Thermal Analysis Of A Gas Turbine Rotor Blade By Using Ansys

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Abstract

In the present work, the first stage rotor blade off the gas turbine has been analyzed using ANSYS 9.0 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 material of the blade was specified as N155. 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 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 in CATIAV5R15. The first stage rotor blade of a two stage gas turbine has been analyzed for structural, thermal and modal analysis using ANSYS 9.0 Finite Element Analysis software. The gas turbine rotor blade model is meshed in HYPERMESH 7.0, meshing software. The thermal boundary condition such as convection and operating temperatures on the rotor blade is obtained by theoretical modeling. Analytical approach is used to estimate the tangential, radial and centrifugal forces. The results obtained are discussed and reported.

Keywords-*ANSYS, CATIA V5R15, HYPERMESH 7.0*

I 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. Mikio Oi, Mariko Suzuki Natsuko Matsuura some of the experiments done on the structural analysis and shape optimization in turbocharger development(1) In this comparison between conventional method and computer aided engineering is done. It is essential to incorporate the Computer Aided Engineering in the turbocharger development and design process. Structural analysis of there component parts has been made so far mainly on the automotive and marine turbochargers, centrifugal compressors. We have made analysis of the stress caused by external force and pressure, analysis of thermal stress caused by heat and analysis of vibrations caused by natural frequency in the compressor impeller, turbine impellers and rotors as rotary parts., Sanford Fleeter, were done on the Fatigue life prediction of turbomachine blading(2), T.Madhusudhan, Need for analysis of stress concentration factor in inclined cutouts of gas turbine blades (3), M.Pradeep, Naveen Babu Chandu, Influence of taper, twist and thickness in rotor blades using Finite Element Analysis(4), Stuart Moffaty, Li He Blade forced Response prediction fro industrial gas turbines(5), M.Venkatarama Reddy, additional Director CVRaman nagar, Bangalore (6) 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, Dr. K. Ramachandra**,** Director, Gas Turbine Research Establishment, Bangalore, (7) describes need for analysis of stress concentration factor in inclined cutouts of gas turbine blades, 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.

II WORKING OF THE GAS TURBINE

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. 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 fig 1.1

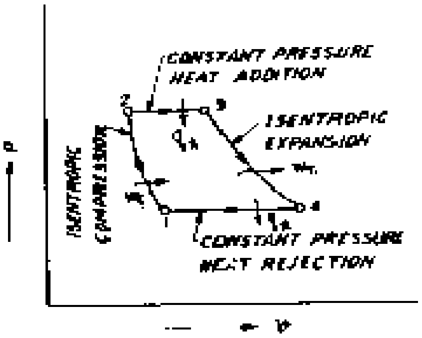


Fig 1.1 Indicator diagram of gas turbine

A. CONSTRUCTION OF TURBINE ROTOR BLADES AND THEIR COMPONENTS

Knowing the fluid conditions at exit of the gas generators, a value of static pressure was assumed at the turbine outlet. From this, the corresponding enthalpy drop required in the power turbine was calculated. The limitation in fixing the velocity triangles come from the peripheral speed of rotor and flow velocities. It is preferable to keep the both in reasonable range so as to minimize the losses.

After the primary fixing of velocity triangles between the axial gaps of the turbine blade rows, the blade profile is selected. In blade section there are two approaches, the direct and indirect approach. The blade profile selected should yield the flow angle required to give the desirable enthalpy drop. Also the pressure distribution at the end of stage should be uniform. If it is not so the blade angles are changed to match these requirements.

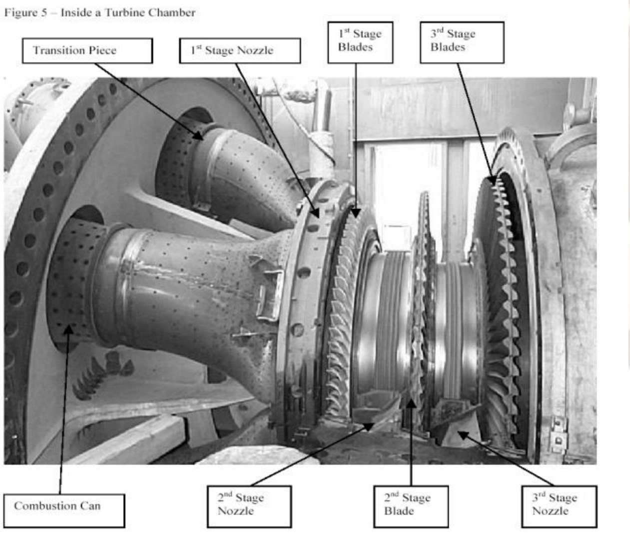


Fig 1.2 CONSTRUCTION OF TURBINE ROTOR AND THEIR COMPONENTS

The gas turbine have been taken from the preliminary design of a power turbine. As the temperature has a significant effect on the overall stresses in the rotor blade, it has been felt that a detailed study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

B. VIBRATION OF BLADES

If a blade of an assembly of blade is acted upon by an instantaneous force free vibrations are setup because of the inherent resilience of the blade or blade assembly. The frequency of these vibrations depends on the dimensions of the blade or blade assembly as well as their method of mounting on the discs. Moving blades in turbine are subjected to time variable loads in addition to the static loads.

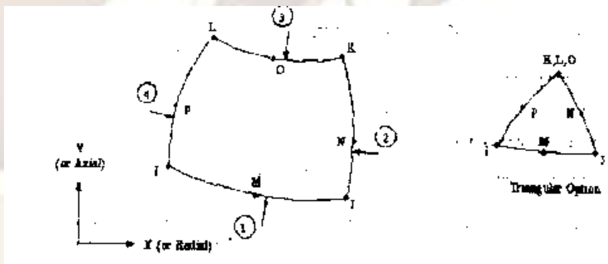
C. PRODUCTION OF BLADES: -

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.

D.TURBINE BLADE ATTACHMENT: -

The attachment of the turbine blade to the rotor is the most critical aspect of gas turbine.design.All the forces are transmitted through the attachment to the rotor. Especially at the low-pressure end of turbine of large output, the attachment has to bear relatively large forces due to high speed; the centrifugal force on the blade is many times its mass. It is therefore necessary to estimate the stresses in the attachment, but sometimes it is very difficult to get the exact values.

There is always the possibility of stress concentration at the sharp corners. Therefore selection of material is very important which can be safeguard from this stress concentration.



E. BRAYTON CYCLE COMPONENTS:

Gas turbines usually operate on an open cycle, as shown in Figure 1. Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure.

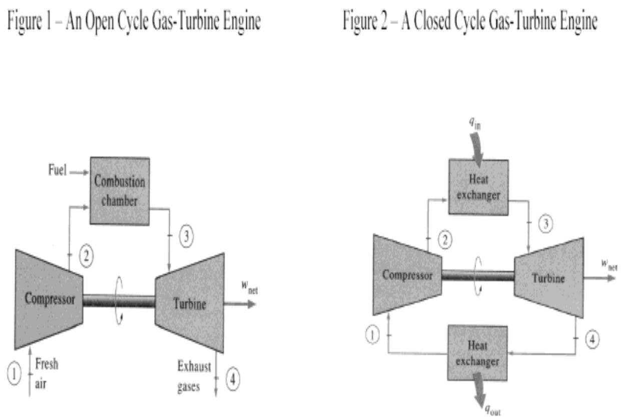


Fig: 1.3 Open & Closed Cycle of Gas Turbine

II. FINITE ELEMENT METHOD FORMULATION

A. 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.

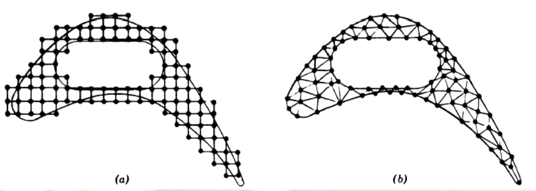


Fig: 1.4 Discretizations Of Turbine Blade Profile

B. PLANE 82TYPE 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

Fig: 1.6 plane 82 2-d structural solid

and can tolerate irregular shapes without as much loss of accuracy.

Element Name Plane 82
Nodes I, J, K, L, M, N, O, P
Degrees of Freedom UX, UY
Real constants none
MaterialProperties EX,EY,EZ
PRXY,PRYZ,PRXZ
NUXY,NUYZ,NUXZ)
ALPX,ALPY,ALPZ,DENS

Surface loads Pressure
Body loads Temperatures
Special features Plasticity, creep, stress stiffening, large deflection, and large strain.

C. 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 The element is defined by 20 nodes having three degrees of freedom per node, translations in the nodal x, y, and z directions.

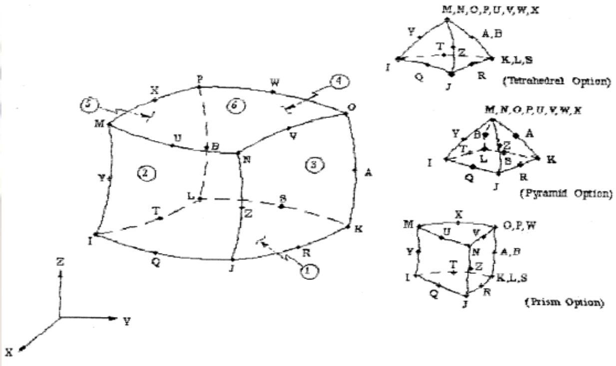


Fig:1.6 Solid 95 3-D structural solid

SOLID 95 INPUT SUMMARY
Element Name Solid 95

Nodes I, J, K, L, M, N, O,

P,Q,R,S,T,U,V,V,W,X,Y,Z,A,B

Degrees of Freedom UX,UY,UZ
Real constants None
Material Properties
EX,EY,EZ(PRXY,PRYZ,PRXZ
NUXY,NUYZ,NUXZ)
ALPX,ALPY,ALPZ,DENS
Surface loads Pressure
Body loads Temperatures
Special features Plasticity, creep, stress stiffening, large deflection, and large strain.

IV.EVALUATION OF GAS FORCE 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.

A. EVALUATION OF GAS FORCES ON THE FIRST STAGE ROTOR BLADE

At the inlet of the first stage rotor blades,
Absolute flow angle $\alpha 2 = 23.850$
Absolute velocity $V2 = 462.21$ m/s
The velocity triangles at inlet of first stage rotor blades were constructed

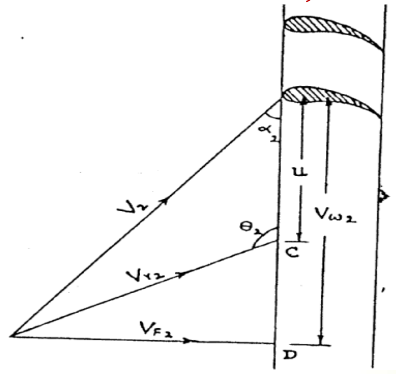


Fig: 1.7 Inlet velocity triangles of I-stage rotor blades

Diameter of blade midspan D = 1.3085 mt.
Design speed of turbine N = 3426 r.p.m.
Peripheral speed of rotor blade at its midspan U = πDN/60
From the velocity triangles in fig we get,
Whirl velocity Vw2 = 422.74 m/s
Flow Velocit, Vf2 = 186.89 m/s
Relative velocity, Vr2 = 265.09 m/s
Blade angle at inlet, θ2 = 135.017 0
At the exit of first stage rotor blades,
Flow velocity, Vr3 = 180.42 m/s
Relative flow angle, θ2 = 37.88 0

B. EVALUATION OF GAS FORCES ON SECOND STAGE ROTOR BLADES

The gas forces and power developed in second stage rotor blades were evaluated using the same procedure and similar equations that were used for first stage rotor blades

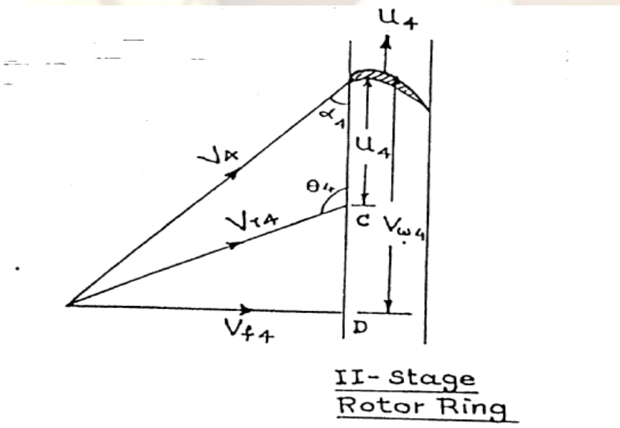


Fig: 1.8 Inlet Velocity Triangles Of Ii-Stage Rotor Blades

Tangential force	Ft = 244.49 Newtons
Axial force	Fa = 0.944 Newtons
Power developed	P = 13.972 Mega Watts

C. ANALYSIS OF FIRST STAGE ROTOR BLADE ON ANSYS 9.0

The structural, thermal, modal modules of ANSYS 9.0 were used for the analysis of the rotor blade. The rotor blade was analyzed for mechanical stresses, temperature distribution, combined mechanical and thermal stresses and radial elongations, natural frequencies and mode shapes.
Element Type 1: 8 node quadrilateral element
Element type 2: 20 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) = 2e5 N/mm2
Density (ρ) = 7136.52 e-9 T/mm3
Coefficient of thermal expansion (α) = 6.12e-6 /0C
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

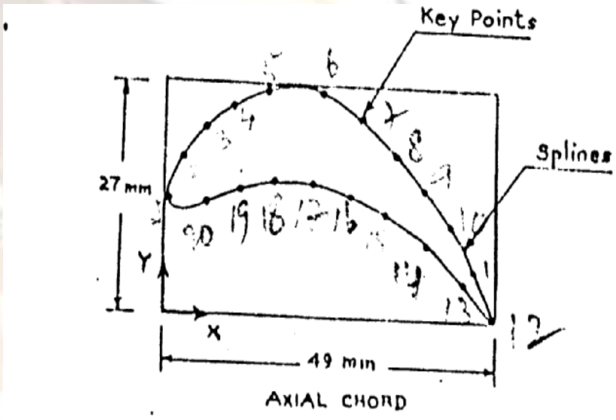


Fig 1.9 Boundary of aerofoil section

LIST OF SELECTED KEYPOINTS

NO (Z=0)	X	Y LOCATION
1.	0.00	0.00
2.	2.6	17.3
3.	5.85	21
4	10	25
5	14.8	26.6
6	22.9	25.3
7	28	22.2
8	33.4	18.5
9	38	14.4
10	42	10.9
11	45.5	5.70
12	49.00	0.00
13	6.18	12.4
14	11.2	14.4
15	16.18	15.5
16	21.1	14.9
17	26	13.6
18	38.2	8.77
19	45	3.95
20	49	0.00
21	49	27.00
22	0.00	27.00

23	19.8	0.00
24	1.00	13.6
25	29.2	0.00
26	29.2	27.00
27	19.8	27.00
28	15.2	27.00
29	18.08	27.00
30	49.00	0.27E-1
31	48.90	0.288E-1
32	29.2	12.49
33	19.8	26.62
34	19.8	15.12
35	29.2	21.25
36	0.00	0.30E-1

Using splines and lines 9 different areas were generated which was shown

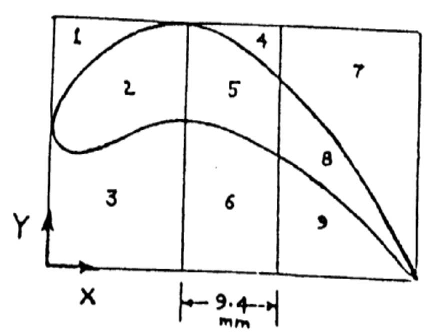


Fig:2. Areas of turbine rotor blade

By using these points ,created the blade modal in CATIAV5 R15 with the help of commands like spline,extrude,add etc.after that export this modal into HYPERMESH7.0 and mesh it by using commands like automesh, tetmesh etc and exported into ANSYS9.0.

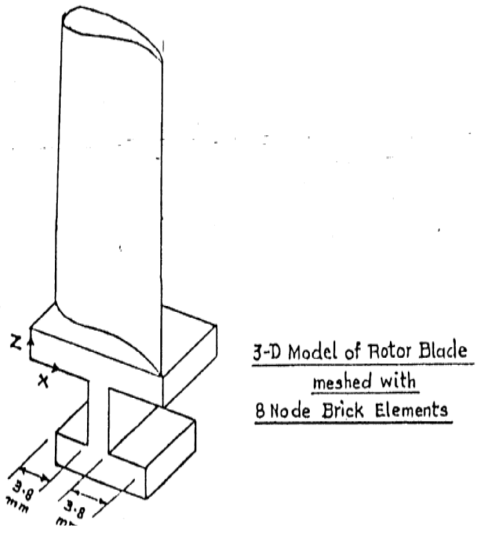


Fig: 2.1 3-D model of rotor blade

V .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.

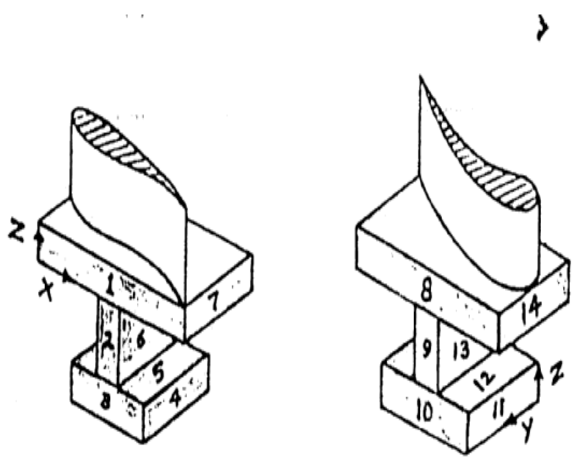


Fig 2.2 Structural boundary conditions on rotor blade

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.

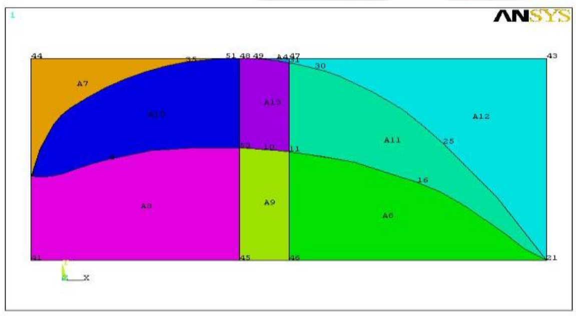


Fig: 2.3 Area Diagram of gas turbine rotor blade

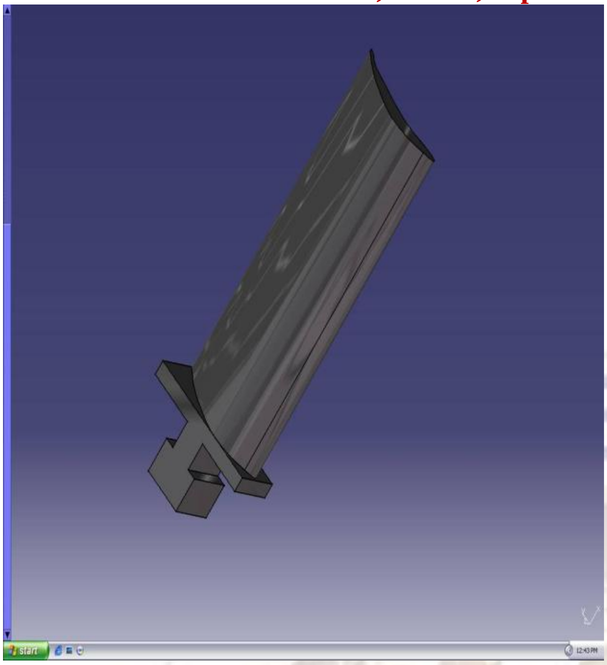


FIG:2.4 GEOMETRIC MODEL OF GAS TURBINE ROTOR BLADE

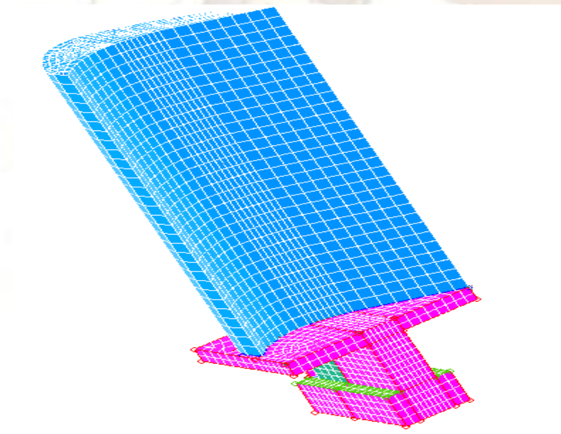


Fig:2.5 Brick mesh gas turbine rotor blade using hypermesh.

V RESULTS

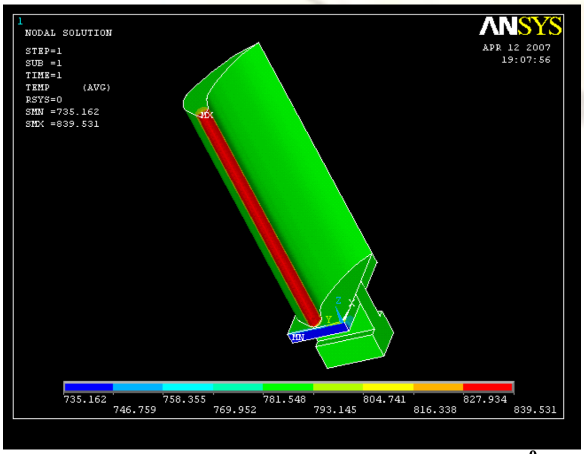


Fig: 2.6Temperature distribution in the blade,^{0}C

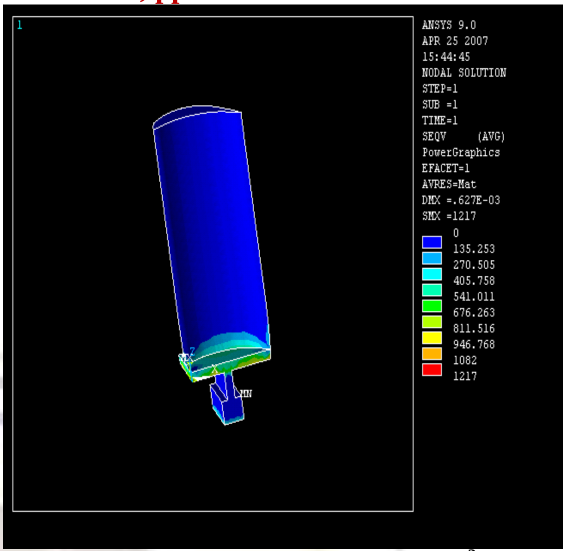


Fig2.7 Thermal stress in the blade,N/mm^2

VI CONCLUSION

It is observed that the temperature variations from leading edge to the trailing edge on the blade profile is varying from 839.5310C to 735.1620C 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 from 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 781.5480C and for another 4 mm length it is almost constant.., it is observed that the maximum thermal stress is 1217.and the minimum thermal stress is.the maximum thermal stress is less than the yield strength value i.e, 1450.so, based on these values

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