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STUDY OF LOAD DISTRIBUTION BETWEEN ROLLING BODY

Abstract. The load distribution between rolling elements of a non-rotating bearing with increasing interference fit of the outer ring is investigated. It is found that the unevenness of the load distribution between rolling elements decreases, and increases with increasing clearance fit. With increasing clearance fit, the load on the central rolling element increases for all loads applied to the bearing.

To establish the influence of the main factors and their interaction on the change in the coefficient of load distribution between rolling elements and to obtain a mathematical model, the studies were carried out using multifactorial experiment planning. The signs at the coefficients of the model show that in order to achieve the most uniform load distribution between rolling elements, the thickness of the polymer coating should be at the upper level, and the radial clearance of the bearing and the load on the bearing should be at the lower level.

Keywords: bearing, seats, clearance, operation, wear, interference, load, fit.

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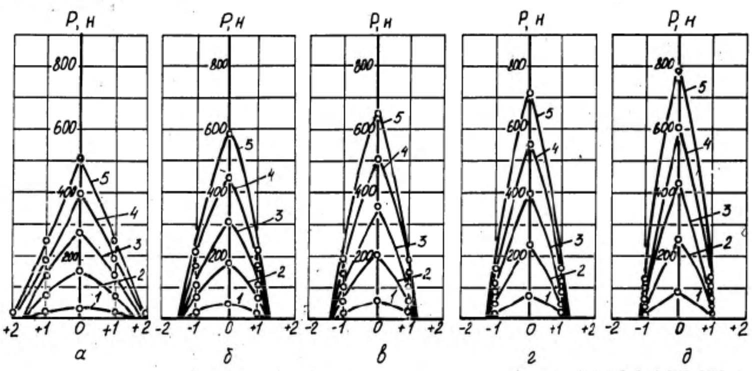
Introduction. Studies of the load distribution between the rolling elements of a non-rotating bearing have shown that with an increase in the interference fit of the outer ring, the unevenness of the load distribution between the rolling elements decreases, and with an increase in the clearance fit, it increases. For example, Figure 1 shows the load distribution between the rolling elements of a bearing with a radial clearance of 0.008 mm with an interference of 0.005 mm and packing clearances of 0.057, 0.123, 0.236 and 0.336 mm.

In Figure 1, the numbers on the abscissa axis indicate the ordinal numbers of the rolling elements: central (0), first lateral (-1, +1), second lateral (-2, +2). The ordinate axis shows the load supported by each rolling element.

With a fit interference of 0.005 mm, the load on the central rolling element increases with increasing bearing load and reaches 518 N with a load of 1044 N (Fig. 1a). Part of the load applied to the bearing is supported by the lateral rolling elements. Thus, with a bearing load of 143 N, the first lateral rolling elements support a load of 20 N, and with a bearing load of 1044-245 N. With maximum bearing load, the second lateral elements support a load of 15 N.



1,2,3,4,5 – bearing load 143, 406, 619, 831 and 1044 N, respectively.

a – fit interference 0.005 mm; b, c, d, e – fit clearance 0.057, 0.123, 0.236 and 0.336 mm, respectively.

Figure 1. Load distribution between rolling elements with a radial bearing clearance of 0.008 mm

With an increase in fit clearance, the load on the central rolling element increases for all loads applied to the bearing. Thus, the load on the central rolling element with a fit clearance of 0.336 mm and a bearing load of 1044 N is 780 N, which exceeds the load on the central rolling element of a bearing with a fit interference of 0.005 mm by 1.5 times.

With an increase in the fit clearance, the load on the lateral rolling elements decreases. With a fit clearance, only the first lateral rolling elements bear the load, while the second lateral rolling elements do not bear any load. If with a load of 1044 N and an interference of 0.05 mm the first lateral elements bear a load of 245 N, then with a fit clearance of 0.057 mm – 214 N, 0.123 mm – 186 N, 0.236 mm – 158 N and 0.336 mm – 130 N.

Thus, with an increase in the fit clearance, the load on the central rolling element increases, and on the lateral rolling elements it decreases, which increases the unevenness of the load distribution between the rolling elements.

If the obtained values of the load on the central rolling element are substituted into the formula, the service life of a rolling bearing with a fit clearance of 0.336 mm will be 3.92 times less than with an interference fit of 0.005 mm.

Materials and methods. The uniformity of the load distribution between the rolling elements can be characterized by the load distribution coefficient, which is defined as the ratio of the load on the first lateral rolling element to the load on the central rolling element. Figure 2 shows the dependence of the load distribution coefficient on the interference fit and fit clearance for a bearing with a radial clearance of 0.008 mm and a bearing load of 1044 N. With an increase in the fit clearance to 0.336 mm, the load distribution coefficient decreases from 0.47 to 0.16.

It was not possible to compare the experimental values of the load distribution coefficient at different values of the fit clearance with the calculated ones, since the known formulas do not take fit clearances into account.

The smaller the fit clearance, the greater the distribution coefficient and the more uniformly the load is distributed between the rolling elements. Therefore, in rolling bearings of tractors, cars and agricultural machinery installed with a clearance, there is a significant unevenness of the load distribution between the rolling elements, which reduces the service life of the rolling bearings. In addition, when installing a bearing in a housing without interference, the outer ring of the bearing rotates and the seating surfaces wear out intensively, which leads to an increase in the fit clearance and an even greater increase in the unevenness of the load distribution between the rolling elements.

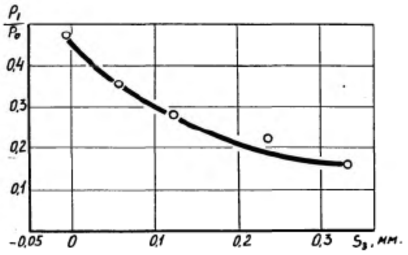
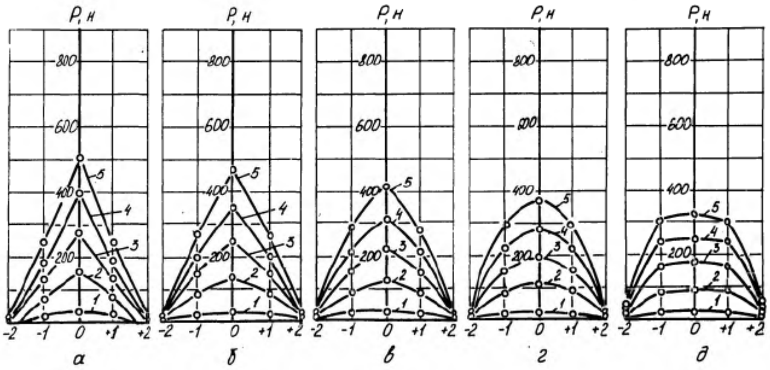


Fig. 2. Dependence of the coefficient of load distribution between rolling elements on the interference fit and clearance with a radial bearing clearance of 0.008 mm

The studies of load distribution between rolling elements during bearing fit restoration with the sealant BF were carried out with a coating thickness of 8, 58, 98, 139, 182 μm under bearing loading with a load of 143, 406, 619, 831, 1044 N.

When restoring fit clearances with the sealant 6F, the unevenness of load distribution over rolling elements is significantly reduced. With a polymer coating thickness of 8 μm (Fig. 3a), the load distribution is close to load distribution between the rolling elements of a bearing installed with an interference fit of 0.005 mm without a polymer coating.



P – bearing load 143, 406, 619, 813, 1044 N, respectively. a, b, c, d, e – polymer coating thickness 8, 53, 98, 139, 182 μm, respectively.

Fig. 3. Load distribution between rolling elements when restoring the bearing fit with 6F sealant

The greatest load falls on the central rolling element. In this case, part of the load is supported by the first lateral rolling elements. The second lateral rolling elements do not support the load at low bearing loads, and with an increase in the bearing load, they begin to support an insignificant part of the load. With increasing thickness of the polymer coating, the load on the central rolling element decreases, and on the lateral rolling elements increases (Fig. 3b, 3c, 3d), the load is redistributed between the rolling elements. With a polymer coating thickness of

182 μm, the load on the central element and the first lateral rolling elements is almost equalized.

When restoring the bearing fit by applying coatings from the 6F sealant solution, the load on the most loaded rolling element decreases by more than 1.5 times compared to a bearing installed with an interference fit of 0.005 mm without a polymer coating, and by more than 2.4 times compared to a bearing installed with a fit clearance of 0.336 mm also without a polymer coating. As a result, the service life of the rolling bearing can be increased by 4.55 and 18.2 times, respectively. Figure 4 shows the dependence of the coefficient of load distribution between the rolling elements on the thickness of the polymer coating with a radial bearing clearance of 0.008 mm. The most favorable case of load distribution between the rolling elements is the case in which the coefficient of load distribution is equal to one. In this case, the load on the central and lateral rolling elements is equalized.

With a polymer coating thickness of 182 μm, the coefficient of load distribution between the rolling elements is close to one. A further increase in the thickness of the polymer coating can lead to an even greater increase in the coefficient of load distribution. However, an excessive increase in the thickness of the polymer coating can be limited by the service life of the fixed connection [1-3].

Thus, when restoring the fits of rolling bearings with elastomers, their service life can be increased by 18.2 times compared to an installation with a fit clearance of 0.336 mm.

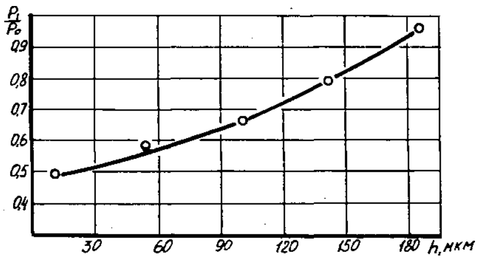
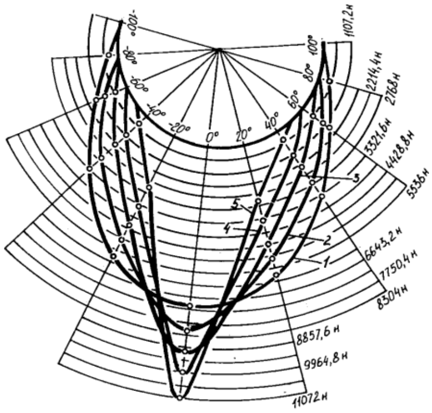


Fig. 4. Dependence of the coefficient of load distribution between rolling elements on the polymer coating thickness with a radial bearing clearance of 0.008 mm

Research results. To confirm the results of the experiments carried out with a stationary bearing, additional experiments were conducted to study the distribution of the load between the rolling elements during bearing rotation and at high load values. The developed experimental research technique made it possible to determine the load distribution along the circumference at any point. Figures 5 and 6 show the load distribution at angles of 0, 20, 40, 60, 80 and 100° relative to the vertical axis of the bearing. The lower half of the bearing was under load, and at angles of 100° and higher, it was not possible to record the load.

Analysis of the experimental results showed that with an increase in the fit clearance, the unevenness of the load distribution between the rolling elements increases (Fig. 5). This in turn leads to a decrease in the loading zone and an increase in contact stresses.

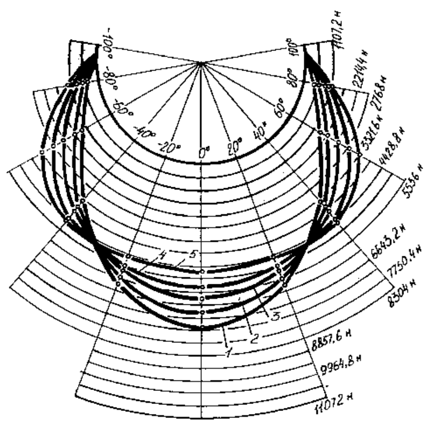
Thus, if with an interference of 0.010 mm the central rolling element takes a load of 7050 N, the first lateral rolling element 3422 N, the second 508 N, then with a clearance of 0.336 mm the central rolling element takes a load of 11072 N, the first lateral rolling element - 484 N, the second element does not take a load. By changing the fit, it is possible to change the load on the central rolling element by 1.6 times.



1 – interference fit 0.005 mm; 2, 3, 4, 5 – clearance fit respectively 0.057; 0.123: 0.236 and 0.336 mm.

Fig. 5. Load distribution between rolling elements during bearing rotation under a load of 11358.2 N

When restoring fixed joints with elastomers, the unevenness of the load distribution between the rolling elements decreases (Fig. 6), the bearing load zone increases and the specific pressure on the working surfaces of the bearing parts decreases. With a polymer coating thickness of 8 μm, the load on the central rolling element is 7041 N, on the first lateral ones – 3428 N, on the second lateral ones – 513 N. An increase in the coating thickness leads to a decrease in the load on the central rolling element and an increase in the load on the lateral rolling elements. Thus, with a polymer coating thickness of 182 μm, the load on the central rolling element is 4694 N, on the first lateral ones – 4675 N, on the second lateral ones – 1201 N. Thus, when restoring the fits of rolling bearings with elastomers, it is possible to increase the load distribution coefficient between the rolling elements by 22.6 times compared to a fit clearance of 0.335 mm, which contributes to a significant increase in the service life of rolling bearings.



1, 2, 3, 4, 5 – polymer coating thickness respectively 53, 98, 139, 182 mm.

Fig. 6. Load distribution between rolling elements during bearing rotation under a load of 11358.2 N and with fits restored with 6F sealant

The experiments showed that the main factors affecting the load distribution coefficient between rolling elements are the radial clearance of the bearing (X1), the load on the bearing (X2), the fit clearance (X3) and the polymer coating thickness (X3/).

Discussion. To establish the influence of the main factors and their interaction on the change in the load distribution coefficient between rolling elements and to obtain a mathematical model, the studies were carried out using multifactorial experiment planning. Due to the incompatibility of two factors: the fit clearance and the polymer coating thickness, the studies were carried out in two stages. The effect of the fit gap and the polymer coating thickness were determined separately.

The results were processed and calculated on a computer using a standard program. The average values of the output parameters for each experiment, the coefficients of the regression equations, the square roots of the reproducibility variances for each experiment and the regression equations are presented in tabular form.

According to the results of calculations on the computer, the regression equations are presented with reliable coefficients normalized by the smallest modulus. Therefore, for the convenience of further calculations, we will write regression equation with true coefficients in the following form.

For experiments without polymer coating:

$$У=0,246 - 0,0738X_1 - 0,031X_2 - 0,01158X_3 - 0,003X_1X_2 + \\ + 0,0762X_1X_3 + 0,0201X_2X_3 - 0,0321X_1X_2X_3 \quad (1)$$

For experiments with polymer coating:

$$У=0,688 - 0,052X_1 - 0,002X_2 + 0,223X_3^{/} + 0,016X_1X_2 + 0,017X_1X_3^{/} + \\ + 0,018X_2X_3^{/} + 0,015X_1X_2X_3^{/} \quad (2)$$

Model adequacy variance

For the first case:

$$S_{ag}^2 = \frac{\sum_{i=1}^{N}(\bar{y}_i - \hat{y})^2}{f} = \frac{0,000008}{4} = 0,000002$$

For the second case:

$$S_{ag}^2 = \frac{0,000008}{4} = 0,000002$$

Fisher's criterion for checking the adequacy of the model for each case:

$$F = \frac{S_{ag}^2}{S_y^2} = \frac{0,000002}{0,000057} = 0,0350$$

$$F = \frac{S_{ag}^2}{S_y^2} = \frac{0,000002}{0,000285} = 0,0070$$

The tabular value of the Fisher criterion for the number of degrees of freedom of the numerator 3 and the denominator 16 is FT = 3.0 [4-6]. The calculated values of the F-criterion in both cases are much less than the tabular one, so the hypotheses about the adequacy of the models are accepted. The experimental plans and results are presented in Table 1 and Table 2 for the cases without and with polymer coating, respectively.

Table 1

Plan and results of the FFE of 2^3 experiments without a polymer coating

Experience №	Factor level			Output parameter value			Average value, $\bar{y}$	Reproducibility variance, S_y^2	Calculated value, $\hat{y}$
	X_1	X_2	X_3	y_1	y_2	y_3			
1	-	-	-	0.651	0.658	0.648	0.651	0.000009	0.652
2	+	-	-	0.258	0.259	0.255	0.257	0.000004	0.256
3	-	+	-	0.473	0.475	0.470	0.473	0.000009	0.474
4	+	+	-	0.208	0.210	0.205	0.208	0.000009	0.207
5	-	-	+	0.115	0.117	0.112	0.115	0.000009	0.116
6	+	-	+	0.197	0.198	0.195	0.197	0.000004	0.196
7	-	+	+	0.166	0.168	0.165	0.166	0.000004	0.167
8	+	+	+	0.094	0.096	0.091	0.094	0.000009	0.093
$\sum_{i=1}^{N} S_y^2 = 0.000057$									

Table 2

Plan and results of the FFE 2^3 experiments with polymer coating

Experience №	Factor level			Output parameter value			Average value, $\bar{y}$	Reproducibility variance, S_y^2	Reproducibility variance, $\hat{y}$
	X_1	X_2	X_3	y_1	y_2	y_3			
1	-	-	-	0.555	0.559	0.550	0.555	0.000025	0.556
2	+	-	-	0.414	0.419	0.410	0.414	0.000025	0.415
3	-	+	-	0.515	0.518	0.510	0.514	0.000016	0.513
4	+	+	-	0.378	0.383	0.370	0.377	0.000049	0.378
5	-	-	+	0.960	0.966	0.956	0.961	0.000025	0.962
6	+	-	+	0.830	0.836	0.820	0.829	0.000064	0.830
7	-	+	+	0.934	0.939	0.922	0.932	0.000081	0.933
8	+	+	+	0.921	0.928	0.919	0.923	0.000025	0.922
$\sum_{i=1}^{N} S_y^2 = 0.000285$									

Conclusion. From the regression equation (1) we see that the greatest influence on the distribution of the load between the rolling elements is exerted by the clearance in the fixed joint. After the clearance, the radial clearance of the bearing has a significant effect, and then the load on the bearing. The signs at the coefficients of the model show that in order to achieve the most uniform distribution of the load when assembling a bearing without a polymer coating, all factors should be at a lower level, i.e. the clearance of the fit, the radial clearance of the bearing, the load on the bearing should have minimum values. From equation (2) it is evident that when restoring the bearing fit by applying coatings from the 6F sealant solution, the distribution of the load between the rolling elements is primarily affected by the thickness of the polymer coating, and then by the radial clearance of the bearing. The bearing load in this case has little effect on the distribution of the load between the rolling elements. The signs at the model coefficients show that in order to achieve the most uniform distribution of the load between the rolling elements, the thickness of the polymer coating should be at the upper level, and the radial clearance of the bearing and the load on the bearing should be at the lower level.

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ЖҮКТЕМЕНІҢ АЙНАЛҒАН ДЕНЕ АРАСЫНДА БӨЛУІН ЗЕРТТЕУ

Аңдатпа. Айналмайтын мойынтіректердегі домалақ денелер арасындағы жүктеменің таралуы сыртқы сақинаның қону кернеуінің жоғарылауымен зерттелді. Домалау денелері арасындағы жүктеменің біркелкі бөлінбеуі төмендейтіні және қону саңылауының ұлғаюымен өсетіні анықталды. Қону саңылауының ұлғаюымен мойынтірекке қолданылатын барлық жүктемелер кезінде орталық домалақ денеге жүктеме артады.

Негізгі факторлардың әсерін және олардың өзара әрекеттесуін анықтау үшін жылжымалы денелер арасындағы жүктеменің таралу коэффициентінің өзгеруіне және математикалық модельді алуға зерттеулер көп факторлы экспериментті жоспарлауды қолдана отырып жүргізілді. Модель коэффициенттеріндегі белгілер жылжымалы денелер арасындағы жүктеменің біркелкі таралуына қол жеткізу үшін полимерлі жабынның қалыңдығы жоғарғы деңгейде, ал мойынтіректің радиалды саңылауы және мойынтіректің жүктемесі төменгі деңгейде болуы керек екенін көрсетеді.

Тірек сөздер: мойынтірек, орындықтар, саңылау, пайдалану, тозу, созылу, жүктеме, қону.

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ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЯ НАГРУЗКИ МЕЖДУ ТЕЛАМИ КАЧЕНИЯ

Аннотация. Исследованы распределения нагрузки между телами качения при невращающемся подшипнике с увеличением натяга посадки наружного кольца. Установлено, что неравномерность распределения нагрузки между телами качения снижается, а с увеличением зазора посадки возрастает. С увеличением зазора посадки нагрузка на центральное тело качения возрастает при всех нагрузках, приложенных к подшипнику.

Для установления влияния основных факторов и их взаимодействия на изменение коэффициента распределения нагрузки между телами качения и получения математической модели исследования проводили с использованием планирования многофакторного эксперимента. Знаки при коэффициентах модели показывают, что для достижения наиболее равномерного распределения нагрузки между телами качения толщина полимерного покрытия должна находиться на верхнем уровне, а радиальный зазор подшипника и нагрузка на подшипник на нижнем уровне.

Ключевые слова: подшипник, посадочные места, зазор, эксплуатация, износ, натяг, нагрузка, посадка.