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A PECULIARITY OF DETERMINING A STATIC CARRYING CAPACITY FOR THE ONE-ROW BALL SLEWING BEARING LOADED THE LARGE RADIAL FORCE

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Abstract

Slewing bearings are applied commonly in the following devices inter alia: harbour cranes, traveling cranes, radar stations, machinery underground and an opencast mining, armaments industry, building machines, medical analysis devices, rotary kilns, manufacturing systems, a power engineering. A static limiting load curve of the slewing bearings describes ranges of the allowable loads, which the bearing can be safely carried for assumption by a manufacturer durability. The static carrying capacity of a slewing bearing describe the relationship between a tilting moment M and an axial force Fa for assumed a value of a radial force Fr. The article concerns problems related to catalo selection of rolling bearings which are loaded the large radial forces which may by differently directed in relation to a tilting moment's vector. Manufactures of the slewing bearings mostly does not present in product catalogs of a static limiting load curve, which have taken into account an action the radial forces. According to an INA company, the radial forces are reduced to determining an equivalent tilting moment and an equivalent axial force. In this work, the static limiting load curves have been determined based on the FEM models, the equations of contact mechanics for the ball and the bearing raceway. The models were performed by use the ADINA system. Juxtaposition of results obtained on a basis of method's INA company and own model have been presented in form the static limiting load curves. The object of the analysis was the one row ball slewing bearing, domestic production, which is used in excavator type F250H.

Keywords: *slewing bearing, one row ball slewing bearing, radial force, axial force, tilting moment, curve of the static carrying capacity, numerical modelling*

1. Introduction

The basic criterion of classification of rolling bearings is ability for taking over main external loads: longitudinal (axial) in relation to an axis of rotation of the bearing, and the transverse (radial) loads. Directionality of resultant forces acting on the bearings refers to the static and dynamic carrying capacity of the bearings as parameters defining the correctness of selection of the bearing in relation to its durability. Variety of design solutions of the roller bearings used in machines introduces mutual dependencies between ranges of a permissible external loads and directions of an action. The radial and axial loads are characteristic for the ordinary rolling bearings, generally classified as radial bearing and axial bearing. In the case of the another group of the rolling bearings, which are slewing bearings, besides the axial forces Q, as well as the radial forces H, a predominant role plays the tilting moment M. The slewing bearings are adapted to simultaneously taking over the specified three components of the external load. In case of the ordinary bearings during determining both the static and the dynamic carrying capacity, the external forces are reduced to the axial or radial direction. Whereas in the case of low-speed bearings, which are the slewing bearings, the static carrying capacity (dependent on a deformability of the contact zone the rolling elements – raceway) is normatively described by curves of the static carrying capacity. These curves specifies mutual dependences between the tilting moment M and the axial force Q for the assumed value of the radial force H. Introducing the different nomenclature in defining the global parameters of endurance of the slewing bearings in compared to bearings of a general application is a result of characteristic differences. The basic characteristics of the slewing bearings, distinguishing it from other types of roller bearings are: large values of the track diameters d_t (of up to a few meters), different system of mounting the rings to the body and the head (most using the mounting bolts located in the circumferentially spaced holes), static nature of the work (most often work as low-speed bearings at rotation speeds not exceeding several rotation per minute), the load specificity (large values of axial forces Q, radial forces H and the tilting moment M applied to the driving head), a large number of roller parts (of up to several hundred), the toothed rim incised on circumference of the one ring, the high flexural-torsional susceptibility of the bearing rings in relation to support structure susceptibility and susceptibility of contact zone the rolling element – raceway, the use of other materials for the production of the rings and the rolling parts [6].

Selection of the slewing bearings, especially in the initial phase of design structures of the working machines is carried out on a basis of the curves of the static carrying capacity developed by the manufacturers. From review of catalogues of leading manufacturers of the slewing bearings, results that the presented curve of static carrying capacity are determined on the assumption of the zero value of radial force H [10, 12, 13, 19]. In work [10], it was found that a value of the radial load not exceeding 10% of the axial load practically does not affect the change in the static carrying capacity. Whereas, in accordance with a methodology using to selecting the slewing bearings published by [5] during determining the curve of static carrying capacity are not taken into account the radial forces. Procedure for identification of the work points of the slewing bearing for the three components of the external load M, Q, H boils down to designate an equivalent tilting moment M_{eq} and an equivalent axial force Q_{eq} – based on nominal loads M, Q, H, and relevant factors (application, radial loads and safety). The calculated values of the M_{eq}, Q_{eq} are compared with course of curve of the static carrying capacity of the bearing, determined for the null value of the radial force.

By knowing the working conditions of the carrying components in a working machinery with installed the slewing bearing, can be stated that radial forces may have a significant contribution to the resultant load of the bearing. In some cases their action may be temporary (e.g. in excavator with one bucket), but it cannot be ruled out the continuous action occurring in wind turbine in which a same rotor's mass has a radial character, or in the support system of the wagon tippler. Therefore, in order to facilitate by the constructor, the appropriate selection of a slewing bearing to a designed machine, the knowledge about a course of the curve of static carrying capacity of a slewing bearings with taking into consideration the full range of the radial forces can be very useful. Issue of an influence of the radial forces on changing the remaining components of the static carrying capacity was widely considered in the work [8] on basis the twin slewing bearing. In the presented models utilized the finite element method (FEM) and the analytical equations, which were used to determine a permissible load that can act on a single contact zone ball-raceway [8]. The modelling method presented in this article is complement to the issues initiated by the authors of work [8].

It should be mentioned that the vectors of the radial and axial forces whose values of variables of the static carrying capacity contains in the same plane, which is perpendicular to the vector of the tilting moment. This type of load system was analysed in the works [6, 8] and is generally used. In this system the positively and negatively directed, the radial forces are distinguished. Interpretation of these values is presented in a later section. Additionally, it may by a situation, that the slewing bearing applied in a machine will be subjected to a load wherein a direction of a vector of radial force and a direction of a vector of the tilting moment will conform. Therefore, the first aim of the study is to determine the curves of the static carrying capacity for selected the slewing bearing with taken into account the direction of action of the radial forces. Whereas the second aim of this work is to compare the results of calculations of the static carrying capacity obtained on the basis the own model and a methodology proposed by INA

2. Description of a model bearing

Acceding to consideration a formulated problem of the load capacity of a slewing bearing was chosen the one-row ball slewing bearing with the four-point contact zone and catalo number 1.4P.Z.H.44.1105.5.1.01.A [12]. The fact that this type of bearing is used in the one-bucket excavator F250H has decided about selection this bearing. A comprehensive model of working structures of the bodywork and the chassis the excavator of type F250H joined with the modelled slewing bearing was presented in work [9]. An outline of a cross-section for considered the bearing is shown in Fig 1, and a basic design parameters are following: track diameter of the bearing d_t = 1105 mm, ball diameter d_k = 44 mm, quotient rays of ball and raceway k = 0.96, high of ring h = 175 mm, axial clearance L_a = 0.5 mm, clearance between the rings L_p = 7 mm, nominal contact angle $\alpha_o = 45°$, number of the bearing balls 64, number of the bolts mounting the internal/external ring 42/42, surface hardness of balls 62 HRC and raceway 56 HRC, the size and strength class of mounting bolts M24-12.9 and the remaining dimensions d_{zp} = 1260 mm, d_{zo} = 1200 mm, d_{wo} = 1010, d_{wp} = 960 mm, a = 10 mm, b =71 mm, h_w = 117 mm, h_z = 122 mm.

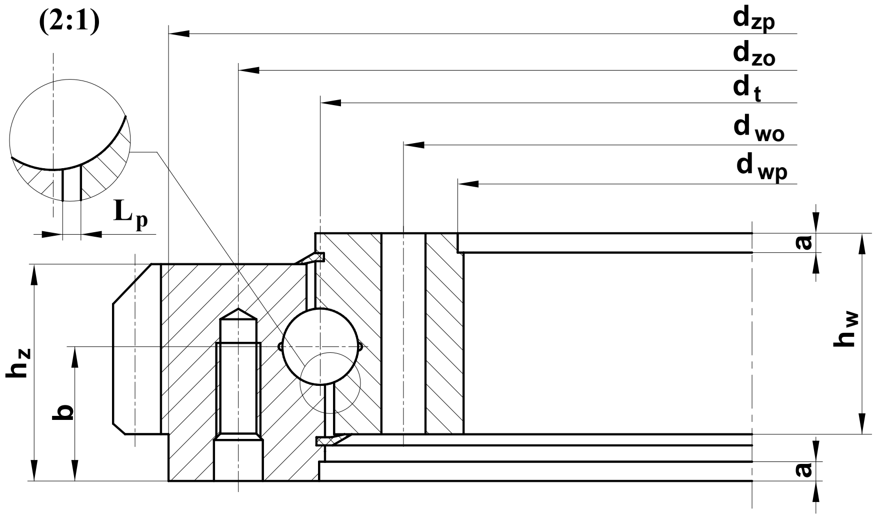

Fig. 1. One-row ball slewing bearing with marked the basic parameters

By realizing the objectives of this work, it was assumed that the fundamental method of the analysis of the static carrying capacity of the slewing bearing would be the finite element method (FEM). In order to analyse the static carrying capacity of the slewing bearing, which will operate in an external load system, where the direction of the vector of the radial force will be conform to the direction of a vector of the tilting moment or may be perpendicular – it is required to elaborate a full-scale bearing model.

In the light of the above, in the environment of an ADINA program [1] has been developed a comprehensive the FEM model for one-row ball slewing bearing, which a mesh is shown in Fig. 2. As shown in Fig. 2: the inner ring of the bearing 1, outer ring 3, the upper casing 2 and lower casing 4 structure of the heads of the mounting bolts 5, and plate 6 were discretized by the eight-nodal finite elements type 3D-Solid [1]. The angular pitch of the circumferential distribution of nodes corresponds to the angular pitch of location of the balls in the bearing. Between the upper casing and the inner ring and between the lower casing and the outer ring were defined appropriate contact conditions K. For nodes containing in the flat surface of the lower casing have been taken away all degrees of freedom (*Δx, Δy, Δz = 0*). External load has been defined by utilize of the vectors: F_M, Q, H_M, H_N. The tilting moment M has been mapped by using the pair of forces F_M has located symmetrically in relation to the YZ plane, which is a plane of symmetry of the bearing.

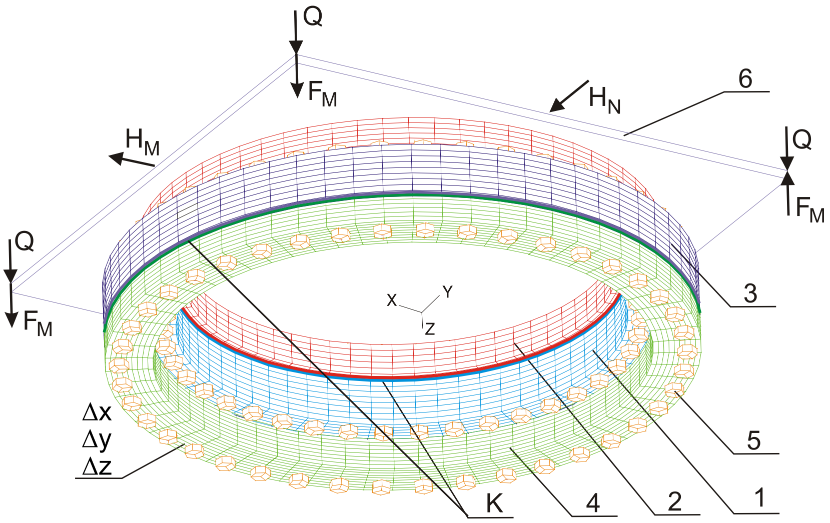

Fig. 2. A mesh of finite elements for model of the one-row ball slewing bearing

Remaining vectors represented respectively an axial force and the radial forces. The vectors F_M, Q, H_M constitute the so-called main system of forces. In such a system standard the static carrying capacity are determined. In this respect, the H_M force was named a *major radial force*, and the H_N force was called an *orthogonal radial force*. Attachment points of the defined load vectors there were in nodes of the one-element group of the finite elements, named perfectly the rigid square plate 6, which have been introduced as the intermediary element in loading the bearing. For nodes of group, 2 contained in a plate plane 6 have been given the conditions of displacements type *glue* [1]. These types of boundary conditions are defined for the 5 group of the finite elements and mapping the heads of the mounting bolts. Boundary conditions type *glue*, during a load simulation, give insured of an immutability of a position a relative location of nodes belonging for a different group of finite elements. A necessary condition for the correct configuration of the displacements for boundary conditions type glue is, that set of particular nodes of the finite element groups formed a separate common flat surface in a plane of contact of the modelled objects. The bolts were mapped by use the two-nodal beam elements type *bolt* [1]. Nodes of beam elements were joined to the central nodes of finite elements of the group 5. In adopting this type simplify, the results of the paper [11] were base to further calculations. This has enabled to calculating the values of an effective stress values, which to a sufficient extent approaching to the results, which may be achieved by the use of a more complicated model. The need of discretization the screw body by elements of the type *3D-solid* [1] and separate the free interstitial space in groups of finite elements 1, 2, 3, 4, treated geometrically as the location of holes for bolts, has been avoided. Consequently, the calculation time was shorten. For elements of the type bolt the shape and the area cross-section, a material model and the force of initial clamp S_w = 242 kN (according to guidelines of work [4] has been defined. Such a procedure is justified, because the ADINA program [1] in the initial iterations is looking of displacements for nodes of model caused by the forces applied to element type bolt [1]. In order to reduce the transverse loads which acting adversely on the bearing bolts, and originating from the radial forces, it has been assumed that the bearing is seated in an annular housing with the centring flange. In order to reduce the transverse loads which are acting adversely on the bearing bolts, and originating from the radial forces, it has been assumed that the bearing is seated in an annular housing with the centring flange. Installation dimensions the upper and lower casing, which determining the stiffness of a housing- bearing ring have been selected in accordance with proportions recommended by one of the producers [5]. It should be noted that cross-section geometry of the deposition is parametrically linked with a cross-sectional geometry of the bearing ring. In order to avoid a solve the multiple contact task formulated by local contact zones, between balls and bearing raceways, balls are replaced by replacement system components called *super elements* [14-16]. In this model was partly used the configuration the replacement elements presented in work [3]. The parts of the replacement elements and a method of use in the presented model are detailed described in the publication [18]. The finite element type *truss* as a part of the replacement elements has specific defined a multilinear material characteristic, which was determined according with description contained in the work [17] and implemented to the model of the slewing bearing. A multilinear material characteristic was determined based on characteristics of a contact zone. A characteristic of the contact zone is defined as dependence the deflection of the raceway caused by a contact force acting between a rolling elements and a raceway. The characteristics of the contact zone obtained as a solution to the issue of the contact zone by using the finite element methods and it was presented in publication [7].

The system of replacement elements a model of bearing represented a local deformations occurring in a contact zone ball-raceway and a change of the contact angle of balls and consequently allow appoint the distributions of a reactions acting on all the balls in a bearing rows. A knowledge of the distribution of the forces acting on each of contact zone allows building a curve of the static carrying capacity of the slewing bearing because about a carrying capacity will decide the most loaded a ball, and a contact force between the ball and the raceway will not be greater than the F_{dop}. In order to determine the permissible force, which can be permanently load a single contact zone it was utilized the criterion of a permissible plastic deformation in the contact zone. This plastic deformation in accordance assumptions with works [2, 6] should not exceed $0.0002d_k$. Hence, the maximum value of the contact force $F_{dop} = 158$ kN, was calculated in accordance with Eq. 1.

$$F_{dop} = \frac{9.9626 \cdot 10^7 \cdot d_k^2 \cdot \left(\dfrac{HV}{750}\right)^2}{\left(\dfrac{858}{a_H b_H} \sqrt[3]{d_k \left(\dfrac{4-2k_p}{d_k} + \dfrac{2\cos\alpha_0}{d_t - d_k \cos\alpha_0}\right)}\right)^2} \text{ [N]}, \tag{1}$$

where:
the remaining (more symbols are described in text) symbols represent the formula a_H, b_H – coefficients of the elliptical contact area according with [2],
HV – hardness of a Vickers scale for a raceway surface.

3. Curves of the static carrying capacity

In the previous considerations, concern the problems an influence of radial forces on a static carrying capacity of slewing bearings usually was taken into account a sense of the major radial force. Identification of sense of the force was associated with the sign of its value. It has a conventional nature and as suggested in publication [6], the action of the major radial force can be equated with the effects induced in computational nodes, which were presented on the example of the twin slewing bearing in work [17].

Accordingly, the force H_M is considered as positive if the sense its operation causes load concentration in the calculation node, in which are the cumulative effects of load by torque M and axial force Q. In case of the sense of the force H_m oriented the contrary, the radial force is treated as a negative. Such a definition gives independence defining of sign of the radial forces on the assumed coordinate system as well as a location of a support and loading of the bearing. However, in the case of deliberations about the orthogonal radial force H_N (Fig. 2) there is no need entering the sign of value of this force, because by the remaining components of the major system of the external load (without force H_M) the sense of the force H_N will not affect the course of curves of the static carrying capacity of the slewing bearing. Determining the points the curves of the static carrying capacity was made in an iterative manner what was wide described in the publication [18]. Comparative summary of curves of the static carrying capacity for defined a sequence of the major radial forces and the orthogonal radial forces are presented in Fig. 3.

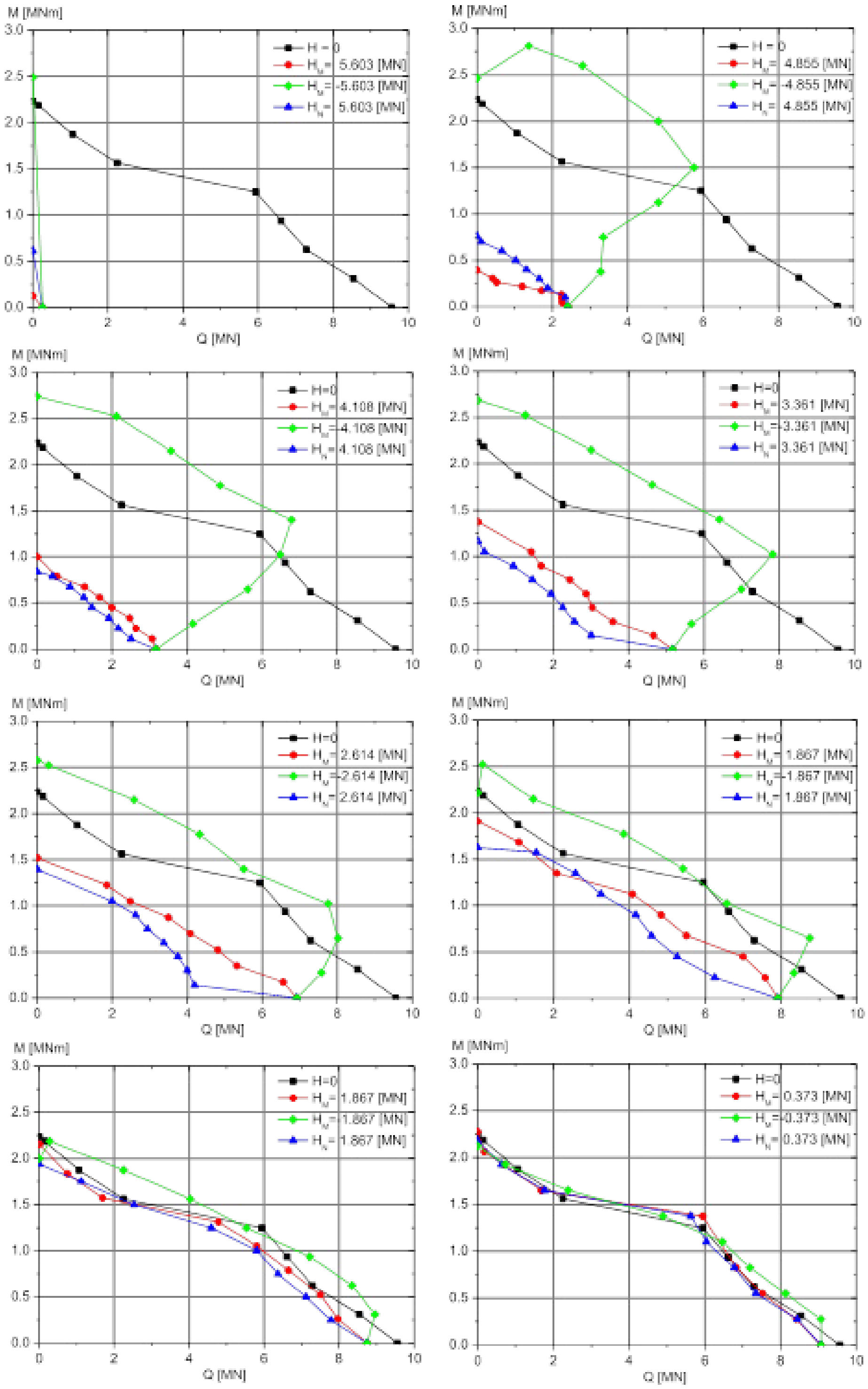

Fig. 3. Juxtaposition of curves of the static carrying capacity for the single-row slewing bearing loaded by constant values of the positively, negatively and perpendicular defined radial forces

Then in accordance with methods of INA company, the authors proceeded to determine the equivalent curve of the static carrying capacity for analysed the slewing bearing. Values of the equivalent tilting moments M_{eq} and the equivalent axial force Q_{eq} are calculated by means equations:

$$M_{eq} = M \cdot f_a \cdot f_s \cdot f_{or} \text{ [5]}, \tag{2}$$

$$Q_{eq} = Q \cdot f_a \cdot f_s \cdot f_{or} \text{ [5]}, \tag{3}$$

$$k = \frac{M}{0.5 \cdot Q \cdot d_t} \text{ [5, 6]}, \tag{4}$$

where:
k – load eccentricity parameter which was utilize in work [6] too,
f_a – application factor [5],
f_s – factor for additional safety [5],
f_{or} – static radial load factor, which is, depend on ratio H/Q and k. It is determined by utilized of charts, which are specified by manufacturer e.g. [5].

Values of tilting moments and axial forces corresponding to coordinate of points forming the curve of the static carrying capacity for a constant value of the radial force H_M = 4.108 MN have been selected in order to performed the calculations. Furthermore it was assumed that the value of factors f_a and f_s have been equal to one. The results of the calculations for the equivalent static carrying capacity shown on the background of curves of the static carrying capacity of the slewing bearing taking into account the direction and sense of the constant radial force (Fig. 4).

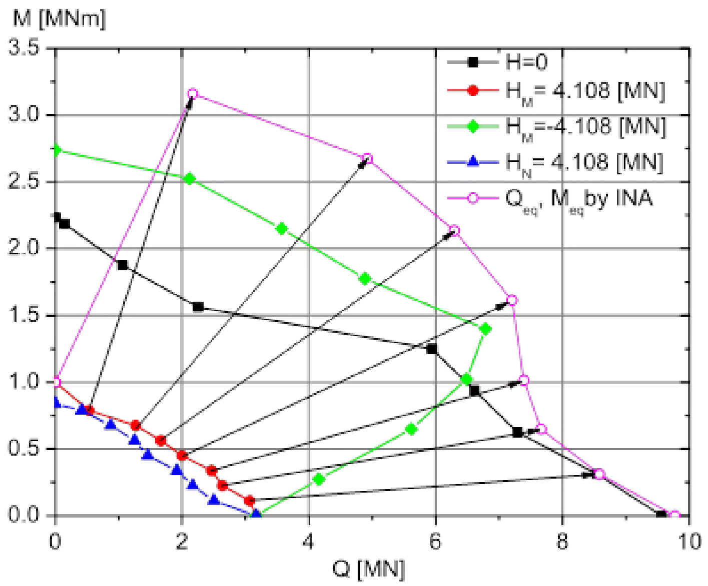

Fig. 4. Equivalent curves of the static carrying capacity (determined according to INA) on the background of curves of the static carrying capacity (according to FEM model) for analysed the slewing bearing with taken into account the large radial forces

4. Conclusions

As a result of the performed calculations obtained a value of the maximum radial load of the bearing H_{max} = 5.976 [MN]. Considering the course of curves of the static carrying capacity for the analysed bearing in relation to the values and directions of the radial forces it can be stated that in a range of loading from 0.8 H_{max} to H_{max} the less value of carrying capacity is generated by the H_M forces. In contrast to the range from 0.3$Hmax$ to 0.8$Hmax$ the lower value of carrying capacity is generated by the H_N forces. Consideration of results of the equivalent tilting moments and the equivalent axial forces which according with methodology of INA company have allowed take into consideration the operates of radial forces permits state that the points of work are located outside a bounded area the curve of the static carrying capacity determined for the value of zero of the radial force. Based on the equivalent curves of the static carrying capacity in order to satisfy the strength requirements of a bearing exist is a need of selecting the slewing bearings about higher the ranges of the permissible axial forces and the tilting moments. From the results presented in the Fig. 4 can be concluded that values of equivalent loads are strongly overestimated in relation to results which were obtained based the model MES. Therefore, the manner of taking into account the radial forces proposed by INA company requires a broader analysis in a range of the static radial load factor f_{or}. In the curves shown in Fig. 3 and 4 follows that their shape is determined by the value of M_{max}. Very importance significance has it take into account the direction of radial forces and in respect to the research methods the level of model simplifications.

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