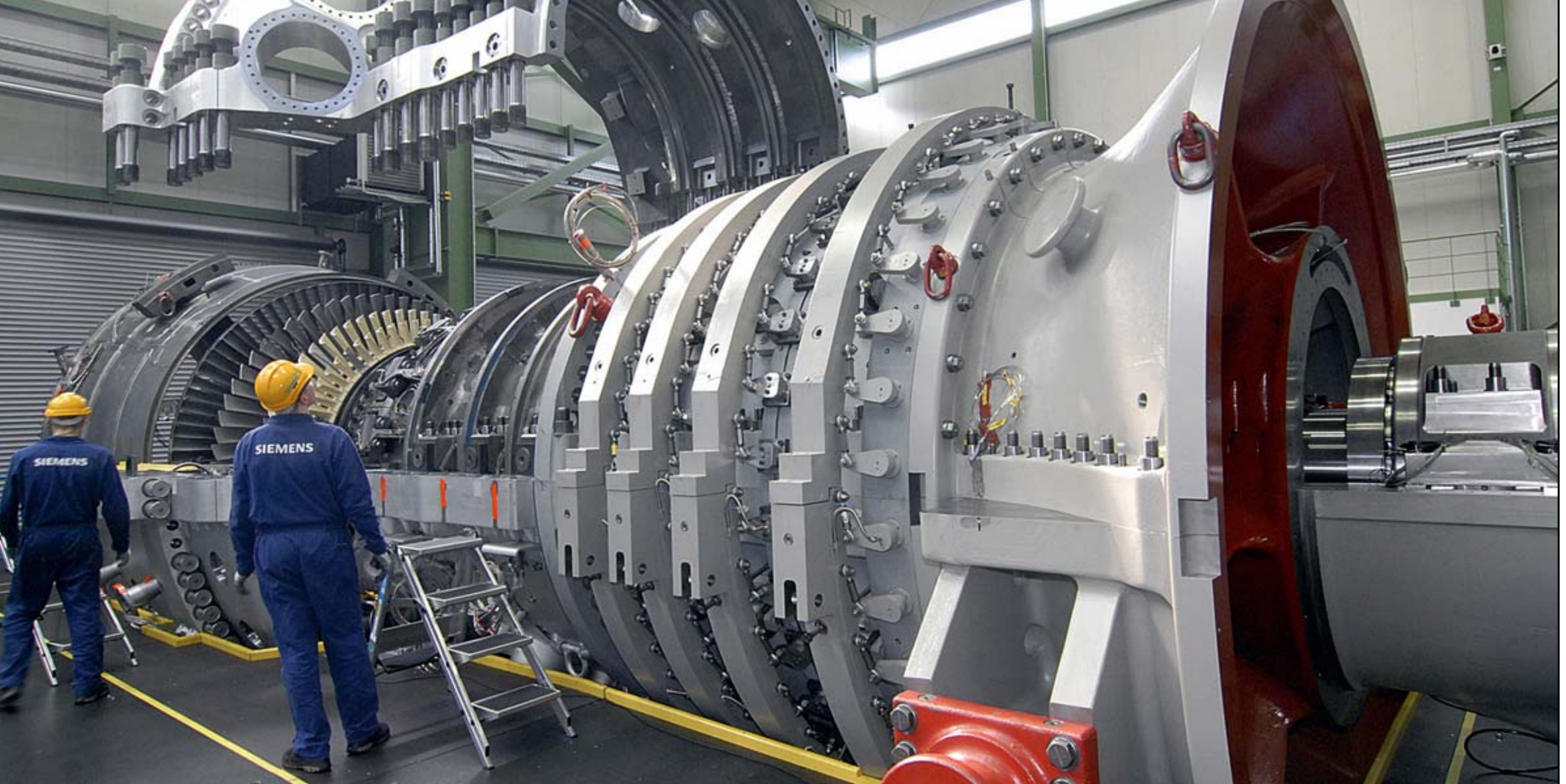

COSTUMER STORY **//** TURBO MACHINERY

FEASIBILITY STUDY OF LARGE GAS TURBINE OUTER CASING BOLTS

Potential improvements are identified with the help of optiSLang for optimizing outer casing bolts of large gas turbines regarding life and cost requirements.

Introduction

The bolted connections at the outer casing of large gas turbines are critical regarding life and cost. One critical feature is the difference in temperature between bolt and flange during transient start-up and shut-down. This can cause, in combination with a hydraulic tensioning pretension close to the yield strength, an overstretching of the bolts. An overstretching causes a loss of pretension and reduces the clamping force at the flanges. Reduced clamping force can cause leakage and requires an expensive seal.

This feasibility study shows the development of a heat transfer model. The heat transfer values are fitted from different site measurement on actual casings in operation. Further, the influence of the manufacturing, tolerances as well as the variation of the heat transfer value caused by different bolt positions or bolt-flange geometries, are studied regarding the robustness of the result and temperature difference.

Finally, the hurdles and potential improvements are identified with the help of the software optiSLang for further use on gas turbine projects.

In order to produce work shaft output, a gas turbine compresses air and adds fuel, which expands after ignition and drives the turbine.

These steps come along with a high temperature gradient of the working gas and all the components involved. These gradients again are the main reason for stresses and thereby crucial for the lifetime of the whole assembly.

During transient start-up and shut-down, temperature gradients also occur in radial direction, especially in the split plane where the rather thin top and bottom housing are bolted together through thick flanges. The small contact area between bolt head and flange causes a slow conduction of the heat into the bolt and an even higher temperature difference between those two parts. This temperature difference is directly proportional to the low cycle fatigue of the bolt. Even an overstretching of the bolts is possible in combination with a bolt pretension close to the yield strength. Overstretched bolts lead to a reduced clamping force which can result in leakage. To prevent this leakage, a relatively expensive seal is placed between the flanges.

The long-term aim is to minimize fatigue, reduce maintenance costs, and maybe even completely remove the necessity for the seal.

This feasibility study shows the development of an appropriate model fulfilling these requirements. The parameters of the heat transfer were fitted from different site measurements on actual casings in operation. Finally, the influence of the manufacturing, tolerances as well as heat transfer value variation caused by different bolt positions or bolt-flange geometries, were studied regarding robustness of the result and temperature difference (Fig. 1).

Numerical Model

An FE-model was developed to study the general behavior of the bolted connection. Taking advantage of symmetries, only the upper housing and half a bolt were modeled (Fig. 2), while the bolt was fully parametric (Fig. 3, see next page).

The heat transfer coefficients (HTC) at the contacts between bolt, washer, nut and flange are essential for the resulting temperatures. Since there is no easy way to obtain exact values these parameter have been just estimated usually. In order to consider this uncertainty, the HTC was also parameterized for each contact (Fig. 4, see next page).

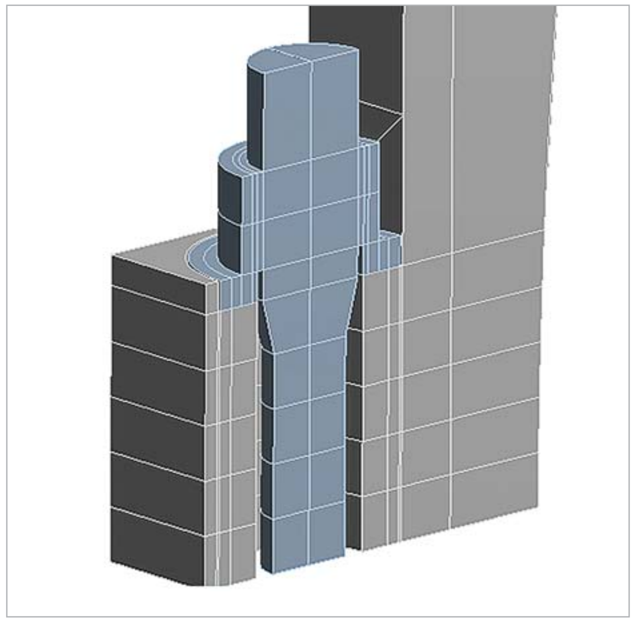

Fig. 2: Overview of the geometry

In general, parameterization of all input data of the model is possible. However, different effort is necessary. Accessing some of the parameters was made possible by using scripts utilizing the Ansys Parametric Design Language (APDL) which allows in-depth access to every detail of the setup (Fig. 5, see next page).

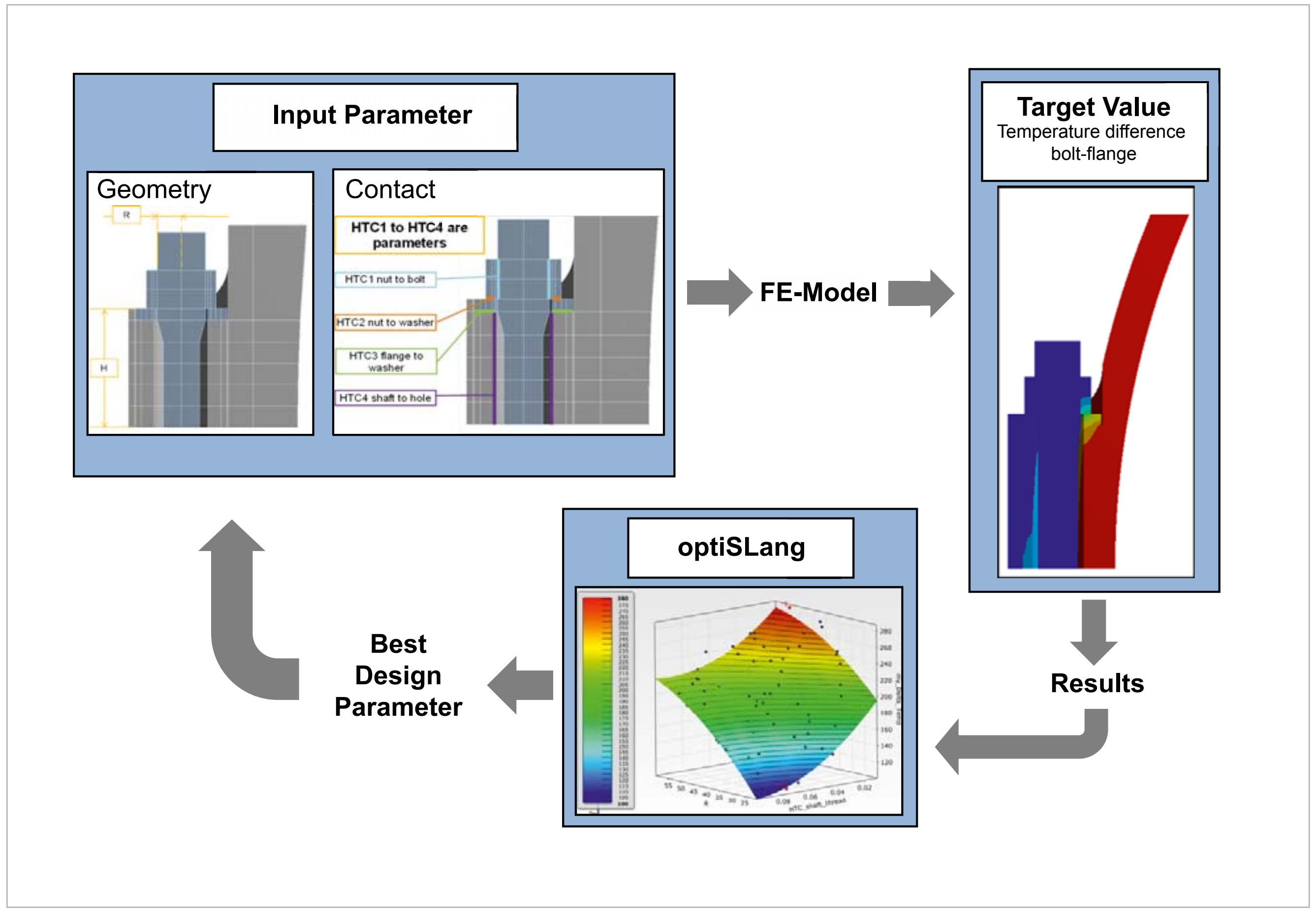

Fig. 1: Workflow

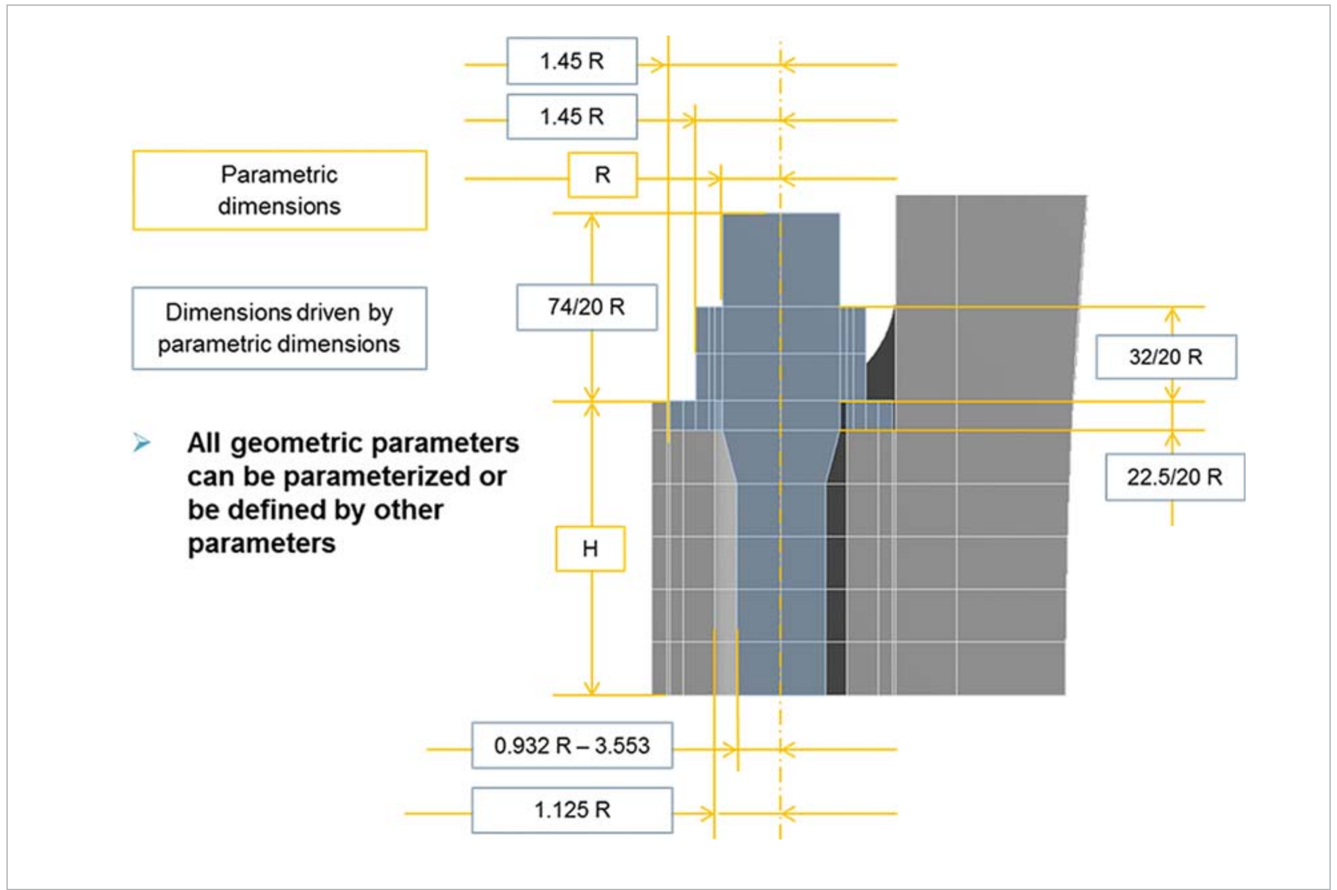

Fig. 3: Parameterization of the geometry

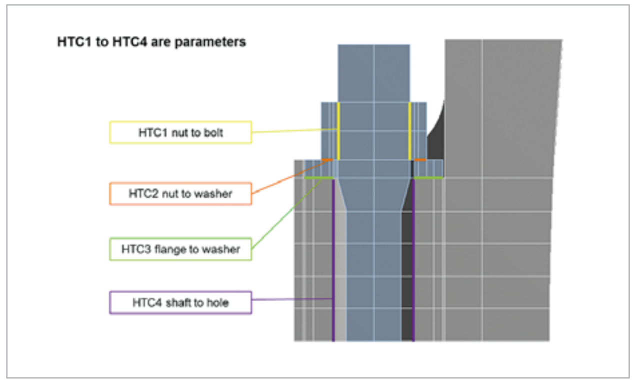

Fig. 4: Definition of heat transfer coefficients

Action	Geometry	Contact Properties	Boundary conditions	Material properties
Values Constant	🟢	🟡	🟢	🟢
Values to depend on temperature	-	🔴	-	🔴
Values to depend on time	-	🔴	🔴	🔴

Fig. 5: Effort for parameterization of certain properties | 🟢 Workbench function, low effort | 🟡 Small APDL commands, low effort | 🔴 APDL commands, high effort

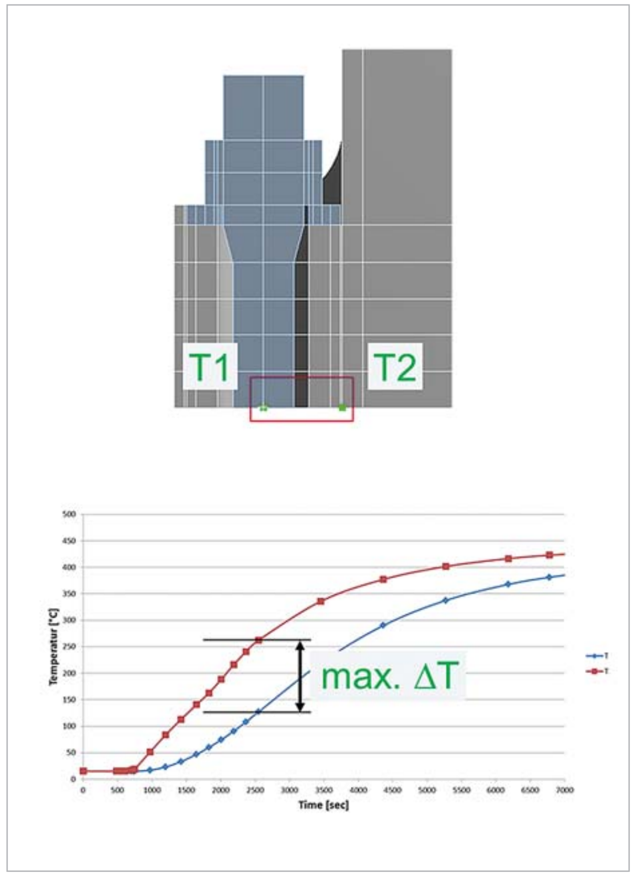

Fig. 7: Definition of the temperature difference

No.	Description	Variable	Range Minimum	Range Maximum	Unit
1	radius	R	20	60	mm
2	flange-height	H	100	400	mm
3	HTC bolt to nut	HTC_bolt_nut	1 000	50 000	W/m² C
4	HTC nut to flange	HTC_nut_flange	1 000	50 000	W/m² C
5	HTC washer to flange	HTC_washer_flange	1 000	50 000	W/m² C
6	HTC shaft to hole	HTC_shaft thread	10	50 000	W/m² C
7	thermal conductivity bolt material	lambda_bolt	25	40	W/mK
8	thermal conductivity flange material	lambda_flange	28	35	W/mK
9	specific heat bolt / flange material	sp_heat_flange	500	600	J/kgK

Fig. 6: Example for parameter ranges for the optimization

All resulting input parameters are shown in Fig. 6. While there are only two geometric variables (bolt radius R and flange height H), the majority of the variables includes the material properties of the parts (thermal conductivity and specific heat) and only roughly known boundary conditions (HTC between parts). Especially the HTC values are usually taken from literature and are often a point of discussion.

Output parameter

Due to similar thermal expansion factors of bolt and flange material, the overall best behavior is expected when there is no temperature difference between these parts. This leads to the target of the optimization to minimize the temperature difference. The difference is simply calculated by subtracting two temperature probes at the bolt and flange (Fig. 7). Since the simulation is transient, at each probe the temperature varies over time resulting in a time dependent temperature difference where the maximum Tmax over all time steps has to be identified. This can be done by utilizing an ANSYS APDL macro or using Dynardo's Extraction Tool Kit (ETK).

Results

For this model, a DOE was created and a sensitivity analysis was performed. As a matter of fact, a Latin Hypercube Sampling (LHS) of 100 samples was already sufficient to achieve a Coefficient of Prognosis (CoP) of 99% for the most important response value. The three parameters with the highest impact on the temperature difference are the bolt radius, the HTC between the bolt's shaft and the bore hole as well as the height of the flange (Fig. 8). The other parameters have a negligible influence on the variation of the results and were automatically filtered by optiSLang MOP algorithm. The correlations turned out to be rather trivial, which is obvious and was expected before. With a small bolt radius R and a high HTC between bolt shaft and bore hole, the temperature difference (my_Delta_Temp) between both parts is small and vice versa (Fig. 9, next page).

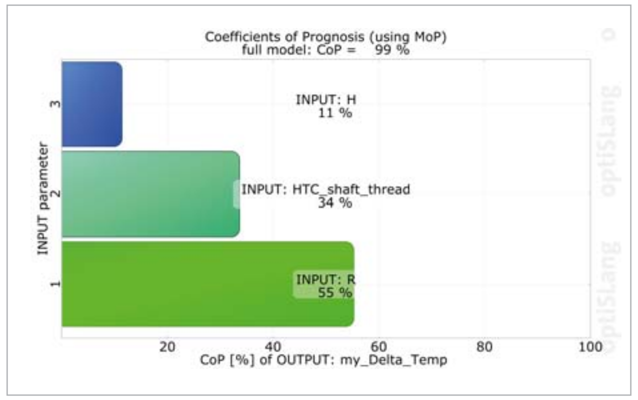

Fig. 8: Coefficient of Prognosis

Calibration of the HTC Value

While the height of the flange and the bolt radius are geometric constants which can easily be measured, fitting the HTC4 shaft-thread (Fig. 10, see next page) value was a challenge.

In this case, the input parameter HTC4 shaft-thread is actually the heat conductivity of a contact without any stiffness, connecting the bore hole through the air to the bolt's shaft. This single parametric conductivity is supposed to replace the whole system of the two HTC, i.e. from the flange to air respectively from the bolt to air as well as the thermal conductivity of the air itself. This problem would usually require a full fluid simulation. To find an appropriate value within the thermal transient environment, the model was fitted to actual measurements of the bolt temperature.

Therefore, the start-up time, where the highest temperature gradients are expected to occur, was divided into several sections, each with its own parametric HTC (Fig. 11, see next page). These values were then fitted by matching the resulting temperatures at the bolt with the corresponding measured temperatures.

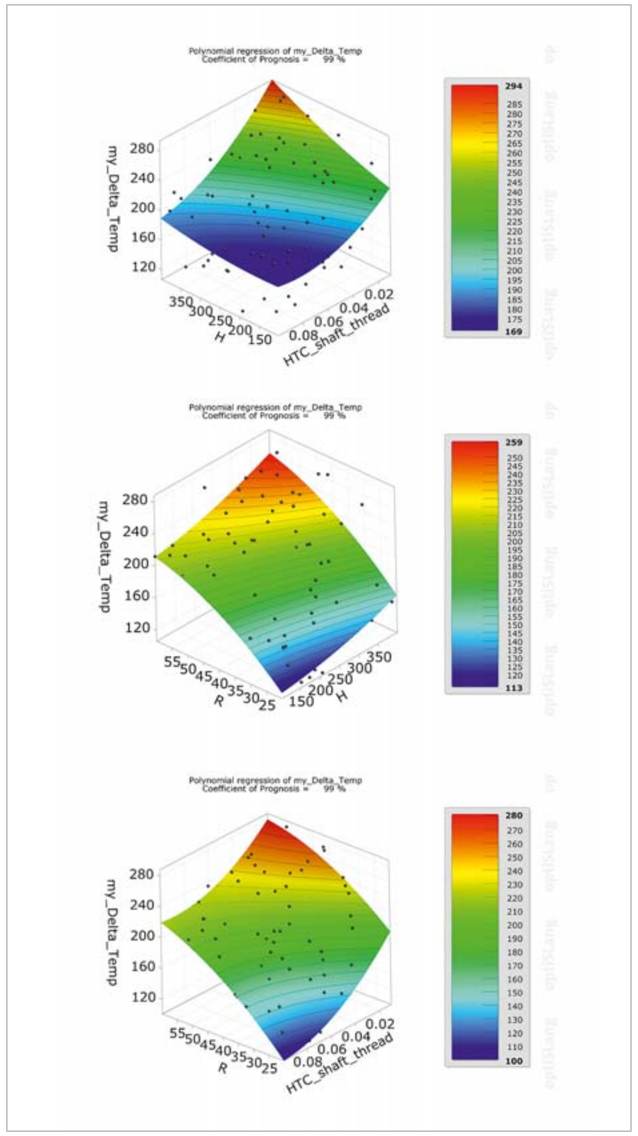

Fig. 9: Response surfaces

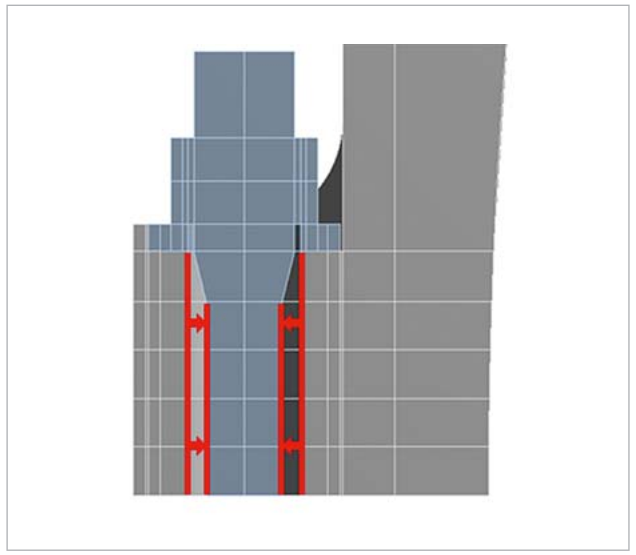

Fig. 10: HTC4 shaft-thread

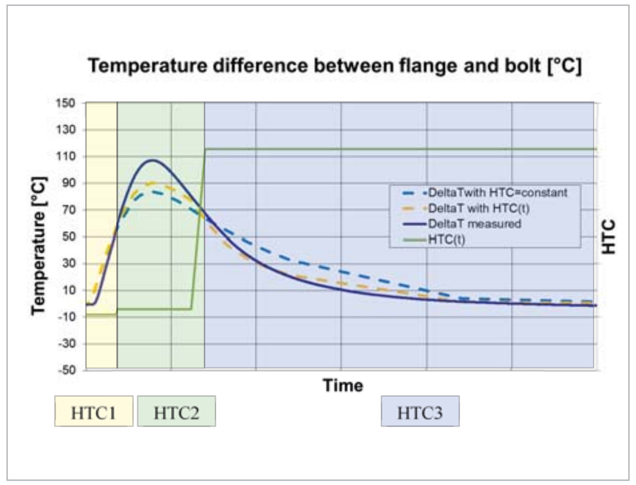

Fig. 11: Temperature difference between flange and bolt

This fitting resulted in three different HTCs, one for every time section, all better matching the actual measured temperatures compared to a constant estimation. Thus, discussions about which HTC should be assumed were ended. With these fitted parameters, the temperature difference between flange and bolt was calculated to improve the original target of the optimization.

In Fig. 11, the temperature differences between bolt and flange are shown. The three graphs compare the measured temperature difference between bolt and flange, the difference resulting from the simulation with a constant HTC and the difference from the simulation with the time depending fitted HTC.

While the fitted HTC values already provide a better match to the measurements, there is still a gap between those two. This was expected, because the second component of the temperature difference – the temperature of the flange - is not yet fitted. This can be done using the same technique as before.

Robust Design Study

For the feasibility, it is of higher interest to take a look at the influences of manufacturing and material tolerances on the model in a Robust Design Study.

For robustness evaluation the metamodel from the sensitivity study was used. Using the metamodel is feasible if all important scattering parameter are part of the sensitivity analysis and the variation range of the sensitivity analysis covers the scatter range. Using distribution functions of the three most influencing parameters, a latin hypercube sampling of 100 designs was generated on the metamodel to see the influence of deviations on the resulting temperature difference (Fig. 12).

Fig. 13 shows the deviations impact on the temperature difference. Obviously, scatter of the parameter HTC_shaft_thread has a major influence on the variation of temperature, while the parameters H's and R's scatter are insignificant, adding even more value to the previously performed fitting of the parameter.

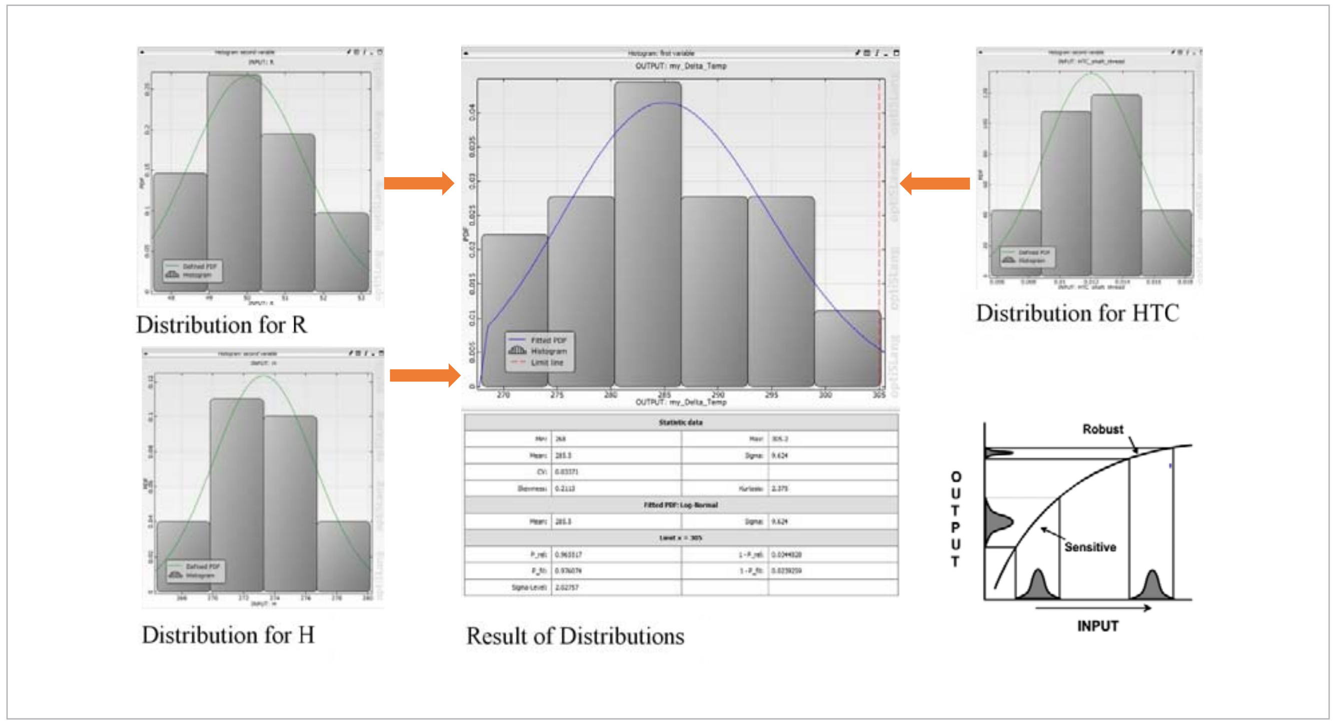

Fig. 12: Impact on the temperature difference - parameter

Conclusion

This feasibility study showed a fast way to optimize the model. Especially the possibility to easily fit the model to measurements and thereby eliminate estimated parameters from the simulation was very useful and increased the overall accuracy of the model tremendously.

The Robust Design Study showed a very small influence of the flanges height deviation on the resulting temperature difference. This is interesting, since the height is still an important parameter for the resulting temperature difference, but the deviations are far less influential than the HTC's deviations. This indicates that loosening the tolerances on the flange height is feasible without increasing the temperature difference and thereby decreasing the parts lifetime, while manufacturing time and costs can be reduced.

Author //
Uwe Lohse , Burkhard Voss (Siemens AG Large Gas Turbines)
Anton Enns (ITB GmbH Dortmund)

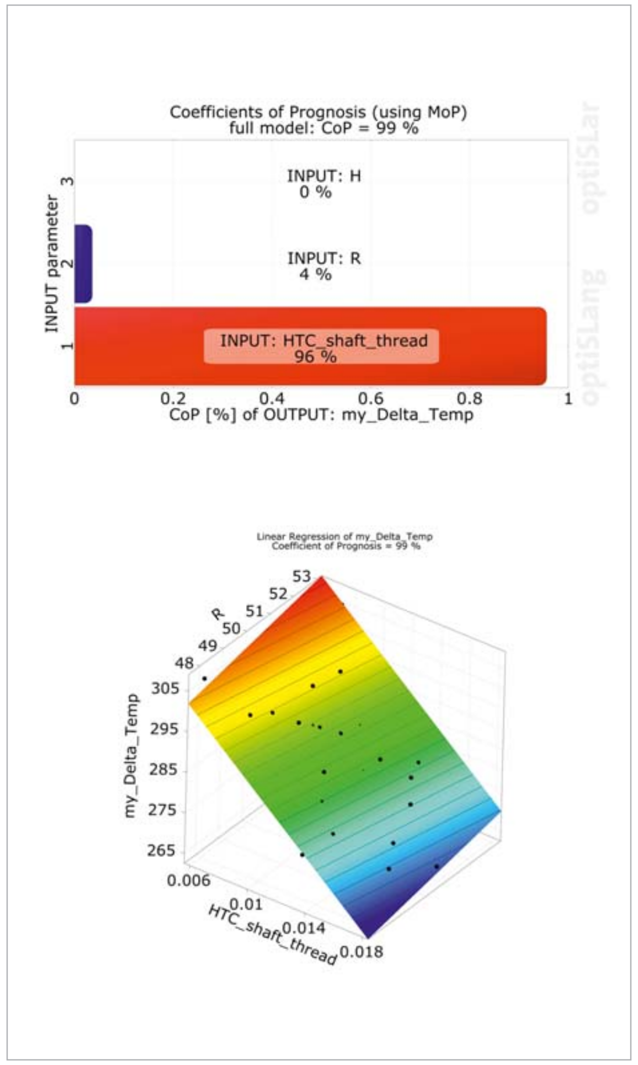

Fig. 13: Impact on the temperature difference - results