KISSsoft Makes it Possible to Analyze Contact Patterns for UAV Helicopter Transmissions in Prototype Trials

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In a research project at the Vienna University of Technology, the *KISSsoft* design software was used to check a new drivetrain concept and the micro-geometry of the bevel gear stage for a UAV (unmanned aerial vehicle). The gear set was then tested in a prototype transmission on a test bench and contact pattern verifications were conducted to validate the design. The tests showed that the contact patterns from the simulation were not achieved during the first trial. After analyzing gearbox displacements in the simulation and correcting the mounting distances of the bevel gear set on the test bench, the contact patterns proved to be consistent between the test and the *KISSsoft* results.

Figure 1 CamCopter S-100 in use.

Introduction and Motivation

The focus of research by the Machine Elements Research Department of the Vienna University of Technology, directed by Professor Dr. Weigand, is on aviation propulsion systems. They include drivetrains for rotary wing aircraft of all sizes as well as transmissions for fixed-wing aircraft and turbines. The activities of this department range from concept designs to detailed analyses of transmissions, certification issues and test bench trials. The segment of new drive designs for UAV's is experiencing rapid growth in aviation. These UAV's include autonomous helicopters with a take-off weight of around several hundred kilograms.

The CAMCOPTER S-100 from the Austrian company Schiebel Elektronische Geräte GmbH is an unmanned helicopter with a maximum take-off weight (MTOW) of 200 kg and a payload of 50 kg which is operated by a Wankel engine. Its maximum speed is 240 km/h, its maximum flight altitude is 5,500 m by an operating time of minimum 6 hours (Figure 1).

As part of the OHE (Optimized Helicopter Drives Made in Austria) cooperative research project between the Vienna University of Technology and the company Schiebel, the new transmission design was reviewed on

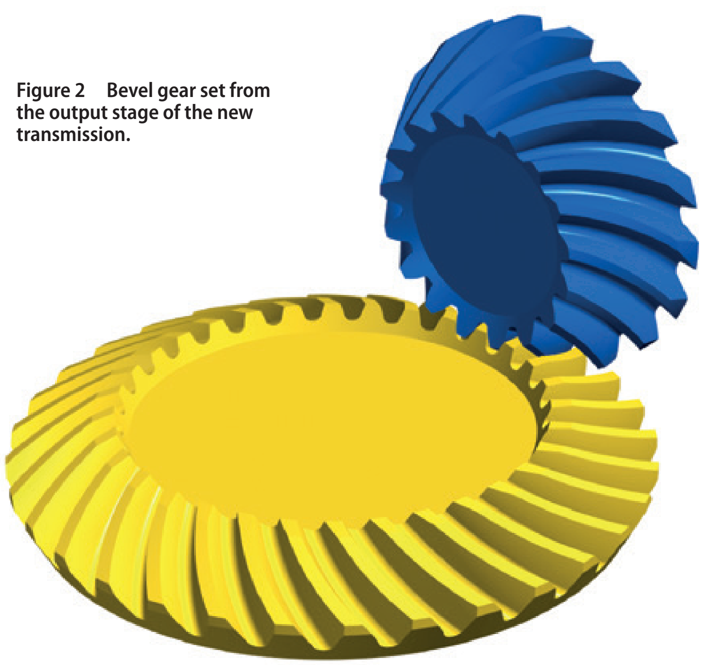

Figure 2 Bevel gear set from the output stage of the new transmission.

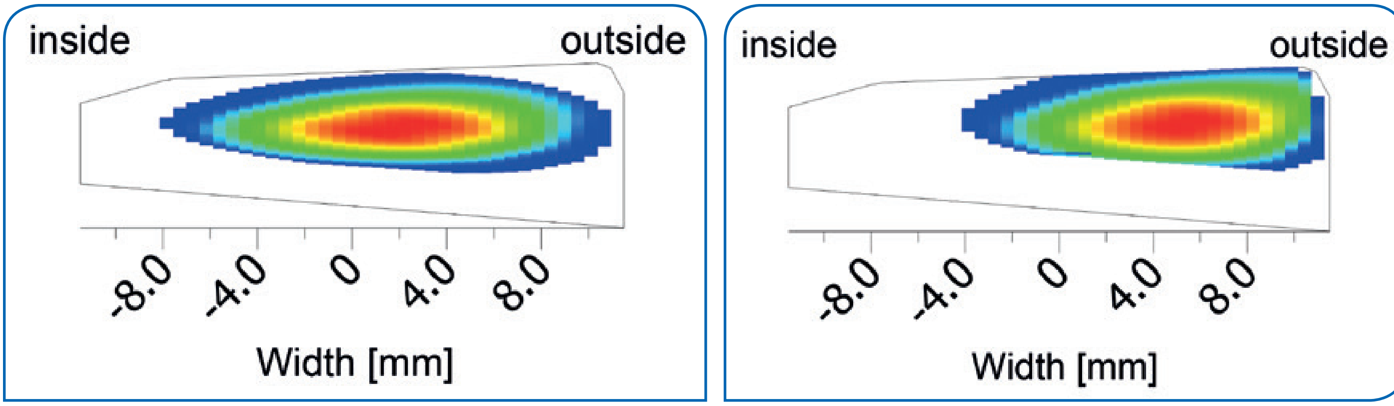

Figure 3 Variation of the mounting distance from the ring gear and its effect on the contact pattern (left without backlash, right with displacement of the ring gear).

a test bench specially made for the CAMCOPTER S-100 at the Institute of Engineering Design at the Vienna University of Technology. The bevel gear stage tested is the output stage to the main rotor and has a transmission ratio of around 1.9 and a shaft angle not equal to 90°. The bevel gear set was manufactured in a conventional face milling process. The micro-geometry was specially designed for this gear set, since the deformations are greater in aviation transmissions than in industrial gearboxes, because of the radical light-weight design, particularly of the housing. The gear set—together with the new contact pattern specifications from the Vienna University of Technology—was given to the bevel gear set manufacturer commissioned to manufacture the transmission and determine the flank modifications (Figure 2).

It was shown on the test bench that the manufactured bevel gear set did initially not have a satisfactory contact pattern. The contact pattern was shifted significantly toward the heel and tip on the ring gear. This led to the issue and challenge of identifying the cause of the error and of determining and eliminating the relevant parameters. The drivetrain and the bevel gear stage were designed with *KISSsys*– the KISSsoft system add-on—software from KISSsoft AG, and the contact pattern was calculated under various loads, including the corresponding profile and lengthwise crowning as well as the spiral angle/pressure angle modifications.

Contact Analysis of the Bevel Gear Stage Using *KISSsoft*

KISSsoft was used to conduct a contact analysis under full load and evaluate the contact pattern on the ring gear. To calculate the contact pattern, the contact analysis software uses a bevel gear model based on the cylindrical-gear profile as well as flank modifications based on the definition of mathematical approaches. In contrast, conventional manufacturing of bevel gears is based on the theoretical generating of the plane gear and flank modifications based on machine settings. Because the bevel gears normally have rather large crowning, the difference between the approach of *KISSsoft* and the conventional manufacturing in the contact pattern is low, and this enables a simulation in *KISSsoft* based on the analytical approach of Weber/Banaschek to obtain a good estimation of the contact pattern under load. The contact analysis also provides an evaluation of the gear set according

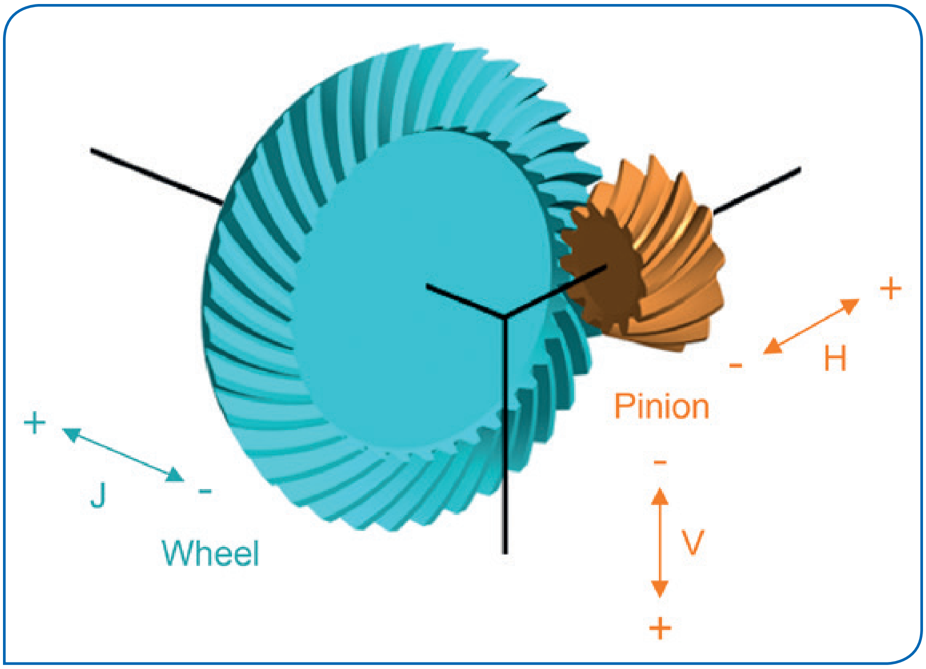

Figure 4 Definition of the displacements on the bevel gear.

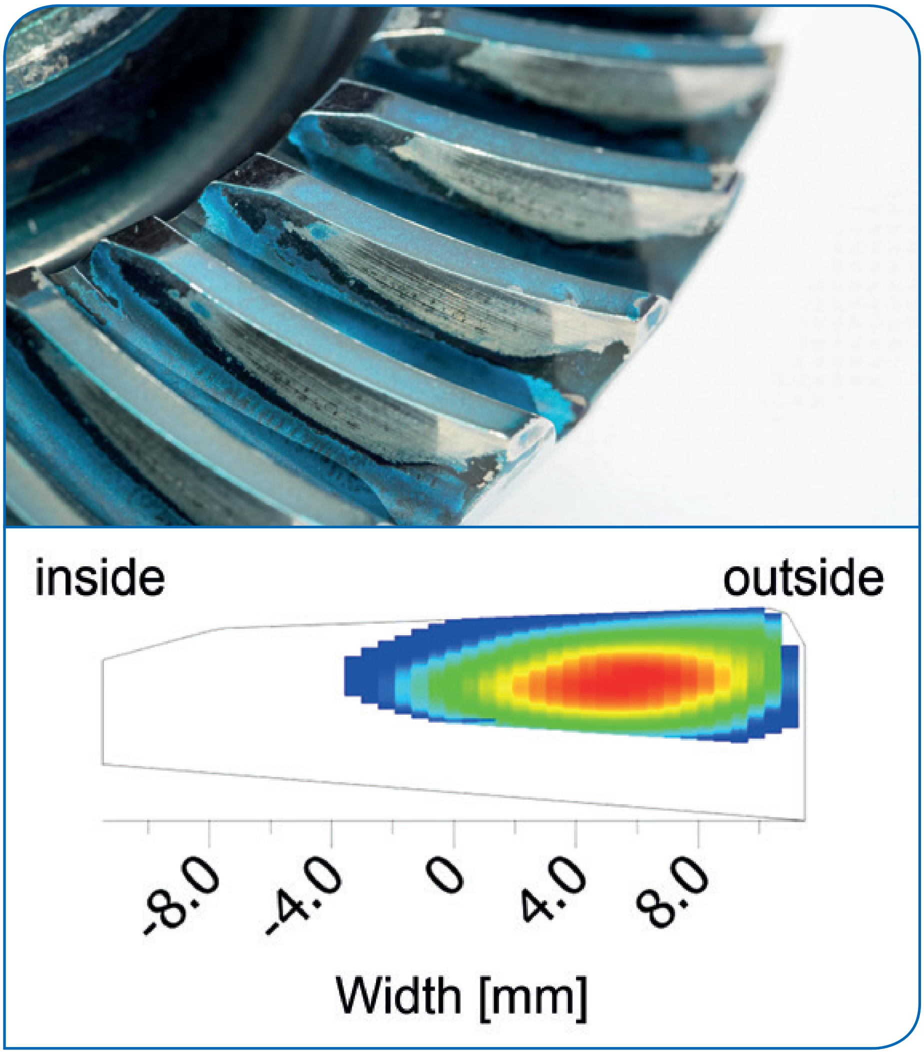

Figure 5 Identical contact pattern from test bench (top) to simulation (bottom) after correcting the mounting distance.

to various criteria such as tooth root stress, tooth flank fracture, or scuffing. On the other hand, experience shows that more sensitive criteria — such as noise evaluation due to transmission error — also require the real topology from the production simulation.

Contact Pattern Displacements in *KISSsoft*

To determine the cause of the poor contact pattern on the test bench, the theoretical gearing data was first compared to the manufacturing data, and the gear set was checked for any potential manufacturing errors. No differences were found here. The load assumptions from the simulation were also correct and agreed with measured values from the test bench. The circumferential backlash, which was adjusted when mounting the ring gear, was then tested as another possible source of the poor contact pattern. For comparison, the parameters for the assembly deviations were subsequently varied in *KISSsoft* to simulate the contact pattern from the test (Figure 3).

Contact Pattern Testing on the Test Bench

In *KISSsoft*, a parametric study was conducted with various mounting distances for the ring gear in the J+ direction (Figure 4). Now, this showed that the faulty contact pattern from the test bench was obtained also in the simulation.

In turn, this finding suggested that, on the test bench, the crown wheel was mounted incorrectly with respect to the mounting distance, thus making the backlash incorrect. Finally, an inspection of the assembly process showed that the backlash was not set correctly, which had led to the unexpected result. After correcting the mounting distance of the ring gear, a contact pattern identical to that of the simulation in *KISSsoft* was obtained on the test bench (Figure 5).

The unfavorable contact pattern leads to nonuniform load distribution over the flank under high loads, and thus to excessively high stresses, which, in turn, have adverse effects on load-bearing capacity. A uniform load distribution was achieved using the correct contact pattern.

Summary and Outlook

In the past, the manufacturer would come up with a new design of a bevel gear pair and define the flank modifications based on their own experience. In aviation, this approach does not always lead to the desired results, because these transmissions are subject to other deformations as well due to the radical lightweight design and different mounting systems. Especially in aviation, it is therefore essential to make use of drivetrain software to predict the contact pattern and verify it in a test run.

In the application example presented, *KISSsoft* was used successfully to lay out the contact pattern and to troubleshoot faults after the production process. State-of-the-art drivetrain software is able to recognize contact pattern displacements in comprehensive analyses and propose suitable flank modifications. This leads to realistic results and contributes significantly to achieving high-end developments at reasonable costs. **PTE**

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