Thrust Collar Bearing Design Optimization using Isight

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Abstract: ABB Turbochargers are required to fulfill the highest demands in terms of cost, reliability, performance and turbocharging efficiency, leading to the application of continuous improvement processes for all turbocharger components. The thrust bearing, for example, has to carry the whole axial force of the rotor with only minimal deformation of the collar surface over the turbocharger's complete operating range. Moreover, requirements for mechanical integrity as well as limitations on installation space represent a set of constraints and targets that make the optimization of this component challenging – and an interesting benchmark for automatic optimization with Isight. This paper describes the parameter-based geometrical optimization of a thrust collar bearing, including the following themes:

- *Creation of an Isight process and strategy for the multi-objective optimization of a parameterized bearing collar design,*
- *An identification technique for filtering out invalid sets of parameters before submitting data to Abaqus and*
- *Customized post processing and reporting.*

Keywords: Thrust bearing deformation; parameterized geometry modification; Isight; design optimization; Multi-objective Optimization.

1. Introduction

In times of increasing fuel costs and emission restrictions there are increasing demands for ABB turbochargers in terms of performance and efficiency. This is accompanied by increasing thermal and mechanical loading, leading to new challenges for the turbocharger and all its components. With the increasing pressure ratios in single and two stage charging designs, the thrust bearing has to withstand varying thrusts up to several tons and broad ranges of temperature under all service conditions. The challenge of thrust bearing design is to ensure a controlled constant oil gap between the floating and thrust collar bearings (cf. Figure 1) in the whole working range to ensure a moderate, but sufficient, oil flow rate and prevent contact incidents during operation and sudden load changes, e.g. emergency stops of the engine.

One concept to achieve this is using all relevant forces together with the overall design of the thrust collar bearing. With the numerous given restrictions limiting design space, it turns out to be a challenging task to fulfill the above mentioned target satisfactorily. Usually, several iterations and a concerted effort are required to find a feasible design at all, adding more iterations in order to make it satisfactory.
As the simulation time per iteration is limited while changes to the design are slightly more cumbersome, the thrust collar bearing has been found suitable for parameterization and automatic optimization using Isight.
The present paper describes how the design process has been prepared and integrated in Isight for the purpose of multi-objective optimization, including a pragmatic method of filtering out invalid parameter combinations. The process has been applied to an example of an ABB A100-L turbocharger which represents world leading technology in several disciplines: turbocharged power up to 28000 kW per unit; air flow volume rates up to 52 m^3/s per charger with first class turbocharging efficiency of up to 74% (Ref. 1). As with all modern turbochargers, the effect of the A100-L is to increase engine output by as much as 400%.

Depending on the details and weighting of the target function, very satisfying designs have been identified.

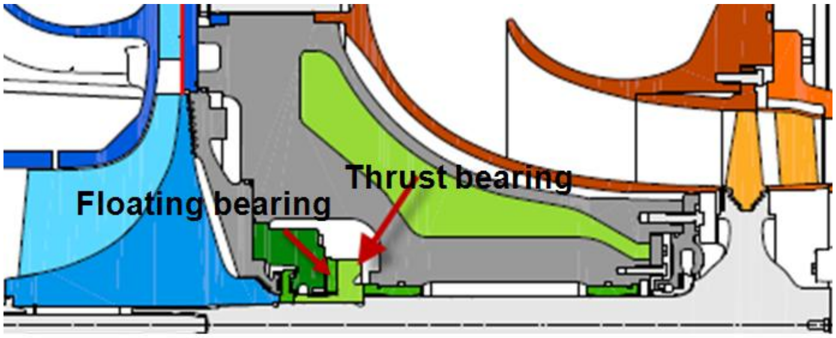


Figure 1. Assembly of bearings

2. Collar Bearing Design Parameter in Abaqus

The analyses of the thrust collar bearing design can be performed on a two dimensional axisymmetric model even if the loading is cyclic periodic due to a cyclic periodic counterpart. To restrict the number of tools to be involved in the process, the geometry has been built and parameterized within the sketch module of Abaqus/CAE, cf. Figure 2. Thus, geometry modification can be readily achieved directly by using the Abaqus component within Isight (Ref. 2).

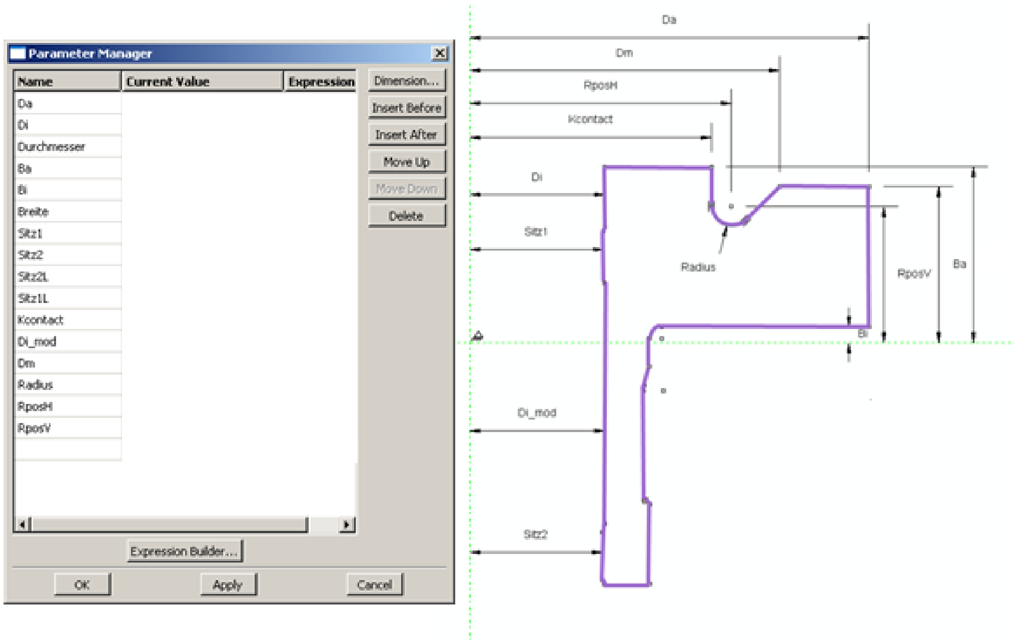


Figure 2. Parameterization within Abaqus/CAE

Dealing with a given number of variable parameters to define complex geometry leads to an increased risk of defining unreasonable parameter combinations, leading to invalid geometries. In the present case these invalid geometries will fail during the Abaqus preprocessing, be too complex in the manufacturing process or violate given design principles, cf. Figure 3. At the least, these would lead to payment of unnecessary Abaqus/CAE license fees while the latter cases would also cause additional analysis costs.

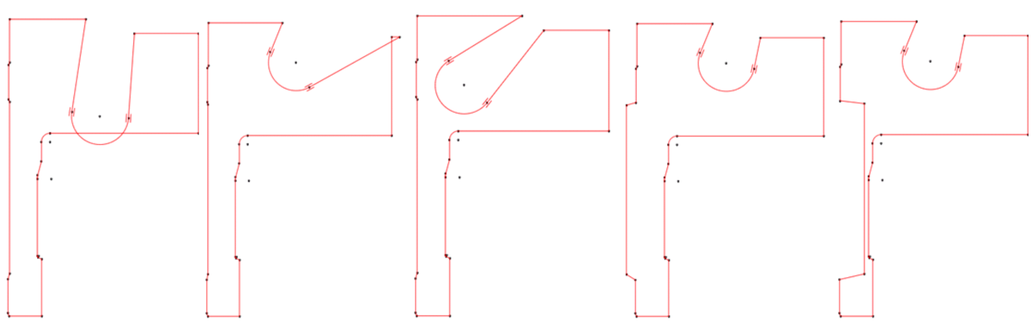


Figure 3. Obviously invalid designs

Apparently, parameter definition within Isight is limited in the sense that complex dependencies in the relationships of parameters cannot be defined directly within the optimization component. Thus, unreasonable parameter combinations can either be prevented in the geometry parameterization phase or filtered out early in the iteration cycle. The second possibility has been chosen for the given trial, as it appeared to be more pragmatic.
A DoE pre-study has been carried out in order to identify the most common types of unreasonable parameter combinations leading to invalid designs as shown in Figure 3. Indeed, the main purpose of this pre-study was to identify the sensitivity of the main design targets towards variations in the given parameters and to prove or adjust the defined design spaces assigned to the parameters.

3. Automatic Design Optimization in Isight

A rather simple process flow is provided in Figure 4. Design work flow in Isight has been defined in Isight to manage the design optimization of the thrust collar bearing. Several design targets have been introduced and weighted within the target function of the optimization. The controlled oil gap shape for all given loading conditions has been more strongly weighted as it was the main target of the optimization. With the given process, however, it was possible to take into account several different target functions or weightings. Additional restrictions concerning the manufacturability and endurance of the collar bearing have been included in the restriction function that penalizes the violations of the given constraints.

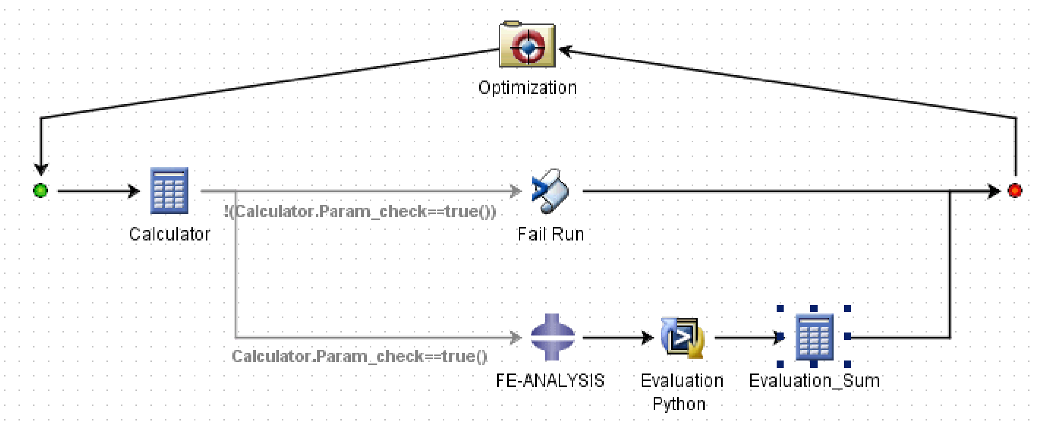


Figure 4. Design work flow in Isight

The invalid designs mentioned above are filtered out prior to the simulations. Several simple equations have been introduced in a “Calculator” module to check for all known types of invalid geometry. If an invalid geometry is detected (Param_check == false) the module provides a “Geometry Failure” label to the given parameter combination by using a script component.

```
if (Param_check == false) {
throw new com.engineous.sdk.runtime.RtException("Geometry Failure");
}
```

All parameter sets labeled in this way skip the simulation path and are treated as a “failed run” by the optimizing component. Alternatively, it would have been possible to provide a violation based penalty value to the optimizer component together with the “Geometry Failure” label, to allow for a more detailed post processing of the design space at a later time.

All valid parameter sets passed through the simulation path to be evaluated with regard to the given target function. Within the simulation path the following tasks have to be completed:

1. In the sketch module of Abaqus/CAE the geometry is updated based on the given parameter set.
2. The 2D-axisymmetric model is meshed with rather restrictive mesh tolerances to ensure the required simulation quality and prevent convergence issues in the subsequent nonlinear calculations, which include complex contact conditions with friction (Ref. 3).
3. Within the simulation, first the assembly is realized including all loads due to its fixation on the rotor shaft. In the following steps several different loading conditions are established to explore the designs’ behavior in service with regard to the given targets and restriction criteria (Ref. 4).
4. A part of post processing is carried out within the Abaqus component. The so called “AbqConfig.txt” has been adjusted to extract some specific output. The remaining post processing on the Abaqus simulations is conducted using an Abaqus scripting interface Python script to collect the additional required information in order to evaluate the target and the restriction function.
5. According to the design directives and additional requirements, more complex targets and restrictions are evaluated in the calculator component before providing the corresponding values back to the optimizing component for the “decision process”.

4. Design Optimization

The optimization process has been applied to a realistic example of a collar bearing from an ABB A100-L turbocharger, which represents the best-in-class product for today’s largest and most efficient low speed two-stroke engines.

During the first trials it was possible to establish that the target function provided contains several local minima distributed in the design space. As the simulation time has been acceptably low due to the 2D axisymmetric model, it was possible to use a genetic algorithm for the optimization without exceeding useful optimization times and causing excessive consumption of Abaqus licenses (Ref. 5). As expected from previous experiences of manual designing, it was difficult to find an optimal compromise for all loading conditions, especially as thermal and mechanical loadings do not appear to be proportional for the different service and emergency conditions which are possible. Thus, depending on the weighting of the target function, rather different solutions can be derived.

An interesting observation is that for certain weighting conditions, designs were created that look different to those normally been designed but which still fulfill all the design criteria. In Figure 5 one of these unusual designs is shown in comparison with the normal design chosen as the initial solution. For realistic service conditions it is noticeable that the optimized variant provides much less inclination of the bearing surface without violating any of the given restrictions. However, it might be worth mentioning that the rotating velocity of these large turbochargers is approximately 10,000 rpm.

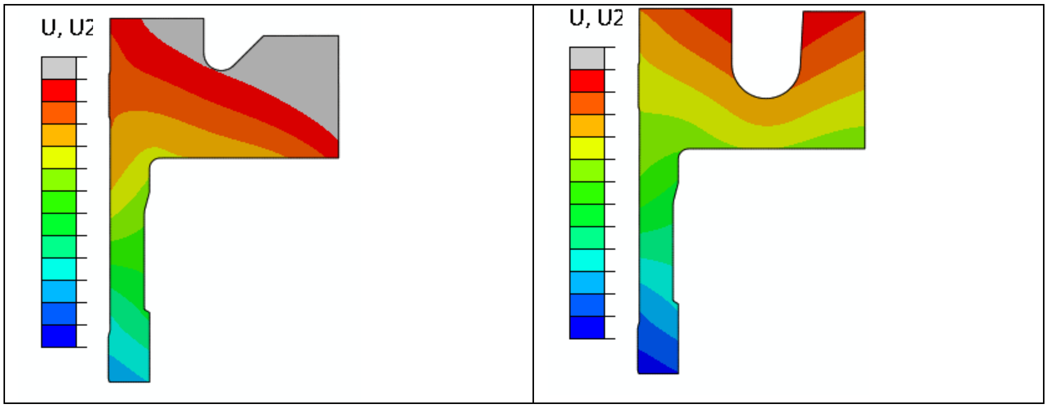
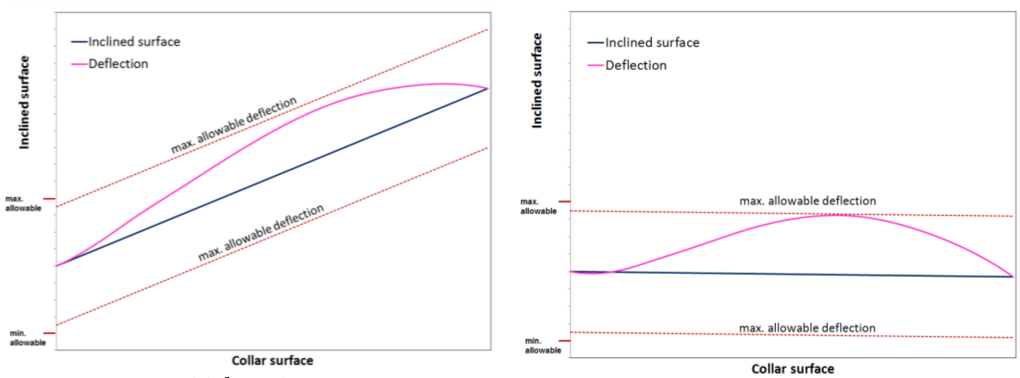


Figure 5. Comparison of an initial design (left) and an interesting improved design (right) under service conditions - axial displacement distribution

Finally, a satisfactory design was found that provides good control over the oil gap in service while still working sufficiently well in the emergency situations considered. Figure 6 provides an impression of the improvement in the skewing and deflection of the collar bearing surface under realistic loading conditions. While the initial design, as shown on the left, still skews far too much to fulfill the given design criteria, the improved design demonstrates just a minimum of skewing and deflection under realistic loading conditions in service.



Initial Design

Improved Design

Figure 6. Inclination and deflection of the bearing surface under realistic loading conditions

5. Conclusions

A thrust collar bearing design has been successfully optimized using Isight. The design obtained fulfills ABB Turbocharging's exacting quality demands in terms of efficiency, oil flow control and reliability in all the service and emergency conditions required by demanding ABB Turbocharging customers.

Excluding the effort for the adaptation of Isight to a certain given computational environment that appears to be far from a "plug and work" solution, the cost-benefit relationship between the process realization and optimization in Isight is considered favorable compared to the conventional way of designing a part like this. The DoE pre-study and the optimization itself revealed rather interesting information, both on the design and on the influence and interaction of the given variable parameters. Some interesting designs were discovered, opening the mind for completely new design features and thus supporting the creativity of the engineers.

Naturally, the optimization does not change the nature of the challenge to find an acceptable or even optimal compromise among competing targets. This has been done using multi-objective optimizations followed by an evaluation of Pareto surfaces, by including and weighting all targets within a single objective. Depending on the weighting of the target, different improved solutions are obtained that still need to be leveraged by the designer.

Most probably, all complex designs that are based on a certain number of parameters and target functions with competing contents will reveal several local optima in addition to the global one. As a result, stochastic or genetic algorithms will be generally required unless an acceptable pragmatic solution can be obtained using a simple gradient-based optimizing component. The pure number of iterations required by the more explorative methods presupposes an even more intelligent model, providing perfect accuracy and robustness in a still lean analysis. However, without the Abaqus token reduction feature in Isight, most optimizations of this kind would become impracticable.

The current optimization has been conducted with constant mechanical and thermal boundary conditions derived from CFD analyses which did not account for the deformations in the thrust collar bearing. As these deformations are known to have a considerable influence on the mechanical and thermal conditions in the thrust bearing, the introduction of a simplified feedback loop is under consideration in the given process to account for these effects during the optimization.

6. References

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