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Investigation of Stress Intensity Factor of Axial Compressor Blade of Helicopter

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Abstract— **A compressor blade is one of the main components of the helicopter engine. Without compressor, engine cannot develop static trust. Where the major function of the compressor is to compress the air and that compressed air is further used in the combustion process. Compress blade fails under several factors like high cycle fatigue, due to high rotational velocity, corrosiveness area, due to impinging foreign particle on compressor blade and also hard landing. This paper presents the failure analysis of compressor blade of helicopter engine. The crack was initiated at contact region of the compressor blade. A linear finite element method was used to determine maximum principal stress at contact region i.e. 463.32 MPa was observed at operational speed of 10000 rpm and also minimum principal stress (128.71 MPa) were observed during same operational speed. In this analysis undamaged compressor blade was considered. In the second part of analysis compressor blade damaged due to impinging foreign particles was considered to study crack growth behavior. A finite element method was used to determine stress intensity factor at crack region. The stress intensity factor range obtained is utilized to predict the fatigue crack growth behavior using Paris law. 0.3mm of crack length stress intensity factor observed is 64 MPa$\sqrt{m}$. 602.24 m/cycle of crack growth is observed during 0.3mm of crack length.**

Index Terms— **compressor blade, stress analysis, stress intensity factor, foreign object damage, crack initiation, crack growth, etc..**

I. INTRODUCTION

A compressor blade is one of the main components of the helicopter engine. Without compressor engine cannot develop static trust. Engine which do not contain compressor such engines are called as ramjet engines. Those type of engines works under condition like compression air through intake and until it will reach transonic stage engine will never starts. For this reason compressor is widely used. Where the major function of the compressor is to compress the air and that compressed air is further used in the combustion process. Compressor and pumps both are similar: both increase the pressure on a fluid. The blade and disc of the compressor, works under the low temperature and high rotational velocity. Compressor consists of stages namely impeller or rotor which is moving part and another one is stationary part which is diffuse or stator.

1. Axial flow compressor

In this present work we are given more importance to the axial flow compressor blade of helicopter engine. The axial flow compressor is one in which air enters at axial direction which is parallel to the axis of rotation, leaves out compressor region at axial direction only. At axial flow compressor, in which compresses the air at first accelerating and spreading the air to obtain increases in pressure.

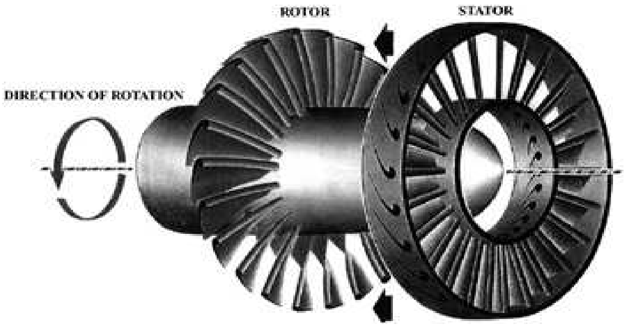


Figure 1 axial flow compressor.

The air is accelerated by a row of rotating blades (aero foils) called as rotator. The air is scattered by row of stationary blades. Diffusion of air increases velocity at stator and at rotor, pressure increases [1]. Below figure 1 shows the arrangement of axial flow compressor.

II. PROBLEM DEFINATION

Due to high rotational velocity of compressor blade, the blade is going to fail. If the blade is failed at initial stage before its predicted life than it is huge loss to organizational in terms of material, money and also time. Several experimental works have published in the papers but experimental works requires time, so cycle time of the product is going to increase, for this reason we are using approximate called FEM to simulate the blade and estimate the stress, stress intensity factor (k), fracture toughness, and life estimation for different crack length to reduce cycle time and manufacturing cost of the product.

1. OBJECTIVE OF INVESTIGATION

Even though a perfect components have a certain finite life, after certain number of cycles. If the problem arises in compressor region it will directly effect to the whole engine part. Due to high airflow required to create a huge trust or powerful suction this effect which leads to drag the small particles which are present around surrounding area. That small object is impacting on compressor blade will cause structural damage to compressor blade.

In this work mainly considering or focusing on two main causes for material failure. In first case we are considering due to high rotational velocity crack propagation will occur at certain rotation per minute after certain RPM material going damage.

In the second case we are focusing on foreign object damage (fod), compressor blades of engine normally going to damage when foreign particles hit the rotating the blade. There will be high rotational velocity and acceleration of foreign particles makes high forces and made local damage to the compressor blade. Usually this type of damage causes at the leading edge of the compressor blade and makes form of notch in the leading edge. These two cases are prime reason for maintenance and reparation of military jet engines.

III. FINTE ELEMENT MODELS OF THE COMPRESSOR BLADE.

In this work CATIA V5 has been used as 3D modelling. CATIA V5 is the comer stone of the Dassault System product life cycle management software suite. CATIA V5 software provides collective engineering across corrections, including shape and design, mechanical engineering, surfacing, and system engineering.

CATIA gives a group of surfacing, reverse engineering, and visualization solution to create, validate, and modify complex innovative shapes.

CATIA allows the creation of 3D modelling, from 2D sketches, sheet metal, moulded, forged, composites or tooling parts up to the assemble of mechanical definition. CATIA provides tools to complete product definition.

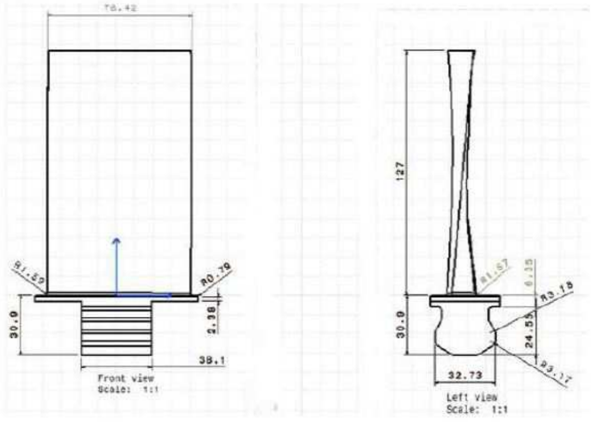


Figure 2 Front View and Side View of Compressor Blade (all dimensions are in mm) [2]

A few blades with different notch length belong to the second group of FE models (Figure. 3). In the stress and fatigue analysis, models with the following notch length: 0.1 mm; 0.2 mm, 0.3 mm, 0.4mm and 0.5mm were considered. The V-notch in FE model was located about 20 mm above the blade locking piece (Fig. 3). During analysis the blade was fixed on the bottom surface of the compressor blade.

The geometric model of the blade is made using CATIA V5 and meshed with tetrahedron meshing in the Ansys workbench software, this tetrahedron meshing creates tetra mesh pattern consist of 23559 nodes and 111626 number of elements.

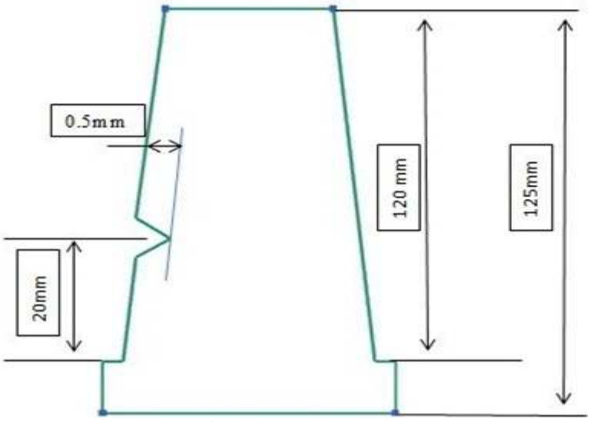


Figure 3 Dimensions of the Blade with the Notch Location.

In this present work the model was meshed with element size of 2mm figure 4 shows the mesh generated model.

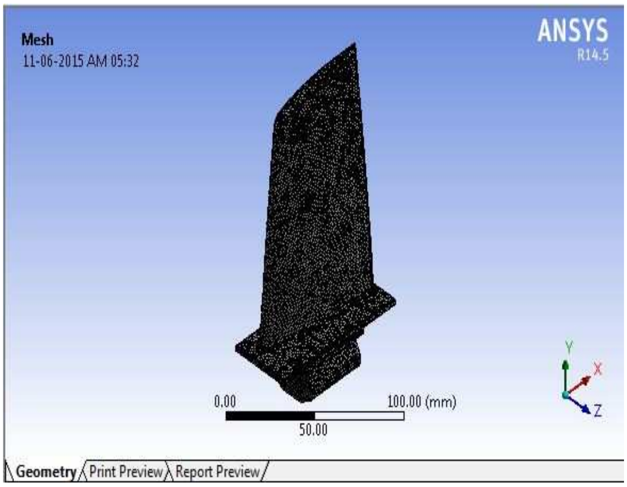


Figure 4 Tetrahedron meshes of 2mm.

IV RESULT AND DISCUSSION.

1. Stress analysis of the compressor blades without preliminary defects.

The main objective of the work is to identify the crack initiation in compress blade through finite element method.

The geometric configuration of the compressor blade is fed to the pre-processor Ansys workbench, through which resultant load calculated and the boundary condition as in the real model are applied to the finite element model of the compressor blade. Complete details are given to the Ansys workbench for linear structural analysis. As per output, result obtained for finite element method of compressor blade which includes stress contour.

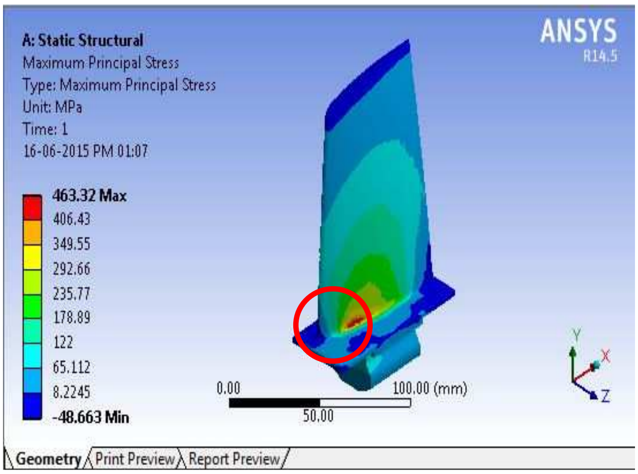
The result can be viewed by erasing remote displacement and free end of the compressor blade because the stress distribution is distributed at this region due to boundary condition effect. In this analysis operational compressor blade speed is 10000 rpm (Rotation per Minute) is applied. It is found that maximum principal stress is located at the contact region of the compressor blade it can be viewed in figure 5 and the maximum principal value is 463.32 MPa and minimum principal stress value observed is 128.71MPa at operational speed of 10000 rpm respectively which are show in figure 6.

According to maximum principal stress theory or normal stress theory, the material going fail when the maximum principal stress developed in a body cross the limit of the ultimate tensile strength of the material. This theory of failure is normally suitable for brittle material. As per maximum principal stress theory material will be safe when maximum stress will below the ultimate tensile strength of the material.

i.e. σ max< σut

The maximum principal stress 463.32MPa is less than ultimate tensile strength of the Titanium alloy (Ti-6Al-4V) which is 950 MPa.

The crack initiation is started at this region, the endurance limit of the Titanium alloy (Ti-6Al-4V) which is 475 MPa.



A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
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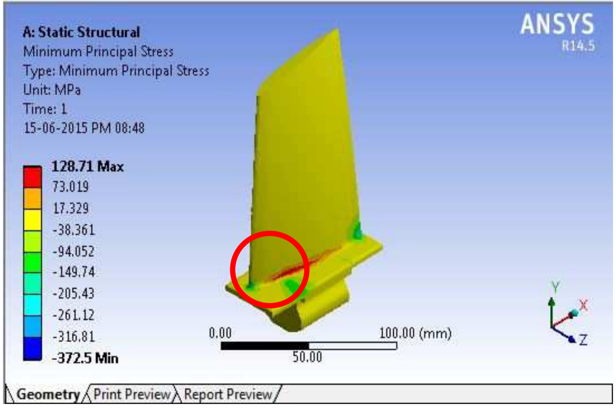
Figure 5 Maximum principal stress.



A: Static Structural
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: MPa
Time: 1
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Figure 6 Minimum principal stresses

2. FATIGUE LIFE CALCULATION

In this analysis work, from the reference of crack initiation fatigue life of compressor blade is calculated. The ultimate tensile strength of the titanium alloy is 950 MPa, factor of safety of this alloy is 2 therefore endurance limit of the titanium alloy is 475 MPa. If the stress occurs in this region means below the endurance limit that should be the safe. If the stress cross the factor of safety, than there will be chance of crack initiation. So in this analysis at 10000 rpm maximum principal stress will be cross the endurance limit. On that basis calculated the estimated flight hours.

Calculation

$\sigma max = 463.32$ MPa
$\sigma min = 128.71$ MPa
Stress range (σr) = $\sigma max - \sigma min$
= 463.32 - 128.71
=334.61 MPa

Stress amplitude (σa) = $\sigma r/2$
= 334.61/2 = 167.30 MPa

Fatigue limit σf = 1.6×Ultimate tensile strength
= 1.6× 950 = 1520MPa

b = -0.301 from S-N curve [2]

$Nf-0.301 = (167.30)/(2^{(-0.301)}\times 1520)$
= 764 flight hours.

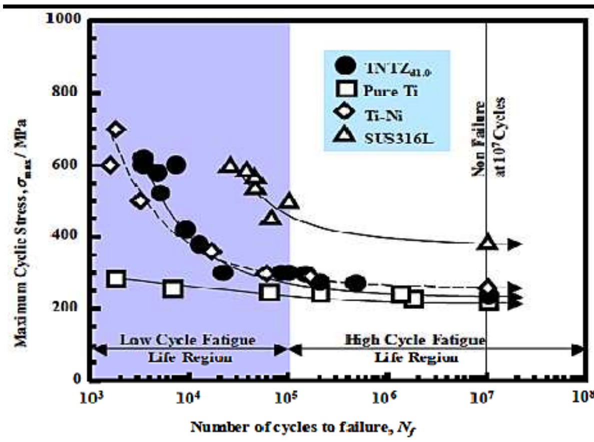


Figure 7 S-N curves [3]

3. CRACK GROWTH RATE

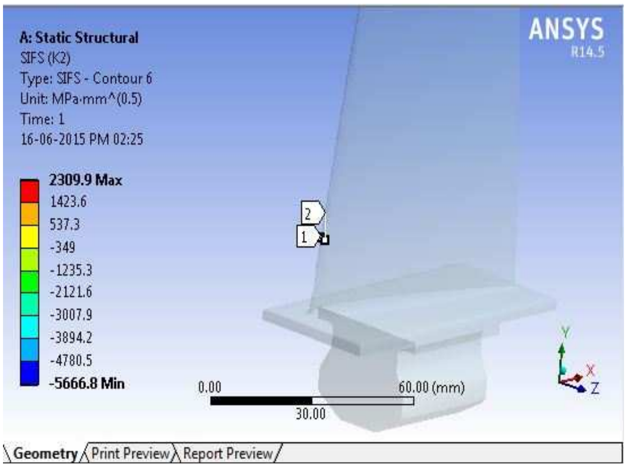
In aerospace industries, or any other structures it is very important role that engineers can able to predict crack growth rate during loading condition so the part can be replaced before crack reaches its critical stage.

Crack growth rate can be related with the cyclic variation in the stress intensity factor. Crack growth rate can be expressed with help of "Paris law" which is expressed as below:

$da/dn=C\Delta Kn$……………………ref[4]

Where, da/dn is the fatigue crack growth rate per cycle. $\Delta K=K_{max}-K_{min}$, C and n are material constant.

The maximum stress intensity factor value obtained is 19.58MPA√m. The total crack growth is calculated using above equation.



A: Static Structural
SIFS (K2)
Type: SIFS - Contour 6
Unit: MPa·mm^(0.5)
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Kmax= 73.04 MPA√m

Since Kmin= 0 MPA√m

ΔK= 73.04 MPA√m

$da/dn=1.0\times10^{(-11)}\ (73.04)^{3.2}$

$=919.16\times10^{(-8)}$m/cycle

Therefore the crack growth rate is 919.16× 10^(-8)m/cycle for 0.3mm crack length.

V CONCLUSION

In this study the effort was made to understand the behavior of foreign object damage, stress intensity factor at crack region and crack initiation at compressor blade.

Three dimensional finite element analysis of the compressor blade is carried out to evaluate the maximum stress concentration at the contact region of the compress blade. From the maximum principal failure theory if the maximum principle stress crosses the ultimate tensile strength of that material than that material will go under failure, maximum principle stress occurs in this analysis is 463.32 MPa to the operational speed of 10000 rpm, this indicates material is safe. But on the point of endurance limit of material is 475 MPa, the crack initiation is going to start for this point, calculated flight hours for the operational speed of 10,000 rpm is 764 flight hours after reaching 764 flight hours the compressor blade is under surveillance of maintenance.

Conclusion drawn from the study of foreign object of a compressor blade, fracture toughness of the material (Ti-6Al-4V) is 75MPa√m. For the 0.3mm of crack length of a compressor blade calculated fracture toughness is 64.01 MPa√ m. Considering fracture toughness of the material as reference, if the martial crosses 0.3mm of crack length than the compressor blade going to fail. If the crack length of the compressor blade reached 0.3mm than the safety factors should be taken.

SCOPE FOR THE FUTURE WORK

1. The stress intensity facture values which are obtained in this study can be used to predict the fatigue life of damaged compressor blade.
2. By considering the inlet pressure acting on the compressor blade, can be predict the fatigue life.

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