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Research Article

Cooling Gas Turbine Blades with Advanced Thermal Management System

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This project aims to enhance the efficiency of jet engine turbine blades through a novel cooling approach. Traditional methods rely on bleed air to reduce internal temperatures, but this project proposes a combination of liquid evaporation and thermoelectric technology for more efficient cooling. By integrating heat pipes and vapor cooling techniques with thermoelectric heat pumps, the cooling effect on the blades can be significantly increased. In this setup, the thermoelectric material provides cooling for the heat pipe, while the rejected heat is carried away by bleed air. This process effectively lowers the blade temperature, allowing for higher efficiency. The project's validation involves an experimental setup with sensor arrays and a data acquisition system, along with computational fluid dynamics to confirm the results. In simpler terms, the project aims to make jet engine turbine blades cooler by using a combination of liquid cooling and advanced thermoelectric technology. This could potentially lead to higher engine efficiency, as cooler blades can withstand higher inlet temperatures. The project's success is verified through experiments and computer simulations.

Keywords: Gas Turbine, evaporation, thermoelectric, cooling effect, efficiency.

1. Introduction

In the pursuit of enhancing the efficiency and power output of modern gas turbines, engineers are pushing the boundaries of turbine rotor inlet temperature (RIT). In recent years, there has been a significant increase in RIT, thanks to advancements in cooling techniques and a deeper understanding of heat transfer within the turbine passage. This increase in RIT has been crucial for improving engine performance.

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However, the quest for higher RIT poses challenges. Elevated gas temperatures result in higher blade temperatures and more pronounced temperature gradients, which can negatively impact the durability of turbine components. Given the intricate three-dimensional flow conditions within modern turbomachinery, achieving further performance enhancements requires a thorough understanding of gas flow dynamics.

To optimize turbine design, engineers must delve into the complexities of the flow field near the hub and tip regions. In these areas, interactions between the side-wall boundary layer and the stream-wise boundary layer significantly influence aerodynamic performance. Even though this region is thin, its impact on overall turbine efficiency cannot be overlooked.

Achieving high-performance turbines demands a detailed understanding of the three-dimensional flow characteristics near the hub and tip. Turbulence transport near solid walls and wake regions behind blade airfoils play critical roles in determining key flow parameters. Under specific operating conditions, adverse pressure gradients can intensify boundary layer development on blade surfaces, affecting subsequent rotor stages.

In summary, designing high-performance turbines requires engineers to meticulously analyze the intricate flow dynamics near hub and tip regions, considering factors such as turbulence transport, boundary layer development, and wake effects. This comprehensive understanding is essential for optimizing turbine performance and achieving efficiency gains.

2. Design, Fabrication and Testing

A. Design and fabrication detail

The basic design is first done using auto cad, the Fig.1 shows the auto cad design.

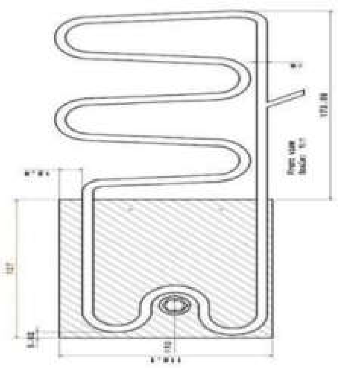

Fig.1. Model designed in auto CAD

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 airconditioning because of their efficient heat transfer characteristics, we selected copper tubes for making the heat exchanger loops for this blade cooling experiment.

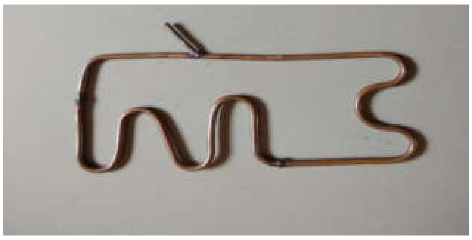

Fig.2. Copper pipe

It is designed giving a special geometry so that it will allow better heat transfer through the coolant circulating inside the heat exchanger.

Fig.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.

Fig.4. Thermoelectric cooler

The thermoelectric cooler is fixed on the aluminium block which cooldown the coolant using electricity more efficiently.

B. Testing

The 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.

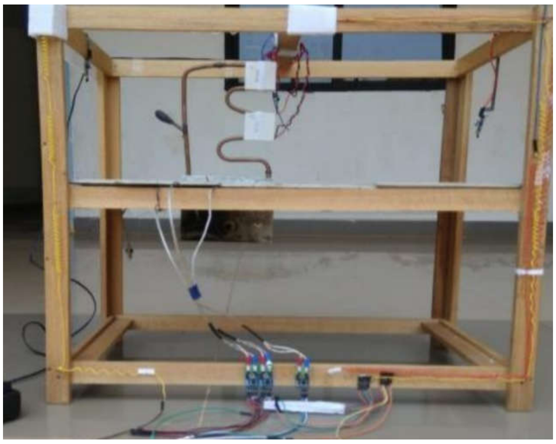

Fig.5. Test Setup

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.

3. Result and Discussion

The blade model is assigned in the test setup and test is carried on. Initially the set-up is calibrated for room temperature that can be seen in the table 1. Then the reading is taken for every 30 seconds. First 30 second the flame temperature is about C. And the blade leading edge heated up to C and trailing edge up to C after the atmospheric losses. The temperature T5 represents the thermoelectric cold side, at first 30 second it reduced to C. 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

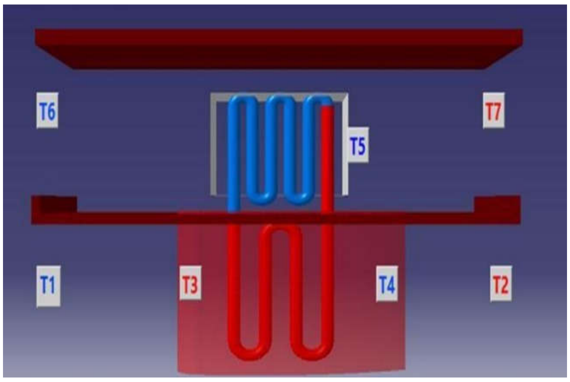

Fig.6. Proposed experimental setup

The below graphs shows the variation of temperature at different location with time

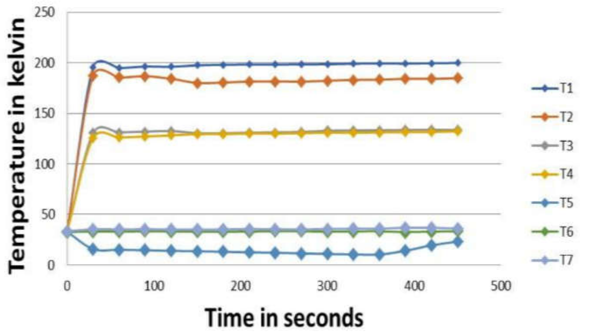

Fig.7. Ratio of blade temperature to flame temperature

From figure 7, 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 8. This plot represents the temperature variation of thermoelectric cooler for cold sides.

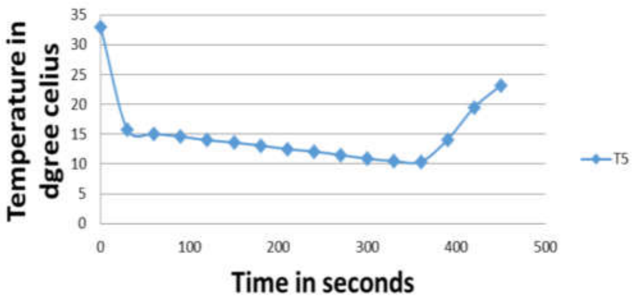

Fig.8. Variation of condenser temperature T5

4. Conclusions

The project's validation involves an experimental setup with sensor arrays and a data acquisition system, along with computational fluid dynamics to confirm the results. In simpler terms, the project aims to make jet engine turbine blades cooler by using a combination of liquid cooling and advanced thermoelectric technology. This could potentially lead to higher engine efficiency, as cooler blades can withstand higher inlet temperatures. The project's success is verified through experiments and computer simulations.

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.

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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