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Short Article

Failure Analysis of Gas Turbine Rotary 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 9.0, which is a powerful Finite Element Software. In the present work, the first stage rotor blade of the gas turbine has been analyzed 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 9.0 for the temperature distribution. The material of the blade was specified as N155 but its properties were not given. This material is an iron based super alloy and structural and thermal properties at gas room and room temperatures. The turbine blade along with the groove is considered for the static, thermal, modal analysis. The first stage rotor blade of a two-stage gas turbine has been analyzed for structural, thermal using ANSYS 9.0 Finite Element Analysis software.

Keywords: Gas Turbine; Rotor Blade; Rotor Shaft; CATIA; ANSYS

Introduction

The finite element method (FEM) has now become a very important tool of engineering analysis. Its veracity is reflected in its popularity among engineers and designers belonging to nearly all the engineering disciplines.

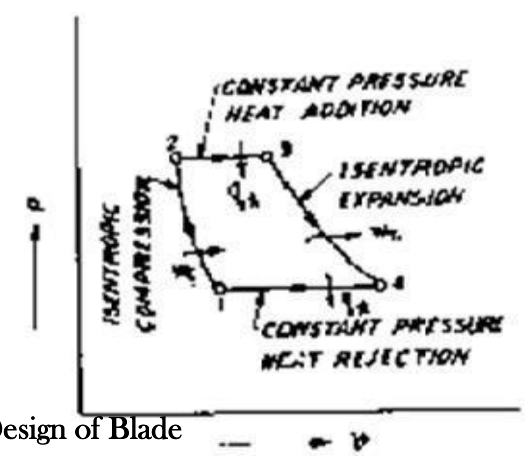
Traditional methods of engineering analysis, while attempting to solve an engineering problem mathematically, always try for simplified formulation in order to overcome the various complexities involved in exact mathematical formulation

Methodology

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.

Figure (1): Indicator diagram of gas turbine



Design of Blade

A good design of the turbo machine rotor blading involves the following:

1) Determination of geometric characteristics from gas dynamic analysis.

2) Determination of steady loads acting on the blade and stressing due to them.

3) Determination of natural frequencies and mode shapes.

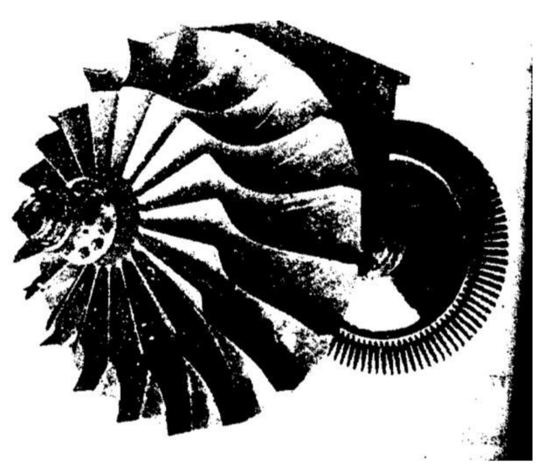
4) Determination of unsteady forces due to stage flow interaction.

5) Determination of dynamic forces and life estimation based on the cumulative damage fatigue theories.

Stress Analysis

The stress analysis of the rotor blade being the key phase of the turbo machine design requires much attention and careful determination of the blade loading to get realistic results. The stress analysis is performed to determine the critical section as well as the stressing pattern. As the blade vibration is also a cause of failure in many cases, the determination of natural frequencies and mode shapes is also of paramount importance. The designer should take care of dynamic forces such that the frequencies of these must be away from those of the rotor blades to avoid resonance, which is an undesirable phenomenon.

Figure (2): Turbine blade coupled to centrifugal compressor



- The commonly used blade materials are: -
- Brass
- Copper nickel
- Nickel brass
- Manganese copper
- Phosphor bronze
- Monel metal
- Mild steel
- Nickel steel

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 thermo syphon 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 3500 c below the prevailing gas temperature after efficient 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 aluminum, nickel, and chromium.

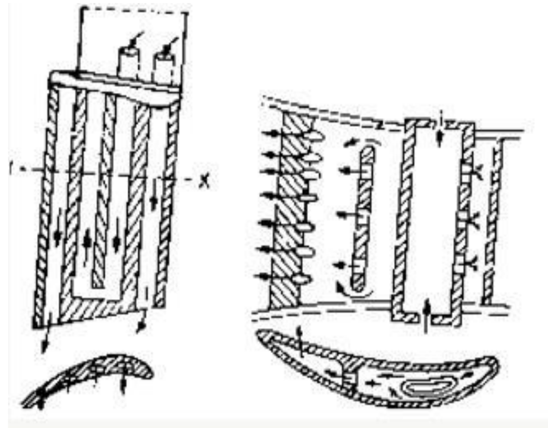


Figure (3): Turbine blade cooling

Applications of Gas Turbine

Land Applications

1) Locomotive Propulsions
2) Central Power stations

a) Standby plants for hydro installations.

b) Fully automatic booster stations at end of transmission lines.

c) Standby and peak load plants for small system.

d) Bomb proof power plants.

e) At location where water is not available.

Industrial

a) Pumping stations.

b) Space applications-

Turbo jet, Turbo propulsion, marine applications.

Computer Aided Structural Analysis of A Gas Turbine Rotor Blade

Element Type 1: 8 node quadrilateral element

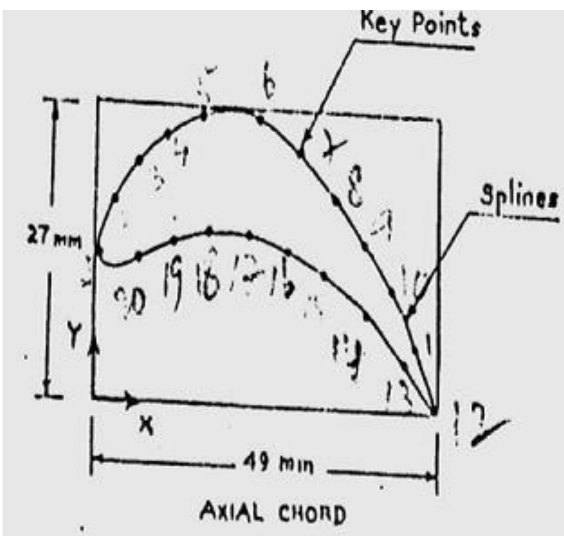
Element type 2: 10 node Brick solid element

The following material properties were defined in the material property table named as material type 1.

Young's Modulus of Elasticity (E)	2e$_5$ N/MM2
Density (ρ)	7136.52 e$_{-9}$
Coefficient of thermal expansion (α)	6.12e$_{-6}$

The aerofoil profile of the rotor blade was generated on the XY plane with the help of key points defined by the coordinates as given below. Then a number of splines were fitted through the keypoints. A rectangle of dimensions 49*27 mm was generated as shown.

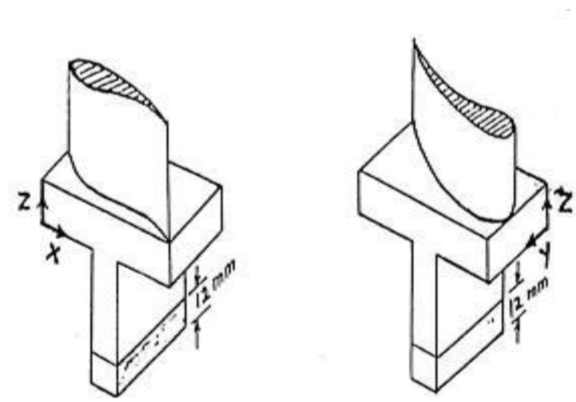
Figure (4): Boundary of aerofoil section



In the shape and size option, the number of element edges along the lines surrounding the areas 1 to 9 were specified. In the attribute option element type 1 and material type 1 were assigned to all the areas. Using the mesh option all the areas were meshed with 8-node quadrilateral element.

Areas 1 to m9 were extruded upwards in the positive Z direction through a height of 5mm.Before the extrusion option, the element and material type have to be assigned to the areas to be extruded. Element type 2 and material type 1 +were assigned to these areas. After extrusion, the rectangular block as shown was generated which was meshed with 3-D 20 node Brick element.

Figure (5): Volume of rotor blade



The shaded areas shown in figure were extruded along the X-direction through a distance of 3.8 mm using 3-D 20 node Brick elements.

The model was generated in the preprocessor of ANSYS 9.0

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.

U represents displacement and suffix X, Y, Z represents the direction in which the displacement was constrained.

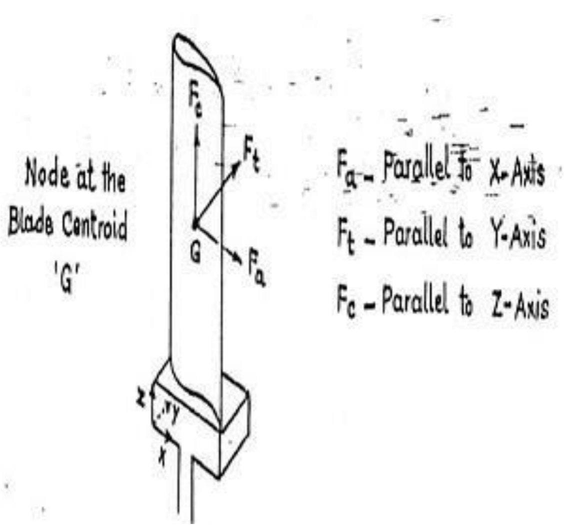
Since the gas forces were assumed to be distributed evenly, the tangential and axial forces acts throughout the centroid of the blade. The centrifugal force also acts through the centroid of the blade and in radial direction.

For first stage rotor blades

Tangential force f_t	248.199 Newtons.
Axial force F_a	3.82 Newtons.
Centrifugal force F_c	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.

Figure (6): Static loading on rotor blade



Analysis of Stress and Elongations

The ANSYS software then analyzed the mechanical stresses and elongations experienced by the rotor blade. The results were viewed in the post processor part of Ansys. The geometry, loads and results were stored in a file named 'X'.

Thermal Boundary Conditions applied on the Rotor Blade Model

A new file was opened in ANSYS and the thermal module of ANSYS was activated. The rotor blade model was copied into this file from which the previous structural analysis file 'X'. The structural boundary conditions that were applied previously on the rotor blade model were deleted.

The element type was stitched from structural to its equivalent thermal element type. The material properties were same as those in the previous file of structural analysis.

For first stage rotor blades,

For area A	h = (hs + hp)/2 = 332.43 w/m2	K and T =839.220 c
For area B	h = hp = 248.95 w/m2	K and T = 7860 c
For area C	h = hs = 379.92 w/m2	K and T = 7860 c
For area D	h = 248.95 w/m2	K and T = 7860 c
For area E	h = 379.92 w/m2	K and T = 7860 c
For area F	h = 231.19 w/m2	K and T = 7330 c

The thermal analysis file 'y' was reopened.

The element type was switched from thermal to its equivalent structural element type. The structural boundary conditions namely displacements and forces were again applied on the model. In the thermal analysis the temperature distribution is stored in a .rth file. The temperature distribution was imposed on the blade by recalling it from .rth file. The stresses and elongations were then analyzed using software results were viewed in the post processor.

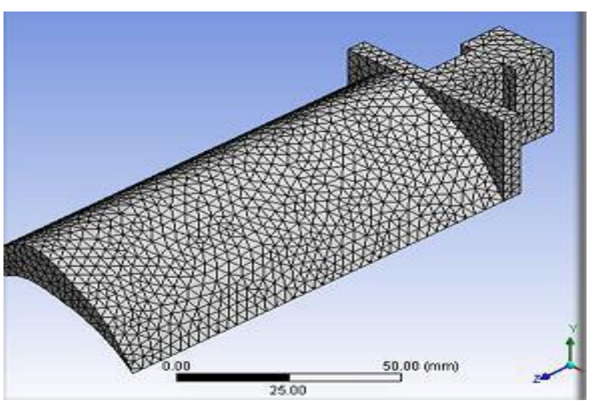
The solution part of ANSYS was opened and Heat flux = 0 was applied on the areas shaded and numbered in figure

Heat flux = 0 fro areas 1,2… to 16

Areas 1,2,3 and 8,9,10 come in contact with similar areas on the adjacent rotor blades. Hence due to symmetry boundary conditions, these areas are assumed to be insulated.

Areas 4,5,6 and 11,12,13,15 on account of their small dimensions are assumed to be insulated. In the convective boundary condition, the convective heat transfer coefficient (h) and temperature of surrounding gases (T) have to be specified on the areas subjected to convection

Figure (7): Brick mesh gas turbine rotor blade



Analysis of Stress and Elongations Taking Temperature Effect into Consideration

The thermal analysis file 'y' was reopened. The element type was switched from thermal to its equivalent structural element type. The structural boundary conditions namely displacements and forces were again applied on the model. In the thermal analysis the temperature distribution is stored in a .rth file. The temperature distribution was imposed on the blade by recalling it from .rth file. The stresses and elongations were then analyzed using software results were viewed in the post processor.

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.
- Maximum stresses and strains are observed at the root of the turbine blade and upper surface along the blade roots.
- Elongations in X-direction are observed only at the blade region in the along the blade length and elongation in Y-direction are gradually varying from different sections along the rotor axis.