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REVIEW ON STEADY STATE THERMAL & STRUCTURAL ANALYSIS OF GAS TURBINE BLADE WITH COOLING SYSTEM 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 N155, Inconel 718and 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.

1. 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.

Advanced gas turbine engines operate at high temperatures (1200 ^{o}C –15000 ^{o}C) to improve thermal efficiency and power output. With the increase in temperatures of gases, the heat transferred to the blades will also increase appreciably resulting in their thermal failure. With the existing materials, it is impossible to go for higher temperatures.

Taking into account the metallurgical constraints, it is necessary to provide cooling arrangement for turbine blades to keep their metal temperature with in allowable limits. Therefore, developments in turbine cooling technology play a critical role in increasing the thermal efficiency and power output of advanced gas turbines. The following three types of cooling methods have been adapted to varying degree of success.

1. Convection cooling
2. Film cooling
3. Transpiration cooling

While all three methods have their difference, they all work by using cooler air (bled from the compressor) to remove heat from the turbine blade.

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.

2. Literature Survey

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. It is concluded that the blade configuration with 8 holes gives an optimum blade temperature of 8000C.

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.

A.K.Mattaet.al. studied the stress analysis for N – 155 & Inconel 718 material. On solid blades it is reported that Inconel 718 is better suited for high temperature operation. It is suggested by **Ervin** that high turbine efficiency can be obtained by minimising the air flow required for cooling by effectively utilising its cooling potential. He suggested a cooling technology which has three main parts: a) The leading edge is provided with impingement cooling; b) the middle section of blade contains cooling pipes with obstacles provided along the length to enhance turbulence in the cooling air and c) The trailing edge of the blade is provided with pin – fins for effective cooling.

K hari brahmaiah et.al. Examine the heat transfer analysis of gas turbine with four different models consisting of blade with and Without holes and blades with varying number of holes(5,9&13) were analyzed. Transfer rate and temperature distribution, the blade with 13 holes is considered as optimum. Steady state thermal and structural analysis is carried out using ANSYS software with different blade materials of Chromium steel and Inconel 718. While comparing these materials Inconel 718 is better thermal properties and induced stresses are lesser than the Chromium steel.

R d v Prasad et.al. Examine steady state thermal& structural performance for N155& Inconel 718 nickel chromium alloys. Using finite element analysis Four different models consisting of solid blade and blades with varying number of holes (5, 9&13 holes) were analyzed of cooling holes. The analysis is carried out using ANSYS software package. While comparing materials, it is found that Inconel 718 is better suited for high temperature .the graphs drawn for temperature distribution, von misses stresses and deflection, the blade with 13 holes is considered as optimum. The induced stresses are minimum and the temperature of the blade is close to the required value of 800C.

G. Narendranath et.al. examine the first stage rotor blade off the gas turbine analyzed using ANSYS 9.0. The material of the blade was specified as N155. Thermal and structural analysis is done using ANSYS 9.0 Finite element analysis software. The temperature variations from leading edge the trailing edge on the blade profile is varying from 839.5310C to 735.1620C at the tip of the blade. It is observed that the maximum thermal stress is 1217 and the minimum thermal stress is the less than the yield strength value i.e., 1450

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"

3. Fundamentals of Gas Turbine Engines

The gas turbine is an internal combustion engine that uses air as the working fluid. The engine extracts chemical energy from fuel and converts it to mechanical energy using the gaseous energy of the working fluid (air) to drive the engine and propeller, which, in turn, propel the airplane.

The basic principle of the airplane turbine engine is identical to any and all engines that extract energy from chemical fuel. The basic 4 steps for any internal combustion engine are:

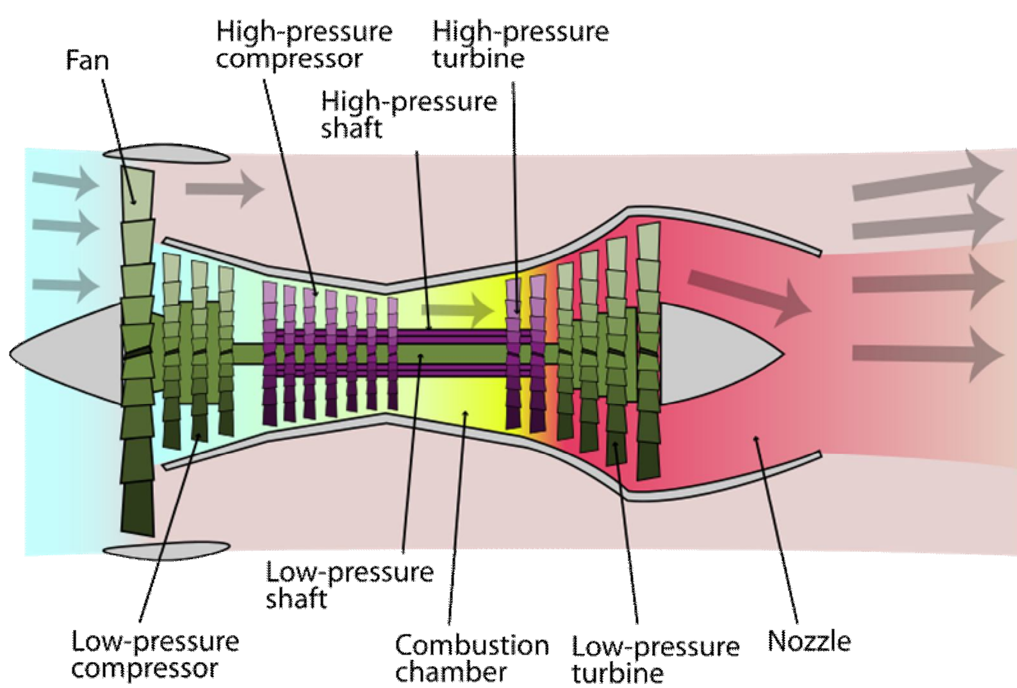
1. Intake of air (and possibly fuel).

2. Compression of the air (and possibly fuel).

3. Combustion, where fuel is injected (if it was not drawn in with the intake air) and burned to convert the stored energy.

4. Expansion and exhaust, where the converted energy is put to use.

In the case of a piston engine, such as the engine in a car or reciprocating airplane engine, the intake, compression, combustion, and exhaust steps occur in the someplace (cylinder head) at different times as the piston goes up and down. In the turbine engine, however, these same four steps occur at the same time but indifferent places. As a result of this fundamental difference, the turbine has engine sections called:



1. The inlet section
2. The compressor section
3. The combustion section (the combustor)
4. The turbine (and exhaust) section.

The turbine section of the gas turbine engine has the task of producing usable output shaft power to drive the propeller. In addition, it must also provide power to drive the compressor and all engine accessories. It does this by expanding the high temperature, pressure, and velocity gas and converting the gaseous energy to mechanical energy in the form of shaft power.

A large mass of air must be supplied to the turbine in order to produce the necessary power. This mass of air is supplied by the compressor, which draws the air into the engine and squeezes it to provide high-pressure air to the turbine. The compressor does this by converting mechanical energy from the turbine to gaseous energy in the form of pressure and temperature.

If the compressor and the turbine were 100% efficient, the compressor would supply all the air needed by the turbine. At the same time, the turbine would supply the necessary power to drive the compressor. In this case, a perpetual motion machine would exist. However, frictional losses and mechanical system inefficiencies do not allow a perpetual motion machine to operate.

Additional energy must be added to the air to accommodate for these losses. Power output is also desired from the engine (beyond simply driving the compressor); thus, even more energy must be added to the air to produce this excess power.

Energy addition to the system is accomplished in the combustor. Chemical energy from fuel as it is burned is converted to gaseous energy in the form of high temperatures and high velocity as the air passes through the combustor. The gaseous energy is converted back to mechanical energy in the turbine, providing power to drive the compressor and the output shaft.

3.1. Environment and Failure Modes

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. Turbine blades are subjected to stress from centrifugal force (turbine stages can rotate at tens of thousands of revolutions per minute (RPM)) and fluid forces that can cause fracture, yielding, or creep failures. Additionally, the first stage (the stage directly following the combustor) of a modern turbine faces temperatures around 2,500 °F (1,370 °C), up from temperatures around 1,500 °F (820 °C) in early gas turbines.[6] Modern military jet engines, like the Snecma M88, can see turbine temperatures of 2,900 °F (1,590 °C). Those high temperatures weaken the blades and make them more susceptible to creep failures. The high temperatures can also make the blades susceptible to corrosion failures. Finally, vibrations from the engine and the turbine itself (see blade pass frequency) can cause fatigue failures.

3.2. List Of Turbine Blade Materials

Note: This list is not inclusive of all alloys used in turbine blades.

- U-500this material was used as a first stage (the most demanding stage) material in the 1960s, and is now used in later, less demanding, stages.
- Rene 77
- Rene N5
- Rene N6
- PWA1484
- CMSX-4
- CMSX-10
- Inconel
- IN-738 - GE used IN-738 as a first stage blade material from 1971 until 1984, when it was replaced by GTD-111. It is now used as a second stage material. It was specifically designed for land-based turbines rather than aircraft gas turbines.
- GTD-111 Blades made from directionally solidified GTD-111 are being using in many GE Aviation gas turbines in the first stage. Blades made from equated GTD-111 are being used in later stages.
- EPM-102 (MX4 (GE), PWA 1497 (P&W)) is a single crystal super alloy jointly developed by NASA, GE Aviation, and Pratt & Whitney for the High Speed Civil Transport (HSCT). While the HSCT program was cancelled, the alloy is still being considered for use by GE and P&W.

3.3. Methods of Cooling

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 discharging 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.

4. Modelling and Analysis of Gas Turbine Blade

The blade model profile is generated by using CATIA software. Key points are created along the profile in the working plane. The points are joined by drawing B spline curves to obtain a smooth contour. The contour (2D model) is then converted into area and then volume (3D model) was generated by extrusion. The hub is also generated similarly. These two volumes are then combined into single volume.

This model of turbine blade is then imported into ANSYS software. The blade is then analysed sequentially with thermal analysis preceding structural analysis. The model is discretized using 10 nodes tetrahedral solid element (Solid 87).The surface of the blade is applied with Surface element (Surf 152) for applying the convection loads. The temperatures of blade are then determined by thermal analysis. Followed by this, the structural analysis is carried out by importing the temperatures determined in thermal analysis. 10 nodes tetrahedral solid element (Solid 187) was used for structural analysis. The loads considered for structural analysis are centrifugal, axial & tangential forces

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4.1 Nomenclature

α Coefficient of thermal expansion

E Young’s Modulus

µ Poisson’s ratio

L Length

D Diameter of shaft

N Speed of turbine in RPM

K Thermal conductivity

D Diameter of cooling air passage

4.2 Details of Turbine blade

PARAMETER	VALUE	UNIT
Blade height, **h**	0.081833	m
Chord width, **c**	0.02727	m
Pitch, **s**	0.02264	m
Number of blade	69	
Blade inlet angle, β_2	18.3^{0}	deg
Blade outlet angle, β_3	54.56^{0}	deg
Mean radius, r_m	0.2475	m

4.3 Mechanical properties of TitaniumT6, Inconel 718, N155

Properties	Units	N 155	Inconel 718	Titanium T 6
E	Pa	143 E09	149 E09	1.06 E5 Mpa
Poisson's Ratio	-	0.3	0.31	0.3
ρ	Kg/cu m	8249	8220	4420 kg/m^3
K	W/m-K	20.0	25.0	---
μ	---	0.344	0.331	---
α	E-06/0C	17.7	16.0	---
Cp	J/Kg K	435	586.2	---
Melting Point	0 C	1354	1344	---
Yield stress	MPa	550	1067	---

5.Software Tools Used For Modeling And Analysing

5.1 Application software

Application software is developed to meet the user requirement. Some of these software are of a general nature and can be purchased as a package, while other software are developed to meet the specific need of the user. There are number of general purpose CAD packages are available which may be categorized as

1. Computer Aided Drawing.
2. Geometric modelling.
3. Finite Element Analysis Packages.

5.2 Software package for modelling

There are number of software packages available for modelling. Some of the important packages are

1. Auto cad
2. Pro-E
3. IDEAS
4. Unigraphics
5. CATIA
6. Solid works
7. Solid edge.

5.3 ANSYS

ANSYS is a general - purpose finite element analysis (FEA) software package. Finite element Analysis is a numerical method of deconstructing a complex system into very small pieces called elements. The software implements equations that govern the behaviour of these elements and solves them all, creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

6. Modelling of the Turbine Blade

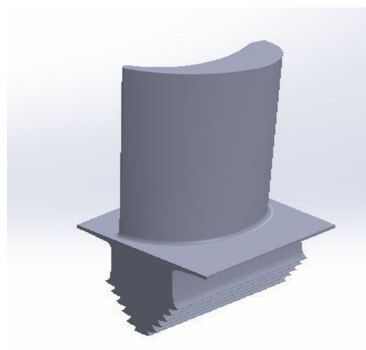
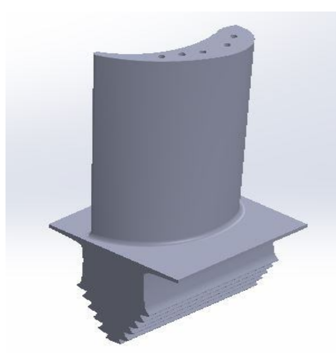


Figure 6.1 Modelling of Turbine Blade without holes using Solid works 2014



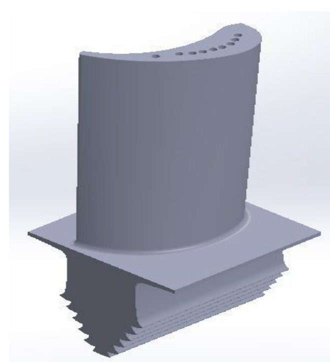


Figure6.2 Modelling with 6 Holes Figure 6.3 Modelling with 9 Holes

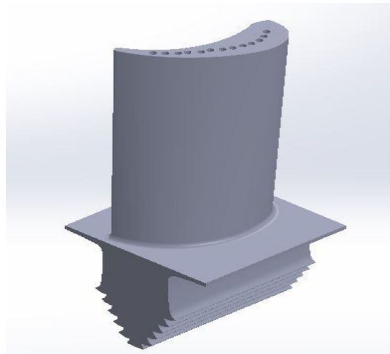


Figure 6.4 Modelling with 12 Holes

7. Conclusion

This review concerned with the design and thermal analysis of turbine blade with radial holes. The first section is concern with material selection and design of the turbine blade, which is the portion of the turbine blade and has designed with radial holes (6 9 12 holes). So next we going to continue the Thermal and structural analysis of the turbine blade using FEA software and compare the results of them.

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