Design of a Rotating Test Rig for Transient Thermochromic Liquid Crystal Heat Transfer Experiments

Christian Waidmann, Rico Poser, Sven Nieland, Jens von Wolfersdorf, Institute of Aerospace Thermodynamics, University of Stuttgart, 70569 Stuttgart, Germany

ISROMAC
SYMPOSIA ON ROTATING MACHINERY
Since 1985

Long Abstract

Introduction

Heat transfer can significantly differ between a non-rotating and a rotating cooling channel. Coriolis forces and rotational buoyancy forces in a rotating cooling channel induce secondary flows which alter the flow structure and thus the heat transfer distribution at the channel walls.

A test rig to investigate engine-similar turbine blade cooling geometries under the influence of rotation has been designed. Currently, the rig is being set up at the Institute of Aerospace Thermodynamics (ITLR) at the University of Stuttgart. The transient thermochromic liquid crystal (TLC) technique will be used to obtain spatially resolved heat transfer measurements [1]. For this technique optical access to the TLC-coated channel walls is required. Therefore, the cooling channel geometry is manufactured out of Perspex. The test model will be mounted inside an aluminum housing at the end of the rotor arm at a mean model radius of 750 mm. Cooling air will be supplied to the model through insulated pipes inside the hollow shaft and the hollow rotor arm.

Rotational speeds of up to 900 rpm in combination with the possibility to operate the test model with fluid pressures of up to 10 bar provide a wide range of achievable test conditions. This ensures that the required rotation numbers (Ro) and buoyancy numbers (Bo) can be reached.

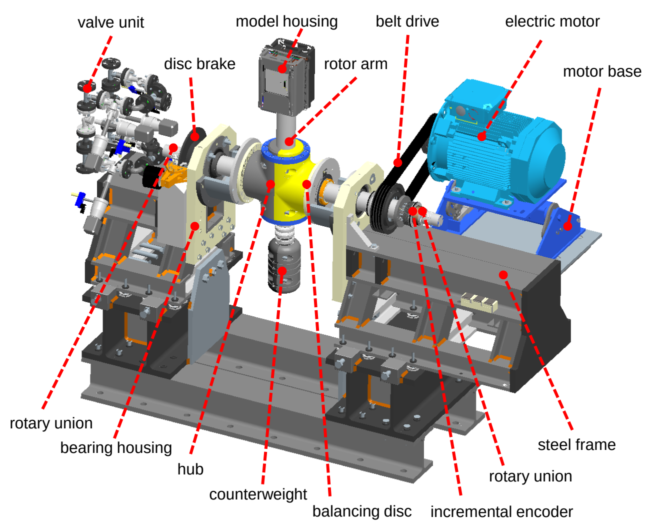

Figure 1. Rotating Test Rig for Transient Heat Transfer Measurements

To validate the functionality of the test rig, preliminary tests have been conducted to investigate particular measurement aspects. A non-rotating preliminary test rig with comparable air supply passages has been set up to assess the achievable temperature change, that is required for the TLC tests. TLC mixtures have been investigated in non-rotating tests to determine whether they can be applied to cope with the expected spreading of heat transfer coefficients in rotating channels. Furthermore, preliminary rotating tests have been conducted to validate the synchronization of a stationary camera and strobe light with the speed of a rotating disc. Test patterns on the disc allowed to evaluate motion blur effects for different strobe flash settings.

1. Fluid Temperature Change

The transient TLC technique is based on the measurement of TLC indication times in conjunction with a change in fluid temperature. Most non-rotating TLC experiments make use of electrical heaters to generate the fluid temperature change and thus obtain the heat transfer from the fluid to the channel walls. However, the temperature gradients inside the fluid determine the direction of the rotational buoyancy forces. Hence, the heat flux needs to be in the correct direction from wall to fluid for rotating experiments. Therefore, LN_2-cooled air is used to generate the fluid temperature change.

A bypass valve unit consisting of six switching valves is positioned near to the rotary union, which introduces the fluid into the supply pipes inside the hollow shaft. This valve unit allows the air supply passages between heat exchanger and valve unit to be cooled prior to the experiment. Thus, heat losses can be minimized to achieve a steep gradient for the temperature change. Additionally, the supply pipes inside the shaft can be precooled by cooling air provided through an additional rotary union on the second end of the shaft.

2. TLC Mixtures

Rotation-induced secondary flows can significantly increase the spreading of heat transfer coefficients compared to a non-rotating channel. Heat transfer can be enhanced on one channel wall and at the same time drastically reduced on the opposite wall, depending on the flow direction and direction of rotation. This results in a wide range of indication times. In preliminary tests a TLC-mixture of five different narrow band TLC types to achieve multiple TLC indications in a single experiment has been investigated.

3. Stationary Cameras

The TLC colorplay will be captured by stationary cameras installed along the circumference of the rotor. An incremental encoder on the shaft will be used to synchronize the cameras and strobe lights with the rotational speed, resulting in the frame rate to be directly dependent on the rotational speed. For low speeds the frame rate of a single camera would be too low, so additional cameras will be needed. In post processing image registration algorithms will be applied to match the frames from several cameras and to combine the footage into a single video. To validate the camera and strobe light trigger scheme, preliminary tests on a rotating disc have been conducted. The rotating TLC tests will be conducted without ambient light, so that the exposure time is determined only by the strobe flash duration. In preliminary tests motion blur depending on rotational speed and strobe flash intensity has been evaluated.

References

[1] R. Poser and J. von Wolfersdorf. Transient liquid crystal thermography in complex internal cooling systems. *VKI Lecture Series - Internal Cooling in Turbomachinery, von Karman Institute for Fluid Dynamics*, (VKI LS 2010-05), 2010.