ISSN 0976 – 1411

Available online at www.internationaleJournals.com

International eJournals

INTERNATIONAL eJOURNAL OF MATHEMATICS AND ENGINEERING

www.InternationaleJournals.com

International eJournal of Mathematics and Engineering 156 (2012) 1434 - 1433

DESIGN AND ANALYSIS OF SECOND STAGE GAS TURBINE ROTOR BLADE

T. Punnamma and M. Vimal Teja*

Department of Mechanical Engineering, Nimra College of engineering & Technology, Vijayawada.
<purna330@gmail.com>

ABSTRACT:

The finite element method (FEM) has now become a very important tool of engineering analysis. Its versatility is reflected in its popularity among engineers and designers belonging to nearly all the engineering disciplines. 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 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 this paper, the second stage rotor blade of 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 rotor blade was then analyzed using ANSYS 9.0 for the temperature distribution. For obtaining temperature distribution, the convective heat transfer coefficients on the blade surface exposed to the gas have to fed 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 9.0 for the combined mechanical and thermal stresses. The radial elongations in the blade were also evaluated.

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 were taken from the design data books.

Keywords: gas turbine, Structural, Modal and Thermal Analysis, Finite Element Analysis

---

1.0 INTRODUCTION

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.

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 modern technological environment the conventional methodology of design cannot compete with the modern trends of Computer Aided Engineering (CAE) techniques. The constant search for new innovative design in the engineering field is a common trend.

To build highly optimized product, this is the basic requirement of today for survival in the global market today. All round efforts were put forward in this direction. Various design packages have been developed by software professional and technologists.

2.0 DESCRIPTION

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.

2.1 Construction of Turbine Rotor and Their Components

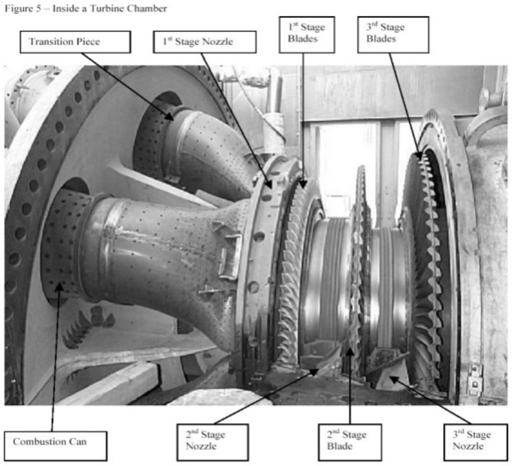


Fig: 1 inside a turbine chamber

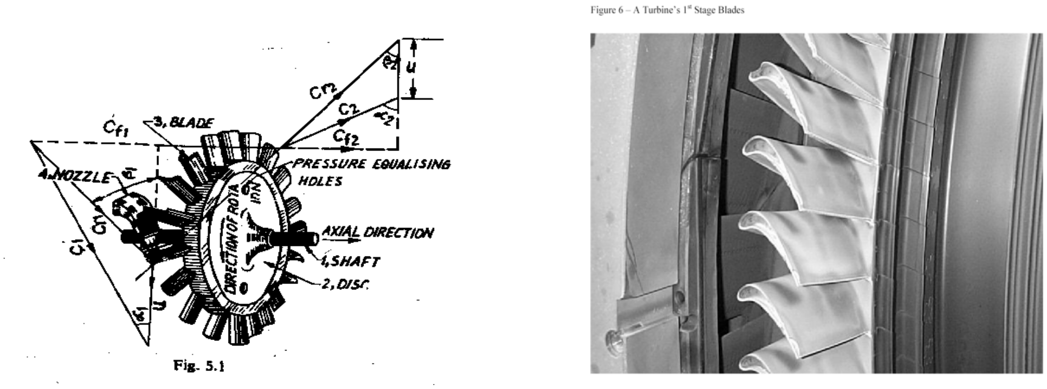


Fig: 2 Turbine's Second Stage Blades

2.2 FINITE ELEMENT PROCEDURE

- Discretize the Continuum
- Select Interpolation Functions
- Find the Element Properties
- Assemble the Element Properties to obtain the System Equations
- Impose the Boundary Conditions
- Solve the System Equations
- Make Additional Computations

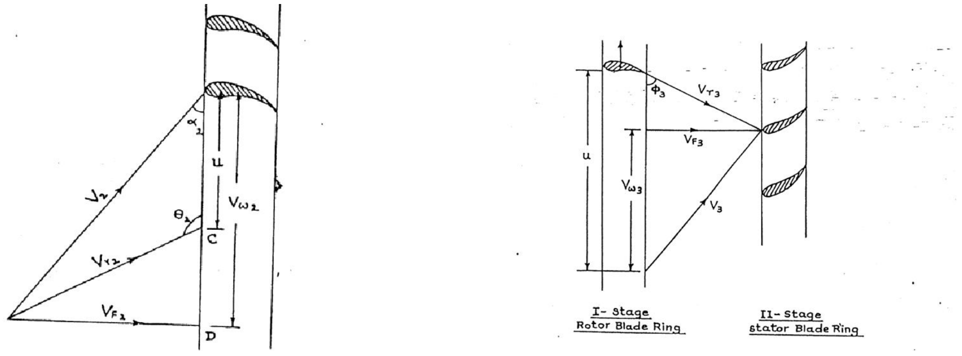


Fig: 3,4 Evaluation of convective heat transfer coefficient (hr) on the two rectangular faces at inlet and exist of second stage rotor blades.

3.0- 3D MODELLING AND ANALYSIS

The solid model of the gas turbine rotor blade was created using the following co ordinates using CATIA V5 R16

LIST OF SELECTED KEYPOINTS

Table: 1

SECTION A – A

CONCAVE SIDE		CONVEX SIDE	
X	Y	X	Y
-45.1282	6.2001	-45.1282	6.2001
-44.8818	6.6040	-45.1764	5.7302
-44.7269	6.7462	-45.1333	5.5220
-44.5846	6.8428	-45.0774	5.3594
-44.4500	6.9164	-45.0139	5.2197
-44.3205	6.9774	-44.9453	5.0952
-44.0106	7.0917	-44.7599	4.8158
-43.4213	7.2212	-44.3535	4.3612
-42.0345	7.3304	-43.2613	3.4569
-39.3624	7.3355	-40.9753	1.9253
-36.7614	7.2288	-38.6182	0.5994
-34.2036	7.0739	-36.2179	-0.5944
-29.1821	6.7056	-31.3207	-2.6594
-24.2545	6.3271	-26.3322	-4.3739
-19.3878	5.9665	-21.2776	-5.7760
-14.5720	5.6413	-16.1773	-6.8834
-9.7892	5.3542	-19.0414	-7.7064
-7.0292	5.1029	-5.8826	-8.2499
-1.2819	4.8717	-9.7112	-8.4938
9.4653	4.6380	4.4602	-8.4201
9.2278	4.3891	9.6164	-8.0163
14.0183	4.1605	14.7447	-7.3177
18.8493	3.9853	19.8349	-6.3576
23.7236	3.8887	24.8768	-5.1565
28.6487	3.8964	29.8729	-3.7317
33.6245	4.0386	34.8158	-2.1208
38.6461	4.3459	39.7129	-0.3419
43.7058	4.8666	44.5719	1.5646
48.7858	5.6566	49.4132	3.5509
53.8226	6.8758	54.2950	5.4635

Table: 2

SECTION B - B

CONCAVE SIDE		CONVEX SIDE	
X	Y	X	Y
-44.5618	9.1237	-44.5618	9.1237
-44.3078	9.4894	-44.6227	8.6817
-44.1477	9.6139	-44.5897	8.4836
-44.0055	9.6952	-44.5389	8.3261
-43.8709	9.7587	-44.4805	8.1890
-43.7413	9.8069	-44.4170	8.0670
-43.4315	9.8933	-44.2443	7.9020
-42.8473	9.9771	-43.8607	7.3355
-41.4757	9.9898	-42.8168	6.4084
-38.8341	9.8146	-40.6197	4.8133
-36.2610	9.5352	-38.3489	3.4036
-33.7312	9.2126	-35.0274	2.1158
-28.7579	8.5115	-31.2826	-0.1651
-23.8658	7.7978	-26.4338	-2.1285
-19.0271	7.1044	-25.5062	-3.8075
-18.2265	6.4389	-14.5176	-5.2172
-10.4564	5.8090	-17.4783	-6.3652
-8.7015	5.2146	-5.3983	-7.2568
0.0432	4.6355	-1.2878	-7.8715
4.7879	4.0538	4.8456	-8.1966
9.5453	3.4519	8.9891	-8.2118
14.3281	2.8651	14.1800	-7.9527
19.1465	2.3241	19.2557	-7.4472
24.0132	1.8517	24.3586	-6.7110
28.9255	1.4681	29.4335	-5.7336
33.8938	1.2040	34.4805	-4.6685
38.9153	1.0871	39.4970	-3.3985
43.9826	1.1582	44.4906	-2.0091
49.0380	1.4783	49.4741	-0.5512
54.1807	2.1946	54.4855	0.8280

Table: 3

SECTION C – C

CONCAVE SIDE		CONVEX SIDE	
X	Y	X	Y
-39.6850	21.7754	-39.6850	21.7754
-39.4411`	21.9481	-39.7634	21.4859
-39.2963	21.9837	-39.7459	21.3360
-39.1643	21.9939	-39.7104	21.2115
-39.0423	21.9939	-39.6672	21.0947
-38.9255	21.9862	-39.6164	20.9906
-38.6486	21.9456	-39.4818	20.7416
-38.1279	21.8135	39.1719	20.2997
-36.9113	21.3690	38.3134	19.3192
-34.5669	20.3657	-36.4871	17.5006
-32.2783	19.3040	-34.5872	15.7861
-30.0203	18.2143	-32.6415	14.1402
-25.5524	16.0045	-29.6360	11.0119
-21.1226	13.7897	-25.5161	8.0569
-17.7132	11.5849	-80.2997	5.2629
-14.3139	9.3980	-25.9969	2.6187
-9.9197	7.2339	-16.6154	0.1194
-8.5230	5.0902	-7.1577	-2.2327
1.8738	2.9566	-2.6238	-4.4272
5.2680	0.8204	6.9837	-6.4541
9.6596	-1.3310	7.6675	-8.3007
19.0691	-3.4772	11.4148	-9.9847
19.4988	-5.6007	26.2128	-11.5240
22.9641	-7.6937	28.0515	-12.9286
27.4676	-9.7434	29.9283	-14.2021
32.0167	-11.7323	30.8356	-15.1097
36.6992	-13.6449	35.7657	-16.4567
41.2801	-15.4584	40.7111	-17.4650
46.0096	-17.1374	45.6692	-18.4353
50.8305	-18.5801	50.6146	-19.4640

Table: 4

SECTION D - D

CONCAVE SIDE		CONVEX SIDE	
X	Y	X	Y
-37.0078	25.9613	-37.0078	25.9613
-36.8071	26.0452	-37.0535	25.7505
-36.6827	26.0410	-37.0256	25.6261
-36.5684	26.0223	-36.9849	25.5194
-36.4617	25.9944	-36.9367	25.4178
-36.3601	25.9613	-36.8859	25.3238
-36.1112	25.8699	-36.7462	25.0977
-35.6438	25.6489	-36.4414	24.6812
-34.5389	25.0292	-35.6108	23.7160
-32.3952	23.7160	-33.8709	21.8821
-30.2895	23.3647	-32.0751	20.1143
-28.2016	20.9956	-31.2412	18.3921
-24.0614	18.2448	-26.4846	15.0546
-19.9390	15.4915	-22.6390	11.8364
-15.8217	12.7508	-18.7147	8.7198
-11.7069	10.0254	-14.7168	5.7074
-7.5844	7.3203	-19.6528	2.7889
-5.4569	4.6355	-8.5227	-0.0279
9.6731	1.9583	-4.3241	2.7432
4.8082	-0.8112	8.9431	-5.3442
2.9408	-3.3884	9.2814	-7.8257
16.0886	-6.0554	10.6782	-10.2032
17.2542	-8.7020	15.1308	-12.4790
21.4452	-11.3259	19.6266	-14.6660
25.6667	-13.9167	24.1656	-16.7665
29.9263	-16.4643	28.7376	-18.7960
34.2265	-18.9586	33.3426	-20.7565
38.5775	-21.3868	37.9679	-22.6720
42.9895	-23.7236	42.6060	-24.5567
47.4853	-25.9105	47.2338	-26.4770

Table: 5

SECTION E - E

CONCAVE SIDE		CONVEX SIDE	
X	Y	X	Y
-35.9969	27.3177	-35.9969	27.3177
-35.8191	27.3685	-36.0248	27.1348
-35.7022	27.3507	-35.9918	27.0205
-35.5981	27.3202	-35.9461	26.9215
-35.4965	27.2821	-35.8953	26.8249
-35.4000	27.2415	-35.8419	26.7360
-35.1663	27.1297	-35.6997	26.5176
-34.7218	26.8808	-35.3924	26.1112
-33.6626	26.2001	-34.5654	25.1562
-31.6001	24.7802	-32.8447	23.3223
-29.5681	23.3299	-31.0744	21.5443
-27.5514	21.8669	-29.2735	19.8018
-23.5407	18.9332	-25.5956	16.4059
-19.5402	16.0020	-24.8389	13.1039
-15.5423	13.0835	-19.0137	9.8908
-14.5418	10.1803	-14.1224	6.7615
-9.5311	7.2974	-10.1702	3.7109
-5.5154	4.4323	-8.1620	0.7442
4.5105	1.5799	-6.0904	-2.1387
9.5390	-1.2649	2.0447	-4.9276
8.5725	-4.1097	6.2433	-7.6175
12.6162	-6.9418	13.4978	-10.2210
16.6776	-9.7587	14.8006	-12.7432
20.7645	-12.5476	19.1465	-15.1827
24.8793	-15.3111	23.5356	-17.5641
29.0271	-18.0340	27.9578	-19.8786
33.2105	-20.7137	32.4079	-22.4151
37.4421	-23.3350	36.8833	-24.3535
41.7271	-25.8826	41.3741	-26.5430
46.0882	-28.3058	45.8546	-28.7579

Using splines and multisection solid different areas were generated which was shown in figures.

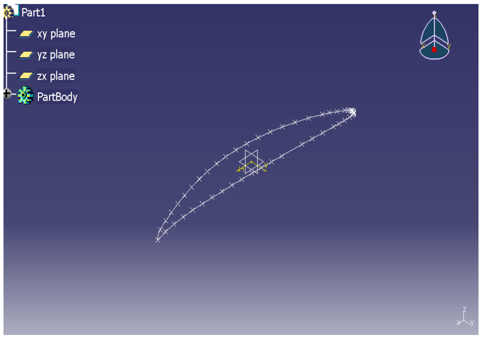


Fig: 5 Blade profile section A-A

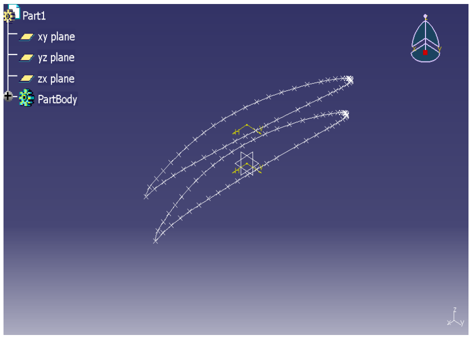


Fig : 6. Blade profile section A-A and B-B

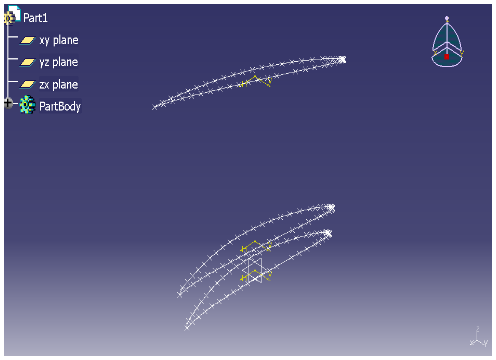


Fig:7 Blade profile section A-A ,B-B and C-C

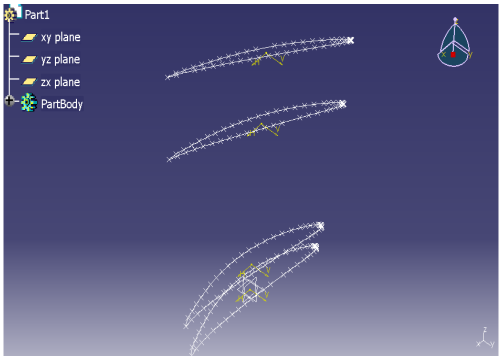


Fig:8 Blade profile section A-A ,B-B ,C-C and D-D

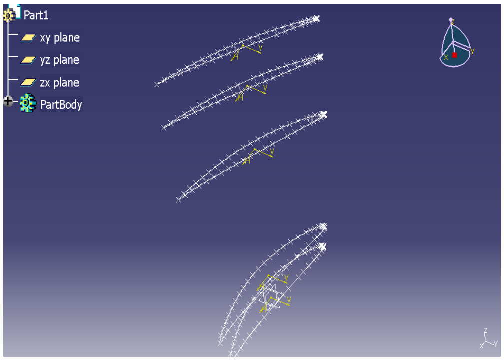


Fig: 9 Blade profile section A-A, B-B, C-C , D-D and E-E

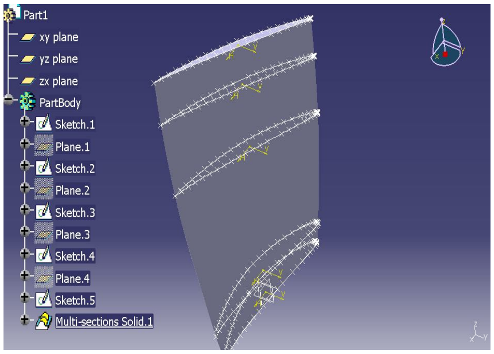
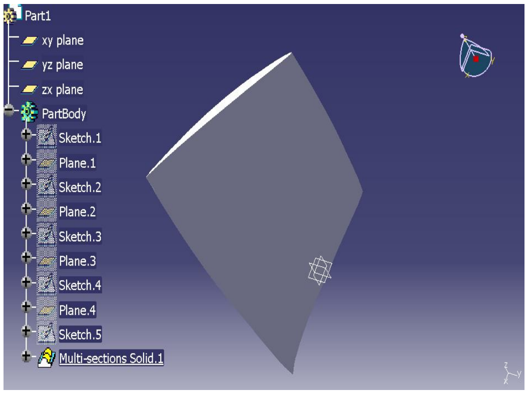


Fig:10 Blade profile with sections and without root



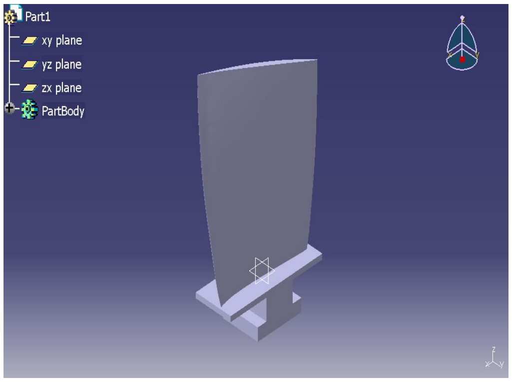


Fig .11 Blade profile without root

Fig .12 Blade profile with root

4.0 OVERVIEW OF STEPS IN MODAL ANALYSIS

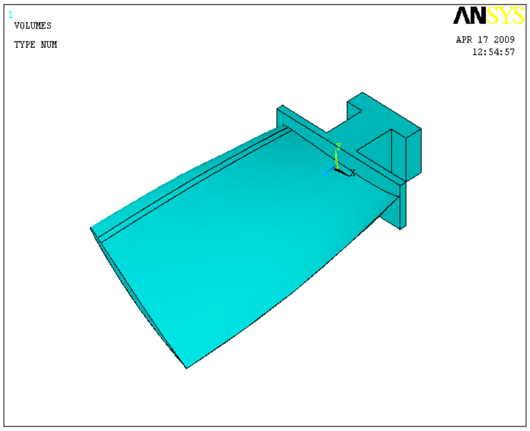
The procedure for modal analysis consist of four main steps

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

Table: 6 Natural frequencies Modal Analysis

Sr.No	Time/Freq.	Load step	Sub step	Cumulative
1	12.109	1	1	1
2	29.245	1	2	2
3	46.862	1	3	3

5.0 RESULTS AND DISCUSSIONS



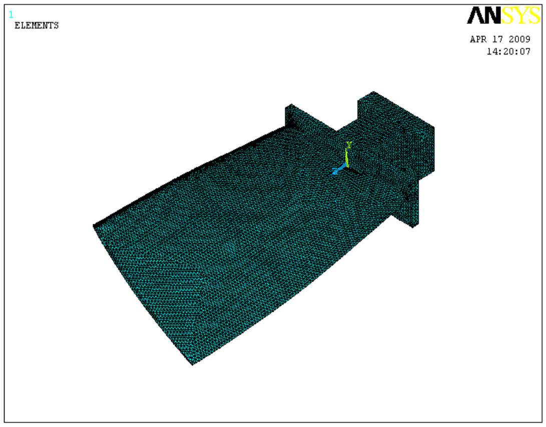


Fig.13 Solid modal of gas turbine blade

Fig.14 Finite Element model Free Mesh

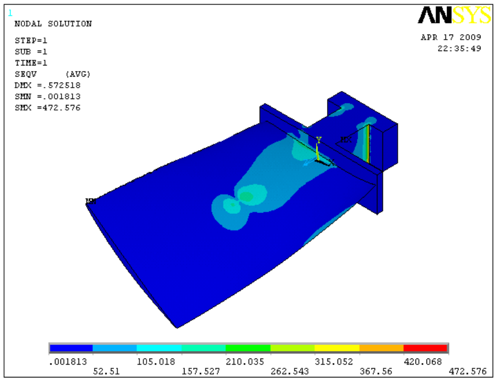


Fig. 15 Von mises stress of gas turbine rotor blade

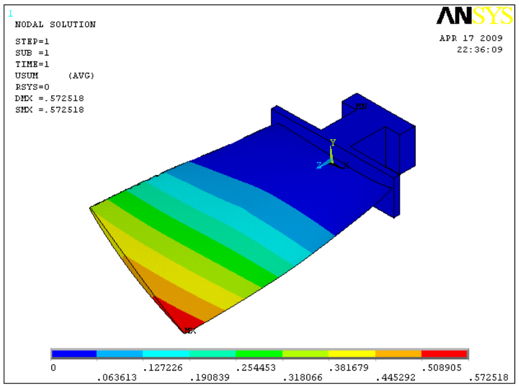


Fig. 16Displacement Vector sum USUM

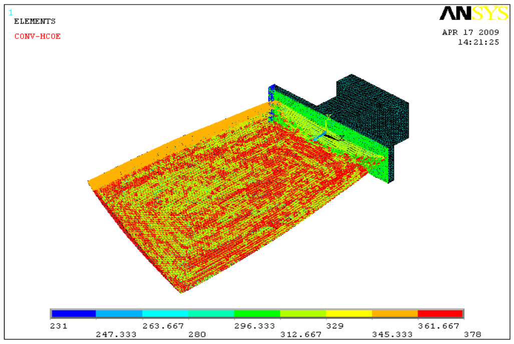


Fig.17 model with thermal loads

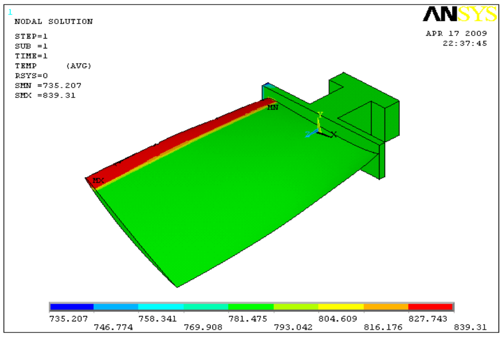


Fig .18 Temperature distribution

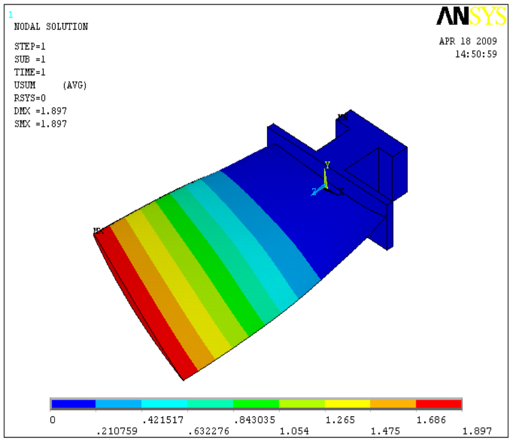


Fig. 19 Thermal displacements

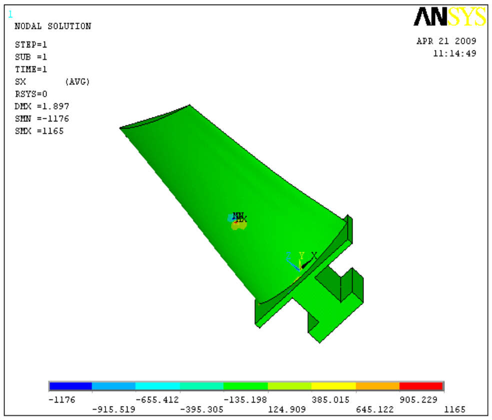


Fig .20 Thermal stress

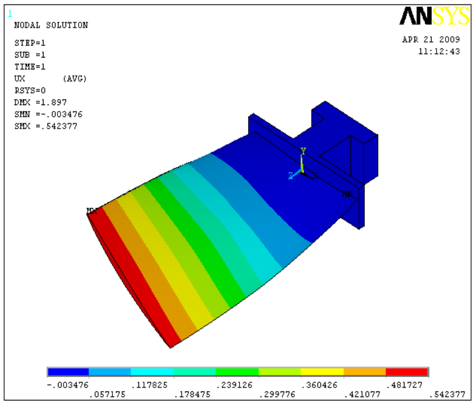


Fig .21 Thermal displacements after applying forces

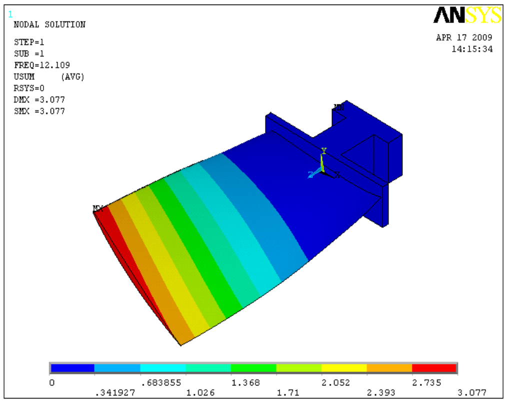


Fig .22 Modal 1

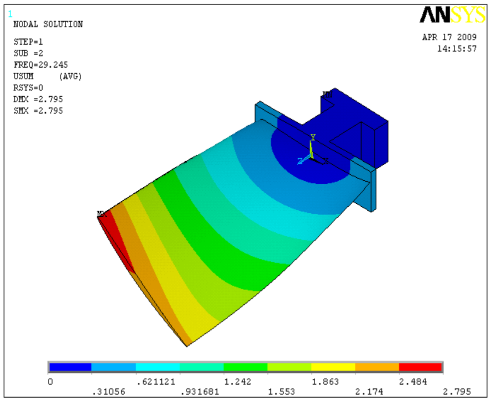


Fig .23 Modal 2

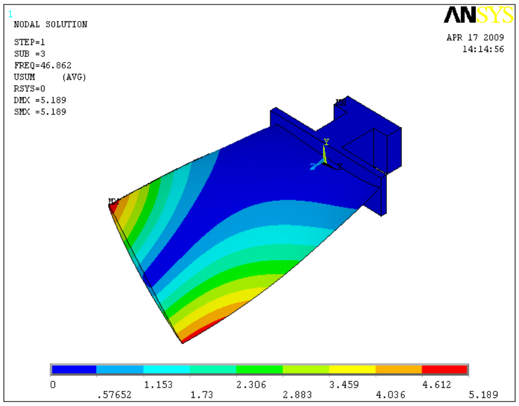


Fig .24 Modal 3

5.1 THERMAL ANALYSIS

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 839.531^{0}C to 735.207^{0}C 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 781.548^{0}C and for another 4 mm length it is almost constant. Wherever maximum curvature is occurring the temperature variation is less. The temperature decreases gradually along X-direction.

The thermal stresses are obtained as shown in the fig from figure, it is observed that the maximum thermal stress is 1165. The maximum thermal stress is less than the yield strength value i.e. 1450.so, based on these values

For the thermal analysis the design of turbine blade is safe.

5.2 STRUCTARAL ANALYSIS

The von misses stresses are obtained as shown in the fig from figure, it is observed that the maximum von misses stress is 472.576.this value is less than the yield strength value i.e.650. The maximum deformation in USM Overall direction is 1.765mm.based on these values For the structural analysis the design of turbine blade is safe based on the strength criteria and rigidity criteria..

5.3 MODAL ANALYSIS

Maximum deformation of gas turbine rotor blade at 12.109HZ for first Sub step is 3.077mm
Maximum deformation of gas turbine rotor blade at 29.245HZ for second Sub step is 2.795mm.
Maximum deformation of gas turbine rotor blade at 46.862HZ for third Sub step is 5.189mm

6.0 CONCLUSIONS

- 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.
- Maximum stress induced is within safe limit.
- Maximum thermal stresses are setup when the temperature difference is maximum from outside to inside.
- Maximum stresses 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.
- It could be concluded that these contour maps and profiles enables us to ascertain the areas of rotor blades that are vulnerable for failure

- Maximum thermal stresses are setup when the temperature difference is maximum from outside to inside.
- Maximum stresses 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.
- It could be concluded that these contour maps and profiles enables us to ascertain the areas of rotor blades that are vulnerable for failure

7.0 REFERENCES

1) S.S.Rao,”The Finite Element method in Engineering”, BH Publications New Delhi, 3rd Edition, 1999.
2) O.C.Zeinkiewicz,”The Finite Element method in Engineering Science”, Tata McGraw Hill, 2nd Edition, 1992.
3) T.R.Chandrupatla, Belegundu A.D.,”Finite Element Engineering”, Prentice Hall of India Ltd, 2001.
4) O.P.Gupta,”Finite and Boundary element methods in Engineering”, Oxford and IBH publishing company Pvt.Ltd.New Delhi, 1999.
5) V.Ramamurti,” Computer Aided Design in Mechanical Engineering”, Tata McGraw Hill publishing company Ltd.New Delhi, 1987.
6) Jean-Claude Sabonnadiere and Jean-Louis Coulomb,” Finite Element method in CAD”, North Oxford University, 1987.
7) C.S.Krishnamoorthy,”Finite Element Analysis, Theory and Programming, 2nd edition, Tata McGraw Hill publishing company Ltd.New Delhi, 2002.
8) P.Ravinder Reddy,”CADA Course Book”, AICTE-ISTE sponsored programmer, August 1999.