Ansys + KTM

At KTM, Statistics on Structures is used for the consideration of scattering production and material parameters to optimize the design phase of lightweight components used in the automotive and motorcycle industry.

Motivation

Due to their great weight-specific properties, fiber composite materials have been currently applied in a wide range of industries. Due to high costs, in the past, they were almost exclusively used in the aerospace industry. Now, various parts in the automotive and motorcycle industry are made of this material. By combining different fiber and matrix materials as well as by the creation of laminar structures with different layer orientations, it is possible to specifically influence the mechanical properties in order to produce very lightweight components.

Although there are a variety of different manufacturing processes, all these methods have a common aspect, which is that the final material properties are set up during production, whereby the process parameters have a decisive influence on this. Depending on the type of process, scattering might occur in the production procedure. In addition to geometry and angular errors of the individual layers, these include manufacturing errors such as waviness of the fiber bundles, fiber or resin accumulations, insufficient fiber impregnation or incomplete hardening. Depending on the quality of the manufacturing process, these features can be reduced, but not completely avoided. For this reason, it is important to know that the scattering should be taken into account in an appropriate manner during the design phase.

Based on an exemplary fiber composite structure from the motorcycle sector, a new approach using the Ansys software solution Statistics on Structure will be presented in this article to quantify these production scatterings and to directly transfer them back into the simulation. This opens up the possibility to consider scatterings locally in the simulation, which results in an advantage of light-weight quality compared to the application of global safety and reduction factors.

Front structure Rallye 450

The production of geometrically complex and intensely three-dimensional structures is demanding because of the limited draping capability of fiber semi-finished products. They potentially show increased production characteristics as already described. For this reason, the roadbook base carrier (RB-BC) shown in Fig. 1 was chosen as an application example for the evaluation of the developed scattering approach. In addition to carbon fibers, this base carrier also contains aramid fibers. Here, semi-finished products with woven fabrics of the type "twill 2/2" are applied.

The main function of this base carrier is the load-carrying of the IriTrack, a GPS emergency transmitter, as well as the connection of the light unit and the roadbook to the motorcycle frame structure. The roadbook is the paper-based navigation aid which contains all necessary direction and distance information. In addition, the panel (not shown in Fig. 1) is partly connected here.
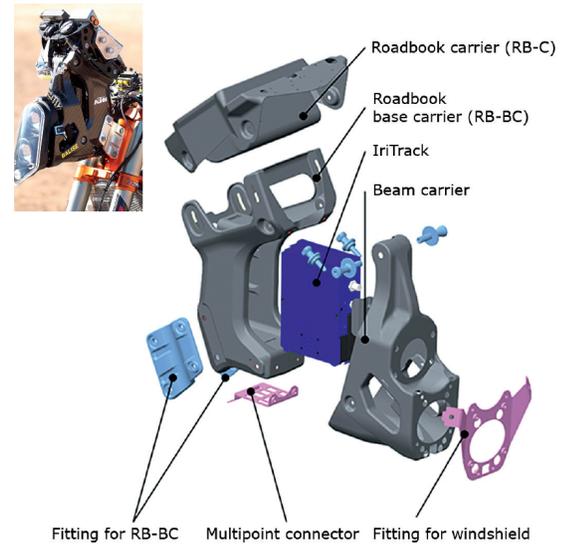

Figure 1. Front structure of the KTM Rally 450 motorcycle: assembly view with all functional components and fittings (left) and exploded drawing of the main structural components on the right.

Overview

In order to provide an overview of the procedure, all steps are initially sketched in an application example. As a starting point, the RB-BC is used with a predefined layer structure and relevant load cases are defined. They were also selected in such a way that they could be applied with a high measuring accuracy in the experiment. The evaluated stiffness loading conditions reflect the use of the RB-BC in practice, but represent only a part of the operating load cases used for the design. A pretest analysis using Statistics on Structures determines suitable measuring points with maximum information benefit of occurring scatterings.

The three test scenarios are again carried out on three RB-BCs that are identical but slightly scattering due to the manufacturing process. In each experiment, four measurement points determined by the pretest analysis are chosen, which are also easily accessible in the experimental design. The test procedure is repeated five times in each case in order to detect the measurement errors caused by the test facility. Thus, a total of 240 deformation values is considered. These measurement data are evaluated, applied to the simulation as reference points and used for the definition of target functions for a subsequent calibration. For the uncertainties that must be calibrated, the following parameters are introduced for the mapping of scattering properties into the simulation model:

- Layer orientation.

- Layer thickness.

- Material properties.

- Degradation fields for the detection of further scattering.

With the calibrated simulation models, robustness evaluations can then be conducted using the same parameters and conclusions can be derived from the results to improve the product quality.

Simulation of design load cases

The loading conditions in the component design are complex and include not only static stiffness and strength loads, but also dynamic crash loads for the consideration of specific falls and rollovers. Exemplary operating and maximum loads are shown at the top and on the bottom in Fig. 2.

Since it is too time-consuming to consider all design load cases for the evaluation of the scattering methodology, they were reduced to stiffness cases for the roadbook base carrier which is separately considered in order to eliminate the effects of the surrounding components (and their scattering) on the results.

Simulation of test loads

Fig. 3 shows the defined simulation load cases for the RB-BC. On the one hand, these were selected in a way that they still represent the original test load scenario and, on the other hand, to ensure the experiment is conducted with as little measurement scatter as possible. They represent the essential stiffness, which can be described in the subsequent measurements by means of displacements at defined points. The modeling of the object-oriented layer structure is strictly conducted within Ansys Composite Prepost according to manufacturing instructions, which are summarized in the so-called plybook. The orientation is regulated by the adjustment of several coordinate systems, thus allowing a fast variation of the fiber orientations.

Figure 2. Exemplary samples of load cases for component design — maximum load impact upper body on roadbook (top), operating load while jumping (bottom).

The roadbook base carrier, which is meshed with shell elements, is joined with the load application elements via a modular building block system. Here, a consistent meshing is ensured, avoiding undesired effects from mesh noise (i.e. the influence of the mesh on the results) and spares the necessity of mapping routines for the uniform display of results in the later field statistics. The avoidance or minimization of such numerical effects is important in order to clearly separate and describe the investigated physical scatterings.

The connection of the roadbook base carrier with the fittings is represented by bonded contacts and non-linear contacts. Here again, the numerical effects have to be kept small. Thus, a study is carried out with regard to minimized tolerances in the contact regions. The weights used in the experiment are represented by mass points, which are symbolically depicted as spheres in Fig. 3. In order to calibrate the simulation model and to carry out robustness evaluations subsequently, a corresponding variability is introduced to the simulation models. For example, the modulus of elasticity, the shear model as well as the layer thickness and orientation can be changed via parameter lists. Further variability is integrated by degradation fields which still will be described more detailed.
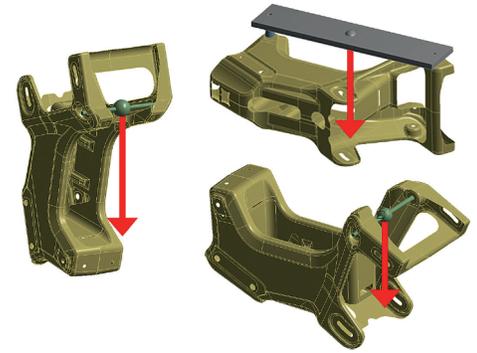

Figure 3. Simulation setup of the three test load cases 1, 2 and 3. The areas of the support (red) as well as the point masses for the representation of the weight force are shown.
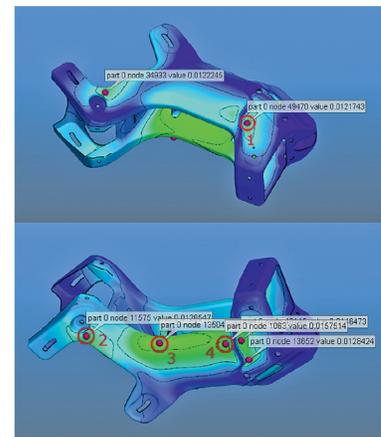
/ Pretest analysis and experimental procedure

The test procedure can be summarized in three main steps:

1. Tolerance analysis in order to determine the manufacturing accuracy of the fittings.

2. Pretest analysis to predict the locations for the most meaningful measurement points.

3. Repeated test runs for the three load cases for detecting the deformations and the inaccuracies occurring during the measurement.

A tolerance analysis is carried out first in order to avoid a situation in which the deformations measured in the test are not dominated by the deviations in the manufacturing process, but mainly by insufficiently tolerated fittings. The results are taken into account in the manufacturing of the fittings. For clamping the roadbook base carrier, a U-profile is manufactured in two parts in order to prevent tensions during the mounting of the specimen. Thus, non-parallel fitting points on the specimen can be compensated. Pretest analyses are conducted afterwards. Here, scattering is applied to the still not calibrated simulation model, variation calculations are carried out, and average values, standard deviations and variation coefficients are evaluated by superimposing the field results. The variation coefficients indicate information about the correlation between experiment and simulation.

Figure 4. Most meaningful measuring points for load case 2 determined with a pretest analysis.

Therefore, the dial gauges are not placed at the locations of the maximum deflection but at the places of the presumed greatest variation of deformations. Fig. 4 shows the result of such an analysis. Suitable measuring points are determined by a hot spot detection. The red marked spots are selected for the measurement, considering the necessity of an easy accessibility in the experiment.

Fig. 5 shows the setup of the experiments. The specimen is clamped in the required positions and loaded with a weight. Under these conditions, five measurements are carried out at four measuring points for each load case and RB-BC. Although the tests are conducted in an extremely careful manner, ex-perimentally induced scattering cannot be avoided completely. Reasons can be found in varying zero adjustments of the dial gauges, in different preloading forces, in deviating positioning of the dial gauges as well as in other environmental influences.

/ Use of field statistics to describe scattering

As already mentioned, the simulation model representing the experiments contains variables in order to investigate and to evaluate the scatterings. Also, the mentioned effects, such as manufacturing errors, fiber waviness of the bundles, fiber or resin accumulations, insufficient fiber impregnation as well as incomplete hardening can only be represented with an extremely high amount of calculation time. This makes the procedure economically inefficient. However, what they all have in common is that they cause a change of the local material properties. For this reason, degradation fields are introduced in Ansys at this point, i.e. overlapping fields which can change the implemented material properties at any location by a definable factor. Because of such a factor can be assigned to each FE element, a conventional parameter calibration would no longer be possible due to the extremely high amount of resulting parameters. It can also be assumed that the scaling factors locally correlate. For this reason, random fields are introduced for representing the degradation. By means of an eigenvalue decomposition, the fields can be described via basic functions (scatter shapes) and amplitudes. Thus, the large number of random variables in the whole field can be reduced to a small number of random amplitudes. The field can be re-assembled by multiplying the basic functions with the amplitudes and a subsequent summing up of these terms.
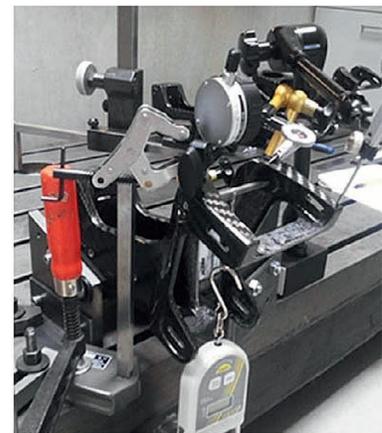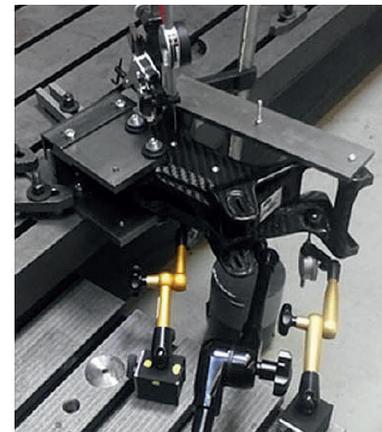

Figure 5: Experimental setup for load cases 1, 2 and 3 carried out at the Chair of Engineering Design (KTmfk) at Friedrich-Alexander-University Erlangen-Nuremberg.

Fig. 6 shows three of a total of 100 artificially created degradation fields. The prognoses regarding the areas are based on the experience of CFRP manufacturing and CFRP experts at the OEM. By a different scaling of the scatter shapes, new fields can be created very quickly, which finally allows a calibration of the prognoses for the degradation locations with regard to the experiments.

By using random fields for the creation of degradation fields, their descriptiveness contributes to the understanding of the functional correlation between the location of the degradation and the resulting influences on stiffness at different locations of the RB-BC. In other words, the visualization of the most influential scatter shapes helps to understand at which locations production-induced material weaknesses have a great influence on product properties.

Figure. 6: Three exemplary artificially created degradation fields.

/ Calibration of the simulations to the test results

The following parameters are now available for the calibration of the simulations to the test results:

Tolerance analysis in order to determine the manufacturing accuracy of the fittings:

- Material properties (elasticity modulus transversely directed or in fiber direction, shear modulus).

- Layer thickness.

- Layer orientations.

- Amplitudes of the scatter shapes for describing the degradation fields (representing of further effects as already mentioned).

In order to calibrate the simulation results to the test results, optimizations are carried out for each roadbook base carrier. The aim is to minimize the deviation simultaneously at all 12 measuring points. The 12 terms of the target function are weighted with regard to the reference value of the respective measurements. The still very large number of parameters to be calibrated (> 50) would lead to a high amount of calculation runs. For this reason, in advance, sensitivity studies are performed in order to separate the unimportant from the important parameters and to eliminate them in the subsequent optimizations. The use of 12 measuring points in the target function increases the probability of a clear result.
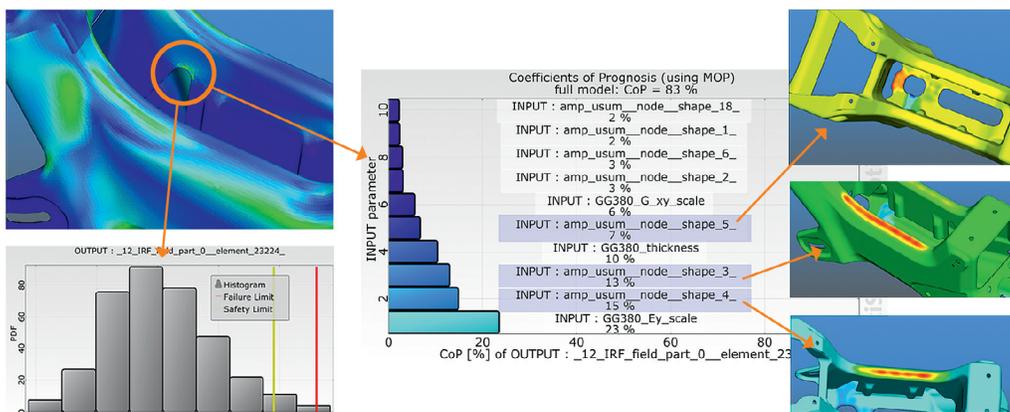

Figure. 7: Scatter influences on a specific failure point — distribution curve of the failure criterion, influence on the most important input scatterings, translation of the most important amplitudes into degradation regions (for illustrative purposes).

/ Conclusion

Now there are answers to several important questions:

- Which parameters must be set to represent the current behavior of the RB-BC?

- Which parameters influence which type of stiffness to what extent?

- How accurately can the correlation between the input parameters and the stiffness be described?

Answering these questions is necessary for a meaningful robustness evaluation and target-oriented optimization. Scattering is now applied to the calibrated scalar parameters and degradation fields. With more than 100 calculations, the scatter of the stiffness, the failure criteria and other properties can be estimated. Even more important is the capability to identify the influence of the input variables on the stated output variables.

Thus, after the robustness evaluation, targeted measures can be executed at the locations with the greatest amount of influences — either manually via reinforcements or by means of design changes as well as by optimizing the already defined parameters, for example, the orientation of the layers. Fig. 7 shows the influence of the main scattering input parameters on a critical failure spot. Such information can be noted in plybooks to be considered in future production in order to minimize the failure probability of the roadbook base carrier by means of target-oriented and locally specified improvements in production processes.

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