STEADY STATE THERMAL & STRUCTURAL ANALYSIS OF GAS TURBINE BLADE USING FEA

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Abstract

Cooling of gas turbine blades is a major consideration because they are subjected to high temperature working conditions. Several methods have been suggested for the cooling of blades and one such technique is to have radial holes to pass high velocity cooling air along the blade span. The forced convection heat transfer from the blade to the cooling air will reduce the temperature of the blade to allowable limits. Finite element analysis is used in the present work to examine steady state thermal & structural performance for Inconel718and N155 and Titanium T6. Four different models consisting of solid blade and blades with varying number of holes (6, 9 & 12 holes) were analysed in this Project to find out the optimum number of cooling holes. The analysis is carried out using ANSYS CFD software package.

Introduction

With the advent in Gas turbine technology, its usage as a prime mover has become prominent, since last few decades. One of the most important applications of gas turbines is in power generation, though it has been in use for aircraft propulsion since long time. The efficiency and power output of gas turbine plants is dependent on the maximum temperatures attained in the cycle. Extensive work has been reported in the literature on cooling of gas turbine blade. Deepanraj et.al. Have considered titanium – aluminium alloy as the blade material and performed structural and thermal analysis with varying number of cooling passages. They also studied the effect of varying the cooling air temperature on the temperature distribution in the blades. Bhatt et al. performed transient state stress analysis on an axial flow gas turbine blade and disk using finite element techniques. They have chosen Inconel 718, a high heat resistant alloy of chromium, nickel & niobium. The study was focused on centrifugal & thermal stress arising in the disk. V.Vijaya Kumar et.al. examine the “preliminary design of a power turbine for maximization of an existing turbojet engine”. For a clear understanding of the combined mechanical and the thermal stresses for the mechanical axial and centrifugal forces. The peripheral speed of rotor and flows velocities is kept in the reasonable range so to minimize losses. In which the base profiles is analyzed later for flow condition through any of the theoretical flow analysis method such as “potential flow approach. Convection cooling works by passing cooling air though passages internal to the blade. Heat is transferred by conduction to the blade and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling passages are generally provided with small fins. Finite element analysis is used in the present work to examine steady state thermal & structural performance for N155 & Inconel 718 nickel-chromium alloys and Titanium T6. Four different models consisting of solid blade and blades with varying number of holes (6, 9 & 12 holes) were analyzed in this Project to find out the optimum number of cooling holes. The analysis is carried out using ANSYS CFD software package.

Materials and Methods

A key limiting factor in early jet engines was the performance of the materials available for the hot section (combustor and turbine) of the engine. The need for better materials spurred much research in the field of alloys and manufacturing techniques, and that research resulted in a long list of new materials and methods that make modern gas turbines possible. One of the earliest of these was nimonic, used in the British Whittle engines. The development of super alloys in the 1940s and new processing methods such as vacuum induction melting in the 1950s greatly increased the temperature capability of turbine blades. Further processing methods like hot iso static pressing improved the alloys used for turbine blades and increased turbine blade performance. Modern turbine blades often use nickel-based super alloys that incorporate chromium, cobalt, and rhenium. Aside from alloy improvements, a major breakthrough was the development of directional solidification (DS) and single crystal (SC) production methods. These methods help greatly increase strength against fatigue and creep by aligning grain boundaries in one direction (DS) or by eliminating grain boundaries all together (SC).

Internal Cooling

Convection cooling it works by passing cooling air through passages internal to the blade. Heat is transferred by conduction through the blade, and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling paths tend to be serpentine and full of small fins. The internal passages in the blade may be circular or elliptical in shape. Cooling is achieved by passing the air through these passages from hub towards the blade tip. This cooling air comes from an air compressor. In case of gas turbine the fluid outside is relatively hot which passes through the cooling passage and mixes with the main stream at the blade tip.

Figure 1 Gas turbine blade

Blade Cooling by Convection

Impingement cooling variation of convection cooling, impingement cooling, works by hitting the inner surface of the blade with high velocity air. This allows more heat to be transferred by convection than regular convection cooling does. Impingement cooling is used in the regions of greatest heat loads. In case of turbine blades, the leading edge has maximum temperature and thus heat load. Impingement cooling is also used in mid chord of the vane. Blades are hollow with a core. There are internal cooling passages. Cooling air enters from the leading edge region and turns towards the trailing edge.

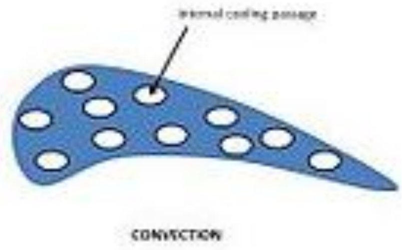

Figure 2 Convection Cooling

Impingement Revised

External Cooling film cooling Film cooling (also called *thin* film cooling) is a major type of cooling which works by pumping cool air out of the blade through small holes in the blade. This air creates a thin layer (the film) of cool air on the surface of the blade, protecting it from the high temperature air. The air holes can be in many different blade locations, but they are most often along the leading edge. A United State Air Force program in the early 1970s funded the development of a turbine blade that was both film and convection cooled, and that method has become common in modern turbine blades. There are orifices on the surface through which the cool air flows on the surface and makes a film on the surface which acts as a barrier to heating and provides effective cooling. Besides cooling blade surface it decreases heat transfer from metal surface to the hot fluid. One consideration with film cooling is that injecting the cooler bleed into the flow reduces turbine efficiency. That drop in efficiency also increases as the amount of cooling flow increases. The drop in efficiency, however, is usually mitigated by the increase in overall performance produced by the higher turbine temperature.

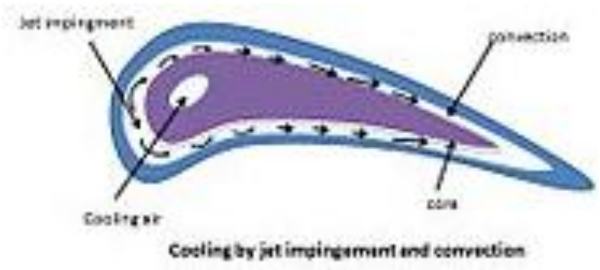

Figure 3 Impingement Revised

Film Cooling Revised

Cooling effusion Blade surface is made of porous material which means having infinite number of small orifices on the surface. Cooling air is forced through these porous holes which form a film or cooler boundary layer. Besides this uniform cooling is caused by effusion of the coolant over the entire blade surface.

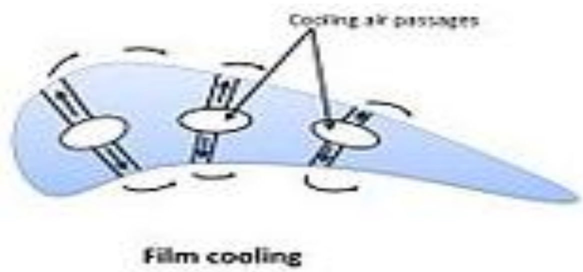

Figure 4 Film Cooling Revised

Cooling by Effusion

Pin fin cooling in the narrow trailing edge film cooling is used to enhance heat transfer from the blade. There is an array of pin fins on the blade surface. Heat transfer takes place from this array and through the side walls. As the coolant flows across the fins with high velocity, the flow separates and wakes are formed. Many factors contribute towards heat transfer rate among which the type of pin fin and the spacing between fins are the most significant.

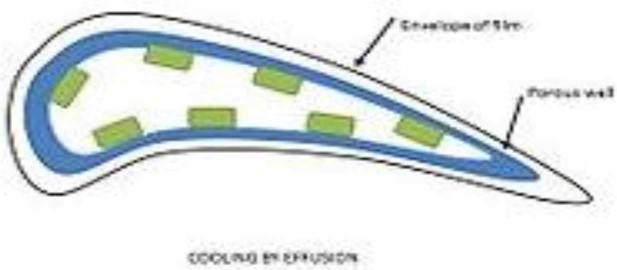

Figure 5 Cooling by Effusion

Transpiration cooling it is similar to film cooling in that it creates a thin film of cooling air on the blade, but it is different in that air is "leaked" through a porous shell rather than injected through holes. This type of cooling is effective at high temperatures as it uniformly covers the entire blade with cool air. Transpiration-cooled blades generally consist of a rigid strut with a porous shell. Air flows through internal channels of the strut and then passes through the porous shell to cool the blade. As with film cooling, increased cooling air decreases turbine efficiency, therefore that decrease has to be balanced with improved temperature performance.

Result and Discussion

At first thermal analysis has been done on Inconel 718 blade profile at three different holes of three different material and contour obtained corresponding to heat flux and thermal distribution are as follows

Temperature Result for Inconel 718

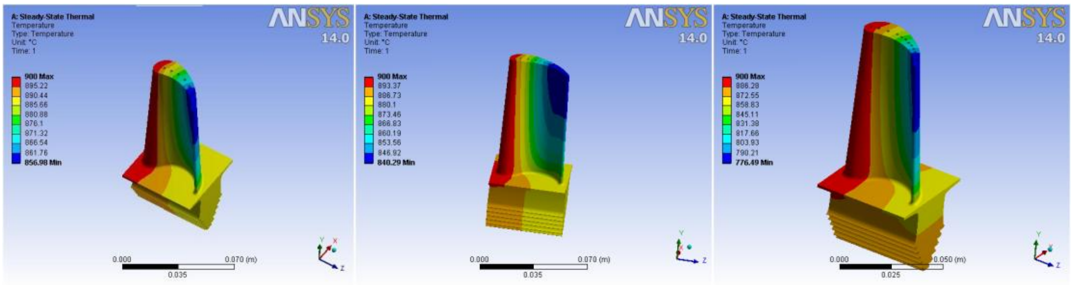

Figure 6 Temperature distribution of the Inconel 718 for 6, 9 and 12 holes

Heat Flux Result for Inconel 718

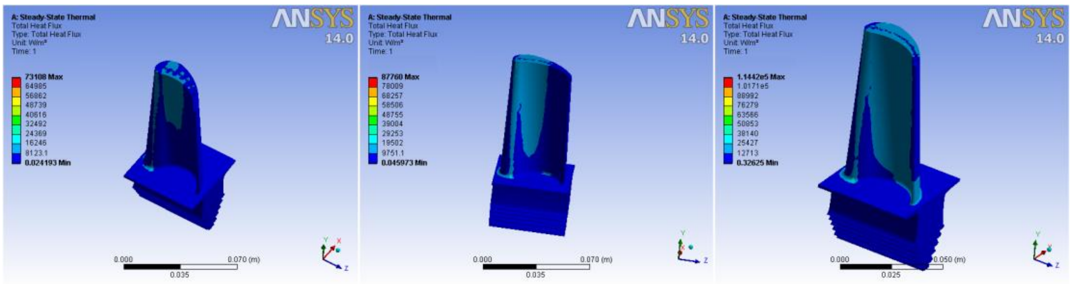

Figure 7 Heat Flux for Inconel718 for 6, 9 and 12 Holes

Temperature Result for Titanium T6

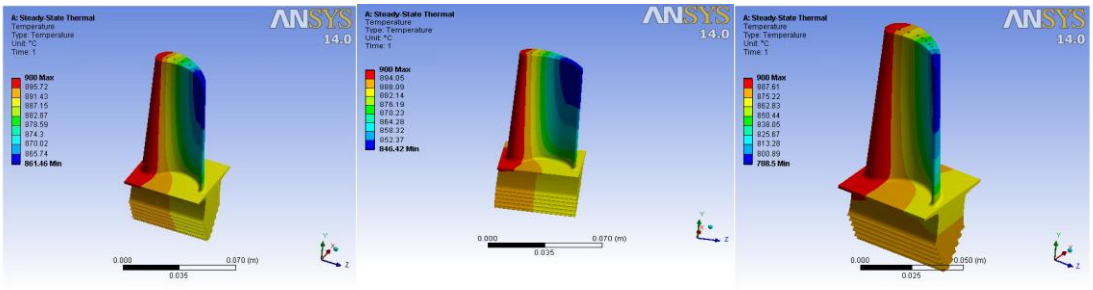

Figure 8 Temperature Distribution of Titanium T6 for 6, 9 and 12 holes

Heat flux Result for Titanium T6

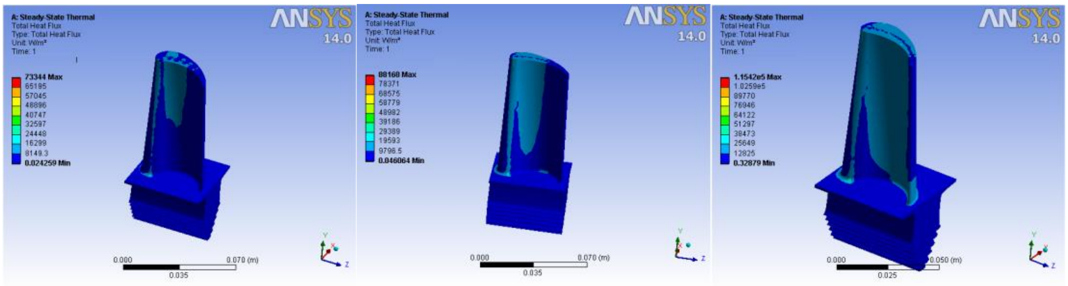

Figure 9 Heat flux for Titanium T6 for 6, 9 and 12 holes

Temperature Result for N155

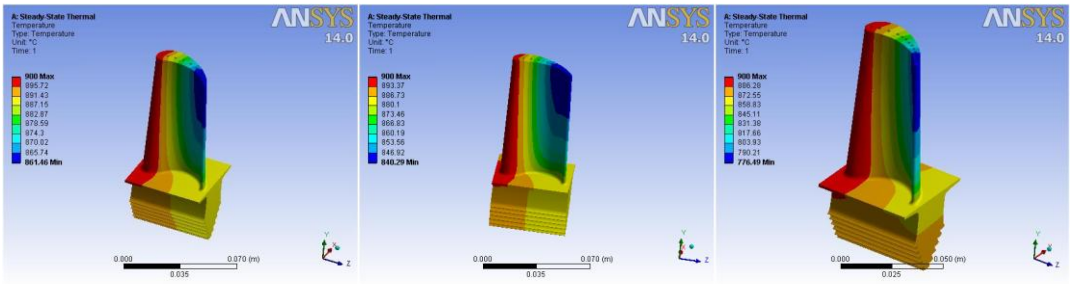

Figure 10 Temperature Distribution of N155 for 6 , 9 and 12 holes

Heat Flux Result for N155

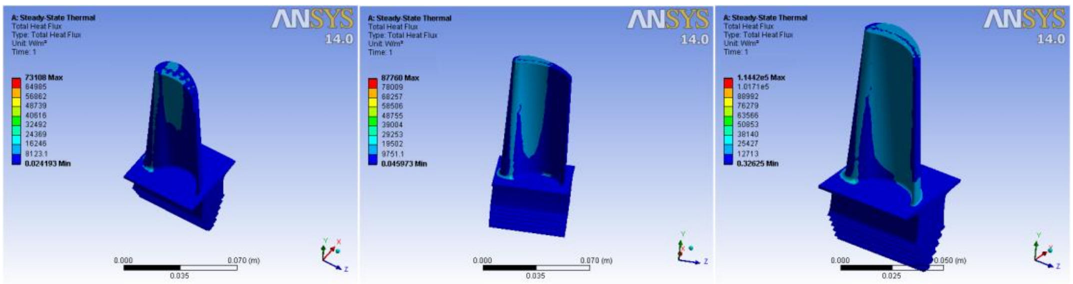

Figure 11 Heat flux for N155 for 6, 9 and 12 holes

Table 1 Result for Temperature Distribution of Three Different Materials (Max 900 ^{O}C)

S. No	Temperature (6 Holes)	Temperature (9 Holes)	Temperature (12 Holes)
Titanium T6	861.46	846.42	788.5
N155	859.45	843.5	778.6
Inconel 718	856.98	840.29	776.49

Conclusion

While comparing these materials, In compare of Titanium T6 and Inconel 718 and N155. it is found that Inconel718 is better suited for high temperature applications. On evaluating the contours for temperature distribution, heat flux the blade with 12 holes is considered as optimum. This conclusion was drawn based on the fact that the induced stresses are minimum and the temperature of the blade is close to the required value of 900^{0}C. And further increase in the number of holes will bring down the temperature below the required value of 900^{0}C.

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