Software for gearbox development

Accurate Prediction of Damage Over the Operating Life of Bevel Gears

The FVA-Workbench is a manufacturer-neutral tool for the simulation and calculation of transmission systems. As product development cycles become shorter, powerful modeling approaches and calculation algorithms become increasingly important. The predominantly analytical approaches in the FVA-Workbench deliver fast and reliable solutions to all important issues related to drive technology. For bodies that cannot be accurately described analytically, the results are supplemented by suitable numerical methods. The intuitive modeling techniques in the FVA-Workbench guarantee simulation of consistent, valid, and manufacturable gears every time.

The calculations are developed, analyzed, and validated in research projects by Forschungsvereinigung Antriebstechnik e.V. (FVA, the Research Association for Drive Technology). Through member contributions and public funding, the FVA is able to organize 14,9 million euros annually in research projects at leading German universities, chairs, and research institutions. The FVA-Workbench serves as a knowledge platform, making the results of FVA research projects available and accessible to all engineers. It is no longer necessary to read through and study countless pages of scientific documentation, making the development of innovative gearboxes considerably more efficient and user friendly.

Bevel and Hypoid Gear Calculation Methods in the FVA-Workbench

Marine, rail, automotive, aviation: bevel and hypoid gears are used in a wide variety of industrial applications. One thing all of these applications have in common is that the power flow changes directions. The design requirements, and therefore the calculation methods, are as diverse as the possible applications. These can range from standard calculations with only a few input variables to calculation of the local load carrying capacity with consideration of the gear environment and the expected load spectrum.

For calculations according standards and classification societies, the only required input variables are the macro-geometry of the bevel gear; the operating conditions, consisting of the speed, torque, and operating mode; as well as the material and lubricant specifications. The foundation of these load capacity analyses is the suitable conversion of the bevel gear geometry into a substitute cylindrical gear that sufficiently approximates the meshing conditions of the bevel gear to be calculated. As a result, safety factors are provided that allow statements to be made regarding the load capacity of the gear under the specified load.

Current and historic versions of all relevant load carrying capacity standards are available in the FVA-Workbench. Additionally, methods developed by the FVA that have a normative character can also be used (e.g. FVA Research Project 411, "Load Capacity of Hypoid Gears," Technical University of Munich Institute of Machine Elements, Prof. Dr. Karsten Stahl). Furthermore, marine classification society rules are also included for simple use. However, these standard calculation methods can only approximately describe the complex meshing conditions of bevel gears. The microgeometry, which includes modifications to the effective flank among other things, is insufficiently considered in the calculation or not at all. Likewise, relative position deviations also cannot be directly considered in these calculations. Due to the sensitivity of bevel gears to displacement, the shape of the contact pattern, which results directly from the microgeometry, plays a decisive role. For this reason, the local bevel gear calculation methods in the FVA-Workbench provide crucial support.

The required nominal geometry of the gear is determined via a manufacturing simulation. All necessary information such as the basic geometry; machine setting data; tool data; and kinematics, including additional movements, are taken from manufacturer-specific interfaces (e.g. KIMoS neutral data) and converted to the universal bevel gear cutting machine. The tooth flanks, including the tooth root area, are simulated point-by-point and mathematically mapped via fitting surfaces. As all manufacturing information is incorporated into the simulated gearing points, the nominal geometry, including the ratio of curvature, is mapped from the modeled tooth flanks. In the tooth contact simulation, the tooth flanks are brought into mesh and rolled.

When considering the bevel gear stage in the overall system, the operating conditions, installation dimensions, and load-dependent displacements as well as supplementary wheel body geometry descriptions are included in the complex tooth contact simulation, and thus all subsequent calculation steps, in addition to the determined nominal geometry.

Load-free tooth contact simulation: The results of the load-free tooth contact simulation - from the ease-off and contact pattern calculation and the optional calculation of the circumferential backlash and ductility of the bevel pinion - form the basis for all subsequent calculations, and include important statements on the effectiveness of the micro-geometry design (ease-off) on the displacement behavior and meshing interference (size and position of the contact pattern).

Local stress calculation: Building on these results, the stress calculation is performed based on the influence numbers method, a numerical calculation method with which the load and stress distributions at discrete points can be efficiently calculated. By default, the stiffness of the wheel body is approximated by an elastic half-space. With the FVA-Workbench, a wheel body and its clamping can optionally be specified as a complex wheel body geometry. Wheel bodies can easily be loaded as CAD geometry and then positioned and meshed in the FVA-Workbench. The influence numbers are then calculated, taking the specified wheel body into account according to FVA Research Project 223 XVI ("BECAL Wheel Bodies," Technical University of Dresden Institute of Machine Elements and Machine Design, Prof. Dr. Berthold Schlecht). As a result, the user receives the locally solved load and pressure distribution as well as the local sliding speeds. A resulting efficiency is determined for the considered stage and from the calculated geometry and the contact description of the mesh stiffness curve over the mesh positions and the transmission error. The transmission errors are a measurement for the running behavior of the gear at an operating point.

In the assembly process, the load-free contact pattern is the decisive parameter with which the bevel gear stage is configured and the bevel gears are aligned to each other. In order to be able to compare the contact pattern with the calculation, a guideline for measuring and characterizing contact patterns was developed in FVA Research Project 223 XV ("Contact Pattern Measurement," Technical University of Dresden Institute of Machine Elements and Machine Design, Prof. Dr. Berthold Schlecht). At the same time, the bevel gear calculation was also extended to output the relative position of the contact patterns. The tests performed in the research project show that the load-free and loaded contact patterns in the FVA-Workbench correlate very well with the actual contact patterns. This provides the user a powerful tool for analyzing the contact patterns of bevel gears. An example of an FVA-Workbench report is shown in Figure 1.

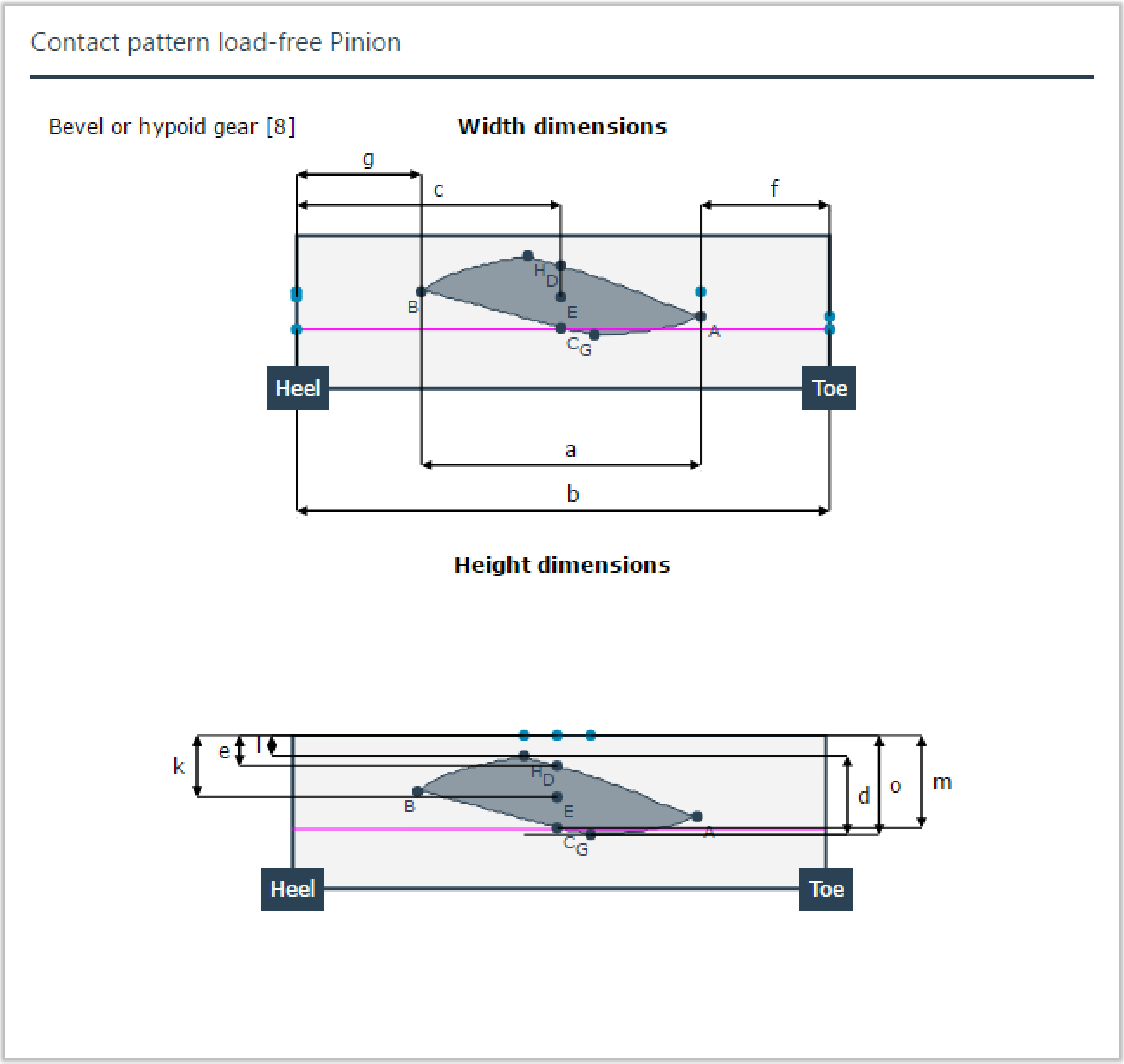

Figure 1: Contact pattern measurement

Local load carrying capacity calculation: The material stresses can be derived from the contact pressure and converted to a pitting safety factor. The safeties are carried out in the same way as the standardized calculation methods, as the same strength values are used. The local material fatigue load capacities were developed and validated in FVA research project 411. The local safety against micropitting was examined in FVA Research Project 516 ("Micropitting of Hypoid Gears," Technical University of Munich Institute of Machine Elements, Prof. Dr. Karsten Stahl). In contrast to damage from material fatigue, the safeties against pitting according to FVA 411 (see Figure2) and micropitting according to FVA 516 on the tooth flank are calculated, as are the safety against root fracture according to ISO 10300 and the safety against scuffing due to excessive contact temperature according to FVA Research Project 519 ("Scuffing of Hypoid Gears," Technical University of Munich Institute of Machine Elements, Prof. Dr. Karsten Stahl).

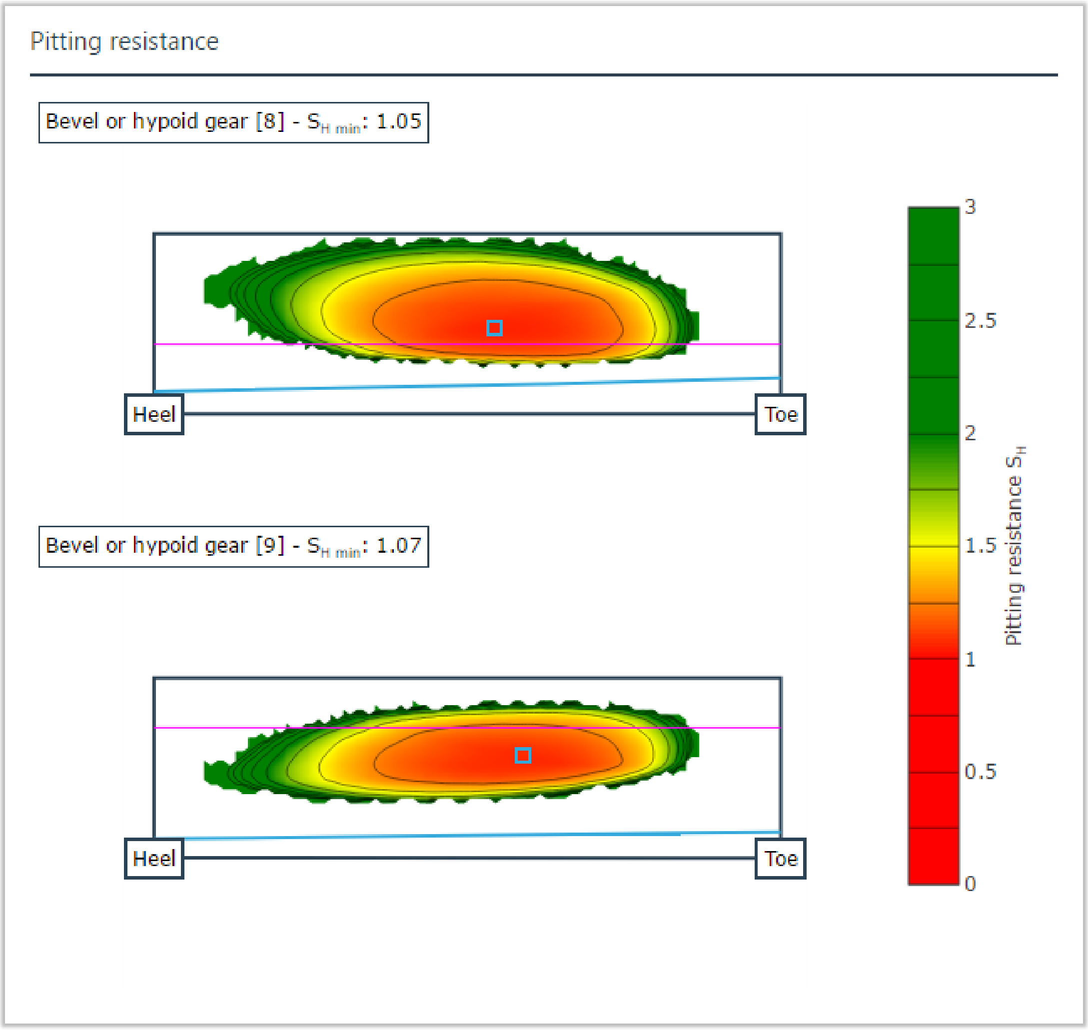

Figure 2: Local pitting resistance

The local load carrying capacity in connection with the overall system calculation is of particular interest. The system calculation in the FVA-Workbench considers the stiffness of all components in the gearbox and uses them to calculate the occurring deformations. The relative displacements of the bevel gear stage are calculated from the shaft bending line and automatically considered. In this way, bevel gear stages can very easily be calculated and evaluated, taking all relevant influences into account.

Local damage accumulation in the load spectrum: With a local damage accumulation calculation the real load conditions, which change during the operating period, can be considered in the tooth contact simulation and subsequent local load carrying capacity calculation. In this way, the user receives the first indication of the location of the greatest damage and thus the area at which pitting damage and root damage are most likely to occur, as well as an estimation of the amount of fatigue.

In addition to the local methods described above, embedded in the overall system, a bevel gear can also be considered as a single stage. Additional calculation options are available as analysis tools, such as variational calculations and damage simulation. For the single stage calculation, it should be noted that the relative locations as well as the operating conditions must be specified by the user, independent of the overall system.

Variational calculations: A specific characteristic of bevel gears is their sensitivity to displacement, i.e. changes to the size and position of the contact pattern due to relative position changes. Automatic variation of the torque and speed combined with load-dependent relative position deviations provides a quick overview of the changes to the local stresses and safety factors. The individual results are compiled in graphical representations to facilitate their evaluation.

Local damage simulation: In addition to the usual local load carrying capacity calculation, the local damage to the tooth flank can also be simulated according to the implementation of FVA Research Project 223 XII ("Damage Progress," Technical University of Dresden Institute of Machine Elements and Machine Design, Prof. Dr. Berthold Schlecht). The simulation of the formation of pitting and micropitting is based on the determination of the load carrying capacity, the calculated resulting cumulative damage, and determination of the resulting flank deformation. As the simulation includes damage from constant changes to the flank form, the interactions between micropitting and pitting damage as well as the influence of the damage on the flank load carrying capacity can be shown. As the calculation of the local damage simulation corresponds to the current state of research, the validation process is not yet complete. However, the current status shows promising results.

About FVA GmbH:

FVA GmbH is a joint venture of VDMA (Verband Deutscher Maschinen- und Anlagenbau, the Mechanical Engineering Industry Association) and FVA e.V. (Research Association for Drive Technology). Founded in 2010, FVA GmbH works hand-in-hand with top-level German research institutions and leading companies from the drive technology industry toward the practical application of knowledge gained from FVA research projects. Our core competencies are the development of calculation and simulation software for drive technology, processing and conversion of legacy code structures into modern software architectures, professional service and support, and hosting technical seminars and conferences.