

Analysis of Dynamically Loaded Rolling Bearing Cages with Abaqus/Explicit

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Abstract: The main functions of rolling bearing cages are the separation and distribution of rolling elements. The cage is not directly affected by the loads acting on the bearing but by the dynamic interaction with other bearing components. Critical conditions for the cage can occur during operating conditions with shock loads or vibrations. For the strength assessment of the cage, a dynamic simulation is often necessary. One option is a dynamic FEA of the whole bearing, however, that can be very expensive. A model reduction is possible by means of adequate connector elements. An alternative to that is a multi body simulation (MBS) of the bearing and a subsequent dynamic FEA of the cage for a single impact with the impact speed result of the MBS. This allows an effective fatigue analysis for the cage. The outcome could be verified by measurement of cage motion and strains on different test rigs. As a result, this shows that Abaqus/Explicit is a powerful tool for the analysis of dynamically loaded cages.

Keywords: Abaqus/Explicit, Rolling Bearings, Fatigue, Dynamics, Impact, MBS, Connectors.

1. Introduction

The main functions of rolling bearing cages (or retainers) are the separation and the distribution of the rolling elements (Fig. 1). Other functions are often to prevent rolling elements from falling out of separable bearings and to guide the rolling elements in the unloaded zone of the bearing (FAG, 1999; Harris, 2004).

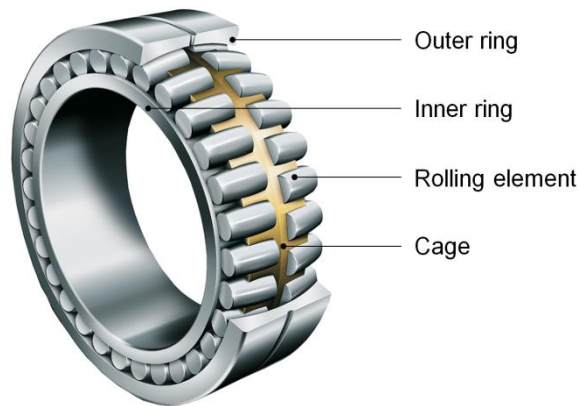


Figure 1: Components of rolling bearings

For the various bearing types and a wide range of applications, a lot of cage types made of different materials have been designed. Fig. 2 shows some examples. Cages can be classified into pressed cages, machined cages and molded cages. Usual materials for cages are steels, copper alloys, reinforced plastics, aluminum alloys and phenolic resin. (FAG, 1999)



Figure 2: Types of cages

In many cases cages work without any failures. Whereas the contacts between raceways and rolling elements are usually highly stressed, the cage is not. The cage is not directly affected by the bearing loads. Its loading results from the interaction with rings and rolling elements. However, the cage may have an influence on the operating behavior of the bearing. The lubrication of the contacts can be improved or degraded by the cage. The friction moment and the noise emissions are enhanced by the cage. Not least the cage can have a significant impact on the costs of the bearing. For this reasons, a targeted design of the cage can be important to improve the bearings behavior or to reduce the costs of the bearing. Therefore and for the assessment, when severe operating conditions occur, the strength analysis of cages becomes more and more essential. Due to the sliding contacts between the cage, the rolling elements, and often one of the rings, the strength analysis can also require the analysis of the contacts to estimate the wear behavior. The cage loading can become critical especially in applications where high accelerations, impacts or vibrations occur.

2. Dynamic cage behavior

The cage has to be guided by the rolling elements or by one of the rings (Fig. 3). To avoid any constraint loads on the cage, a tangential clearance of the rolling elements in the cage pockets is necessary as well as a radial clearance of the cage. The clearance of the rolling elements is called pocket clearance and the radial clearance of the cage is called guidance clearance (Fig. 4). The possibility of cage movement depends on the guidance clearance. The cage is pushed by rolling elements in the load zone of the bearing and drives the unloaded rolling elements around the path. The movement of the rolling elements in the pocket leads to mass and impact loads that are only important for larger rolling elements. Fig. 5 shows the measured bar forces for a larger cylindrical roller bearing.

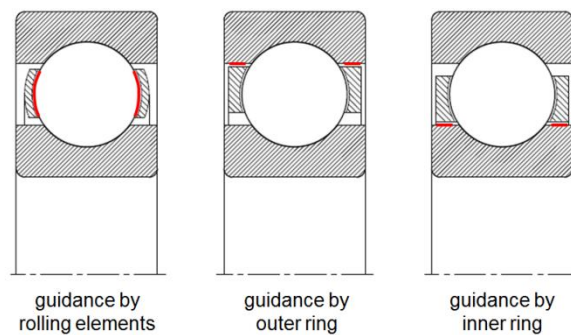


Figure 3: Cage guidance (FAG, 1999)

Under operating conditions without great variation in speed and critical shock loads or vibrations, the center of mass should be located in a stable position and the cage loads are small or moderate. When shock loads are acting on the bearing, the cage is pushed by the guiding surface and will collide with the another point of the guiding surface. The characteristics of these impacts depend on the dynamics of the shock loads, the masses, and in particular on the guidance clearance.

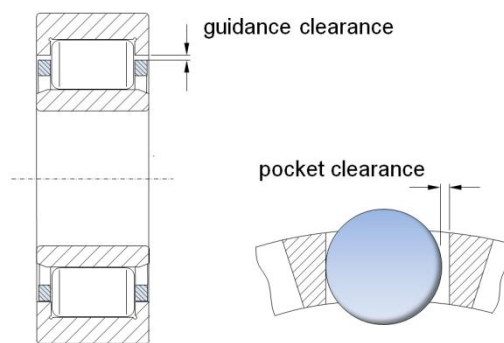


Figure 4: Guidance clearance and pocket clearance

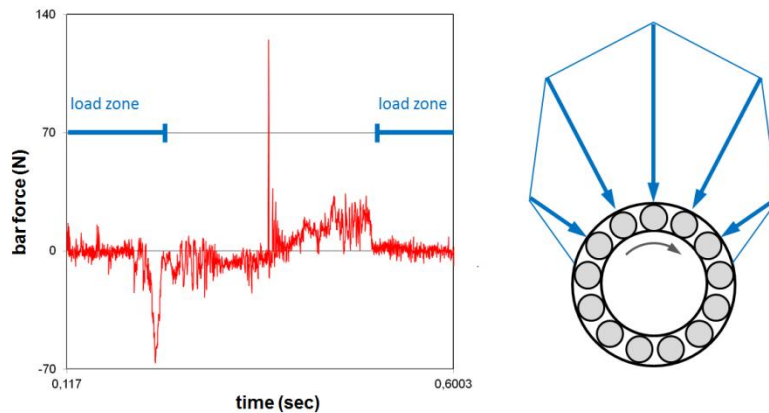


Figure 5: Measured bar forces in a cylindrical roller bearing

Vibrations (radial or torsional) may have the same result. The cage can be excited to jump on the guiding elements. However, radial cage movement can also occur for operating conditions without dynamic loading. The reason for the cage motion is the transformation of energy from the rolling elements through friction in the cage pockets. This cage instability had been described by many authors (Boesinger, 1992; Gupta, 1984; Ghaisas, 2004). The self exciting mechanism can result in different motion curves of the cages center of mass (Fig. 6) and may lead to higher frictional torque, wear, noise, and cage fracture. The influencing factors are the operating conditions, the friction coefficient in the pockets, the internal clearance of the bearing as well as the guidance and the pocket clearance of the cage.

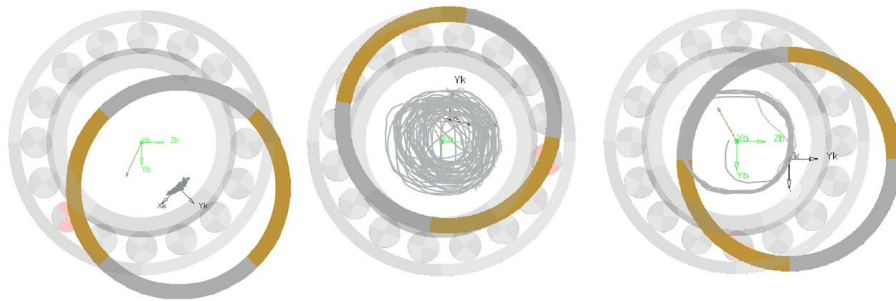


Figure 6: Cage motion (magnified)

The dynamic motion of the cage as a result of dynamic bearing loads or cage instability may lead to fatigue damage through repeated collision processes. An important point can be a continuing plastification of contact surfaces (Engel, 1976). This can result in growing clearances which change the dynamics of the cage to such an extent that higher impact forces lead to damage.

3. Analysis

A suitable analysis for the strength assessment of the cage requires the analysis of the dynamic cage behavior and the dynamic analysis of the impact events. One option is the dynamic FE analysis (FEA) of the rotating bearing with rigid and elastic bodies (Golbach, 2004). Due to the complexity of the model with very small contact areas between rolling elements and raceways as well as the necessity of an analysis for several revolutions, this is often very difficult to model and very expensive. In some cases, the analysis is possible with a simplified model without detailed rolling contacts. For the consideration of realistic motion of rolling elements, connector elements can be used. A beneficial option to improve the model is the contact smoothing feature in Abaqus/Explicit (*SURFACE PROPERTY ASSIGNMENT, PROPERTY=GEOMETRIC CORRECTION).

An alternative to the dynamic FEA is the analysis of the cage dynamics by means of a multi-body simulation (MBS) and the subsequent analysis of a single impact by means of a dynamic FEA (Binderszewsky, 2012). For the dynamic simulation of rolling bearings, the powerful in-house tool CABA3D is available at Schaeffler.

3.1 Dynamic rolling bearing simulation with CABA3D

CABA3D (Computer Aided Bearing Analyzer 3D) is a universal rolling bearing multi-body simulation program (MBS), which can be used to carry out realistic simulations of all types of rolling bearings (Bakolas, 2009). It can be used to simulate ball and roller bearings, axial and radial bearings, single row and multiple row bearings as well as bearings with cages and those with a full complement of rollers. The cages can be split cages or be made up of spacers. The bearing is subjected to load by means of forces and moments on the rings that can act in all directions. The load can be specified as a constant load or as a function of time. The rolling bearings can be moved on any path during this process, that means it is possible to simulate planet gear bearings or bearings subject to vibrations and shocks.

The user then receives all kinematic values, forces and moments, contact parameters (pressure, slippage, lubricant film thickness) and damage parameters. This allows a comprehensive assessment of the operating behavior of rolling bearings in the application to be made.

The overall elasticity of the cage can be considered by means of a rigidity matrix of a segment from a previous finite element calculation. Here, the cage is split into several sections that are connected to each other via spring elements. The attached mass of the single cage segments enables the simulation of natural frequencies and natural modes.

This means that it is possible to analyze the dynamic cage behavior for any loads using CABA3D. Figure 7 is a magnified diagram of the path of motion of the center of gravity of a cage in a bearing during torsional vibration of the inner ring.

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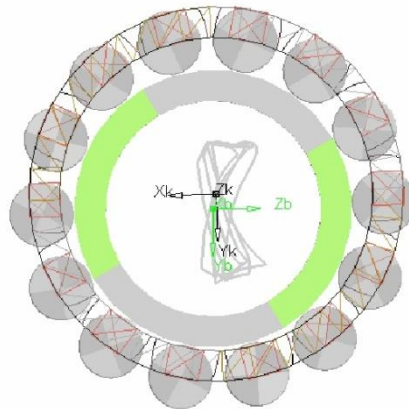
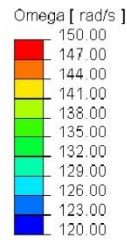


Figure 7: Motion of the center of gravity of the cage (magnified) as the result of a CABA3D simulation

3.2 Analysis of dynamic impact

To analyze the stresses caused by the dynamic motion of the cage, a FEA is necessary. The determination of a static FE model is difficult because the contact forces occur often only for a short time. A very easy option is the transient dynamic analysis of a single impact between the cage and the guiding elements with Abaqus/Explicit. The initial velocity as the relevant input (Goldsmith, 1960) is the result of the dynamic simulation with CABA3D. The FEA allows to consider non-linear behavior of materials and the contact behavior. The calculated stress-time function together with the information of occurrence of impact events allow a strength assessment.

Strain measurements on a cylindrical roller bearing under dynamic load were used to compare the calculation results. Figure 8 shows a good correlation in the comparison between the calculated and measured stresses.

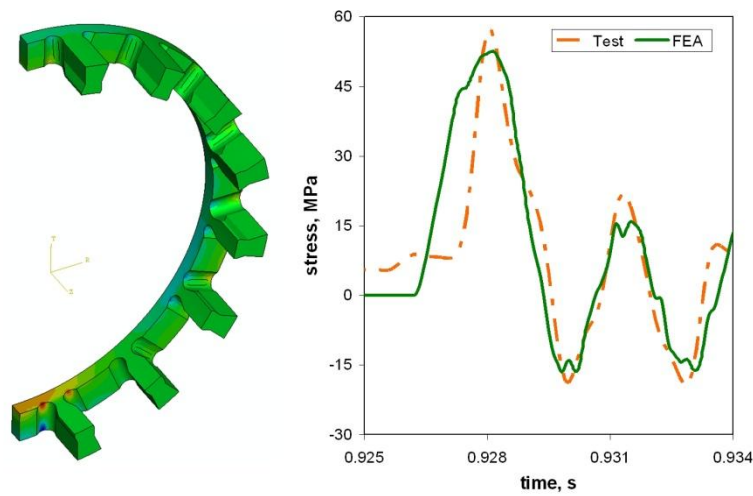


Figure 8: Stress results of dynamic FEA and correlation with test results

4. Analysis examples

4.1 Ball bearing in an idler pulley

In modern vehicles, the combustion engine provides power to numerous accessory drives by means of the accessory belt drive system (Kelm, 2004). One component of the belt drive system is the tensioner. It keeps the belt at proper tension and damps belt vibrations. The force between the tensioner and the moving belt is transferred by a pulley with a double row ball bearing inside (Fig. 9).



Figure 9: pulley with double row ball bearing

The cages are snap-in cages made of reinforced plastic material. The task of the analysis is to prove the strength of the cage for excessive belt vibrations of a specific engine. The vibrations acting on the pulley have been measured.

Assuming that the bearing rotation can be neglected the model consists only of the cage and the balls. The balls are rigid bodies and the material behavior of the cage is simplified as linear elastic. The excitation is applied to three balls in the load zone of the bearing as a defined motion in vertical direction (Figure 10).

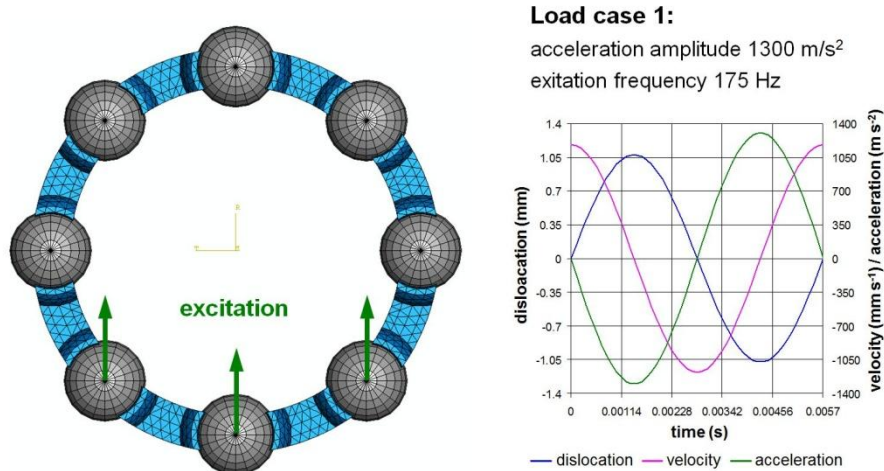


Figure 10: FE model and excitation

The balls outside the load zone are not clamped between the rings but their possibility of relative movement is limited by the local radial clearance. This depends on the bearing clearance and the deflection between inner and outer ring. An option to consider this without modeling the raceways with contact to the balls is the application of connectors of the type “stop” (Figure 11).

The analysis was performed for two cycles of translational oscillation. Figure 12 shows the stress distribution for an increment and the stress-time curve for a node in the middle of one pocket. The filtering of the curve is necessary to get more realistic stresses. The stress-time curve allows an estimated strength assessment with adequate safety factors. Important influences for the plastic materials are the temperature and the lubrication (Sonsino, 2008).

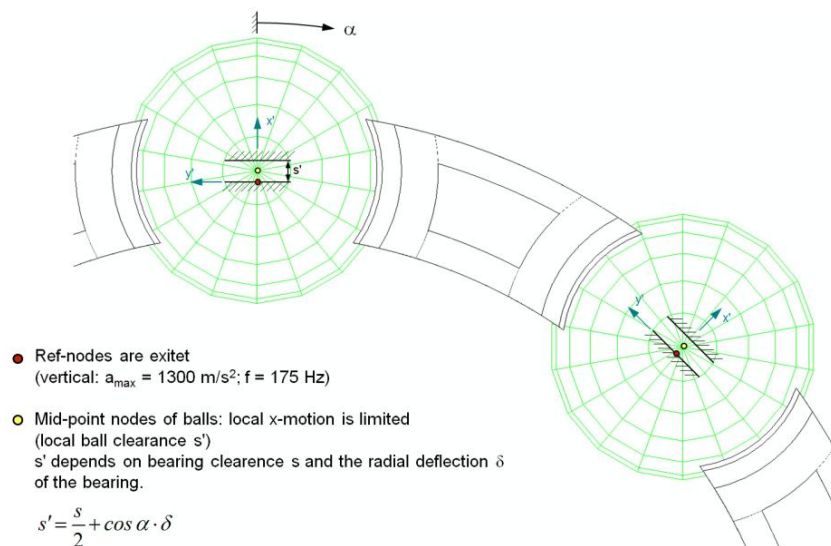


Figure 11: Definition of connector elements

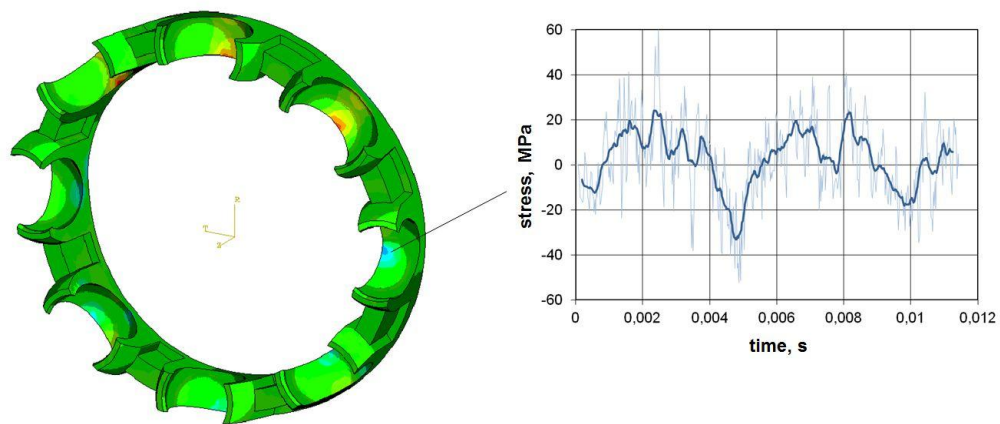


Figure 12: Stress results

4.2 Cylindrical Roller Bearings in Railway Applications

Highly loaded cylindrical roller bearings are used in axle boxes, gearboxes and traction motors. The bearings are subjected to shock loads and vibrations and have to meet high requirements regarding operating life, reliability and safety (Schaeffler, 2008). This requires a specific cage design as well as an adequate validation.

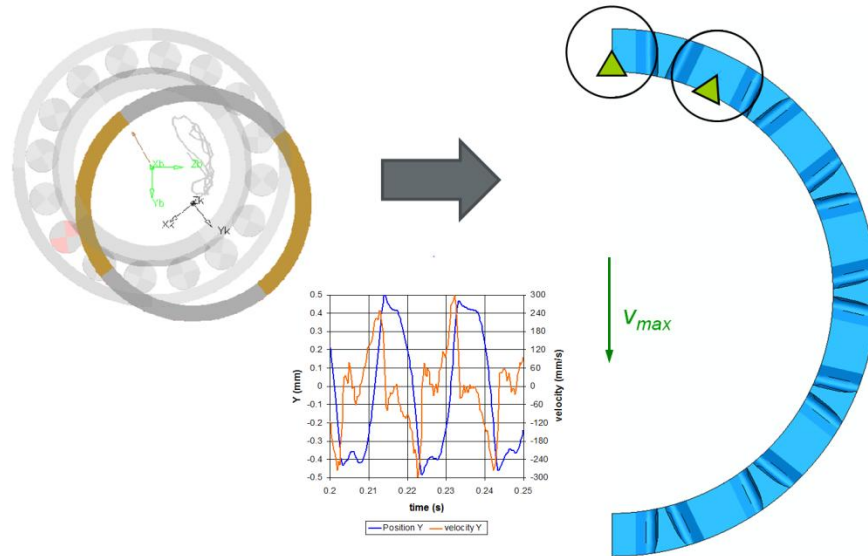


Figure 13: FE model for impact analysis

In fundamental tests of cylindrical roller bearings under severe dynamic loading, the cage motion and cage strains have been measured (Fraunhofer, 2012). The cage motion has been simulated by means of CABA3D and the subsequent shock analysis by means of Abaqus/Explicit. As input for the shock analysis the maximum impact velocity result from CABA3D was used (Figure 13). In this case, the cage was guided by the rollers. Figure 14 shows the measured and the simulated cage orbits and figure 15 the measured and simulated stress-time curves of the highly stressed point. All results show a good correlation.

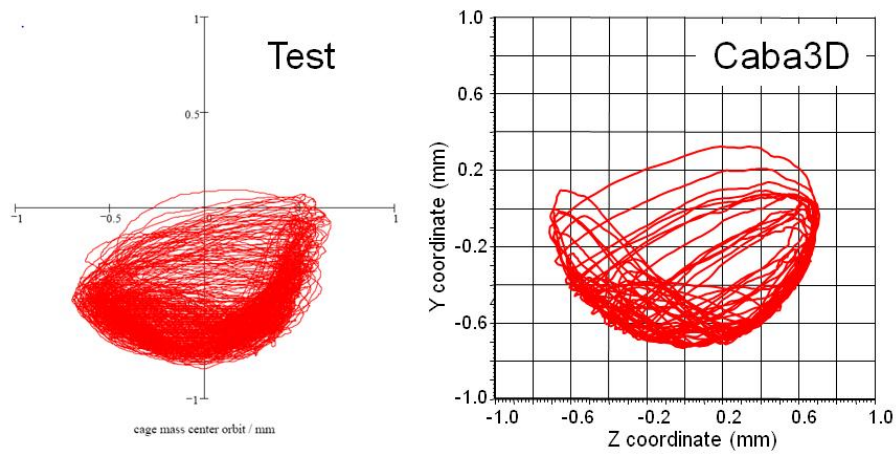


Figure 14: Motion of cage center

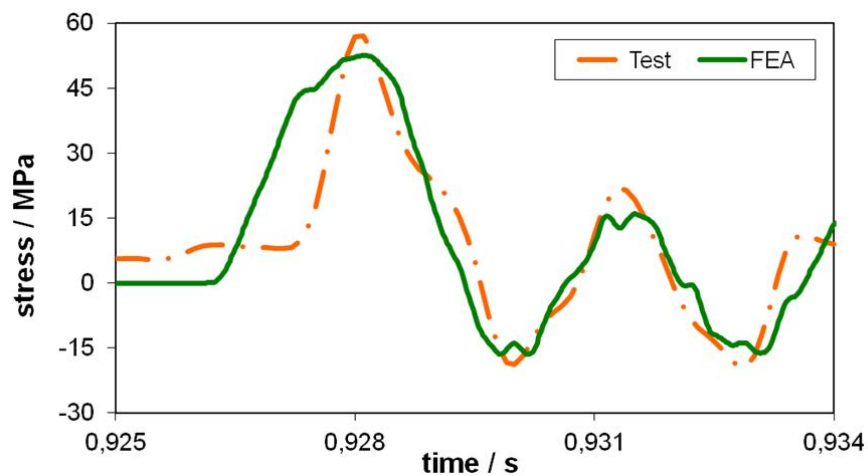


Figure 15: Stress-time curves

5. Conclusion

Rolling bearing cages are components with significant impact on the bearing behavior. A targeted cage design requires a strength analysis. The cage can be affected by higher stresses, especially when dynamic loads are acting on the bearing. The analysis requires the dynamic simulation of the cage movement as well as the stress analysis during the impact events between the cage and other bearing components. A suitable dynamic simulation of the bearing, can be performed by means of

CABA3D, that covered high graded contact and friction models for rolling contact. The dynamic impact analysis can be effectively achieved by the use of Abaqus/Explicit. In specific cases, connector elements are useful for vibration analyses of cage-ball assemblies.

Powerful simulation tools like CABA3D and Abaqus enable a targeted design of rolling bearing cages. This leads to better products within a shorter development time.

6. References

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