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DESIGN AND FEASIBILITY ANALYSIS OF CLOSED LOOP COOLING SYSTEM OF TURBINE BLADE USING HELIUM AS COOLANT

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ABSTRACT

Turbine blades are the critical component of the gas turbine engine which have to withstand the highest temperature and the resulting stresses in the entire engine. The operational limit of a gas turbine engine is often limited by the temperature which the turbine can withstand. The average temperature range which a normal turbine has to withstand in a gas turbine engine is between 1300 - 1800^0 C, this is higher than most materials can withstand. Hence the cooling of the turbine is critical component of design in any gas turbine engine.

This project proposes an innovative approach towards the cooling of the turbine blade. This involves a feasibility analysis of using Helium as a coolant to cool turbine blades by circulating it in a loop. Helium has been selected for being inert and having a better cooling property than air. The modifications required to accommodate this system, namely the modification of the hub and shaft, has been mentioned. The project also analyzes the natural frequency of the modified hub-shaft design to ensure that natural frequencies do not occur at the operating rpm of the engine.

The project concludes by mentioning the development of a backup, fail-safe mechanism to revert to the existent air-bleed cooling cycle in case the proposed mechanism undergoes failure. The implementation of this project will enable a higher Turbine Inlet Temperature, thereby increasing engine efficiency and enabling production of more thrust. This will result in gas turbine engines being smaller while producing the same amount of power output.

Keywords: Helium, Turbine, Closed Loop Cooling.

1. Introduction

A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use advanced materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. The stress is developed in the turbines are so high that they require special material and careful design. The design of the blades is very complicated and the material chosen should be such that they can withstand high temperature and have high strength.

In a high-pressure turbine rotor, tip clearances between rotating turbine blades and casing are necessary to prevent rubbing. The difference in pressure between the blade pressure and suction sides drives leakage flow across the tip of the blade through this clearance gap. This tip-leakage flow can cause excessively high metal temperatures and loss of material on the blade tip, resulting in a reduction of aerodynamic efficiency. Additionally, the tip of the high-pressure rotor blade is one of the parts that deteriorates in the gas turbine. Obtaining a good thermal performance of the blade tip to avoid local high metal temperatures represents a major challenge for turbine designers. Hence it is necessary to provide cooling for the turbine blades.

The important parameter which increase gas turbine performance is the turbine inlet temperature. Turbine is the part which is directly after the combustion chamber. So that high temperature, high pressure combusted gas has high impact on the turbine blade. If we improve turbine inlet temperature, performance can also be improved. But there will be material limitations for increasing the turbine inlet temperature. For this reason we need sufficient cooling for turbine blade. The main challenge in turbine blade cooling is that the rotor blade is rotating with very high rpm.

Cooling of components can be achieved by air or liquid cooling. Liquid cooling seems to be more attractive because of high specific heat capacity and chances of evaporative cooling but there can be problem of leakage, corrosion, choking, etc. which works against this method. On the other hand air cooling allows to discharge air into main flow without any problem. Quantity of air required for this purpose is 1–3% of main flow and blade temperature can be reduced by 200–300 °C. There are many types of cooling used in gas turbine blades; convection , film, transpiration cooling, cooling effusion, pin fin cooling etc. which fall under the categories of internal and external cooling. While all methods have their differences, they all work by using cooler air (often bled from the compressor) to remove heat from the turbine blades. The various types of cooling includes:

1. Internal Cooling
    a. Impingement Cooling
    b. Convection Cooling
2. External Cooling
    a. Film Cooling

b. Transpiration Cooling

This paper proposes an internal convection cooling mechanism.

2. Proposed Design

2.1. *The Hub and Shaft*

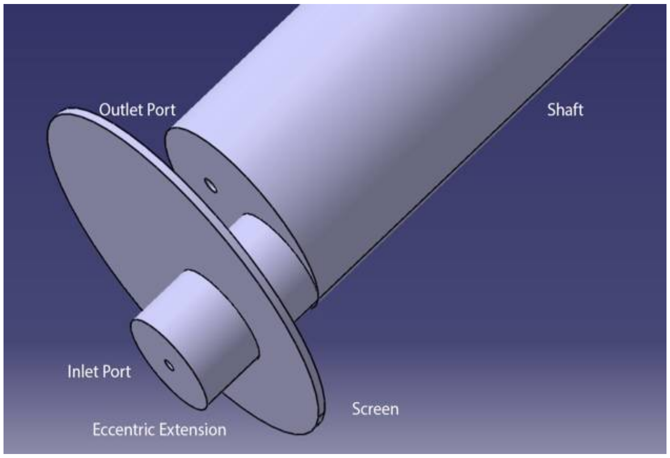

Figure 1 : 3-D Model of modified hub

The design proposal put forth by this project involves a significant design alteration in the present cooling system in the conventional jet engine. The regions involving significant changes include the engine hub, the shaft and the turbine.

The design involves the creation of supply and return chambers for the coolant inside the hub. This also requires an extended shaft. The chambers created inside the hub will be provided with pressure differences using a turbo pumps which may be housed elsewhere. The coolant inlet into the turbine and the return lines from the turbine will pass through the main shaft. The turbine will have internal passages inside its blades to allow for the passage of coolant. Unlike the conventional air bleed cooling, no coolant will be bled into the main flow from the combustor, instead the coolant will be cycled. The heat from the turbine after being absorbed by the coolant will be dissipated with the help of a heat exchanger which is to be housed external to the engine.

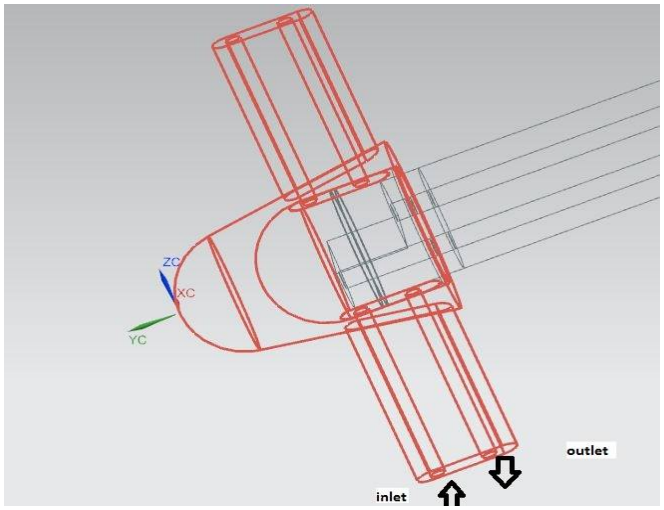

Figure 2: Cross sectional view of hub and shaft including passages for inlet and outlet of helium

The shaft has been extended forward and an eccentric cut section has been created. On this eccentric extension a dividing screen has been fixed along with a bearing. This arrangement when placed inside the hub creates a double chamber. The sealing separating the two chamber is created using labyrinth seals placed between the hub and the screen. The rotation of the screen inside the hub is enabled by the placement of a single bearing between the both. The part of the shaft inside each chamber is provided with openings to pipelines which run through the length of the shaft from the hub to the turbine disc. These pipelines will be used to carry the coolant to and from the turbine. The coolant flow is achieved with the pressure difference created between the two chambers with the help of a turbo pump.

2.2. The Turbine

The turbine method adopted here internal cooling. Hence the turbine will consist of very small internal passages to allow for the coolant to pass through it. For simplicity, we have assumed the turbine to be of integral type i.e., the turbine and the turbine disc to be one solid piece. This project however, isn’t limited by this consideration and can be extended to turbine blades with root fixing with some minor modifications.

2.3. Salient Features of the proposed design

- Helium supply chamber is housed inside the hub of the gas turbine engine
- The tubing to the turbine blade is done via the shaft
- Internal Cooling mechanism is employed in turbine blades
- Additional accessories (like, heat exchangers, coolant storage tanks, turbo pumps etc.) may be placed external to the engine

3. Design And Analysis Technique

3.1. Design

The coordinates for the turbine blade were obtained from the US Patent: **HP Turbine Blade Airfoil Profile US 7306436 B2.** These were then modelled in Siemens NX 9.0 CAD software.

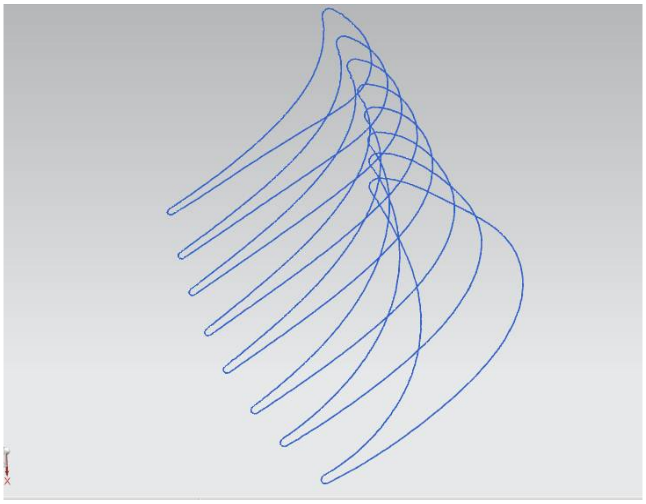

Figure 3: Full length HPT blade cross section

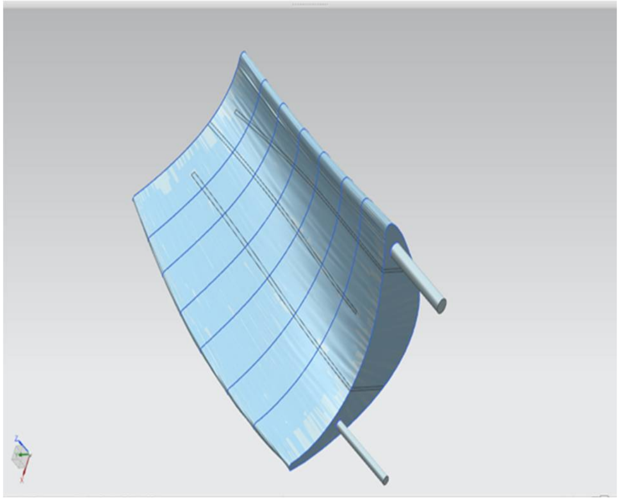

Figure 4: Solid HPT blade with baffles

3.2. Thermal Analysis

The analysis of the blade was done in 2 phases. The software used for this purpose was ANSYS CFX. The first part involved the thermal analysis of the blade with air as the coolant. The second part used helium gas for the same. The objective was to provide a side-by-side comparison of the effect of both the coolants with all other input parameters remaining the same except the coolant gases. The walls of the blade were set at a gradient from 1800°C at leading edge to 1700°C at trailing edge.

The inlet properties of the gases were as follows:

Inlet Velocity	150 m/s
Inlet Temperature	25°C
Inlet Mach Number	0.441

4. Result

As expected, helium gas supplied at 25°C performed better as coolant in terms of overall heat reduction over the entire blade area. The maximum temperature that the turbine could reach was 1195 °C, while the air cooled turbine reached a temperature of 1799 °C at its hottest point.

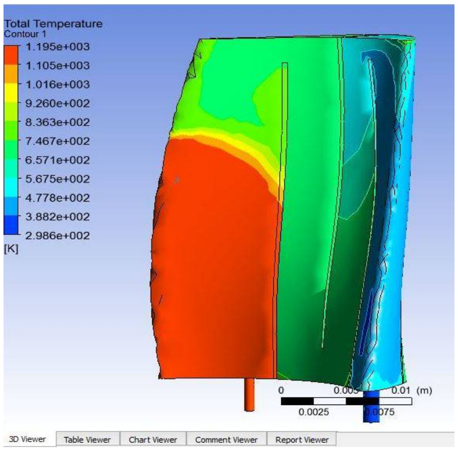

Figure 5: Contour of Heat Transfer on and inner sections of blade for Helium (at 298 K) as a coolant and blade wall temperature at 1800 K

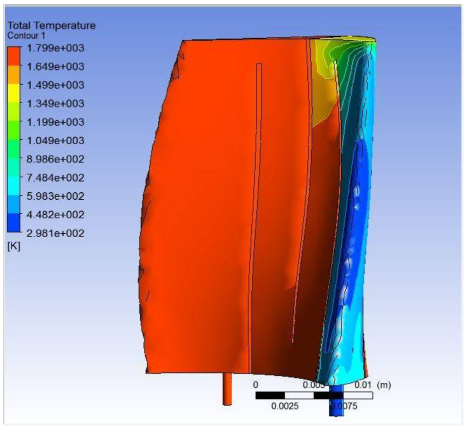

Figure 6: Contour of Heat Transfer on and inner sections of blade for Air (at 298K) as a coolant and wall of blade at 1800 K

5. Conclusion

From the above result it can be concluded that helium performs much better in terms of cooling than air. The implementation of the proposal put forward by this project will enable production of higher amounts of thrust by increasing the turbine inlet temperature. This will enable jet engines to be smaller in size and still produce the same amount of thrust for an engine producing an equal amount of thrust.

It is to be noted that this paper has only undertaken the thermal analysis of using such a system in turbine blade cooling. The impact of the modified hub-shaft assembly has not been thoroughly studied. Also an accurate analysis which studies the integrity of the turbine blade is required for this method to be conclusively approved.

6. References

- High pressure turbine blade airfoil profile PATENT US 7306436 B2 (Coordinate values of HPT stage blade airfoil profile section 1 to 8).
- Turbine blade cooling google search, Wikipedia.
- ANSYS CFX-Pre user guide, ANSYS Inc., 2013
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A Brief Author Biography

***ARUN BABY* –** I am currently in my final year of Bachelors in Aeronautical Engineering degree from the Jawaharlal College of Engineering and Technology under University of Calicut. My areas of interest include propulsion, aerospace vehicle design and gas turbine aerodynamics. I plan to pursue my Masters in Aerospace Engineering from the University of Manchester.

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***DERIN DAVIS B* -** I am currently doing in my final year of Bachelors in Aeronautical Engineering degree from the Jawaharlal College of Engineering and Technology under University of Calicut. I hope to join an aircraft maintenance organization after attaining the necessary qualification and I also interested in Aerospace Research in future Aeronautics field with pursue Higher Studies in United States.

***JEBIN KUMAR K J* -** Pursuing my bachelors in aeronautical engineering from Jawaharlal College of Engineering and Technology. I intend to work in an Aerospace software simulations and design related field. I like computational modelling of complex aerospace vehicle designs.