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Design and Analysis of Gas Turbine Blade with Cooling

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Abstract

The turbine inlet temperature in advanced gas turbine engine is very high and it is above the melting point of blade material. In this project radial convective cooling method is used. The turbine blade with cooling holes (6, 8, 9,10, and 11) is designed using CATIA V5. The models are analyzed using the analysis package ANSYS to determine the thermal and structural behaviour by high temperature materials such as Inconel and Nimonic. The turbine has to be coated with ceramic coating (Zirconia) to improve the efficiency and power. The main role of Thermal Barrier Coating is to provide thermal insulation of the blade and reduce the need of blade of cooling and increase the creep life of the blade.

Keywords: convective cooling, CATIA V5, ANSYS, Inconel, Nimonic, Thermal barrier coating, zirconia, yitria

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1. Introduction

The gas turbine 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.

Thermal efficiency of gas turbine still demands higher values of Turbine Entry Temperature (TET) without compromising on the structural integrity of the turbine components. The current TET level in advanced gas turbines is far above the melting point of the blade material. So, it is contingent to cool the turbine blades so that blade metal is within permissible metallurgical limits. Convection cooling is most widely used cooling concept in present day gas turbines. The coolant passes through small internal holes, leading to internal heat convection to cool the wall.

2. Literature Survey

The literature survey conducted has shown that various material such as Nickel alloy (Nickel 167 &188), Inconel (718,625) etc, Titanium-aluminium alloy, aluminium alloy, copper alloy, Stainless steel, super alloy, Zirconium alloy, Haste alloy and cast iron etc. Inconel 718 alloy gives better thermal properties. Stress and deformation is low for Nimonic (N155). Titanium alloy gives minimum stress and it is light weight. Zirconium alloy gives minimum deformation. So, for our further numerical study using ANSYS we are going to use material properties of Inconel 792, Nimonic and Molybdenum base alloys with circular convection cooling holes. The number holes used for the analysis is 6, 8,9,10 and 11. The shape of the holes to be designed is a circle since circular holes gives better result from literature survey. Cast iron coated with partially stabilized Zirconium gives better strength in terms of thermal and structural strength. So, during progression of analysis the blade material is coated with zirconium alloy to get a better result. Conventionally aluminium oxide is used for ceramic coating over blade material.
In the present work CATIAV5 CAD software is used for design and ANSYS software for thermal analysis. From the study it was found that convection heat transfer with radial holes along the blade span will reduce the temperature of blade to allowable limits.

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3. Aerofoil Selection and Modelling

For this project, National Advisory Committee for Aeronautics (NACA) 4412 aerofoil is selected for turbine blade airfoil and its coordinates is taken from airfoil tools website. We have selected a chord of 130mm.Blades with 6, 8, 9, 10 and 11 holes are designed using CATIA.

4. Geometry Creation & Meshing

In this process geometry for the blade model is imported. The blades were modeled in CATIA earlier which is a 3D model. Then the blade has to be coated for thermal barrier coating which is going to be a thickness of 0.3 mm. The surface over the blade is generated by the use of surface from faces option. The final design model of the turbine blade with coating is shown in the figure.

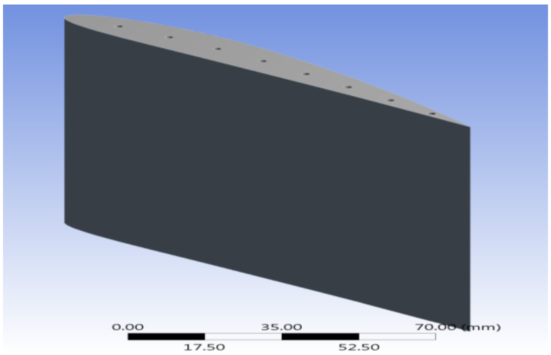

Figure 1: Turbine blade with coating

The triangular shape surface mesh was used due to its proximity to changing curves and bends. These elements easily adjust to the complex bodies used in automobile and aerospace bodies. The mesh parameters defined is as given below:

Size Function : on Proximity & Curvature

Relevance Center : Fine

Span Angle Center : Fine

Minimum Size : 1.94 mm

Max Face size : 9.722 mm

Growth Rate : 1.2

Number of Nodes : 190786

Number of Elements : 46340

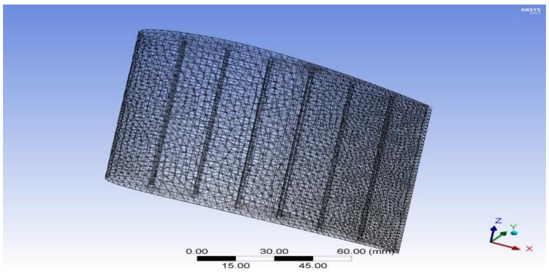

Figure 2: Mesh model of the turbine blade

5. Boundary Conditions

The gas force that acts over the blades is axial force, tangential force and centrifugal force. The gas forces are computed by the use of theoretical formulas and values of those are given below. The major parameter in the boundary is thermal condition, the temperature over the blade is due to the combusted gas is 1500 K and temperature of air used for cooling is 310K. The convection coefficient of the blade is given by 4000 W/m^{2}k. The boundary condition defined for static thermal analysis is shown in figure 03 and in figure 04 boundary condition for static structural analysis is given.

- Axial Force : 37580 N
- Tangential Force : 16743 N
- Centrifugal Force : 473321 N (for Inconel) / 475765 N (for Nimonic)

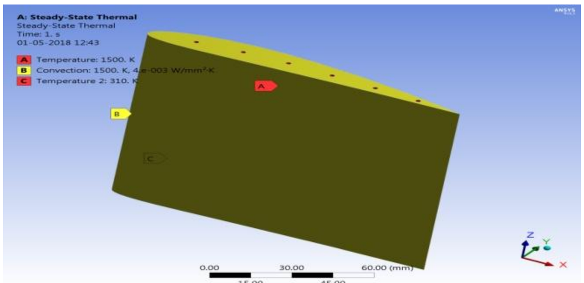

Figure 3: Thermal Boundary condition for turbine blade

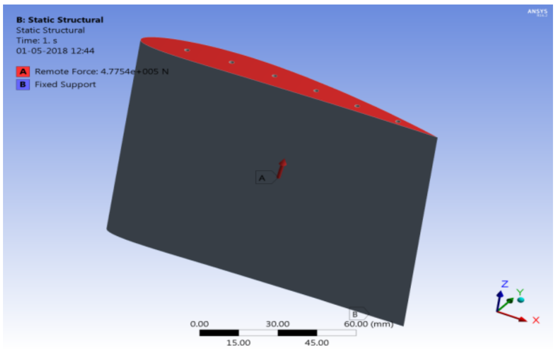

Figure 4: Structural Boundary condition for turbine blade

5. Simulation Results

The blades are analysed for static thermal analysis and static structural analysis conditions. From the thermal analysis we obtain maximum temperature distribution. the results of thermal analysis are given as input for structural analysis. From structural analysis we can find deformation, stress and strain distribution over the blade. The simulation result done with ANSYS software are tabulated here. The contours of the deformation, stress and temperature are also given below.

Table1: Nimonic Material simulation results

Number of Holes	T_{max} (K)	Deformation (mm)	Min. Stress (MPa)	Max. Stress (MPa)
6	1289	1.925	44.058	2192.9
8	1190	2.47	33.49	2295.9
9	1123	2.41	58.88	2335.4
10	1094.6	2.37	41.14	2282.3
11	1055.5	2.3	22.83	2194.8

Table2: Inconel Material simulation results

Number of Holes	T_{max} (K)	Deformation (mm)	Min. Stress (MPa)	Max. Stress (MPa)
6	1295	1.75	16.101	2520.7
8	1207.6	2.36	12.86	2214.4
9	1145.3	2.32	51.98	2328.5
10	1103.6	2.28	73.77	2366.9
11	1082.1	2.23	75.94	2202.8

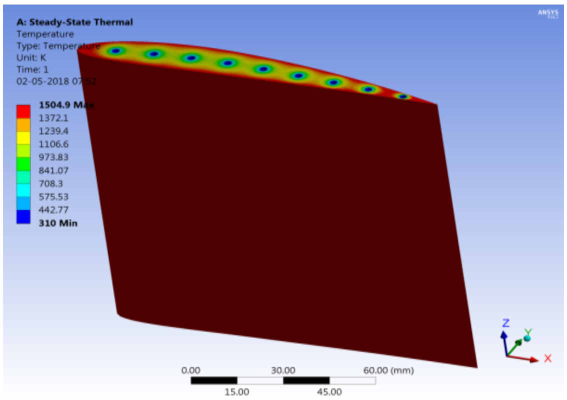

Figure 5: Temperature distribution for nimonic with 9 holes

The above figure describes the temperature distribution of nimonic material with 9 holes. Maximum temperature distribution is obtained at upper and lower surface of the blade. Minimum Temperature is noticed at camber line. T_{max} obtained is1123 kelvin.

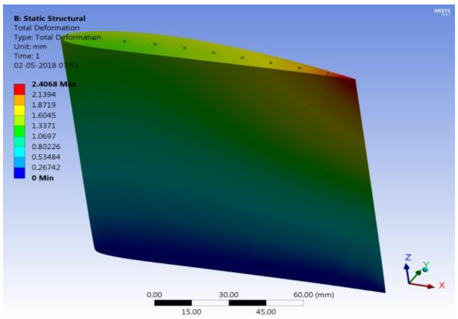

Figure 6: Deformation for nimonic with 9 cooling holes

The maximum deformation is obtained at tip of blade that is green at leading edge and very high at trailing edge which is red. Minimum at root of blade which is blue colour in above contour.

6. Conclusion

When we consider the temperature parameter, while we increase the number of holes there has been a huge temperature drop over the blade in both the cases but the nimonic material has a higher temperature drop when compared to Inconel material. But while we go for the deformation the Inconel material has less deformation when compared to the Nimonic material, whereas the stress generated due to the forces is also higher for the Inconel material. Based on the requirement we can choose the material and number of holes for the turbine blade.

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