Liquid Cooling Of Gas Turbine Blade Using Thermo Electric Cooler

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Abstract- **Cooling the turbine blades in jet engine is one of the important and complex task. If turbine blades are cooled efficiently then more inlet temperature can be drawn to the turbine and thus high efficiency is the result. Present cooling technique mainly done by bleed air to reduces the blade internal temperature. The aim of this project is to use liquid evaporation along with thermoelectric technology for temperature reduction. The project involves taking the traditional heat pipe and vapor cooling techniques designed for turbine blades and combining it with a thermoelectric heat pump to increase the cooling effect on the blade. The cooling action for the heat pipe is provided by the thermoelectric material and the rejected heat is carried away by the bleed air. This decreases blade temperature to higher extent and thus high efficiency can be expected. The validation of the project is done using experimental setup involving sensor array and the data acquisition system. Computational fluid dynamics also used which confirms the results.**

Index Terms- **Turbine blade cooling, thermoelectric cooler, liquid coolant.**

I. INTRODUCTION

To increase the efficiency and the power of modern gas turbines, designers are trying to raise the maximum turbine rotor inlet temperature (RIT). Over the last decade this temperature has risen from 1500 K to 1750 K in some high-performance engines. New materials, such as ceramics, could help increase this maximum temperature even more in the future engines.

However, most of the recent improvements in inlet temperature of turbine rotor come from better cooling of the blades and a greater understanding of the heat transfer and the three-dimensional temperature distribution in the turbine passage. Increased gas temperature generally causes increased blade temperature and greater temperature gradients, both of which can have a detrimental effect on service life. In fact, modern turbo machinery operates under extremely complex three-dimensional flow conditions, and further enhancement in performance requires detailed knowledge of the gas flow structure. Particularly, the need to estimate operating conditions, turbulence, secondary flows and heat transfer rates demands that viscous models be examined. Near the hub and tip of a turbine stator/rotor passage, the flow is affected by the interaction between the side-wall boundary layer and stream-wise boundary layer. Although this region is thin, its effect on the overall aerodynamic performance cannot be neglected.

To design a high-performance turbine, designer has to understand the detailed three-dimensional flow field near the hub and tip. However, some important characteristics and flow parameters are strongly influenced by the turbulence transport near the solid walls and the wake region behind the airfoils of the blade. Under certain operating conditions, the boundary layer development on the blade surface is much enhanced due to the presence of adverse pressure gradients, which have considerable effect on the following rotor stage.

II. DESIGN, FBRICATION and TESTING

A. Design and fabrication detail

The basic design is first done using Catia V5, the Figure 1 shows the Catia design.

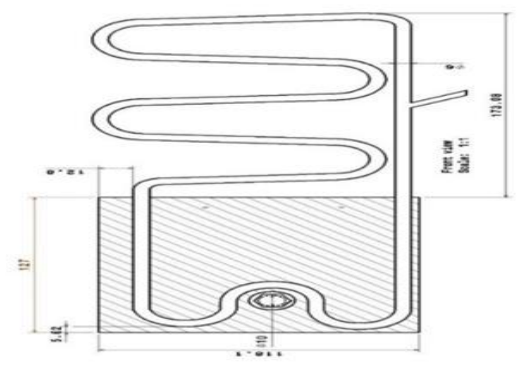

Figure 1. Model designed in Catia

Copper tubes have excellent heat transfer characteristics, it is easy to process and repair and easily available. Since they are widely used in refrigerators and air-conditioning because of their efficient heat transfer characteristics, we selected copper tubes for making the heat exchanger loops for this blade cooling experiment. It is designed giving a special geometry so that it will allow better heat transfer through the coolant circulating inside the heat exchanger.

Figure 2. Copper Pipe

For making the blade, two aluminum plates of size 4 inch x 5 inch are selected for the experimental purpose. To make the fabrications economical, above dimensions of blade is selected and this blade allows fitting of the heat exchanger loop which is already bent for minimum possible curvatures.

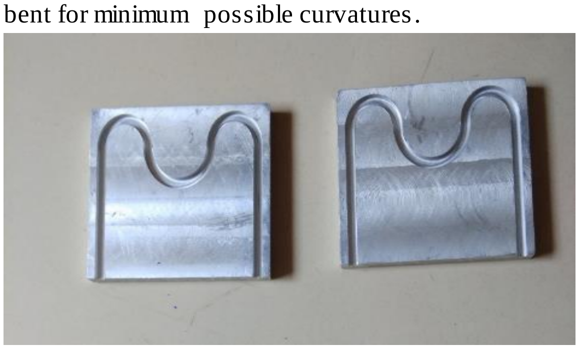

Figure 3. Grooves machined in aluminum block

CNC machining is the process used here for making grooves on 4 inch x 4 inch aluminum plate. The dimension of groove is of width 6.5mm, depth 3.5mm and sufficient tolerances have been given for thermal expansion. Two aluminum slabs were used and on both the plates grooves are made and then joined to form single rectangle plate.

B. TESTING

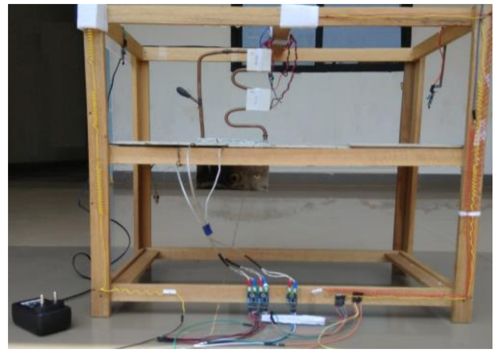

Figure 4. Test setup

This testing setup is custom made set up that consists of previously mentioned Arduino based Data Acquisition System. The blade is heated by LPG flame. The blower is used to cool the thermoelectric hot side. The heat from the blade is absorbed by the copper pipe by the help of coolant inside. Coolant vaporized by absorbing the heat from pipe and this evaporation gets condensed by ejecting heat to the atmosphere with the help of thermoelectric material. The heat removal increases in the thermoelectric material as the heat from condenser is given to the cold side of thermoelectric material. The thermoelectric material is powered by the 12 V and 2A DC current. The thermoelectric material is cooled by the blowing the air using blower.

III. RESULT AND DISCUSION

The blade model is assigned in the test set-up and test is carried on. Initially the set-up is calibrated for room temperature that can be seen in the table 4.1. Then the reading is taken for every 30 seconds. First 30 second the flame temperature is about 195^0C. And the blade leading edge heated up to 130^0C and trailing edge up to 125^0C after the atmospheric losses. The temperature T5 represents the thermoelectric cold side, at first 30 second it reduced to 15^0C. That means the heat from blade is carried by the coolant to the cold side and thermoelectric extracted heat from coolant and ejected it to atmosphere. Same thing happened even for next few minutes but as the saturation limit of the thermoelectric material reached hence, it failed to transfer the heat from hot side to cold side. So that blade temperature started rising. Table shows the values of test.

Table-1. Results from the experimental test

Time	T1	T2	T3	T4	T5	T6	T7
0	33	33.5	33	32.8	33	32.6	33.3
30	195.6	187.3	130.5	125.4	15.8	33.2	35.4
60	194.8	185.4	131.2	126.1	15.1	33	35.1
90	196.3	186.7	129.9	127.1	14.6	33.4	35.4
120	196.1	184.2	127.5	126.2	14	33.2	35
150	197.5	180.1	127.3	126.5	13.6	33	34.9
180	198.1	180.4	125.3	124.6	13.1	32.9	35.2
210	198.3	181.5	125.2	123.9	12.5	33.1	35.5
240	198.3	181.6	125.2	123.9	12.1	33.4	35.4
270	198.5	181.4	127.6	126.4	11.5	33.4	35.1

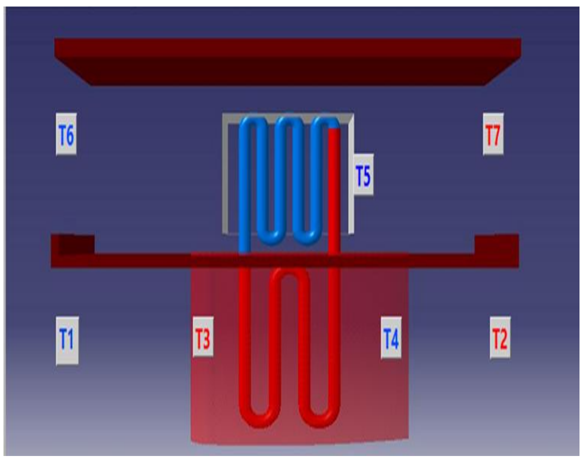

Figure 4. proposed experimental setup

Below graphs shows the variation of temperature at different location with time.

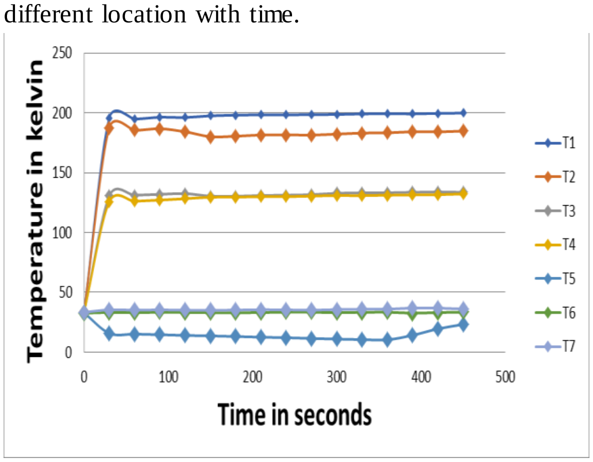

Figure 5. Variation of temperature with time

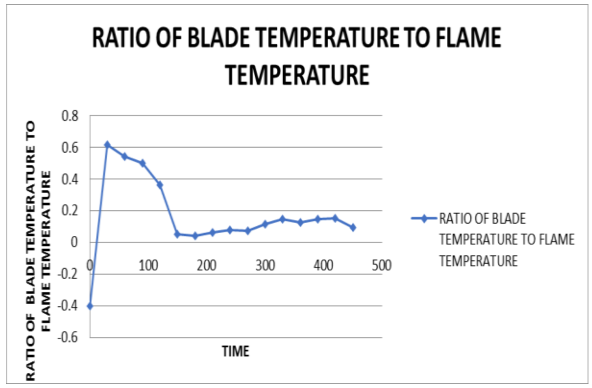

Figure 6. Ratio of blade temperature to flame temperature

From Figure 5 it is clear that inlet flame temperature remains almost constant. Now seeing at Figure 6 which is ratio of blade temperature to flame temperature it can conclude that blade is cooling.

The clear picture of cooling effect can be observed in the graph as shown in figure 7. This plot represents the temperature variation of thermoelectric cooler for cold sides. The initial atmospheric temperature is 33°C. When thermoelectric material is powered up one side becomes cold; this cooling side is exposed to the copper tube containing the coolant. Hence heat is removed from the coolant. The removed heat is dumped over to the hot side of the thermoelectric cooler. Because as the temperature increases the provided convective heat transfer is not enough hence the cooling effect decreases and temperature increased at the end.

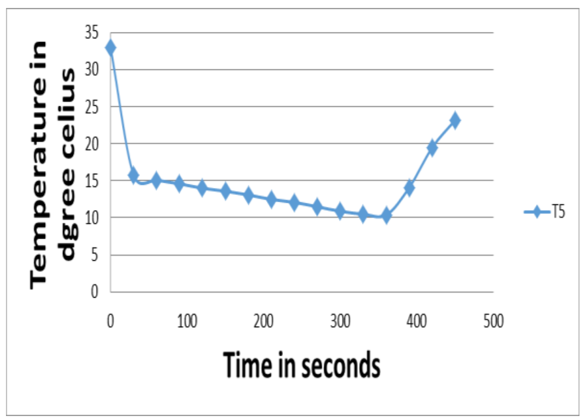

Figure 7. Variation of condenser temperature T5 with time

IV. CONCLUSION

From the results it can be concluded that there is a reduction in temperature in blade of about 4°C in short time. The objective of the project of increasing the cooling effect of the heat by using thermoelectric material is achieved.

It is also seen that there is a scope for further improvement in the design of the heat exchanger and also in the region of condenser.

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