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Structural and Thermal Finite Element Analysis of Gas Turbine Rotor Blade

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Abstract:

In the present work the first stage rotor blade of a two-stage gas turbine has been analyzed for structural, thermal using ANSYS, which is a powerful Finite Element Software. In the process of getting the thermal stresses, the temperature distribution in the rotor blade has been evaluated using this software. The design features of the turbine segment of the gas turbine have been taken from the preliminary design of a power turbine for maximization of an existing turbojet engine. It was observed that in the above design, the rotor blades after being designed were analyzed only for the mechanical stresses but no evaluation of thermal stress was carried out. As the temperature has a significant effect on the overall stress on the rotor blades, it has been felt that a detail study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

In the present work, the first stage rotor blade of the gas turbine has been analyzed using ANSYS for the mechanical and radial elongations resulting from the tangential, axial and centrifugal forces. The gas forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. The rotor blade was then analyzed using ANSYS for the temperature distribution. For obtaining temperature distribution, the convective heat transfer coefficients on the blade surface exposed to the gas have to feed to the software. The convective heat transfer coefficients were calculated using the heat transfer empirical relations taken from the heat transfer design dada book. After containing the temperature distribution, the rotor blade was then analyzed using ANSYS for the combined mechanical and thermal stresses. The radial elongations in the blade were also evaluated.

INTRODUCTION (Heading 1):

The finite element method (FEM) has now become a very important tool of engineering analysis. Its versality is reflected in its popularity among engineers and designers belonging to nearly all the engineering disciplines. Whether a civil engineer designing bridges, dams or a mechanical engineers designing auto engines, rolling mills, machine tools or an aerospace engineer interested in the analysis of dynamics of an aeroplane or temperature rise in the heat shield of a space shuttle or a metallurgist concerned about the influence of a rolling operation on the microstructure of a rolled product or an electrical engineer interested in analysis of the electromagnetic field in electrical machinery-all find the finite element method handy and useful. It is not that these problems remained unproved before the finite element method came into vogue; rather this method has become popular due to its relative simplicity of approach and accuracy of results.

LITERATURE SURVEY:

Turbo machine rotor blades are subjected to different types of loading such as fluid or gas forces, inertia loads and centrifugal forces. Due to these forces various stresses are induced in rotor blades. So stress and strain mapping on a rotor blade provide a vital information concerning the turbo machine design and lead to the detection of critical blade section. Analysis of static and dynamic behavior of a rotor blade is a basic problem in aero elasticity of turbo machine blades. The present paper deals with the stress analysis of a typical blade made up of nickel super alloy, which is subjected to centrifugal loading. The analysis results shows that stress is sever due to centrifugal forces compared that due to dynamic gas forces.

Here in this case the effect of thickness, twist and taper of the blade was considered at the root of the blade where generally failure is occurring. The various blade shapes viz. rectangular, aerofoils with some angle twist, taper aerofoil are taken into consideration. In this paper linear static analysis for determining von mises stresses, deformation in Z direction was determined using Finite element analysis software. The Solid brick 20-node element is used.

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Aero engine turbine and compressor blades operate at speed range 5000 to 15000 r.p.m. With temperature ranging from 50 to 900 degree centigrade. Hence depending on the stage of operation, blading material is usually an AL alloy, stainless steels, titanium alloys and nickel-based alloys. The tolerances on the blades are usually in the range of 0.05 mm to 0.15 mm on the aerofoil. The blades have a complex aerofoil structure and with varying aerofoil shape at different sections along the length of blade. There is always twist in the aerofoil sometimes of the order 60 degrees. These complex configurations are required as the gases are to be smoothly guided along the different stages of the compressor and turbine without turbulence to achieve maximum thrust from the engine.

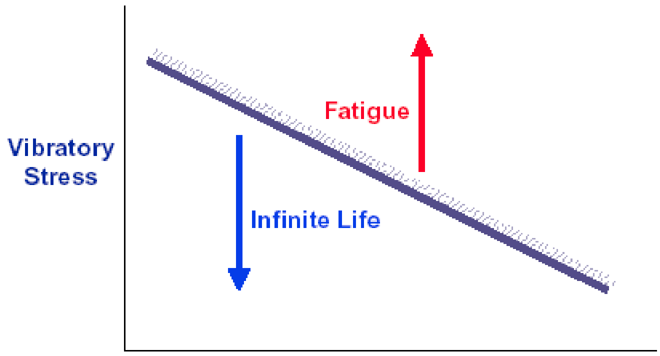

Figure 1.1 stress range diagram

Advanced turbomachinary blading is designed to have high steady stress levels. Thus high cycle fatigue occurs because of high mean stress low amplitude vibratory loading of aerofoils as shown.

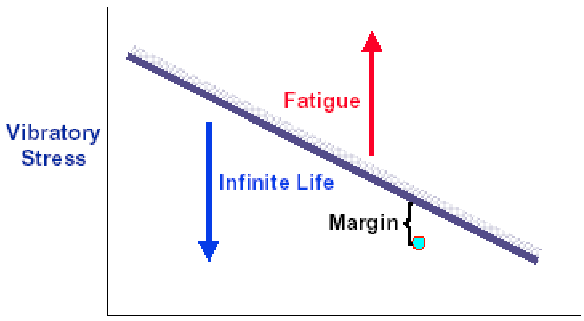

Figure 1.2 Advanced Airfoil stress range diagram

METHODOLOGY INTRODUCTION:

The purpose of turbine technology are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time.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 ring of fixed and moving blades. To get a high pressure of order 4 to 10 bar of working fluid, which is essential for expansion a compressor, is required. The quantity of ten working fluid and speed required are more so generally a centrifugal or axial compressor is required.

The turbine drives the compressor so it is coupled to the turbine shaft. If 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 these 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. Gas turbines have been constructed to work on the following: -oil, natural gas, coal gas, producer gas, blast furnace and pulverized coal. Gas turbines may be classified on the basis of following: -

a) On the basis of combustion process the gas turbine is classified as follows: -

1)Continuous combustion or constant pressure type-The cycle working on this principal is called Joule or Brayton cycle.
2)The explosion or constant volume type-The cycle working on this principal is called Atkinson cycle.
b) On the basis of the action of expanding gases similar to steam turbine is classified as: -
1) Impulse turbine or Impulse-reaction turbine.
c) On the basis of path of working substance the gas turbine is classified as –
d) On the basis of direction of flow

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1) Axial flow
2) Radial flow

A gas turbine is an engine where fuel is continuously burnt with compressed air to produce a steam of hot, fast moving gas. This gas stream is used to power the compressor that supplies the air to the engine as well as providing excess energy that may be used to do other work.
The engine consists of three main parts.

1)The Compressor
2)The Combustor and
3)The Turbine

Compressor usually sits at the front of the engine. There are two main types of compressor, the centrifugal compressor and the axial compressor. The compressor will draw in air and compress it before it is fed into the combustion chamber. In both types, the compressor rotates and it is driven by a shaft that passes through the middle of the engine and is attached to the turbine as shown.The combustor is where fuel is added to the compressed air and burnt to produce high velocity exhaust gas as shown.

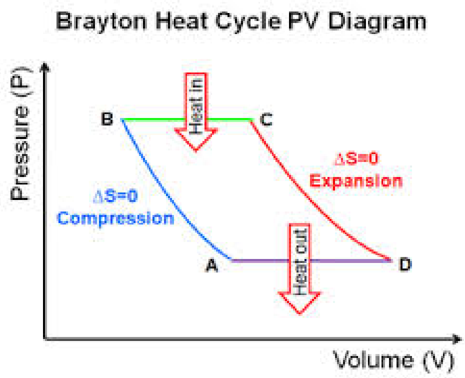

Figure 1.3 Indicator diagram of gas turbine

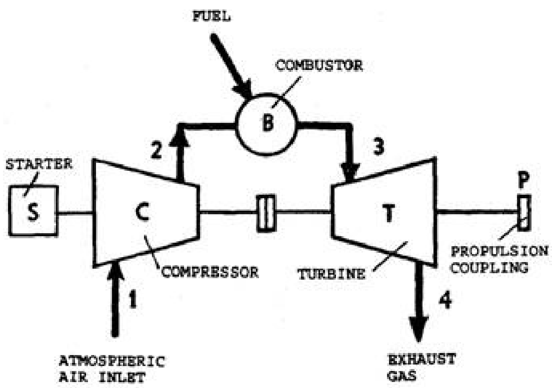

Figure 1.4 Simple open cycle gas turbine

TURBINE BLADE COOLING:

Unlike steam turbine blading, gas turbine blading need cooling. The objective of the blade cooling is to keep the metal temperature at a safe level to ensure a long creep life and low oxidation rates. Although it is possible to cool the blades by liquid using thermosyphon and heat pipe principal, but the universal method of blade cooling is by cool air or working fluid flowing through internal passage in the blades.The mean rotor blade temperature is about 3500c below the prevailing gas temperature after efficient blade cooling.

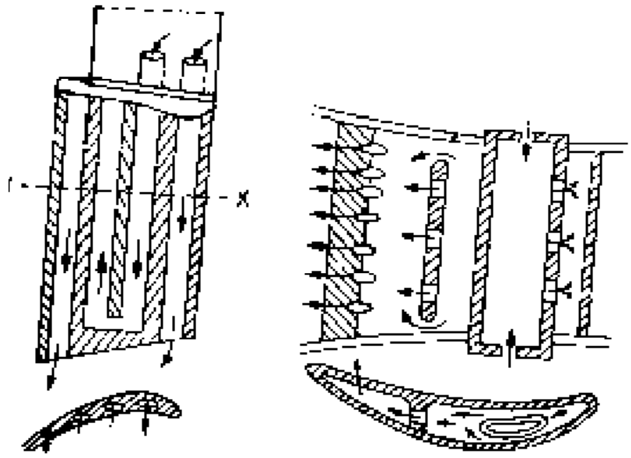

Figure 1.6 Turbine blade cooling

Due to corrosion and corrosion deposits turbine blades fail. To protect it from corrosion, the uses of pack-aluminized coatings are used. The main elements used are aluminium, nickel, and chromium.

SOLID 95 3D 20-NODE STRUCTURAL SOLID ELEMENT

Solid 95 is higher order version of the 3-D 8-node solid element. It can tolerate irregular shapes without as much loss of accuracy. Solid 95 elements have compatible displacement shapes and are well suited to model curved boundaries as shown. The element is defined by 20 nodes having three degrees of freedom per node, translations in the nodal x, y, and z directions. The element may have any spatial orientation. The element has plastically creep, stress stiffing, large deflection and large strain capabilities. The following table provides the summary of element input.

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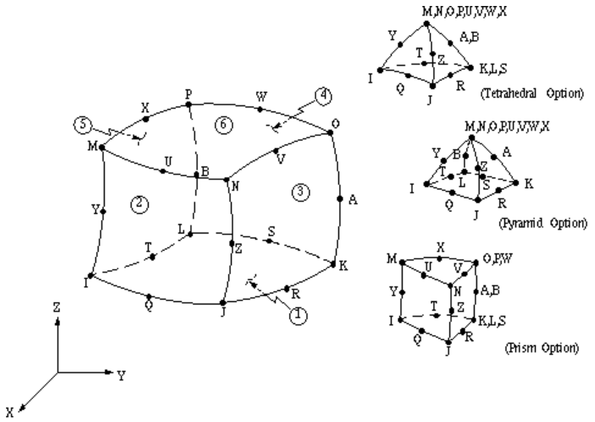

Figure 1.8 Solid 95 3-D structural solid

WHAT IS THE FINITE ELEMENT METHOD?

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Although originally developed to study stresses in complex airframe structures, it has since been extended and applied to the broad field of continuum mechanics. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering schools and in industry.

HOW THE FINITE ELEMENT METHOD WORKS :

(a) Finite difference and (b) finite element discretizations of a turbine Blade profile.

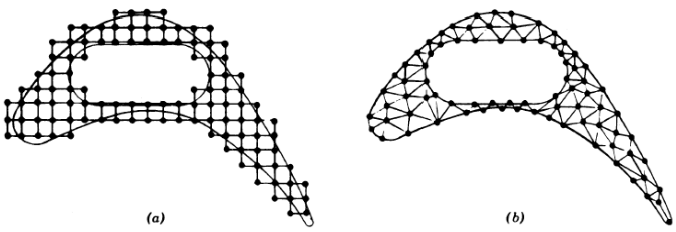

Figure 1.9 Discretizations of turbine blade profile

On the other hand, the finite element Model (using the simplest two-dimensional element—the triangle) gives a better approximation to the region. Also, a better approximation to the boundary shape results because straight lines of any inclination represent the curved boundary. This example is not intended to suggest that finite element models are decidedly better than finite difference models for all problems.

The only purpose of the example is to demonstrate that the finite element method is particularly well suited for problems with complex geometries. Still another numerical analysis method is the boundary element method (boundary integral equation method) this method uses Green's theorem to reduce the dimensionality of the problem; a volume problem is reduced to a surface problem, a surface problem is reduced to a line problem.

STRUCTURAL BOUNDARY CONDITIONS TO BE APPLIED ON THE ROTOR BLADE MODEL:

Two structural boundary conditions namely displacement and force were applied on the rotor blade model. The solution part of ANSYS was opened and the displacement constraints (U) were imposed on the areas shaded and numbered.

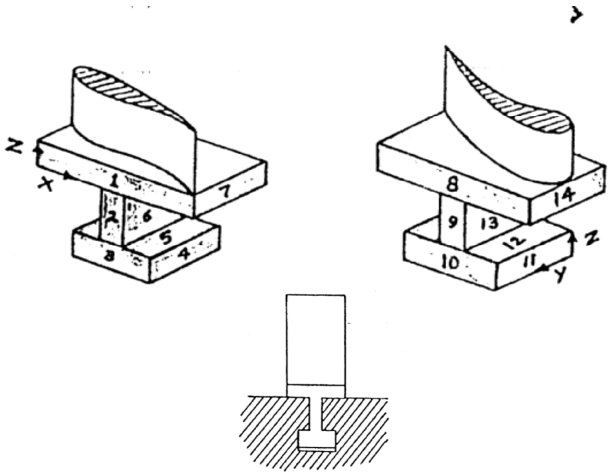

Figure 3.5 Structural boundary conditions on rotor blade

Ux = 0 for areas 4,5,6,7 and 11,12,13,14
Uy = 0 for areas 1,2,3 and 8,9,10
Uz = 0 for areas 5 and 12
U represents displacement and suffix X, Y, Z represents the direction in which the displacement was constrained. Since the gas forces were assumed to be distributed evenly, the tangential and axial forces acts throughout the centroid of the blade. The centrifugal force also acts through the centroid of the blade and in radial direction.
For first stage rotor blades,
Tangential force ft = 248.199 Newtons.
Axial force Fa = 3.82 Newtons.
Centrifugal force Fc = 38038.73 Newtons.
In the solution part of Ansys the blade forces namely tangential, axial and centrifugal were applied on the node located at the centroid of the blade as shown.

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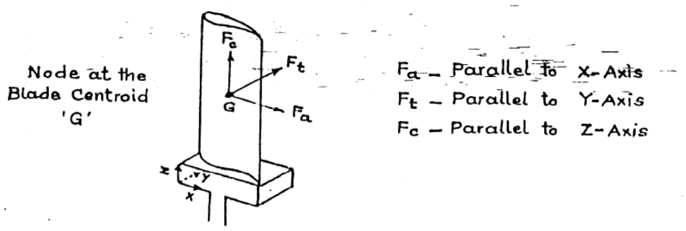


Figure 3.6 Static loading on rotor blade

STRUCTURAL AND THERMAL ANALYSIS USING ANSYS:

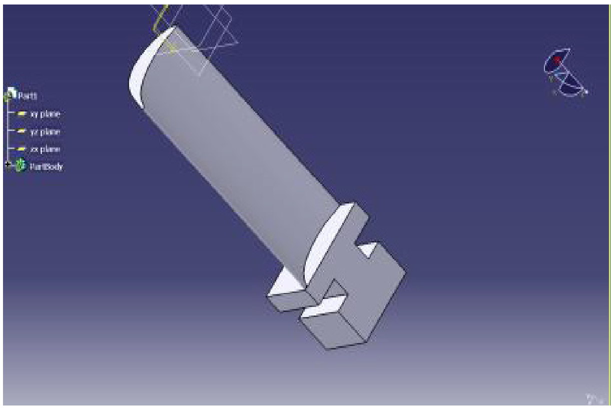


Figure 3.8. Turbine Rotor blade designed in CATIA

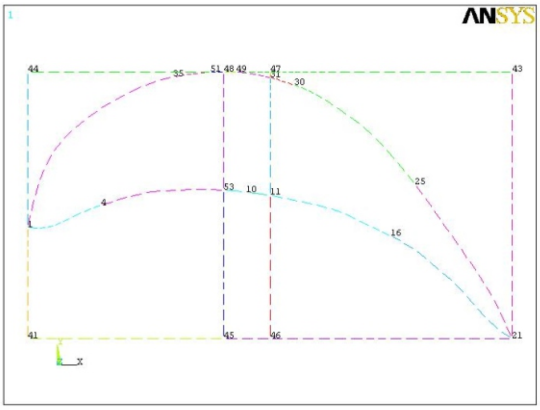


Figure 3.9 Line Diagram

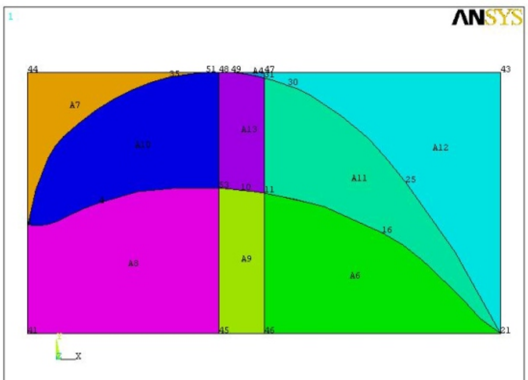


Figure 4.0 Area diagram of rotor blade

EXPERIMENTAL RESULTS:

II.

III.

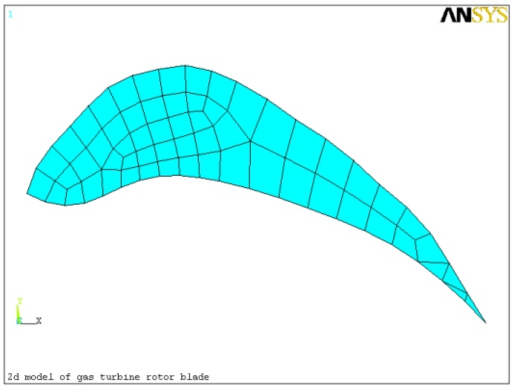


Figure 4.1 2 D model of gas turbine rotor blade

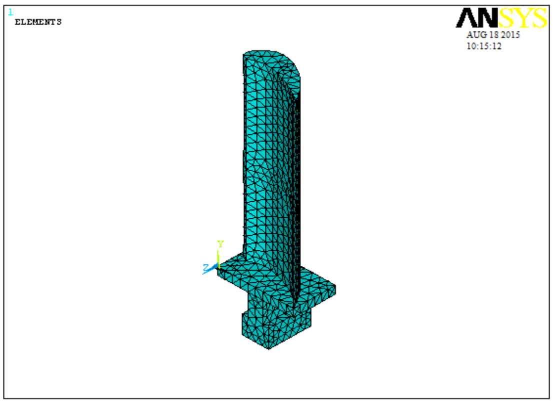
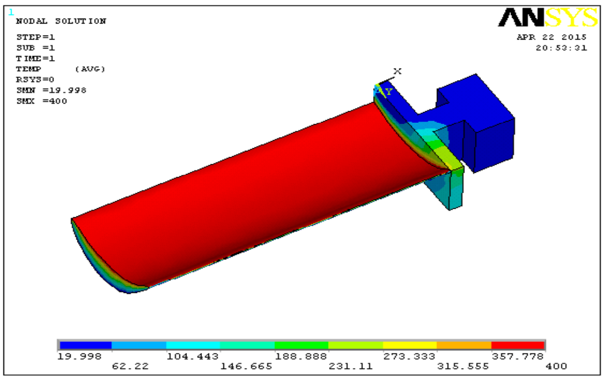


Figure 4.2. Finite Element model mapped mesh

Themal Analysis:

For Aluminium 2024 Alloy:



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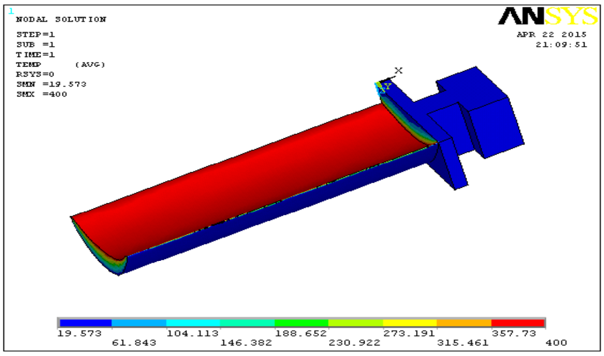
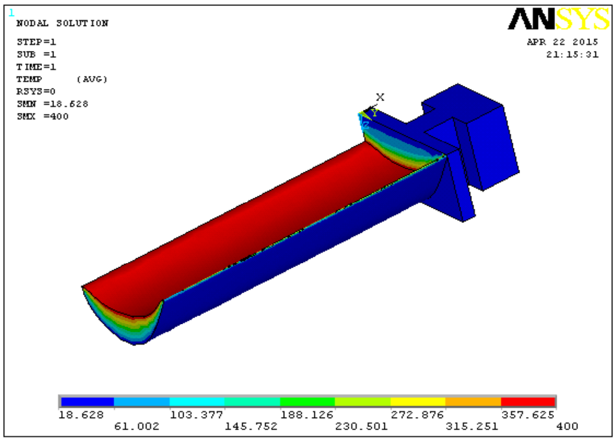
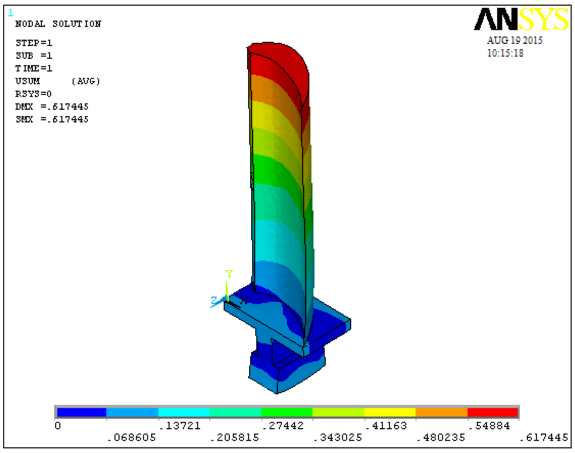


Copper Alloy



Stailess Steel Alloy



Total Deformation

RESULTS AND DISCUSSIONS
Table 1.4: Results Obtained
Thermal Analysis:

At constant nodal temperature for all the materials thermal flux is varying from 0.04107-0.049625 W/mm2 .

It is observed that the temperature varies from leading edge to the trailing edge on the blade profile and the variation is linear along the path from both inside and outside of the blade.

Thermal Analysis:

at constant nodal temperature for all the materials thermal flux is varying from 0.04107-0.049625 w/mm2 .it is observed that the temperature varies from leading edge to the trailing edge on the blade profile and the variation is linear along the path from both inside and outside of the blade.

STRUCTURAL ANALYSIS:

THE VON MISSES STRESSES ARE OBTAINED AS SHOWN ON ABOVE FIGURE; IT IS OBSERVED THAT THE MAXIMUM VON MISSES STRESS IS 12072N/MM2 FOR ALUMINIUM 2024 ALLOY, 19531N/MM2 FOR COPPER ALLOY, 3170N/MM2 FOR STAINLESS STEEL ALLOY.THE DEFORMATIONS ARE OBTAINED AS SHOWN IN FIGURE ; IT IS OBSERVED THAT THE MAXIMUM DEFORMATION IS 0.633974MM, 0.657864MM, 0.617445MM FOR ALUMINIUM 2024 ALLOY, COPPER ALLOY AND STAINLESS STEEL ALLOY RESPECTIVELY. FROM ABOVE DISCUSSION IT IS OBSERVED THAT THE STRESS, DEFORMATION ARE LOW FOR STAINLESS STEEL ALLOY.

CONCLUSION:

» The finite element analysis of gas turbine rotor blade is carried out using 20 noded brick element. The static and thermal analysis is carried out.
» The temperature has a significant effect on the overall stresses in the turbine blades.
» Maximum elongations and temperatures are observed at the blade tip section and minimum elongation and temperature variations at the root of the blade.
» Temperature distribution is almost uniform at the maximum curvature region along blade profile.
» Temperature is linearly decreasing from the tip of the blade to the root of the blade section.
» Maximum stress induced is within safe limit.
» Maximum thermal stresses are setup when the temperature difference is maximum from outside to inside.

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» Maximum stresses and strains are observed at the root of the turbine blade and upper surface along the blade roots.
» The deformation and stress values are less for stainless steel alloy and thermal gradient is more than other two materials.
» So we can conclude that Stainless steel alloy is better

Material Type	Vonmises Stresse (MPa)	Deformation (mm)	Nodal Temp (°C)	Therma Flux (W/mm²	Therma Gradien (°C)
Alluminium 2024 Alloy	12072	0.633974	400	0.04825	0.26807
Copper Alloy	19531	0.657864	400	0.04962	0.84524
Stainless Steel Alloy	3170	0.617445	400	0.0410	1.226

material for Turbine rotor blade than aluminium 2024 alloy and copper alloy materials.

» From the obtained results it is found that aluminium 2024 alloy has lesser thermal gradient when compared to that of copper alloy and Stainless steel alloy.
» On comparing the results stainless steel has much better stresses sustained over the turbine rotor blade.

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