

Original Research Article

System model of a technical level rolling bearings

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SUMMARY:

Purpose: to develop system hierarchical model of a technical level of rolling bearings, to prove efficiency of the modernization of standard designs providing increase of operational characteristics of axle boxes of railway transport.

Methodology: the hierarchy of structure and functional communications between rolling bearing elements as mechanical system is established; quality indicators are proved; dependences for calculation of elements of a matrix of quality for the standard and modernized design are offered; results of solutions of system model are presented in the form of "a quality web"; efficiency of the proposed constructive solutions is confirmed.

Results: The directions of modernization of a design of roller cylindrical bearings as a part of axle boxes of railway transport providing increase of their dynamic loading capacity for 10,5%, the power efficiency for 59%, a resource for 19%, decrease by 11% of level of internal dynamic loadings, nominal temperature condition of operation at speeds of train service up to 300 km/h are proved. As a result the indicator of a technical level of the upgraded bearings is raised for 47%.

Conclusion: further development was gained by a system method of estimation and management of a technical level of production of mechanical engineering at stages design and modernization.

Keywords: roller cylindrical bearing, operational characteristics, settlement models, quality indicators

1. INTRODUCTION

In practice of modern mechanical engineering there is no the universal method of the analysis of quality of design of bearings providing an objective choice and scientific justification of optimum versions of constructive and technological decisions [1]. In relation to roller cylindrical bearings as a part of axle boxes of high-speed railway transport the solution becomes complicated lack of complex researches of influence of number of bodies of swing, material of a separator, temperature condition, etc. factors of the characteristic of their quality [2 – 4]. As the most perspective directions of modernization of axle boxes of wheel axes are considered: use of bearings of cassette type with conic rollers (the producer - firm BRENCO, USA) [5] or cylindrical roller bearings with the increased quantity of rollers (SKF firms, Sweden, and NSK, Japan) [3]. Operating experience with conic rollers in axle boxes of railway transport of Ukraine was shown by more considerabl, than for cylindrical bearings, heating at operation [6]. Replacement of conic bearings by the cylindrical roller restrains absence of information on influence of the increased number of rollers in the bearing on other production characteristics of axle boxes.

Therefore, development of the system model of a technical level of rolling bearings providing a

scientific basis for a choice of effective decisions at early stages of design and modernization should be considered an actual problem of engineering science.

2. METHODOLOGY

The system method of an assessment of technical level of production of mechanical engineering in relation to transfers by gearing, to restrictive couplings, mechanisms of parallel structure, etc., is presented in works [7 – 9]. The universal method of display of a technical level provides functional-structural integrity, objectivity of display and physical informational content of indicators of quality of the knowledge-intensive products of mechanical engineering in uniform system basis their internal and external (structural and functional) functional properties. Adequacy of modeling of a set of indicators of quality $\{Q\} = \{q_1, q_2, \dots, q_n\}$ and the relations $\{q_i \xleftrightarrow{c} q_j\}$ as uniform information system is axiomatically proved. At each level application of subjective expert methods for establishment of weight coefficients isn't required, extension of the list of the functional properties inherent in system in general, and also the analysis of designs analogs and selection of options on the basis of a uniform system indicator of $U(Q)$ of a technical

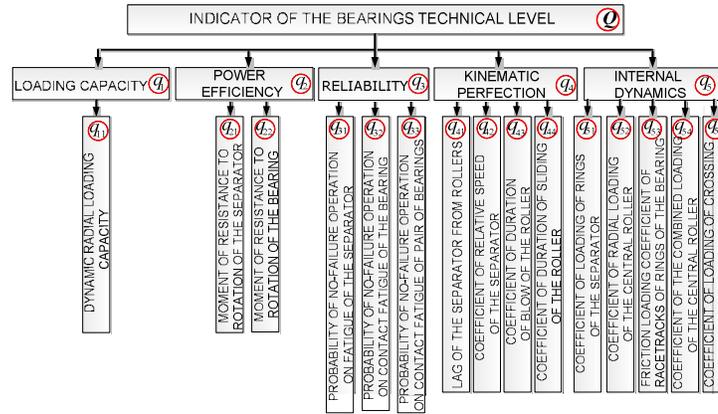


Fig. 2. Hierarchical model of an indicator Q of the bearing technical level

Table 1. Indicators of quality of roller cylindrical bearing

Properties	Indicators	Settlement formulas	References
1. Loading Capacity	1.1. Dynamic radial loading capacity of the bearing, N	$C = \mu (i l_w \cos \alpha)^{7/9} z^{3/4} D_w^{29/27}$ (1)	[1]
2. Power efficiency	2.1. Moment of resistance to rotation of a separator, $N \cdot m$	$M_S = 0,5 d_b f_b [F_s(\psi) + F'_s(\psi)] \cos \psi - 0,5 D_w f_s [F_s(\psi) + F'_s(\psi)]$ (2)	*
	2.2. Moment of resistance to rotation of the bearing, $N \cdot m$	$M_n = 0,5 d_l [(F_{fi} + F'_{fi}) + z_{lk} F_{kl}]$ (3)	*
3. Reliability	3.1. Probability of no-failure operation on fatigue of separator	$u_{PF} = - (n_F - 1) / (n^2 F v^2_{\sigma 0} - (2) 1/2 (PF)$ (4)	[13]
	3.2. Probability of no-failure operation on contact fatigue of rings and rollers	$u_{PF} = - (n_F - 1) / (n^2 F v^2_{\sigma 0} - v^2_{\sigma})^{1/2} \Rightarrow P_F$ (5)	[14]
	3.3. Probability of no-failure operation on contact fatigue of pair of bearings	$P_{2L} = 1 - (1 - P_L)^2$ (6)	[1]
4. Kinematics perfection	4.1. Relative lag of a separator from rollers	$\Delta = 200 S_0 z / (d_0 \pi)$ (7)	[15]
	4.2. Coefficient of relative speed of a separator	$k_w = \omega_s z_2 / \omega_c$ (8)	*
	4.3. Coefficient of duration of blow of a roller	$k_w = t_s / t_c$ (9)	*
	4.4. Coefficient of duration of sliding of a roller	$k_{\psi} = (\psi_F - \psi_e) / \psi_F$ (10)	*
5. Internal dynamics	5.1. Coefficient of loading of rings of a separator	$k_{FR} = F_R / F_{f0}$ (11)	*
	5.2. Coefficient of radial loading of the central roller	$k_{Fr} = F_r / F_{r0}$ (12)	*
	5.3. Coefficient of a friction loading of race tracks of rings	$k_{Ff} = F_{f0} / F_{fi}$ (13)	*
	5.4. Coefficient of the combined loading of the central roller	$k_F = F_{r0} / F_{a0}$ (14)	*
	5.5. Coefficient of loading of crossing points of separator	$k_{Fs} = F_s / F_{f0}$ (15)	*

Designations: μ – coefficient of the accounting of geometry of details of the bearing, accuracy of their production and materials; i – quantity of

ranks of bodies of swing; l_w – length of a roller, m ; α – nominal corner of contact; z – quantity of rollers; z_{lk} – quantity of rollers in the loading

zone; D_w – diameter of a roller, m ; d_r , d_b – diameters of fit of an internal ring and boards of an external ring, m ; f_s , f_b – coefficients of friction of a crossing point with a roller and separator rings with boards of the basing ring; f_n – the provided coefficient of friction of the bearing; F_r – radial load of the bearing, N ; Z_z – quantity of rollers in a zone of radial loading; F_s , F_s – forces of interaction of the separator conducted rollers with crossing points in a zone of radial loading, N ; F_{fo} , F_{fi} – friction forces of rollers on running paths of external and internal rings, N ; F_{fb} , F_{fi} – friction forces of sliding of rollers; F_{ki} – friction force of swing of rollers on an internal ring; S_0 – a clearance in a window of a

separator, m ; d_0 – diameter of the centers of rollers, m ; ω_w , ω_s , ω_c – angular speeds of rollers, separator and internal ring, s^{-1} ; t_s , t_c – duration of contact of a roller with a separator and a cycle of loading of a separator, s ; ψ_F , ψ_e – settlement corner of a zone of radial loading of the bearing and experimentally certain corner of sliding of a roller, rad ; F_{r0} , F_{a0} – the radial and axial forces operating on the central roller, N ; F_R – force of interaction of a separator with the basing ring of the bearing, N .

Table 2. Matrix [Q] of rated values of indicators of quality standard and advanced bearing 2726**

Loading capacity	The power efficiency	Reliability	The kinematics perfection	The internal dynamics	Models level
0,39	0,25	0,59	0,55	0,36	1 – system "bearing"
(0,65)	(0,61)	(0,82)	(0,55)	(0,43)	
	0,64	0,60	0,72	0,39	2 – subsystem
	(0,96)	(0,85)	(0,72)	(0,55)	"separator – rollers"
		0,74	0,76	0,61	3 – subsystem "separator"
		(0,88)	(0,76)	(0,88)	
			0,79	0,64	4 – subsystem "ring"
			(0,79)	(0,93)	
				0,73	5 – "the weak element"
				(0,98)	(race path)

** All calculations of indicators of quality are those of the authors

Calculation of an indicator of a technical level $U(Q)$ of standard and advanced designs is executed on a basis of next system of the non-uniform linear equations [7]

$$\begin{bmatrix} q_{11} & q_{12} & q_{13} & q_{14} & q_{15} & -1 \\ 0 & q_{22} & q_{23} & q_{24} & q_{25} & -1 \\ 0 & 0 & q_{33} & q_{34} & q_{35} & -1 \\ 0 & 0 & 0 & q_{44} & q_{45} & -1 \\ 0 & 0 & 0 & 0 & q_{55} & -1 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \\ U \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \quad (16)$$

where $q_i = 0,1 + 1,18th [(y_i - y_i^-)/(y_i^+ + y_i^-)]$ – at a positive gradient of an indicator;

$q_i = 1,0 - 1,18th [(y_i - y_i^-)/(y_i^+ + y_i^-)]$ – at a negative gradient; y_i^- , y_i^+ – lower and top borders of statistically average range of change of an indicator of a certain property; $\lambda = \{\lambda_1, \lambda_2, \dots, \lambda_5\}$

– a column of the weight coefficients determined by the decision of system.

For example, the moment of resistance to rotation caused by a separator decides by friction of crossing points on rollers and friction of rings with boards of basing bearing ring, hydrodynamic losses in greasing and in seals. Disregarding losses on friction of the rollers which are out of a zone and also losses in greasing and in seals, the moment of resistance to rotation caused by a separator according to model of loading of a separator (fig. 3) [10], analyzed on a formula (2)

as the sum of the moments of every effort applied for a separator (see table 1):

$$M_s = 0,5d_b f_b [F_s(\psi) + F'_s(\psi)] \cos \psi - 0,5D_w f_s [F_s(\psi) + F'_s(\psi)].$$

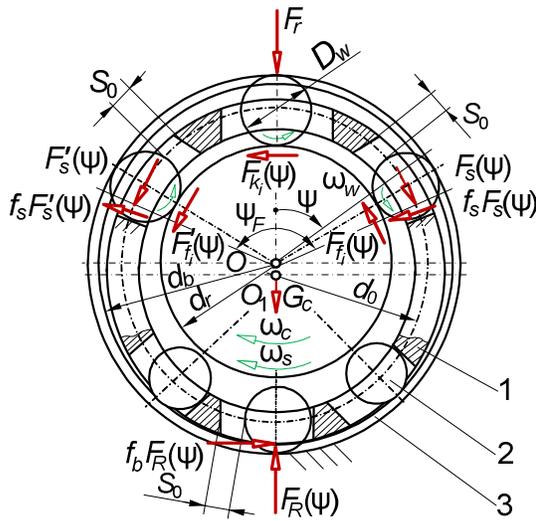


Fig. 3. Model of loading of a separator:
1 – separator; 2 – roller; 3 – ring

Force $F_s(\psi)$ of interaction of the leading roller decides on a crossing point of a separator at the time of the beginning of slipping of a roller in a zone of radial loading of the bearing by a solution of system of the equations of the movement of a roller, and force $F'_s(\psi)$ of interaction of the conducted roller decides on a crossing point of a separator on the basis of the theorem of change of kinetic energy of a separator for a cycle of its loading [10].

Below the example of calculation of rated value of the moment of resistance to rotation caused by a separator for the following basic data is given: resistance moments taking into account settlement forces of interaction of a roller with a crossing point of standard and advanced separators $M_s = (1,018 \dots 1,363) \cdot 10^{-3} \text{ N}\cdot\text{m}$ and $M'_s = (0,521 \dots 0,692) \cdot 10^{-3} \text{ N}\cdot\text{m}$; resistance moments taking into account experimentally certain forces of interaction of a roller with a crossing point of standard and advanced separators $M_{Se} = (1,190) \cdot 10^{-3} \text{ N}\cdot\text{m}$ and $M'_{Se} = (0,680) \cdot 10^{-3} \text{ N}\cdot\text{m}$. The normalized value of the M_s moment of resistance to rotation caused by a standard separator

$$q_M = 0,1 + 1,18 \text{th}[(M_{Se} - M_{S(\min)}) / (M_{S(\max)} - M_{S(\min)})] = 0,1 + 1,18 \text{th}[(1,190 - 1,018) / (1,363 - 1,018)] = 0,1 + 1,18 \text{th}(0,499) = 0,64.$$

The normalized value of the M'_s moment of resistance to rotation caused by an advanced separator

$$q'_M = 0,1 + 1,18 \text{th}[(M'_{Se} - M'_{S(\min)}) / (M'_{S(\max)} - M'_{S(\min)})] = 0,1 + 1,18 \text{th}[(0,680 - 0,521) / (0,692 - 0,521)] = 0,1 + 1,18 \text{th}(0,93) = 0,96.$$

On the basis of normative conditions of production and operation of bearings as a part of

axle boxes of wheel axes, results of theoretical and pilot studies of authors and other researchers, numerical sizes of indexes of quality are determined (see table 2). Results of calculation of a system indicator of a technical level U for standard and advanced designs are presented in the form of the chart called by a "quality web" (fig. 4), where settlement corner $\varphi_i = \lambda_i \cdot 2\pi$.

Value of a system indicator of a technical level is received 47% more in comparison with a standard design. Efficiency of performance of the offered modernization providing at the expense of increase in quantity of rollers increase of dynamic loading capacity and a resource of the bearing respectively for 10,5% and 19%, decrease in loads of a separator by 11% by improvement of internal dynamics of the bearing, possibility of stabilization of temperature condition of operation of the bearing at increase of speed of the train to 200...300 km/h thanks to separator material replacement is as a result confirmed.

Dynamic load-carrying capacity and resource of bearings are calculated according to standards of ISO [1].

Increase of power effectiveness of the upgraded bearings is reached due to application for a separator of polymeric material with a smaller friction coefficient. The decrease in loads of a separator is explained by the following:

- at increase in quantity of rollers in the bearing their number in a loading zone ψ_F increase (see fig. 3);

- as a result each roller is affected by smaller radial and axial forces, loads of a separator from rollers at edges of a zone of a radial loading also decrease.

Improvement of internal dynamics of the bearing is promoted weakening of loading at contact of a roller with the middle of a convex crossing point of a separator and decrease of thickness of crossing points.

Theoretical and pilot studies of a heat generation in bearings of axle boxes are very actual for high-speed passenger trains [16, 17]. For the studied range of loadings (radial 30 ... 50 kN and axial 5 ... 20 kN) and speeds of an forced air cooling (28 ... 83 m/s at traveling speeds of trains 100 ... 300 km/h) the calculated gradient of temperatures for the upgraded bearings is than 0,4 ... 1,4 °C less in comparison with standard designs.

Results of the executed researches confirmed the increased load ability and reliability of roller cylindrical bearings with the increased quantity of rollers that coincides with the published results of resource tests and statistics of operational supervision [2, 3, 14]. Tolerance of the accepted indicators of kinematic perfection of the bearing to the made changes in a design of a separator is explained by the following:

- characteristics of the movement of a separator for bearings with the rotating internal and motionless external ring don't depend on errors

of production of details, contact and assembly deformations;

- indicators of quality of kinematics are defined only by separator dimensions, gaps in windows and the angular size of an area of coverage of

radial loadings [12]. Therefore, at an assessment of a technological level of similar bearings indicators of kinematics perfection can be excluded from system (16).

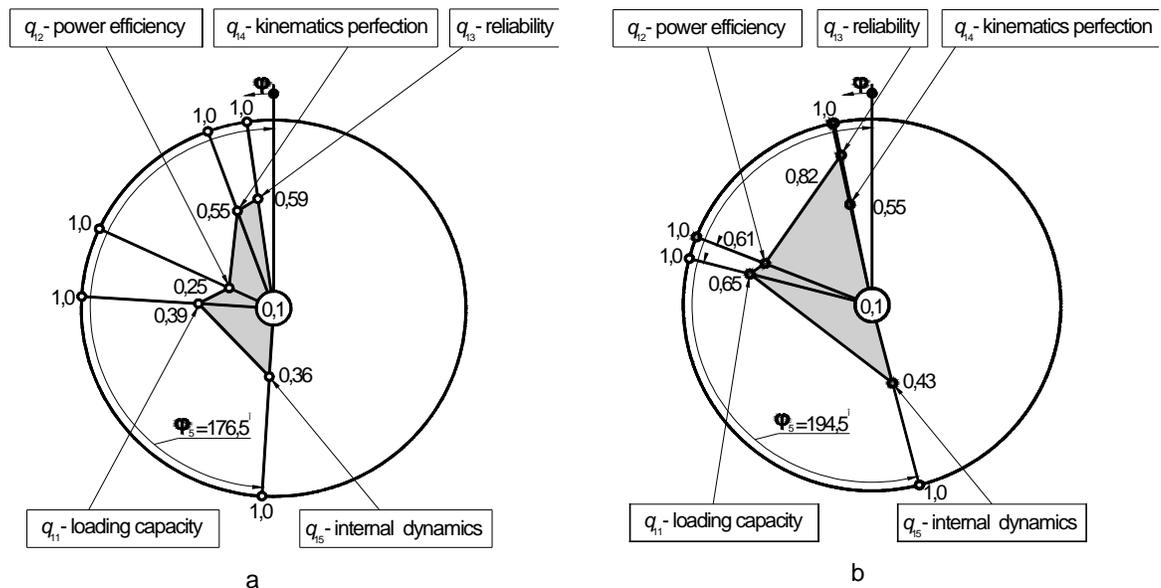


Fig. 4. "Quality webs" for standard (a) and advanced (b) bearing 2726

Efficiency of modernization of axle boxes of wheel axes of modern railway transport on the basis of the offered system of single and

complex indicators of quality of roller rolling bearings is for the first time comprehensively analysed and proved.

4. CONCLUSION

In the presented article the system method of the analysis and management of the technical level of the science-intensive products of mechanical engineering at stages of their design and modernization gained further development and application. On the example of roller cylindrical bearings as a part of axle boxes of railway

transport efficiency is confirmed numerical display of quality indicators of the main structural and functional properties of bearings, allowing to consider known and new structures, designs, details, elements of details as the uniform universal system of models which is based on the uniform principles, axioms, hypotheses.

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