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РОЗРАХУНОК ДУГИ КОНТАКТУ СЕПАРАТОРА З БАЗУЮЧИМ КІЛЬЦЕМ ПІДШИПНИКА

Розроблено методику аналітичного розрахунку розміру дуги контакту сепаратора як пружного кільця з жорстким базуючим кільцем циліндричного роликопідшипника, що дало можливість уточнити розрахункову схему сепаратора за рахунок заміни точкового контакту дуговим. Досліджено вплив розміру дуги контакту сепаратора з базуючим кільцем залежно від зазору між сепаратором і базуючим кільцем.

Ключові слова: *підшипник, сепаратор, розрахункова схема, дуга контакту, згинальний момент, базуюче кільце.*

1. Introduction

The cage of roller bearings of support assemblies of rail transport is heavy-loaded part, reliable operation of which greatly affects the operational safety. Destruction of the cage of roller bearings of support assemblies, for example, of rail cars, can lead to the wheelset destruction and a train crash.

Currently, there is no fully scientifically based idea of the calculation scheme of the design of the roller bearing cage, needed to assess its stress-strain state. Therefore, designing the framed structures of bearing cages is based on selecting their geometric parameters by empirical formulas, tables, and graphics. Test calculations of strength and rigidity of cages are performed using the simplified calculation scheme by numerical methods based on experimentally determined loads. Herewith, experimental studies of kinematics and dynamics of bearings of some machines are sometimes associated with significant material costs.

Such technology for designing bearing cages needs to be improved. The main stage of improving the bearing cage design is specifying its known calculation scheme in the zone of contact with the locator ring.

2. Analysis of recent studies

In known publications [1–7], devoted to studying the dynamics of bearings, point contact of the solid structure of the cage with locator rings is accepted. This is a rough approximation, which leads to overestimating the calculated bending moment in the sections of the cage. In actual practice, due to deformation of the cage under the pressing force of rolling elements on a jumper, its contact with the outer ring occurs on some arc [8]. The size of the contact arc of the cage with the locator ring of the bearing depends on the load, rigidity of the cage, the gap between the cage and the locator ring. Taking into account the contact arc of the cage with the locator ring will allow to improve the accuracy of calculating the cage and the effectiveness of its designing.

3. Purpose and methodology

The purpose is to develop the methodology for calculating the contact arc of the cage with the locator ring of the cylindrical roller bearing.

To achieve this goal, it is necessary to determine displacements of the cage model under the load and compare them with the gap between the cage and the locator ring.

4. Theoretical part

In solving the task of improving the calculation scheme of the cage, the following assumptions are made:

- the cage is presented as a thin elastic ring;
- the locator ring of the bearing is absolutely rigid;
- radial displacements of the cage sections coincide with full displacements.

Changing the floating gap S_f (Fig. 1) between the cage and the locator ring of the bearing is determined by calculating the cage as statically indeterminate system on elastic foundation by the force method [9].

Conventional support rods are introduced between the cage and locator ring symmetrically about the vertical axis (Fig. 2).

The cage ring is reduced to the statically determinate system by making the cut in its upper part and exerting the unknown forces x_1, x_2, x_3, as well as rejecting all conventional support rods and replacing their action with unknown forces x_4, x_5, ..., x_n (Fig. 3).

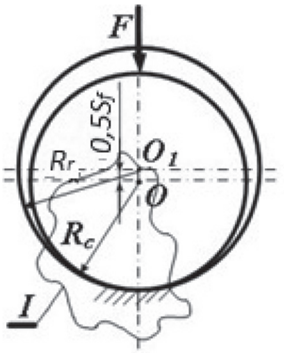

Fig. 1. Bearing cage in contact with the outer locator ring

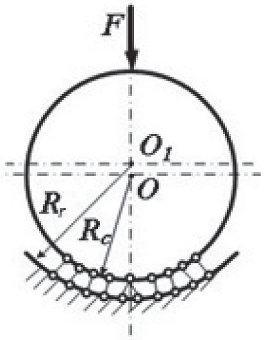

Fig. 2. Bearing cage on the conventional support rods

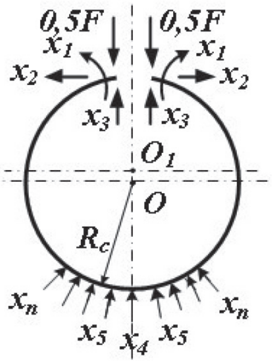

Fig. 3. Calculation scheme of cage

System of canonical equations of the force method is made, including all unknown forces, relating to the contact arc of the cage and its upper part:

$$\begin{aligned}&\delta_{11}\cdot x_1+\delta_{12}\cdot x_2+\ldots+\delta_{1n}\cdot x_n+\Delta_{1F}=0,\\&\delta_{21}\cdot x_1+\delta_{22}\cdot x_2+\ldots+\delta_{2n}\cdot x_n+\Delta_{2F}=0,\\&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots,\\&\delta_{n1}\cdot x_1+\delta_{n2}\cdot x_2+\ldots+\delta_{nn}\cdot x_n+\Delta_{nF}+\Delta_{n\alpha}=0.\end{aligned} \qquad (1)$$

Coefficients at the unknown δ_{ik} and free members of equations Δ_{iF} are determined using the Mohr's integral:

$$\delta_{ik}=\int_S\frac{\bar{M}_i\cdot\bar{M}_k}{E\cdot I}\,dS,\ \Delta_{iF}=\int_S\frac{\bar{M}_i\cdot M_p}{E\cdot I}\,dS, \qquad (2)$$

where $i=1,2,\ldots,n;\quad k=1,2,\ldots,n;\quad p=1,2,\ldots,n.$

Members of equations $\Delta_{i\alpha}$ are displacements of the investigated sections of the cage until the occurrence of forces x_i in them, i. e. up to closing the gap between the cage and the outer ring (according to the calculation scheme on the Fig. 3, for displacements $i=5,6,\ldots,n$). Values of $\Delta_{i\alpha}$ are determined by the geometric dependences on the Fig. 4.

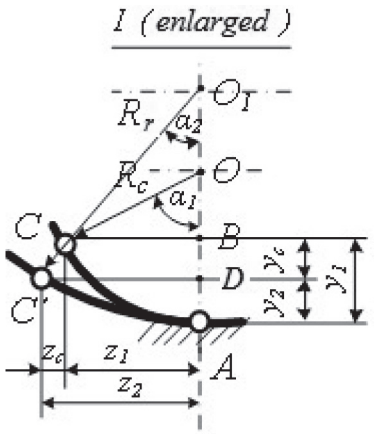

Fig. 4. Fragment of the support zone of the bearing cage

During the deformation of the cage under the force F, section C will move to the position C' and then the arc AC of the cage will take the position AC'. Since the difference between the radii of the cage R_c and the support surface of the ring R_r is negligibly small (up to 0,5 %) we assume that:

$$R_c\cdot\alpha_1=R_r\cdot\alpha_2,\ \text{hence}\ \alpha_2=\frac{R_c}{R_r}\alpha_1. \qquad (3)$$

Coordinates of points C and C' are determined according to the expressions:

$$z_1=R_c\cdot\sin\alpha_1,\ y_1=R_c\cdot(1-\cos\alpha_1), \qquad (4)$$

$$z_2=R_r\cdot\sin\alpha_2,\ y_2=R_r\cdot(1-\cos\alpha_2). \qquad (5)$$

Full displacement of the section C is determined as:

$$f_c=\sqrt{z_c^2+y_c^2}, \qquad (6)$$

where $z_c=z_2-z_1;\quad y_c=y_2-y_1$.

For small values of the angle α_i, radial displacements $\Delta_{i\alpha}$ of cage sections slightly differ in magnitude and direction from the full displacements f_c. This gives grounds to determine the expression for $\Delta_{i\alpha}$ as:

$$\Delta_{i\alpha}=\sqrt{z_i^2+y_i^2}, \qquad (7)$$

where

$$z_i = R_r \cdot \sin\frac{R_c}{R_r}\alpha_{1i} - R_c \cdot \sin\alpha_1;$$

$$y_i = R_c(1-\cos\alpha_{1i}) - R_r\left(1-\cos\frac{R_c}{R_r}\alpha_{1i}\right).$$

Solution of the system (1) taking into account the expressions (2) and (7) allows to obtain the values of bending moments in sections of the cage. To quantify the effect of the contact arc size on the bending moment value in the weak section of the cage, stiffness coefficient χ_i, characterizing the ratio of the bending moment in the weak section A (Fig. 4) at the point contact $M_{A(\alpha=0)}$ to the bending moment in the same section at the contact along the arc $M_{A(\alpha=\alpha_i)}$ with the angle $2\alpha_i$ is introduced:

$$\chi_i = \frac{M_{A(\alpha=0)}}{M_{A(\alpha=\alpha_i)}}. \qquad (8)$$

5. Results and discussion

The methodology for analytical calculation of the contact arc of the cage with the locator ring of cylindrical roller bearing comprises constructing the cage model in the form of elastic ring, presenting its contact area by conditional support bars, selecting the calculation scheme of the cage as a statically determinate system. For the proposed calculation scheme of the cage, canonical equations of the force method with unknown reactions of the support bars at the ring bottom and reactions in the vicinity of the section at the ring top are composed. Within the contact arc of the cage with the locator ring, the radius of the locator ring and the radius of the cage together with the radial displacement of its sections coincide. Outside the contact arc between the cage and the locator ring, wedge gap is formed. The beginning of the wedge gap defines the boundary of the contact arc. Bending moments within the contact arc are found by solving the system of canonical equations of the force method, taking into account geometric relationships for the boundary of the contact arc.

Based on the proposed method, calculations of the bending moments in the middle and on the edge of the contact zone of the cage with the locator ring for different values of the floating gap of the roller bearing 2726 of support assemblies of railcar wheel sets are performed. The results of calculations are presented in the Tabl. 1 for standard gaps.

The angular size of the contact arc of the cage with the locator ring of the roller bearing 2726 of support assemblies of railcar wheel sets for standard gaps; was 6°, 8°, 10° respectively. With the increase in the contact angle for each of the investigated gaps, the bearing area of the cage with the locator ring raises, and therefore the value of the bending moment reduces. This pattern is reflected in the table by the increase in the stiffness coefficient. The decrease in the bending moment is more intense with reducing the gap.

Table 1

Results of calculations of the bending moments in the cage

$S_f = 0{,}8$ mm		
α_i °	$M_{A(\alpha=\alpha_i)}$, $H\cdot m$	χ_i
0	11,13	1,00
1	9,94	1,12
2	9,51	1,17
3	9,20	1,21
$S_f = 0{,}6$ mm		
α_i °	$M_{A(\alpha=\alpha_i)}$, $H\cdot m$	χ_i
0	11,13	1,00
1	10,12	1,10
2	9,68	1,15
3	9,35	1,19
4	8,91	1,25
$S_f = 0{,}4$ mm		
α_i °	$M_{A(\alpha=\alpha_i)}$, $H\cdot m$	χ_i
0	11,13	1,00
1	10,21	1,09
2	9,85	1,13
3	9,60	1,16
4	9,28	1,20
5	8,76	1,27

Further reduction of the bending moment in the bearing cage in a constructive way by a further decrease in the values of gaps, for example, to or is impossible since the friction conditions in the cage will worsen, the moment of rotation resistance and its working temperature will increase.

Table results of calculations are presented as graphs in the Fig. 5.

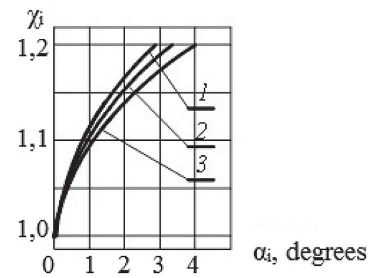

Fig. 5. The bending moment reduction coefficient in the support zone of the brass cage: 1 — $S_f = 0{,}8$ mm; 2 — $S_f = 0{,}6$ mm; 3 — $S_f = 0{,}4$ mm

Thus, the calculated values of the angles of the contact zone of the cage with the locator ring of the bearing increase from 6° to 10° with decrease in the floating gap from 0,8 mm to 0,4 mm. A further decrease in the values of floating gaps is impossible because of deterioration of friction conditions in the bearing, increase in the antitorque moment and its operating temperature. Experimental studies of the All-Russian Scientific Research Institute of Railway Transport on performance of roller bearings of axle boxes of car wheel pairs with typical brass cage have shown that the angle of the contact zone $2\alpha_i$ of the cage with the locator ring does not exceed 10° [10].

6. Conclusions

1. The scientific novelty of the work lies in the fact that the effect of the contact arc of the cage with the locator ring of the bearing on the value of the bending moment in the weak section is first considered by the analytical method. Mating of parts cage-locator ring of the bearing is represented by the model of interaction of elastic ring, loaded by a concentrated force, with a hard ring of larger diameter on the value of the floating gap. The adequacy of the results, obtained by analytical calculation of the angle of the contact zone of the cage with the locator ring of the bearing, is confirmed by experimental studies of the All-Russian Research Institute of Railway Transport.

2. The practical value of the work consists in improving the accuracy of the calculation scheme of the cage by replacing the point contact with the locator ring of the bearing by the arc contact. This facilitates reduction of the bending moment in the weak section and increase in the structural strength of the cage. The analysis of influence of floating gaps of the cage on its performance has allowed reasonably select the best values in terms of resistance to rotation of the bearing.

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РАСЧЕТ ДУГИ КОНТАКТА СЕПАРАТОРА С БАЗИРУЮЩИМ КОЛЬЦОМ ПОДШИПНИКА

Разработана методика аналитического расчета размера дуги контакта сепаратора как упругого кольца с жестким базирующим кольцом цилиндрического роликоподшипника, что дало возможность уточнить расчетную схему сепаратора за счет замены точечного контакта дуговым. Исследовано влияние размера дуги контакта сепаратора с базирующим кольцом в зависимости от зазора между сепаратором и базирующим кольцом.

Ключевые слова: подшипник, сепаратор, расчетная схема, дуга контакта, изгибающий момент, базирующее кольцо.

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