Optimized Approach for the Determination of the Solid Temperature in a Steam Turbine in Warm-Keeping-Operation

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Long Abstract

Introduction

The determination of the temperature distribution in the thick-walled components in steam turbines is increasing in relevance. Due to the growing share of renewable power generation, power plants with a high flexibility and a high integral efficiency are required. The prior feed-in by renewables in liberalized energy markets forces the conventional power plants into high load ramps and fast start-ups. These operational conditions lead to high thermal stress inside the heavy components and thus to more frequent damages and a reduced lifetime [1].
Most affected by these thermal stresses is the steam turbine, especially the high and intermediate pressure parts. During a cold or warm start-up high temperature gradients arise resulting in Low-Cycle-Fatigue. One option to prevent this risk is to keep the steam turbine warm between a shut down and a start-up. General Electric has developed a concept for warm-keeping respectively pre-warming of the steam turbine with hot air [2]. After a certain cool-down phase, hot air is passed through the turbine while the turbine is rotated by a turning engine.
To improve the ability for a fast start-up, information about the metal temperature inside the rotor and the casing are crucial. However, the temperature distribution of the inner casing and especially the rotor cannot be measured without high additional effort. Furthermore, coupled numerical solid and fluid dynamic approaches (i.e. Conjugate-Heat-Transfer (CHT)) with a high level of detail are not able to simulate a whole multistage turbine. Thus, a calculation model with a sufficient accuracy and also manageable calculation effort is required. In the present work, a hybrid – numerical Finite-Element-Method (FEM) and analytical – approach has been developed to calculate the solid body temperatures of a steam turbine in an efficient way.
The present paper is separated into three main parts: At first, the description of a Conjugate-Heat-Transfer reference model. Second, the introduction of the optimized approach – called Hybrid-FEM-Model – and finally, the comparison of CHT and Hybrid-FEM-Model.

Method

The *Hybrid-FEM-Model* is based on a solid body (FEM) model with additional analytical equations (expressions) describing the external heat transfer. Two separate analytical calculation approaches are developed: A flow model and a radiation model. For the flow model, an analytical correlation for the convective heat flux from the main flow to the solid surfaces has been developed. Due to the different flow phenomena at the blade, the vane and the shrouds, separate correlations for these main surfaces are used. This semi-empirical correlations, which are based on isolated CHT calculations [3], have a wide scope for warm-keeping operation with air.
The radiation model is also based on an analytical approach by the use of view factors, which have to be determined once for characteristic geometries. These view factors are calculated with two different numerical Software-Tools (ANSYS Fluent & CFX). A comparison of these results is given in the present paper.

The numerical solid body mesh of the Hybrid-FEM-Model has much bigger cells compared to that one of the CHT-Model. Since, no flow field has to be calculated, the mesh size can be reduced rapidly. A mesh study offers a mesh reduction ratio of 80. The reduced mesh size connected with the saved effort for fluid dynamic calculations lead to much faster calculation time. The Hybrid-FEM-Model is able to calculate a steady-state warm-keeping operation point in 0.5 % of the time which is required by the CHT-Model.

Figure 1 shows a scheme of the Hybrid-FEM-Model with the main heat transfer mechanisms. The model has been developed on the basis of one repetitive stage of an intermediate pressure steam turbine and has been verified with steady-state CHT simulations in several warm-keeping operation points.

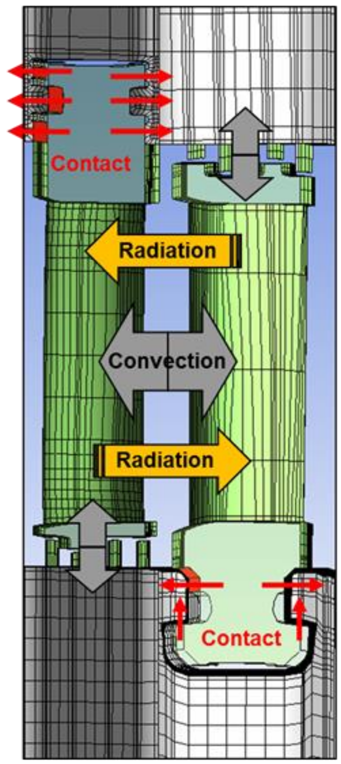

Figure 1: Scheme of the Hybrid-FEM-Model

The single-stage model serves for the development of the hybrid approach. Furthermore, the calculation results of the Hybrid-FEM-Model can be compared to various simulation results of the CHT-Model due to the manageable calculation effort. For further investigation, the Hybrid-FEM-Model has to be extended to several stages to enable the determination of the temperature distribution of a whole multistage Turbine.

References

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