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Raceway crowning in roller bearings

- Simulation of contact pattern
- Optimization
- Development of a simplified method for families of similar applications

Abstract

Contact pressure distribution in bearings is determined by micro-geometry of the contact surfaces, related axial and radial loads and by misalignment between shaft and housing, while especially cylindrical and tapered roller bearings are very sensitive for misalignment which can be caused by both initial manufacturing deviations or by elastic deflection due to operation conditions. In most applications, loads and misalignment can hardly be influenced why optimization of micro-geometry is very important for reaching proper contact pattern without any critical pressure peaks and thus providing sufficient lifetime of the bearing.

By means of finite-elements-method, contact pattern due to operational loads and deflections can be assessed which allows discussion of different concepts for micro-geometry. Subsequently both optimized geometry can be determined and influence of tolerances can be estimated. Based on that, detailed specifications for micro-geometry can be developed for each particular bearing and application.

As optimization based on sophisticated simulation of each particular case is very expensive, in a second step, a simplified method has been developed which allows transferring of results from one case to a family of similar applications. Subsequently, micro-geometry of roller bearings can be controlled by reasonable effort and precision which is sufficient for a broad spectrum of applications.

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1 Simulation

The numerical simulation shall provide precise information on contact pressure distribution which requires excellent mesh properties close to the contacts. For this reason, rollers and rings have been meshed using hexahedral elements with local refinement in those areas where contact can be expected. Elements in this region are almost rectangular while aspect ratio (ratio between longest and shortest edge) is limited to 4. The further partitions of rings and rollers, however, can be meshed using rather coarse elements.

Apart from that, surrounding parts like shaft and housing have to be considered. Here, stress values do not need to be discussed as this is not the goal of the simulation. Nevertheless, global stiffness and subsequent deflection have to be calculated precisely as these quantities are most relevant for contact pattern. On the other hand, meshing of the surrounding parts should consider total simulation effort for both modelling and calculation. For this reason, surrounding parts have been meshed using second order tetrahedral elements which are suitable for automatic meshing of complex geometry and provide accurate results with most common solvers.

For all parts, acceptable simplifications have to be discussed. In context of contact simulation, especially chamfers, small radii, bolts etc. can be neglected. Also contact definition between rings and housings and shafts can be simplified. Here, tied contacts have been used at both interfaces.

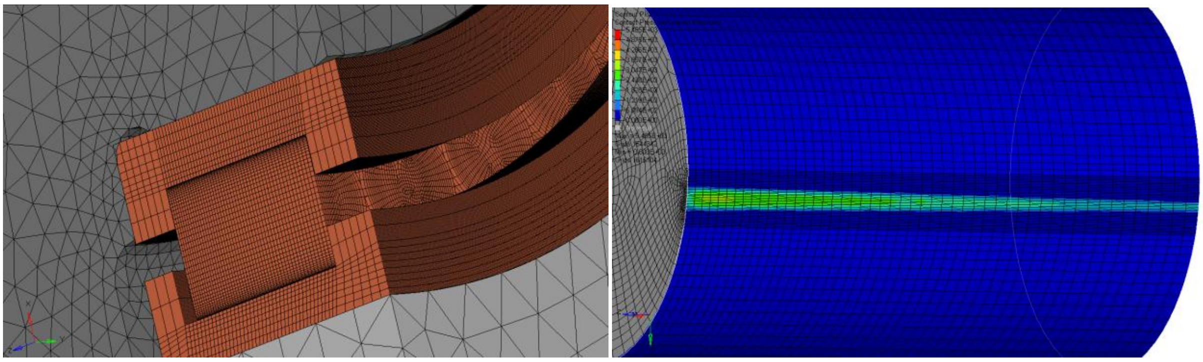

Figure 1: model of a cylindrical roller bearing

As the objective of the optimization is to find geometry which prevents both edge contact and plastic deformation, both plasticity and edge definition of the rollers can be neglected. This allows higher mesh quality at critical positions and reduces calculation effort due to simplified mechanical theory. Subsequently, results will not be valid for improper versions; however, behavior of optimized version can be predicted properly.

2 Optimization

The goal of the optimization is minimization of peak pressure considering boundary conditions which means that pressure at edges of the raceway has to be significantly less than peak pressure – here, one decided to define 50 % of maximum pressure as limits at edges of the raceway. Subsequently, transition to radii at roller faces may cause up to 100 % increase of local pressure.

In general, two different phenomena have to be discussed: deflection of bearing parts due to high loads and misalignment between bearings rings towards each other due to shaft and housing deflection. For the first item, the best approach is to apply convexity on both rings while both circular, logarithmic and combined circular-straight profiles are very common. Convexity of rollers is not discussed so far as only total convexity of one contact pair is relevant for contact pressure distribution – no matter which part takes with portion of total convexity. Subsequently, rollers have been assumed to be perfectly straight while crowning is applied only on the rings.

However, investigation showed that in context of misalignment, one should design one contact pair rather straight while only the opposite contact is made with significant convexity. Subsequently, edge contact at the rather straight pair will be reduced by bending of the rollers. The advantage of this approach is that the flatter contact pair clearly defines roller position in the bearing and subsequently position of centre of gravity of pressure area. In case of two convex contact pairs, the position of the pressure area is likely to move in axial direction so that reduction of peak pressure by convexity is overcompensated by edge contact effect.

The main conclusion in this context is that two completely different approaches are required depending on whether misalignment or high peak loads are the most relevant issue that has to be covered by crowning of surfaces. Subsequently, crowing concepts which are optimized for low speed heavy duty applications, e. g. wheel bearings of mining trucks, are not feasible for e. g. railway gearboxes, where rather high speed and high number of total revolutions at medium loads but significant elastic deformations have to be considered.

Optimization does not only lead to identification of geometry which provides best possible contact pattern, it helps also to discuss influence of tolerances. Wide tolerances are desired for manufacturing reasons; however, the wider tolerances are, the higher maximum expectable pressure will be which will affect product performance. Based on data gathered during iterative optimization, a suitable compromise between both objectives – maximum performance and minimum manufacturing costs – can be achieved.

3 Development of a simplified approach for families of similar applications

If desired crowning parameters for one bearing including acceptable tolerances have been defined, transferring these parameters to similar bearings in comparable applications will be likely to save plenty of engineering effort. For this reason, a simplified method has been developed which helps to analytically calculate parameters for a whole family of application cases based on optimized parameters for a reference bearing. However, this approach is only valid for circular crowning and precision of this method is limited by difference between related geometry and loads.

The first step of such an approach is to simplify the system that has to be discussed and to reduce the number of parameters. Here, the first simplification is to reduce contact between roller and convex rings to an equivalent system of a convex roller which is in contact with an ideal flat, using the assumption that diameter of rings do not significantly affect contact pattern. This means subsequently that diameters within one bearing family should be within a limited range.

Further, both contacts of one roller are defined by different crowning parameters while contact pressure distribution is influenced by bending of the rollers. Consideration of bending, however, allows reducing this two-parametric system to only one parameter which will be a mean convexity of both contacts as convexity of one contact is likely to reduce edge pressure on the opposite contact as well. At the end of this approach, one assumes that the ratio of both crowning parameters has to be constant within one bearing family.

Based on these simplifications, maximum contact pressure and contact width can be calculated according to Hertz theory dependent on contact force per roller, roller diameter and mean convexity. For tapered rollers, the mean roller diameter will be considered. For the purpose of finding equivalent crowning parameters, it is assumed that parameters are equivalent if maximum pressure is equal for such contact forces per roller which lead to contact width equal 80 % of raceway width.

Using this assumption, required mean convexity can be calculated. Subsequently, inner ring and outer ring convexity will be defined using a constant ratio between these values for all bearings of one family. Finally, tolerances have to be adapted, while ratio between tolerance field width and mean convexity is kept constant too. In this context, it is recommended to slightly reduce tolerances in relation to geometrical difference towards reference bearing in order to cover the influence of simplification.

4 Conclusion

Using numerical simulation methods by means of finite elements method, raceway crowning of bearings can be optimized regarding particular applications. Here, one has to distinguish between influence from internal bearing deflection and from deflection of shafts or housing. Both influences on contact pattern have to be covered by completely different approaches. Apart from optimal parameters, a reasonable compromise between tolerances and bearing performance can be achieved.

Within one bearing family, equivalent parameters for different bearings can be derived based on one reference bearing using a simplified approach. However, this approach is limited by differences between macro-geometry and operation conditions.