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SIMPACK News

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Crankshaft Durability Analysis at BMW Motorrad

The effects of cyclical stresses and loading on the durability of components have become an important aspect for simulation engineers. SIMPACK, together with finite element and fatigue software, provides the simulation engineer with an accurate and efficient durability analysis solution when designing new components.

BMW Motorrad (motorcycle) division has been using this approach for the last two years, which has helped in the development process of the crankshaft for the K1200 S engine. It was necessary that calculations could be performed quickly, but not at the expense of accuracy.

The article details how BMW went about performing this analysis and the ways in which the process was optimised.

When performing calculations with combustion engines, the crankshaft is one of the most critically loaded components. Due to the gas forces in the combustion process and the inertia loads generated by additional masses, the crankshaft is subjected to millions of cycles of bending and torsion during its life cycle. A combination of different simulation techniques often shows the best results when solving these high frequency and dynamically demanding problems.

As the calculations have to be fast, but also must deliver reliable results, the simulation process shown (fig. 1, page 2) combines linear Finite Element Analysis (FEA) with non-linear Multi-Body Simulation (MBS) and Fatigue Software.

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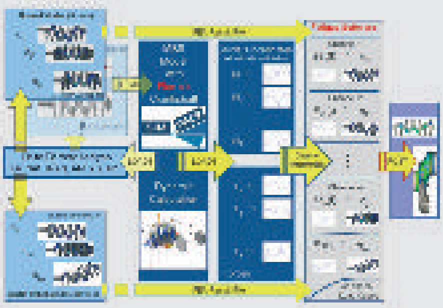

Fig. 1: Simulation Process - Durability Calculation

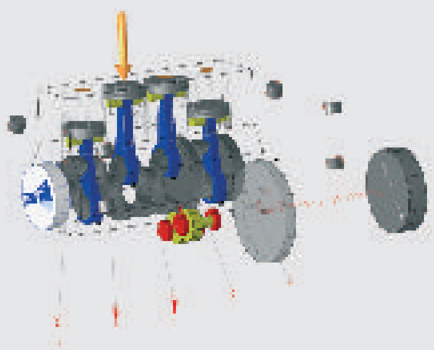

Fig. 2: SIMPACK MBS-Model of the Crankshaft Calculation

Fig. 3: FEM-Mesh of the K1200 S BMW Motorrad Crankshaft

The aim of the different simulations was to calculate the bearing forces, the torque generated by the crankshaft, the forces on the conrods and the inclination of the crankshaft. The durability of the crankshaft was calculated by coupling FE results with a Multi-Body Simulation.

The case study done by BMW Motorrad focused on the following aspects:

- Quality of FE-mesh (discretisation) of the crankshaft
- Comparing the FE-modelling techniques of Rigid-Body-Elements (RBE) in FEM, using RBE2 and RBE3 elements as connecting nodes for the bearings
- Comparing the FEM reduction methods (Guyan-reduction vs. Craig-Bampton-reduction)
- Increasing the number of eigenmodes
- Taking Frequency-Response-Modes (FRM) into account using SIMPACK FEMBS

This article only focuses on the effects the number of eigenmodes and Frequency-Response-Modes have on the accuracy of the durability results (safety factors).

The MBS model of the four cylinder in-line engine of the BMW K 1200 S (fig. 2) is mainly taken from a highly detailed engine database with fully parameterised models and sub-models provided by INTEC GmbH, with some enhancements according to BMW Motorrad's requirements. In this way it was easy to prepare different operating conditions for the simulations. For example, discrete revolutions per minute of the crankshaft and linear "Run Ups" have been simulated with this model.

The elastic body of the crankshaft acts through highly non-linear connections, considering inertia terms (e.g. gyroscopic effects), joint forces as well as external loads such as gas forces.

As the main focus of the case study was set on the modelling and modal settings/discretisation of the crankshaft, all parts of the model were rigid, except for the crankshaft. FE calculations were needed for two tasks.
The first was for the representation of the dynamics of flexible bodies in the MBS model. The FE mesh of the crankshaft (fig. 3), with a large number of degrees of freedom, was dynamically reduced by the FE solver. This reduced body was exported to SIMPACK and the structural deformation behaviour was characterised by eigenvectors.

The FE analysis was also required for modal stress calculations and therefore an appropriate discretisation and modelling of the crankshaft had to be done. As in the classical approach, the modal stress calculation requires a very large number of modes and therefore a longer computational time. In this process the stress calculations were divided in two sections, the Normal Modes and the Inertia Relief Modes.

The unique feature in this approach is that only the modes contributing to the relevant dynamic effects have to be taken into account. In general, this is a small number of eigenmodes, combined with some Inertia Relief Modes. The relevant Inertia Relief Modes are automatically defined by the MBS interface SIMPACK LOADS. The case studies on the K1200 S crankshaft show the influence on the results, via the safety factors, when taking different numbers of eigenmodes and Frequency-Response-Modes into account.

Based on the modal co-ordinates, which are the results of the MBS system analysis and the modal stress vectors, stresses are calculated from their linear combination. The superposition of the modal stresses and the durability analysis is performed with the durability software FEMFAT. In order to obtain the stresses, the modal stress vectors must be assigned to their corresponding time series.

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Each Inertia Relief stress vector must be assigned to its corresponding attachment force and each eigenmode stress vector must be assigned to its corresponding modal co-ordinate. The formalistic combination of dynamic loads and static stress results are done by SIMPACK LOADS Durability and the results are then given to fatigue software.

The superposition of torsional and bending stresses and the fatigue and durability predications are then done in FEMFAT.

In order to evaluate this process and find out the optimal settings BMW Motorrad performed an extensive case study.

First a reference solution had to be generated to which all other calculation cases were compared. There was no measurement data available from a real engine so the reference analysis had to be highly detailed.

The model consisted of a highly detailed FE-Mesh, particularly at the crankshaft fillets, with RBE3 couplings at each bearing- and connection-node. A flexible crankshaft with 300 eigenmodes calculated in FEM using NASTRAN was used. 130 eigenmodes and frequencies up to 35000 hz were taken into account for the Multi-Body Simulation. Furthermore additional Frequency-Response-Modes were defined in FEMBS for each coupling-node. This reference calculation was used for the main bearing forces, the pin orbital paths, the conrod forces and the results of the durability calculation. It was used to determine the safety factors for the fillets of the crankshaft at different locations and the modal co-ordinates of the eigenmodes and of the Frequency–Response–Modes. As already mentioned, only the results concerning the variation of the eigenmodes and Frequency-Response-Modes are described here. The reference solution contained a large number of eigenmodes.

The analyses were then performed with much fewer eigenmodes and these were gradually increased.

For the following calculations the discretisation of the FE mesh was left unchanged. As it can be seen from figures 4 and 5, only including a small number of eigenmodes had a detrimental effect on the results, shown here by safety factors at two different locations of the crankshaft.

As the number of eigenmodes was gradually increased it can be seen that a saturation point was reached in terms of result quality and it was no longer necessary to increase the number of eigenmodes.

The reference solution could, therefore, be easily achieved using much fewer eigenmodes compared to the reference solution.

As SIMPACK offers the user the possibility of taking Frequency–Response–Modes into account, the number of eigenmodes could be reduced even further. The Frequency–Response–Modes, which are calculated in SIMPACK FEMBS, are dependent upon the number of eigenmodes calculated in FEM.

It can be seen from figure 6, that even after a few tests a saturation point could be determined. The effects were tested on a crankshaft model, both with and without applying gas forces.

BMW Motorrad has managed to achieve an optimum balance of result accuracy and calculation performance for the analysis of flexible crankshafts by investigating how many eigen- and Frequency-Response-Modes are considered in the MBS model. BMW Motorrad is still working on ways to further improve both the FE and MBS modelling of the crankshaft.

This process has now been applied to a number of crankshaft models and has greatly assisted BMW Motorrad in reducing their development times.

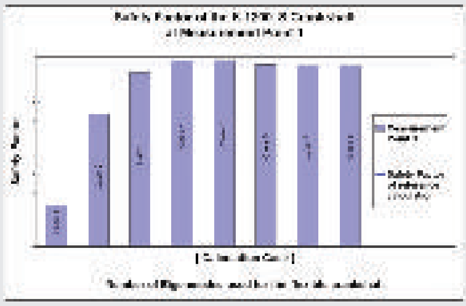

Fig. 4: Safety Factor at Location 1

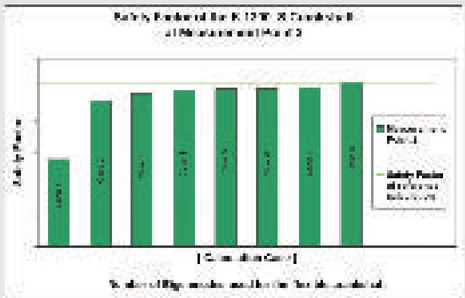

Fig. 5: Safety Factor at Location 2

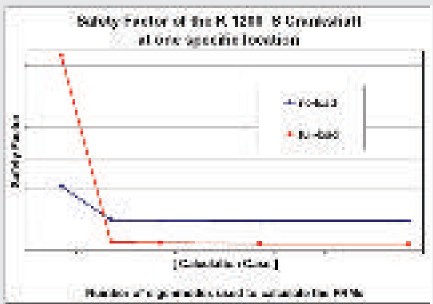

Fig. 6: Safety Factor