Optimization of a Turbine Vane Endwall Using a Combined Natural and Numerical Approach

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Aerodynamic performance and cooling management in a gas turbine is directly related to the overall performance of an engine. In order to achieve higher efficiency, modern gas turbine development is focused on improvement of external and internal aerodynamic & thermal management. Therefore, the present study is dedicated to the optimization of a vane-endwall-junction in a turbine cascade.

In previous years, the design of vane-endwall-junctions in turbine passages has been the subject of investigation in terms to reduce the losses caused by secondary flow phenomena and also to reduce the adiabatic wall temperatures of the endwall itself. These two objectives – minimization of losses and endwall-temperature – were achieved with a change of the endwall shape, either by fillets or bumps or highly three-dimensional endwall shapes.

In the present research however, a novel approach of a combined natural and numerical optimization of a turbine vane endwall is presented. In a first step, the endwall of a linear turbine cascade is covered with an ice-layer and shaped due to the natural design goal of minimum energy dissipation. This endwall contour is determined after achieving steady-state and acts as a starting contour for a subsequent classical numerical optimization by using a genetic algorithm. The numerical optimization has a single-objective goal, either minimum aerodynamic losses in the turbine passage or minimum heat transfer rates on the endwall.

The optimization of complex geometries exposed to fluid flow plays a key role in the development of high performance industrial components. However, each change of geometry influences the flow characteristics, often in an unpredictable way. The iceformation method presents a natural optimization procedure for finding optimal shapes concerning minimum energy dissipation. Therefore, the endwall of a linear turbine cascade is covered with an ice-layer of constant thickness and exposed to a water flow. During the formation process, the flow field alters the shape of the endwall and, at the same time, the ice layer contour influences the flow field. The steady-state ice contour is measured using a laser-based triangulation sensor.

Then, the determined 3d-scatterplot is converted into geometry defining points. This parameterization of the geometry is done using a Bezier-plane approach using 18 design variables. The geometry is generated using GAMBIT™ and the grid is generated using CENTAUR™. Momentum and energy equations are solved by FLUENT™ 6.3.26. The geometry determined by the solver is classified according to its "fitness", represented by the minimum aerodynamic drag on one side and minimum heat transfer on the other side. The optimum is searched using the real-coded NSGAII Genetic Algorithm (GA) from Deb in a single-objective application.

As a result of the experimental investigations, the iced endwall contour greatly adapts to the flow field in the turbine cascade. The ice-layer contour represents points of high turbulence, e.g. the leading edge horseshoe vortex, in terms of thin ice thickness. In a large range of test parameters, the basic ice-layer-topology remains constant apart from thickness variations. Numerical calculations using the experimentally determined endwall show a reduction of heat transfer peaks due to the specific accumulation of ice. The aerodynamic performance of the contoured endwall did not change significantly due to the already well performing vane profile.

In a next step, the experimentally found ice contour of the endwall determines naturally the parameterization for the starting configuration of the subsequent numerical optimization, see figure 1. The goal functions in this procedure can be minimized drag in the passage or minimized thermal load.

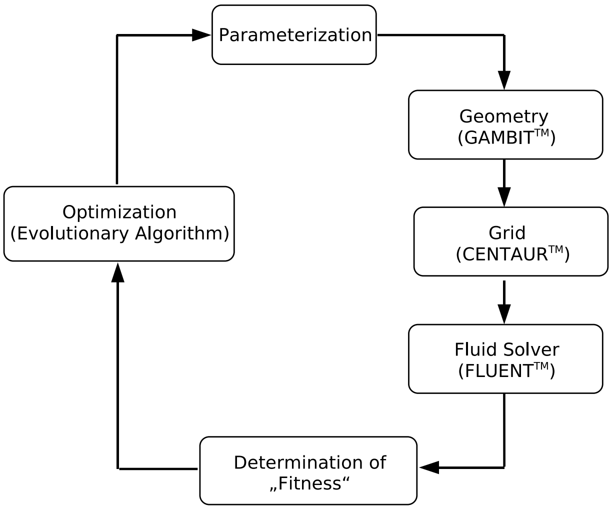

Figure 1: Optimization process

An interesting result occurs for the optimization with the goal function of minimum heat transfer to the endwall: The shape of the ice layer was basically maintained but changed slightly in the area of the horseshoe vortex.

Contrary to that, the shape of the endwall with the goal function of minimized drag is more flattened, only the radius at the vane-endwall-junction preliminary given by the ice contour, is kept.

These two results lead to the conclusion that the two chosen goal functions are opposing each other and that a final optimized endwall shape that increases the performance of the complete turbine stage can only be found with a further multi-objective approach in the algorithm.

Yet, the presented results with the combination of an experimental and numerical optimization approach could lead to innovative and new endwall designs in terms of mitigate all losses that occur in turbine passages caused by the secondary flow losses due to the vane-endwall-junction while at the same time surface temperatures are kept at an acceptable level.