Thermal Analysis on Gas Turbine Blade Cooling Through Optimized Hole Geometry

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Abstract - The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. In this work gas turbine blade cooling is analyzed thermally by selecting 3 different types of turbine blade materials viz. Ni–Cr alloy, Ti alloy, Ni alloy. For the analysis purpose the geometry of the blade is considered with no of holes present. Initially the blade geometry is started with 6 numbers of holes, later followed to 8 numbers of holes, finally ended with 12 numbers of holes. By changing the blade materials and holes geometry temperature & pressure distributions across the blade material is modeled in ANSYS - Fluent. The 3D modeling is done with the help of Pro/e. Based on the best results the optimized blade geometry along material is found out.

Key words: Turbine Blade, cooling, geometry, super alloys, temperature, pressure.

I. INTRODUCTION:

A Gas 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 exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. In a gas turbine engine, a single turbine section is made up of a disk or hub that holds many turbine blades. That turbine section is connected to a compressor section via a shaft, and that compressor section can either be axial or centrifugal. Air is compressed, raising the pressure and temperature, through the compressor stages of the engine. The temperature is then greatly increased by combustion of fuel inside the combustor, which sits between the compressor stages and the turbine stages. Turbine blades are subjected to very strenuous environments inside a gas turbine. They face high temperatures, high stresses, and a potentially high vibration environment. All three of these factors can lead to blade failures, which can destroy the engine, and turbine blades are carefully designed to resist those conditions. The first stage (the stage directly following the combustor) of a modern turbine faces temperatures around 1,370 °C, up from temperatures around (820 °C) in early gas turbines. Modern military jet engines can see turbine temperatures of 1,590 °C.

II. Blade Material:

Over the 70 years of material development in 1941, Weight of gas turbine blades remains 317 kgs, Thrust to weight ratio 1.2: 1, Blade Temperature around 600°C, Blade Materials: Ni 20 Cr. Weight of gas turbine blades remains 5408 kgs, Thrust to weight ratio 5.4: 1, Blade temperature around 1800°C, Blade Materials: Ni 9.6 Co 6.5 Ta 6.4 Cr 6.4 W 5.6 Al 3 Re 1 Ti 1. Titanium alloys are preferred to steel because of its low density (nearly 50%) has superior oxidation resistance & it has a decreasing strength with temperature by alloying with elements its strength can be stabilized. Titanium alloys have a good properties up to about 550°C, has a lower coefficient of thermal expansion which helps to reduce thermal stresses. Titanium alloys has been the high reactivity at high temperature. Titanium dissolves oxygen at high temperature, which is worked with vacuum. Nickel alloys have also been developed extensively and are
currently being used for turbines. These alloys have superior strength and oxidation resistance even though nickel by itself has poor oxidation resistance.

![Fig No: 1. Components of Gas Turbine](image1.png)

**Fig No: 1. Components of Gas Turbine**

**III. Turbine Blade Cooling:** At a constant pressure ratio, thermal efficiency increases as the maximum temperature increases. But, high temperatures can damage the turbine, as the blades are under large centrifugal stresses and materials are weaker at high temperature. So, turbine blade cooling is essential. 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 the discharged 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. Various internal and external cooling techniques are employed to bring down the temperature of the blade material below its melting point.

![Fig No: 2 Blade Geometry](image2.png)

**Fig No: 2 Blade Geometry**

**V. Results:**

**IV. Turbine Blade Modeling:**

![Fig No : 4 Noof Holes = 6](image3.png)  ![Fig No: 5 No of Holes = 8](image4.png)  ![Fig No: 6 No of Holes = 12](image5.png)
V. Conclusions:

By using fluent analysis as a tool, the flow analysis is carried out sequentially. The blade with different no. of holes 6, 8 and 12 were used for analysis. It was found that the blade with 8 holes has the moderate cooling rate for both materials of the blade when the coolant temperature was 300ºC. The placement of cooling holes in the blades resulted in increasing turbine efficiency. The overall cooling rate is 20% from both materials with 6 and 12 holes models. One can study the effect of cooling rate of the gas turbine blade in better way with different methods and analysis by changing blade material and increasing the number of holes, by changing the shape of the Hole. By calculating the Thermal Stresses Using Factor of Safety we can decide whether that material with stand or Not. The flow is considered in the present study to be in steady state however the simulation studies need to be considered under unsteady state with appropriate boundary conditions.

This detailed pressure and temperature measurements also provides a reference for further experimental or computational study.

Table No: 1 Comparision of T & P Values

<table>
<thead>
<tr>
<th>No. of Holes</th>
<th>Pressure(Pa)</th>
<th>Temperature(ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ti alloy</td>
<td>Ni alloy</td>
</tr>
<tr>
<td>6</td>
<td>2.76e6</td>
<td>9.80e5</td>
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<tr>
<td></td>
<td>6.68e2</td>
<td>6.65e2</td>
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<td>8</td>
<td>2.46e6</td>
<td>2.63e5</td>
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<td></td>
<td>5.25e2</td>
<td>5.06e2</td>
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<tr>
<td>12</td>
<td>1.38e6</td>
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<tr>
<td></td>
<td>3.95e2</td>
<td>2.64e2</td>
</tr>
</tbody>
</table>

V. References:

[8] Shridhar Paregouda1, Prof. Dr. T. Nageswara Rao,CFD Simulation on Gas turbine blade and Effect of Hole Shape on leading edge Film Cooling Effectiveness.