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[Extended Abstract]

Robust design optimization of a steam turbine labyrinth seal based on surrogate models

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Introduction

The general steam turbine development goals are to generate high performance with a low amount of costs. In the case of labyrinth seals, high performance can be realized with low sealing mass flow and to avoid high costs by using cost-effective materials. The hurdle in labyrinth seal development is friction windage, which can be reduced by a high sealing mass flow or high-cost materials, due its properties to withstand high temperatures. These options are contrary to the objectives to generate high performance with a low amount of costs. Therefore in this case a multi-objective optimization is a useful approach to tackle both aspects. Furthermore typically the conditions during the design phase of these components are assumed to be deterministic, which can result in unwanted differences in operating behavior, since design and process parameters should also be seen as stochastic parameters. Therefore the optimization should also take into account these uncertainties, which leads to a so called robust design optimization.

Methods

This paper will present a robust multi-objective optimization of a labyrinth seal like shown exemplary in 1, used in steam powered power plants. The contrary objectives of this optimization are to minimize the mass flow and to minimize the total enthalpy increase in order to increase the performance and to reduce the temperature, which result in lower-cost materials. This kind of optimization was already presented for the deterministic case in [1].

Therefore the focus topic should be the robustness aspect regarding varying thermodynamical conditions (e.g. the pre-swirl), manufacturing tolerances (geometric tolerances) and operational conditions to be involved into the optimization. So that the final design is not only optimized for its deterministic values but also robust under its uncertainties.

To achieve a robust and optimized design, surrogate models are trained and used to replace the computational fluid dynamic solver (CFD), in order to speed up the calculations. Compared to most used techniques in literature, the robustness criteria are directly involved in the multi-objective optimization, which means, that every design, which is a potential candidate for the final Pareto front of the multi-objective optimization, is checked for the robustness criteria. If the robustness criteria are not met, then the objective values are penalized. This will lead to a more robust Pareto front in the end of the optimization, as in a pure deterministic one. This method needs a lot of design evaluation, which would be not effective, if a CFD solver is used.

In most literature a single [2] or double loop approach [3] is used for this kind of optimization, which means that the deterministic optimization is performed and afterwards the robustness of the optimal design is verified. If the wanted robustness is not given, the optimization with adjusted constraints is repeated, until the robustness criterion is reached. These methods do not take into account the robustness criteria directly during the optimization, which might be a drawback to obtain a optimal compromise solution between robustness and the objectives. Further more its difficult to perform these steps for a complete Pareto Front.

The presented approach also requires that the surrogate models are very accurate in order to evaluate the objectives and robustness criteria correctly. Therefore a self-developed hybrid surrogate model is used.

The focus of the paper will be the description of the surrogate model creation and the methodology to use them for the robust multi-objective optimization. To show the benefit of the robust design optimization, there will be also a comparison between the pure deterministic and the robust optimization. Furthermore a short description of the used parametric labyrinth seal and the CFD setup will be given.

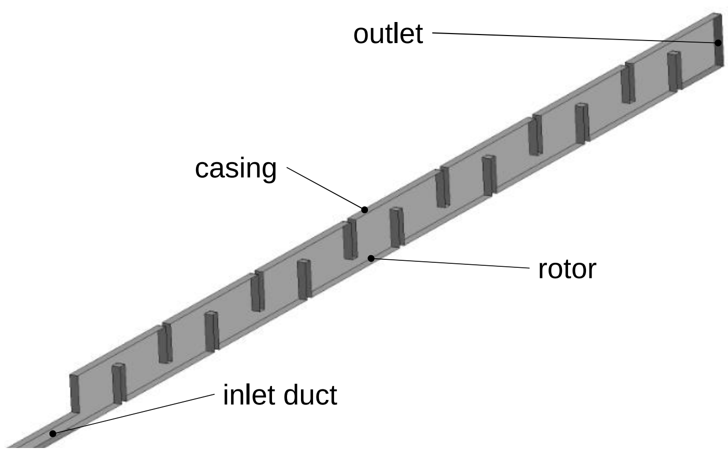

Figure 1. Exemplary labyrinth seal

References

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