DETERMINATION OF STATIC LIMITING LOAD CURVES FOR SLEWING BEARING WITH APPLICATION OF THE FINITE ELEMENT METHOD

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Resume

In slewing bearings, a great number of contact pairs are present on the contact surfaces between the rolling elements and raceways of the bearing. Computations to determine the load of the individual rolling elements, taking into account the flexibility of the bearing ring, are most often carried out using the finite element method. Construction of a FEM full model of the bearing, taking into account the shape of the rolling elements and the determination of the contact problem for every rolling element, leads to a singularity of stiffness matrix, which in turn makes the problem impossible to solve. In FEM models the rolling elements are replaced by one-dimensional finite elements (linear elements) to simplify the computation procedure and to obtain an optimal time for computations. The methods of modelling the rolling elements in the slewing bearing, in which balls have been replaced by truss elements with a material non-linear characteristic located between the raceway centres of the curvatures in their axial section, are presented in the paper.

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1. Introduction

At present rolling slewing bearings is the most often applied rotational connection between the body and support structure of working machines. The most important feature of rolling slewing bearings in comparison to standard rolling bearings is their ability to transfer axial load *Q*, radial load *H* and tilting moments *M* acting in planes crossing the longitudinal axis of the bearing (Fig. 4). In contrast to typical rolling bearings, the flexibility of support subassemblies, including the flexibility of the bearing rings and size of clearance in the bearing rows, has a decisive influence on the load-carrying capacity of the slewing bearings [1, 2]. Although these types of bearings have been applied for eighty years, brand catalogues still contain simplified characteristics of their static load-carrying capacity. The existing state of technical knowledge is only apparently sufficient and still needs further investigation. The selection of a bearing, made on the basis of the above mentioned catalogue characteristics could lead to serious structural errors, such as a drastic reduction in the life of the bearing node and the bearing capacity to be under-used [3].

Knowledge of the values of the forces acting on the bearing rolling elements during work is the basis for estimating the bearing's ability to fulfil its function. The method of computation of internal load distribution is the main topic of papers dealing with slewing bearing problems [4, 5]. Generally, the problem of determining the force distribution in a slewing bearing is repeatedly treated as statically indeterminate problem. The computational methods used to determine the loads of individual rolling elements can be divided into classical methods and numerical methods with the use of FEM. In the classical methods the solution is determined by the assumption of the ideal rigidity of the rings, while the numerical methods allow the flexibility of the bearing rings to be taken into account.

2. Modelling the contact between the rolling elements and the raceways

Building of FEM models of the slewing bearings, due to their complex construction, causes many difficulties. An adequate modeling of rolling elements is one of them. The FEM model of the contact zone of one rolling element with raceway at sufficient accuracy contain from several to tens of thousand degrees of freedom [1]. Due to large number of these elements (tens or more), construction of a full model of the bearing, taking into account the shape of rolling elements and the modelling the contact problem for each of them, is practically impossible. The difference in scale of systems rolling element – raceway and support-construction makes it difficult to obtain exact accuracy of computations and to obtain convergence of numerical solution due to too high differences in rigidities between individual finite elements. It should be noted that computations considering geometrical and physical nonlinearity are required to be carried out. So, to simplify computation procedures and to obtain optimal time of computations, the rolling elements in FEM models have been replaced by one-dimensional finite elements (linear elements). The most often applied finite elements replacing rolling elements in computational models of slewing bearings are:

the truss elements with adequate unilateral non-linear material characteristic stress – strain, special elements (super-elements), mainly for ball bearings, on the basis of super-element proposed by T. Smolnicki in [1, 6].

Replacement elements in the form of the truss elements are applied first of all to roller bearings where rollers are replaced by singular truss elements with the length equal to the diameter of roller (Fig. 1). This kind of replacement elements can be applied to computational models of ball bearings with constant contact angle equals 90 º [7, 8].

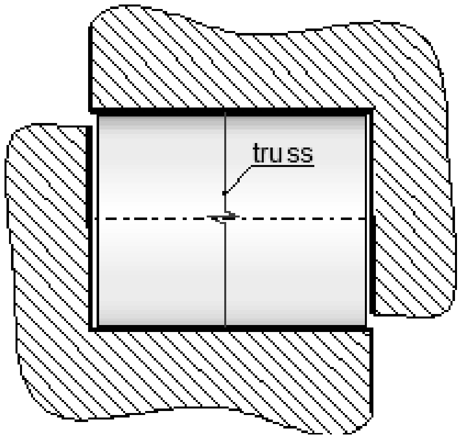

Fig. 1. Replacement truss elements for rollers - singular truss element

The truss element is of exactly definite length and cross-section as well as appropriately determined material characteristic σ (ε). This element is performing a role of a non-linear spring [9, 10].

Super-element is mostly applied to model balls in slewing bearing with variable contact angle due to the loads carried out by the bearing. Finite beam elements with joints as well elastic element with non-linear characteristic *force – deflection* have been used to build super-element (Fig. 2).

FEM software defined optional non-linear materials for the truss element [11]. The definition of a material characteristic is based on introduction into the software particular points of this characteristic, it means strain ε and corresponding stress σ, in a tabular form. Therefore every strain of the truss element causes corresponding stress, what in turn allows the force carried by the truss element to be determined. Interruption of computation took place when deformation of the truss elements would exceed values given by material

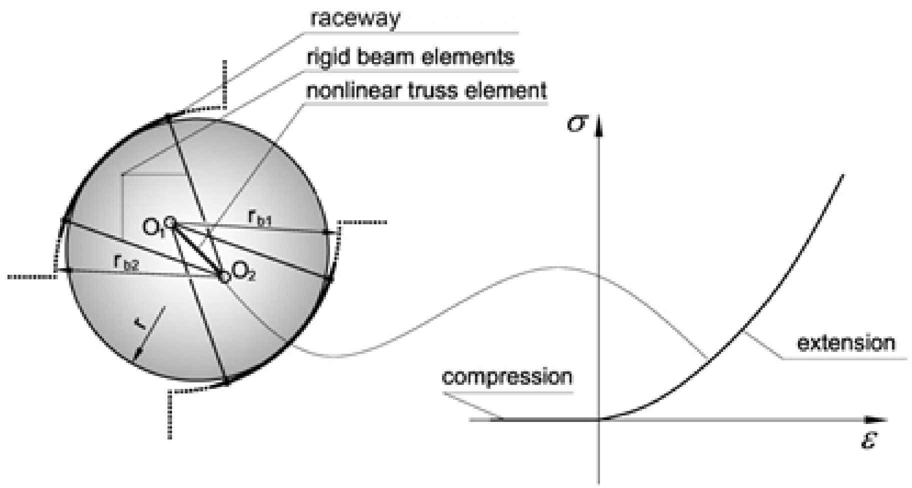

Fig. 2. Super-element with non-linear asymmetric material characteristic for balls

definition due to deficiency in convergence of the solution. Simulation of strain in the contact area of the contact pair is carried out using the characteristics described above. Super-element allows the displacement of real rolling element and the changes in the contact angle of the ball bearings to be determined. The real rolling element is subjected to external load transferred to rolling elements by the bearing rings.

Examples of application of the truss elements to the modeling cross-roller and three-row roller bearings are presented in Figs. 3c and 3d, while applications of super-element to the modeling the balls in a single-row and a double-row ball slewing bearings are shown in Figs. 3a and 3b.

3. Computational example

The computation was carried out for single-row bearing with 84 balls of $d = 50$ mm in diameter, placed on the track diameter $d_t = 1400$ mm. The contact coefficient of the ball and raceway was equal to $k_p = 0.96$, and hardness of raceway - 54 HRC. It is the bearing

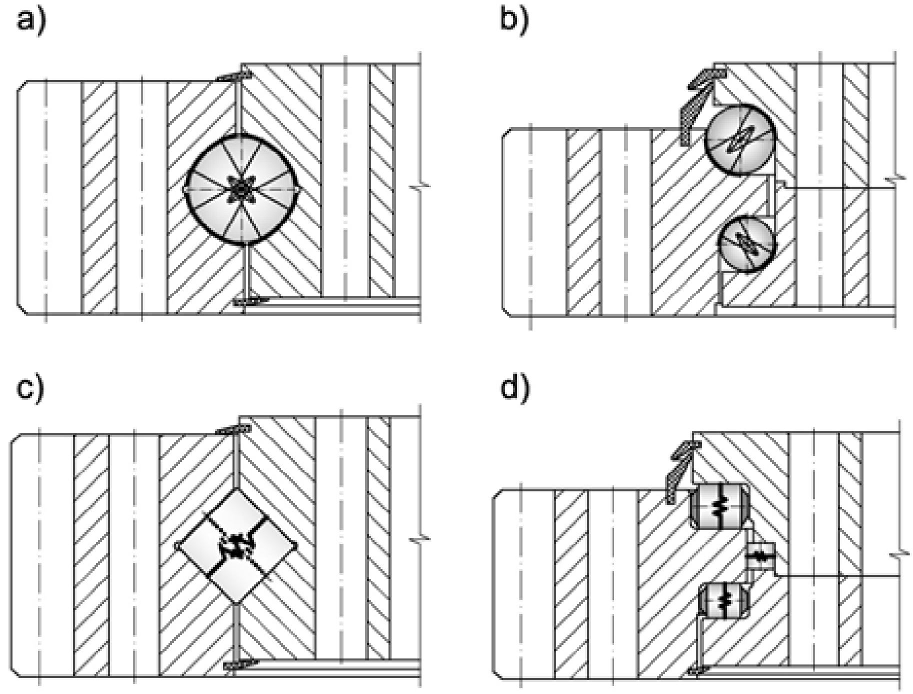

Fig. 3. Replaced rolling elements in: a) single-row four-point bearing, b) double-row ball bearing, c) cross-roller bearing, d) three-row roller bearing

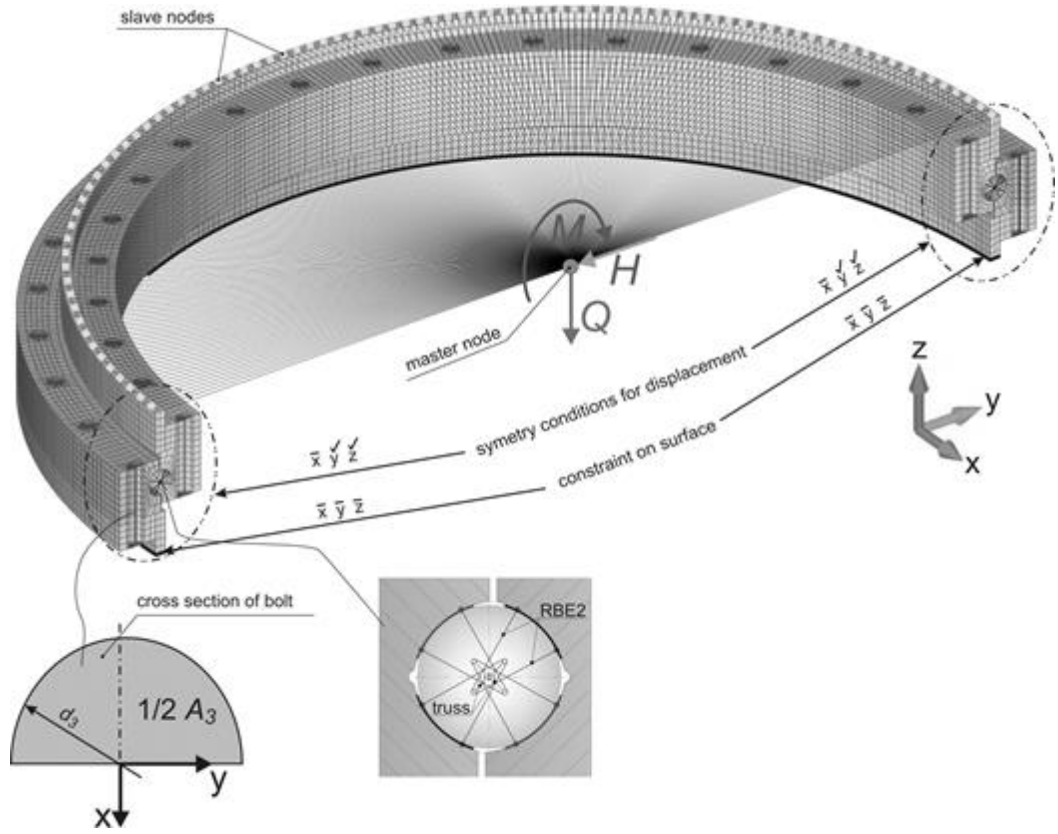

Fig. 4. Boundary conditions

of a standard construction with the nominal contact angle $\alpha_0 = 45°$. The bearing is fixed to the rings of enclosure by 36 M24 bolts of 10.9 class with corresponding initial stress $F_M = 239$ kN. The bearing model used in computations is presented in Fig. 4.

Half of the bearing and rings of enclosure were assumed for analysis. Suitable boundary conditions, resulting from the model symmetry, were introduced into the model. The bolts fastened the bearing, placed in the symmetry plane of the bearing, were modelled as beam elements with half core of a cross section of A_3 bolt. Initial stress equals $\frac{1}{2} F_M$ of clamping screw initial stress was imposed to edge bolts with intersection of $\frac{1}{2} A_3$. Similarly, half of intersection A_t computed is assumed in the truss elements replacing nodal rolling elements. Adequate contact surfaces between the bearing rings and enclosure rings were defined. The friction factor equal to 0.15 was assumed in the contact zone of the elements.

Lower surface of support ring, to which external bearing ring is fixed, was rigidly supported. Internal ring is fixed on the upper surface of enclosure ring. The constrains between nodes placed on this surface (slave nods) and the central node (master node) placed in the centre of gravity of nodes slave was imposed on the upper surface of enclosure ring. Pairs of nodes, formed in such a way, create “rigid spider” with master node as a central point. External load in the form of concentrated force and concentrated moment is imposed on the master node. When model undergoes deformation, slave nodes are forced to displacement and rotation in such a way that distance between slave and master nodes stays constant and that rotations of slave nodes are identical as adequate rotations in the main node. The bearing load is generated by given tilting moment M, axial force Q and radial force H (Fig. 4).

Distribution of internal load and the load of clamping screws, obtained from computations at the bearing loading by limited tilting moment M_{max} when $Q = 0$ and $H = 0$, are shown in Fig. 5 and Fig. 6.

The characteristic of static bearing capacity considering the flexibility of the bearing rings, obtained by computation of numerical model using super-element, are presented in Fig. 7. The curve of the bearing limiting capacity obtained assuming non-deformability of its ring is placed in this figure for the comparison [4].

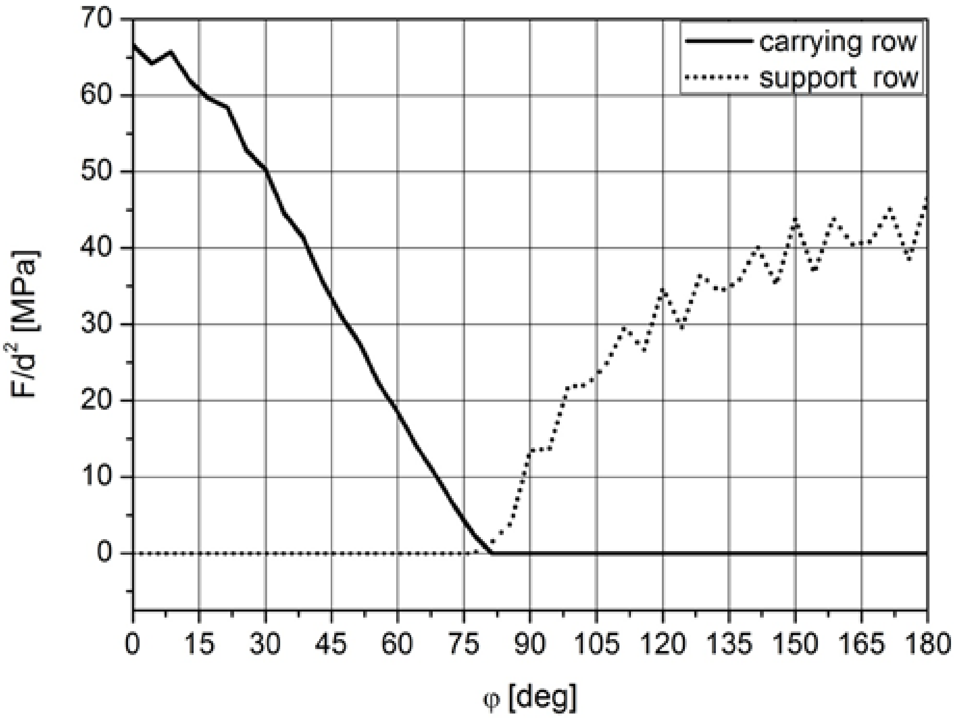

Fig. 5. Comparison of distribution of internal load at the bearing loading by maximal tilting moment

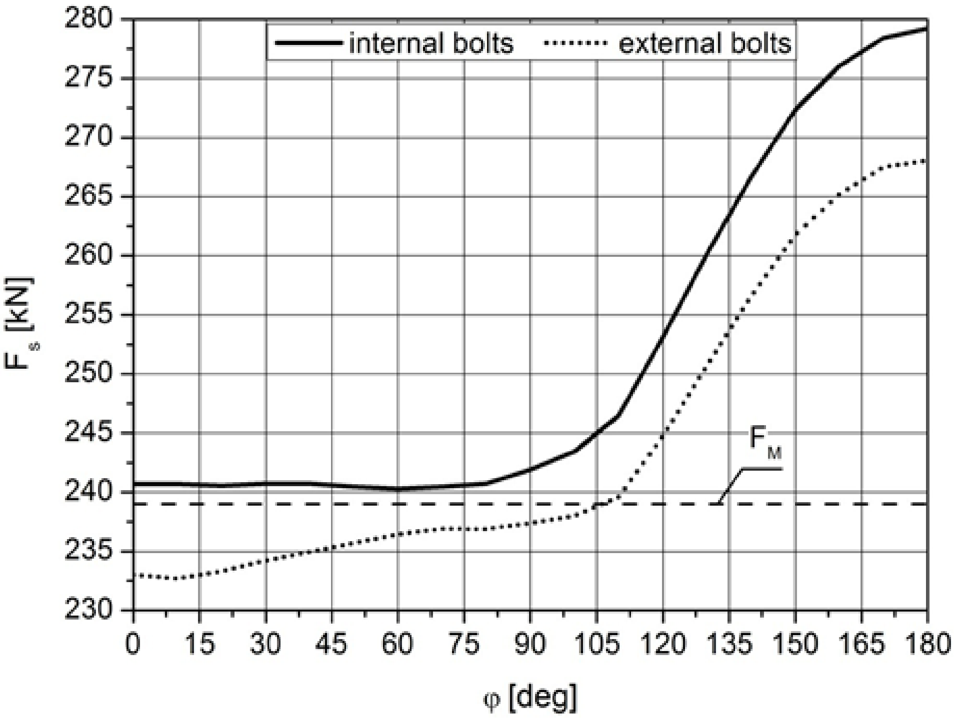

Fig. 6. Comparison of the load distribution of individual clamping screws of internal ring, and screws of external ring

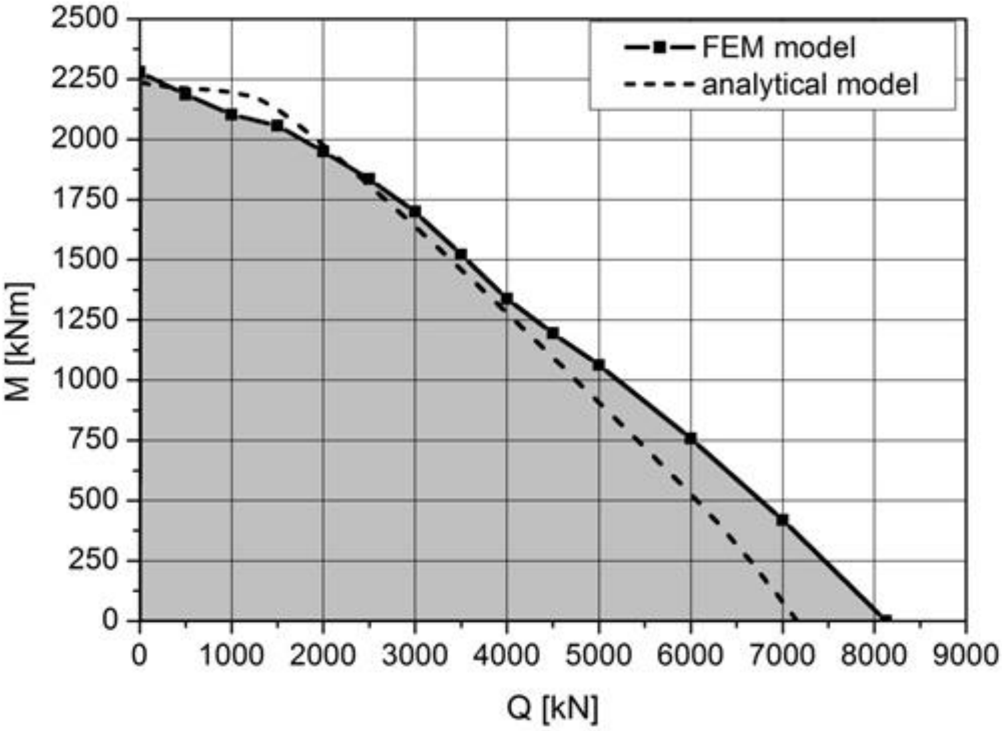

Fig. 7. Characteristic of the bearing capacity (FEM model and analytical model)

4. Conclusions

Computational models of slewing rolling bearings must undergo simplifications due to their complexity. The same goes for the computation of the bearing capacity using the finite element method.

The presented analysis justifies the usage of numerical methods in practical computations. The analysis allows the force distribution in the individual rows of the bearings to be exactly determined, which is impossible using analytical methods. The analytical methods are reduced for the bearing computations by the assumption of the non-deformability of the bearing rings. Computational modelling allows all constructional and technological changes introduced into the geometry of the real bearing to be quickly verified, and also allows the geometrical characteristic of mounting structure of the bearing in machine to be taken into account. The method of modelling the rolling elements, which are replaced by special elements (super-elements), is the key stage in the presented computational methodology. Both the structure of the super-element and its substitute characteristic can have a profound influence on the obtained results of computations. To obtain an adequate characteristic of the bearing capacity one must take into account both phenomena proceeding in the contact zone of the rolling elements and raceways, and the influence of the method of rolling element modelling in the FEM numerical model of the bearing.

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