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QUANTITATIVE DETERMINATION OF THE REASONS OF ERRORS CONCERNING CALCULATION OF THE BEARING CAPACITY OF SLEWING BEARINGS

10.1 INTRODUCTION

Human desire to receive the best product has led to emergence of tools and methods of quality management that needs to monitor and act to strive for perfection of a product. The concept of quality is not limited to product or service, it is a broader concept and can be applied everywhere [5]. Along with the development of quality management, emerged many methods, having impact on quality while sing data collected with the help of quality tools. Methods of quality management more are oriented on the analysis of collected data, however tools have more basic character and serve for the collection of data concerning given product. The important thing is the ability to see the information contained in the methods and use of it to improve other processes or products [1, 8]. The article presents the factors to improve the quality and process of calculating of slewing bearing load capacity. The objective of conducted deliberations is identification and elimination of sources of errors in determining characteristics of slewing bearing capacity. The result of the research is determination of the risks of making mistakes and advice for designers of slewing bearings.

10.2 FACTORS INFLUENCING THE CAPACITY AND DURABILITY

Slewing bearing is a subgroup of rolling element bearing commonly used in large industrial machineries such as turntable, steel mill cranes, offshore cranes, rotatable trolley, excavators, stackers, swing shovels, and ladle cars. A slewing bearing is basically a bearing with a gear wheel integrated in the inner or outer ring, which is subjected to a complex set of heavy loads. They typically support high axial Q, high tilting moment M and high radial load H (Fig. 10.1). Slewing bearings are often critical production part. An unplanned downtime when a bearing breaks down can be very expensive due to the loss of production. Moreover as replacement of large slewing bearing can take several months to arrive due to long manufacturing and delivery time, plants often carry spare bearing to guard against these unforeseen circumstances adding an extra cost. A condition monitoring and prognosis method is needed [7].

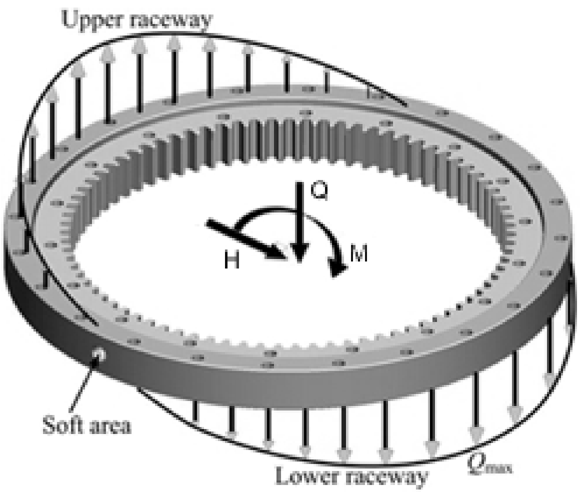


Fig. 10.1 Load distributions over the outer ring raceway in a slewing bearing

Source: own study

There are many different types of slewing bearings depending on the number of rows and in the type of rolling elements. Thus, there are bearings with one, two and three rows, and the rolling elements can be balls or cylindrical rollers [6].

Slewing bearings designed and manufactured for a specific application, this requires knowledge of the design of the device on which the bearing will work, the approximate dimensions of the bearings, the diameters of the bearing rings mounting screws locations, as well as all the types and magnitude of loads that are transmitted through the bearing (Fig. 10.2).

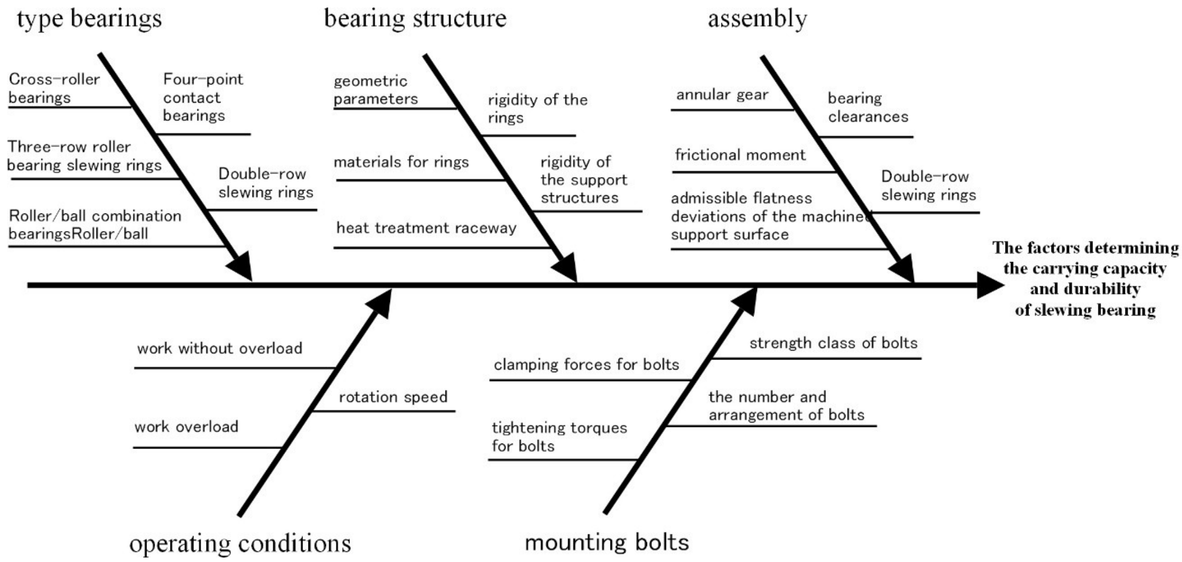


Fig. 10.2 Factors influencing the capacity and durability of the slewing bearings

Source: own study

10.3 CALCULATION OF SLEWING BEARINGS CARRYING CAPACITY

The load capacity of slewing bearings is determined by different calculation methods. Simple model calculations allow determining the characteristics of the bearing under the condition of a number of simplifications. The consequence of the applied simplifications is an inaccurate assessment of actual bearing capacity [2]. Load capacity of slewing bearing is dependent on a number of factors, such as [3]:

- the flexibility of the bearing rings,
- the flexibility of fastening bolts on the bearing rings in the structure of the working machines,
- the sizes of the contact areas of rolling elements with raceways,
- nominal angle of action of the forces transmitted through the rolling elements, and its change under load bearings,
- the coefficient of adhesion of beads to the raceways,
- fill factor parts rolling around the circumference of the raceways of the bearing,
- clearance of the bearing,
- the flexibility of the supporting structures.

In addition, when calculating the bearing capacity of slewing bearings the following assumptions have been made [6]:

- due to low speed of rotation of these bearings ignore the centrifugal force, rotating balls or rollers;
- the ideal forms of rings and rolling elements;
- similar diameter of all parts of rolling;
- similar hardness all on the raceway of the bearing;
- the materials of rings and rolling parts are homogeneous and isotropic;

  allowable load element rolling is the force that causes relative deformation $\delta_{pl\ dop}/_{d} = 0{,}0002$.

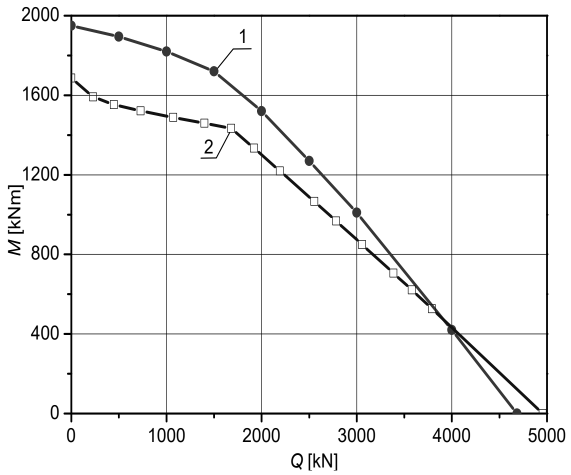
Static load rating of slewing bearings presented in graphs, called characteristics. Generally it is the curve described by the function $M(Q, H)$, where M denotes the maximum value of the tilting moment, Q, the maximum axial force, and H is the radial component of the load. Component H is often accepted as a constant value, which is determined by the functions $M(Q)$.

Fig. 10.3 shows a comparison of the characteristics of the capacity which have been obtained for the cross roller bearing, under the assumption of infinite stiffness of the bearing rings (curve 2) and taking into account the flexibility to its rings (curve 1). The calculations were performed for the bearing rolling diameter of 1390 mm.

The next Fig. 10.4 shows the comparison of the static load rating of three-row roller slewing bearing rings depending on the class and amount used of mounting bolts. Clearly see a change in bearing load capacity, depending on the number and type of bolts. In the case of a small number of bolts and their low strength class, bearing load capacity decreases greatly due to its lower stiffness.

Fig. 10.5 shows a comparison of characteristics for four-point contact bearings, taking into account the changes of the contact angle of the rolling elements in the result of transferred loads. The contact angle of the rolling elements is an included angle between the moving direction of the force on the ball and the plane determined by the axis of rotation of the bearing.

a)



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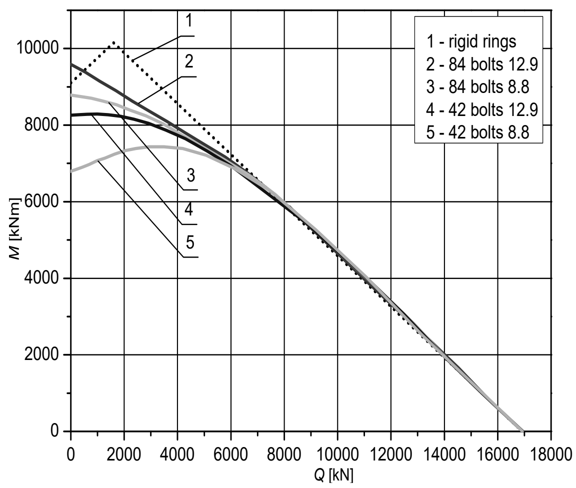


Fig. 10.3 Characteristic load carrying capacity of the cross-roller bearings for the flexibility rings (curve 1) and for rigid rings (curve 2)

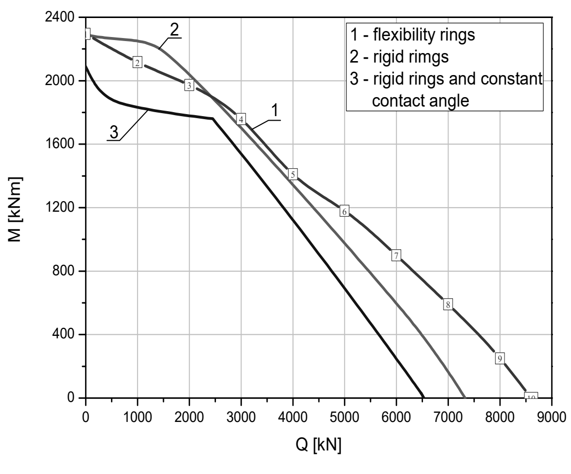
Source: own elaboration

Fig. 10.4 The comparison of the static load carrying capacity of three-row roller bearing slewing rings depending on the strength class and the number of used bolts

Source: own elaboration

Fig. 10.6 shows the distribution of the maximum and minimum angles of the individual points of bearing capacity characteristic. In the bearing rings with flexibility, there is a significant increase in the angles of operation of the rolling elements, which reaches up to 25% of the angles of operation of the rolling elements in the infinitely rigid rings bearing. However it should be noted that too large contact angle in the four-point contact bearings can lead to of rolling out the edge of the raceway, i.e. bringing the field of balls contact with the raceway to the edge of raceway.

a)



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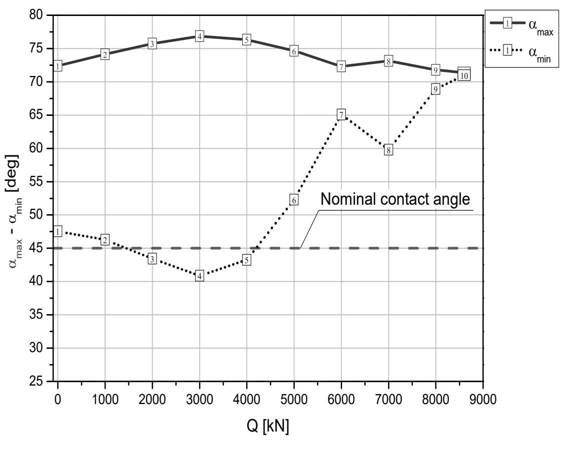

Fig. 10.5 Comparison of characteristics for four-point contact bearings

Source: own elaboration

Fig. 10.6 The minimum and maximum angles of contact of the rolling elements to separate points of characteristic static load carrying capacity

Source: own elaboration

It is also envisioned that the bearing clearances formed during operation cause an additional increase of angles of operation of the rolling elements, which in extreme cases can lead to accelerated wear of the raceways of the bearing. The difference in bearing carrying capacity between the bearing which takes into account the effect of exposure of the rings and change of the operation angle of the bearing and bearing of rigid rings and constant operation angle are significant. For loads with a large proportion of tilting moment M this difference is about 9%, while for bearing load of large axial force Q occurs even 31% increase in static bearing capacity of the slewing bearing. Thus, in determining the performance of ball slewing bearings load-capacity important is the changing angles of contact, i.e., the direction of force distribution through the rolling elements. The specified load capacity for bearings with infinitely rigid rings is approximately 17% less than bearing load capacity with flexible rings.

Fig. 10.7 shows the effect of the adhesion coefficient of balls to the raceway k_p on the characteristics of bearing capacity. The coefficient of adhesion is the ratio of the diameter of the balls to the diameter of the profile of the raceways of the bearing. A significant increase in loads in the bearings, which have a greater coefficient of adhesion of k_p stems from the large field of the contact of ball and raceway, which increases the load limit, which can move the rolling elements. In addition, when the contact geometry with a large coefficient of adhesion decreases the distance between the centers of curvature of the raceway, which in turn will lead to higher contact angle between the rolling elements and the result is moved across the element the load.

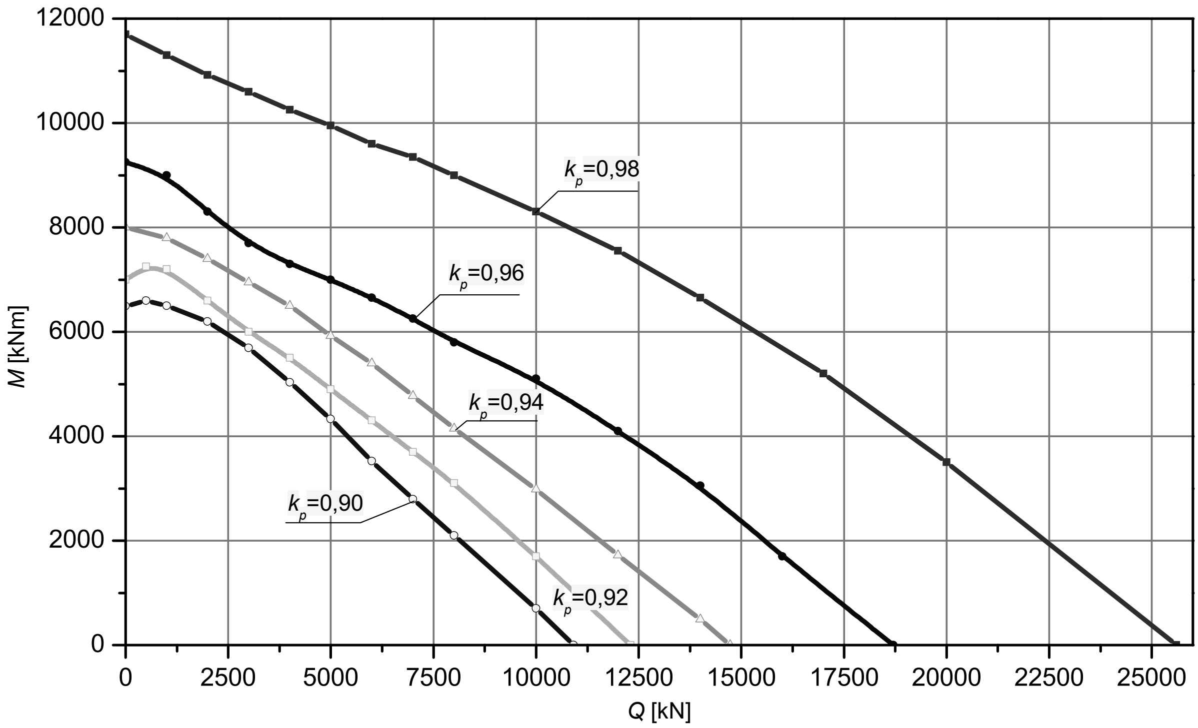

Fig. 10.7 Characteristic bearing capacity of the bearing for different coefficients of adhesion of balls to the raceway

Source: own elaboration

In the construction of computation slewing bearing models important is the consideration of bearing system stiffness of the machine which carries the rotary bearing [4]. Design of support structures must ensure the load distribution without excessive and concentration, which reduce the carrying capacity of the bearing, lead to premature wear and cause a significant reduction in service life [4].

Fig. 10.8 shows the numerical model of the FEM of the bearing, working in the crane and Fig. 10.9 shows compare the catalogue capacity of the bearing (curve 1) with characteristics, which were obtained for the same bearing in the case, when a member node of rotation of the crane self-propelled (curve 2).

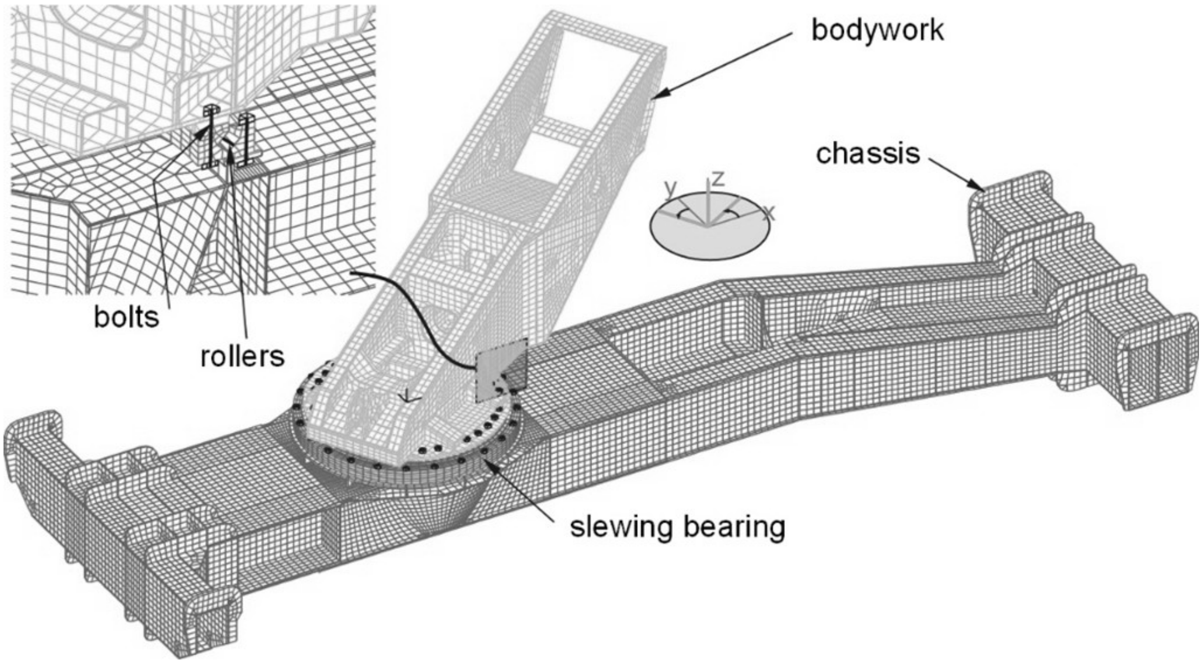

Fig. 10.8 Computational model of FEM self propelled crane

Source: own elaboration

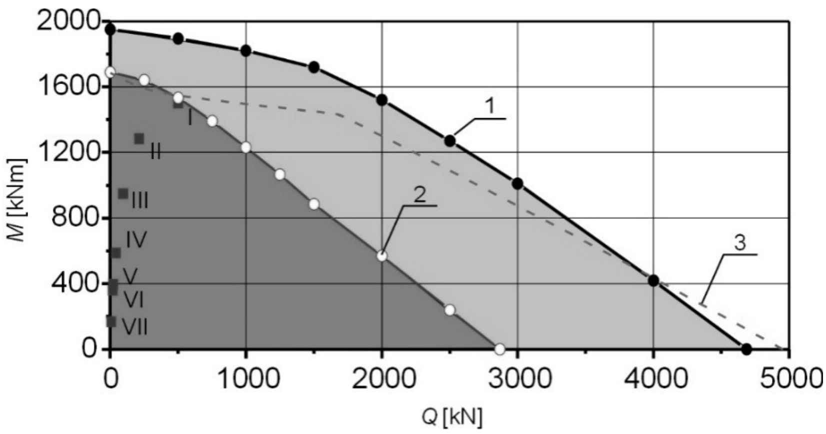

Fig. 10.9 The static load characteristic of slewing bearing

Legend:
1 – Catalogues capacity, taking into account the flexibility of the rings bearing.
2 – Bearing capacity of the bearing is built up in the self-propelled crane.
3 – Load capacity at infinitely stiff rings.
Source: own elaboration

A significant reduction in the bearing capacity for large axial load, is associated with large malformations of the crane body (Fig. 10.10). The chassis of the supporting crane have a low stiffness in the neutral axis steps of tilting moment M. Hence the largest deformation in these areas will occur for large axial load Q.

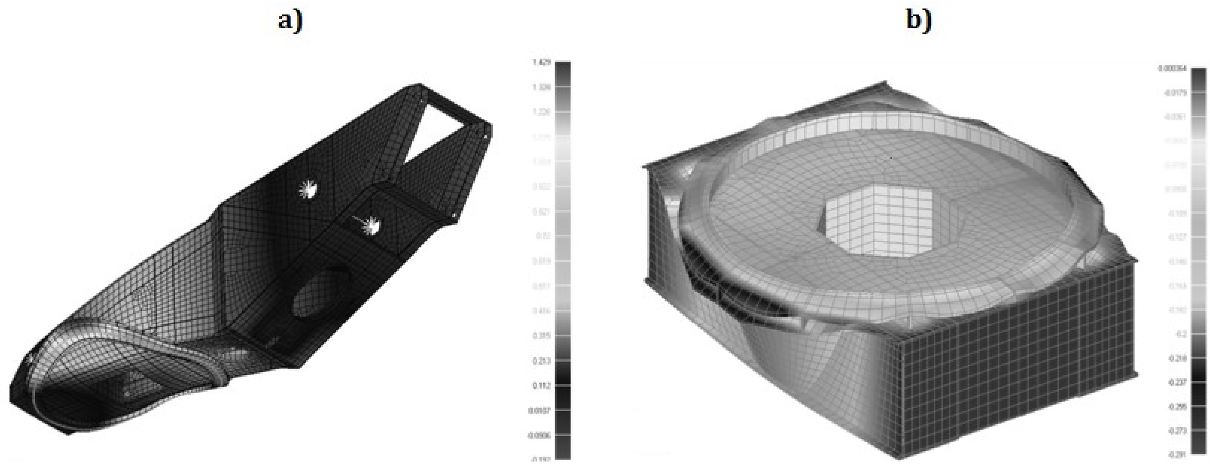

Fig. 10.10 The contour lines of the axial displacements under loading by the vertical force on the *e = 0*:
a) The body of the crane b) The chassis of the crane

Source: own elaboration

10.4 QUANTITATIVE ASSESSMENT OF THE CAUSES OF ERRORS IN DETERMINING THE BEARING CAPACITY

To determine the risk associated with the determination of the bearing capacity of rolling bearings, which are as a result of the simplifications adopted in models of computation, the FMEA method was used. This method analyzes the causes and consequences of errors. The purpose of this analysis-search for possible causes and effects of errors in the design stage and eliminate them before it becomes a finished product. It has also wide application at the stage of operation where there are already failures caused by errors in the implementation of products, that is, in the production process. This method is mainly used in project and research activities and production [9].

In studies the risk was determined by identifying the criteria for selection of coefficients, i.e.: R – the risk of error, Z – the error value and W – the difficulty of accounting errors in the calculations. A number of priority risk was defined by using dependencies:

$$RPN = R\,x\,Z\,x\,W \tag{10.1}$$

In the FMEA analysis, it is assumed that the causes of the error estimation of the bearing capacity, where the number of priority $1 < RPN < 100$, does not require the introduction of protection measures. But if the priority number $RPN \geq 100$, you should take precautions for reasons arising out of errors in determining the bearing capacity. Tab. 10.1 shows the individual factors and risks that are there, if not their relative in the calculations of the bearing capacity of rolling slewing bearings.

The greatest risks related to incorrect evaluation of the slewing bearing capacity include ignoring susceptibility of bearing supporting structures for machine and bearing clearance.

Tab. 10.1 Analysis of the causes and consequences of errors in the calculation of the bearing capacity of the slewing bearings

Potential error	The effects of errors	The cause of the error	Tools/ research methods	The current state				Recommended action
				R	Z	W	RPN	
Ignoring the flexibility of bearing rings	Revaluation static load capacity	The assumptions made in the model computing	Classical computation models bearings	5	4	7	140	Construction of numerical models using FEM
Ignoring the bolts of the bearing ring	Revaluation static load capacity	Simplification of the model computing with respect mounting bolts	Classical computation models of bearings, without the possibility of input of the bolts	6	3	6	108	In numerical calculations the finite element method to model the bolts with beam elements with pre-tension
Ignoring changes in the nominal contact angle of balls	The risk of damaging the edges of the raceway bearing, the underestimation of the static load capacity	Calculations of ball bearings on models of computation relating to roller bearings, in which there is the change of angle of contact	Classical and numerical model for the calculation of bearings	7	4	6	168	In computational models, the balls should be replaced superelementem special which allows, in particular, in accordance with the change in the angle of operation of the parts of rolling due to portable loads
Ignoring the bearing clearance	Revaluation static load capacity, incorrect meshing geometry of gear ring and pinion	Simplification of computational models without the possibility of introducing bearing clearance	Calculation of replacement characteristics of the rolling elements	7	5	3	105	Clearance introduced into the computational model by moving the replacement material characteristic for rolling elements
Ignoring the initial clamp	The underestimation of the moment of rolling friction during rotation of the bearing	Simplification of computational models without the possibility of introducing preliminary clamp	Calculation of replacement characteristics of the rolling elements	8	2	3	48	preliminary clamp through the substitution bias characteristics of the materials for parts of rolling
Ignoring the flexibility of systems of reference and of bearing used for machine	Revaluation static load capacity	Lack of knowledge of the geometry of supporting structures at the stage of calculation of the bearing capacity	Classical computation models bearings	9	6	9	486	It is necessary to know the structure of bearing installation and execute a computational model taking into account the entire structure of the machine relative to the site of rotation
Ignoring the deviation from flatness of the surface retaining	Revaluation static load capacity	The assumptions of the model calculation	Classical computation models bearings	6	4	7	168	The deviation from flatness must be considered in the geometry of the model calculation, concerning the seats of the bearing

Legend:
R - The risk of error. Z - The error value.
W - The complexity of errors. RPN - Number of risks.
Source: own elaboration

CONCLUSIONS

The study analyzes the methods quality of calculating the slewing bearing static load capacity. In relation to the classical methods used currently are considered the main factors that formed the basis of a simplification of the classical methods of calculating the bearing capacity, namely:

- the flexibility of the bearing rings,
- the flexibility of the bolts securing the ring to the structures it is installed,
- deformation and change of contact geometry in the contact zone of rolling elements contact with the raceways of the bearing,
- flexibility and deformation of the supporting structure of the working machine caused by the load.

In the light of the obtained results, when determining the bearing capacity of slewing bearings, located on load-bearing structures, do not have a corresponding stiffness, it is necessary to consider that flexibility is not only rings, bearings and bolts, as well as exposure to the entire load-bearing system of the working machine.

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Abstract: *In the article the factors influencing the improvement of the quality and improvement of process of calculation of bearing capacity of rolling slewing bearings. An aim of conducted deliberations is the identification and elimination of sources of errors in determining the characteristics of slewing bearing capacity. The result of the research is to determine the risk of making mistakes and tips for designers of slewing bearings.*

Key words: *slewing bearing, carrying capacity, FMEA, the Ishikawa diagram*

KWANTYFIKACJA PRZYCZYN BŁĘDÓW DOTYCZĄCYCH OBLICZANIA NOŚNOŚCI ŁOŻYSK TOCZNYCH WIEŃCOWYCH

Streszczenie: *W artykule przedstawiono czynniki wpływające na poprawę jakości i udoskonalenia procesu obliczania nośności łożysk tocznych wieńcowych. Celem prowadzonych rozważań jest znalezienie i wyeliminowanie źródeł powstawania błędów przy określaniu charakterystyk nośności łożysk tocznych wieńcowych. Wynikiem prowadzonych badań jest określenie stopnia ryzyka popełniania błędów oraz wskazówki dla projektantów łożysk tocznych wieńcowych.*

Słowa kluczowe: *łożysko wieńcowe, nośność statyczna, metoda FMEA, diagram Ishikawy*

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