Enhanced Modeling of Rolling Bearings

SCHAEFFLER

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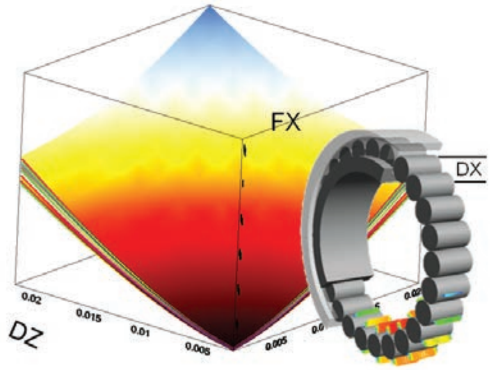

Current developments in hardware, and particularly, in software tools, make it possible to simulate increasingly complex models with an ever increasing level of detail. The design of complete systems requires an in-depth knowledge and understanding of the individual components and their interactions. Depending on the key perspectives involved in the simulation, it is appropriate to allow the selection and definition of the degree of detail in the complete model and the subsystems. At Schaeffler, work has been carried out for years in order to develop and apply rolling bearing models and calculation tools such as BEARINX®.

INTRODUCTION

A simulation and the associated model are always an abstraction of reality. The decision on a particular abstraction level and a specific modeling requires a good understanding of the actual system. A complex model does not automatically constitute a correct model and a simple model is not always an inferior one. The decisive factor here can be newly acquired knowledge relating to the actual system. The following article presents methods for modeling rolling bearings in dynamic multi-body simulation (MBS) and recommendations for their use.

"The aim is always to offer the customer optimum support for his product development."

THE WHOLE IS MORE THAN THE SUM OF ITS PARTS

The development of tools for simulation and design has a long and successful tradition at Schaeffler. Appropriate solutions are available for each task, ranging from the complete system via its components to the simulation of dynamic and transient processes at the individual contact. The aim is always to offer the customer optimum support for his product development. The program with the widest scope of application for the design of bearings in complex systems at Schaeffler is BEARINX® (Fig. 1).

This raises the question as to how the rolling bearing know-how present in BEARINX® can be made available to the customer for efficient simulation in SIMPACK.

MODELLING OF ROLLING BEARINGS

The state-of-art in MBS comprises either constant stiffness values or non-linear stiffness characteristic lines for the main degrees of freedom of the bearings. Coupling terms are not taken into consideration in these models. However, coupling terms may have a significant influence on the quality of results for the bearings. Depending on the key perspective of the investigation, different models can be considered.

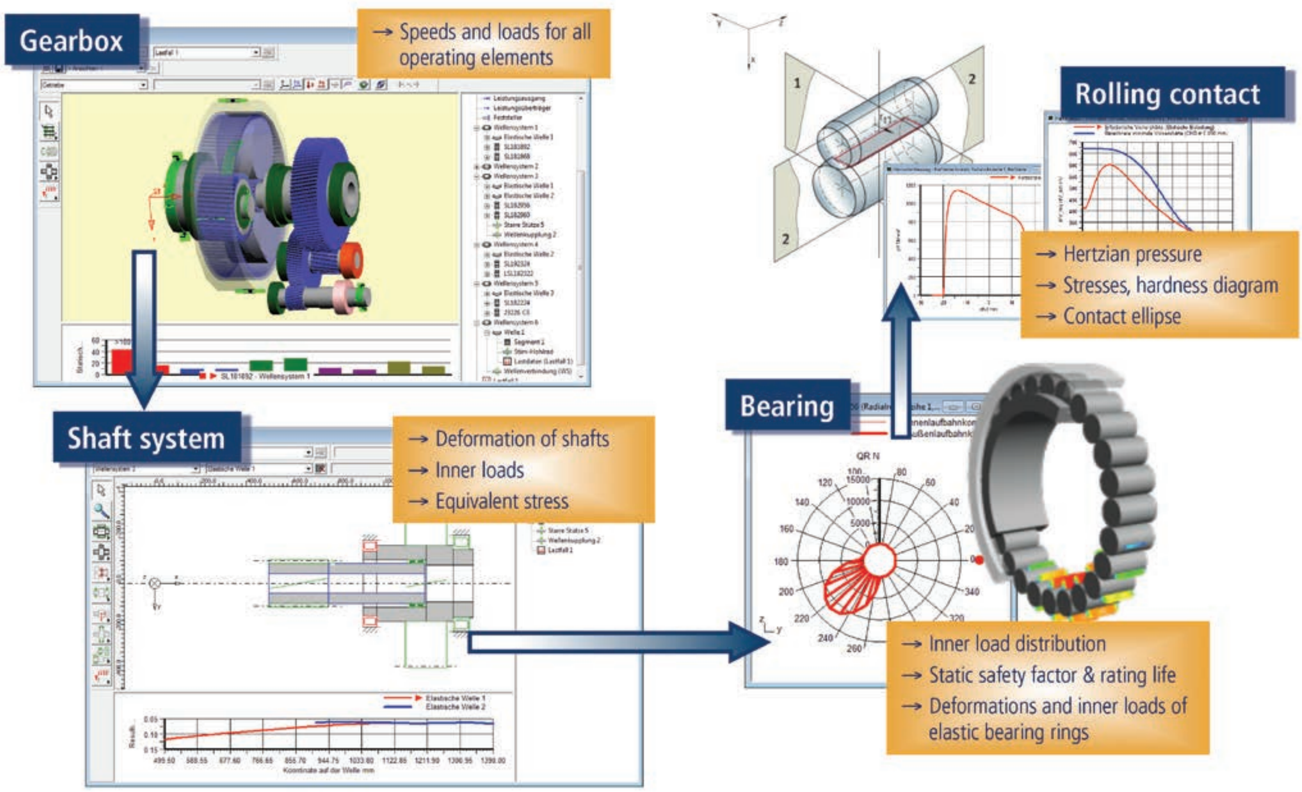

Fig. 1: BEARINX® — bearing analysis from gear to rolling contact

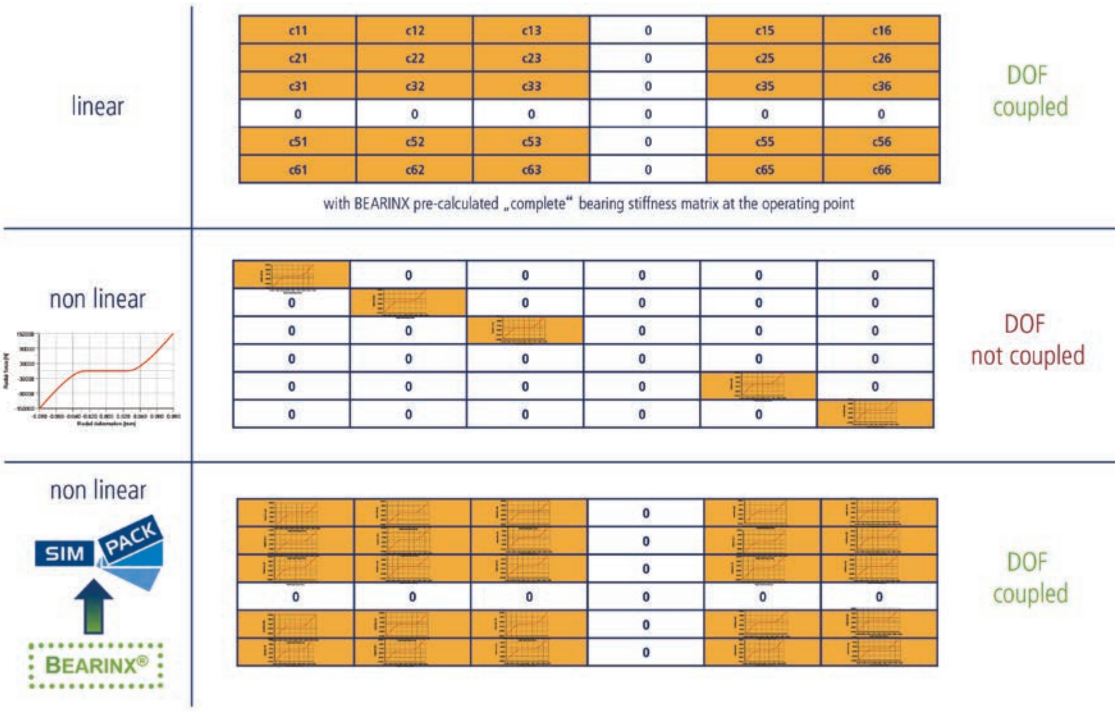

Fig. 2: Bearing modeling

LINEAR STIFFNESS MATRIX

The linear fully occupied stiffness matrix (Fig. 2, top section) is calculated for a particular operating point for each bearing using BEARINX®. If the loads remain within this order of magnitude during the simulation, this bearing model is a suitable compromise between quality of results and simulation time. Coupling effects of the degrees of bearing freedom are reflected correctly. However, the displacements are not normally correct since this linear model takes no account of bearing clearances.

NON-LINEAR CHARACTERISTIC LINES

Bearings are very frequently represented in simulations with the aid of non-linear stiffness characteristic lines for the main degrees of freedom (Fig. 2, center section). These can be easily calculated at an early stage by means of BEARINX® via parameter analyses. The bearing clearance is well represented in this modeling. The disadvantage is, however, that there is no coupling of the degrees of freedom. If a radial load is applied to a tapered roller bearing, for example, no forces occur axially in the model. It is therefore not possible to correctly represent all bearing characteristics using this model. If the coupling terms do not play a decisive role in the simulation, such as in the case of a roller bearing under predominantly radial load, this method gives good results.

BEARING FORCE ELEMENT FOR SIMPACK

In order to represent the non-linear coupled stiffness behavior of a rolling bearing in a dynamic system, the new Bearing Element can be used for SIMPACK (Fig. 2, bottom section). This can be used for accurately representing bearing types with their stiffness characteristics. The non-linear coupled stiffness characteristics of the rolling bearing are described using special characteristic maps. These characteristic maps are calculated before simulation with the aid of BEARINX®. Characteristic maps

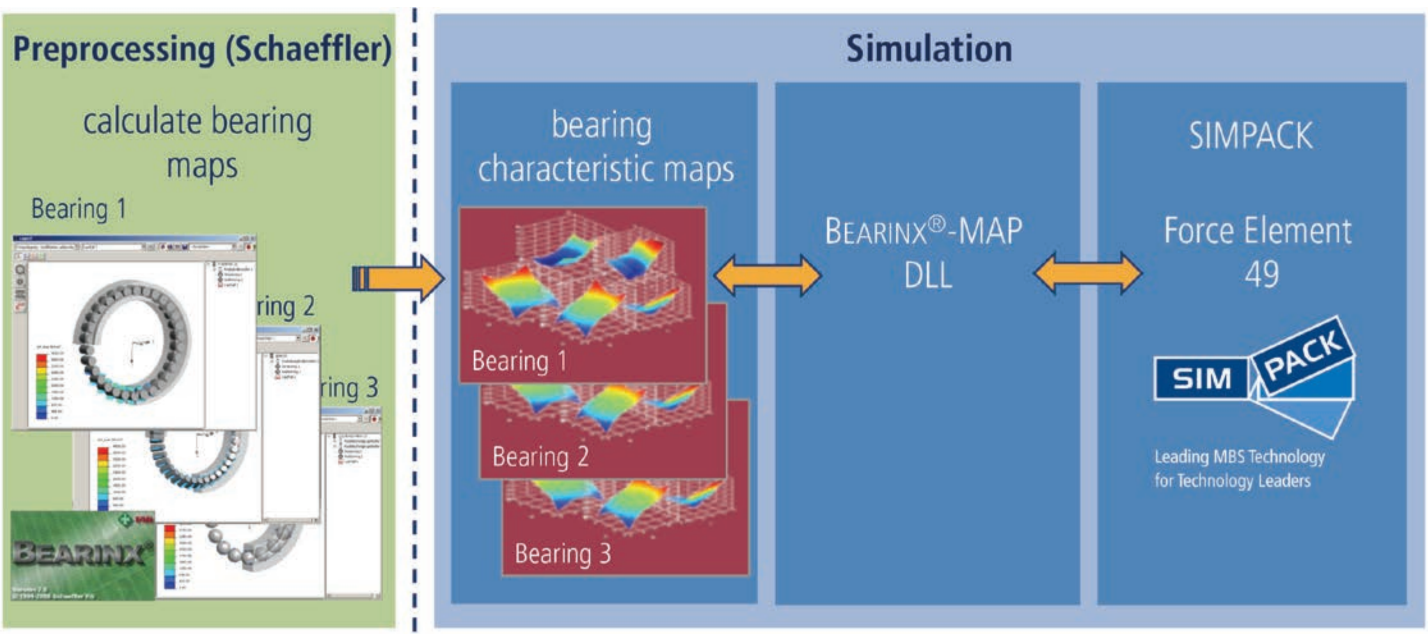

Fig. 3: BEARINX®-MAP simulation process

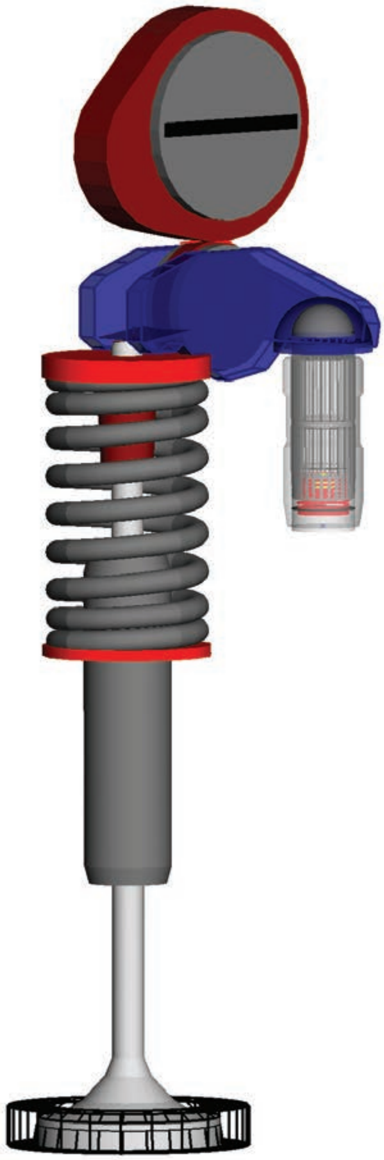

Fig. 4: Valve train

are created separately for each bearing and bearing clearance. The characteristic map interface is comprised of three components: bearing characteristic maps, a dynamic link library (DLL) and a SIMPACK Force Element. The advantages of the characteristic map solutions can be seen in the realistic representation of non-linear, coupled stiffnesses including the clearance run-through.

The dynamic link library is incorporated in SIMPACK by means of a Force Element. During simulation, the forces and moments are calculated with the aid of the relative displacements between the inner and outer ring on the basis of characteristic maps created in the preprocessing stage (Fig. 3).

"The characteristic map interface is comprised of three components: bearing characteristic maps, a dynamic link library (DLL) and a SIMPACK Force Element. "

CALCULATION RESULTS

In addition to forces and moments, the user of the Bearing Force Element has access to the maximum pressures occurring at the rolling contact. The pressure is a value that can be used to check whether the permissible load was exceeded during the simulation and the risk of plastic deformation is present. It can thus be assessed whether the bearing used is correctly dimensioned and suitable for the simulated load cases.

EXAMPLE: SIMULATION OF A VALVE TRAIN

A single valve train simulation was carried out as an application closely representative of reality.

The simulation model is comprised of a single valve train with parameters set in detail in accordance with customer specifications (Fig. 4). The cam follower is a finger follower that is supported on one side by means of a hydraulic insert element. On the other side, the lever is supported on the valve. The valve is held in the cylinder head by means of a valve spring. The valve spring is described in a multi-mass approximation that takes into account the natural vibration behavior of the spring especially at high speeds. The valve train is excited by rotation of the camshaft at constant speed. The shape of the cam profile determines, as a function of speed, the dynamic response of the system. The camshaft is supported by a Bearing Force Element for SIMPACK. Tilting motion of the shaft is suppressed by coupling to the adjacent construction.

For analysis of the results, the displacement of the camshaft can be considered first (Fig. 5). Due to the detailed description of the bearing responses by the Force Element, a complex structure of shaft movement in both directions is created. In realistic terms, the bearing forces (Fig. 6) essentially follow the camshaft displacement. The maximum pressures are important for design of the bearing in a valve train application (Fig. 7). Conspicuous vibration patterns occur during the event concerning the maximum of the valve lift that are determined on the one hand by the natural vibration of the valve spring but whose form and magnitude are influenced on the other hand by the characteristics of the camshaft bearing arrangement. Due to the dynamic response of the valve train at high speeds, peak loads occur at the end of the valve lift. The precise height of these force peaks is critical in the design of the bearing. The

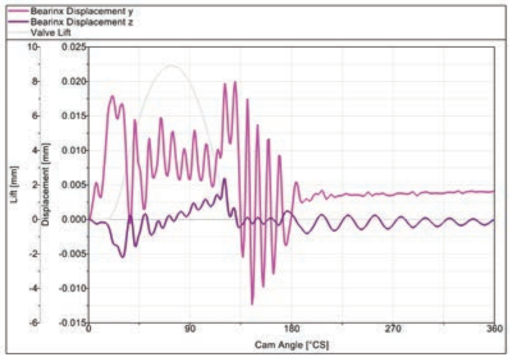

Fig. 5: Displacements of bearing

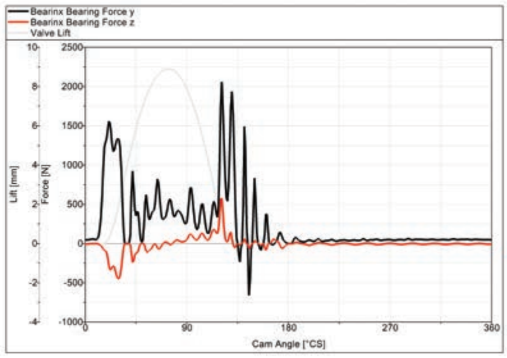

Fig. 6: Bearing forces

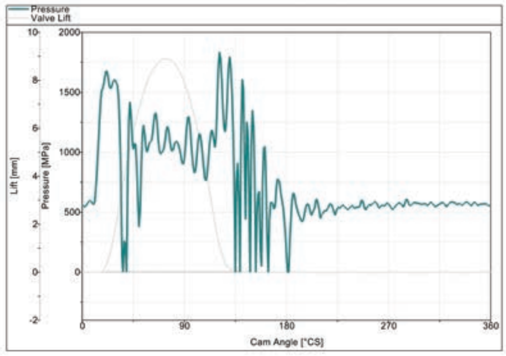

Fig. 7: Maximum pressure in contact

BEARINX®-based Force Element allows a significantly more precise description of the force and pressure curve than with conventional bearing arrangement models.

SUMMARY

The Bearing Force Element for SIMPACK permits accurate representation of rolling bearings in dynamic simulations. By means of the method presented, users can access extensive know-how in BEARINX® in order to make better estimates of the influence of rolling bearings on dynamic system behavior.