MODELING AND DYNAMIC ANALYSIS OF WIND TURBINE BLADE

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ABSTRACT

In the present work, the first stage rotor blade off 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 exit of rotor blades. The convective heat transfer coefficients were calculated using the heat transfer empirical relations taken from the heat transfer design data book. After containing the temperature distribution, the rotor blade was then analyzed for the combined mechanical and thermal stresses. The radial elongations in the blade were also evaluated.

The turbine blade along with the groove is considered for the static, thermal, modal analysis. The blade is modeled with the 3D-Solid Brick element. The geometric model of the blade profile is generated with splines and extruded to get a solid model. The first stage rotor blade of a two stage gas turbine has been analyzed for structural, thermal and modal analysis using Finite Element Analysis software. The thermal boundary condition such as convectional and operating temperatures on the rotor blade is obtained by theoretical modeling.

And finally the results are obtained within the safe limit of the gas turbine blade.

INTRODUCTION:

The purpose of turbine technology is 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 in creasing 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.

Organization of Dissertation: -

The first chapter deals with introduction of dissertation work, which gives brief idea of need and objective of Finite Element Analysis of a gas turbine rotor blade.

The second chapter deals with literature survey and critical review of gas turbine rotor blade. The various papers are collected and based on that analysis of a gas turbine rotor blade is done.

The third chapter deals with introduction and actual working of gas turbine. In this complete methodology for determining gas forces is done which is used for structural, thermal and modal analysis.

The fourth chapter deals with results, discussions and graphs for structural, thermal and modal analysis for free mesh and also for combination of structural and thermal analysis.

Lastly, conclusion is given based on complete work of Finite Element Analysis of a Gas Turbine Rotor Blade using ANSYS software.

LITERATURE REVIEW

M.Venkatarama Reddy, Additional Director CVRaman nagar, Bangalore [1] describes the influence of taper, twist, thickness in rotor blade using Finite element analysis. 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.

Dr. K. Ramachandra, Director, Gas Turbine Research Establishment, Bangalore, [2] describes need for analysis of stress concentration factor in inclined cutouts of gas turbine blades. In this paper, aero engine gas turbine blades are aerofoil in cross section and are twisted mounted on annular plate, which in turn is fixed to rotating disc. Blades operate at very high speed and temperature leading to induction of respective stresses. For air-cooling purpose, blades are provided with number of minute cooling holes (0.5 to 0.8 mm) on the hollow walls of the blades through which pressurized air is ejected. Holes are oblique, oriented at compound angles and are stress raisers and lower the resistance of the blade to thermal and mechanical fatigue. Investigation is carried on theses holes to relate the stress concentration with the presently available solutions, and found that geometry of these holes is influenced by the varied thickness along both the axes and stresses induced are highly complex and Dependent on geometry of the hole (due to varied thickness & twist) and location of each hole (due to temperature gradient).

Studies point that cooling holes on turbine blades are stress raisers and can affect the Creep and fatigue life of the blades. The holes are oblique and orientated at compound angles. These holes cannot be related to oblique holes on flat plate, as the geometry of the holes vary depending on plate twist and plate cross section. On detail investigation it is found that stress distribution on typical gas turbine blade cooling holes does not resemble any of the presently available solutions for different geometry of holes and loads. Towards an attempt to increase the design efficiency of the cooling holes, a thorough three-dimensional stress analysis of the same with the said parameters is essential the magnitude of the stresses induced in these holes is dependent on, geometry of the isolated hole (taking account of pitch effect) and location of the hole, which is influenced by temperature gradient. Thus at first analysis of stress in oblique hole in a varied thickness plate for different compound angle orientation taking into account, effect of pitch and thermal stresses, may be tried to simplify the problem as this may give lot of deviation to presently derived solutions. The suggested technique for the analysis is, FEM and verification by experimental stress analysis method**.**

METHODOLOGY

principle of gas turbine: it is type of internal combustion engine where working fluid is air . Air is compressed using compressor and high pressere air is send to combustion chamber where the fluid is ignited and this high pressure gass is expanded in turbine and thus mechanical work is obtained. Fraction of work is obtained at the turbine by used in running the compressor.

in the present work 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 temperatures were taken from the design data books that were available in the library of BHEL Hyderabad.

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.

c) On the basis of path of working substance the gas turbine is classified as –

1) Open cycle gas turbine (working fluid enters from atmosphere and exhaust to atmosphere.

2) Closed cycle gas turbine (Working fluid is confined in the plant)

3) Semi closed cycle (part of the working fluid is confined within the plant and another part flows from the atmosphere.

d) On the basis of direction of flow

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.

The Compressor

The Combustor and turbine

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 in

The combustor is where fuel is added to the compressed air and burnt to produce high velocity exhaust gas as shown in

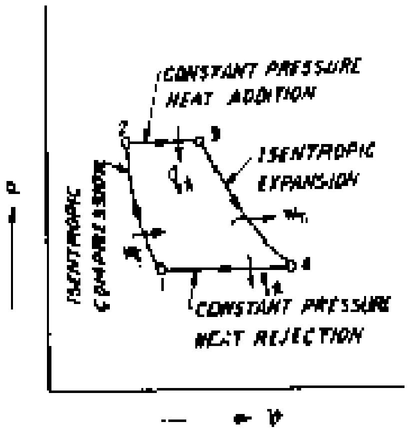


Fig Indicator diagram of gas turbine Simple open cycle gas turbine (constant pressure heat addition) or air standard Brayton (or joule) cycle.

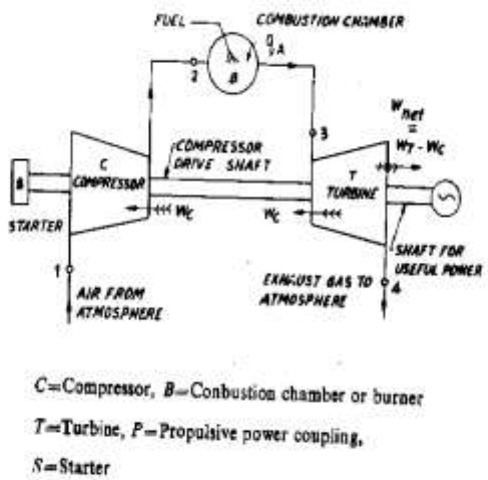


Fig Simple open cycle gas turbine

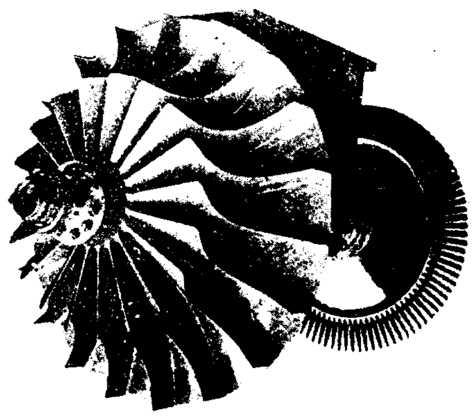
Production of Blades: -

Blades may be considered to be the heart of turbine and all other member exist for the sake of the blades. Without blading there would be no power and the slightest fault in blading would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades.

1) Rolling: - Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured by this method do not fail under combined bending and centrifugal force.

2) Machining: - Blades are also machined from rectangular bars. This method has more or less has the same advantage as that of first. Impulse blading are manufactured by this technique.

3) Forging: - Blade and vane sections having airfoil sections are manufactured by specialist techniques. The simplest way is to determine the profile required at the hub and tip and join then by straight ruled lines. Once the geometry of the ruled line is established they may be machined by a milling machine, rest carefully by each line to generate the shape required in a master block from which the forging die may be copy machined. This method ensures the accurate forging of blades to their finished size, requiring only



finishing. The machining of the fir-tree root is often done by broaching and electrochemical machining may be used in some parts to avoid the conventional cutting processes.

In advance methods, computers are used to determine the blade shape required by aerodynamic and stress criteria. The computer may then instruct a numerically controlled milling machine to prepare the dies.

4) Extrusion: - Blades are sometimes extruded and the roots are left on the subsequent machining. This method is not reliable as rolled sections, because of narrow limits imposed on the composition of blade material.

Advantages and Disadvantages of Gas Turbines

Advantages are: -

1) Better balanced due to absence of reciprocating masses,
2) Better mechanical efficiency due to absence of numerous sliding or bearing members.
3) High power plant of grater capacity than diesel engines can be built.
4) It can operate with cheaper fuels like any of the hydrocarbon fuels from high-octane gasoline down to heavy diesel oil.
5) It requires less lubrication and it is easy and inexpensive,
6) It has a much higher operating speed.
7) Smoke less exhaust.
8) It can be used in jet propulsion unit because of continuous exhaust at high temperature and pressure.
9) The system is flexible and thus reheating, regenerative and intercooling arrangements can be added to increase efficiency and output.
10) It has lower inlet temperature of air at high altitude, which increases the thermal efficiency.

Disadvantages are: -

1) It has poor part load efficiency.
2) It has a higher air arte so that open cycle is not suitable in marine applications.
3) It is sensitive to changes in compressor and turbine efficiencies.

Finite Element Formulation

Plane 82 2-D 8-Node Structural Solid Element

Plane 82 is a higher order version of the two dimensional four-node element. It provides more accurate results for mixed (quadratic-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible shapes and are well suited to model curved boundaries. The 8-node element is defined by 8-nodes having two degrees of freedom at each node-translations in the nodal x and y directions. As shown in fig 4.1.the element may be used as a plane element or as an axissyymetric element. The element has plastically creep, stress stiffening, large deflection, and large strain capabilities. The following table provides the summary of element input.

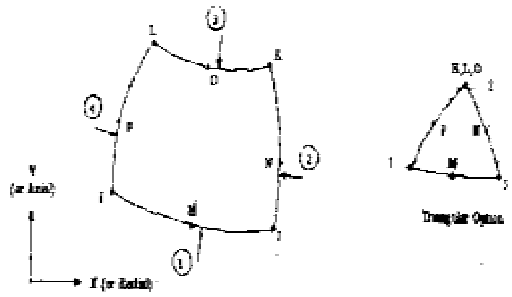


Fig lane 82 2-d structural solid

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 in 4.2. 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.

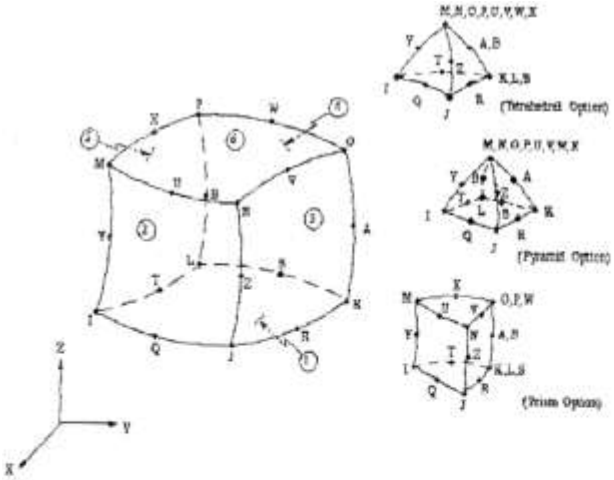


Fig Solid 95 3-D structural solid

Evaluation of Gas Forces on the Rotor Blades

Gas forces acting on the blades of the rotor in general have two components namely tangential (Ft) and axial (Fa). These forces result from the gas momentum changes and from pressure differences across the blades. These gas forces are evaluated by constructing velocity triangles at inlet and outlet of the rotor blades. The rotor blades considered for analysis are untwisted and same profile is taken throughout the length of the blade. If the gas forces are assumed to be distributed evenly then the resultant acts through the centroid of the area.

Evaluation of Centrifugal Force Experienced by Second Stage Rotor Blades

Using the same methodology that was used for the first stage for the second stage rotor blades we get,

$\underline{X}$ = 657.77 mm

Fc = 35164.39 Newtons.

Convective Heat Transfer Coefficients over the Blade Surfaces

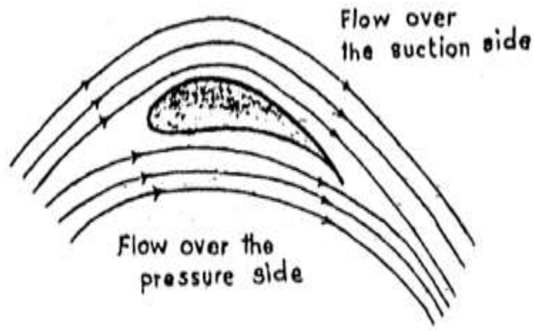


Fig gas flow over suction and pressure side of rotor blade

Table No Reynolds Number

ReD	C	M
0.4 – 4.0	0.989	0.330
4.0 – 4.0	0.911	0.385
40.0 – 4000	0.683	0.4666
4000 – 40000	0.193	0.618
40000 – 4000000	0.0266	0.805

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 in fig.

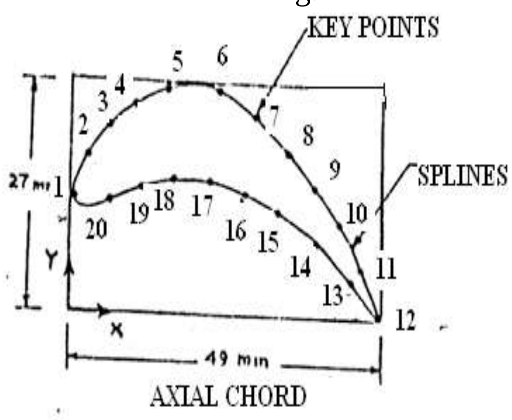


Fig: Boundary of aerofoil section

Table List Of Selected Keypoints

S.NO.	X	Y
1.	0.00	0.00
2	49	0
3	49	-5
4	29.2	-5
5	29.2	-19.5
6	33	-19.5
7	33	-31.5
8	16	-31.5
9	16	-19.5
10	19.8	-19.5
11	19.8	-5
12	0	-5
S.NO.	X	-Z
13	2.6	17.3
14	5.85	21
15	10	25
16	14.8	26.6
17	22.9	25.3
18	28	22.2
19	33.4	18.5
20	38	14.4
21	42	10.9
22	45.5	5.70
23	49.00	0.00
24	6.18	12.4
25	11.2	14.4
26	16.18	15.5
27	21.1	14.9
28	26	13.6
29	38.2	8.77
30	45	3.95
31	48.5	0.00
32	1.00	13.00

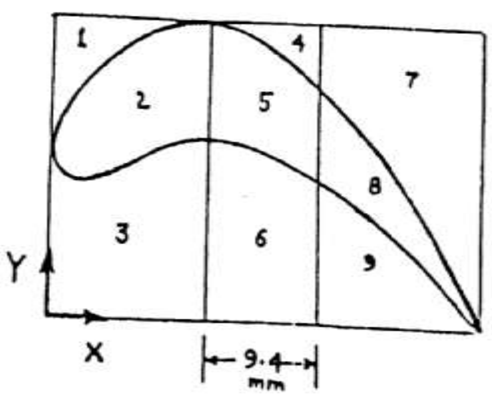


Fig: Areas of turbine rotor blade

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 in fig was generated which was meshed with 3-D 20 node Brick element.

Analysis of Stress and Elongations

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

Analysis of Temperature Distribution

The temperature distribution on the rotor blade was then analyzed by using the ANSYS software. The calculations were carried out in the solution part of Ansys.The results were viewed in the postprocessor part of software. The geometry, loads and results were stored in a separate file ' y'.

Analysis of Stresses 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 file. The stresses and elongations were then analyzed using software results were viewed in the post processor.

Computer Aided Modal Analysis Of A Gas Turbine Rotor Blade

MODAL ANALYSIS

You can use the modal analysis to determine the vibration characteristics- natural frequencies and mode shapes of a structure or a machine component while it is being designed. It can be also a starting point for another dynamic analysis such as a transient dynamic analysis, a harmonic analysis, and a spectrum analysis.

USES FOR MODAL ANALYSIS

You use modal analysis to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of the structure for dynamic loading conditions.

You can do modal analysis for a pressurizes structure such as spinning turbine blade. Another useful feature is model cyclic symmetry, which allows you to review the mode shapes of a cyclically symmetric structure by modeling just sector of it.

Modal analysis in the ANSYS family of product is a linear analysis. Any nonlinear analysis such as plastic and contact elements are ignored even if they are defined. You can choose several mode extraction methods namely subspace, blocklanczos, reduced, powerdynamics, unsymmetric and damped. The damped method allows you to include damping in the structure.

OVERVIEW OF STEPS IN MODAL ANALYSIS

The procedure for modal analysis consist of four main steps

1) Build the model
2) Apply loads and obtain the solution
3) Expand the modes
4) Review the results

Fig: Free mesh gas turbine rotor blade Femap

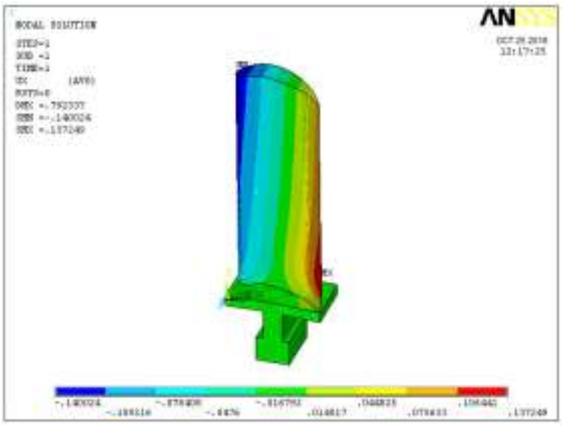


Fig Displacement Diagram Of Gas Turbine

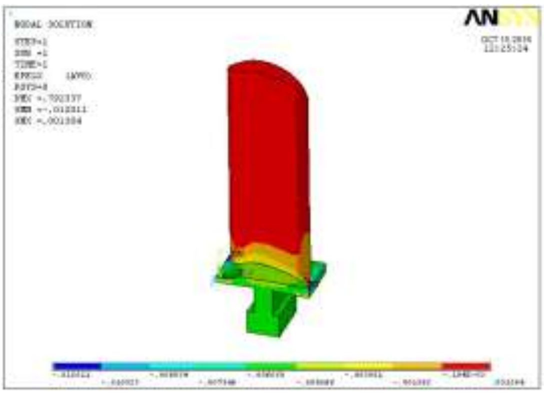


Fig Elastic Strain Diagram Of Gas Turbine

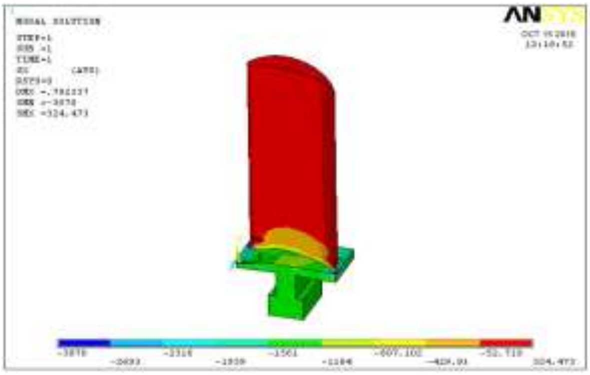


Fig Stress Diagram of Gas Turbine

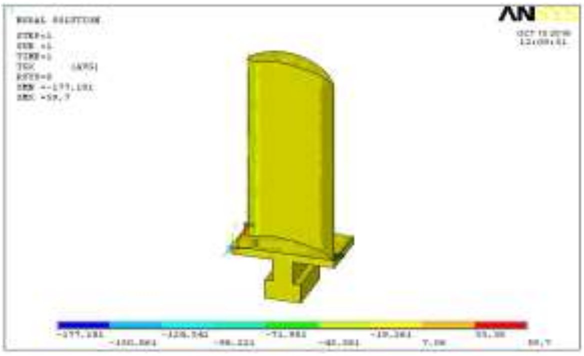


Fig Thermal Gradient Diagram of Gas Turbine

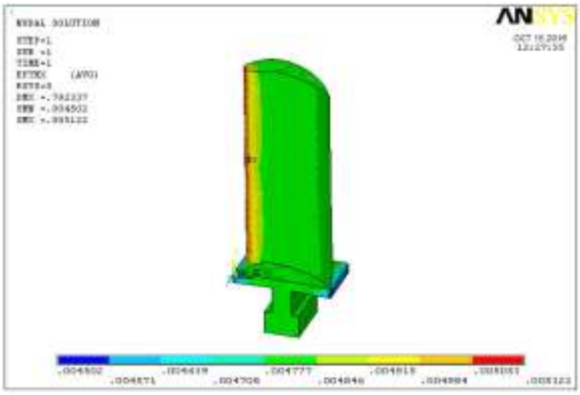


Fig Thermal Strain Diagram Of Gas Turbine

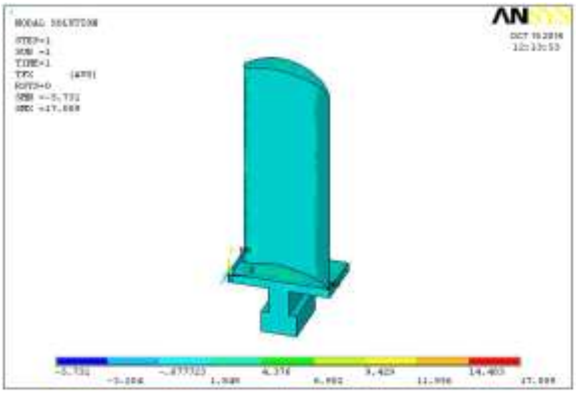


Fig Thermal Flux Of Gas Turbine

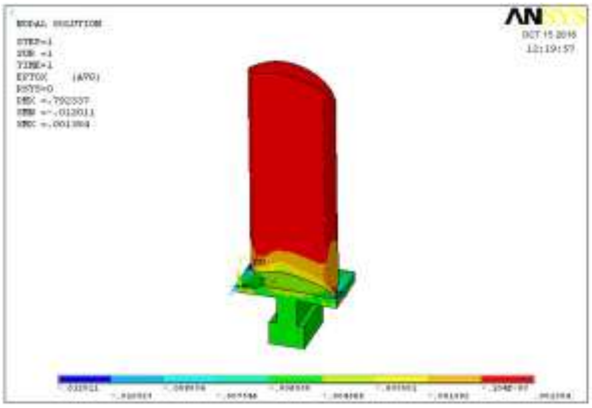


Fig Total Strain Diagram Of Gas Turbine

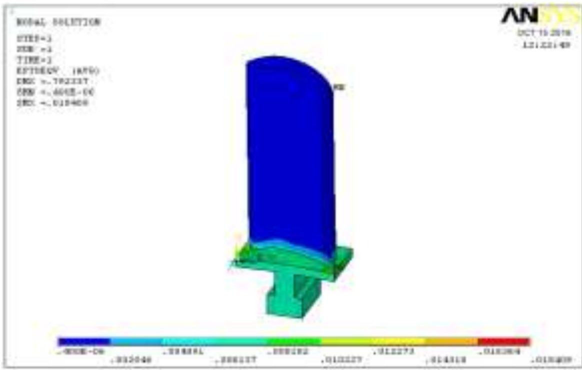


Fig: Von-Mises Total Strain Diagram Of Gas Turbine

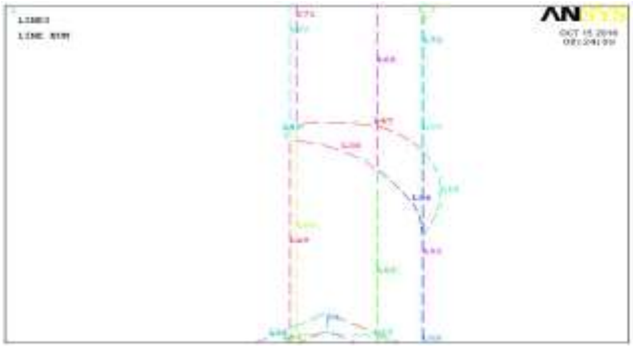
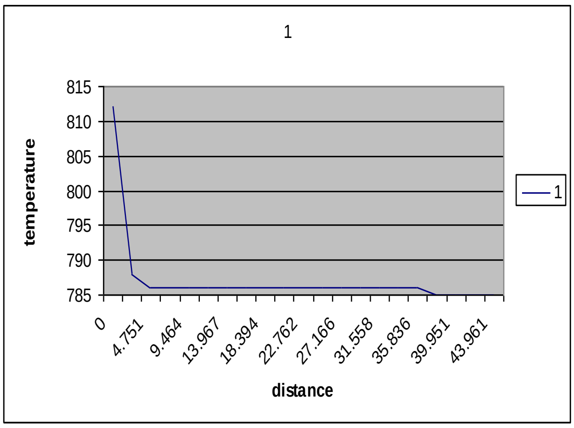


Fig Line Diagram of Gas Turbine



Temperature distribution along curved path

RESULTS AND DISCUSSIONS

From the post processing, the temperature variation obtained as shown in fig. From figure, it is observed that the temperature variations from leading edge to the trailing edge on the blade profile is varying from 810.567 to 786.005 at the tip of the blade and the variation is linear along the path from both inside and outside of the blade. Considerable changes are not observed for the first 6 mm length from the leading edge and from there to next 36 mm length of blade the temperature is gradually decreasing and reaching to a temperature of 796.317 and for another 4 mm length it is almost constant. Again from this point onward it is sloping downwards and reaching795.38 at the trailing edge. Where ever maximum curvature is occurring the temperature variation is less. At the root of the blade i.e.. The top flange of base, the temperature variation along X-direction is varying from 807.442 to 786.37 on front side i.e. inside and 804.505 to 790.13 on the backside of the blade. The temperature decreases gradually along X-direction. There is very small temperature gradient is occurring along -zdirection at the blade leading edge, on the suction side of blade and at the exist side of the blade and at the exist side the temperature is varying from 788.067 to 796.317.

CONCLUSION

The finite element analysis of gas turbine rotor blade is carried out using 20 noded brick element. The static, thermal and modal 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 -Z direction are gradually varying from different sections along the rotor axis.
- It could be concluded that these contour maps and profiles enables us to ascertain the areas of rotor blades that are vulnerable for failure

For the power turbine used for marine application, the rotor blade was analyzed for mechanical stresses at only a few sections. Hence an attempt is made in the present work to use the ANSYS software to obtain the temperature distribution, thermal and mechanical stresses and radial elongations at several cross sections of the rotor blades of the two stage power turbine selected from the earlier work.

The results obtained were presented in the form of contour maps and profiles of temperature distributions, radial elongations and mechanical, thermal stresses for the rotors. This information will supplement to optimize the mechanical design of the rotor blades for power turbines especially those developing outputs of the order of 15 MW. The results obtained in the present work add to the information for the design of rotor blades of multi-stage gas turbines of higher outputs.

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