Commentary

Development of Technical Calculation Systems for Rolling Bearings

Tomomi ISHIKAWA *
Hiroyasu HIRUKAWA *
Mariko IZUMI *
Cedric BURNET **

The performance requirements for rolling bearings are diverse, and the pace of this diversification has accelerated in recent years due to environmental concerns and other factors. The use of Computer-Aided Engineering (CAE) technology is indispensable for **NTN** to respond quickly to these requirements. Two technical calculation systems developed by **NTN** to improve the efficiency and sophistication of rolling bearing design will be introduced in this technical review.

1. Introduction

Introduce a wide variety of competitive bearing products to the market that consider market trends and customer needs in a timely manner, it is necessary to improve the sophistication and efficiency of product development work. To this end, **NTN** is promoting the use of Computer-Aided Engineering (CAE) technology. In October 2018, **NTN** established the CAE Research and Development Center[1)] to accelerate our research and development of CAE technology.

In the past, **NTN** used both commercial software and the **NTN**-proprietary CAE system for bearing product development work. There were several challenges for efficient design, such that engineers were required to select and use multiple, unlinked subsystems repeatedly based on their specific applications to derive design values that met the design requirements. Furthermore, even routine Finite Element Method (FEM) analysis had to be carried out by a Computer-Aided Engineering (CAE) specialists.

To improve the efficiency of the entire development process, **NTN** developed two systems: SharcNT, an integrated technical calculation system for rolling bearings that consolidates existing calculation systems with additional features, and ABICS, an integrated calculation automation system that automates the design work of third-generation (GEN3) hub bearings. This paper describes an overview of these systems.

2. Integrated technical calculation system for rolling bearings

2.1 Background

Rolling bearings are an essential machine element used in mechanical systems. They require a long operating life, low torque, high stiffness, high precision, and other performance capabilities. In recent years, energy saving and decarbonization have been advanced to achieve carbon neutrality. This has led to greater diversity in rolling bearing design to meet required specifications and performance needs. For example, electrified automobiles and various industrial machines require smaller, lighter bearings with ultra-high speed specifications, while wind power generation requires larger bearings with long operating lives as wind turbines become larger and are used offshore. **NTN** must adapt to these market trends and customer needs; there are strong demands for highly reliable, high-performance bearing designs and shorter design lead times. The use of CAE technology is essential to meet these demands.

In the initial stage of designing rolling bearings, life and internal bearing load calculations based on theoretical calculations are used as the primary performance evaluation. In recent years, calculation models have become larger, more complex, and more sophisticated. Calculations of entire applications, including power transmission mechanisms, and calculations considering elastic deformation around the bearing are essential.

NTN developed SharcNT (Shaft, Housing and Roller Coupling with **NTN** Technology), **NTN**'s proprietary integrated technical calculation system for rolling bearings, to enable designers to design reliable, high-performance bearings quickly using CAE technology.

2.2 Global integration of calculation systems

In the past, **NTN** conducted design studies by utilizing multiple calculation systems according to the design requirements of rolling bearings. However, making full use of multiple systems required a certain level of experience. Therefore, SharcNT was developed by combining the main calculation functions of **NTN**'s conventional calculation systems **(Fig. 1)** based on a system developed and used by **NTN** subsidiary company **NTN**-SNR.

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* CAE R&D Center
** NTN-SNR ROULEMENTS Research, Innovation & Development

In addition to the calculation functions required for performance evaluation such as bearing operating life, bearing load, load distribution, contact stress, bearing stiffness, and bearing torque, SharcNT can construct a multi-axis calculation model in which bearings are arranged using an intuitive graphical user interface (GUI) **(Fig. 2)**.

Integration of multiple systems made it possible for designers to perform a wide variety of calculations within a single system and acquire skills and experience more easily.

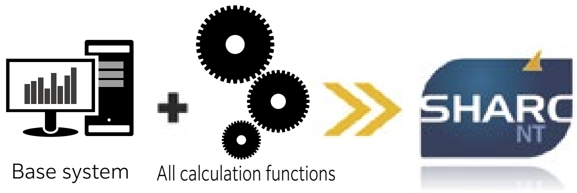

Fig. 1 Integration of calculation systems

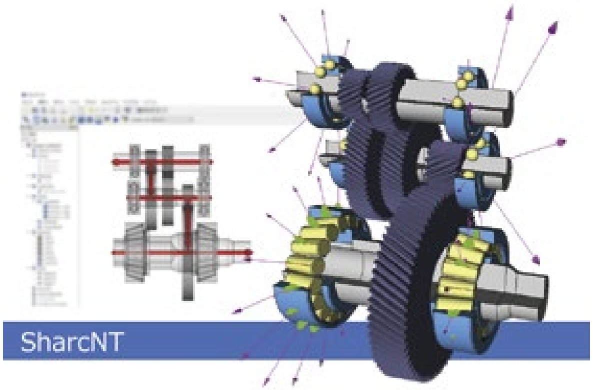

Fig. 2 Integrated technical calculation system SharcNT

2.3 Calculation for entire applications

In recent years, gearbox manufacturers have diversified their products to cater the wider needs of the markets, for example to meet the varying requirements of the automobile market which provides gasoline vehicles, hybrid vehicles, and electric vehicles, ranging from simple structures to multi-stage and complex structures. When bearings used in more complex structures are examined throughout their application, the calculation model becomes complex. It is not only difficult to understand and verify the calculation results, but it is also difficult to do so in a short period of time. Even in the case of complex structures, one must accurately and quickly grasp the bearing characteristics.

To enable complex gearbox construction, SharcNT makes it possible to create a calculation model with many parallel and orthogonal axes to analyze the bearing in detail while taking into account the power flow (power transmission path). In addition, the overall life of the bearing can be determined by setting the duration of time that the bearing spends at each operating condition. In addition, advanced calculations that consider elastic deformation around the bearing, which will be discussed in the next section, can be completed in a short time.

To understand the internal load of the bearing obtained by calculation, it is necessary to confirm how the shaft displaces with deformation due to conditions such as gear load and bearing position. Depending on the structure, it may be extremely difficult to verify the calculation results using only the numerical information shown for each power flow. **Fig. 3** shows an example of a calculation for the gearbox. The calculation model is displayed in a 3D model, and the vector of the internal load and the displacement of the axis on the model can be confirmed visually. In addition, detailed results for each bearing are output as various graphs and numerical data. These improvements make it easier for the user to grasp the characteristics of the calculation conditions.

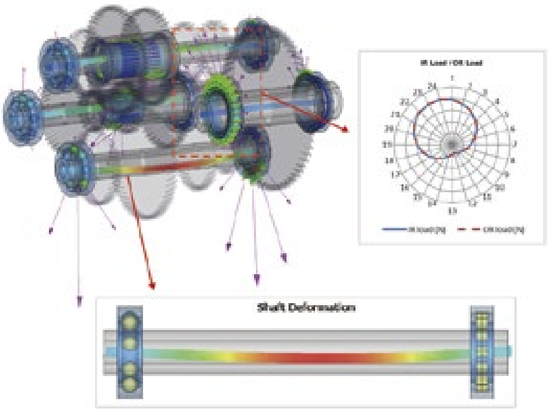

Fig. 3 Calculation for entire applications

2.4 Calculation that considers bearing elastic deformation

Normally, the internal bearing loads are calculated on the assumption that the contact between the rolling element and the raceway surface will cause infinitesimal deformation. However, in some applications, the stiffness of the housing is low (due to thin thickness, aluminum alloy, etc.), and the internal load of the bearing cannot be accurately determined unless the elastic deformation of the outer ring and the housing is considered. In this case, although it is possible to use FEM to perform calculations that consider the elastic deformation of the outer ring and housing, high-precision calculations demand expertise and involve a series of calculations, which takes time. SharcNT has a function[2] that can consider elastic deformation of the outer ring and the entire housing as a contracted stiffness matrix (“virtual spring”), which can be combined with the contact calculation between each rolling element and a raceway with relevant degrees of freedom. This function allows calculation that takes elastic deformation of the outer ring and housing into account at higher calculation speeds when compared to FEM.

Calculations can also be performed that consider elastic deformation of the inner ring and shaft using the “virtual spring”. However, the fit between the inner ring and the shaft is usually highly rigid when compared to the fit between the outer ring and the housing, and it is often sufficient to consider only the deflection of the shaft. In such cases, the calculation time can be shortened by modeling the shaft with the beam element[3].

3. Integrated calculation automation system for hub bearings

3.1 Background to development

Hub bearings are used in automobile undercarriages to support the rotation of the vehicle's wheels. Since the late 1970s, hub bearings have evolved into unit products incorporating peripheral components.[4] This was done in response to market demands for easier bearing assembly into vehicles, bearing downsizing, reducing bearing weight, and higher bearing performance (load-carrying capacity, low-torque performance, resistance against muddy water, stiffness, strength, etc.). Currently, the predominant hub bearing is the 3-generation hub bearing called GEN3 shown in **Fig. 4**.

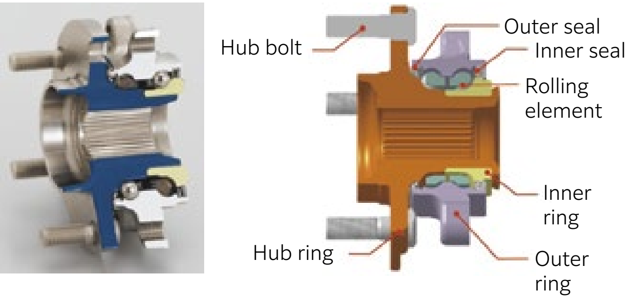

Fig. 4 GEN3 hub bearing

In the design of unitized GEN3 hub bearings, automobile manufacturers require a balance between long bearing operating life and high stiffness on the one hand and compactness and light weight on the other. While a larger bearing size is required to reduce contact stress and increase stiffness to improve bearing life and steering stability, smaller bearing size and lighter weight is optimal for vehicle fuel efficiency. In addition to these bearing design optimization tasks, CAD and FEM analyses are also required in the design process. All of these tasks are performed by human workers and required a long time to complete.

To solve these problems, **NTN** developed an integrated calculation automation system Axle Bearing Integrated Calculation System (ABICS) for hub bearings that automates each area of design work and shortens the design and lead time.

3.2 System overview

To automate the various tasks required for the design study of hub bearings, **NTN** developed the ABICS **(Fig. 5)**, which has the following four primary functions.

- Search function for optimal bearing specifications
- Automatic creation of 3D shape models
- Automatic execution of FEM analysis
- Data management

The use of this system enables designers to perform tasks that were previously performed by separate people in charge of each task. This further reduces design and lead time through automation. Details of each function are described in the following sections.

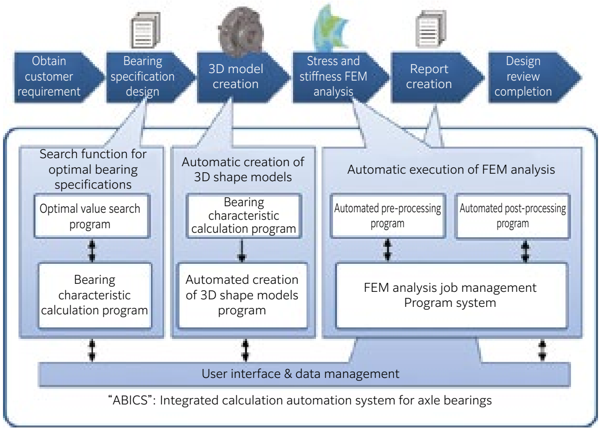

Fig. 5 ABICS system overview

3.3 Search function for optimal bearing specifications

In the past, when determining the bearing characteristics of a hub bearing, the **NTN** designer would repeatedly change each parameter and calculate the characteristics until the required characteristics (life, internal mass (mass within a certain area around the rolling element), internal stiffness, torque, etc.) had been met **(Fig. 6** left**)**. Multiple calculation tools for each characteristic were used for the characteristic calculation. The human work therefore required time for both the search for optimal results and the calculations.

In ABICS, **NTN** has created a bearing characteristic calculation program that combines these calculation tools. An optimal value search function **(Fig. 6**, right**)** has been developed to automatically select desired values for specifications.

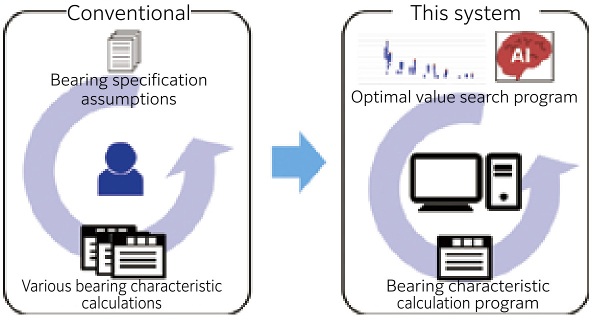

Fig. 6 Optimization of bearing specifications

The optimal value search program employs a genetic algorithm (GA), which is classified as AI. For the search, the desired bearing characteristics to be optimized are set as the objective function and the design parameters that affect the characteristics of the objective function are set as explanatory variables. Under these conditions, the explanatory variables selected by the GA are sent from the optimal value search program to the bearing characteristic calculation program, where bearing characteristics are calculated. The characteristic values are returned to the optimal value search program, and the GA selects new explanatory variables. This iterative process results in optimal values.

An example of an optimal value search is shown in **Fig. 7**. The objective function is set to the conflicting properties of life and internal mass, and the explanatory variables are the three design parameters related to these two properties. **Fig. 7** shows the results of the search. The Pareto solution for the bearing life relative to the mass (marked in red) determines the candidates of optimal values. Based on the results, the designer selects the value that meets the customer's required characteristics. In this example, about 34 000 calculations are required to find the optimal value by exhaustive search, where the search for the optimal value is completed in about 300 calculations (marked in blue) with GA. In addition to the computational cost, automation of the search also reduced the work time required of personnel.

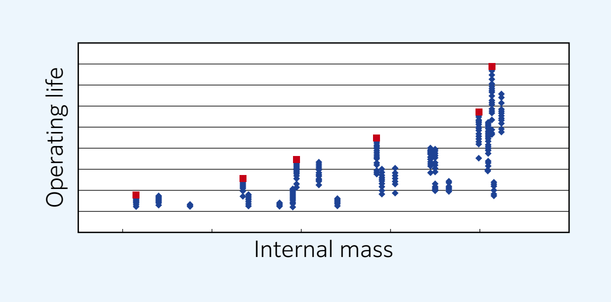

Fig. 7 Example of optimal value search

3.4 Automatic creation of 3D shape models

In the past, a CAD specialist created the 3D shape model required for FEM analysis and drawing **(Fig. 8**, top**)** based on previously-determined bearing specifications. Since CAD work was done manually by dedicated personnel, model creation was time consuming. In addition, there was time spent waiting for preliminary meetings with designers and for the completion of work in progress.

In the ABICS, an automatic 3D shape model creation program has been developed to automate this model creation process **(Fig. 8**, bottom**)**. The program has a variety of shape templates and automatically creates a 3D shape model by automatically inputting dimensions derived from bearing characteristics obtained from the optimal value search function and the bearing characteristic calculation program described in the previous section. In the case of shapes for which it is difficult to create templates, the program automatically creates a similar shape and then allows manual modification.

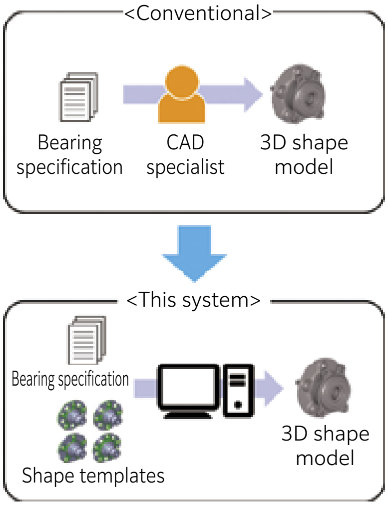

Fig. 8 Creation of 3D shape model

3.5 Automatic execution of FEM analysis

In the past, based on a previously-created 3D shape model, a CAE specialist would perform the pre-processing, calculation execution, and post-processing required for FEM analysis stress and stiffness characterization[5)] **(Fig. 9**, top**)**. As with the other tasks described above, time was required to complete these tasks due to the skill level of the specialist, prior discussions with the design engineer, and waiting time before starting the work.

A program and system were created to automate these tasks, and an automatic FEM analysis execution function **(Fig. 9**, bottom**)** was developed. Details of each program are shown below.

- Automated pre-processing program
  Automatically create a mesh for each part of the 3D shape model to be analyzed, combine the peripheral components necessary for analysis, and set the boundary conditions.
- Automated post-processing program
  The system automatically obtains characteristic values of stress and stiffness from calculation results, obtains contour plots, checks calculation logs, etc.
- FEM analysis job management program / system
  Computers to execute each of the above programs and FEM calculation jobs are automatically assigned according to the computer utilization status. **Fig. 10** shows this job management system. Jobs are distributed from the ABICS server to the job management computer (the computer executing this program) based on the input information of the user computer. From the job management computer, jobs are allocated according to the usage status of multiple computers prepared for pre-processing, calculation execution, and post-processing. This system reduces the waiting time for jobs and improves the availability of computers and software licenses used for FEM analysis.

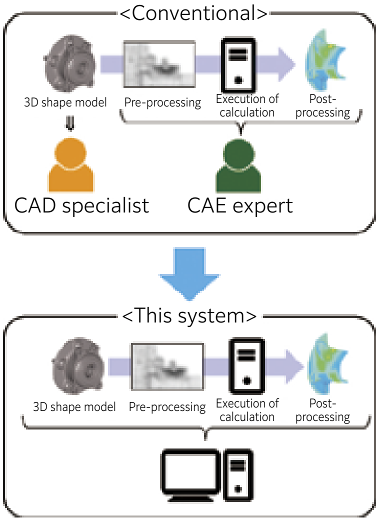

Fig. 9 FEM analysis work

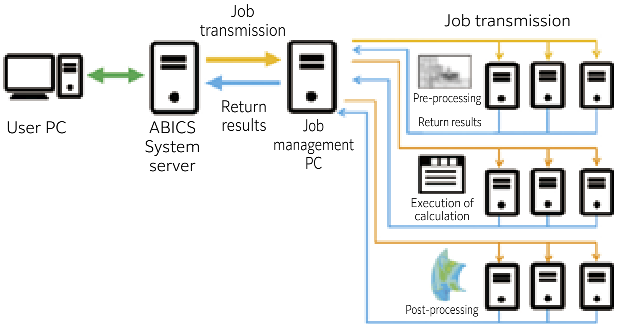

Fig. 10 FEM analysis job management system

3.6 Data management function

All ABICS usage information (input/output results, etc.) is stored and managed in a database. Information designed with ABICS can thus be capitalized on and used effectively. The search function makes it easy to view past design results, while the input data used in calculations can be reused, enabling efficient redesign when improving products.

In addition, design reports can be automatically generated based on the stored input/output results, reducing the time spent by designers and shortening lead times.

4. Conclusion

This paper introduces the integrated technical calculation system SharcNT, which is used to evaluate the performance of rolling bearings, and the integrated calculation automation system ABICS, which automates the design work of GEN3 hub bearings.

Going forward, **NTN** will continue to research, develop, and utilize CAE technology to further enhance the sophistication and efficiency of product development operations. As we do so, we will build a structure that will enable us to quickly bring to market the bearings that the market demands.

References

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Photo of authors

Tomomi ISHIKAWA
CAE R&D Center

Hiroyasu HIRUKAWA
CAE R&D Center

Mariko IZUMI
CAE R&D Center

Cedric BURNET
NTN-SNR
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