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Analysis of causes and effects errors in calculation of rolling slewing bearings capacity

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Abstract: In the paper the basic design features and essential assumption of calculation models as well as the factors influencing quality improvement and improvement of calculation process of bearing capacity of rolling slewing bearings are discussed. The aim of conducted research is the identification and elimination of sources of errors in determining the characteristics of slewing bearing capacity. The result of the research aims atdeterminingthe risk of making mistakes and specifying tips for designers of slewing bearings. It is shown that there is a necessity fora numerical method to be applied and that real conditions of bearing work must necessarily be taken into account e.g. carrying structure deformations as the first ones.

Key words – FMEA method,slewing bearing, carrying capacity, quality

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 a product or service, it is a broader concept and can be applied everywhere (ULEWICZ R. 2013).

Alongsidewith the development of quality management, emerged many methods which have an impact on quality while sing data collected with the help of quality tools. Methods of quality management are more oriented on the analysis of collected data, however,tools have a more basic character and serve the collection of data concerning a given product. Animportant thing is the ability to see information contained in the methods and use of it to improve other processes or products (ULEWICZ R., JELONEK D., MAZUR M. 2016).

The article presents the factors that aim to improve the quality and process of slewing bearing load capacity calculation. The objective of conducted research is identification and elimination of sources of errors in determining characteristics of slewing bearing capacity. The result of the research is determination of risks of making mistakes and providing advice for designers of slewing bearings.

2. Factors influencing the capacity and durability of the slewing bearings

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. 1).

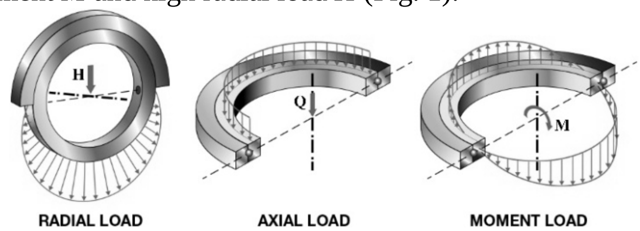

Fig. 1. Load distributions in a slewing bearing.

Source: http://www.silverthin.com/.

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. In order to prevent unplanned downtime, a condition monitoring and prognosis method is needed (KRYNKE M. 2015, ŚPIEWAK S. 2016).

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 (SMOLNICKI T. 2013).

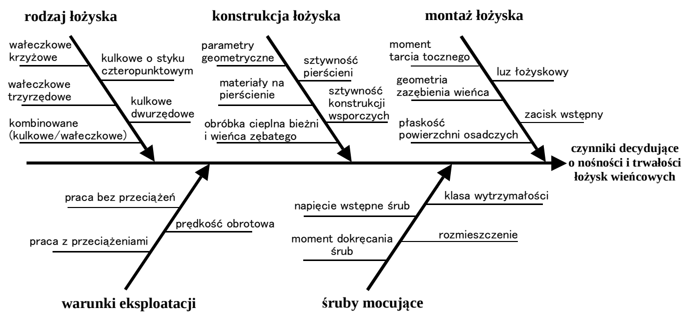

Fig. 2. Factors influencing the capacity and durability of the slewing bearings.

Source: own study

Slewing bearings designed and manufactured for a specific application requiring 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. 2).

3. Calculation of slewing bearings carrying capacity

The load capacity of slewing bearings is determined by different calculation methods. Simple model calculations allow to determine 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 (KANIA L. KRYNKE M. 2013). Load capacity of slewing bearing is dependent on a number of factors, such as (KRYNKE M., BORKOWSKI S. 2014):

- 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.

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 (Fig. 3). Component H is often accepted as a constant value, which is determined by the functions $M(Q)$.

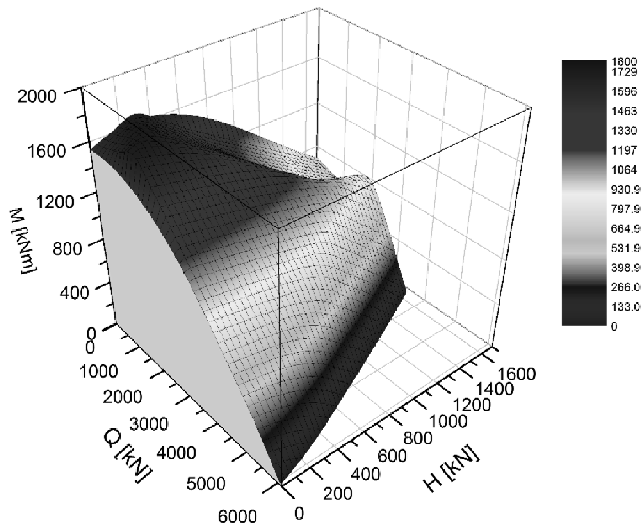

Fig. 3. 3D graph the static load of slewing bearing M = f(Q,H).

Source: own study.

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 (JAGUSIAK-KOCIK M. KNOP K. 2016).

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:

$$RPN = R \times Z \times W \quad (1)$$

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 ≥ 100, you should take precautions for reasons arising out of errors in determining the bearing capacity. Tab. 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.

Table 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 pretension
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 element 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

Source: own study.

5. Summary

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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