influences, while ensuring reliability and durability, overall quality, and this issue requires a comprehensive study of cushion joints [7, 8].

Modern trends in the development of mechanical engineering are aimed at increasing the productivity of machinery and equipment and the speed of working bodies, increasing the efficiency of machines, and ultimately improving the quality, reliability and durability of machine parts [5, 6].

It is known that increasing the productivity of machinery and equipment is directly related to increasing the speed of the working bodies. Increasing the speed of the working bodies creates additional dynamic forces. Under the influence of these forces, additional forces are created on the friction parts of the machine, the parts are subjected to elastic deformation, as a result of which the course of technological processes is disrupted. Efficiency factor and reliability of machinery decreases [4, 5].

Statistical analysis shows that the main cause of failure of machinery and equipment is the wear of moving parts of the working bodies due to friction. It is estimated that almost 33% of the world's energy resources are used to repel friction [9, 10].

Low reliability of machinery and equipment leads to increased operating costs and troubleshooting. When reliability is insufficient, the failure of nodes and parts occurs as a result of violation of technological regulations, resulting in serious accidents, which require large costs [7].

However, the increase in reliability is due to the complexity and cost of the equipment. For this reason, the design, manufacture and maintenance costs of the equipment should be kept to a minimum [7, 8]. That is, a level of reliability must be chosen to ensure the optimal cost of design, development and operation.

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Analysis of recent research and publications. The literature review showed that the methods for determining the resource and reliability of roller bearings are not sufficiently developed, and the issues of reducing the material capacity and ensuring the accuracy of the bearings are pending [9, 10]. There is a need for a comprehensive study of the handling and carrying capacity of analytical methods, taking into account the high level of reliability of rolling pads.

Purpose of the article. Thus, the purpose of this work is to increase the level of reliability of rolling pads on the basis of analytical assessment of leadership.

Presentation of the main material. *Analytical model of pillow-block conductivity.* It is known that many factors affect the longevity and conductivity of rolling pads. These factors can affect the research object individually or in combination, as well as in combination with several factors [3, 5].

Some factors can affect the pillow-block by overlapping, some can disappear, and in turn, the sum and difference of each factor can be added or subtracted, and the factors can interact with each other. This means that the effect of many factors on the performance of pillow-blocks has a complex synergistic nature [4, 6].

If we consider the residual conductivity of the pillow-blocks as a result of the combined effect of these factors, then it is necessary to take into account the combined or synergistic effect of the factors to determine the dispersion of performance.

It is known that the equivalent load or overload can be considered as a more important factor, the nature of which allows to assess the condition of the roller bearings and increase the accuracy of the probability of uninterrupted operation. Other factors include the quality characteristics of the construction material, the kinematic and dynamic loading parameters.

However, in order to synergistically evaluate all of these effects, a function must be obtained that takes into account the scattering of the affected loads and the corresponding change in the scattering function of the dynamic load-bearing or conduction capacity [4-6].

It is practically impossible to determine experimentally the function of pillow conduction distribution by conducting an excessive number of experiments [6]. However, at a given value of the resource of the node, the required amount of data from different values of the dynamic load *(C)* can be used for statistical processing.

Try to determine the distribution law of dynamic load *g (C)* analytically. Let $L = \Psi (C)$ be defined as a function of the random argument of longevity by a known law of distribution [6].

Let us examine the logarithmic normal distribution as the assumed distribution laws of longevity:

$$f(L) = \frac{\lg e}{(L-L_0)\sqrt{2\pi \cdot G_y}} \exp\left\{ -\frac{\left[\lg(L-L_0)-a_y\right]^2}{2G_y^2} \right\}, \tag{1}$$

$$f(L) = \frac{b}{c}\left(\frac{L-L_0}{c}\right)^{b-1} \exp\left\{ -\left(\frac{L-L_0}{c}\right)^{b} \right\}, \tag{2}$$

where L_0 – the slip parameter when $L > L_0$; $a_y - y = log(L - L_0)$ – the average value of the random limit; G_y – the mean quadratic inclination of the random limit y.

Taking into account the formula (1), the value of the dynamic load can be determined as follows [6]:

$$C = \phi(L) = \left(a_1 a_{23}\right)^{1/m} PL^{1/m}. \tag{3}$$

As can be seen, the function (3) is monotonous and $C > (a_1 a_{23})^{1/m} P L_0^{1/m}$, then the distribution density or conductivity of the dynamic load bearing of the roller bearing can be represented as the distribution law of the function:

$$g(C) = f\left[\psi(C)\right] \cdot \left|\psi'(C)\right| = f\left[a_1 a_{23}(C/P)^m\right] \cdot \left|\left[a_1 a_{23}(C/P)^m\right]'\right|, \tag{4}$$

where the derivative quantity:

$$\psi'(C) = (a_1 a_{23}(C/P)^m)' = a_1 a_{23} m C^{m-1} / P^m. \tag{5}$$

Using formula (4) and referring to the results of (5), the differential function or conductivity of the dynamic load distribution of rolling pads for the three-parameter logarithmic normal distribution law of longevity (1) can be determined as follows:

$$g(C) = \frac{a_1 a_{23} m C^{m-1} \lg e}{P^m \left(a_1 a_{23} C^m / P^m - L_o\right)\sqrt{2\pi \cdot G_y}} \cdot \exp\left\{-\frac{\left[\lg(a_1 a_{23}(C^m / P)^m - L_0) - a_y\right]^2}{2G_y^2}\right\} \tag{6}$$

for the Veybull's distribution:

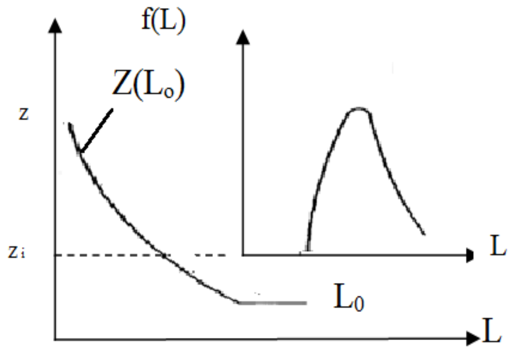
$$g(C) = \frac{a_1 a_{23} m C^{m-1} b}{P^m c} \cdot \left(\frac{a_1 a_{23}(C^m / P)^m - L_0}{c}\right)^{b-1} \cdot \exp\left\{-\left(\frac{a_1 a_{23}(C^m / P)^m - L_0}{c}\right)^b\right\}. \tag{7}$$

The probability of uninterrupted operation of the pads, taking into account the operating modes. By determining the law of distribution of the conductivity of the pads and the loading modes, the probability of continuous operation of the roller pads can be found as the difference of independent random quantities [6]:

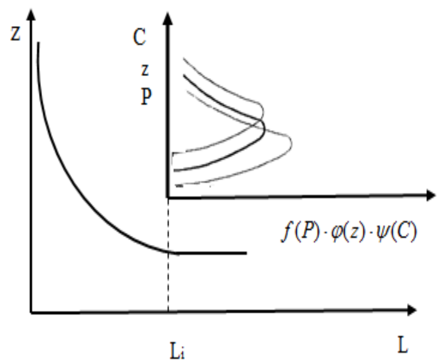
$$C - P = Z.$$

The loading curve $Z (L_o)$ of the left roller bearings is shown in the figure below (Figure 1,a). The left side of the curve shows the probability of continuous operation and the distribution density of longevity for the Z_i load level. The figure on the right shows the differential graphs of their compositions for a certain L_i value of the acting load, dynamic load and longevity (Fig. 1, b).

The condition for continuous operation of roller bearings is that they do not exceed any limit value of the quantity Z for the distribution densities $f(P)$, $\Psi(C)$, $\varphi(Z)$ selected on the right. The probability that this condition is met is determined by the area below this selected curve.



a)



b)

Fig. 1 – Probability of continuous operation of roller bearings

If we consider that the most important random factors for roller bearings are the characteristics of dynamic load C (conductivity) and equivalent loading P (loading function - $f(P)$), then the residual carrying capacity is an integral sum, taking into account the symbols in the formula $Z = C - P$ is defined as, and the scattering function is as follows:

$$\psi(z)=\int_0^{+\infty}\psi(C)f(C-z)\cdot dC=\int_0^{+\infty}\psi(P+z)f(P)dP. \quad (8)$$

Thus, the final equation *Z* of the distribution density of the random value of the residual conductivity can be written as follows for the typical variable operating modes, taking into account the three-parameter logarithmic normal distribution law of longevity – (6) and normal, equal probability and *β*-distribution functions:

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e\cdot\exp\left\{-\left[(C-z)/P_{\max}-\overline{n}\right]^2/2G^2\right\}}{P_{\max}P^m\left(a_1a_{23}C^m/P^m-L_0\right)2\pi\cdot G_y\cdot G}\cdot\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dC, \quad (9)$$

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e}{P^m\left(a_1a_{23}C^m/P^m-L_0\right)\sqrt{2\pi\cdot G_y\cdot(B-A)}}\cdot\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dC, \quad (10)$$

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e\cdot\left(\frac{C-z}{P_{\max}}\right)^A\left(1-\frac{C+z}{P_{\max}}\right)^B}{P^m\left(a_1a_{23}C^m/P^m-L_0\right)\sqrt{2\pi\cdot G_y}\cdot B(A,B)}\cdot\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dC. \quad (11)$$

The equations of the distribution density of a random quantity *Z*, the three-parameter Veybull's distribution for the longevity of roller bearings – (7) and the normal, equal probability and *β*-distribution functions can be written as follows for typical variable operating modes:

$$\phi(z)=\int_0^{+\infty}\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\cdot\exp\left\{-\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^b\right\}\frac{a_1a_{23}mC^{m-1}b}{P^mc}\times$$
$$\times\frac{\exp\left\{-\left[(C-z)/P_{\max}-\overline{n}\right]^2\right\}}{\sqrt{2\pi\cdot G\cdot P_{\max}}}dC, \quad (12)$$

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}b}{P^mc\cdot(B-A)}\cdot\left(\frac{a_1a_{23}C^{m1}/P^m-L_0}{c}\right)^{b-1}\cdot\exp\left\{-\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^b\right\}dC, \quad (13)$$

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}b}{P^mc}\cdot\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\cdot\frac{\left(\frac{C-z}{P_{\max}}\right)^A\left(1-\frac{C+z}{P_{\max}}\right)}{B(A,B)}\cdot\exp\left\{-\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^b\right\}dC. \quad (14)$$

Thus, the dependencies (9)÷(14) express the integral effects of the main factors on the residual conductivity through random functions, which in turn are determined by the appropriate coefficients of longevity and conductivity.

Probabilistic-statistical models of longevity of pillow-blocks. It is necessary to determine the main characteristics of the obtained distribution laws in order to identify the different designs of rolling pads, the conditions of damage and the general characteristics of the loading regimes.

Variations in residual conductivity can be estimated by mathematical expectation, which determines the average value of the random effects of the relevant factors [5, 6]:

$$\hat{M}\{Z\} = \int_{-\infty}^{\infty} z \cdot \phi_i(z) \cdot dz. \quad (15)$$

The function *M {Z}* and its variances determine the scattering of the residual lead:

$$\hat{D}\{Z\} = \int_{-\infty}^{\infty} \left(z - \hat{M}\{Z\}\right)^2 \phi_i(z) \cdot dz = \int_{-\infty}^{\infty} z^2 \phi_i(z) \cdot dz - \hat{M}^2\{Z\}. \quad (16)$$

The accuracy of the statistical characteristics of residual conductivity *M(z)* and *D (z)* is determined by the limits of possible deviations of the obtained values or confidence intervals at the required level of significance α. When the variance is unknown *(1-α)*, the mathematical expectation in the corresponding confidence interval can be defined as follows:

$$\hat{M}\{Z\} - t_{a,N} - 1\sqrt{\frac{\hat{D}\{X\}}{N}} \le M\{X\} \le \hat{M}\{X\} + t_{a,N} - 1\sqrt{\frac{\hat{D}\{X\}}{N}}. \quad (17)$$

The variance in an unknown mathematical expectation can be found as follows:

$$\frac{(N-1)\hat{D}\{X\}}{\chi^2_{i,\alpha}} \le D\{X\} \le \frac{(N-1)\hat{D}\{X\}}{\chi^2_{i,\alpha}}, \quad (18)$$

where $t_{a,N}$ – F_{N-1} ($t_{a,N-1}$) = 1-0,5α, $F_{N-1}(t)$ – is the root of the (17) equation; N – the number of degrees of freedom of the Student's distribution function *N-1* is the number of observed random quantities; $\chi^2_{r,\alpha}$ and $\chi^2_{l,\alpha}$ with α – are the roots of the equations; $F_N(X)$ – is a distribution function with degree of freedom F_N ($\chi^2_{r,\alpha}$)=1-0,5α and F_N ($\chi^2_{l,\alpha}$)= 0,5α .

For each factor determined by any random quantity, and the optimal value of the integral permanent conduction capacity determined by random quantities affecting the conductivity in contact with other factors, the coefficient of variation can be determined:

$$\hat{V} = \sqrt{\hat{D}\{Z\} / \hat{M}\{Z\}}\,. \quad (19)$$

By paying attention to the value of the coefficient of variation, it is possible to judge the effect of each factor on how one or another factor affects the performance of roller bearings. If the factors taken into account are constant, then the solution of the problem is much simpler, ie only one parameter can be taken as a variable, for example, the number of revolutions of the shaft on the cushion.

The results of numerical calculations showed that the assessment of the reliability of roller bearings depends on the operating time of the bearings during the control selection, the volume of the selection and the distribution of longevity.

It was found that the experimental-statistical approach is the optimal method of estimating the residual conductivity of pillows and allows to determine a random quantity from another – through the longevity of pillows and obtain regression models. The accuracy of the mathematical model and the importance of individual factors can be assessed by Fisher's and Student's criteria.

Thus, for the longevity of roller bearings, the three-parameter logarithmic normal distribution law and the equation that characterizes the scattering of the operating load, taking into account the Veybull's distribution, can be expressed as follows:

$$\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e\cdot\exp\left\{-\left[(C-z)/P_{\max}-\bar{n}\right]^2/2G^2\right\}}{P_{\max}P^m(a_1a_{23}C^m/P^m-L_0)2\pi\cdot G_y\cdot G}\times$$
$$\times z\cdot\exp\left\{-\frac{\left[\lg(a_1,a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dCdz, \quad (20)$$

$$\hat{M}\{Z\}=\left(\int_0^{+\infty}\int_0^{+\infty}\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\exp\left\{-\left(\frac{a_1a_{23}\dfrac{C^m}{P^m}-L_0}{c}\right)^b\right\}\times$$
$$\times\frac{a_1,a_{23}mC^{m-1}b\cdot z}{P^mc}\frac{\exp\left\{-\left[(C-z)/P_{\max}-\bar{n}\right]^2\right\}}{\sqrt{2\pi\cdot G\cdot P_{\max}}}dCdz, \quad (21)$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e\cdot\exp\left\{-\left[(C-z)P_{\max}-\bar{n}\right]^2/2G^2\right\}}{P_{\max}P^m(a_1a_{23}C^m/P^m-L_0)2\pi\cdot G_y\cdot G}\times$$
$$\times z^2\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_o)-a_y\right]^2}{2G_y^2}\right\}dCdz-\hat{M}^2\{Z\} \quad (22)$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\exp\left\{-\left(\frac{a_1a_{23}\dfrac{C^m}{P^m}-L_0}{c}\right)\right\}x\frac{z^2a_1a_{23}mC^{m-1}b}{P^mc}\times$$
$$\times\frac{\exp\left\{-\left[\dfrac{[lC-z]}{P_{\max}}-\bar{n}\right]^2/2G^2\right\}}{\sqrt{2\pi\cdot G\cdot P_{\max}}}dCdz-\hat{M}^2\{Z\}. \quad (23)$$

The significance of the mathematical expectation and variance values for the longevity of roller bearings, taking into account the equivalent probability of operation load distribution, logarithmic normal and Veybull's distribution, can be expressed as follows:

$$\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{z\cdot a_1a_{23}mC^{m-1}\lg e}{P^m(a_1a_{23}C^m/P^m-L_0)\sqrt{2\pi}\cdot G_y\cdot(B-A)}\exp\left\{-\frac{\left[\lg(a_1,a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dCdz, \quad (24)$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{z^2 a_1 a_{23} m C^{m-1}\lg e}{P^m(a_1 a_{23} C^m/P^m-L_0)\sqrt{2\pi}\cdot G_y\cdot(B-A)}\cdot\exp\left\{-\frac{\left[\lg(a_1 a_{23} C^m/P^m-L_0)-a_y)\right]^2}{2G_y^2}\right\}dCdz-\hat{M}^2\{Z\} \tag{25}$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1 a_{23} m C^{m-1} b}{P^m c\cdot(B-A)}\cdot\left(\frac{a_1 a_{23} C^m/P^m-L_0}{c}\right)\cdot z^2\exp\left\{-\left(\frac{a_1 a_{23} C^m/P^m-L_0}{c}\right)^b\right\}dCdz-\hat{M}^2\{Z\} \tag{26}$$

The importance of the values of mathematical expectations determines the average value of the indicated random effects of the corresponding factors and variances. This average value characterizes the scattering of the operational load for the β-distribution of the scattering capacity. Taking into account three-parameter logarithmic normal and Veybull's distribution, we can write for the longevity of roller bearings:

$$\begin{gathered}\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1 a_{23} m C^{m-1}\lg e\left(\frac{C-z}{P_{\max}}\right)^A\left(1-\frac{C+z}{P_{\max}}\right)^B}{P^m(a_1 a_{23} C^m/P^m-L_0)\sqrt{2\pi}\cdot G_y\cdot B(AB)}\times\\ \times z\cdot\exp\left\{-\frac{\left[\lg(a_1,a_{23} C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dCdz,\end{gathered} \tag{27}$$

$$\begin{gathered}\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1 a_{23} m C^{m-1} b\cdot z}{P^m c}\cdot\left(\frac{a_1,a_{23} C^m/P^m-L_0}{c}\right)^{b-1}\cdot\frac{\left(\frac{C-z}{P_{\max}}\right)^A\left(1-\frac{C+z}{P_{\max}}\right)^B}{B(AB)}\times\\ \times\exp\left\{-\left(\frac{a_1,a_{23} C^m/P^m-L_0}{c}\right)^b\right\}dCdz,\end{gathered} \tag{28}$$

$$\begin{gathered}\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1 a_{23} m C^{m-1}\lg e\cdot\left(\frac{C-z}{P_{\max}}\right)^A\left(1-\frac{C+z}{P_{\max}}\right)^B}{P^m(a_1 a_{23} C^m/P^m-L_0)\sqrt{2\pi}\cdot G_y\cdot B(AB)}z^2\exp\left\{-\frac{\left[\lg(a_1 a_{23} C^m/P^m-L_0)-a_y)\right]^2}{2G_y^2}\right\}dCdz-\\ -\hat{M}^2\{Z\}\end{gathered} \tag{29}$$

$$\begin{gathered}\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{a_1 a_{23} m C^{m-1} b\cdot z^2}{P^m c}\left(\frac{a_1 a_{23} C^m/P^m-L_0}{c}\right)^{b-1}\left(\frac{C-z}{P_{\max}}\right)^A\cdot\frac{\left(1-\frac{C+z}{P_{\max}}\right)^B}{B(AB)}\times\\ \times\exp\left\{-\left(\frac{a_1 a_{23} C^m/P^m-L_0}{c}\right)^b\right\}dCdz-\hat{M}^2\{Z\}.\end{gathered} \tag{30}$$

Let us determine the significance of the values of the mathematical expectation that determine the average value of the relevant factors and variances. These, in turn, determine the scattering of residual conductivity for a stable loading regime and a dynamic loading or conducting capacity composition.

Given the possible longevity models of roller bearings, it is possible to write for logarithmic normal and Veybull's distribution, respectively:

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}\lg e}{P^m(a_1a_{23}C^m/P^m-L_0)\sqrt{2\pi}\cdot G_y}\cdot\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dC, \quad (31)$$

$$\phi(z)=\int_0^{+\infty}\frac{a_1a_{23}mC^{m-1}b}{P^mc}\cdot\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\exp\left\{-\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^b\right\}dC, \quad (32)$$

$$\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{za_1a_{23}mC^{m-1}\lg e}{P^m(a_1,a_{23}C^m/P^m-L_0)\sqrt{2\pi\cdot G_y}}\cdot\exp\left\{-\frac{\left[\lg(a_1,a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dCdz, \quad (33)$$

$$\hat{M}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{z\cdot a_1a_{23}mC^{m-1}b}{P^mc}\cdot\left(\frac{a_1,a_{23}C^m/P^m-L_0}{c}\right)^{b-1}\cdot\exp\left\{-\left(\frac{a_1,a_{23}C^m/P^m-L_0}{c}\right)^b\right\}dCdz, \quad (34)$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{z^2a_1a_{23}mC^{m-1}\lg e}{P^m(a_1a_{23}C^m/P^m-L_0)\sqrt{2\pi\cdot G_y}}\cdot\exp\left\{-\frac{\left[\lg(a_1a_{23}C^m/P^m-L_0)-a_y\right]^2}{2G_y^2}\right\}dCdz-\hat{M}^2\{Z\}, \quad (35)$$

$$\hat{D}\{Z\}=\int_0^{+\infty}\int_0^{+\infty}\frac{z^2a_1a_{23}mC^{m-1}b}{P^mc}\cdot\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)\exp\left\{-\left(\frac{a_1a_{23}C^m/P^m-L_0}{c}\right)^b\right\}dCdz-\hat{M}^2\{Z\}. \quad (36)$$

Thus, the system of equations (20)-(36) obtained as a result of analytical studies represents mathematical models of the continuous operation of roller bearings, taking into account the typical variable loading modes. To ensure a high level of reliability and to more accurately determine the effect of the equivalent load, the significance level was assumed to be 0.01 when the relative error of the reliability index was 0.05. These conditions are described in «Methods for estimating the reliability of experimental data / PD 50-690-89» normative technical document.

Conclusions

Based on the analysis of the longevity of the pillow-blocks and the generalization of the research results, the method of assessing the impact of the main factors on the longevity of the roller pillows has been clarified. A mathematical model was obtained to express the longevity of rolling pads as a function of a random argument based on a known law of distribution of conductivity. The scattering of the longevity of ball bearings by the law of normal logarithmic distribution has been confirmed.

Probability-statistical models for estimating the continuous operation of roller bearings as a result of the composition of the distribution function of the dynamic load, taking into account the typical variable loading modes and real operating conditions, have been clarified. Given the need to justify the adequacy of probabilistic-statistical mathematical models and to obtain more accurate results, the probability of continuous operation of high-reliability roller bearings was assessed.

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