Stress Analysis of High Pressure Compressor Rotor Blade of Gas Turbine Engine

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Abstract— The compressor is a device that pressurizes a working fluid/gas/steam, which flow from the inlet and leaves the gas with higher temperature and pressure to the outlet. Load imposed upon the components of compressors results in compressor blade stresses, which vary considerably over the operational envelope of the compressor edge of the blade stresses, which is important in evaluating the operational limits of the compressor speed and total pressure combination. Stress analysis of high pressure compressor rotor blade of an experimental gas turbine engine will be carried out. The analyses will be performed for different combinations of speed, mass flow rate and pressure gradient across the stage. Reduced order stress model will be developed and verify for an arbitrary loading condition. The above activities include 3D solid model generation (UG), Finite element meshing (HYPERMESH) of rotor blade and static stress simulations using ANSYS software. Using the simulation results a mathematical model (Reduced Order Stress Function) will be developed.

Key words: Compressor Rotor Blade, Design, Meshing, Finite Element Analysis and Reduced Order Stress Function

I. Introduction

A. *Use of Compressor Rotor Blade*

The compressor rotor blade is a non – stationary rotating part of the machine which continuously pressurize gas by increasing the incoming fluid which flows through the compressor in which the rotor blade produces torque on the fluid and in general it consists of two types of compressors that is centrifugal and axial compressor.

The blade is subjected to forces in three directions such as:

- Radial force
- Axial forces
- Tangential force

B. *Aim of work*

There are problems which occur in engineering which can be solved by mathematical equations such as integral or differential. So results obtained from the above equation will provide an accurate solution for the given problem. But if the given model and its boundary conditions are complex the exact solution cannot be obtained and even if we get the solution done it will consume more time for obtaining those solution. According to the product cycle time, engineer should obtain a solution for a given problem in less amount of time as much as possible.

So, I took Finite element method as one of the technique for obtaining a solution. Normally it is a numerical method used for many problems in engineering field. In this if the model is complex then it is discretized into simple geometric elements in which nodes are been formed. And when the boundary conditions and loads are applied on the model the solution will be in the form of linear or nonlinear equation and the obtained solution will show an exact behaviour of the model.

The upcoming process deals with various stresses acting on the blade due to high pressure at various locations and this project is carried out with different conditions of speed, mass flow rate and pressure gradients. As the forces are acting on the model it is necessary to determine the stresses at the fixed section and also the stresses affected at the aerofoil section. In this the component is modelled in Uni graphics NX8, meshing is done in hyper mesh and static stress analysis is done using ANSYS and by the obtained results a mathematical model is developed. Hence by this mathematical model we can calculate result in a short period of time.

Fig. 1: Compressor Rotor Blade

II. Objectives

- To develop a 3D model of high pressure compressor blade.
- Generating a Mesh for the Model
- Conduct static stress analysis to the blade
- Finding the maximum stress acting on the compressor blade.
- To develop a mathematical model (Reduced order stress function) for the analyzed compressor blade.

III. Geometric modelling

In this project the compressor blade as been modelled by using solid modelling software and the software that I have used is Uni-graphics NX8 for modelling. And the model is saved in iges (initial graphics exchange specification) format which helps in digital exchange of data among various CAD software.

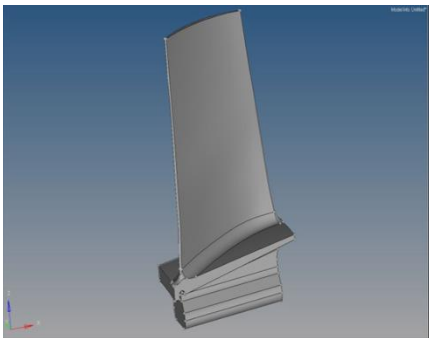

Fig. 2: Compressor Blade Modelled in Uni-graphics

IV. FINITE ELEMENT MESHING

In this the compressor blade as been meshed in hyper mesh V13 software. The first step in meshing is mental visualization or planning before starting the job in right direction for good meshing. The second step is time estimation of meshing a component. The third step is the geometry checking of the model before meshing such as free edges, scar lines, small fillets, small holes etc. The last step is selection of type of element used for meshing and in this project the model is meshed with 3d element.

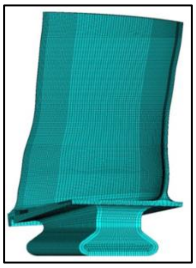

Fig. 3: Meshed model

- Number of Nodes: 1, 97,807
- Number of Elements: 1, 69,063
- Element type: Solid 185

V. FINITE ELEMENT ANALYSIS

In this the analysis of compressor blade is carried out in ANSYS 16 so the main purpose for using this software is that it enables test or working conditions and it determines and improves the weak points in the components and it can carry out advanced engineering analyses quickly, safely and practically by its variety of contact algorithms and non-linear material models.

A. Loads and Boundary Conditions

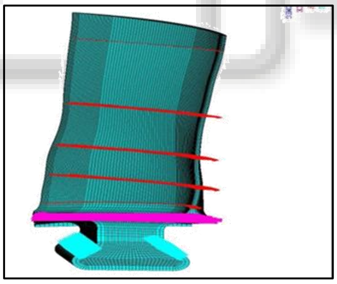

Fig. 4: Finite element model with Loads & Boundary condition

U = Displacement
F = Axial and tangential loads
CE = Coupling equation
OMEG = Inertia

VI. RESULTS

A. Analytical Result

Taking one of the input conditions as RPM the results have been plotted.

1) Trail 1: Material Properties

- Material used – Titanium alloy
- RPM – 16000
- Young's Modulus – 96.11 * 103MPa
- Mass flow rate – 89.72 kg/s
- Density – 4.45 * 10-9tonne/mm3
- Poisson ratio – 0.3

2) Applying RPM to the model

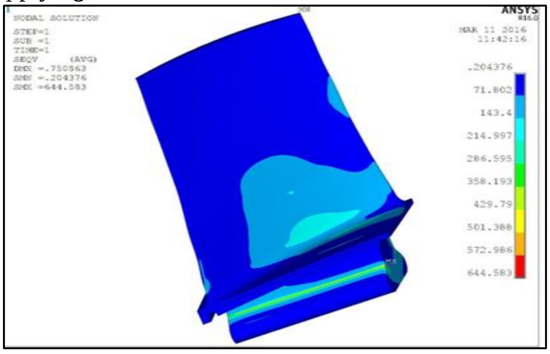

Fig. 5: Von – mises stress with RPM - 16000

In the same way, analysis is done for other three different trials of RPM and Material properties, the results are tabulated as follows:

Trials	RPM	Analytical Results Stress (Mpa)
1	16000	645
2	15200	583
3	13000	427
4	10500	279

Table 1: Analytical Results RPM - 16000

B. Theoretical Result

In this the result have been taken by plotting graph for RPM versus STRESS values obtained analytically and generating a mathematical equation or reduced order stress function by the curve obtained in the graph.

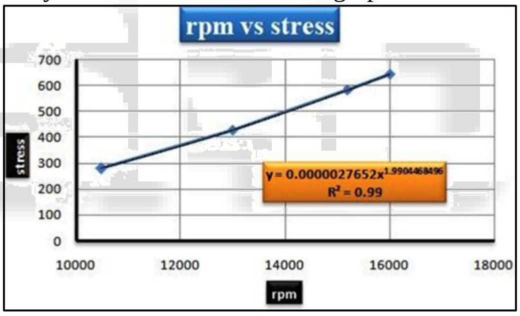

Fig. 6: RPM vs Stress

From the graph the Reduced order stress function for the compressor blade under the given condition is :

$$y = 0.0000027652 * (x)\ 1.9904468496$$

Where x = RPM y= Stress in Mpa

Theoretical results are tabulated according to the obtained reduced order stress function as follows :

Trials	RPM (x)	Theoretical Results Stress in Mpa (y)
1	16000	645.363
2	15200	582.725
3	13000	426.886
4	10500	279.055

Table 2: Comparing both Analytical and Theoretical stress values the results are nearly equal.

Comparing both Analytical and Theoretical stress values the results are nearly equal.

VII. VALIDATION

In this, the results have been validated by taking the intermediate values in between different trials and applying it in mathematical equation and check whether the result correlate with the analytical value.

A. Theoretical Result

In this the results are obtained by taking the intermediate values between the above four trials of RPM and applied it in the obtained reduced order stress function

$$y = 0.0000027652 * (x)^{1.9904468496}$$

Trials	RPM(x)	Theoretical Results Stress(Mpa) (y)
1	15000	605.842
2	14500	530.528
3	11500	334.448

Table 3: Theoretically Result

B. Analytical Result

1) Trail 1: Material Properties

- Material used – Titanium alloy
- RPM – 15500
- Mass flow rate – 69.27 kg/s
- Density – 4.45 * 10-9tonne/mm3
- Poisson ratio – 0.3

2) Applying RPM to the model

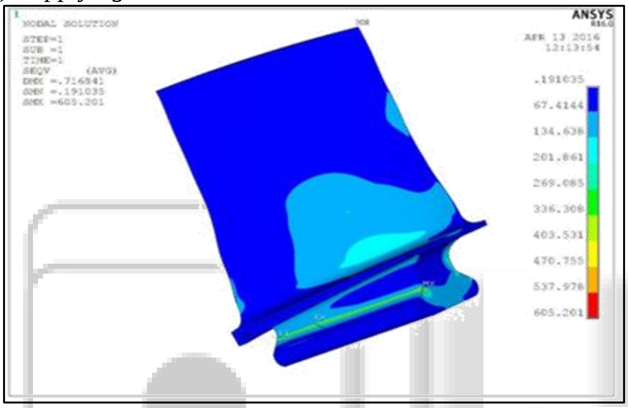

Fig. 7: Von–mises stress with RPM – 15500

In the same way, analysis is done for other two different trials of intermediate RPM values and Material properties, the results are tabulated as follows:

Trials	RPM	Analytical Results Stress(Mpa)
1	15500	605.201
2	14500	530.113
3	11500	334.878

Table 4: RPM values and Material properties

Comparing both Theoretical and Analytical stress values the results are nearly equal.

Note: Same procedure is followed in finding a Reduced order stress function for other two inputs that is mass flow rate and Pressure gradients (Gas loads)

VIII. CONCLUSION

Since the blade geometry is complex it is difficult to calculate stress values by using integral and differential equation, so the following process have been carried out to obtain the stress value for different condition by which a mathematical equation is determined which is used to obtain stress value of the blade within a short amount of time and the following process are,

- Static Stress analysis has been carried out.
- Mathematical function have been derived by plotting graph for given four conditions in which each condition consist of three different cases such as applying only RPM, applying only gas load and combining both RPM and gas load.
- The results have been validated by taking the intermediate values between the given four conditions and calculated numerically and then correlated with the analytical results.

So the final conclusion is that by obtaining the mathematical function for this blade geometry there is no need to undergo the above three steps for any point of RPM or Gas loads in which stress value can be obtained directly by using the Reduced order stress function for which there will be advantage of reduction of time in the process.

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