Heat Transfer in turbine blades
Report

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December 8, 2010

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1 Introduction

Turbine blades often operate in very high temperature condition because the efficiency at high temperatures is much better than at lower. The blades can't operate at any temperature. There's a upper limit given by the material. It has a melting point and so a loss in its strength at high temperatures. Thus the blades have to be cooled. In practice this is realised by blowing air from the compressor stage inside of them.
The aim of the experiment is to maximize the amount of removed heat by convection. There are different possibilities to reach that goal. We can increase the convection coefficient α, the temperature difference between the cooling air and the blade, the surface area or changing the fluid. To increase the α there are different possibilities. The flow speed could be increased or we produce a turbulent flow instead of a laminar. In the case of the turbine most of the parameters are fixed. The only parameters we can change is the shape of the flow and the surface area.
Our experiment is designed to test different obstacles. We only tested one due to the short time slot.

2 Labaratory description

The test section ist shaped as shown in figure 1. At the back there's a aluminium plate with a bonded thermochromatic liquid crystal (TLC) sheet on its surface. At the top there's a plexiglas so that we can observe the liquid cristal layer. In the middle channel there are some obstacles for the flow.

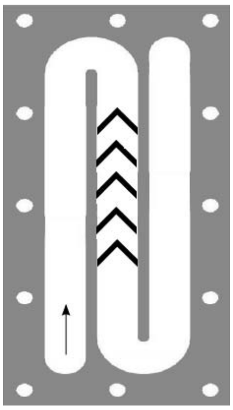

Figure 1: Testsection with obstacles [1]

In front of the plexiglas there's a camera which is focussed on a small area between two obstacles. The test section is enlighted by a lamp so that the camera is able to get better pictures. The test section is connected to a water cycle. With a three-way valve we can connect the test section to it. There's also a valve to control the mass flow.

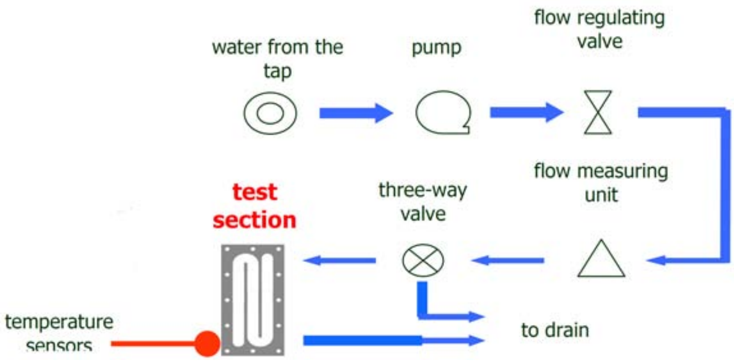

Figure 2: Experimental setup [1]

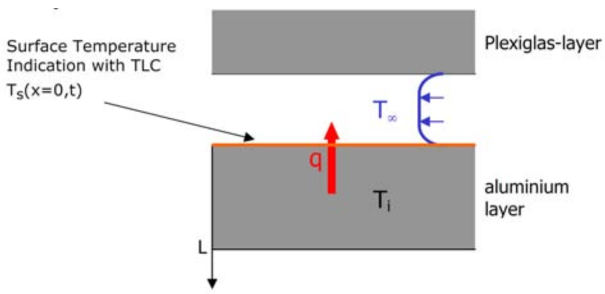

Figure 3: Test section [1]

2.1 Operating procedure

As mentioned we use water instead of air for cooling. So that we can compare the measurements with a real system we use the same Reynolds number in our test section. To reach that we control the mass flow.
First we pump warm water through the test section to get the same temperature in each device. Is this the case we close the three-way valve. Now there's no flow through the section anymore. After changing the hot water with cold water we reopen the three-way valve to cool the test section and start the measurement.

3 Theory

Liquid crystals reflect only a specific wavelength at a specific temperature. So it is possible to calculate the temperature out of the color after a calibration. To calculate α we compare the conductive heat flux through the aluminium layer with the convective heat flux which has to be the same. For the calculation of the conduction a 1D situation is assumed. This is fine because the length and the width are large compared to the thickness of the aluminium plate. We also assume a semi infinit plate. This is valid for a short time because the temperature change at the back of the aluminum plate is very small compared to the temperature difference between the fluid and the ceiling of the plate. In our case the approximate time for which the assumption is accurate is $1.6s$. With this assumption we've got the same temperature at x equals infinity for every time where x is the position behind the TLC sheet. We also know the temperature of the ceiling of plate which we calculate out of the color of the TLC sheet. Finaly we get the following equation for α which can be solved numerically.

$$\frac{T_s - T_i}{T_\infty - T_i} = 1 - \exp\left(\frac{\alpha^2 at}{\lambda^2}\right) \operatorname{erfc}\left(\frac{\alpha\sqrt{at}}{\lambda}\right) \tag{1}$$

Where λ equals the heat flux coefficient, α the convective heat transfer coefficient, t the time, a a composed material constant, T_∞ the temperature of the cold entering fluid, T_s the calculated temperature at the surface and T_i the initial temperature at the back of our plate.

4 Results

4.1 Calibration process and results

For calculating the heattransfer coefficient we need a numerical value of the temperature at the cooled surface T_s. The camera instead gives an electronic signal describing the color of the liquid cristal. To transform this into a numerical value we need reference points. Because this is time-consuming it has been made before our experiment. We remain with a short description of the procedure.

To get exact values it is important that all measurements are made under steady state conditions. The temperature stays constant if there is no gradient anymore. In our case this means that the fluid needs to have almost the same temperature as the channel and in addition the temperature inside the aluminium layer needs to be constant- $T_s = T_\infty$. Now one can measure the temperature with the integrated sensor and match it to the observed color. This needs to be done for the whole range that the liquid cristal covers. The behaviour of the temperature indicators can change in time. To get even tough accurate results the calibration should be repeated before each experiment.

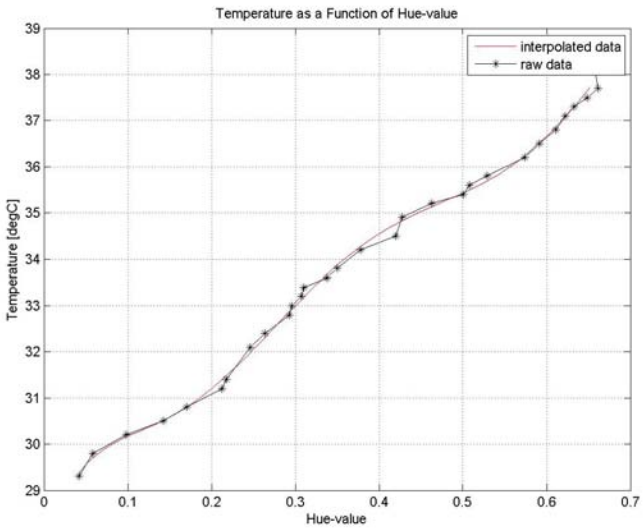

Figure 4: Used calibration to transform the observed colors into a temperature

4.2 Heat transfer coefficient

The heat transfer coefficient can be calculated numerically with the formula (1). The resulting analysis of the taken pictures are shown in figure 4.

Due to our assumptions only the values for $t > 1.6s$ are of interest. The decreasing α at the beginning does not make much sense, either the increase at $t = 0.7s$. This part of the curve discribes the non- steady state of fluid temperature in the beginning of the measurement.For $t = 1.5s$ theres the maximum of the curve and no gradient anymore. So our alpha equals $7.286 \cdot 10^4 \frac{W}{m^2K}$.
The reason why the coefficiecient α decreases after 1.6s can be explained with the assumptions that have been made for the experiment. We used the semi infinite slab to describe our cooled aluminium plate. This simplification can be made as long as the temperature of the wall stays constant. This is true for the meantioned $t > 1.6s$. Later the temperature difference decreases and with it the calculated heat transfer coefficient.

5 Conclusion

This experiment showed how easy it is to make temperature measurements using liquid cristals. The obvious errors in the graph make clear that there may occur inaccuracies due to the calibration. In this case it can be explained by the long time between calibration and experiment.

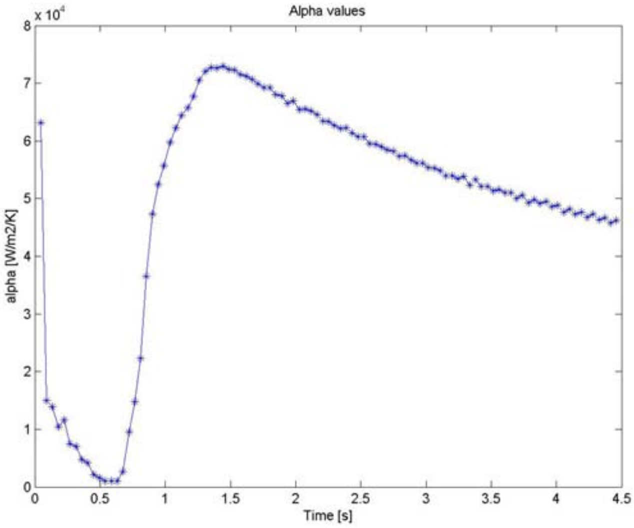

Figure 5: Coefficient alpha computed out of the measurements

5.1 Possible improvements

There are many possible ways of improving the experiment. Due to the length of all tubes the temperature at the begin of the cooling process is not uniform. It takes some time till all warm water inside of the tube is replaced. There are two ways to solve this problem. For one thing one can make all tubes as short as possible so that the timedelay gets shorter or you could use a threeway valve. This would be the best solution because the temperature of the fluid changes immediately. The measurements would also be more accurate if the main valve would be connected with Matlab so that the measurements would start automatically as soon as the valve is open.

References

[1] Heat Transfer Analysis Using Thermochromatic Liquid Crystal. http://www.ifd.mavt.ethz.ch/education/Lectures/exp_methods/Handouts/Handouts2010/Lab_HTC_2010; visited on November 25th 2010.