Conjugate Heat Transfer Simulations for a Film Cooled Nozzle Guide Vane of a Highest-efficient Industrial Gas Turbine

Karsten Kusterer and Jens Dickhoff, B&B-AGEMA GmbH, Aachen, Germany
Ryozo Tanaka and Tomoki Taniguchi, Kawasaki Heavy Industries LTD., Akashi, Japan
Dieter Bohn, RWTH Aachen University, Germany

Long Abstract

Introduction

In order to achieve high process efficiencies for the economic operation of stationary gas turbines and aero engines, extremely high turbine inlet temperatures at adjusted pressure ratios are applied. The allowable hot gas temperature is limited by the material temperature of the hot gas path components, in particular the vanes and blades of the turbine. Intensive cooling is required to guarantee an economically acceptable life span of the components (e.g. combustor walls, turbine vanes and blades, disks, etc.) that are in contact with the hot gas.

The initial design process of the cooled vanes and blades still depends on fast design procedures for the temperature field determination in the blade sections based on 1D and 2D calculation models for the internal flow path (1D network model) and the external flow of hot gas around the airfoil (2D boundary-layer code or 2D RANS calculation) coupled to the solid body heat conduction code by application of heat transfer correlations. However, the Conjugate Heat Transfer method for fully coupled three-dimensional flow field, heat transfer and heat conduction achieved more and more attention in the design process for modern gas turbines. With regard to the inter-relations between the external fluid flow, the internal fluid flow and the heat conduction, it is obvious that a coupled calculation can lead to a higher accuracy in thermal load predictions during the design process. Taking these considerations into account, a coupling process was developed by Bohn et al. [1 – 3] at the Institute of Steam and Gas Turbines (IDG), RWTH Aachen University, which follows a homogeneous coupling procedure for the Conjugate Heat Transfer (CHT) calculations to be applied for thermal load prediction of cooled components in gas turbines. The method involves the direct coupling of the fluid flow and the solid body using the same discretisation and numerical principle for both zones. This makes it possible to have an interpolation-free crossing of the heat fluxes between the neighbouring cell faces. The detailed description of the conjugate calculation technique and its validation is provided by Bohn et al. in [4]. Today, the conjugate heat transfer procedure as explained above already became a standard application option in almost all modern commercial Computational Fluid Dynamics (CFD) tools. Furthermore, the CHT simulations of the cooled vanes and blades represent a state-of-the-art technology and an important step in the design process for the modern gas turbines. Depending on the kind of applied grid structures, such models include today usually more than 20 million cells enabling the designers also to include more and more geometric details in the simulation models.

Due to an application of the technology, it is possible to detect early in the design process deficiencies in the cooling design, which are caused by complex three-dimensional flow phenomena and uncertainties of applied heat transfer conditions. Their impacts cannot be considered by the simpler design approaches. The improved design based on the CHT technology contributes to the advanced design of the hot gas components by reducing the cooling air amount required to fulfil the cooling task and, as a result, it also contributes to the increase in thermal efficiency of the gas turbine cycle. Therefore, modern industrial gas turbines can achieve thermal cycle efficiencies above 40%. The recently developed Kawasaki L30A 30MWel gas turbine can be given as one example, claiming for the presently highest efficiency in its class [5].

1. Description of investigated configuration

The investigated configuration is a complex cooling configuration for a test version of a 1st stage nozzle guide vane of a high efficiency industrial gas turbine. It includes an internal convective cooling scheme with impingement cooling for further enhancement of the heat transfer on the internal walls. Furthermore, numerous geometric features as ribs and pin fins also contribute to the advanced design for enhanced internal heat transfer. The leading edge of the vane is extensively film cooled by a showerhead cooling design consisting of several rows of inclined cooling holes. Additional film cooling is established along the suction side. A Trailing edge injection of cooling air is provided through modern type of cutback slots.

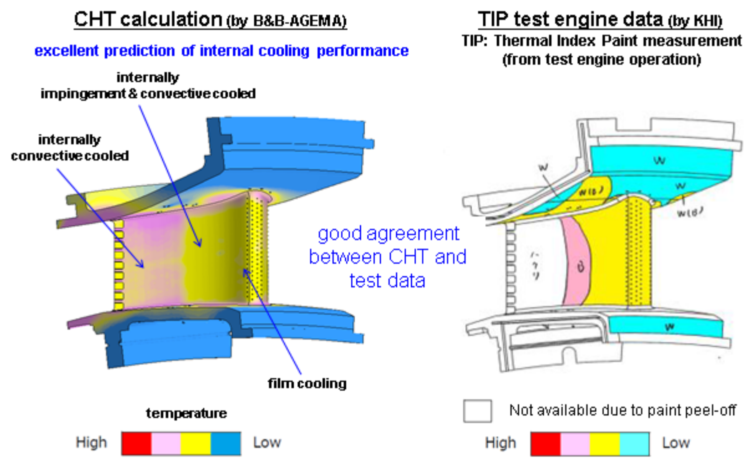

Figure 1. Example results for comparison of thermal load

2. Exemplary Results

The complex configuration of the vane has been analyzed by the CHT technology under boundary conditions as to be expected in the gas turbine engine, i.e. realistic high temperature combustion gas flow. Further, the test configuration was implemented into a test engine at the Kawasaki Akashi plant and operated under typical load condition of the gas turbine. Thermal Index Paint (TIP) measurements allowed the determination of the thermal load distribution qualitatively and quantitatively. Figure 2 shows an example for the comparison between numerically obtained CHT results and the TIP measurement results. The paper will discuss the results in detail. In addition, the effect of a Thermal Barrier Coating (TBC) application on the thermal load of the substrate materials is analyzed and discussed as well as the impact of advanced-shaped film cooling holes [6], which have the potential to establish anti-vortex film cooling structures.

References

[1] Bohn, D., Bonhoff, B., “Berechnung der Kühl- und Störwirkung eines filmgekühlten transsonisch durchströmten Turbinengitters mit diabaten Wänden, ” *VDI-Berichte 1109*:261 - 275, 1994.

[2] Bohn, D., Bonhoff, B., Schönenborn, H., “Combined Aerodynamic and Thermal Analysis of a High-pressure Turbine Nozzle Guide Vane,” IGTC-108, Yokohama, Japan, 1995.

[3] Bohn, D., Bonhoff, B., Schönenborn, H., Wilhelmi, H., “Prediction of the Film-cooling Effectiveness in Gas Turbine Blades Using a Numerical Model for the Coupled Simulation of Fluid Flow and Diabatic Walls”, *ISABE 95-7105*:1150 - 1159, Melbourne, Australia, 1995.

[4] Bohn, D., Krüger, U., Kusterer, K., “Conjugate Heat Transfer: An Advanced Computational Method for the Cooling Design of Modern Gas Turbine Blades and Vanes,” in *Heat Transfer in Gas Turbines*:58-108, Sundén B and Faghri M (eds). WIT Press, Southampton, 2001.

[5] Tanaka, R., Koji, T., Ryu, M., Matsuoka, A., and Okuto, A., "Development of High Efficient 30 MW Class Gas Turbine: The Kawasaki L30A," ASME-paper GT2012-68668, Copenhagen, Denmark, 2012.

[6] Kusterer, K., Elyas, A., Sugimoto, T., Tanaka, R., Kazari, M., and Bohn, D., "The NEKOMIMI Cooling Technology: Cooling Holes with Ears for High-efficient Film Cooling," ASME-paper GT2011-45524, Vancouver, Canada, 2011.

.