Improved Fatigue Prediction for Rotating Components

New method provides more precise analysis of damage, faster for all types of rotating components

FEMFAT software

In contrast to components in which the forces and moments can be expected and applied at fixed locations (e.g. simple attachment parts, chassis, car bodies, etc.), the situation is somewhat more complex with rotating components.
In the steady-state case, unit loads are typically calculated at the points where forces are applied, and scaling is accomplished using measurement data, for example. Subsequent superpositioning then yields to the complete stress-time history for the component. The fatigue life of the overall component can be determined in combination with material data and appropriate fatigue analysis methods (see Figure 1).
Instead, the rolling simulation of rotating components is typically not performed using a transient simulation with real load-time data because it would be too elaborate and cost intensive to calculate with current engineering practices.
However, the rotation involved here does require additional effort to determine the application of forces. One approach is to attempt to create a steady-state, non-rotating case for these components. The rotation is created by altering the application of the point of force to determine the stress history as it changes over time for the component (see Figure 2).
In a case like this, not only is the load itself a function of time, but so is the position at which it is applied. This must be tediously determined manually, and additional tools are required. Consequently, the complex loading of these components is usually simulated using very simple loads (e.g. a constant moment) to ensure a safe design.
Instead, the new approach shown in this article helps to enable a more realistic determination of the damage by taking local and global influences into account. This method has a broad range of applications. It can be used for all components which are subjected to rotating loads, such as wheel carriers, clutches, drive shafts, transmissions, differential cages, rims, and many more.

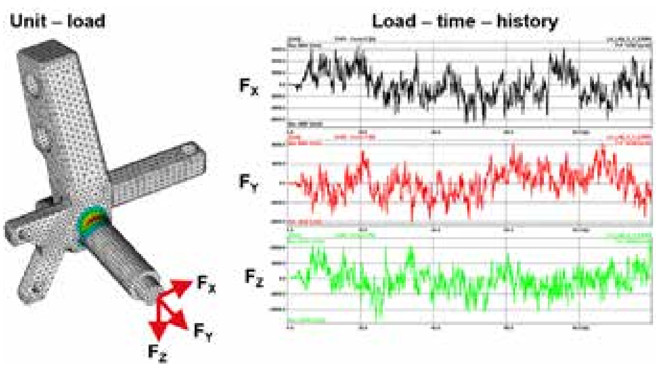

Fig. 1 - Load definition for a multiaxial fatigue analysis

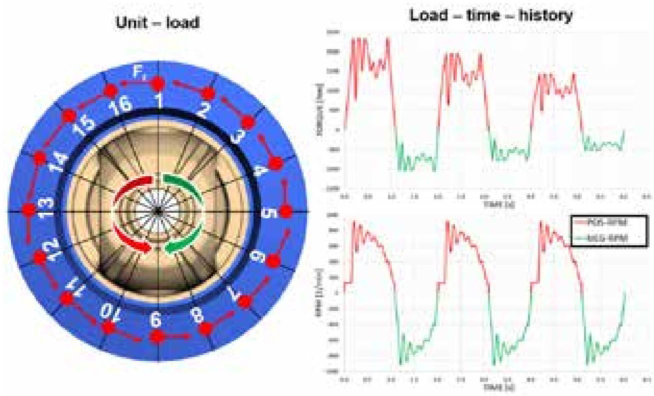

Fig. 2 - Load definition for a multiaxial fatigue analysis of rotating components

Improved damage analysis using the example of a differential cage

The model used is shown in Figure 3. All the relevant parts of the differential cage were modelled with approximated stiffness. The bearings were modelled with non-linear spring characteristics to represent the tension-pressure asymmetry. All the relevant contact points were modelled with friction. The overall system was fixed to the outer bearing rings. Force was applied to the ring gear. The pitch of the force application was defined at 16 positions every 22.5° (see Figure 2).
The non-linear analysis was carried out for a forwards and backwards moment of 1000 Nm.
In the first step of the analysis, the M10 screws were pre-tensioned with a force of 50.6 kN. This state was fixed and then the three analytically-calculated tooth contact forces were applied to the 16 individual load cases. Upon completion of the calculation, a total of 32 stress states were available for the fatigue analysis (16 forwards and 16 backwards). These stress states became the basis for the subsequent fatigue analysis.

Transformation of the torque history into a unit matrix based on real measurement data

Based on the existing simple analyses, more complex loads could now be analyzed for damage. The objective was to calculate the damage of a real torque and speed history (see Figure 2).
Consequently, the following input was required to generate the load:
1) Torque-time history
2) Speed-time history
3) Pitch of the force application on the Finite Element (FE) model

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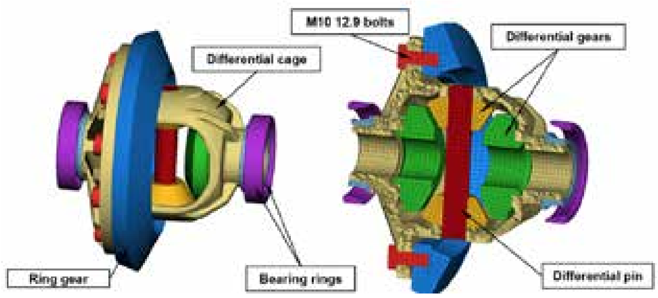

Fig. 3 - FE model of a differential cage

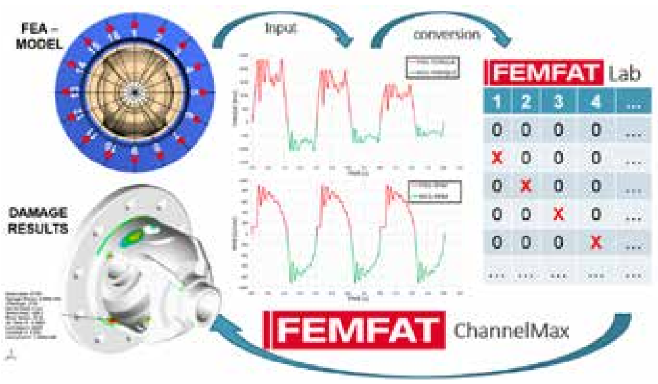

Fig. 4 - Overall process for the analysis of complex load-time signals

The output was a load-time history, in the form of a matrix, in which a scale-factor of the unit moment was generated for each position (1-16) at specific points in time. The overall process is shown in Figure 4.

Necessary steps for the generation of the input data:

1) Division of the torque-time history into positive and negative torque components. While this step is not absolutely necessary, it does increase the accuracy of the analysis by linearizing the contacts at the working point.
2) Normalization of both components using the unit moment from the Finite Element Analysis (FEA). In this case, the torque histories were scaled by a factor of 1/1000.
3) Because the direction (sign of the moment) of the backwards rotation was already included in the FEA, the neg. moment component was multiplied by -1.

The newly-created excitations (see Figure 5) provided the input for the FEMFAT LAB software, in combination with the torque-time history and the specification of the pitch.
The software then created the necessary matrices for the correct depiction of the scale factors for each position on the differential cage at the correct point in time, Tx. It must be mentioned that this method represents an approximate solution in certain areas because non-linear effects are taken into account by means of a working point. In our case, however, this has zero or a negligible effect on the fatigue analysis result. It is possible to minimize this error, however, for example by multiple subdivision of the load-time signal into several unit-moment levels (500, 1000, 1500,…).
With the process shown in Figure 4, it is now possible to analyse any type of measurement signal for its safety factor or for damage. The measurement signals need no processing and can be used directly for the damage analysis. This allows real measurement signals with several million sampling points to be used for the fatigue analysis. This is reflected in the duration of the calculation, of course. However, parallelization allows the calculation to be accelerated. Figure 6 shows the result of the fatigue life analysis.

Summary and outlook

This new and more precise method for damage analysis of rotating components represents a considerable improvement over the standard methods currently in use.

The very accurate analysis of the local damage can be used to create new test bench loads, for example. This method is fast, delivers more accurate local damage information and can be employed for all types of rotating components.
The ongoing development process will focus on making it even more accurate. Moreover, the degree of automation of the method will also be increased to reduce the overall turnaround time required for the process shown.

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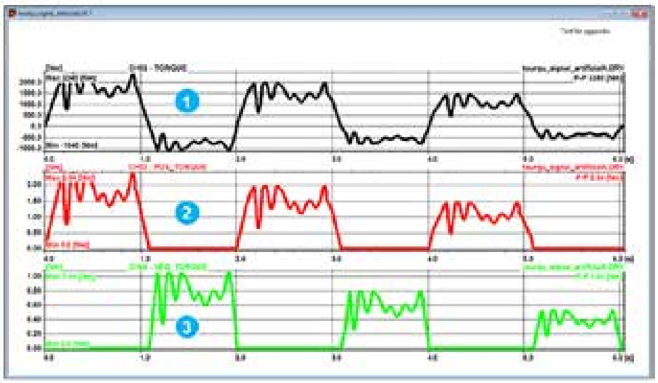
Fig. 5 - 1 Original torque, 2 Pos. component scaled 1/1000, 3 Neg. component scaled -1/1000

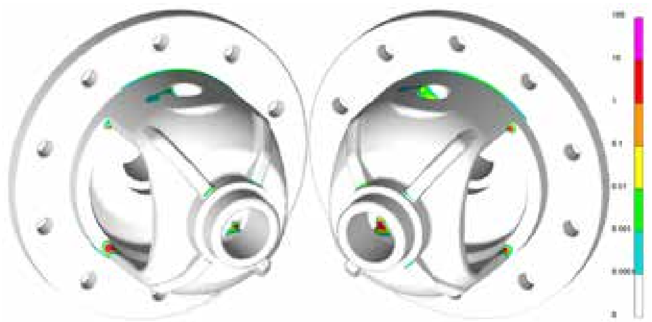
Fig. 6 - Normalized reference damage in [%]