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VIBRATION ANALYSIS OF GAS TURBINE BLADE PROFILE USING FEM TECHNIQUE AND TOOL

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ABSTARCT:

Gas turbine blade is designed to work on high stresses with advance material composition so that it can withstand to high pressure and temperature. As it rotates at very high speed (approximate 25000 rpm) there are several chances of failure even though its advanced design and material composition. With pressure and temperature, vibrations also affect the blade performance and life. During working, the blades undergo high pressure and temperature which may create vibrations in the blade. These vibrations should not reach to blades resonance value. Therefore performing vibration analysis test is very important. Due this analysis vibration effects in gas turbine blade can be calculated. The several modes of frequency can give the values of maximum deformation in their mode.

Here vibration analysis is performed by using FEA technique on gas turbine blade and maximum allowable frequency is calculated. This frequency is called as natural frequency of blade. If the value of blade frequency increases beyond natural frequency of blade the permanent damage can accurse on blade.

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Keywords: *FEA1, Natural Frequency2, Blade Frequency3.*

1. INTRODUCTION

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Deterioration accurse after around 10500 h service in first-stage blades of a gas turbine. Here the service life of blade is 40000 h. But it fails before completion of its service life. When failure Analysis performed on blade, it is observed that blade lost its protective coating from their tips because of wear. Hence at high temperature working it surface suffered to high corrosion. This study proves that uneven clearance between rotor and lining may cause to failure. [1]

Due to the failure of gas turbine blade a several problems will created and it may cause to breakdown of gas turbine. Also the maintenance of blades is critical issue. It requires special treatment for repairing. Some time blades get permanently damaged due to high working temperature. Elevated temperature with approximately 25000 rpm speed also has a great impact on life of gas turbine blade. High cycle fatigue (HCF), law cycle fatigue (LCF) and creep rupture are the major issues related with gas turbine blade defects. These are due to the material composition, manufacturing defects and high working temperature. [2]

At high temperature working there are internal cooling hole cracks at airfoil sections which is due to degradation of coating, base alloy and carbide precipitation in grain boundaries. It also decreases the alloy ductility and toughness. It is observed that coating crack initiation and propagation is due to mixed fatigue/creep mechanism. [3]

In above investigations overall work is concentrated on damage due to high temperature. There other factors also on which we have concentrate like vibrations set-up into the blade. Due to the vibrations the blade frequency i.e. natural frequency of blade can match with resonance frequency. This possibility also has to check. In this study we are performing vibration analysis i.e. also called as model analysis. This can give us resonance frequency of blade. Some other studies are also available which demonstrate different causes of failure.

While investigating failure of gas turbine blade used in thermal power plant, it is found that there is rupture of all blades accurse from the third and subsequent stages. The material of blade is nickel-based superalloy called Inconel 738. During visual observation it is found that the top fir tree root on the turbine blade is fractured. There are two characteristic zones of fractured surface. The first zone is of slow and stable crack growth and the second is of interdendritic fracture. [4]

Oxidizing and corrosive environment generated by the combustion gases will affect the gas turbine blade material hence it must be resistive to oxidation and corrosion. It should also have resistance to erosion. Hot corrosion of gas turbine blade material tends to blade failure and change in microscopic characteristics. [5]

It is in consideration that the modern aviation gas turbine engines are highly reliable in that failures in service are rare. But it also needs the regular inspection and maintains so that most of the defect can be identified and rectified at its initial stage. This will leads to reach the blade life towards completion. Otherwise there are several chances of failure of blade before completion of its lifespan. [6]

When the turbine blade made of Nibase superalloy of CM 247 LC grade and fabricated by DS investment casting failed during the test run of gas turbine. The blade was coated with platinum aluminide. Investigators found that they realize that blade had failed by fatigue and they found cracks on blade coating. The main cause of cracks was excessive bending/vibration which lead fatigue and cause failure. [7]

Above studies are explaining some other types of failure and their possible reasons. But only few investigators have focused on vibrations in blade. There is lot of scope in vibrations of gas turbine blade. In this study we are focusing on vibrations developed in gas turbine blade and also effects of vibration on blade. This investigation will provide various frequency ranges in different modes. Behavior of blade material for various frequency ranges can illustrate the possible deformation. By studying this deformation we can check whether that deformation is harmful to blade material and coating.

To carry out Modal/Vibration Analysis FEA (Finite Element Analysis) tool we are going to use. It is an extensively used tool now days to carry out solution for many engineering problems. It is totally based on Finite Element Method and provides more approximate solution of any engineering problem. To find out vibration effects on blade we have to develop CAD model of gas turbine blade and import this CAD model into FEA package to carry out solution. We are using gas turbine blade material (N-155).

2. CAD MODELING OF GAS TURBINE BLADE

CAD model is prepared by taking dimensions of gas turbine blade using reverse engineering method. For the modeling and analysis purpose we have chosen first stage gas turbine blade. Modeling is done by using CATIA V5R17 software and it is converted into IGES format to import in FEA package. Overall gas turbine blade virtually developed using CAD software. This virtual prototype will exactly simulate the actual gas turbine blade and gives us required effect of vibration on blade profile.

Blade profile modeling is a challenging task, because it directly affects the simulation results. CATIA is advanced CAD software and has good exporting properties hence modeling in CATIA is beneficial. We can go through other CAD software such as Pro-E, NX, Solidworks, Solidedge etc. Dimensions of blade are taken by visual inspection and instruments. After modeling gas turbine blade it is converted into neutral file format. In this study we are using IGES (Initial Graphics Exchange Specification) file format to convert CAD file into FEA package readable file.

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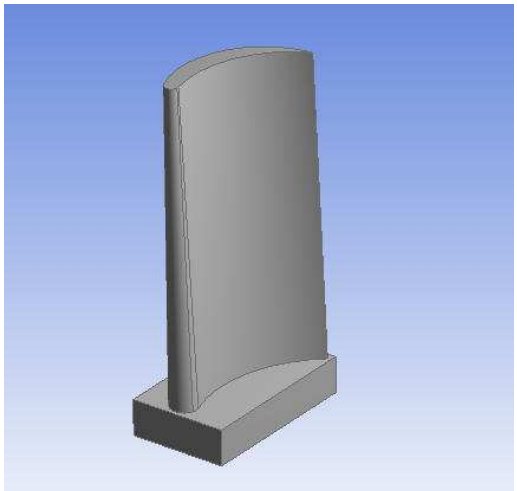

Fig 1. CAD model of first stage gas turbine blade.

3. VIBRATION ANALYSIS OF GAS TURBINE BLADE

Model/vibration analysis is performed with FEA package i.e. ANSYS 14.0 and results are carried out. For that purpose CAD model is converted into IGES file format and then imported into FEA package

A] ASSIGNING PROPERTIES OF METAL

Material properties of gas turbine blade to carry out model analysis are Density of blade, Young's modulus, Possion's Ratio etc. These properties are taken from N-155 nickel based alloy which is used for manufacturing of gas turbine blade. This will affect the analysis result. Our overall vibration analysis results are based on these properties. Because we are finding out vibration effects on blade material and their coating. [8]

Table 1. Mechanical properties of N155 gas turbine blade material.

Properties	Units	N 155
E	Pa	143 E09
ρ	Kg/cu m	8249
μ	---	0.344

Where,
E= Young's Modulus
ρ= Density
μ= Poisson's ratio

Above properties are used to carry out model analysis of gas turbine blade. A set of frequency range will give gas turbine blade natural frequency. More the frequency safer the object.

B] DISCRETISATION OF GAS TURBINE BLADE

In FEM discretisation is very important step. It means forming small pieces of an object which are connected to each other by means of points called nodes and each piece is called as element. Generation of such structure of elements which forms an object is called meshing. Very first step towards solution in Finite Element Analysis is meshing. Elements are of three types 1D, 2D and 3D elements. We use elements according to our convenience. i.e. for lines we use 1D element, for surfaces we use 2D elements and for solid object we use 3D elements.

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Elements are also categoriesed according to their shape and size. Here for performing model analysis we have used 3D tetrahedron element for meshing of gas turbine blade. The meshed model of gas turbine blade is shown in figure 2. Also the details of nodes and element is provided.

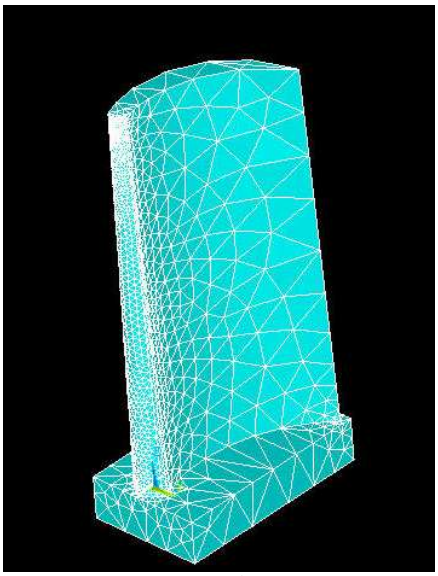

Fig 2. Meshed model of gas turbine blade.

Details of gas turbine blade meshing are as follows.
Maximum Nodes formed= 1999
Maximum Elements created= 7925

C] LOAD APPLICATION ON GAS TURBINE BLADE

To perform model analysis of gas turbine blade it must be constrained at the base. After applying material properties and meshing, it is a next step for finding solution. Here we have taken five modes of frequencies to describe deformation in each step or mode.

All the movements of gas turbine blade are restricted from the base. The frequency range should get from its initial value to maximum value. Therefore frequency range is not set in model analysis.

D] SOLUTION FOR GAS TURBINE BLADE AND EFFECT OF VIBRATION

The solution of vibration analysis is divided into five sets of vibration. It is also called as modes of vibration. Vibrations set up in blade are described in the form of frequency. Each set of frequency gives maximum deformation in that mode. Solution is calculated on the basis of FEM. After applying each required parameter FEA package solve the given vibration analysis problem and obtain frequency sets. Results are further studies to give conclusion. Maximum frequency obtained by this analysis will be the natural frequency of gas turbine blade. If the frequency of blade is match with its natural frequency then resonance phenomenon will accurse. This directly tends to permanent damage of blade.

4. RESULTS AND DISCUSSION

Vibration Analysis obtained various frequency values at each mode of vibration. The maximum frequency obtained by performing vibration analysis is 12.26 Hz. It means that the natural frequency of blade is 12.26 Hz. Bellow table shows the frequency values for various modes of frequency.

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Table 2. Frequency values obtained for each set or mode.

SET	FREQUENCY	LOAD STEP	SUBSTEP
1	1.4017 Hz	1	1
2	3.6061Hz	1	2
3	5.1403Hz	1	3
4	7.0175 Hz	1	4
5	12.268 Hz	1	5

FIRST MODE OF VIBRATION: Maximum deformation of 0.177E-03 mm is obtained in this mode at the top of blade at the frequency value of 1.4016 Hz. The deformation is negligible in this mode. Figure 3 shows the frequency value as well as the maximum deformation in the gas turbine blade.

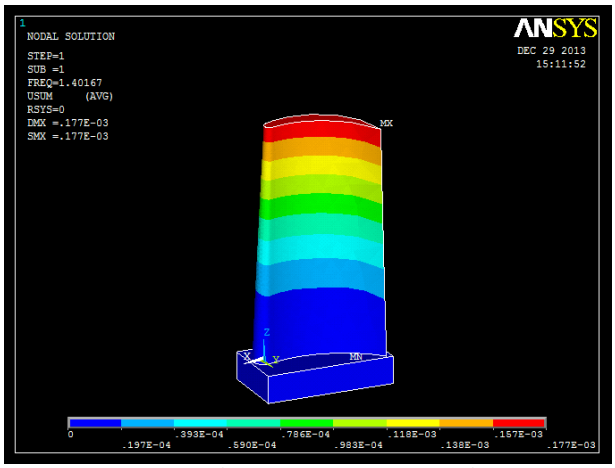

Fig 3 First mode of vibration with maximum deformation.

SECOND MODE OF VIBRATION: At frequency value of 3.6061 Hz the deformation accurse in second mode with value 0.204E-03 mm. This is also negligible vibration for second mode. Figure 4 shows the second mode of vibration with frequency value.

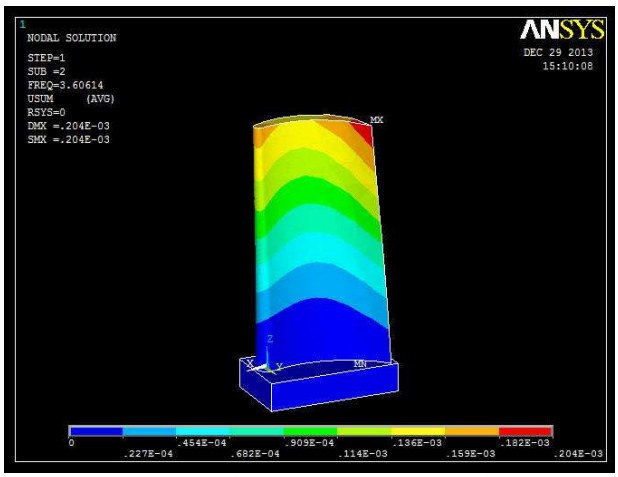

Fig 4 Second mode of vibration with maximum deformation.

THIRD MODE OF VIBRATION: In third mode of vibration the frequency value is increasing with slight increment in deflection. This will affect the performance of blade at high temperature and rotation. The values

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obtained in this mode are 5.14 Hz frequency with 0.266E-03 mm deflection. Figure 5 shows the third mode of vibration with maximum deformation.

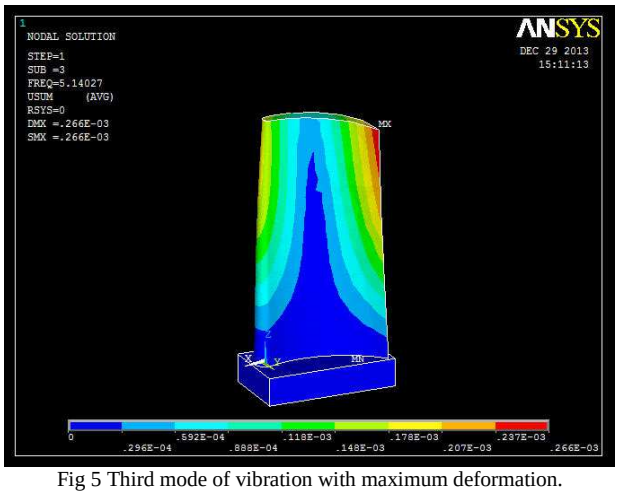

Fig 5 Third mode of vibration with maximum deformation.

FORTH MODE OF VIBRATION: Forth mode explains the increment in frequency value and decreasing value of deformation, which is less than second and third mode of vibration. Frequency value of 7.01 Hz at 0.202E-03 mm deformation is obtained in this mode. Frequency value obtains deformation at top of blade. Maximum deformation in blade for this mode is as shown in figure 6.

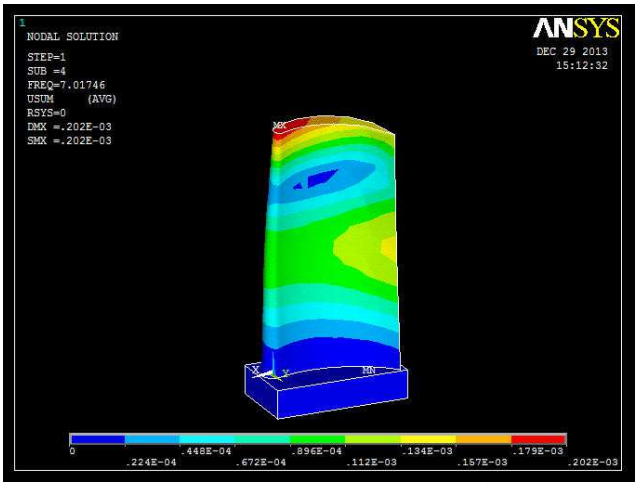

Fig 6 Forth mode of vibration with maximum deformation.

FIFTH MODE OF VIBRATION: Here the maximum frequency with maximum deformation is shown in figure 7. Above this frequency value blade may damage due to maximum deformation. The maximum deformation of 0.274E-03 mm is obtained on frequency value of 12.26 Hz.

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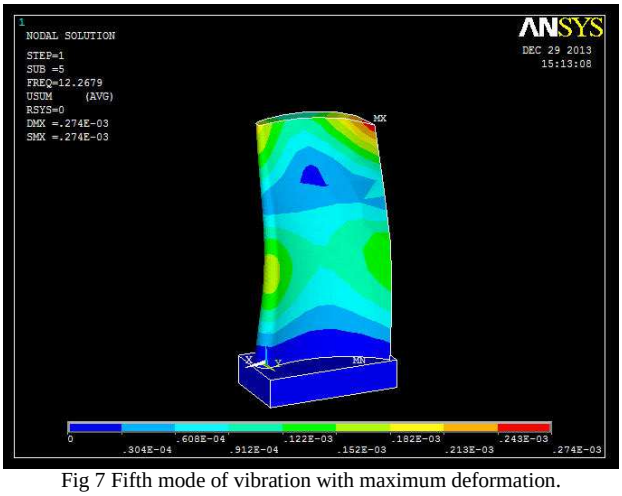

Fig 7 Fifth mode of vibration with maximum deformation.

Bellow table shows the frequency value and its respective maximum deformation in the chassis. Each se has its own deformation value.

Table 3. Frequency values and their deformation for each set

SET	FREQUENCY	DEFORMATION
1	1.4017 Hz	0.177E-03 mm
2	3.6061Hz	0.204E-03 mm
3	5.1403Hz	0.266E-03 mm
4	7.0175 Hz	0.202E-03 mm
5	12.268 Hz	0.274E-03 mm

The maximum value of frequency is 12.268 Hz which is vary less. Maximum frequency safer the object is the fact for each object. Blade deformation is not much but frequency value is very less. Hence the natural frequency of the blade needs to improve.

5. CONCLUSIONS

Vibration Analysis carried out for gas turbine blade is illustrating the following points which can be conclusions for this overall study or investigation.

- Natural frequency of gas turbine blade needs to improve.
- Deformation in gas turbine blade is negligible.
- Blade becomes unstable on slight increment in frequency value.
- Due to less natural frequency cracks may develop on coating and material of blade.
- Needs concentration on dynamic stability of blade as it rotates at high RPM.

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