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Feasibility study of large gas turbine outer casing bolts with optiSlang

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http://siemens.com/energy/power-generation/gas-turbines

ECC

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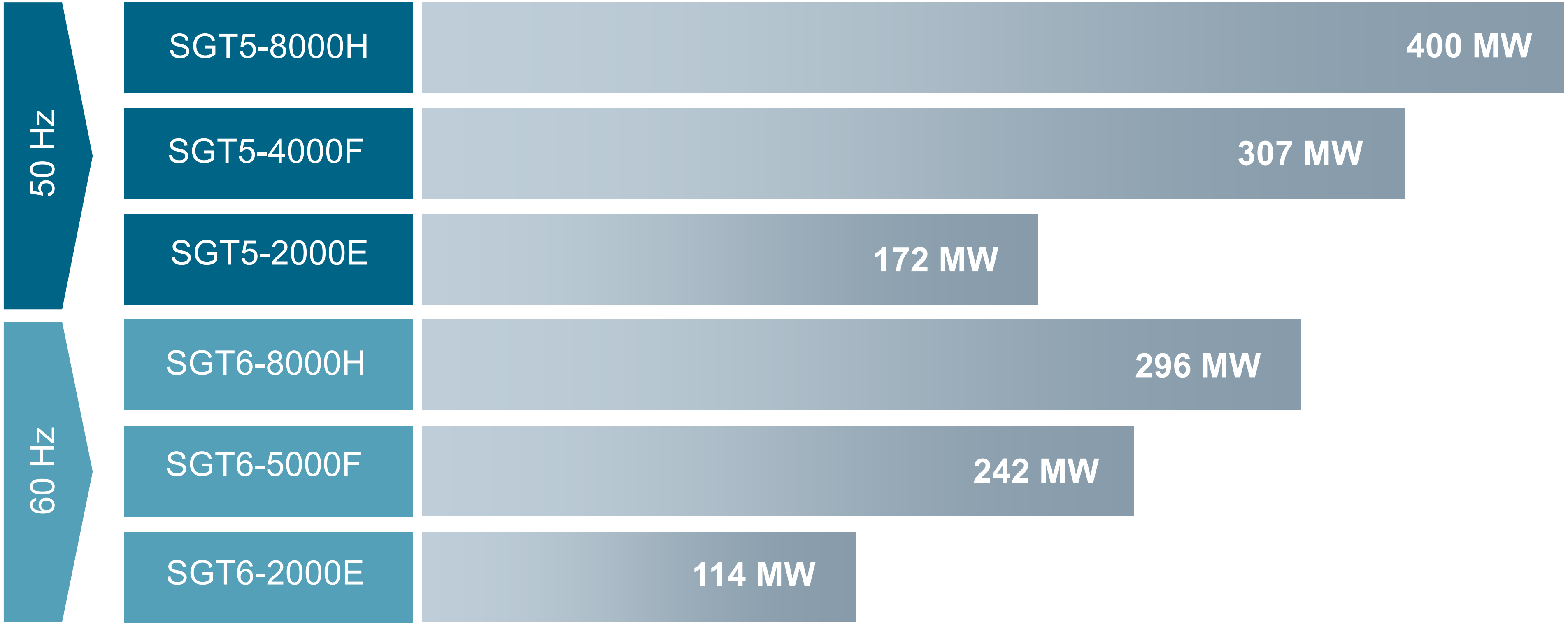
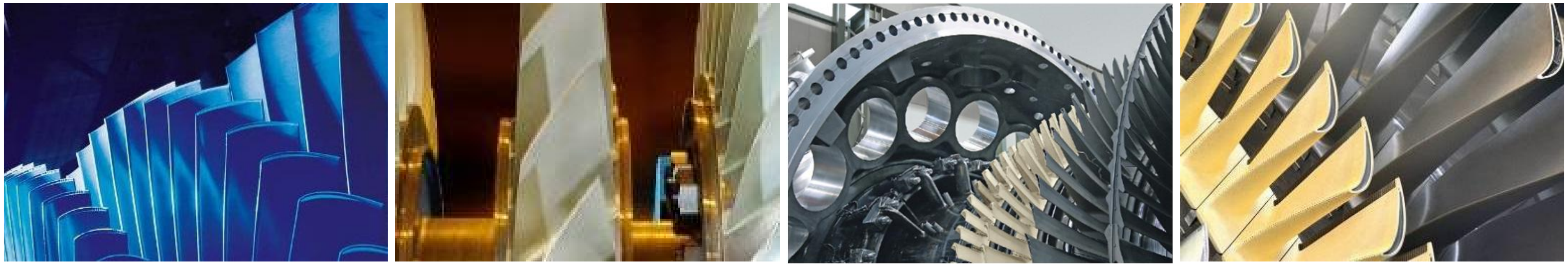
Content

Large scale Siemens Gas Turbines:
The right engine for every power category





Where we are – Gas Turbine Locations & Joint Venture Partners

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SGT5-8000H during assembly at Berlin plant

Efficiency
GT 40%
GUD >60%
With district heating ~85%

Power
GT 400MW
CCPP 600MW

Weight ~390t
Length ~13,1 m
Diameter ~4,9 m

Fleet > 74 units

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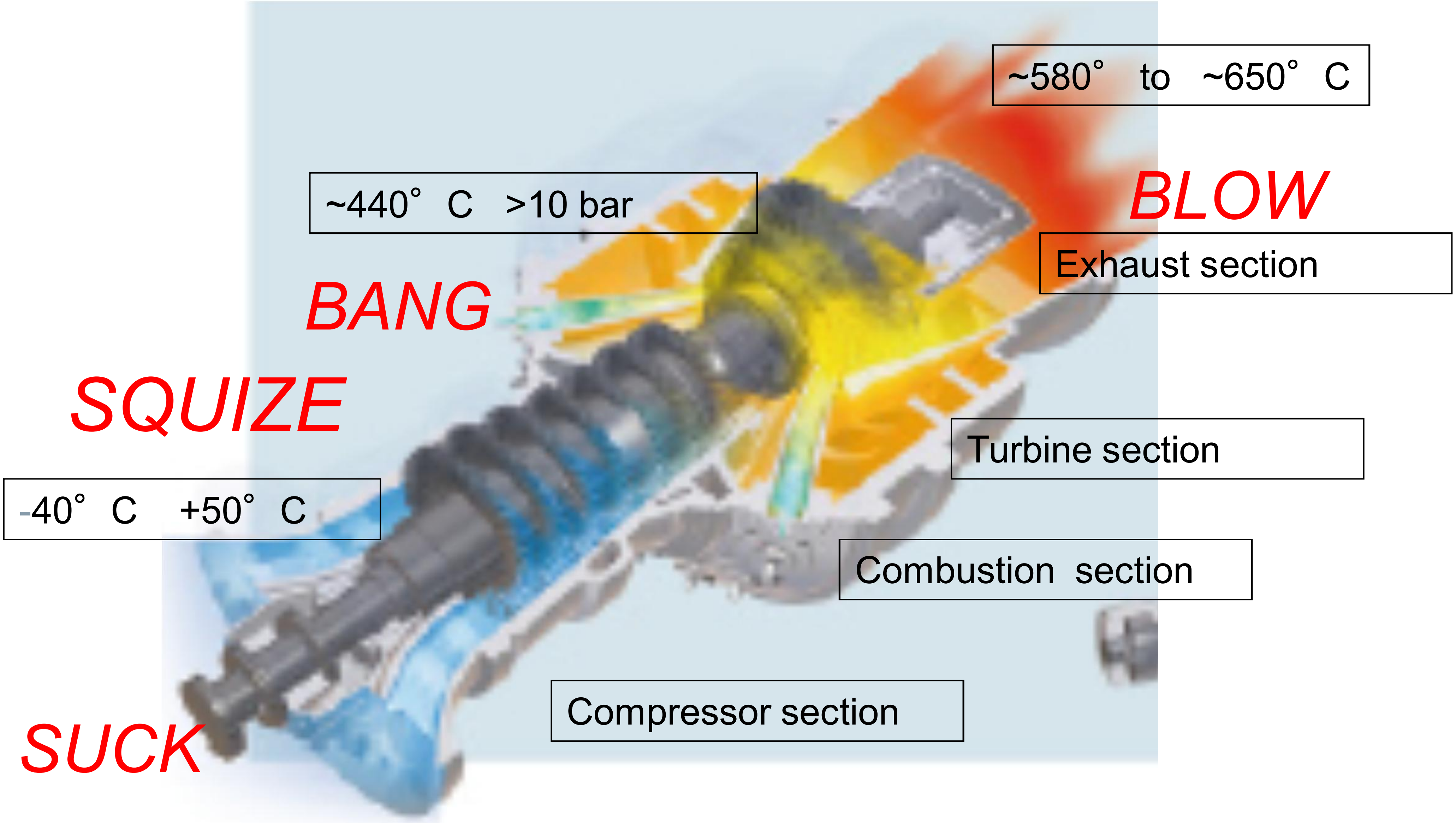
Key thermodynamic values for bolting design



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Introduction – Motivation

- The estimation of the pretension loss due to bolt temperature shows a strong effect of the temperature difference between bolt / flange
- The temperature difference is direct proportional to the low cycle fatigue of the bolts
- To identify the major influences a study by use of optiSlang was performed
- A second goal of this study was to show the feasibility to use optiSlang in the daily design process (optimization, robust design)

Introduction – Procedure

Following steps are performed

1. **Develop a simplified parametric FE-model**
2. **Define design space for estimated parameter**
3. **Run a DOE to find a meta model**
4. **Evaluate the meta model to reduce the model to significant parameters**
5. **Perform a calibration of the FE-model based on measurements**
6. **Investigate the robustness of the design**

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Content

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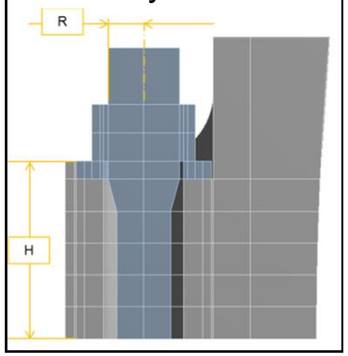
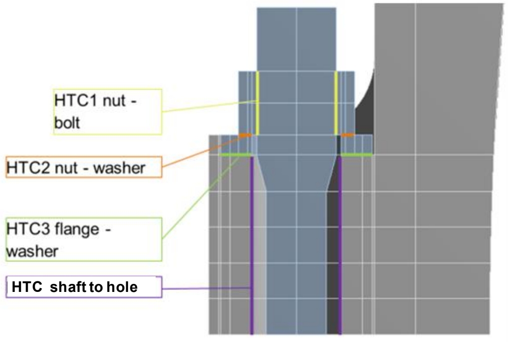
Parameterization and Optimization
FE-Model

Input Parameter

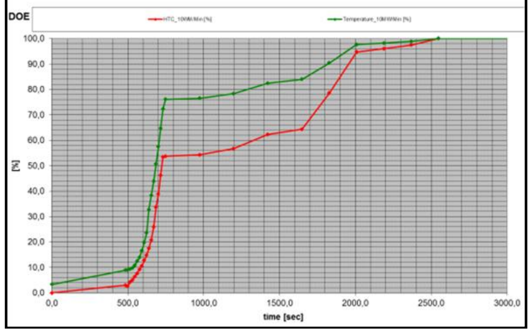
Geometry



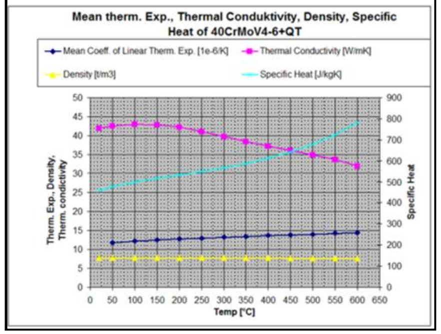
Contact



Temperature over time



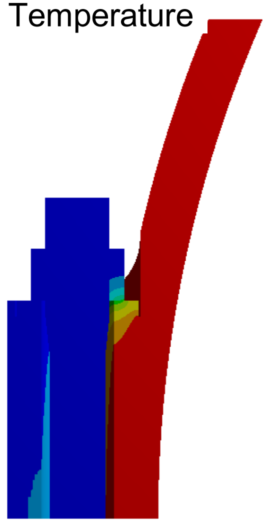
Material Properties



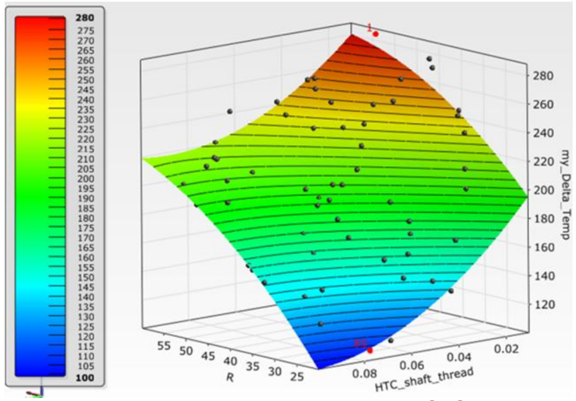
FE-Model

Target Value

Temperature



optiSLang



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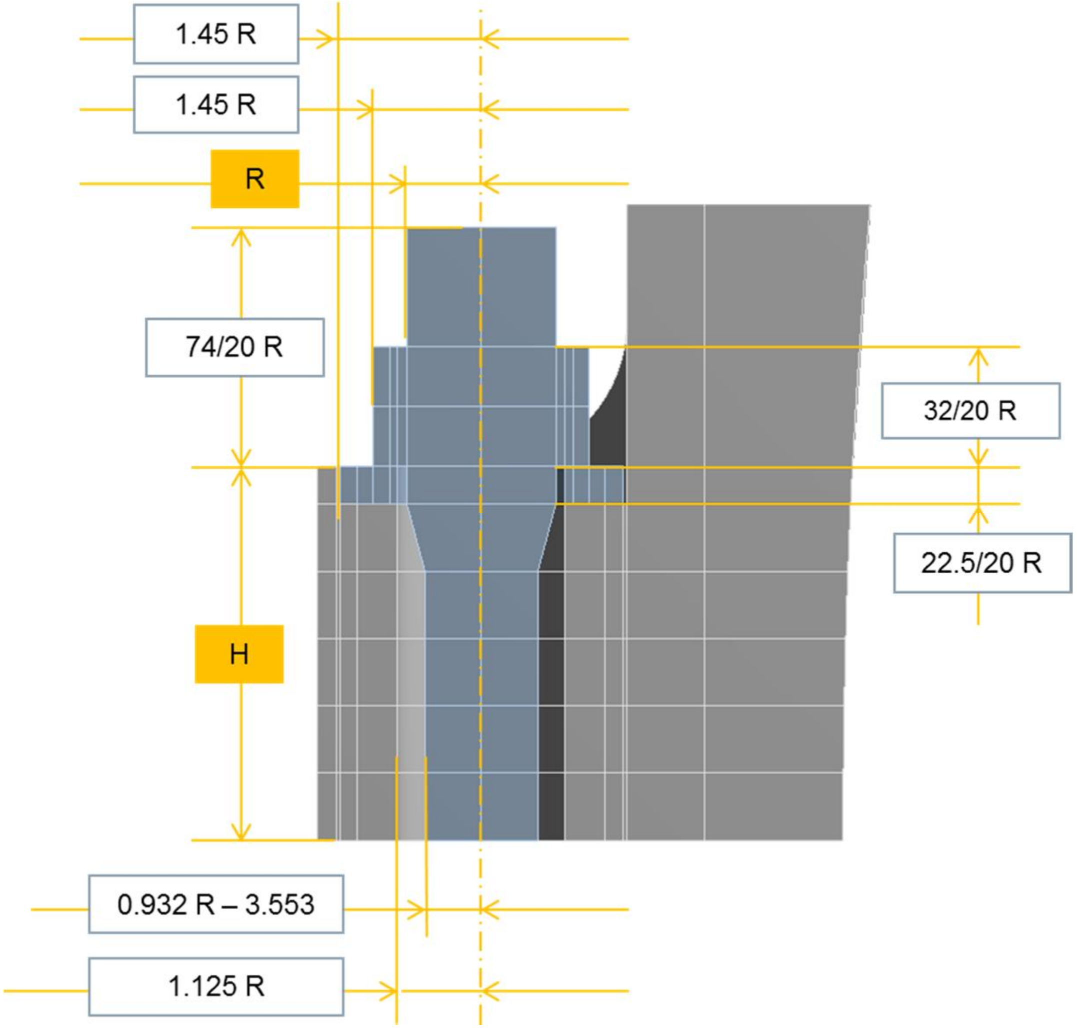
Parameterization
Geometry

Parametric dimensions

Dimensions driven by parametric dimensions



- The parametric geometrical FE model can be defined by two parameters only

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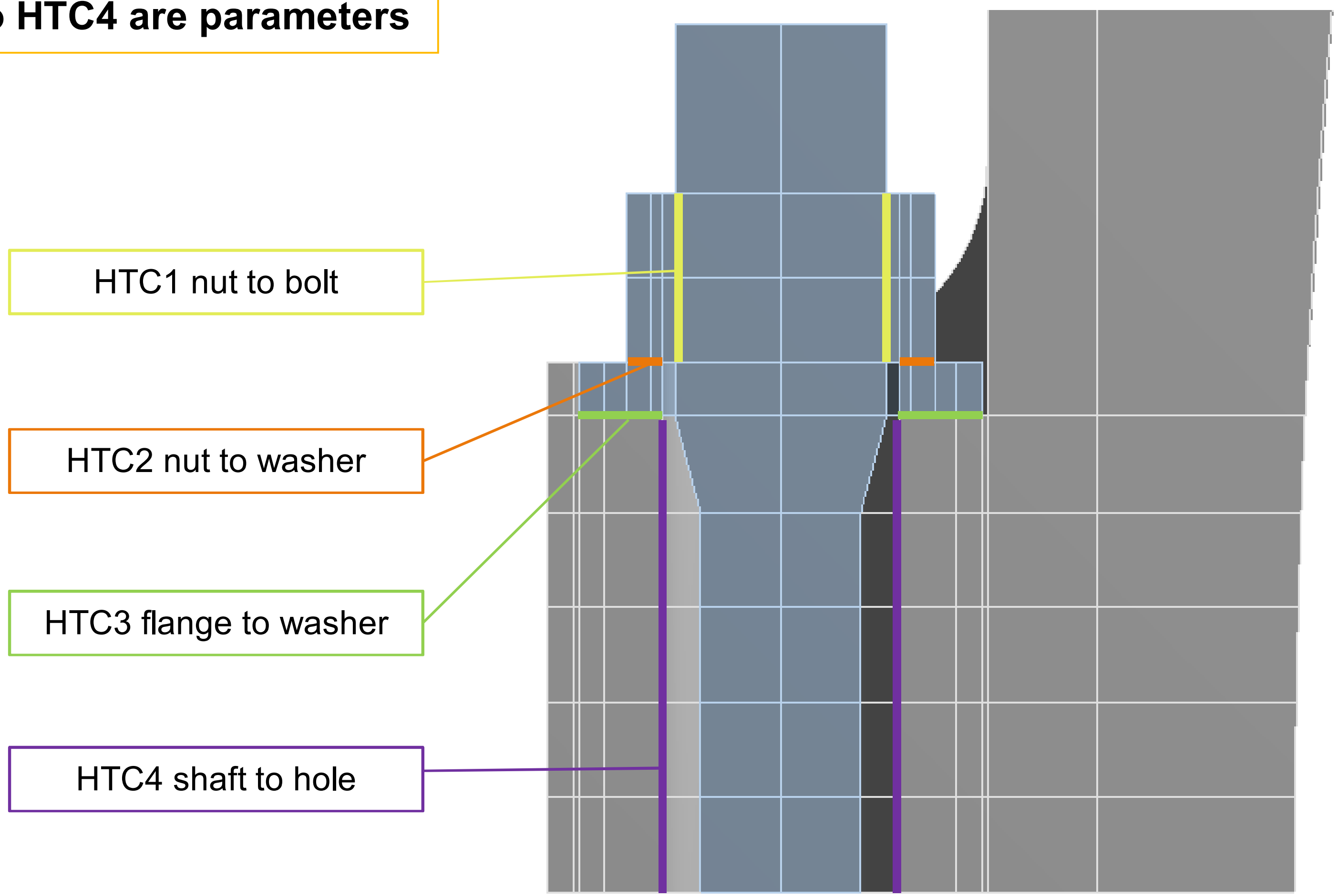
Parameterization
Thermal Contact

HTC1 to HTC4 are parameters



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Parameterization
Summary FE-Model

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- **In General**
  For all input data used in this example a parameterization is possible. However, with different effort.

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

🟢 Workbench function, low effort

🟡 Small APDL commands, low effort

🔴 APDL commands, high effort

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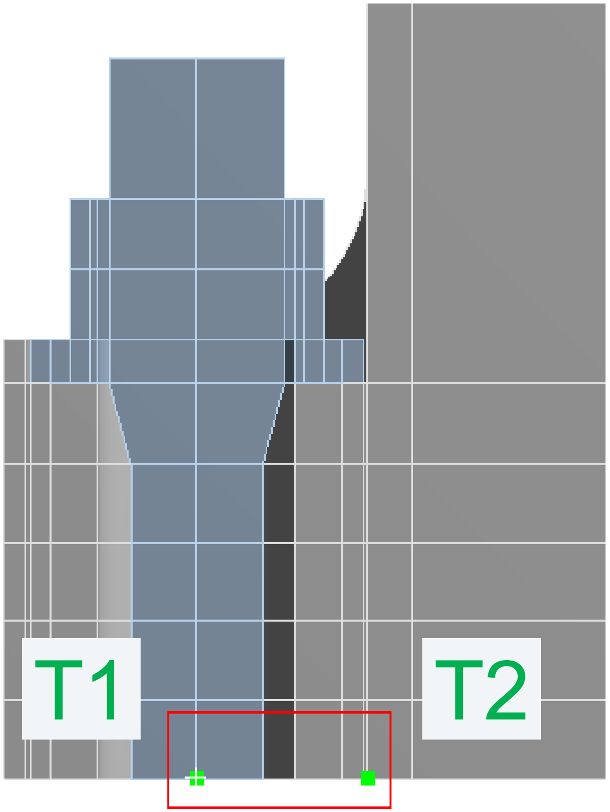
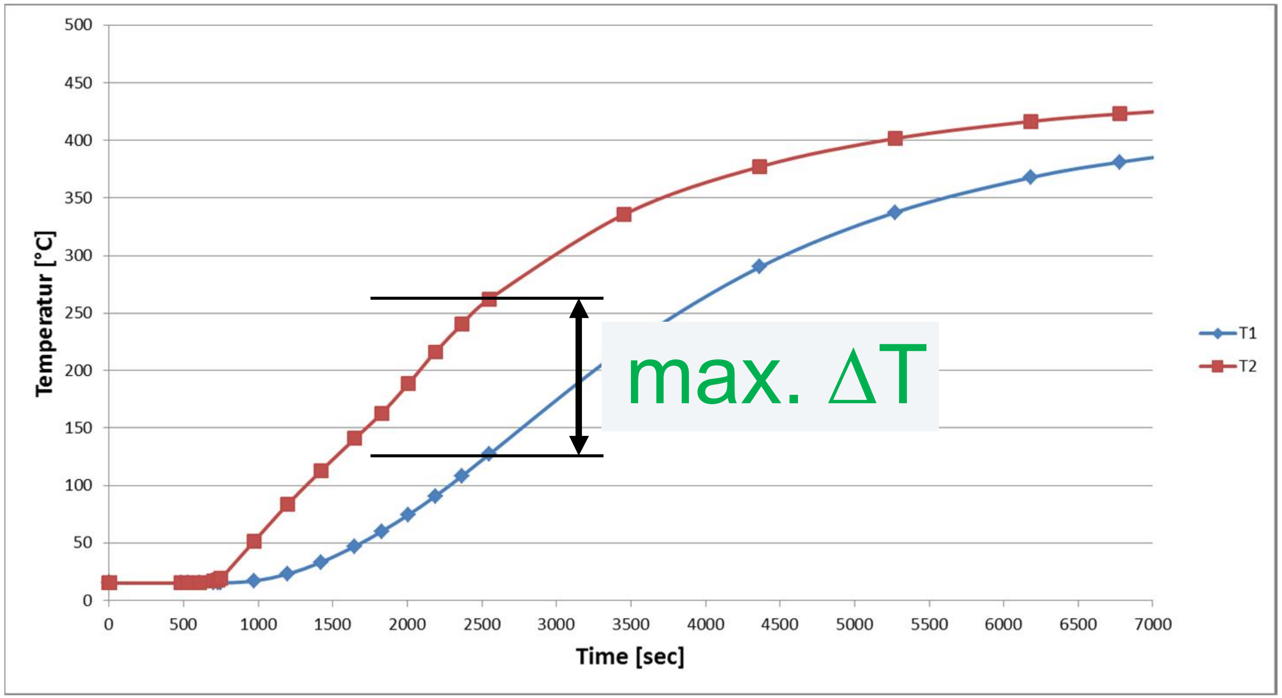
Input Parameters for the Sensitivity Analysis

Number	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 hole	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

Results
Output Parameter

- **Output Parameter:**
  Maximum temperature difference ΔT_{max} between T1 (bolt) and T2 (flange) to be evaluated by APDL or Enhanced Tool Kit (ETK)





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Results
DOE

- **The sensitivity analysis is driven by optiSlang**
- **100 Design Points are calculated**
- **Every Design Point is one correlation of input parameters in the given ranges**
- **With the calculated design points the meta-model is created**

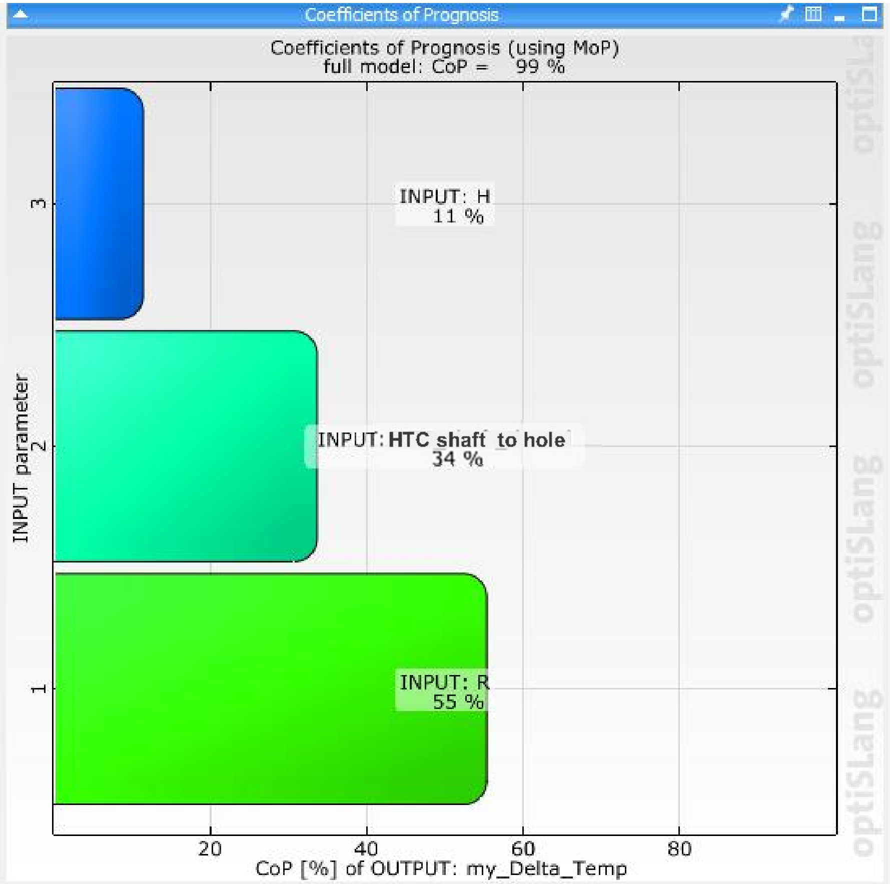
optiSLang – Input Parameters

	Name	Parameter type	Reference value	Constant	Resolution	Range		Range plot
1	R	Opt.+Stoch.	20	☐	Continuous	20	60	
2	H	Opt.+Stoch.	100	☐	Continuous	100	400	
3	HTC_nut_bolt	Opt.+Stoch.	2.8125	☐	Continuous	1	50	
4	HTC_washer_nut	Opt.+Stoch.	2.9375	☐	Continuous	1	50	
5	HTC_washer_flange	Opt.+Stoch.	1.6875	☐	Continuous	1	50	
6	HTC shaft to hole	Opt.+Stoch.	0.039	☐	Continuous	0.01	0.1	
7	_Lambda_Bolt	Opt.+Stoch.	25	☐	Continuous	25	40	
8	sp_heat_bolt	Opt.+Stoch.	500	☐	Continuous	500	600	
9	Lambda_Flange	Opt.+Stoch.	28	☐	Continuous	28	35	

Workbench Design Points

A	B	C	D
Name	Ak...	P1 - split_flange_weight	P2 - bore_ho
Einheit		mm	mm
Aktuell	1	83	45
DP 1	2	213,31	115,65
DP 2	3	151,89	82,35
DP 3	4	85,49	46,35
DP 4	5	102,09	55,35
DP 5	6	150,23	81,45
DP 6	7	113,71	61,65
DP 7	8	216,63	117,45
DP 8	9	186,75	101,25
DP 9	10	248,17	134,55
DP 10	11	231,57	125,55

Results
DOE



Significant influence of input parameters on Output Parameter my_Delta_Temp:

- **Bolt radius 55%**
- **HTC shaft to hole 34%**
- **Flange height 11%**

- **Negligible important input parameters were automatically filtered by optiSlang and not considered in the CoP.**

Results
DOE
ΔT (bolt radius; HTC shaft to hole)

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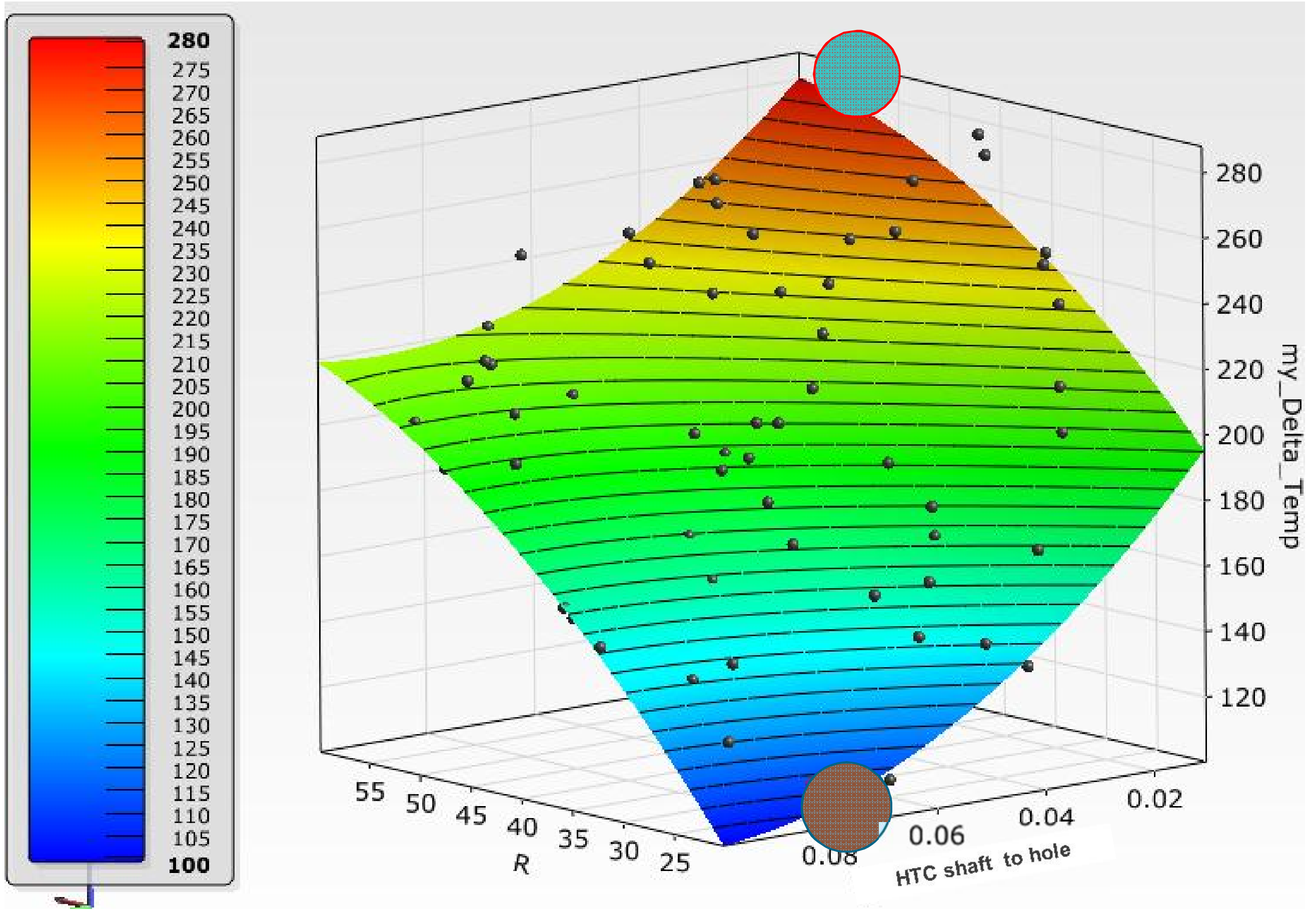

Design Point (DP1) with

ΔT_{max}	= 280.1 °C
R	= 51.4 mm
H	= 350.5 mm
HTC shaft to hole	= 16 W/m²K

Design Point (DP85) with

ΔT_{min}	= 105.6 °C
R	= 21 mm
H	= 212.5 mm
HTC shaft to hole	= 76 W/m²K

- Surface plot shows also points outside of CoP 99%
- Formula is inside of optiSlang

Results
DOE
ΔT (flange height; bolt radius)

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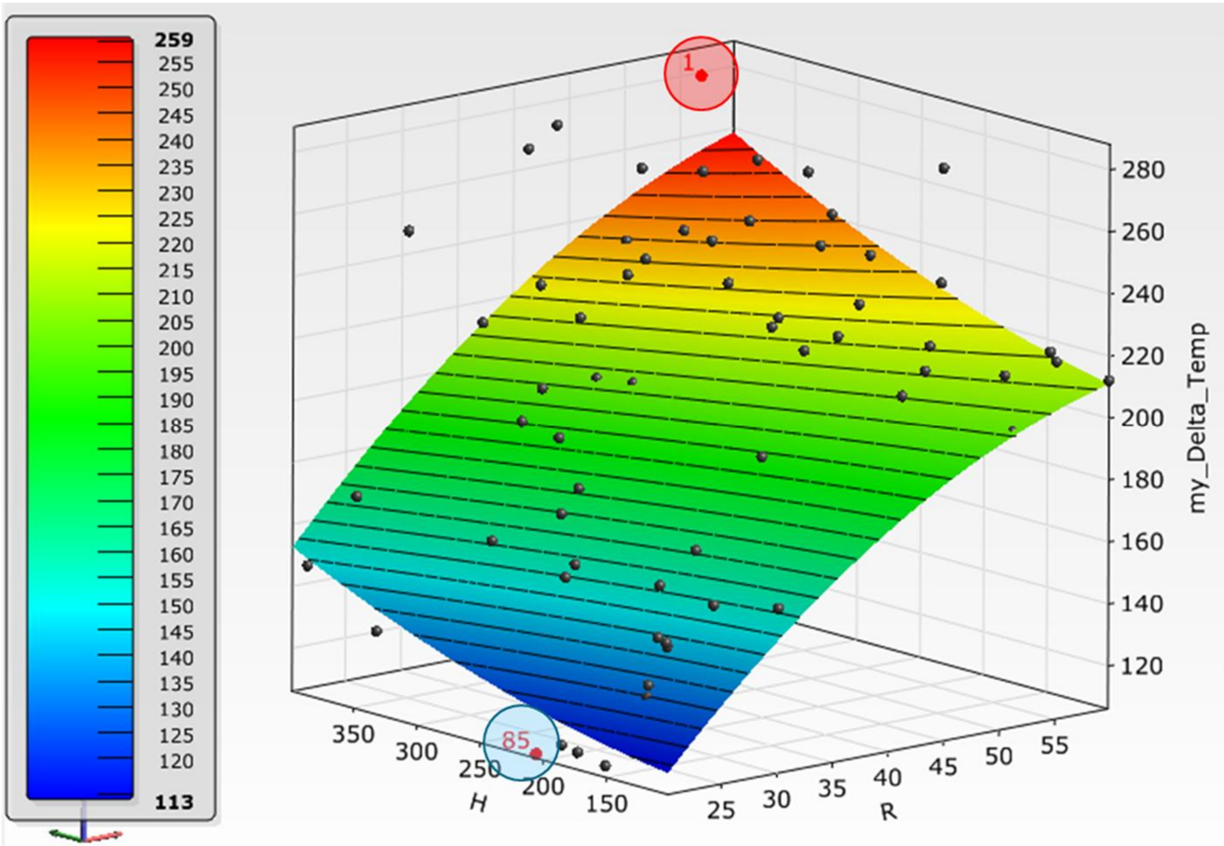

Design Point (DP1) with
ΔTmax = 280,1° C
R = 51,4 mm
H = 350,5 mm
HTC shaft to hole = 16 W/m²K

Design Point (DP85) with
ΔTmin = 105,6° C
R = 21 mm
H = 212,5 mm
HTC shaft to hole= 76 W/m²K

- Surface plot shows also points outside of CoP 99%
- Formula is inside of optiSlang

Results
DOE
ΔT (flange height; HTC shaft to hole)

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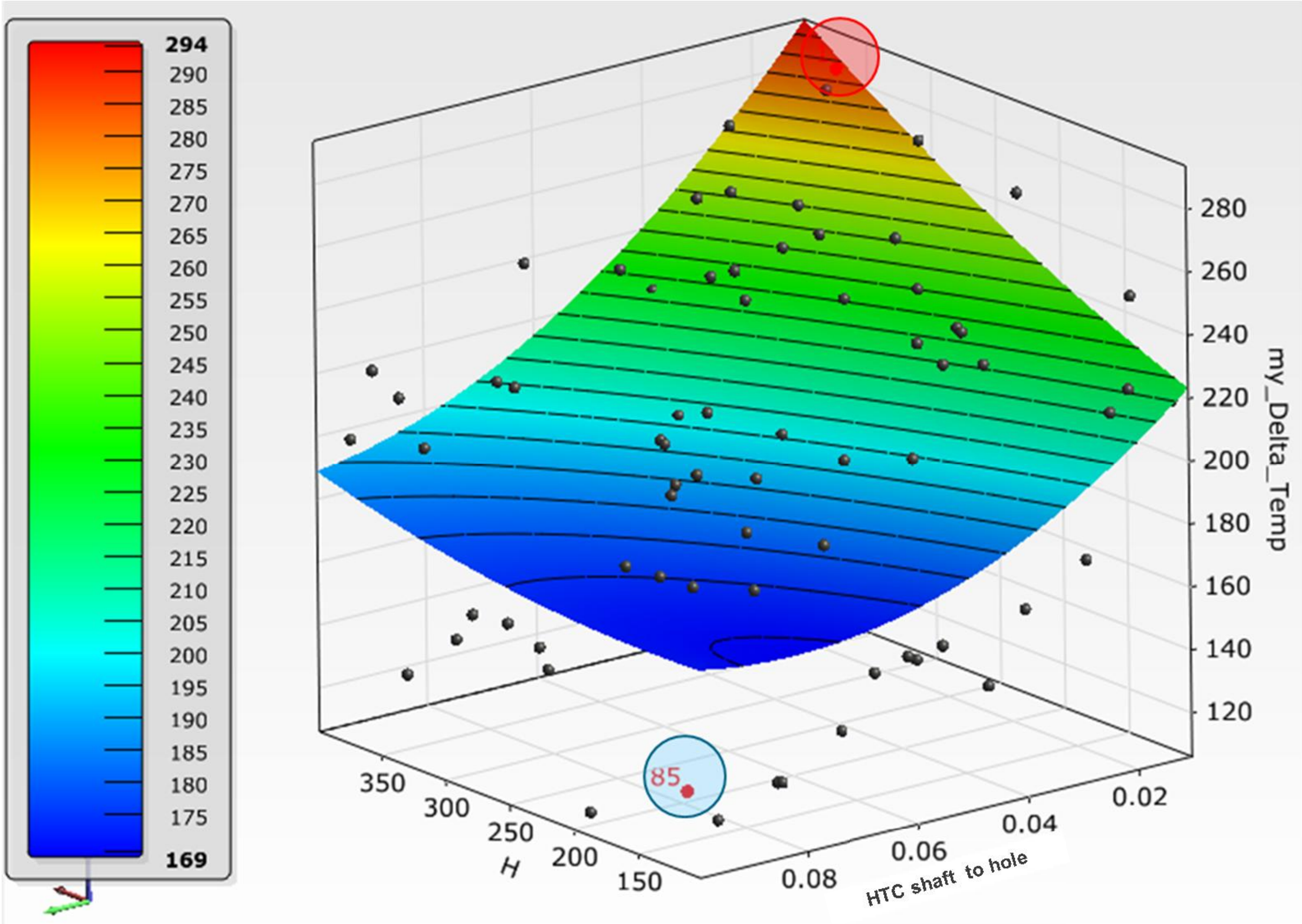


Design Point (DP1) with
ΔTmax = 280,1° C
R = 51,4 mm
H = 350,5 mm
HTC shaft to hole = 16 W/m²K

Design Point (DP85) with
ΔTmin = 105,6° C
R = 21 mm
H = 212,5 mm
HTC shaft to hole = 76 W/m²K

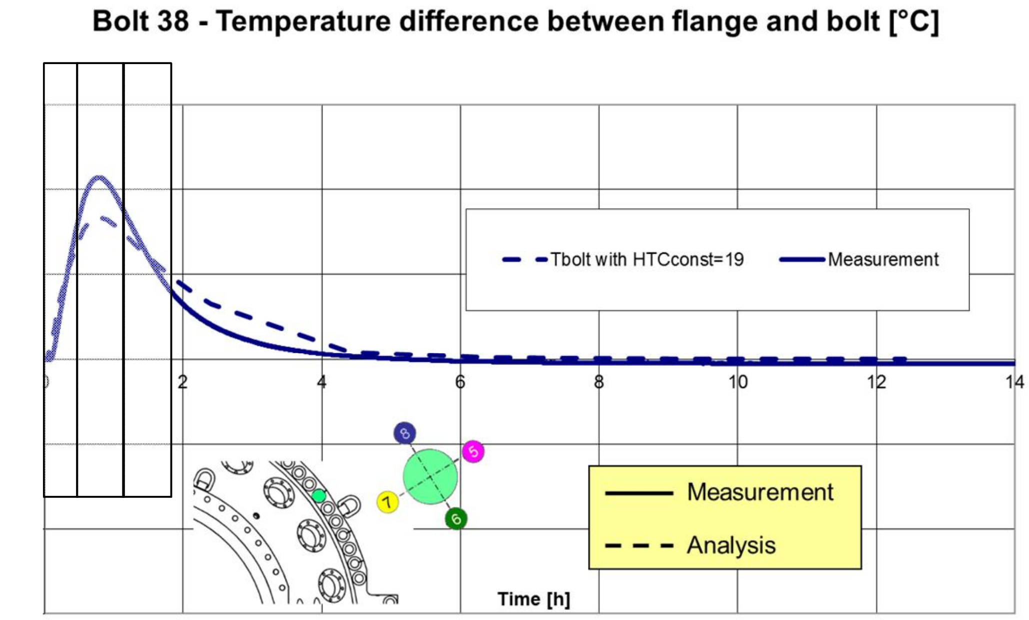
- Surface plot shows also points outside of CoP 99%
- Formula is inside of optiSlang

Content

Detailed calibration of the HTC (variation of the HTC value over time)

- Instead of one HTC value over time, the time vector is divided in several sections
- For every section one HTC value is defined (HTC over time)
- Purpose is to minimize the deviations between the measurement and the analysis for the bolt

HTC 1 | **HTC 2** | **HTC 3** = **HTC (t)**



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Detailed calibration of the HTC in the bolt cavity (variation of the HTC value over time)

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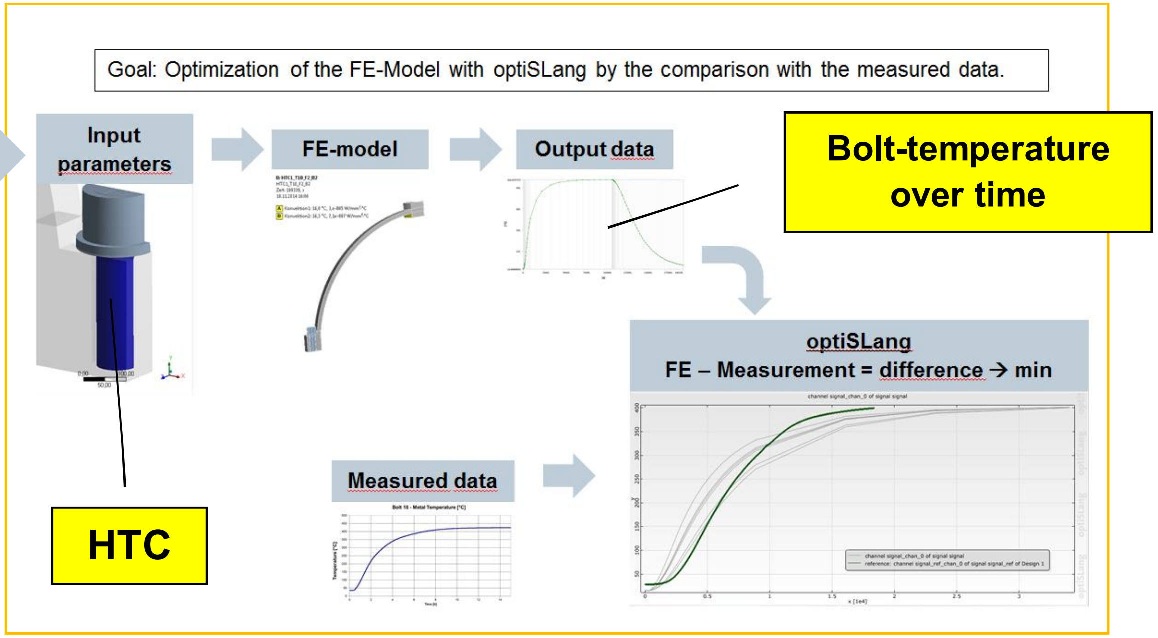
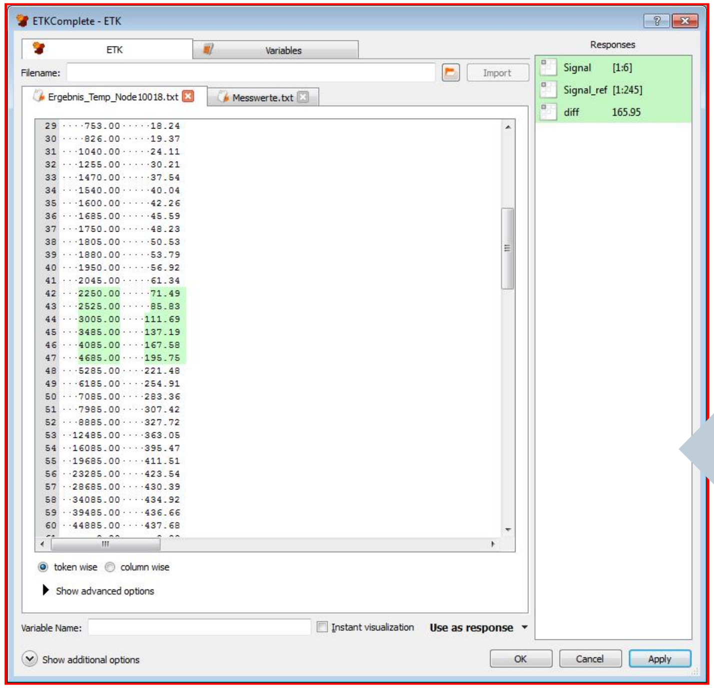
- Process chain for the calibration of the measurement data is shown
- This process will be done three times, for every section of the bolt temperature - curve





- In the ETK one section is selected
- On the next pages the results for every section are presented

Calibration of FE-Model
Results for Bolt
Example for overall calibration

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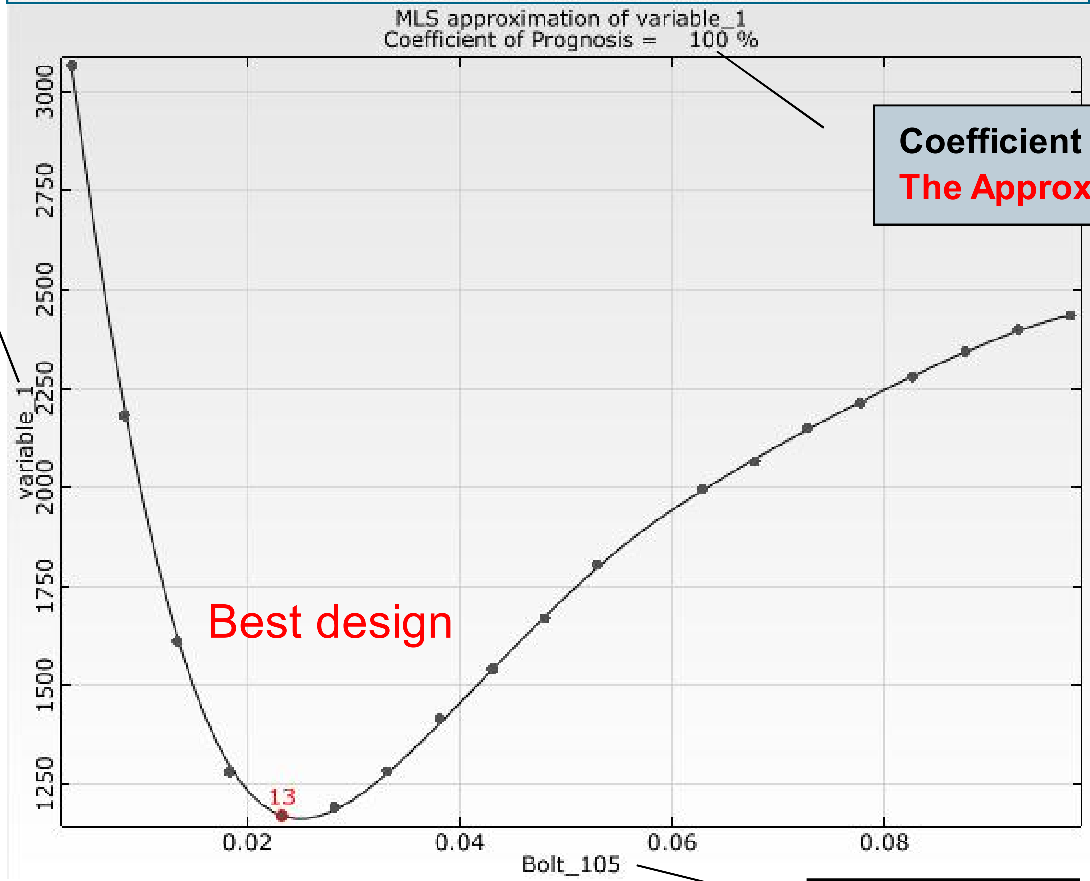
Approximation of results

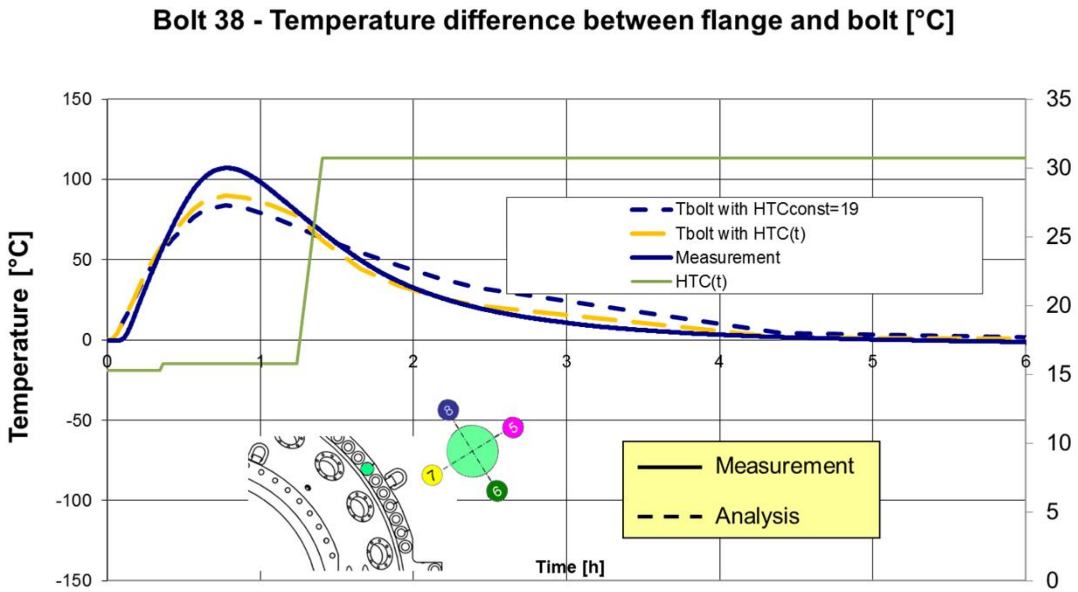


Coefficient of Prognosis = 100 %
The Approximation is very fine.

y-axis:
difference between signal and signal reference

x-axis:
HTC value

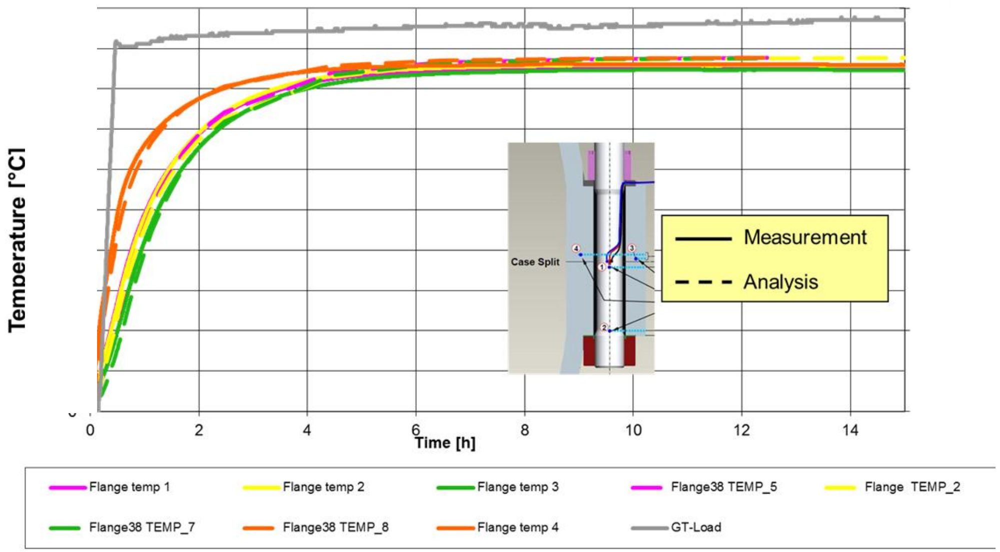
Detailed calibration of the HTC in the bolt cavity (variation of the HTC value over time)

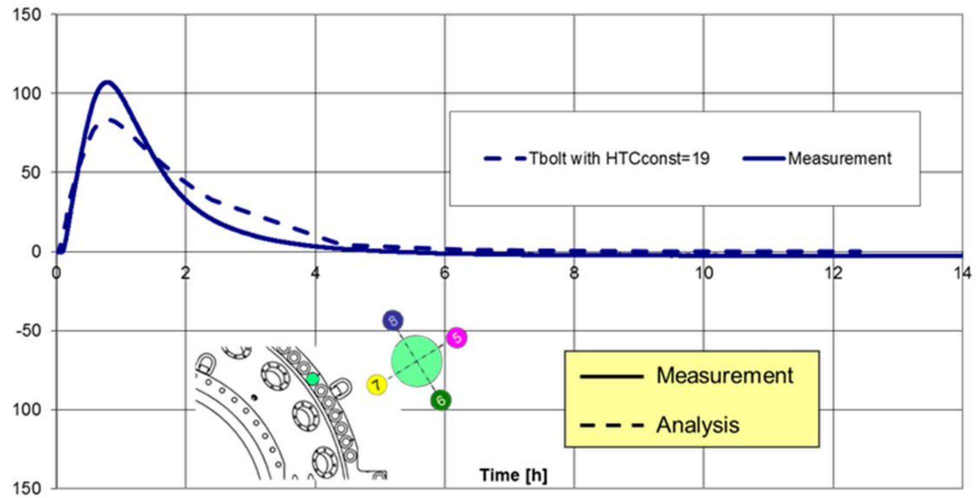


Summary

- The variation of the HTC value over time is possible with ANSYS and opitSlang, by dividing the time vector in several sections
- the calibration of the measurement date with HTC(t) shows improved results
- for a higher improvement a finer resolution of the time vector and more sections are required

Comparison of Calibration with Measurement





Content

Result of Robust Design Study / Sensitivity study

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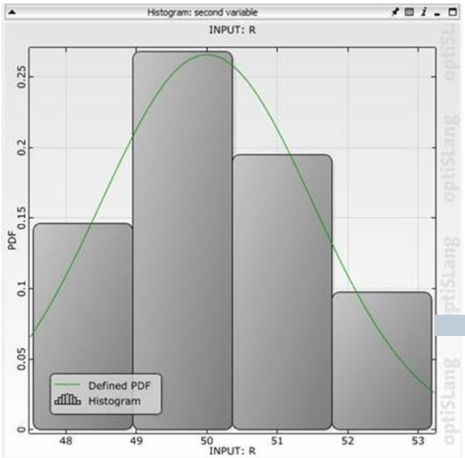
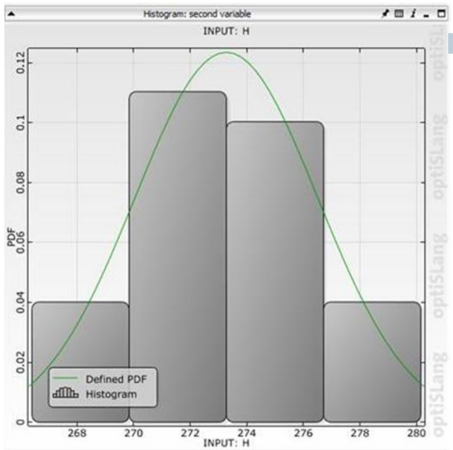
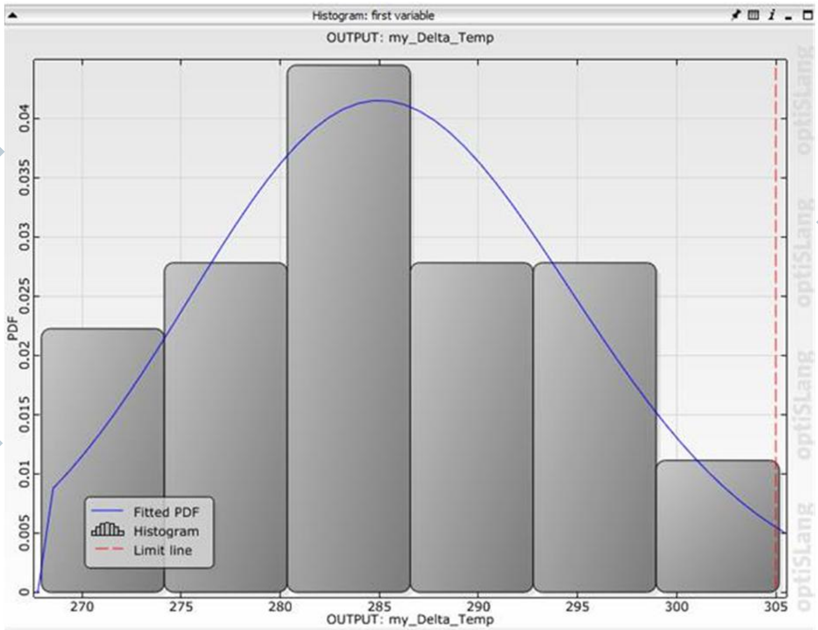


Distribution for R



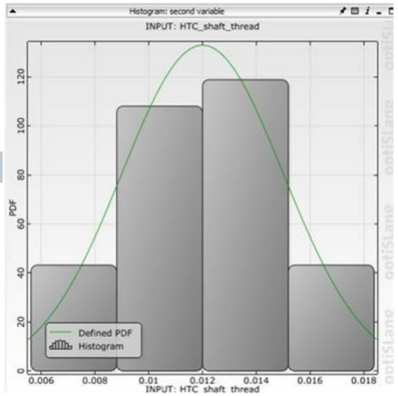
Distribution for H

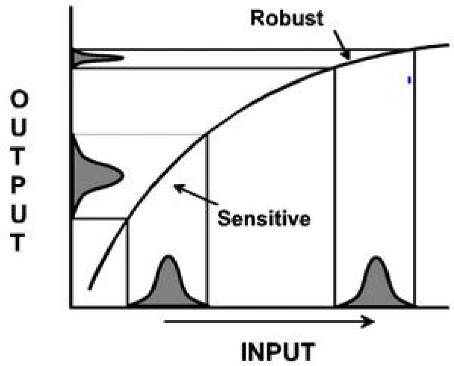
Result of Distributions



Statistic data			
Min:	268	Max:	305.2
Mean:	285.5	Sigma:	9.624
CV:	0.03371		
Skewness:	0.2113	Kurtosis:	2.375
Fitted PDF: Log-Normal			
Mean:	285.5	Sigma:	9.624
Limit x = 305			
P_rel:	0.965517	1 - P_rel:	0.0344828
P_fit:	0.976074	1 - P_fit:	0.0239259
Sigma-Level:	2.02757		

Distribution for HTC





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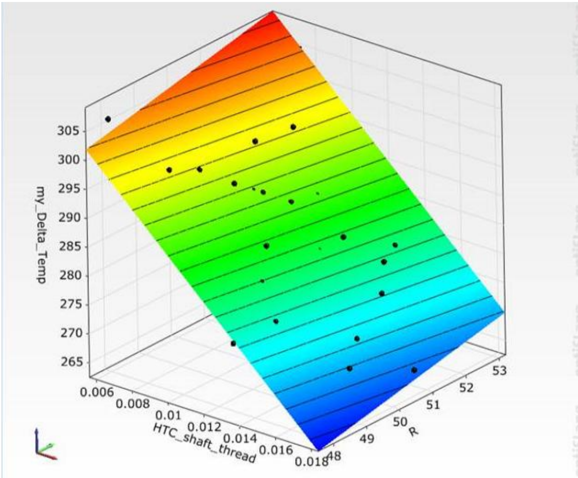
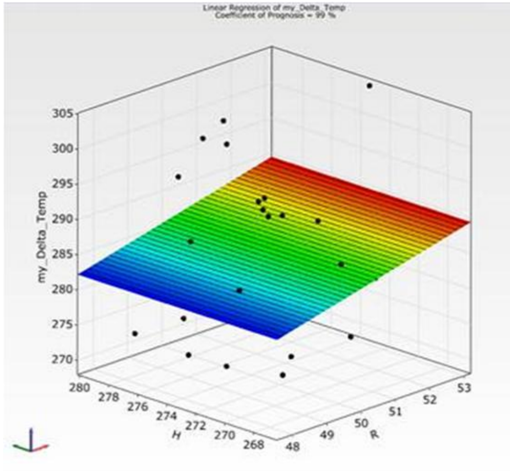
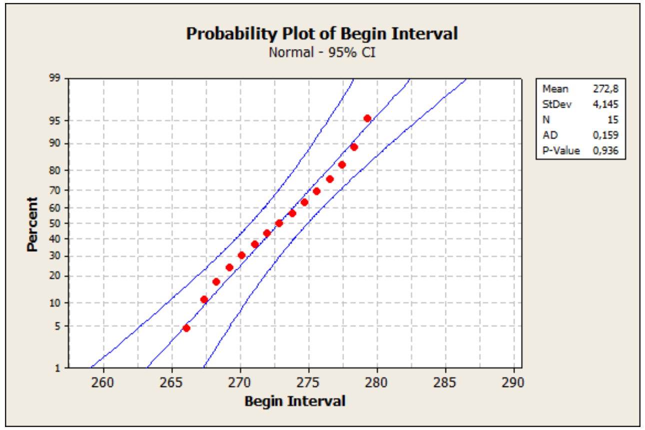
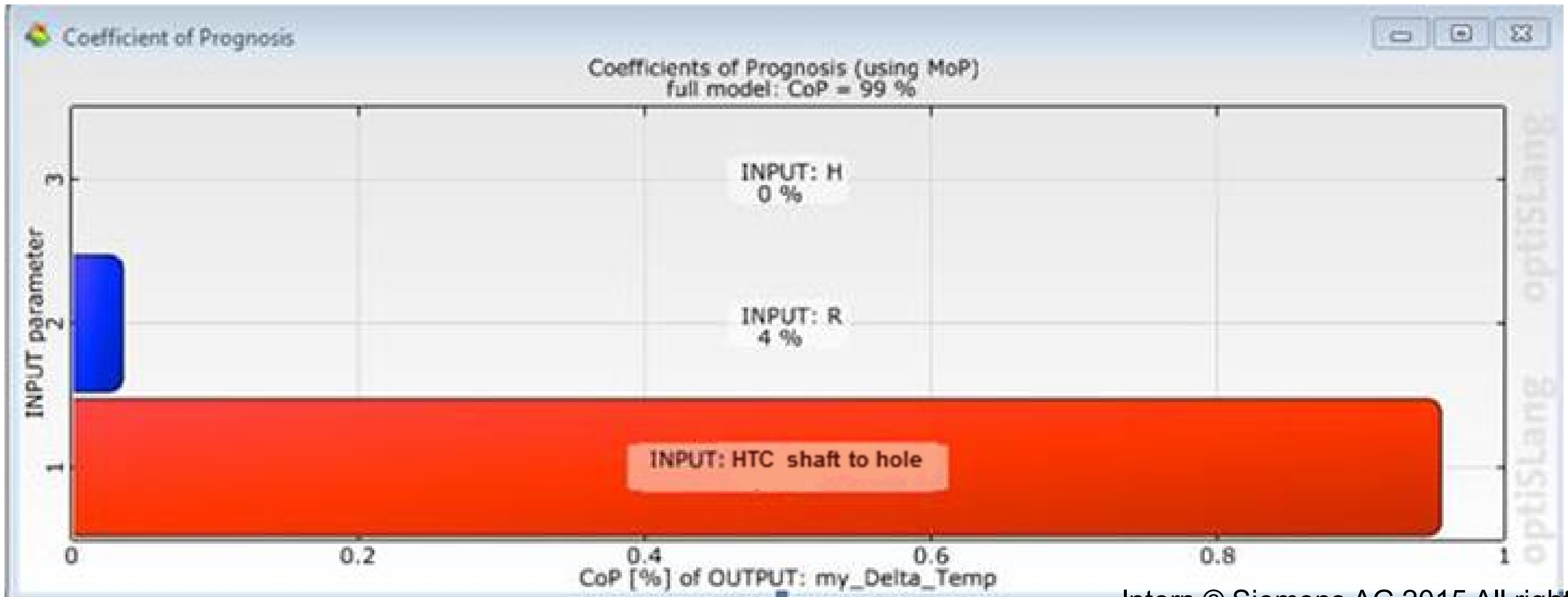
Available plots of the Sensitivity study in optiSlang







Will be probably available in the next optiSlang version



Vision

- Often the designer are asked during a meeting about the influence of parameter to the design. The second question deals with the release of budget and resources, if a potential change of a parameter makes sense.
- Actual the designer has no tool for fast estimations, so he has to answer this question later on or makes statements based on his experiences.
- This may lead to loss of time, budget and reputation of the designer.

- The vision is to have a simplified meta model of the significant parameter as Excel or Mat lab available, e. g. for meetings, for a very fast and first estimation of the effect of a proposed change of the parameter.
- This helps to save money and accelerates the development time.
- The final optimization will be made again with ANSYS and optiSlang!

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MOP Solver in Excel
Actual available solution in optiSlang for the vision

Import 1

Data Set from optiSLang: Input and Output Parameters

Import 2

Meta model based on the data set

MoP solver required as Macro in EXCEL

MoP License required!

Excel-file

New input parameters

- Values within chosen range
- There is an option to extrapolate (not recommended due to deviations to the meta model)

New output parameters

- are calculated from the meta model
- Small deviations to the data set results due to the approximation

Table template

Id	x1	x2	x3	y1	y2
1	1	3	2	5,2	9,2
2	5	2	3	6,7	5,6
3	8	2	6	4,96	4,7

Content

Summary I/II

- The study shows the significant input parameter of the investigated design parameter and design space very fast. The definition of the parametric model takes the most time!
- The results show a very good Coefficient of Prognosis (COP) For the choosen parameter.
- In any case, if possible, the model should validated, by testes. The goal of this to check that the chosen parameter covers all significant impacting parameters is considered in the DOE.
- The data fit with the meta model to real measurements shows a good agreement. This is the additional hint that all major parameters were considered in the study.
- A validation of the identified meta model due to measurements is strongly recommended.
- Robust design study is easily possible with the meta model. Direct input of the parameter distribution in Workbench is possible.

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Summary II/II

- Major hurdles are the definition of the parametric FE-model.
- For the nonlinear material properties and the transient temperature and heat transfer coefficients a script with APDL must be written.
- A direct input in ANSYS Workbench is not feasible. APDL knowledge is required.
- Distribution of the significant parameter have to be known for the robust design study.
- To reduce the data fitting on an interesting section of the transient, ETK has to be used.
- In the transient case the average value over the whole transient is possible to fit. Perhaps calibration of several segments are required, if jumps or kinks found in the measurement.

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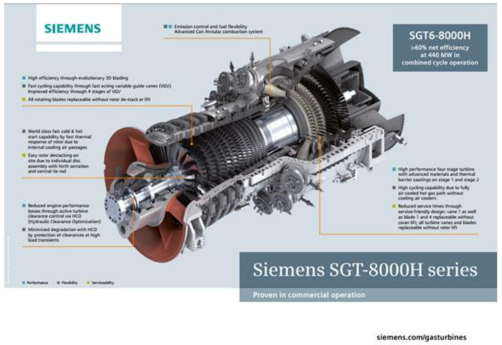
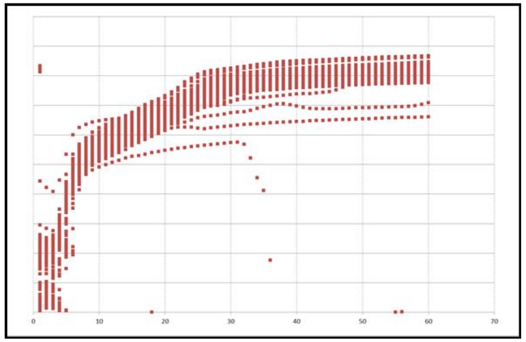
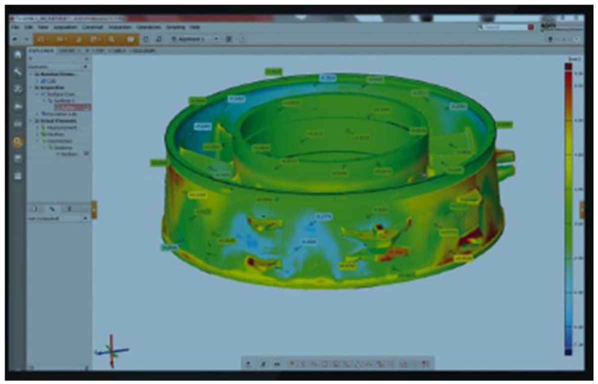
Potential further projects in discussion



Optimization on different components regarding weight, stress, low cycle fatigue, deformation, creep



Probabilistic study of different operation behavior. Regarding low life cycle fatigue



Probabilistic study random casing tolerances regarding low life cycle fatigue

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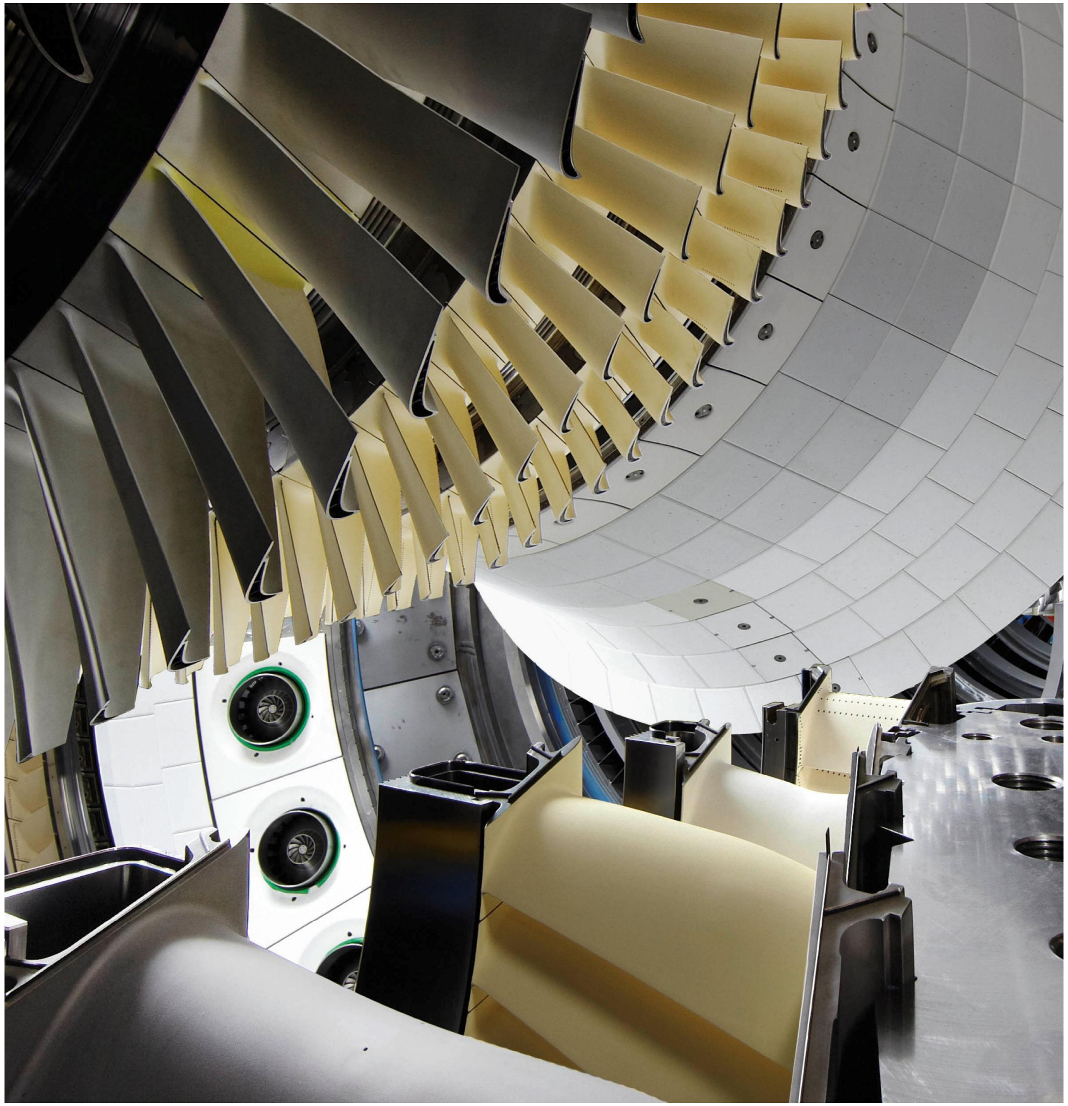

Thanks for your attention!

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