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Design and Simulation of Inconel 718 Gas Turbine Blades for the Transient Thermal Analysis

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Abstract- *The design features of the turbine segment of the gas turbine have been taken from the "preliminary design of a power turbine". It was observed that in the above design, after the rotor blades being designed they were analyzed only for the mechanical stresses. As the temperature has a significant effect on the overall stress in the rotor blades, a detailed study is carried out on the temperature effects to have a clear understanding of the combined mechanical and the thermal stresses. The first stage rotor blade of the gas turbine is designed and analyzed for the transient thermal analysis by setting the blade material as Titanium T6. The next stage rotor blade involves changing the blade material to "Inconel 718 alloy "and analyzing the thermal properties. Finally the two results are compared and their life expectancy is determined.*

Keywords: *Gas turbine blade, Mechanical and the thermal stresses, Inconel 718 alloy, transient thermal analysis.*

INTRODUCTION

The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. The turbine drives the compressor so it is coupled to the turbine shaft. After compression, the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume. Either of there may be done by adding heat so that the temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid, a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid. The turbine escapes energy from the exhaust gas. The present paper deals with the thermal stresses that arise due to temperature gradient within the blade material. The analysis of turbine blade mainly consists of the following two parts: Structural and thermal analysis. The analysis is carried out under steady state conditions using ANSYS software. The study has been conducted with two different materials Inconel 718 and Titanium T6.

Structural Analysis

The structural analysis is the most common analysis of finite element method, which accomplishes various structures such as bridges, naval, aeronautical, mechanism housing and mechanism components such as possible in ANSYS software. They are, Static analysis, Modal analysis, Harmonic analysis, Transient dynamic analysis, Spectrum analysis, Buckling analysis, Explicit dynamic analysis, Fractured mechanics, Composites, Fatigue, and P-method. Out of these 11 analysis options generally we consider the static and modal analysis options only. In the analysis options we have H-method and P-method types of solutions.

Static Analysis

A static analysis calculates the effects of static loads on the structure while ignoring the inertia and damping effects such as those caused

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by time varying loads but it can accomplish steady inertia loads static equivalent loads. Steady loading and response conditions are assumed. The loads and the structures response are very slow in this analysis. The types of loads that can be applied in a static analysis include, Externally applied pressures and forces, Steady state internal forces (such as gravitational velocity), Imposed (non-zero) displacements, Fluencies (for nuclear swelling). A static analysis can also include linear and non-linear analysis. Non-linearity such as creep, large deformation, plasticity, stress stiffening, contact elements, hyper elastic elements etc can be handled very easily. The procedure for static analysis consists of three steps includes, Build the model, Apply the loads and obtain the solutions, Review the results.

Thermal Analysis

A thermal analysis calculating the thermal variations and related thermal quantities in a system or component such as, The temperature distribution, The amount of heat lost or gained, Thermal gradients, Thermal fluxes. Thermal analysis plays an important role in the designing of many components such as heat exchangers, turbines, internal combustion engines and piping systems. The thermal analysis is carried out with static analysis to calculate thermal stresses. The basis of thermal analysis is the heat balance equation obtained from the conservation of energy. The thermal analysis can solve all the modes of heat transfer. Conduction, convection and radiation ANSYS supports 2 type of thermal analysis such as: Steady-state thermal analysis and transient thermal analysis. A steady state thermal analysis-loading situation is the one in where heat-storing effects over a period of varying time can be ignored. In some analysis thermal analysis combined with other phenomenon are used as thermal-structural analysis and magnetic –thermal analysis. This is called as steps includes, Build the model, Apply the loads and obtain the solutions, Review the results.

Construction of Turbine Rotor Blade

To accomplish the analysis of a structure in ANSYS package steps are to be followed:

1. Build the model.
2. Apply the loads and obtain the results.
3. Review the results.

Here, we are considering the blade for analysis. So we need to define the list of operations with respect to the structuring of the blades.

Steps Involved in Designing

In modelling the blade a series of operations are to be followed. The list of operations that are to be followed are:

1. Problem definition.
2. Calculate the dimensions of blade profile
3. Generate the 3-dimentional computer models
4. Prepare finite element model of the 3D computer model
5. Preprocess the 3D model for the defined geometry
6. Mesh the geometry model and refine the mesh considering sensitive zones for results accuracy
7. Post process the model for the required evaluation to be carried out
8. Determine maximum stress induced in blades.
9. Determine the temperature distribution along the blade profile.
10. Conclude the results.

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Details of Turbine Blade Material

DETAILS OF TURBINE BLADE MATERIAL

The turbine blade is subjected to rotational speed of 10800 rpm and firing temperature of 619^{0}C. Factor of safety is 1.6.

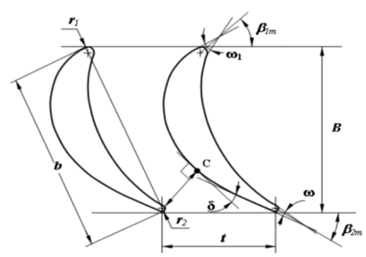
Material properties.

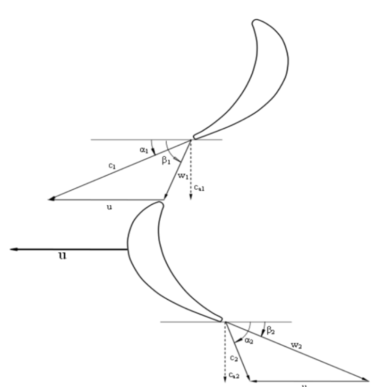
Properties	Unit	Inconel 718	Titanium T6
Young's modulus	MPa	2E5	1.06E5
Density	kg/m^3	8193.3	4420
Poisson's ratio		0.31	0.3
Tensile yield strength	MPa	1069	530
Allowable stress	MPa	641.8	318
Allowable Shear stress	MPa	385.08	190.8
Specific heat	J/kg-K	556.85	527.5

Problems Faced by A Turbine Blade

1) The turbine plates are subjected to high temperature which leads to a higher thermal efficiency, higher power to weight ratio and low specific fuel consumption.
2) If a blade is heated rapidly to a high temperature it causes uneven temperature distribution and several thermal stresses are developed with in the material.
3) Beyond certain level of temperature (65-800C) the blade material does not remain elastic and continuous to stretch under applied forces. This is called creep and if this exits for a long time fracture will occur.
4) So the above problems can be eliminated by using a Inconel 718 alloyed gas turbine blade and improve the life expectancy of the turbine blade.

Geometry of Gas Turbine Blade





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Where,
c = throat width (mm)
b = real chord (mm)
B =axial chord (mm) ω1= leading edge wedge angle (°)
d2= trailing edge diameter (mm) ω2= trailing edge wedge angle (°)
r1= leading edge radius (mm) i = incidence (°)
r2= trailing edge radius (mm) AR= aspect ratio
t= pitch (mm) δ= uncovered turning (°)
β1m = inlet metal angle (°)

β2m=outlet metal angle (°)

Conclusions

Thus the structural and thermal analysis procedure of a gas turbine blade is discussed in this paper. This paper discusses the necessity of the analysis in briefly. The importance of the analysis procedures is listed in this paper.

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