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Structural and thermal analysis of a gas turbine blade

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Abstract*— A gas turbine is a device designed to convert the heat energy of fuel into useful work, such as mechanical shaft power. The gas turbine in its most common from is a rotary heat engine operating by means of series of processes consisting of air taken from the atmosphere, increase of gas temperature by constant pressure combustion of the fuel, the whole process being continuous. Turbine Blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor.The turbine blades are mainly affected due to static loads. Also the temperature has significant effect on the blades. Therefore the turbine blades to be analyzed for the mechanical and thermal stresses. The turbine blades analysis is carried out using finite element analysis software ANSYS.

***Index Terms*—Thermal Analysis, Gas Turbine Blade, ANSYS, Thermal Stresses.**

I. INTRODUCTION

The gas turbine in its most common from is a rotary heat engine operating by means of series of processes consisting of air taken from the atmosphere, increase of gas temperature by constant pressure combustion of the fuel, the whole process being continuous. It is similar to petrol and diesel engines in working medium and internal combustion but is akin to the steam turbines in its aspect of the steady flow of the working medium.

APPLICTION OF GAS TURBINES

The gas turbines are finding application in various fields such as in Gas Pumping, Marine, Transportation, Auto motives, Regenerator, Aircraft, Power Generation, Jet Propulsion, Turbo Machines, production of heat and power, Paper Drying, Heat Building and Air cooling systems. Fluidized bed combustion, Energy storage device and transformation of the liquid fuel into a clean gaseous fuel are future possible applications. Knowing the fluid condition at exit of each gas turbine, a value of static pressure was assumed at the turbine outlet. From this the corresponding enthalpy from required in the power turbine is calculated. The peripheral speeds of rotor and flow velocities are kept in the reasonable range so as to minimize losses. The blade selected from the direct approach in which the base profilers is taken from the standard profiles available and is analyzed later for flow conditions through any of the theoretical flow analysis method such as potential flow approach.

The design features of the turbine segment of the gas turbine have been taken from the “Preliminary design of a power turbine for marinisation of an existing turbojet engine”. It was observed only for the mechanical stresses effect on the overall stresses in the rotor blades, a detailed study is analyzed only for the mechanical stresses but there was no evaluation of thermal stresses. As the temperature has a significant effect on the temperature effects to have a clear understanding of the gas turbine is analyzed for the thermal stresses. The first stage rotor blade of the gas turbine is analyzed for the mechanical stresses and the radial elongation’s resulting from the tangential axial and centrifugal forces.

The latest gas turbine in use is having a power output of 160 MW with 35.6 thermal efficiency, 14.6 pressure ration, 1533 turbine inlet temperature, 435 kg/s airflow and 584D exhaust gas temperature. It is having 16 compressor stages, 4-turbine stage and 6 cooled rows.

TURBINE BLADES

Turbine Blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The blade is subjected to forces in three directions such as:

- The rotor driving forces along the axial direction.
- Axial forces cause by the gas flow.
- Forces acting normal to the turbine shaft due to the centrifugal forces.
- Differential thermal stress, erosion-corrosion and other hostile parameters hampering its smooth functioning.

BLADES MATERIALS

To obtain a high temperature rise in a stage, which is desirable to minimize the number of stages for a given overall pressure ratio there should be

- High blade speed.
- High axial velocity of gases.
- High fluid deflection in the rotor blades.

The stresses developed in the turbines are so high that they require special material and careful designing. The designing of the blades is very complicated and the materials chosen should be such that they can withstand high temperatures and have high strength i.e. heat resistant alloys. The turbine blades are subjected to a continuous stream of gas at temperatures of about 1000C and area subjected to a tensile stress of the order

200-1450kgf/cm2.Materials used in manufactures of blades are as follows:

- Vatallium [Cobalt alloy based at a temperature rating above 760] also called Haynes's stellite21 available in precession cast from with Carbon and Molybdenum as hardening agents.
- Hastelloy B [Nickel alloy based at temperature rating above 730c] available in wrought from with Molybdenum as hardening agent and solution treated.
- Titanium alloys.
- Haynes's series of alloy [Nickel and Cobalt based alloys with temperature ranging between 785-840] with Carbon, Molybdenum as hardening agents available in precession cast from.
- Alloy steels.

II. EVALUATION OF GAS FORCES ON FIRST STAGE ROTOR

At inlet of first stage rotor blades,
The Absolute Velocity V_2 = 462.2 m/s
Diameter of blades mid span D = 1.3085 m
Design speed of turbine u = □ DN/60
From the inlet velocity triangle of a rotor blade we get
Whirl Velocity Vw_2 = 422.74 m/s
Flow Velocity Vf_2 = 186.89 m/s
Relative Velocity Vr_2 = 265.09 m/s
Blade Angle at inlet □ □ = 135.17°
The above figure shows the exit velocity triangles of 1-state Rotor Blade.
At the exit first stage rotor blades,
Flow Velocity Vf_3 = 180.42 m/s
Whirl Velocity Vw_3 = 2.805m/s
Relative Velocity Vr_3 = 293.83 m/s
Evaluation of tangential (Ft), axial force (Fa) and centrifugal force (Fc) on each rotor:
Tangential Force Ft = m $[V_{w2}+V_{w3}]$ Newton
Axial Force Fa = m $[V_{w2}+V_{w3}]$ Newton
Where m is the mass flow rate of gases through the turbine Kg/s
m = 70.925 Kg/s
Total axial force on first stage rotor
Fa = 458.88 N
Total tangential force on first stage rotor
Ft = 29783.88 N
Number of blades passages in first rotor =120
Tangential force on each rotor blade,
Ft = Fa/No/of Blade passages
Fa = 3.82 N.
Axial force on each rotor blade,
Fa = fa/No/of Blade passage
Fa = 3.82 N.
From Euless's energy equation,
Power developed in the first stage rotor
P = m$[Vw_2u+- Vw_33U]$
Using the above equation
P = 6.911 MW
The distance x $(M_1X_1+M_2X_2+M_4X_3)/M_1+M_2+M_3$

Where M_1, M2, and M_3 are masses of volumes 1, 2 and 3 from the axis of revolution.
The density of material □ is graphically measured to be □ = 8900 Kg/M^2
M_1 = 0.382 Kg
M_2 = □ *V_2
M_3 = □ * V_3
Where V_2 and V_3 are volumes of portions 2and 3 of rotor blades.
The distance X is calculated as 648.85 mm
Total mass M =$M_1+M_2+M_3$
Centrifugal force Fc = M* (2□ n/60)^2* X and its value is found to be as 38038.733N
Evaluation of convective Heat Transfer coefficient on section side of first stage rotor blade:
For first stage rotor blades,
Temperature of gases st inlet Ti = 839.22
Temperature of gases at exist Te = 732.88
Mean fluid temperature Tmf =Ti-Te/2
The following properties of air at TMF are noted.
Kinematics viscosity (v)
Prandtl number (pr)
Thermal conductivity (k)
The value of C and M are selected from the tables below

Rep	C	M
0.4-4.00	0.9890	0.3300
4.0-40.00	0.9110	0.3850
40.0-4000	0.6830	0.4666
400-40000	0.1930	0.6180
4000-400000	0.0266	0.8050

Table: II.1 The values of C and M

Nud is found to be as 247.329
Nud = hs D/K
So h_s = 379.921 W/m^{2}K
The thermal fluxes for the structures are kept as Zero. The input convective heat coefficients heat transfer coefficients for the blade structure at different temperatures are as follows:
h_1 = 332.42 W/m^{2}K at T = 839.22 °C
h_1 = 248.95 W/m^{2}K at T = 786 °C
h_1 = 379.92 W /m^{2}K at T = 786 °C
h_1 = 248.95 W /m^{2}K at T = 786 °C
h_1 = 379.92 W /m^{2}K at T = 786 °C
h_1 = 231.19 W/m^{2}K at T = 839.22 °C
h_1 = 224.73 W/m^{2}K at T = 733 °C
In the solution module the input loading conditions are applied and given for the analysis option. While giving the solution element matrices are built within the processor.
The results are reviewed in the POST PROCESSOR module.

III. GENETATION OF THE 3D MODEL OF THE ROTOR BLADE

The structural modules of Ansys 10.0 were opened.
In element type table, 2 element types were defined.
Element type 1: 4 node quadrilateral element
- Element type 2: 8 node brick element

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The following materials were defined in the material property table named as material type 1.Young's modulus of elasticity (E) =206.84 Gpa
Density (ρ) = 8900 kg/m3

- Co efficient of thermal expansion (α) = 1.340 * 10E-5 /K
- Thermal conductivity (K) = 90.7 W/mK

The aerofoil profile of the rotor blade was generated on the X-Y plane with the help of key points define by the coordinates as given in the table. Then a number of splines were fitted through the key points, defining the boundary of the aerofoil section as depicted in the figure 5.1.A rectangle 49×27 mm was generated as shown in figure below. Using splines and lines as boundaries, 9 different areas were generated which are depicted by numbers in figure 5.2. In the shape and size option, the number of element edges along the lines surrounding the areas 1 to 9 was specified. In the attributes option, element type 1 and material type 1 were assigned to all the areas. Using the mesh options all the areas were meshed with 4 node quadrilateral elements.

Areas 1 to 9 were extruded upwards in the positive direction through a height of 5mm. Before the extrude option, the element and material types 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 figure 5.3 is generated, which is meshed with 3D 8 node brick elements. Again using the extrude options, the shaded area shown in figure 5.3 was extruded upwards through the blades height (117mm) along the positive direction using 3D 8 node brick elements.

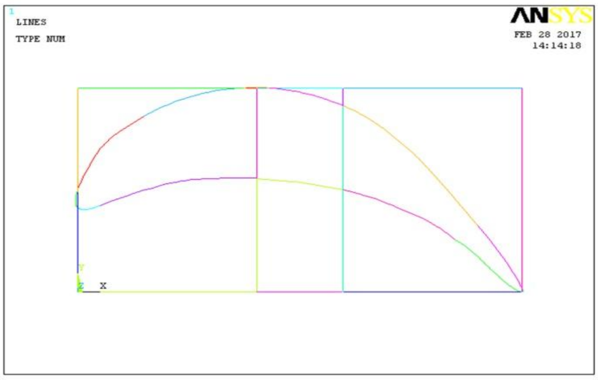

Fig III.1

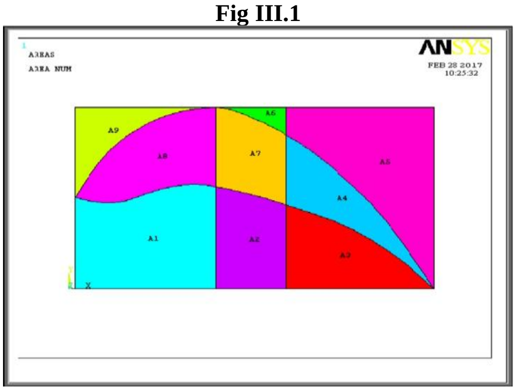

Fig III.2

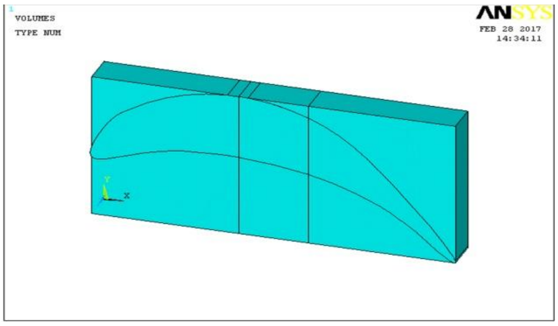

Fig III.3

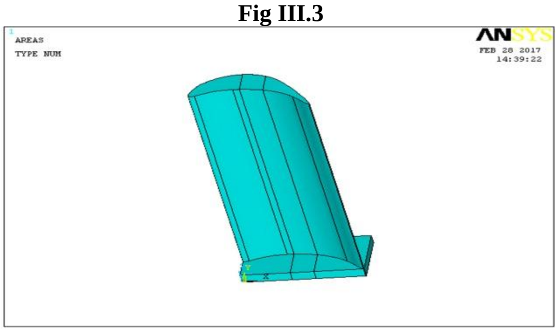

Fig III.4

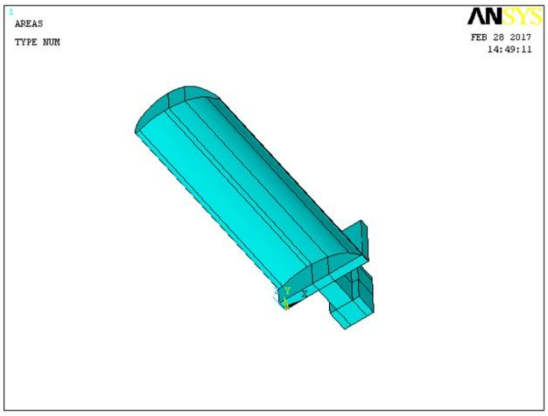

Fig III.5

IV. APPLICATION OF STRUCTURAL BOUNDARY CONDITIONS TO THE ROTOR BLADE

Two structural boundary conditions namely displacement and force were applied on the rotor blade model. The solution part was opened and the displacement conditions were imposed on the required areas.

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

- Tangential forces (Ft) = 248.199 N
- Axial force (Fa) = 3.82 N
- Centrifugal force (Fc) = 38038.73 N

In the solution part of the Ansys, the blade forces namely tangential, axial and centrifugal were applied on the node located at the centroid of the blade.

V.MECHANICAL STRESSES AND RADIAL ELONGATION

The Ansys software then analyzed the mechanical stresses and elongation experienced by the rotor blade. The result was

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viewed in the post processor part of Ansys. The geometry, loads and results were stored in a file.

VI. APPLICATION OF THERMAL BOUNDARY CONDITIONS

A new file was opened in Ansys and thermal modules of Ansys was activated. The rotor blade model was copied into this file from the previous structural analysis file. The structural boundary conditions which were applied previously on the rotor blade model were deleted. The element type was switched from structural to its equivalent thermal element type. The material properties are same as those in the previous file of structural analysis. Two thermal boundary conditions namely heat flux and convection were on the rotor blade model. The solution part of the Ansys was opened and heat flux equal to zero was applied on the areas of base and top. Both sides of the base of the blade comes in contact with similar areas were assumed to be insulated.

In the convection boundary condition, convection heat transfer coefficient and temperature of the surrounding gases (T) have to be specified on the areas subjected to convection.

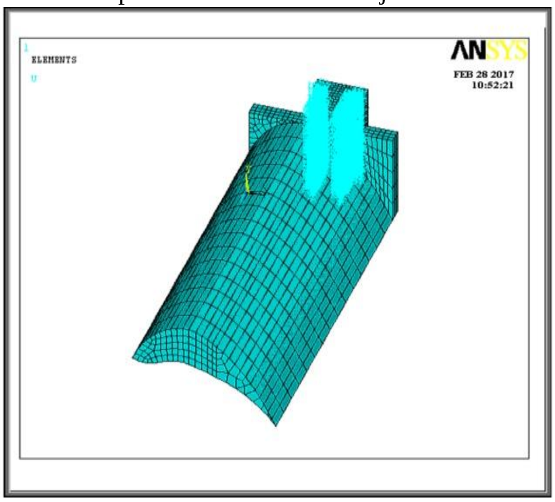

Fig VI.1 MESHED MODEL WITH BOUNDARY CONDITIONS

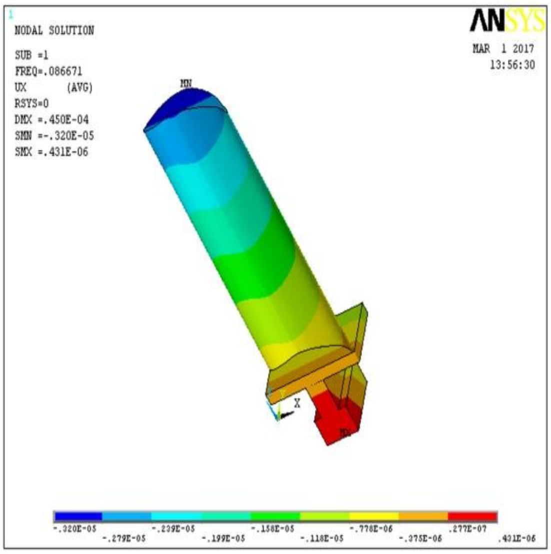

Fig VI.2 DEFLECTION IN X DIRECTION

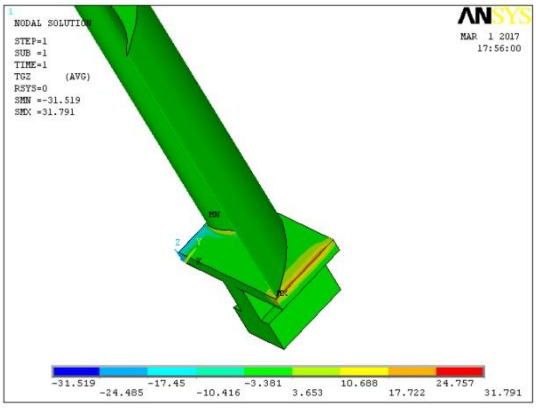

Fig VI.3. ***THERMAL GREDIENT IN Z DIRECTION***

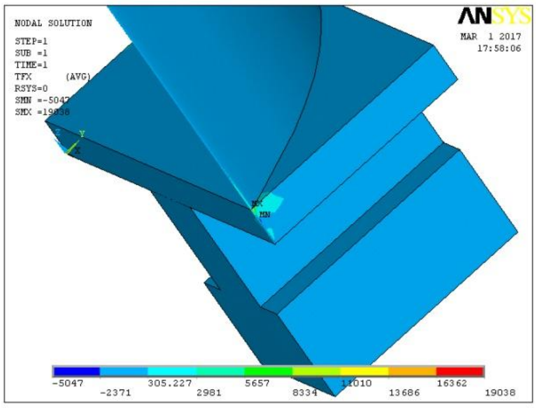

Fig VI.4. ***HEAT FLUX IN X DIRECTION***

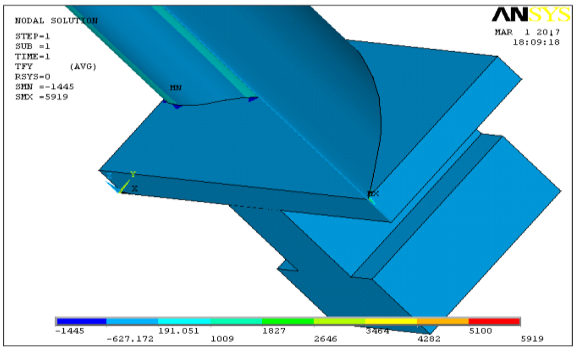

Fig VI.5 ***HEAT FLUX IN Y DIRECTION***

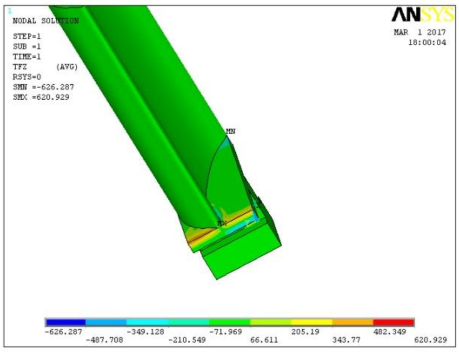

Fig VI.6.HEAT FLUX IN Z DIRECTION

VII. CONCLUSION

The finite element analysis for structural and thermal analysis of gas turbine rotor blade is carried out usingsolid95 element. The temperature has a significant effect on the

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overall 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. Maximum stresses and strains are observed at the root of the turbine blade and upper surface along the blade roots three different materials of construction i.e., N155, Inconel 625 & HASTEALLOY X materials. It is found that the temperature has a significant effect on the overall stresses induced in the turbine blades. The blade temperatures attained and thermal stresses induced are lesser for Inconel 625 as it has better thermal properties.

REFERENCES

[1] S. Gowreesh, N. Sreenivasalu Reddy and N.V.Yogananda Murthy CONVECTIVE HEAT TRANSFER ANALYSIS OF A AEROGAS TURBINE BLADE USING ANSYS", International journal of Mechanics of solids, vol4, No.1, March 2009(ppt55 -62).

[2] P.Kauthalkar, Mr.Devendra S.Shikarwar, and Dr.Pushapendra Kumar Sharma. "ANLYSIS OF THERMAL STRESES DISTRIBUTION PATTERN ON GAS TURBINE BLADE USING ANSYS", International journal of Engineering Education and technology, Vol.2, No.3, Nov 2010.

[3] John.V, T.Ramakrishna. "THE DESIGN ANDANALYSIS OF GAS TURBINE BLADE", International Journal of Advanced Research and Studies, Vol 2, No.1, Dec 2012.

[4] V.Raga Deepu, R.P.Kumar Ropichrla."DESIGN AND COUPLED FIELDANALYSIS OF FIRST STAGE GASTURBINE ROTOR BLADES", International journal of Mathematics and Engineering, Vol13, No.2, Pages: 1603 -1612.

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He has completed post graduation in the specialization of Advanced Internal combustion engineering in 2011 from Jawaharlal Nehru Technological University, Anantapur and pursuing PhD in VIT University, Vellore. He had published various papers and got membership in various professional bodies. He is doing as assistant professor in department mechanical engineering.

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