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Justification of the type of fit depending on the type of loading and radial clearance in rolling bearings

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Abstract. The main cause of failures occurring during the operation of machines is the failure of bearings, the failure of even one lead to the loss of performance of the entire mechanism. The most common are rolling bearings, which have the following advantages: provide more accurate centering of the shaft; have a lower coefficient of friction; have small axial dimensions. One of the most significant factors determining the durability of a bearing is the value of the radial clearance formed in the bearing in its operating condition, which in the same bearings can change dramatically depending on the conditions of their assembly, the fit of the rings on the shaft and in the housing, as well as on the magnitude of the workload. This clearance has a significant effect on the distribution of the load acting on the bearing between its rolling elements, so it is very important to make the right choice already at the design stage.

1 Introduction

It is impossible to imagine modern machines without gearboxes and transmission, which are based on gears mounted on shafts supported by rolling bearings. During operation, rolling bearings experience multidirectional loads, which negatively affects the durability, which is laid down at the design stage [1]. In this case, the failure of even one bearing can lead to the loss of performance of the entire mechanism [2]. When bearing elements are worn, additional distortions and errors appear in gears, seals, excessive noise and vibration, as well as unfavorable redistribution of the load between the rolling elements, which reduces the contact resistance of bearings. All this causes downtime of machines, leads to an increase in repair costs.

In the process of repairing tractors and agricultural machines, the amount of work associated with re-conjugation of joints with bearings is very large. An additional factor affecting reliability is the determination of the actual service life of the bearing, as well as the difficulty in diagnosing them [3-6]. Unlike plain bearings, whose bronze bushings can be repaired, rolling bearings cannot be reused, therefore, it is initially necessary to reduce the influence of possible errors [7, 8]. Also, rolling bearings have the following main advantages compared to plain bearings:

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— provide more precise centering of the shaft;
— have a lower coefficient of friction;
— have small axial dimensions.

The disadvantages of rolling bearings include:
— increased sensitivity to mounting and installation inaccuracies;
— rigidity of work, lack of damping of load fluctuations;
— relatively large radial dimensions.

The service life of a bearing unit depends on many factors determined both by the operating conditions of the bearings (the correct choice of fits, the quality and quantity of lubricants, the magnitude and nature of the load, etc.), and the quality of the bearings themselves (the quality of the metal and heat treatment, the location of the fibers along and across the grooves, the accuracy of geometric parameters, the quality of the processing of rolling surfaces, etc.) [9]. The correct design of both the bearing itself and the bearing assembly is also essential.

Even an average and light operating load causes the destruction of the contact surface of the movable and fixed mates, not only due to their abrasion and crushing, but also due to metal fatigue of the surface layers of the part, which occurs due to repeated mechanical overstress. As a result of repeated loading on certain areas of the working surfaces of the supports, the plastic deformation of their surface layer gradually increases [10].

Molecular bonds that arise between rubbing surfaces and are destroyed during their mutual movement lead to tearing of surface particles and, ultimately, to a change in the dimensions and properties of the working surfaces of the part. The active chemical effect of the environment on the materials of parts, their interaction with lubricants, atmospheric oxygen and other gas or liquid media, the impact of low temperature or humidity lead to corrosive wear, which is usually an integral part of the general process of destruction of machine parts.

The reliability and durability of machines significantly depend on the condition of the fixed connection parts in their design. Mutual microdisplacements of parts mated in such joints cause plastic deformation in their surface layers and, as a consequence, abrasion, first-class seizure, abrasive and oxidative wear [11].

The ratio and development of these types of wear depend on the design and operating conditions of the joint [12]. Landings are weakened due to shape errors (waviness, faceting, etc.), relaxation of contact stresses, crushing and cutting of irregularities in the process of pressing and unpressing bearings, directional plastic deformation of the surface layer of the material that occurs at high specific loads.

One of the reasons for the decrease in the strength of joints with an interference fit during circular bending of the shaft is the sliding of the surface layers of the shaft relative to the hub during bending, which causes fretting corrosion of the seats [13]. Cases of destruction from fretting corrosion are very diverse.

For the development of this process, it is necessary to have a dynamic load and small displacements in the contact (at least an order of magnitude higher than the interatomic distance).

Depending on the degree of affinity of metals for oxygen, the possibility of an active medium entering the contact zone and the strength of the resulting adsorbed and oxide films, the magnitude of the load, etc., processes of mutual diffusion of metals (seizure) or saturation of the metal with oxygen (oxidation) occur.

Corrosion processes are also involved in the destruction of contacted mating surfaces, which can occur both simultaneously with the destruction due to abrasion of the surfaces, and independently of it.

One of the most significant factors determining the durability of a bearing is the value of the radial clearance (Table 1) formed in the bearing in its operating condition, which in the same bearings can change dramatically depending on the conditions of their assembly, the fit of the rings on the shaft and into the body, as well as the magnitude of the workload. This clearance has a significant effect on the distribution of the load acting on the bearing between its rolling elements.

Table 1. Radial clearances gr of single-row radial ball bearings

Nominal bearing bore diameter, d, mm		Clearance size gr, μm									
		min	max	min	max	min	max	min	max	min	max
		Clearance group									
Over	Before	6		Normal		7		8		9	
2.5	10	0	7	2	13	8	23	14	29	20	37
10	18	0	9	3	18	11	25	18	33	25	45
18	24	0	10	5	20	13	28	20	36	28	48
24	30	1	11	5	20	13	28	23	41	30	53
30	40	1	11	6	20	15	33	28	46	40	64
40	50	1	11	6	23	18	36	30	51	45	73
50	65	1	15	8	28	23	43	38	61	55	90
65	80	1	15	10	30	25	51	46	71	65	105
80	100	1	18	12	36	30	58	53	84	75	120
100	120	2	20	15	41	36	66	61	97	90	140
120	140	2	23	18	48	41	81	71	114	105	160
140	160	2	23	18	53	46	91	81	130	120	180
160	180	2	25	20	61	53	102	91	147	135	200
180	200	2	30	25	71	63	117	107	163	150	215
200	225	2	35	30	80	73	130	120	180	167	230
225	250	2	40	34	90	82	145	135	195	180	245

When mating machine parts, it is necessary to choose the right fit, which will ensure the necessary reliability [14]. Despite the existing methods for selecting bearings depending on operating conditions, the question of choosing a bearing fit depending on the load still remains open.

The purpose of the work is to substantiate the types of landings of rolling bearing rings under various types of loading, taking into account the influence of the radial clearance.

Research methods. The work used the provisions of the theory of resistance of materials and machine parts, as well as the theory of accuracy and interchangeability.

Research results and their analysis. The type of loading of the rolling bearing ring significantly affects the choice of its fit. Consider typical loading schemes. The first typical scheme (Fig. 1). The inner ring of the bearing rotates with the shaft, the outer ring is fixed in the housing. The value of the radial load P is constant, and it does not change its position relative to the hull (see Fig. 1, a).

In this case, the inner ring perceives the radial load P sequentially along the entire circumference of the raceway, this type of ring loading is called circulation. The outer ring of the bearing perceives the radial load only by a limited section of the circumference of the raceway, this type of loading of the ring is called local (see Fig. 1, b).

The second typical scheme (Fig. 2). The outer ring of the bearing rotates with the gear. The inner ring, seated on the axle, remains stationary relative to the housing. The value of the radial load P is constant, and it does not change its position relative to the housing (Fig. 2, a), the outer ring perceives the radial load P sequentially, i.e. has a circulation load. The inner ring of the bearing has local loading (Fig. 2, b).

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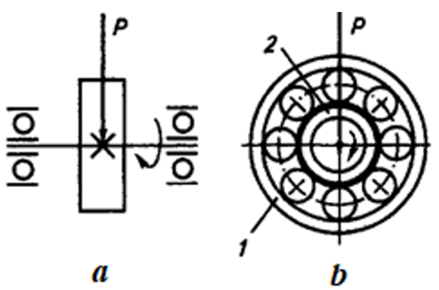

Fig. 1. Local loading at the outer ring 1 and circulation at the inner 2 (I)

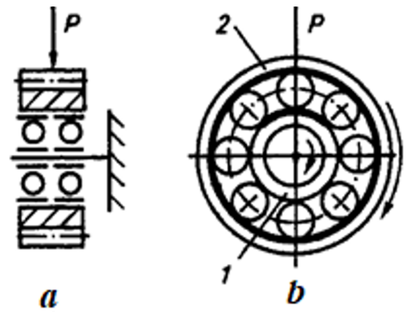

Fig. 2. Local loading at the inner ring 1 and circulation at the outer 2 (II)

The third typical scheme (Fig. 3). The inner ring of the bearing rotates with the shaft, the outer ring - in the housing, motionless. There are two radial loads, the value and direction of one R is constant, the other - centrifugal Rc - rotates with the shaft (Fig. 3, a).

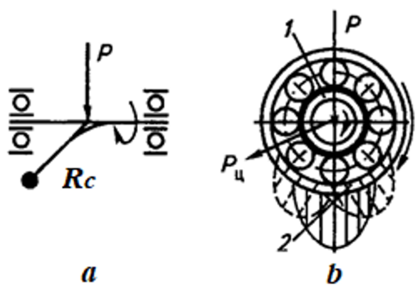

Fig. 3. Vibrational loading (1) at the outer ring and circulation (2) at the inner ring

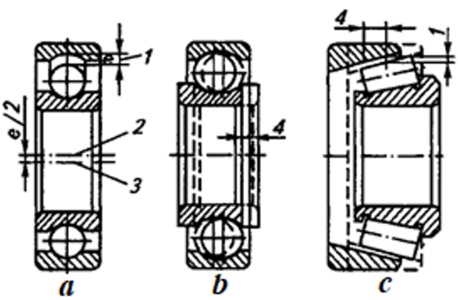

Fig. 4. Radial (a and c) and axial (b and c) clearances in the bearing: 1 - radial clearance; 2 and 3 - the axis of the outer and inner rings; 4 - axial clearance

The resultant of the forces P and Rc performs a periodic oscillatory motion, symmetrical with respect to the direction of the force P. In Figure 3, b, the dashed lines show the sequential position of the loading diagram of the outer ring of the bearing in a limited section of the raceway, which shifts from right to left and changes in magnitude, such a ring loading mode is called oscillatory. The inner ring takes the total radial load sequentially over the entire circumference of the raceway, i.e. has a circulation load.

Circulation-loaded rings must have an interference fit to prevent opening of the joint and shifting of the parts forming the joint. Locally loaded rings should have a slight clearance between the ring and the seat to ensure assembly and disassembly of the assembly, as well as to compensate for the thermal expansion of the shaft relative to the housing. The presence of a clearance leads to regular rotation of the ring along the seating surface and uniform wear of the inner raceway, but adversely affects the durability of the connection of the outer surface of the ring with the housing or shaft, since rotation leads to intense wear [15].

Radial or axial clearance (Fig. 4) is understood as the total radial or axial movement in both directions of one bearing ring relative to the other, with or without load.

Ensuring the optimal radial clearance or axial play for the given operating conditions makes it possible to rationally distribute the load between the rolling elements, reduce the displacement of the shaft and housing in the radial and axial directions, and reduce the noise and vibrations that occur during the operation of the bearing.

The radial clearance between balls and rings should not be converted into an interference, but should be kept as small as possible to ensure the longest life of the bearing.

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Clearances are distinguished into initial (measured before assembling the bearing with mating parts), landing (measured in the bearing mounted on the shaft and in the housing), control (measured in the assembled bearing under a certain load) and working (measured in the running bearing under operating load and temperature).

The seat clearance is always less than the initial clearance due to a change in the diameters of the bearing rings when they are installed with a fit interference, and the working clearance decreases or increases under the influence of temperature difference and increases under the action of the applied load.

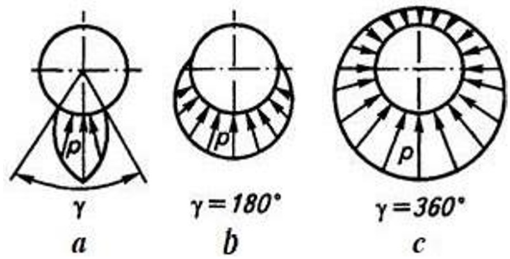

Fig. 5. Influence of clearances-interferences on the distribution of loads on the rolling elements: a - with an increased clearance; b - at zero clearance; c - with preload or with a significant axial load

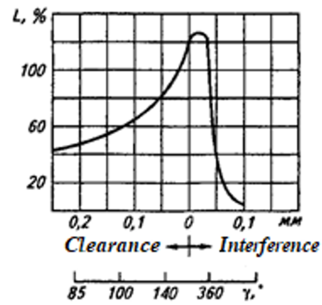

Fig. 6. Influence of clearances and interference on the resource: L - resource in% of the calculated; γ - loading zone angle

If the bearings are assembled with a large clearance, then only one or two balls or rollers take the entire load (Fig. 5, a). Bearings operating conditions with such large clearances are unfavorable (Fig. 6), and therefore such clearances are unacceptable. Typically, bearings are adjusted so that the axial play at a steady temperature regime is close to zero (Fig. 5, b). In this case, when a radial force acts on the bearing, approximately half of the rolling elements are under load. If more than half or all of the rolling elements of the bearing are under load (Fig. 6, c), then the bearing life (L, %) first increases and then rapidly decreases, as plastic deformations of the rolling elements and raceways begin. The rigidity of the support increases with increasing axial load, and therefore, in some bearings, for example, in the bearings of machine spindles, an assembly with a preload is used, which is also used in thrust ball bearings to prevent gyroscopic spinning of the balls. As the seats wear out, not only significant distortions appear, but the center distances increase greatly, as a result of which the smooth operation of the engagement is disturbed, vibration and dynamic loads increase, which in turn leads to a weakening of the body fastening and a violation of tolerability. As a result of these phenomena in gearboxes, the durability of not only the gearing, but the entire machine as a whole is reduced, and the loss of alignment often entails major accidents and long downtime.

Therefore, the rigidity of the support increases with increasing axial load, and therefore, in some bearings, for example, in the bearings of machine spindles, an assembly with a preload is used, which is also used in thrust ball bearings to prevent gyroscopic spinning of the balls.

In angular contact bearings of adjustable types, as well as in thrust bearings, the required axial clearance is achieved by controlled axial movement of the bearing rings.

The relationship between initial, seating and running clearances is valid only for non-adjustable bearings and does not apply to bearings in which the radial clearance and axial play are adjusted during assembly.

When bearings with a tapered bore are mounted on a tapered shaft journal, the initial radial clearance is reduced due to the expansion of the inner ring. Axial movement of the inner ring with a hole having a taper of 1:12 relative to the shaft journal or sleeve causes a decrease in the initial radial clearance, equal to approximately 1/15 of the displacement.

2 Conclusion

Thus, the radial clearance between the balls and rings should not translate into an interference, but should be kept as low as possible to ensure the longest life of the bearing. In this case, it should be taken into account that the relationship between the initial, seating and running clearances is valid only for non-adjustable bearings and does not apply to bearings in which the radial clearance and axial play are adjusted during assembly. Also, when bearings with a tapered bore are mounted on a tapered shaft journal, the initial radial clearance is reduced due to the expansion of the inner ring. Axial movement of the inner ring with a bore having a taper of 1:12 relative to the shaft journal or sleeve causes a decrease in the initial radial clearance equal to about 1/15 of the amount of movement.

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