Ansys

CASE STUDY /

Ansys + Siemens

Ansys

CASE STUDY

SIEMENS AG applies Ansys, Statistics on Structures and Ansys optiSLang for probabilistic analyses of geometric variations and their influence on the fatigue behavior of a gas turbine housing.

/ Motivation

SIEMENS AG manufactures large scale gas turbines for power generation, e.g., the gas turbine SGT5-8000H with 400 MW or CCPP up to 600 MW. The title image shows such a turbine during its assembly. These gas turbines are known for their high efficiency (GT with 40% and GUD even more than 60%). Customers look for power generation units, which are efficient, reliable, available, flexible and cost-effective. The competition with renewable energies imposes strong goals onto power plants to improve the cost effectiveness of their turbines. Technically, this leads to the questions if one can redefine the magnitude of safety factors and lifetime, change maintenance instructions, increase check intervals, or simply find new technical solutions. In any way, the optimization of designs and maintenance cycles will continue towards the limits of product performance. Safety factors are typically applied to material properties (e.g., scatter of properties, distribution in space, scatter in fatigue curve), boundary conditions (e.g., loading, environment parameters, operational parameters) and geometric variations (e.g., manufacturing tolerances). The interaction of these parameters, however, can only be considered by a probabilistic approach.

This article presents a strategy for the probabilistic analysis of geometric variations and their influence on the fatigue behavior of a gas turbine housing. The task is to quantify the influence of the geometric scatter onto stresses and lifetime. This can be done by estimating statistical properties and translating them into failure probabilities. The knowledge can help to adjust safety factors and the duration between maintenance actions or can improve the quality control for manufacturing tolerances.

The workflow of the analyses starts with obtaining knowledge on the real geometric deviations with respect to the target CAD geometry after production. An accurate measurement of the true surface can be done through laser scans. Scans of multiple designs are used to create a statistical model for the geometric variations. Subsequently, the model is capable of generating new virtual random geometries. These serve as input in a CAE analysis. A Monte Carlo-like sampling can be finally used to predict the statistical properties of response quantities, such as stress or durability factors.

/ Workflow Steps

1. Measurements

The generation of the surface laser scans is the first challenge because of the housing size of 4.9 m in diameter, 13.1 m in length and 390 t in weight. Current scanning technology creates large data volumes (more than 1 GB data to store the triangulation of one 180° scan). Several scanner positions are required due to the size of the object. The photogrammetric system GOM Tripod in combination with GOM ATOS Triple Scan was used to support these measurements (Fig. 1).

The possible time to scan the turbine is limited between production and preparation of delivery. Therefore, for some turbine housings only parts of the surface could be scanned. Due to the complex shape of the geometry, also some parts are not accessible by scanning devices. Thus, the triangulation must be edited afterwards, i.e., repair meshes, de-feature, fill holes, remove outliers, reduce number of triangles (see post processing in Fig. 2). The long delivery lead times also cause that only a few turbine housings could be measured within an acceptable project time. Therefore, a very small number of samples is typically available. By taking the symmetry of the geometry into account, a larger number of samples can be obtained virtually.

Figure 1. Measurement of true geometry using laser scans.

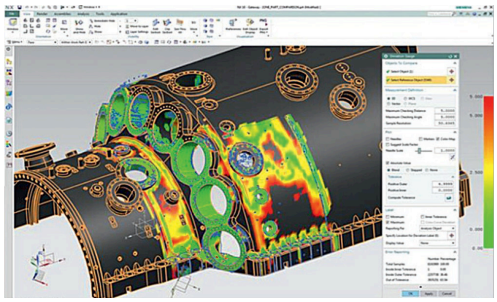

Figure 2. Post processing of laser scan data in SIEMENS NX.

2. Statistical Model of Geometric Tolerances

New random virtual geometries are created in the robust-ness analysis. Using optiSLang, statistical properties (e.g. distribution type, mean value, standard deviation, correlations) are typically assigned to a small set of parameters. The software uses this information to vary the input parameters according to the pre-defined scheme. The statistical properties must be obtained from the analysis of the laser scans. In this project, a random field model ("statistical shape model") was chosen to represent the geometric variations (Figure 3). Here, statistical properties are associated to each point on the housing boundary. This is very different from approaches that try to find a statistical description of CAD parameters. The random field model allows a greater accuracy in the spatial distribution of the variation patterns, because it is tied to the FEM nodes and not to just a few parameters. The parameterization can be automatically obtained by an analysis of the measurements.

First, the measurements are imported to SoS by mapping the measurements (given through STL files defining the boundary) onto the surface of the undeformed FEM mesh. SoS automatically determines the geometric deviation (measured perpendicular to the surface) for each FEM node between each measurement and the reference geometry. A subsequent step is the conduction of a statistical analysis. For each FEM node, the mean deviation and the magnitude of the variation around the mean (= standard deviation) can be determined. A first indication can be derived from this analysis at which locations a large deviation from the CAD geometry can be expected (from checking the mean value) and at which locations a large variation is obtained due to the natural variations in the production process (standard deviation), as shown in Figure 4. Interestingly, these locations are different in our project. If more samples had been available, we would have extended the SoS analysis to search critical locations through quantile values and exceedance probabilities. Anyhow, the analysis can help to investigate the statistics more deeply in the context of quality control.

The next step is the creation of a statistical model for the geometric deviation. The random field model basically consists of "variation patterns" or "scatter shapes". With a pre-defined sufficiently large set of samples (e.g. 80), SoS first analyzes the data for correlated variation patterns (Fig. 5). Once being identified, SoS can represent each measurement by a series expansion, where each variation shape is scaled by some coefficient and added to the mean value. Typically, only a few variation patterns (5-10) are sufficient to represent the original measurements with high accuracy.

In this project, only a very small number of measurements was available. Therefore, the variation patterns were created using analytical functions based on certain engineering assumptions (e.g. correlation length parameters). Nevertheless, the obtained model is accurate enough to represent the mean value and standard deviation for each FEM node as seen in the measurements. In SoS, this is called a "synthetic random field model".

The statistical shape model is not created for the whole boundary. Although non-zero deviations were found for all boundary locations in the measurements, the generation of geometric deviations must be restricted to surface patches. Some surface parts are machined after molding, for example, holes are drilled and grinded to attach other structures, such as screws. Further, some surface parts must not be varied to ensure numerical stability of the CAE model, e.g., contact boundaries. The geometric parts subject to variation are shown in Figure 6.

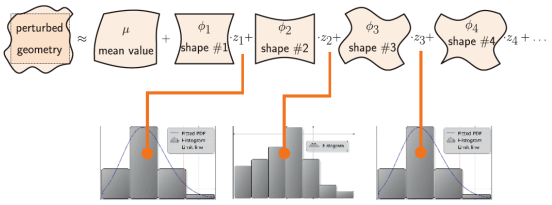

Figure 3. Statistical shape model (Random field) to include geometric scatter in SoS.

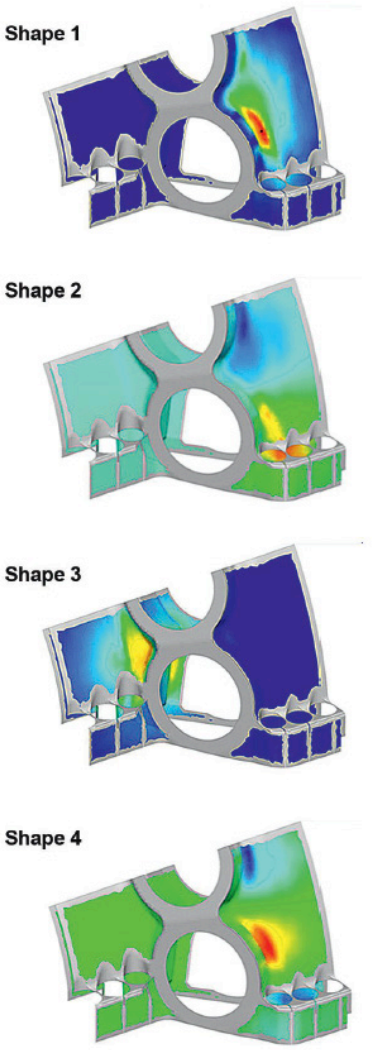

Figure 5. Statistical shape model (random field) of important variation patterns.

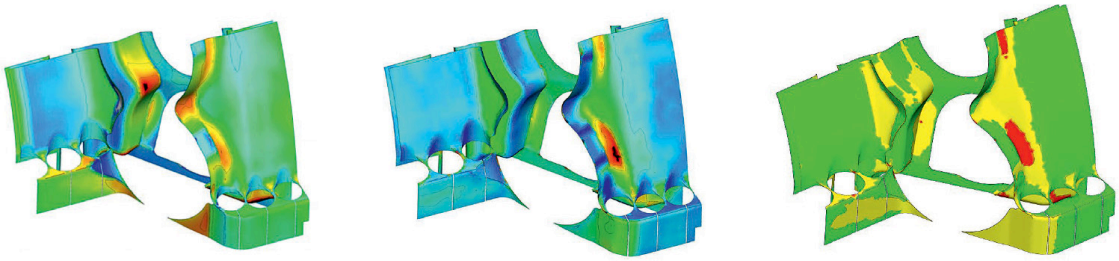

Figure 4. Statistical analysis of the measured geometric tolerances. Left: mean deviation, Center: standard deviation of geometric scatter, Right: Tolerance analysis based on 3-sigma level (yellow and red are critical locations).

3. Numerical Model

The numerical model was mainly generated in Ansys Workbench. Here, a semi analytic thermal model was implemented for the gas flow to be coupled with a transient thermo-mechanical model for the prediction of the spatial distribution of temperature and stresses. Subsequently, a low cycle fatigue (LCF) analysis was carried out with SIEMENS GT internal software. The 3D FEM model includes bolting contacts and a thermal transient defining the time-dependent loading conditions.

The original mechanical model for the 90° housing part consist of 840k nodes and 380k elements. The total computing time for a single design requires more than 30 GB disk space and approximately three days on a medium HPC hardware. Therefore, the run of e.g. 100 samples in a simple Design of Experiments of a robustness analysis is not feasible within project time.

To improve the time and storage demands, only one sub-model was considered with remaining 240k nodes and 270k finite elements (Figure. 7). The hardware demands could be reduced to 7 GB disk space and 2 hours per sample.

The numerical model was created using the CAD geometry model. Once there is an FEM mesh available, the statistical shape model can be built. The geometric changes are not applied to the CAD model, but to the coordinates of the FEM nodes. SoS does not change or re-mesh the FEM mesh, instead, it “morphs” the FEM nodes to their desired positions.

Before the Ansys Workbench model will be evaluated by optiSLang, SoS prepares APDL macros in the Ansys Workbench model folder for instructing Ansys Mechanical how to change the geometry. SoS further uses advanced stabilization and smoothening algorithms, which ensure the stability and computability of the changed FEM mesh. Before doing the robustness analysis, a test run of the solver chain is done using the mean value geometry.

4. Robustness analysis and results

The goal of the robustness analysis is to answer the following questions:

- Is there a difference in stress distribution or endurance factors between a “true” geometry and the reference geometry?
- Is there a significant influence onto stress and endurance factor if the geometric scatter is considered? How large is the influence?

The first question can be answered by transferring each measurement into the CAE model or, simply, by computing the mean geometry. The second question requires a stochastic tolerance analysis. Here, a Design of Experiments (DOE) is virtually created and evaluated. The workflow is illustrated in Figure 8. This involves a variation of the random field parameters according to their statistical distributions. SoS simplifies the choice by assuming uncorrelated standard-normal variables.

The results of the CAE analysis (temperature, stresses, endurance factor, etc.) can either be analyzed in optiSLang (e.g. by their maximum values) or in SoS. For this, the Ansys RST files are reevaluated by SoS. A statistical analysis can now be conducted for the result quantities (Fig. 9/10). The stresses can be compared, for example, with critical limits for different safety levels (exceedance probabilities). Further, the location of possible critical stresses can be easily identified.

A failure probability was not analysed in this project, because the accuracy of the statistical model is not sufficient due to the small number of measurements. Further, a sensitivity analysis can be conducted with the Field Metamodel of Optimal Prognosis (FMOP). The FMOP associates the sensitivity of the stresses or temperatures to each FEM node for the respective input parameters (Fig. 11). In this analysis, each input parameter represents a certain variation pattern. This indicates which geometric variation shape is relevant for the temperature or stress at critical locations. The result further justifies the quality criteria to geometric tolerances in production to the respective variation shapes.

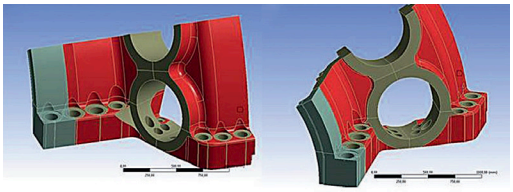

Figure 6. Red: Surface parts to be varied, Gray: machined surface parts (fixed).

Figure 7. Submodel of turbine housing.

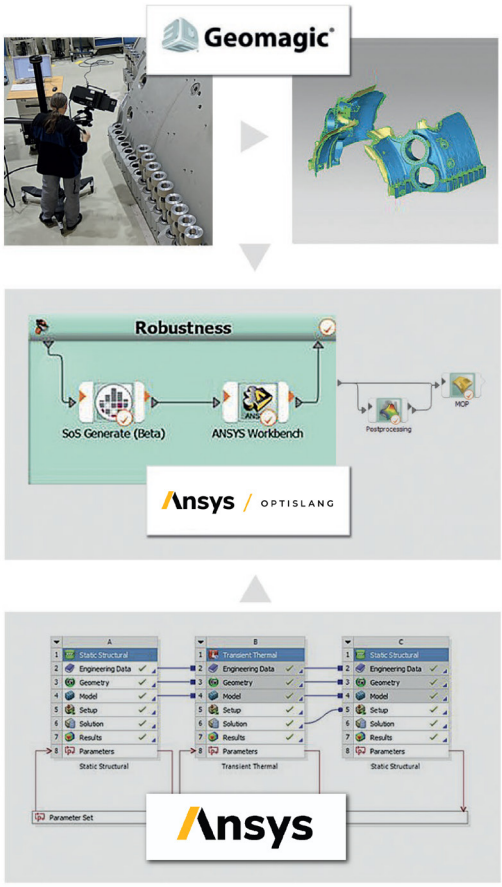

Figure 8. Workflow of the analysis.

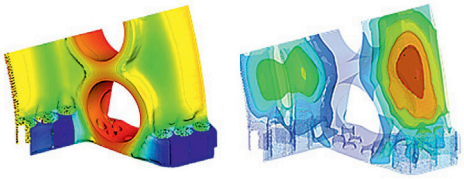

Figure 9. Statistical analysis of resulting temperature field – mean value (left), standard deviation (right).

/ Software and Methodology

List of applied software and their particular functions:

Ansys optiSLang

- Management and automation of the workflow.
- Generation of random parameter values and DOE.
- Analyses of scalar responses.

Ansys

- Generation of the thermo-mechanical model.

Siemens GT

- Low cycle fatigue solver.

Statistics on Structures

- Statistical analyses of the measurements.
- Generation of new random geometries and transfer into the CAE process.
- Statistical analyses of the FEM results in 3D.
- Sensitivity analysis of FEM results with FMOP in 3D.

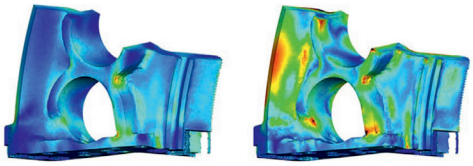

Figure 10. Statistical analysis of resulting von Mises stress field – mean value (left), standard deviation (right).

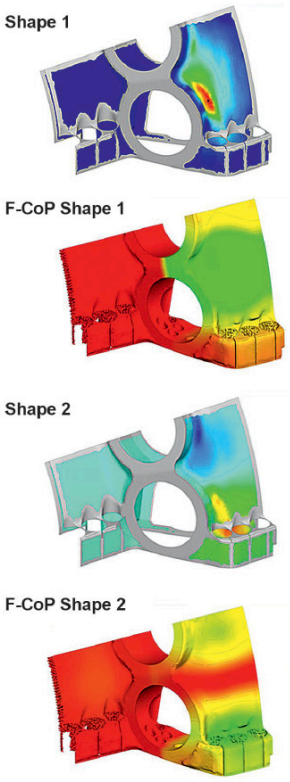

Figure 11. Sensitivity analysis of temperature field with FMOP – Most dominant geometric variation patterns being responsible for changes in temperature with the corresponding sensitivity (F-CoP) of temperature with respect to the geometric variation patterns.

/ Authors

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"Investigation of low cycle fatigue on large gas turbine casings under consideration of geometric tolerances", U. Lohse, B. Voss, Th. Lowitz (Siemens AG Large Gas Turbines), H. Schulze Spüntrup (ITB Dortmund), S. Wolff Ansys; presented at the Weimar Optimization and Stochastic Days, June 1-2, 2017

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