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CAD and FEM analysis improve bearing reliability

Using sophisticated CAD 2D/3D tools, in-house developed computing software and FEM analysis allows to improve bearing quality, reliability and delivery time.
The first part of this article is a simple introduction to the preliminary stages of 2D drafting, 3D modeling and calculation of the main coefficients for two spherical roller bearings that are to be installed on an oil platform rack and pinion jacking system. The second part of this article will cover in detail the steps of FEM analysis for development and validation of the above application.

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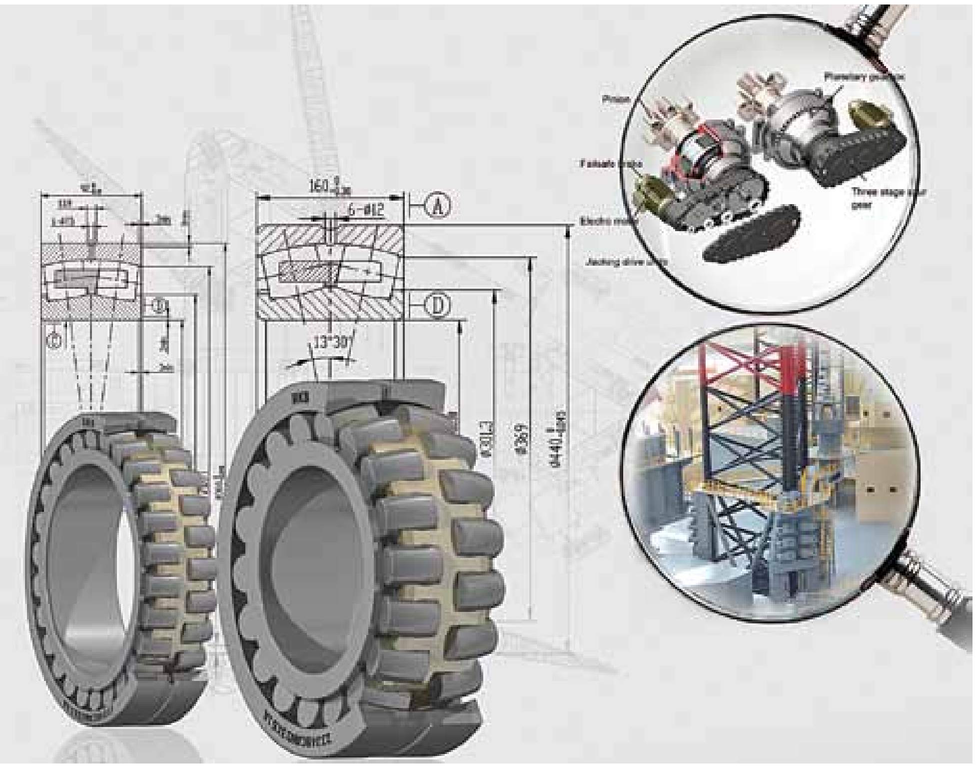

At present, Computer Aided Design (CAD) has become not only a platform to replace the old drafting tools but also the means, due to the increased computational power, to analyze in detail the products before they are launched in production. Being specialized in custom made bearing development for special applications, the RKB Bearing Industries Group uses CAD systems to get optimum product performance, reliability and manufacturing timetables. To illustrate how RKB is using these tools, in the following the steps that the Group took to engineer, manufacture and supply two bearings that are to be installed on an oil platform rack and pinion lifting system will be described. In the past, the development of a design started with the manual drafting of a number of detailed drawings that were subsequently analyzed using complex mathematical formulas. The resulting improvements had to be implemented in the original drawings and this meant going back to the drafting board. The advent of computer aided drafting offered many advantages, including:

- a run time much shorter than manual drafting;
- the possibility of easily doing complex mathematical calculations that can be stored and modified at any moment;
- the opportunity to create a database of the drawings that can be easily modified and used as a base for new designs;
- the removal of most human errors from drawings.

While complying with the technical requirements specified by the customer, for the jacking system of the oil platform (figure 1) we selected and used the spherical

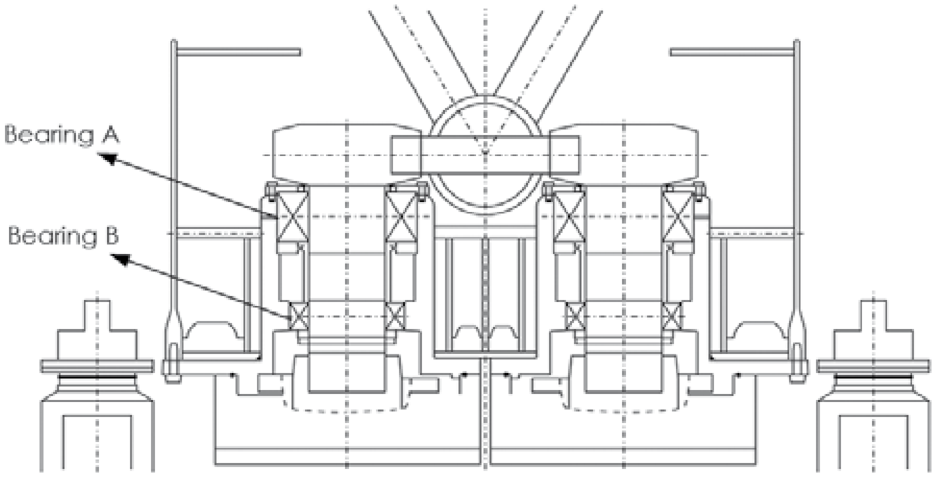

Fig. 1 - Application sketch showing where RKB bearings are located.

roller bearings RKB 23248CAW33XS1A and RKB 23048CAW33XS1A (figures 2a and 2b). Obviously this selection was validated in terms of basic load ratings, theoretical service life, load distribution, equivalent stress and contact surface pressure of the two bearings and the customer was provided with the relevant technical documentation. More particularly, the calculation of basic static and dynamic load coefficients was done using the RKB MTDS (Main Technical Data Sheet) proprietary software, strictly conforming to international standards ISO 76:2006 and ISO 281:2007. The results were then downloaded into another software package named RRLC (RKB Rating Life Calculations) (figure 3), which was entirely devised and created by the RKB Advanced Software Engineering Unit for bearing modified life calculation, as usual in accordance with the latest ISO recommendations. In the calculation, the adverse environmental operating conditions (salty water and occurrence of dirt particles) were also considered and the most suitable lubricant characteristics determined as well. With regard to all the other factors to be validated, it has been decided to rely on FEM analysis and this will be discussed in the second part of this article. Finally, all RKB bearings turned out to be in conformity with all requirements of the customer.

All 2D technical drawings of RKB bearings are made in a standard template where the main product information is introduced (typology/family, part number, technical specifications, RKB manufacturing plant) as well as detailed data for assembly (component location, size, tolerances, load levels, radial clearance and optimum operating temperature).

The crucial role of 3D CAD

In the CAD process followed by RKB, the next step consists in the 3D modeling of bearing components and in the simulating operation of the assembly model. At present, 3D CAD gives designers a new perspective and new design possibilities, which ultimately have a strong impact on the entire production chain. The main benefits of 3D CAD are:

- the possibility to develop complex assemblies and study the interaction among the various elements they are composed of;
- the chance to overcome the complex formulas that are used in 2D drawings to study component tolerances;

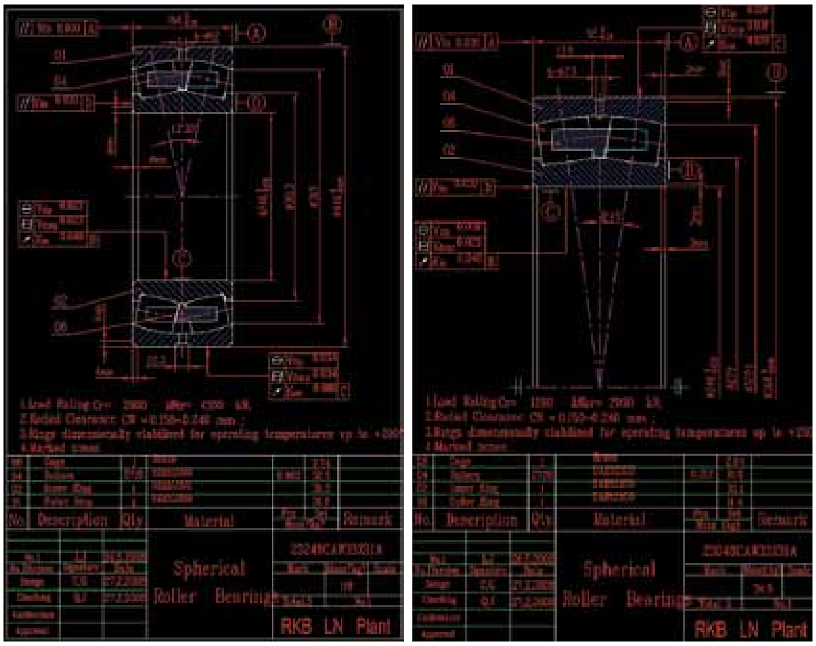

Fig. 2 - General drawings of spherical roller bearings RKB 23248CAW33XS1A and RKB 23048CAW33XS1A.

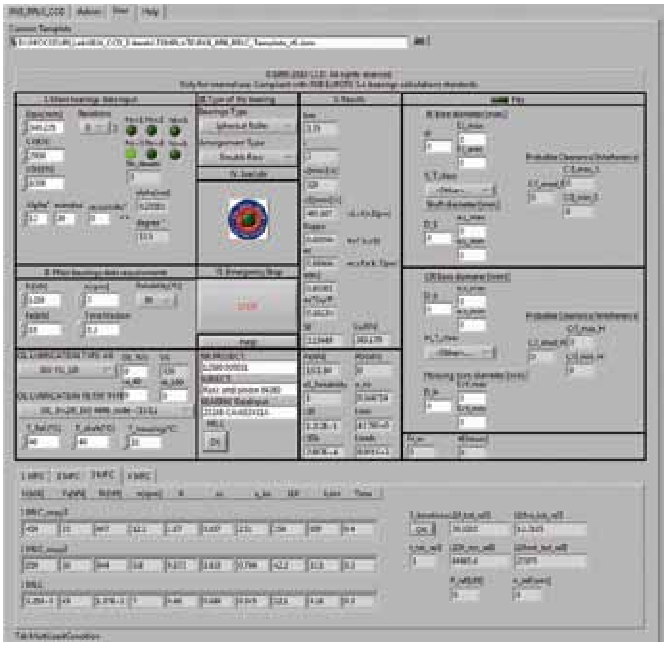

Fig. 3 - A screenshot of the proprietary software RKB Rating Life Calculations (RRLC).

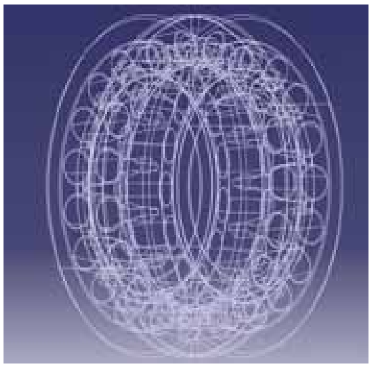

Fig. 4 - Wireframe display.

Fig. 5 - Display with polygon mesh.

Fig. 6 - Solid display.

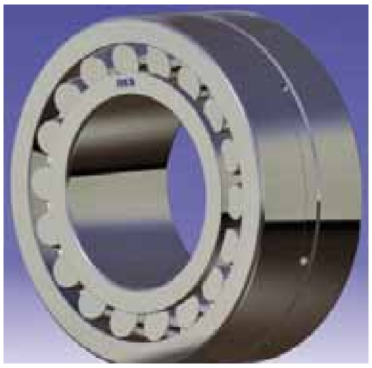

Fig. 7 - Solid display with material.

- the considerable reduction of prototype need with the resulting significant decrease of project development time and overall costs;
- the opportunity to store 3D models for repeated usage;
- the possibility to easily obtain valuable information, such as volume, center of inertia, mass, and so on, while reducing human error incidence to a minimum;
- the opportunity to have extremely accurate 2D drawings at disposal in the final design stage, while eliminating any redundancy from drawing development process;
- the possibility to analyze the 3D model working stress with the Finite Element Method (FEM).

Quite recently, CAD drawing evolution paved the way to Computer Aided Manufacturing (CAM), which allows to directly pass from 3D models to prototyping or even to mass production through CNC machine tools. As the interdependence among the various stages of the development process is quite strong, it is necessary for the designer to become acquainted with not only the design basis but also with manufacturing processes and production technologies. Given the wide range of produced bearings, each one with many constructive and dimensional versions, RKB decided to follow the parametric approach to modeling, as this allows a complete modifying flexibility. RKB uses CATIA V5, a constantly evolving software package that offers a wide range of design tools and model display modalities, encompassing among others:

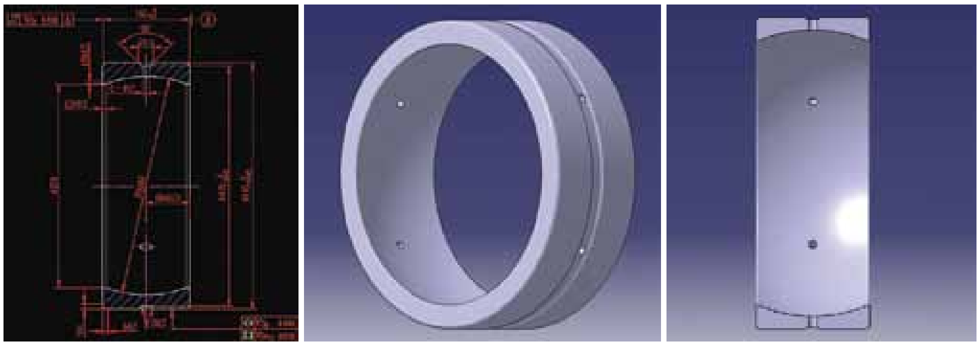

Fig. 8 - Outer ring 2D drawing, 3D model and section.

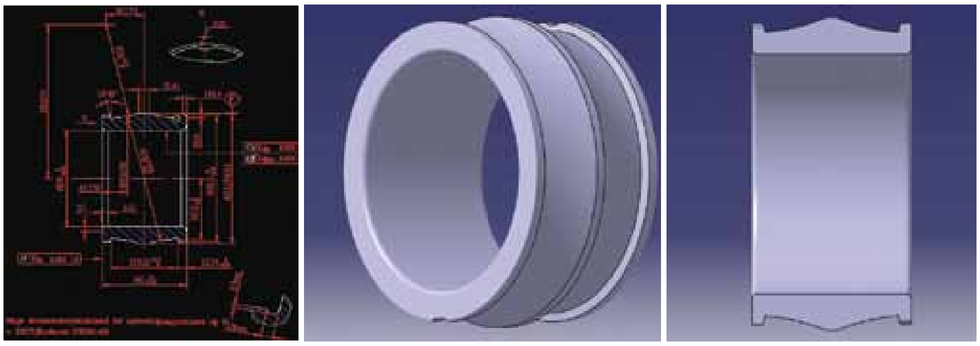

Fig. 9 - Inner ring 2D drawing, 3D model and section.

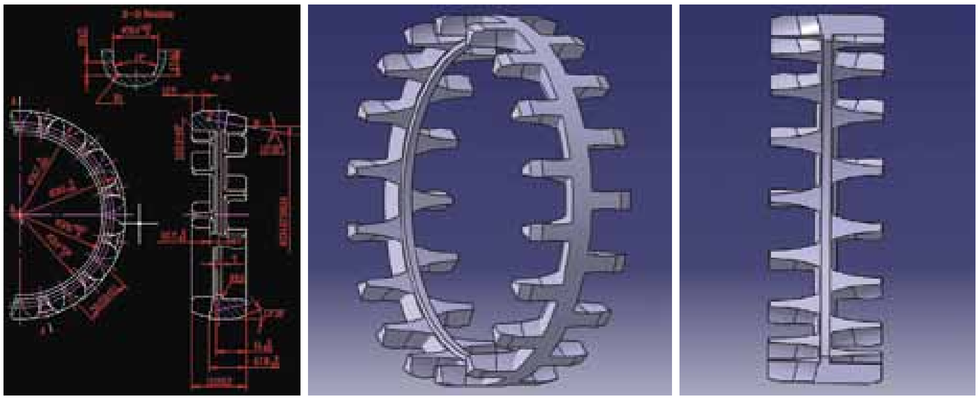

Fig. 10 - Cage 2D drawing, 3D model and section.

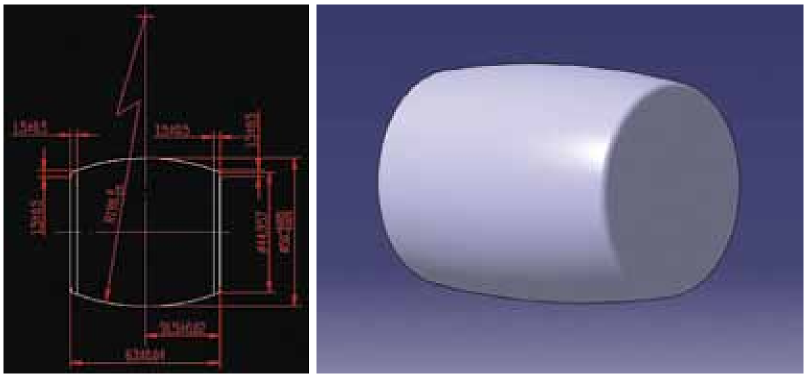

Fig. 11 - Spherical roller 2D drawing and 3D model.

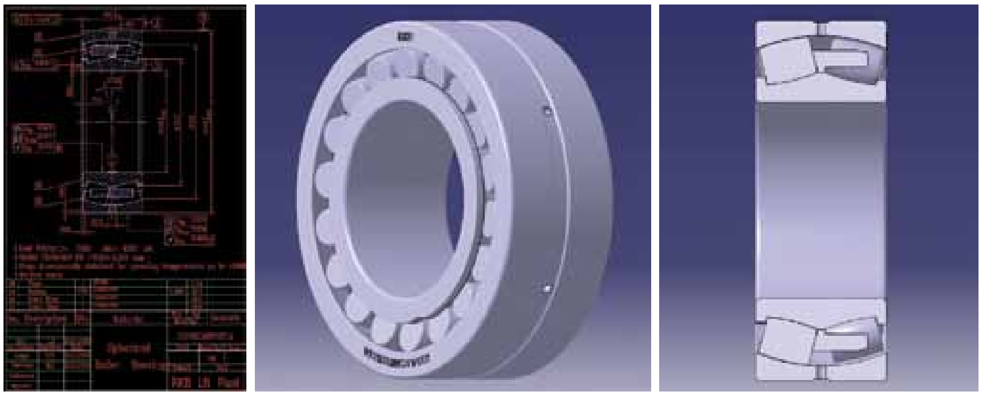

Fig. 12 - Assembly 2D drawing, 3D model and section.

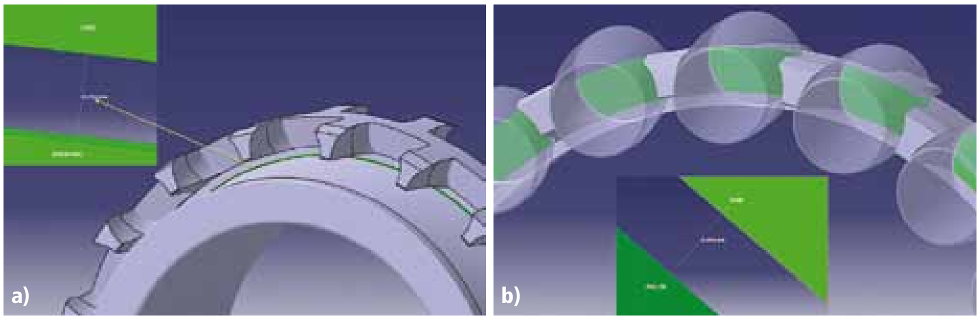

Fig. 13 - Clearance between: (a) cage and inner ring; (b) cage and rollers.

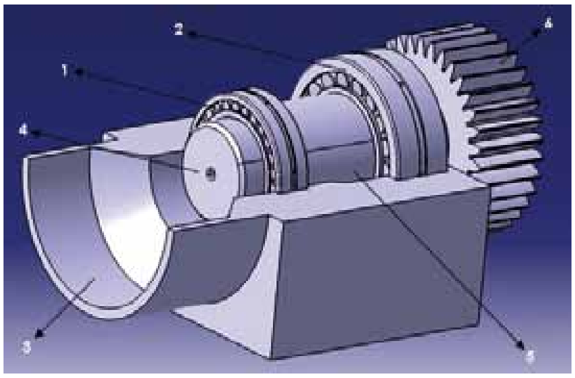

Fig. 14 - Oil platform application 3D.

- *wireframe display*: a skeletal 3D display of the model (figure 4) which only consists of points, lines, curves and no surfaces;
- *polygon mesh display*: including not only edges but even surfaces (figure 5);
- *solid display* (figure 6);
- *solid display with material*: useful to calculate bearing physical properties as it accurately displays the materials used for the real product. The model can be created through constructive solid geometry (that uses Boolean operations) or boundary representation (figure 7).

Provided that it is properly used, the information from 2D drawings (figures 8a, 9a, 10a, 11a and 12a) is sufficient to create the respective 3D model in CATIA V5 (figures 8b, 9b, 10b, 11b and 12b). Furthermore, using 3D CAD systems the designer can obtain sections of the model in different planes. This is particularly useful to study the geometrical interaction among the various assembly components. To emphasize the similarity with the starting 2D model, figures 8c, 9c, 10c, 11c and 12c show a section of all 3D models. The ability to create a 3D model of the assembly in digital environment extremely reduces the need to build costly prototypes. With CATIA V5 it is possible to manipulate all design components, modify them to see the impact on the overall assembly and store them for later use. In addition, 3D modeling offers the possibility to examine the geometrical interactions (contact surfaces, clearances, and so on) among the parts and this would not be possible with prototype parts. As an example, with CATIA V5 the user can accurately calculate the clearance between bearing cage and other components (figures 13a and 13b). When one or more bearing elements are modified, the designer is able to immediately see the effect on clearance level. This action is particularly useful when a comparison has to be made between the radial or axial bearing clearance and the clearance required in the technical specification of the application.

Application model

For the oil platform, the RKB Technical Department created the respective 3D model (figure 14) starting from the application sketch (figure 1). The model contains: 1. spherical roller bearing RKB 23248CAW33XS1A; 2. spherical roller bearing RKB 23048CAW33XS1A; 3. housing; 4. shaft; 5 spacer; 6. pinion. This model is useful not only to have a real representation of the bearings installed in customer application, but also and above all to see in simulated environment how they will behave under the different load conditions to which the entire mechanism is subjected. In order to study and calculate in high detail the reaction forces that are generated within the bearings, RKB turned to Finite Element Method (FEM) in ANSYS environment.

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FEM analysis of bearings for an oil platform

The article will cover the main steps of the development of two spherical roller bearings installed on an oil platform rack and pinion lifting system. After the description of drawing and advanced calculation processes reported in the first part of the article, here the FEM analysis stages that have been performed to validate the above application are illustrated.

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Once drawing and preliminary calculation processes are completed, before the product is sent to production it is necessary to test its functionality an reliability and check if it behaves as intended in the project. An engineering analysis should be performed and this can be done in analytical or experimental mode. In the experimental analysis a final product prototype is tested in real conditions in order to collect all data required for product validation. This type of analysis provides the designers with top quality information on product performance, but it is costly and very time consuming.
On the contrary, in the analytical mode the CAD model is subjected to the desired simulating conditions in software environment. The great benefit of the analytical analysis is that, if properly used, it can provide designers with readily usable information as it is able to solve even very complex problems.
The Finite Element Method (FEM) is probably the most widespread approximation numerical technique. Practically, this type of analysis solves problems that are described by partial derivative differential equations through their reduction to an algebraic equation system. Basically, it divides the object into a number of discrete simpler elements and does the necessary calculations for each of them. The link among the elements consist of nodes and the interaction is described, for instance, as a function of the stress acting in every point, due to the force which the nodes are subjected to.

FEM analysis of bearings for an oil platform

As described in the first part of the article, after the preliminary stages of 2D drafting, 3D modeling and calculation of main coefficients, the RKB spherical roller bearings to be installed on an oil platform rack and pinion jacking system were subjected to FEM analysis for the final validation of the application.

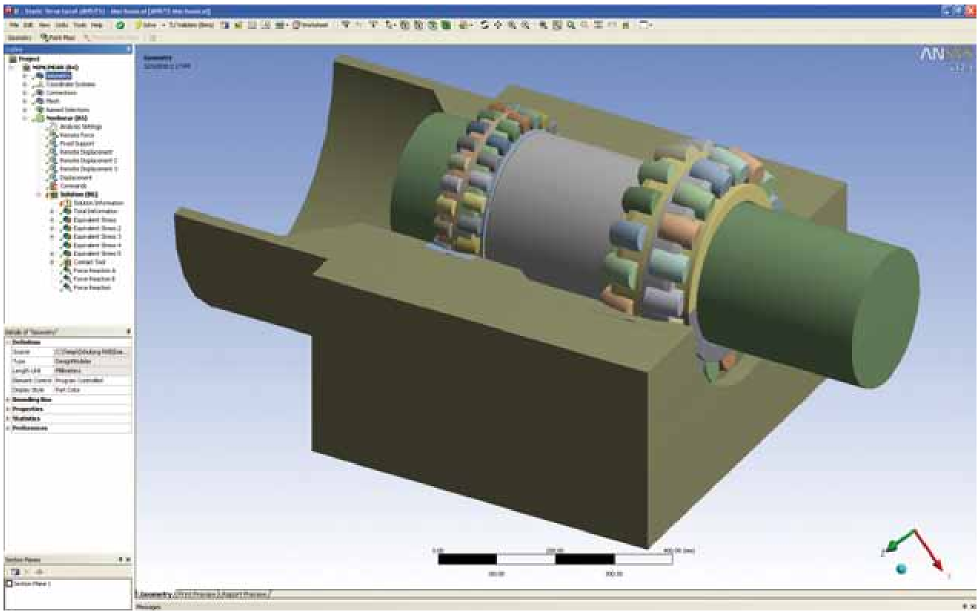

Fig. 1 - 3D model of the assembly imported from CATIA to ANSYS.

Generally, the finite element analysis consists of three main stages:
1. *Pre-processing*: in this stage the geometry of the model to be analysed is divided into a number of discrete elements which are interconnected through nodes. According to application complexity, these models can be very time consuming to prepare.
At the Technological Center of Balerna (Switzerland), the RKB engineers create 3D models using CATIA V5, a software tool that provides an accurate representation of solids and so a better quality in achieving the virtual components according to customer specifications. In the next step the 3D model is imported from CATIA to ANSYS 12 (figure 1) to perform the finite element analysis. During the importing process, the assembly is divided into the different parts to be analysed, which are automatically highlighted by ANSYS through different colours. The next step is the meshing of the model (figure 2).
This stage of the process is extremely expensive in terms of resources and plays a key role for the final quality of the solution. A finer mesh (figure 3) will give better results; however, as it requires extremely high computing abilities, the turnaround time will be very long. Obviously, the expertise gained during the years allows RKB to reach the correct balance between solution exactness and utilized resources.
When the mesh definition is over, the contact is set up between the bodies to be analysed, trying to modeling the reality as accurately as possible. For the two RKB spherical roller bearings the mesh was composed of 237,525 nodes (hexaedrons and tetrahedrons) and 65,117 elements. Subsequently, the properties of the utilized material were assigned to the model in order to correctly simulate the reality. It is important that the material properties imported into the software are exactly those of the material that will be used in the production plants.
This is why RKB metallurgical laboratories carry out regular checks and meas-

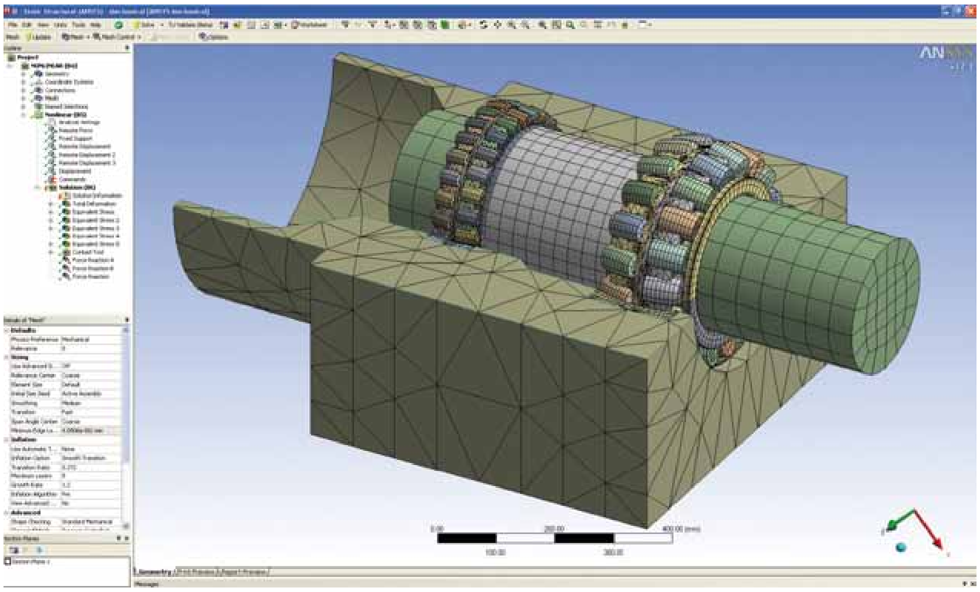

Fig. 2 - 3D model with mesh.

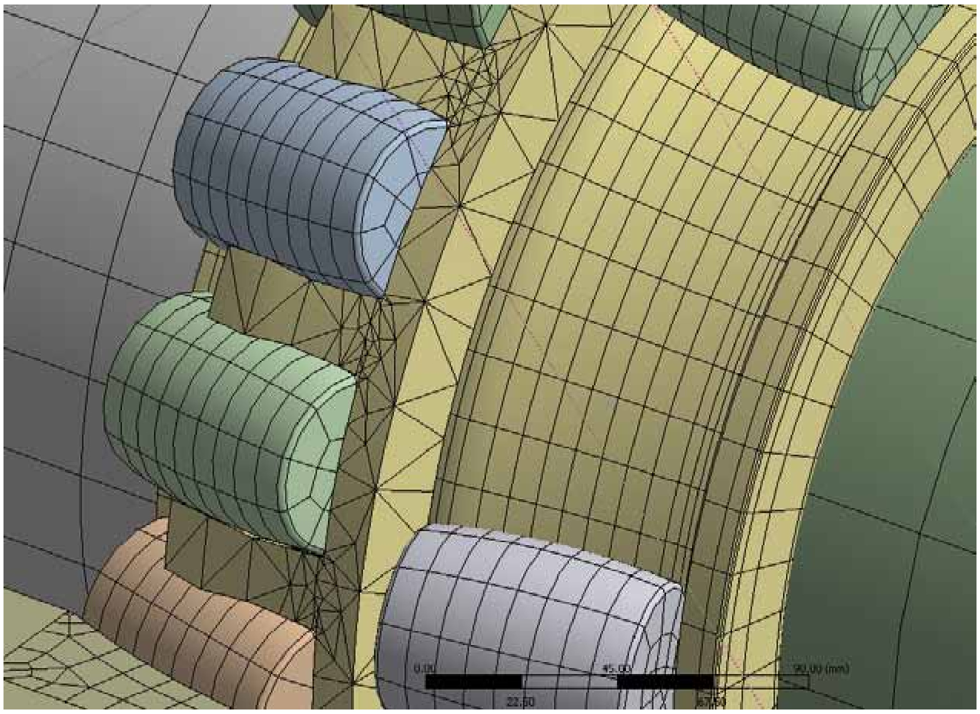

Fig. 3 - Finer mesh in the contact areas.

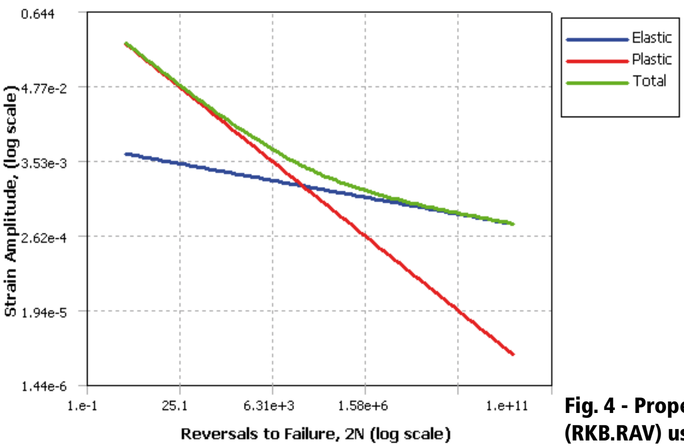

Fig. 4 - Properties of bearing steel (RKB.RAV) used in the model.

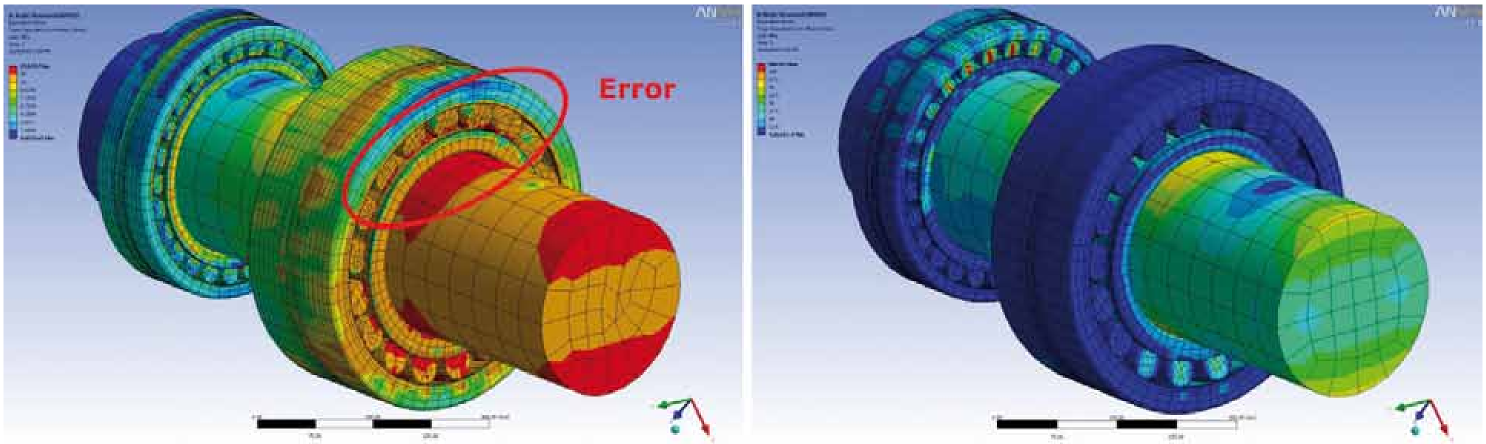

Fig. 5 - Comparison between linear and nonlinear analysis.

urements on steel samples in order to determine the raw material precise characteristics (figure 4), which will be used in the finite element analysis. The next step is represented by the definition of loads and constraints. In the case of the oil platform rack and pinion lifting system, the following information was considered:

- the housing is fixed;
- the outer rings are rigidly connected to the housing;
- the rollers are in sliding contact with inner ring, outer ring and cage;
- the inner rings are rigidly connected to the shaft.

2. *Processing:* the database prepared during the pre-processing stage is used as an input to the real finite element analysis, which is based on creating and solving a system of linear and nonlinear algebraic equations. For this application, both the approaches of linear and nonlinear analysis were followed. Therefore it was possible to compare the results of the two analytical typologies: due to the sliding effect between rollers and inner and outer rings, the more complex nonlinear analysis proved to be more accurate (figure 5).

3. *Post-processing:* in the fifties, at the beginnings of finite element analysis, the FEM expert had to go through a huge quantity of data generated in the processing step. So it was rather common to miss valuable information regarding highly

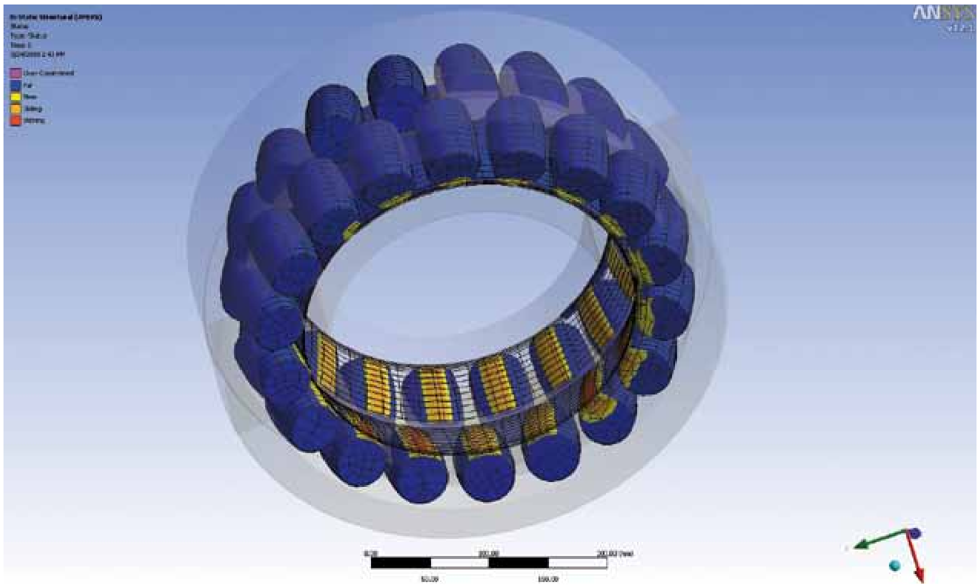

Fig. 6 - Rollers in contact with the rings.

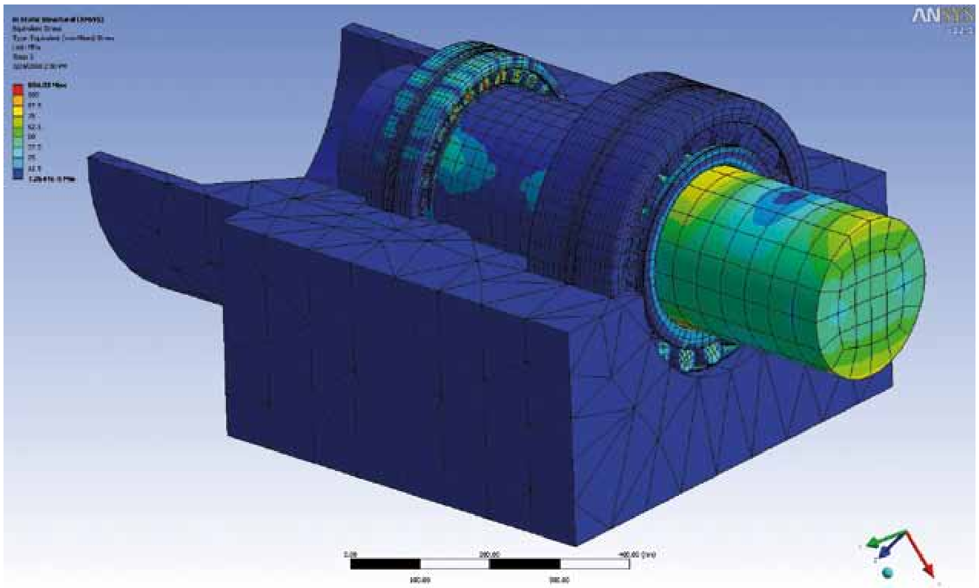

Fig. 7 - Equivalent (von-Mises) stress distribution in the assembly.

stressed points in the assembly model. To avoid this drawback and make the analyses easier, modern software packages for FEM computation offer also the graphic display of data.
In the case of the oil platform rack and pinion jacking system several subjects were identified concerning the RKB spherical roller bearings installed on the application. Particularly:

- *the number of rollers in contact with the rings*: it is possible to find the number of rollers in contact with the rings (figure 6) under load and according to the radial clearance, so optimising the bearing for the considered application. This information is of vital importance for bearing proper working and actual service life;
- *the stress distribution*: the information regarding this point plays a crucial role for determining location and importance of potential weak spots, that is points where the system could begin to be damaged under load (figure 7);
- *the reaction forces*: these forces determine the actual load on the bearings. In figure 8, F is the force acting on the system, F_A the reaction force of bearing RKB 23048CAW33XS1A and F_B the reaction force of bearing RKB 23248CAW33XS1A. The actual values of F, F_A and F_B are still shown in figure 8;
- *the safety factor*;
- *the assembly stiffness and shaft static deformation*;
- *the deformations existing in the model*: measuring their value allows to determine if the loads acting on bearings will lead to elastic or plastic deformations;
- *the stress level in the bearings*: this measurement shows the value of contact stresses appearing inside the bearings, the most important being those between rollers and raceways of inner and outer rings (figure 9).

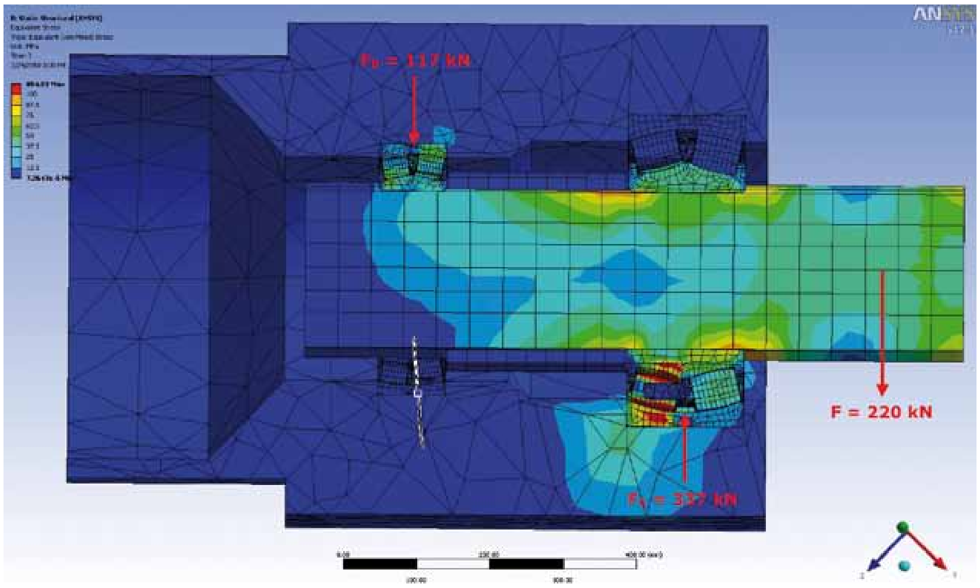

Fig. 8 - Reaction forces acting on the bearings.

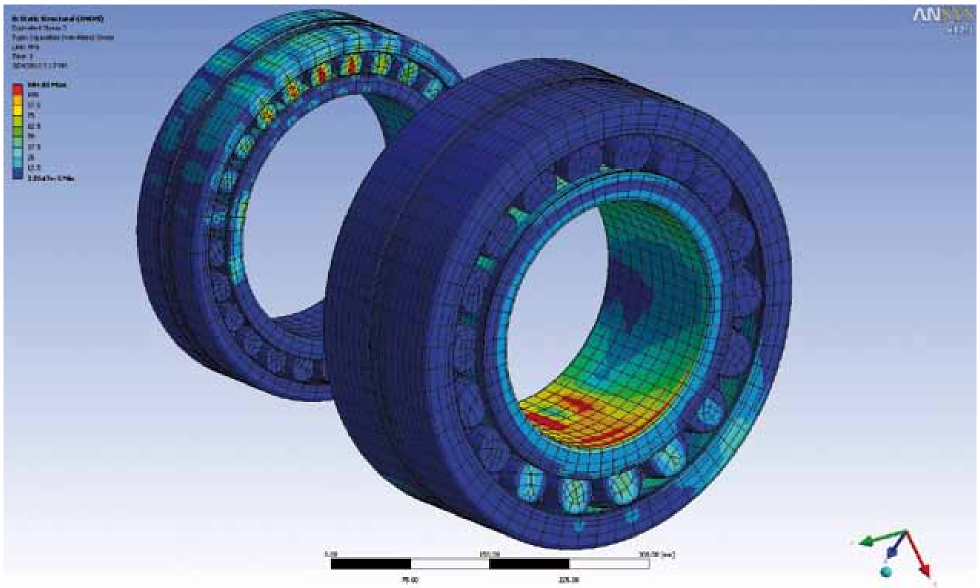
Fig. 9 - Equivalent (von-Mises) stress distribution in the bearings.

Conclusions

In the case of the rack and pinion lifting system installed on the oil platform, the bearings engineered by RKB have proved to be perfectly adequate to customer requirements.
Thanks to the continuing commitment of our engineers and the last generation technologies utilized in every stage of drawing, computing, evaluating, simulating and manufacturing processes, the RKB Group is in a position to develop and manufacture a wide range of high quality bearings that are suitable for the most demanding applications.
In fact the know-how and expertise gained by RKB's Research and Development Department permit to hold in due consideration all the factors having an influence on bearing performance. Each one of the study stages briefly discussed in this article, from 2D drawing production to FEM analysis to locate the possible stress concentration areas, is the core of the assembly validation process, according to customer specifications.
In this way the RKB Group is able to offer the operational reliability of its products, avoiding unnecessary oversizing and meanwhile reducing overall project costs.