# Rolling-Element Bearing Analysis

## *How Multi-body Dynamic Software can Help Identify Issues with Design*

Yijun Fan

This article describes how more sophisticated modeling techniques allow the latest software to identify design issues with bearings, shafts, gears and complicated multi-body systems.

Bearings play an important role in powertrain design. For example, in modern transmission systems, there are three major bearings that support the main shaft from front to back. They include the pilot bearing, the input shaft bearing, and the rear support (angular) bearing. The role of a pilot bearing is to stabilize the nose end of the main shaft and clutch disc with the flywheel. If this bearing fails, this portion of the shaft will be able to vibrate/thrust up and down as the disc rotates. This new clearance will allow the clutch to engage at an axis that is no longer centered along the line of power flow, which can cause catastrophic transmission element failure.

Because of the importance of the bearing, the prediction and control of rolling-element bearings on system performance are becoming some of the major concerns in powertrain design. Important considerations include how bearing clearance could affect the gear mesh, how bearing stiffness could impact the system natural frequency, or how different bearing parameters could change the stress distribution of the rotating main shaft.

Multi-body dynamics software is used to study the dynamics of moving parts and to determine how loads and forces are distributed throughout mechanical systems. Multi-body dynamic software like MSC Software's *Adams* is usually applied to model and analyze the powertrain systems by engineers at major OEMs. However, due to the complication of the bearing model itself, a "bushing element" is usually applied to represent the bearing model. While the bushing element plays a decent role in constraining relative motion between different parts, it lacks the fidelity of incorporating most of the bearing properties and limits engineers' ability to study how different bearings would impact the transmission system performance.

MSC Software has recently released a new member of the *Adams* family, *Adams/Machinery*, which is a set of productivity modules with the capability for wizard-based modeling and adjustable-fidelity simulation of common mechanical subsystems and components, including belts, chains, gears and bearings.

In the *Bearing Module*, there are three modeling methods designed for different levels of fidelity. For example, in the "Detailed" method, a force is used to represent rolling element

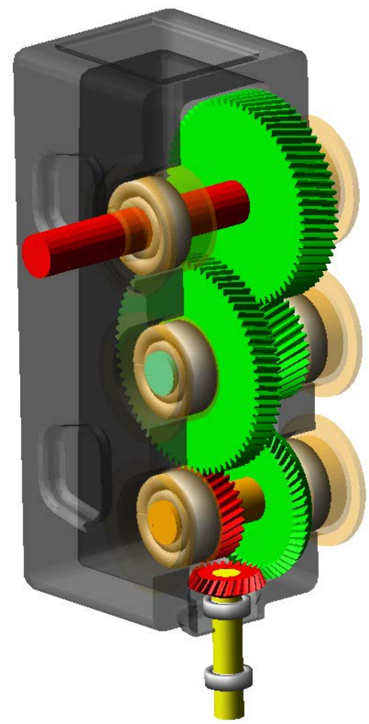

**Figure 1 Gear train model.**

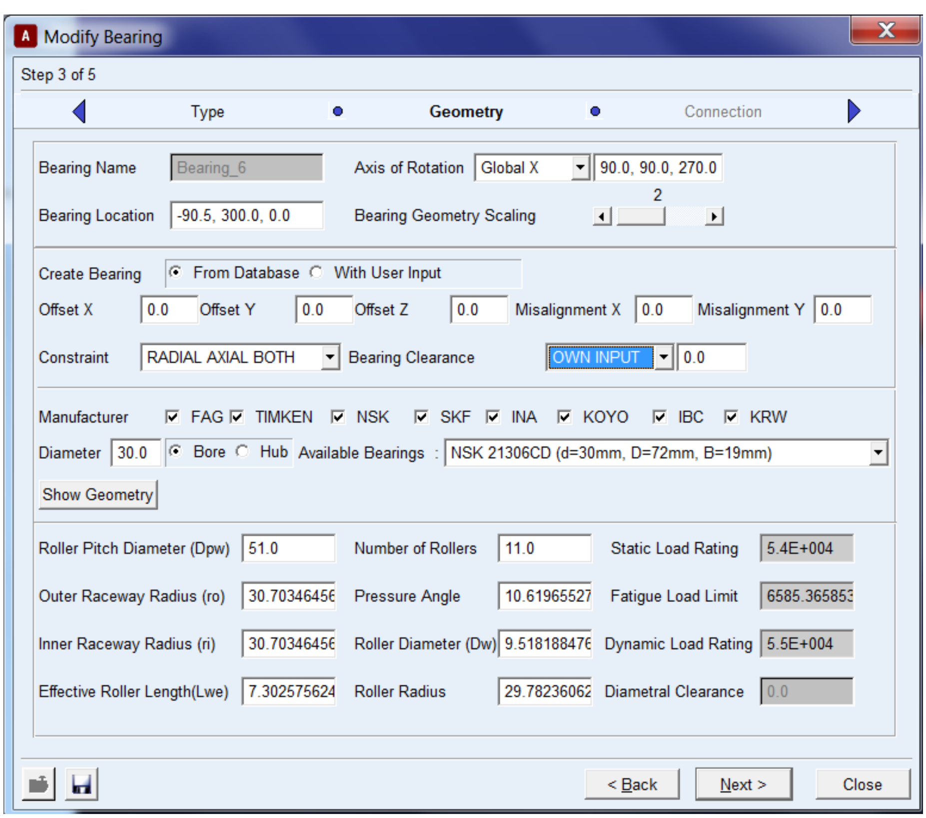


**Figure 2 Bearing creation wizard.**

bearings. Using advanced analysis technology from drivetrain simulation software *KISSsoft* (now embedded in *Adams/Machinery*), stiffness is calculated at every step based on the positions and velocities at the bearing location. Damping is based on user-specified factors. The bearing module enables an engineer to select from a library of more than 24,000 off-the-shelf bearings spanning a range of 14 bearing types, including deep groove ball bearing, cylindrical roller bearing, needle roller bearing, tapered roller bearing and so on. The library supplies characteristic geometry values for bearings from eight leading manufacturers, like Timken and NSK. The *Bearing Module* allows designers and engineers to build more realistic bearing models and systems (Fig. 1) early in the design cycle, with a level of detail that allows them to perform meaningful analyses, long before they get to the stage of building physical prototypes. To understand how the *Bearing Module* enables the engineers to study bearings from a system level, let's look at some of the application examples:

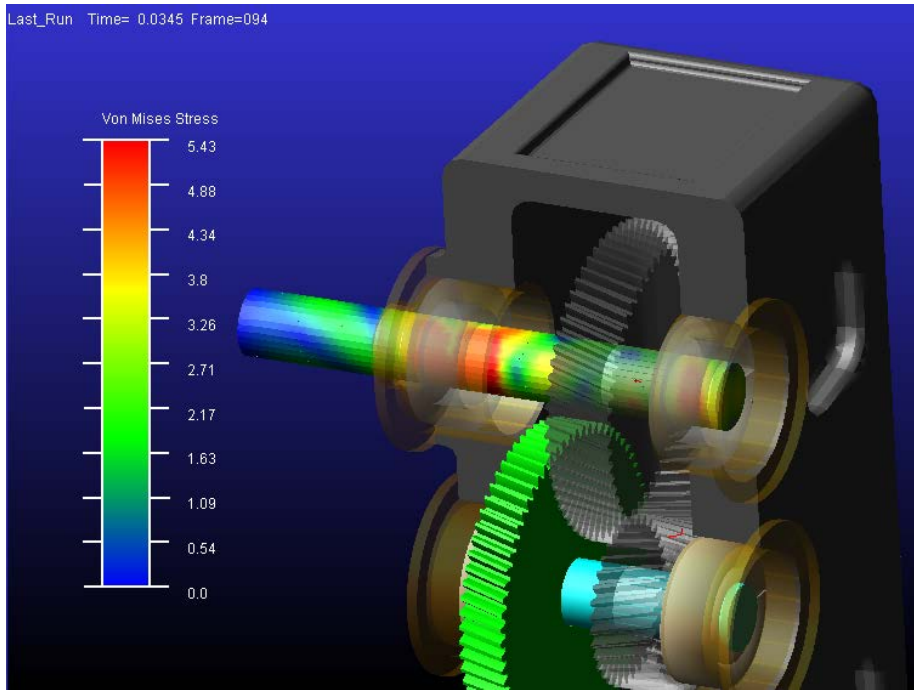

Figure 3 Stress distribution of the input shaft.


Figure 4 Gear mesh.

## How Bearing Parameters Impact the Stress Distribution of the Input Shaft

A shaft is the component of a mechanical device that transmits rotational motion and power. Because of the simultaneous occurrence of torsional shear and normal stresses due to bending, the stress analysis of a shaft virtually always involves the use of a combined stress approach. In order to increase the simulation fidelity, engineers utilize the system-level dynamic model to capture the real loading of the shaft before they perform the stress analysis.

Normally, bearings are used to support a shaft. Different bearing parameters result in different bearing stiffness, which would impact the system performance, such as the radial and axial components of the contact forces between the bearing and the shaft. So, it is important to analyze how different bearings would impact the shaft stress distribution.

Each bearing has its unique set of parameters, such as inner diameter, outer diameter, number of rollers, roller radius, effective roller length and so on. All of those parameters can be defined in the *Adams/Machinery Bearing Creation Wizard* (Fig. 2), either by user input or by picking from the embedded bearing library.

In order to get an accurate loading condition for the shaft, shaft flexibility is usually taken into account in the transmission model. Engineers can choose either to import the MNF file of the shaft from FEA software or to directly generate the flexible body using the *Adams Viewflex* function.

After the flexible shaft is generated, engineers can get the accurate load history of the shaft based on different bearing parameters. And then, they can either export the load history of the shaft to the FEA software as boundary conditions and conduct the stress analysis, or perform the stress analysis within the *Adams* environment using the *Adams Durability* function (Fig. 3).

In this way, engineers can analyze how bearing parameters would impact the stress distribution of the input shaft and choose the right bearing according to the system requirements.

## How Bearing Clearance Affects Gear Mesh

A gear mesh refers to the way that the teeth from one gear engage with those from another gear. If this mesh is incorrectly set, by being either too tight or too loose, you will not be able to get optimal performance from your transmission, and this condition will contribute to premature wear of some components. Many things can cause the misalignment of the gear mesh, and bearing clearance definitely is one of them since it changes the center distance between the gear pairs.

In the *Adams Machinery Bearing* module, engineers can define their own bearing clearance, offset and misalignment when creating the bearing model using the wizard approach.

There are two ways to analyze the gear mesh in the system. Using a 3-D contact gear model created by the *Adams Machinery Gear* module, engineers can observe the gear engagement visually (Fig. 4). Also, one can create a measurement between the center markers of the two gears and get more detailed results for the center distance of the gear pair.

In this way, engineers can quickly study how the bearing clearance would impact the gear mesh.

## How Loads Affect Bearing Service Life

Rolling element bearing life is determined by load, temperature, maintenance, lubrication, installation and other factors. These factors can all have a significant effect on bearing life.

Based on widely-accepted industrial standards ISO/TS 16281, the *Adams Machinery Bearing* module allows engineers to quickly evaluate the bearing service life under load/speed conditions of each output step. It also takes into account the operating temperature and the types of lubricant applied to the bearing when calculating the results (Fig. 5).

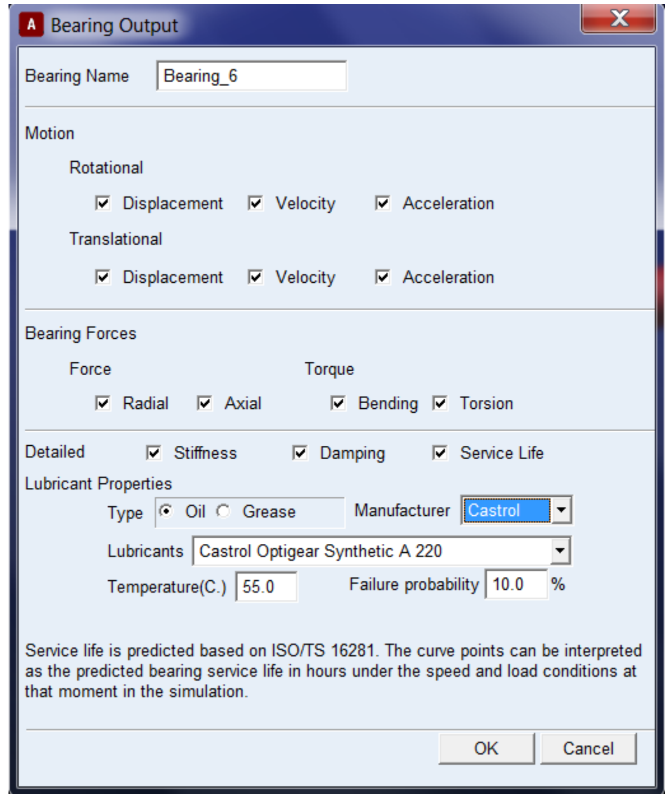


**Figure 5 Bearing output window.**

With this quick evaluation tool, engineers can easily tell how bearing loads or rotational speeds could result in different bearing service life (Fig. 6).

## Conclusion

It is important to study the impact of the design and behavior of rolling-element bearings on overall system performance. The insight gained from the deep analysis capabilities of the *Adams Machinery Bearing* module lets you predict and correct design behavior problems much earlier. And, by predicting system-level functional performance, you are able to more accurately assess the load history of the part to perform more accurate stress analysis, and reduce risk. **PTE**

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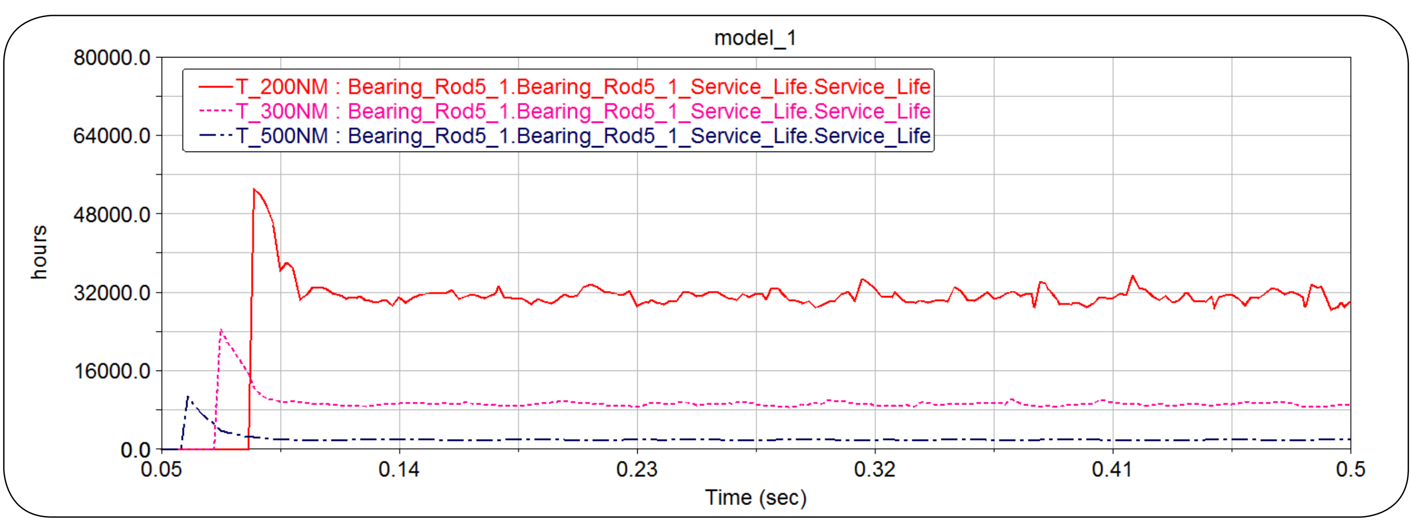


**Figure 6 Bearing service life under different input torques.**