LOW CYCLE FATIGUE ANALYSIS OF GAS TURBINE BLADE

K.Nehru[1], Dr.R. Asokan[2]
[1&2] Aeronautical Engineering Department, Hindustan University, Chennai, India.
[1]nehru1991@gmail.com, [2]tifac@hindustanuniv.ac.in

Abstract-

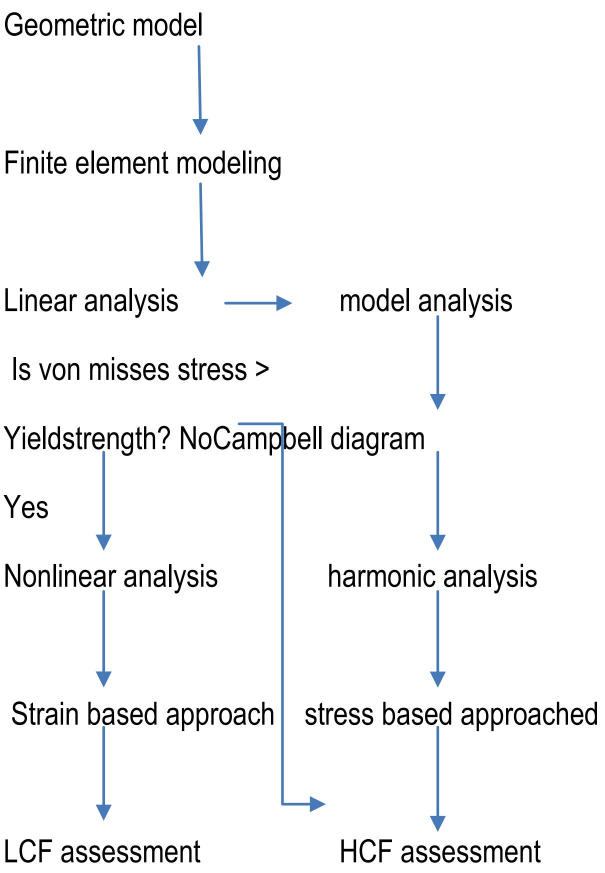
Every startup and shutdown of gas turbine engine the turbine blades are subjected to high centrifugal force due to high rotational speed and also operated at high critical environmental condition. So that the turbine blades are fails by fatigue is common. Based on the stress result the analysis is based on stress based fatigue assessment or strain based fatigue assessment. This paper summarizes the design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS14.0 software for analysis for F.E. model generated, by applying boundary condition, this paper also includes specific post processing and life assessment of blade. How the program makes effective use of the ANSYS14.0 pre-processor to mesh complex gas turbine engine blade geometries and apply boundary conditions. Plastic deformation on the blade leads to low cycle fatigue, which is based on strain life approach.

Keywords: Gas Turbine blade, High cycle fatigue, von misses stress, Low cycle fatigue.

I. INTRODUCTION

Fatigue failure is related to repeat cyclic load on a structural member. The fatigue life of a structural member i.e. the number of load cycles it can survive is in general determined by the magnitude of the stress cycles. The exact relation between the magnitude of the stress and the fatigue life depends on the material properties of the structural member. In general higher stresses lead to a shorter fatigue life. For some materials fatigue only occurs if stresses exceed a certain minimum level for other materials there is no minimal stress level. If the stresses that are present on the turbine blade during operation and the material properties of the turbine blade are known then an estimation of the fatigue life of the turbine blade can be made. [1]Static loading, it is observed that the dovetail regions will have a minimum life in LCF. And in case of dynamic loading, it is observed that the maximum speed of the fan blade is close to one of the blade passing frequencies. [3] First stage blade in ALSTOM gas turbine is investigated and natural frequencies and vibration modes of blade are found in various conditions. Three-dimensional finite element thermal and stress analyses of the blade were carried out for the steady-state full-load operation. The results of these analyses were used for determination of the regions where the combination of high temperature and high tensile stress was sufficient for significant creep-fatigue crack growth. [11]The failure of a second stage blade in a gas turbine was investigated by mechanical examinations of the failed blade. The blade was made of a nickel-base alloy Inconel 738LC.In gas turbine blade the crack growth life assessment method for a turbine component under high-low combine cycle fatigue (HLCCF) loading through experimental and numerical methods were done in the reference [4] and also the growth tests under HLCCF loading with temperature distribution also calculated. Reference [5] explaining the fatigue analysis is done for the notched linearly varying rotating blade, the alternating stress, strain energy, stress intensity and life of the rotating blade is found. [8]In this reference the rain-flow counting method for identifying damaging events and one of two methods(Morrow's or Manson& Helford) to incorporate mean stress effects on fatigue life .thermal analysis also done in this paper to fine the high temperature creep life of the blade.

II. METHODOLOGY



III. DESIGN AND ANALYSIS

A. *CATIA model*

From the gas turbine engine blade data, the design was done in CATIA solid model. The part considered for fatigue life assessment is a turbine blade taken from a turbojet.

TABLE 1
Blade Dimensions

Length of the blade	172mm
Chord length of the blade	86mm
Leading edge radius	5.3mm
Trailing edge radius	3.2mm

A. *Mesh the model*

CATIA model is meshed by using 4 node tetra elements, the total number of nodes and elements are respectively

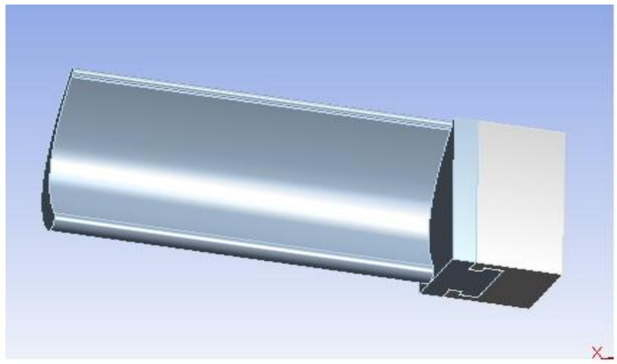


Fig. 1. CATIA model of the blade with disk

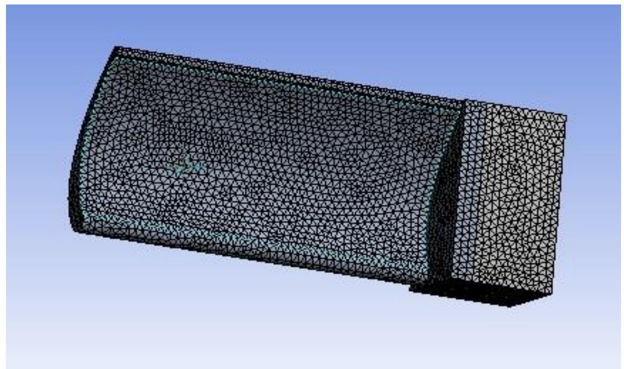


Fig. 2. Mesh view of the blade

TABLE 2

Total nodes	150279
Total element	70303

B. *Boundary condition*

Important input while analysis is the application of boundary condition. In reality the turbine blade clamped to the disc at the dovetail. The gas turbine engine rotate at 3000 rpm, and the turbine entry gas pressure is around 6 to 10 bar, and turbine entry temperature around 1200^0c to 1400^0c. The fir root tree will be fixed support dude to the static structural analysis.

C. *Analysis Stress- life approach(HCF)*

The stress-life analysis of several metals was that of endurance limit which characterizes an applied stress amplitude below which the material is expected to ensure that the stress in structure is below the material fatigue limit. However, this simplistic approach may be inappropriate for many fatigue cases.

D. *Strain-life approach (LCF)*

The strain-life approach is considered to represent better the fundamentals of the fatigue damage process in comparison to the stress-based approach for the following reason, the displacement at the macroscopic level control the damage process; localized plasticity that occurs prior to crack initiation at the critical area is considered and finally, experimental strain controlled fatigue tests represent favorably the material behavior.

E. Material properties of Ti-6Al-4V

TABLE 3
Material properties

S.NO	Mechanical properties	Value
1.	Density	4620 Kg/m^3
2.	Ultimate strength	950 MPa
3.	Yield strength	880 MPa
4.	Modulus of elasticity	117.385 MPa
5.	Fatigue strength	510 MPa
6.	Poisson ratio	0.33
7.	Melting point	1604-1660 ^{0}c
8.	Fatigue limit range	0.06 – 0.1
9.	Fatigue strength factor	1

TABLE 4
Fatigue cyclic data for strain life approach

NO	Cyclic Properties	Values
1.	Cyclic strain hardening coefficient	1938 N/m^2
2.	Cyclic strain hardening exponent	0.109
3.	Fatigue strength coefficient	1737 N/m^2
4.	Fatigue strength exponent	-0.085
5.	Fatigue ductility coefficient	0.396
6.	Fatigue ductility exponent	-0.684

F. Engine Speed vs. Time (per cycle)

From the engine rotational speed 3000 rpm, the total running time of the engine per cycle is 8hours (28800sec)

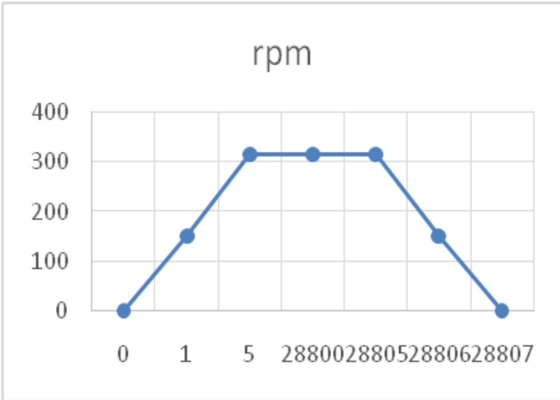


Fig. 3. Engine rotational speed based on starting and shutdown time.

G. Static analysis

Static analysis is carried out by giving centrifugal and gas bending load at very high turbine entry temperature of the gas nearly 1400^{0}c.

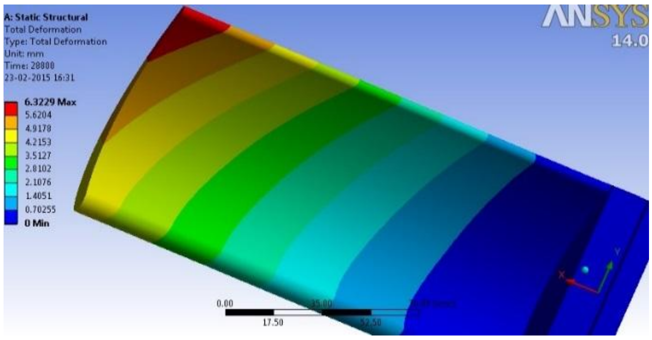


Fig.4. Total deformation of the blade.

H. Von misses stress

From the von misses stress that the blade subjected to low cycle fatigue because the von misses stress is more than the yield strength of the material.

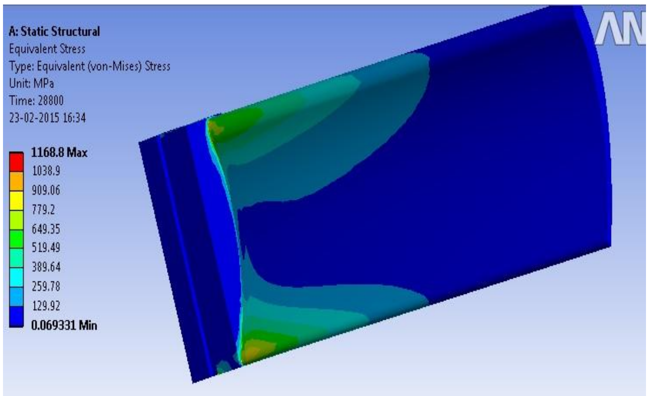


Fig. 5. Von-misses stress

I. Plastic strain

Plastic strain occurring due to the plastic deformation in the plastic zone of the blade. The maximum plastic strain value.

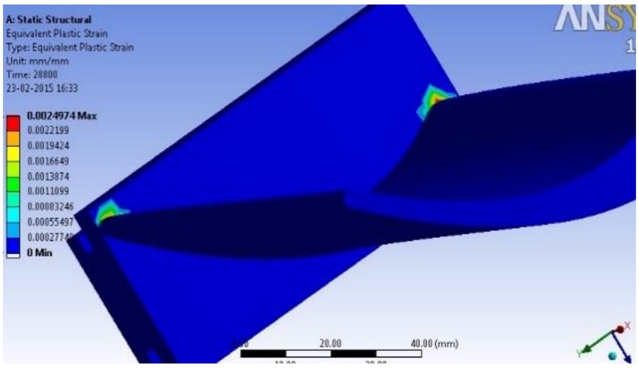


Fig.6. Equivalent plastic strain.

IV. RESULTAND DISCUSSIONS

From the analysis result the following discussions are made,

A. Low cycle fatigue analysis

Where the maximum plastic strain occurring at the root of the blade having the minimum strain based fatigue life of the blade is 17241 cycle.

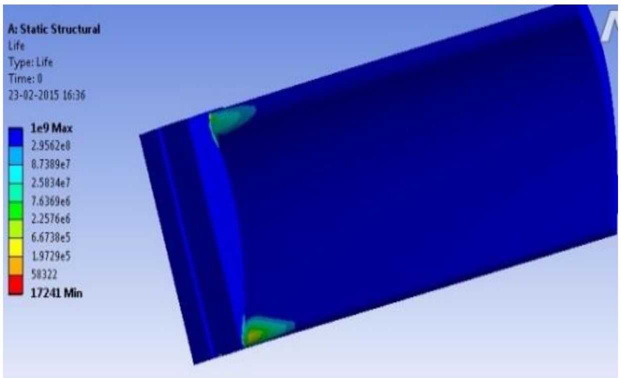


Fig. 7. Strain life of the blade near the root

1. Von misses stress is more than the yield stress of the material, so this analysis is strain based analysis.

2. The maximum plastic deformation occurring at maximum plastic strain region.

3. The life of the blade at plastic region is 17241 which is low cycle fatigue value of the blade.

V. CONCLUSION

Based on the stress result the von misses stress is more than the yield strength of the material so the blade experience the strain based fatigue life. And the plastic deformation occurring at the root of the blade the maximum number of cycle to initiate the crack formation in the turbine blade is N17241.

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