Test Rig for Applied Experimental Investigations of the Thermal Contact Resistance at the Blade-Rotor-Connection in a Steam Turbine

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Long Abstract

Introduction

A high share of the worldwide power generation is based on steam turbines in conventional power plants. However, the operational requirements for these power plants have changed significantly in the past years due to the increasing contribution of renewables. Especially wind and solar power lead to a highly fluctuating electricity feed-in. Thus, conventional power plants are used to compensate the volatility by means of flexible operation.

One method to improve the flexibility of conventional power plants is a reduction of the start-up time by pre-warming respectively warm-keeping of the steam turbine. Thus, the lifetime consumption due to thermal stress and LCF as well as the start-up costs can be reduced. Recent investigations of the authors [1] have shown, that in a new concept of warm-keeping operation with a hot air, the blades and vanes conduct most of the heat to the heavy components (i.e. rotor and casing). The bottleneck for the heat transfer to these components is the connection between the blade / vane root and the rotor / casing.

In literature, various studies about the thermal contact resistance can be found. Yovanovich [2] and Madhusudana [3] give a summary of the research done on this topic. Most of the studies focus on fundamental research by analyzing the influence of different material properties as for example surface roughness, contact microhardness, microgaps and thermal conductivity. Different experimental methods are used to develop correlation equations. As an example the Cooper, Mikic, and Yovanovich contact conductance model can be named.

The present paper introduces a thermal contact resistance test rig, which is designed for application-oriented investigations. The aim of the investigations is to quantify the contact heat transfer at the blade-rotor-connection of a steam turbine. The one-dimensional approaches known from literature cannot be transferred directly to this three-dimensional problem. The used blade root design of an immediate pressure steam turbine has four contact surfaces, two in radial and two in axial direction (Fig. 1). The centrifugal force influences the thermal contact resistance at the radial contacts. This leads to a temperature difference between the blade and the rotor, which results in a bigger thermal expansion of the blade and thus in a higher contact pressure at the axial contacts. Furthermore, the experimental set-up provides the possibility to investigate different operating influences like oxidation. In the second part of this paper, an uncertainty analysis is conducted for quantification of the uncertainties of the relevant variables. First measurement results are presented and discussed in the last chapter.

1. Methods

The test rig, which is shown in Fig. 1, is designed for the measurement of the thermal contact resistance. Different designs of blade or vane roots can be investigated. The test rig offers the possibility to analyze the influence of the rotational speed (i.e. contact pressure), the ambient pressure and the contact surface properties (e.g. roughness, oxidation layer, lubricant). Furthermore, the radiation influence via the air pockets which are located between the contact surfaces can be investigated.

The test rig consists of five parts: The traction system, the cooling system, the venting system, the hydraulic system and the data logging system. The centerpiece of the test rig is the traction system. The tensile force – representing the rotational speed – is initiated by a stamp. The tensile force can be adjusted by the hydraulic system and is measured by a load cell between the specimen and the fixed bearing. A heat flux is induced by two heating cartridges located at the top of the specimen in a horizontal plane. The heat sink is a drilling in the bottom which is passed through with cooling water. The cooling water is provided by the cooling system. An air cooler dissipates the heat absorbed from the specimen. A tempered water tank and a peristaltic pump ensure the reproducibility of the measurement. The specimen and the traction system are surrounded by a chamber for the regulation of the ambient pressure.

The specimen itself consists of two separate components: The blade part and the rotor part. Both parts are made of the same material (X22 CrMoV 12-1) which is heat resistant up to 600°C and similar to the material which is used in modern high and immediate pressure steam turbines. The geometry of the blade has been modified to enable the heat input and the tensile strength. For the design of the specimen, numerical Finite Element Methods and Conjugate Heat Transfer calculations were used to optimize the stability, the homogeneity of temperature and the heating up time. The blade root design is straightened, but the contact surfaces are basically like the original design. The specimen is insulated to minimize the heat loss.

For the measurement of the temperature distribution inside the specimen 26 thermocouples are used in total. These Type-N thermocouples are calibrated in the final experimental set-up to minimize the measurement error. The metering points are shown on the left in Fig. 1. The upper four and the lower six metering points are used to measure the heat input and output. This energy balance is more detailed as the measurement of the electricity input and the temperature difference of cooling water inlet and outlet. The other metering points are used to validate the numerical specimen model and to determine the thermal contact resistance. For monitoring of the experimental set-up, the temperature within the vacuum chamber, the cooling water tank, the reference oil bath and the heating cartridges as well as the pressure within the pressure chamber are recorded.

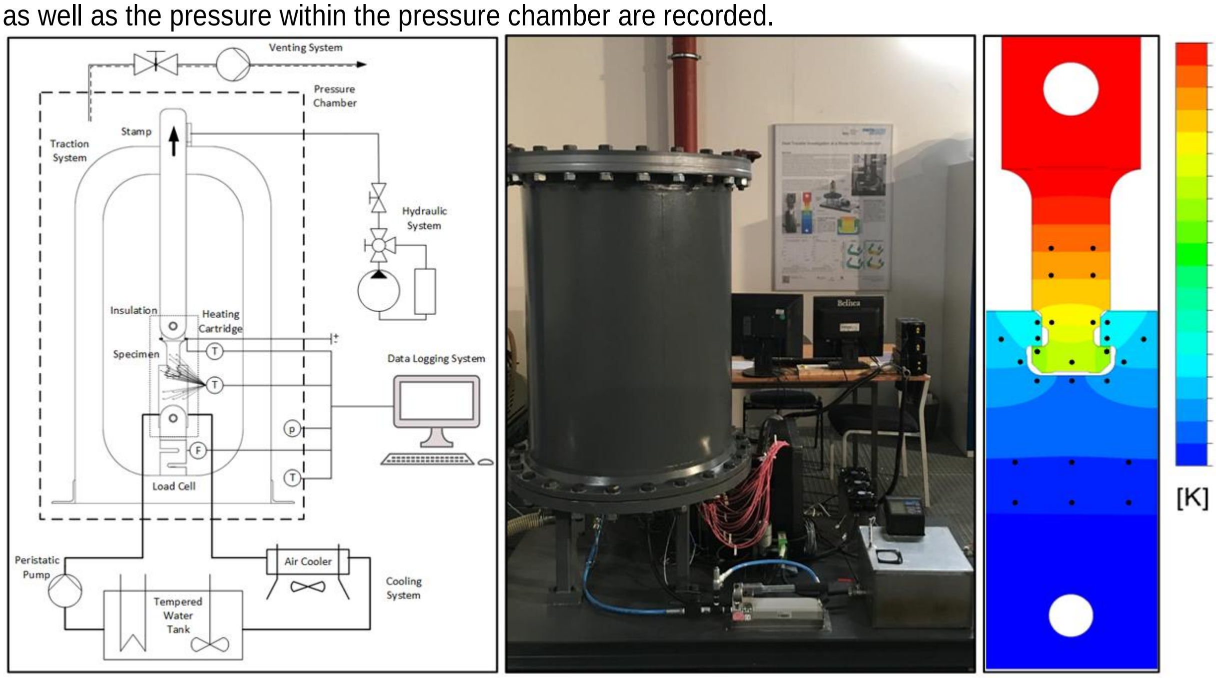

Figure 1: Schematic setup (left), test rig (center), numerical model (right)

References

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