Stress Analysis and Fatigue Failure of Typical Compressor Impeller

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Abstract - *Centrifugal compressors have wide range of applications, previously research were made on centrifugal compressors focusing on the aerodynamic aspects to achieve increased pressure ratio, mass flow and efficiency. All these factors have completed for the latest designs of the compressors for achieving mechanical limits. The mass flow rate and rotational speeds are maximum resulting in increasing higher static mean stresses for the impeller component. Therefore, compressor vanes become highly vulnerable to alternating blade stresses and suffer from high cycle fatigue failure. Vibration of the turbo machinery structure is undesirable but also an unavoidable mechanical phenomenon reducing the life of the structure. The main objective of this project was to find the maximum stresses acting on the typical compressor impeller structure. This is done by generating 3D model using solid edge and then it is meshed by ABAQUS solver, loads and boundary conditions are applied by the same solver. By performing this, the maximum stresses acting on the impeller structure is found. The stresses obtained from finite element analysis, the different modes of vibrations are determined and the factors are used for determining maximum stresses with respect to time in stress distribution. These maximum stresses obtained are used to find the fatigue life analysis of the compressor impeller structure.*

Key Words: Compressor, Impeller, AL2618, Stress analysis, Fatigue, Finite element analysis.

1. INTRODUCTION

During recent years a few researchers have taught about the essentials of turbo machine equipment's. These subjects are applied to all turbo machinery arrangements. Turbo machines utilizing divergent impacts for expanding fluid pressure have been being used for over a century. The soonest machines utilizing this strategy were pressure driven pumps took after later by ventilating fans and blowers.

Centrifugal compressor is defined as a gadget that converts kinetic energy into potential energy. This type of compressors also named as radial compressors. Centrifugal compressor accomplishes a rise in pressure by including kE/speed into consistent stream of liquid which is passing outside from the rotor or impeller. Then the KE is converted causing an expansion in PE, this results in reducing the flow of fluid through a diffuser. An impeller additionally composed as impellor or impella, an impeller is a rotor used to increment or reduction the pressure and flow of fluid. The principle part of centrifugal compressor is impeller, which builds the pressure and flow of fluid by rotational movement. Impellers are most focused on parts of the compressor requesting profoundly exact assembling strategies.

2. METHODOLOGY

As shown in below, the flow chart represents the important basic steps to create a geometric 3D model of compressor impellor and is modeled using SOLID EDGE. Once geometry is created as per specification it is imported into ABAQUS for meshing.

The FEM is prepared by meshing it with appropriate Tetra elements and constraining the model by applying material properties and boundary condition. This finite model is imported to ABAQUS/CAE/Standard Solver to conduct stress and vibration analysis. The fatigue life estimation is made by FE-Safe. Finally, the result is viewed by using ABAQUS software and these results are validated.

2.1 Stress Analysis

Linear static stress analysis of centrifugal compressor impeller structure is carried out using ABAQUS software. Initially the component is meshed in ABAQUS. ABAQUS is the solver. Static stress analysis is performed to determine the maximum stresses induced in the impeller structure to identify maximum compression in the structure.

2.2 Modal Analysis

Modular investigation is the normal attributes of the mechanical structure. Every modular indicates the damping ratio, natural frequency and mode shape during vibration. There are two kinds of modular investigation techniques, experimental modular analysis and calculating modular analysis. In the primary strategy modular parameters are obtained from the securing framework information and yield motions in the test. The reverberation and excitation make the blade to vibrate with single or mixed modular shapes. Along these lines, here the ABAQUS is utilized for investigation, to decide the regular recurrence and mode shape.

2.3 Fatigue Analysis

Fatigue analysis is done after completion of static stress analysis. To determine the maximum crack length in the material, due to the application of stresses on the impeller blade during rotation. Structure after static stress analysis is then imported to FE-Safe solver. FE-Safe correctly predicts the failure location due to low, high and combined level loading.by determine fatigue analysis results are interpreted and compared with standard values.

2.4 Material Properties

The material used for the study is AL2618 as this aluminium is the material with the existing future. Here the aluminium material is used for impeller because of its advantageous properties some are Corrosion Resistance, Strength to Weight Ratio, Electrical and Thermal conductivity, Light and Heat Reflectivity, Toxicity, Recycling etc…

Table -1: Material properties

Sl no	Properties	Magnitude
1	Poisson's ratio	0.3
2	Density 'ρ'(kg/m³)	2700
3	Young's modulus 'E' (GPa)	71
4	Ultimate tensile strength'σ_u'(MPa)	430
5	Tensile yield strength (MPa)	345

2.5 Geometric Modelling

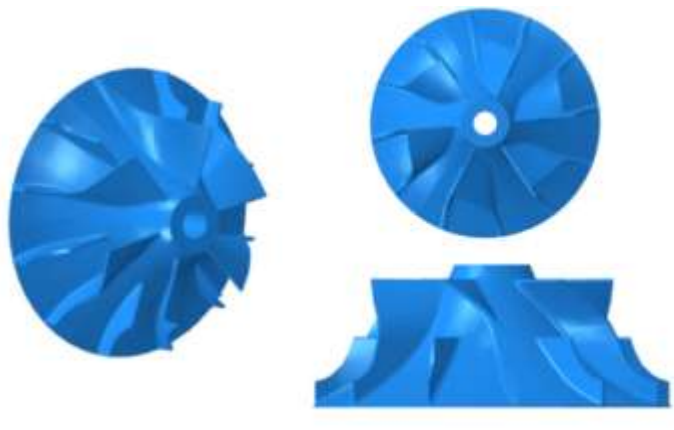

Fig -1: Geometric model

The modeling has been done using the modeling software, SOLID EDGE. Solid works is a modeler which uses a featured based parametric approach to generate model geometry and assembly components. The Constraints are referred as parameters which used to determine the shape of the model geometry or assembly component values. Parameters can be geometric or numeric, numerical may be circle diameter or different lengths of line and geometric parts, such may be parallel, concentric, tangent etc.

Fig -2: FE Meshed model

2.6 Loading conditions

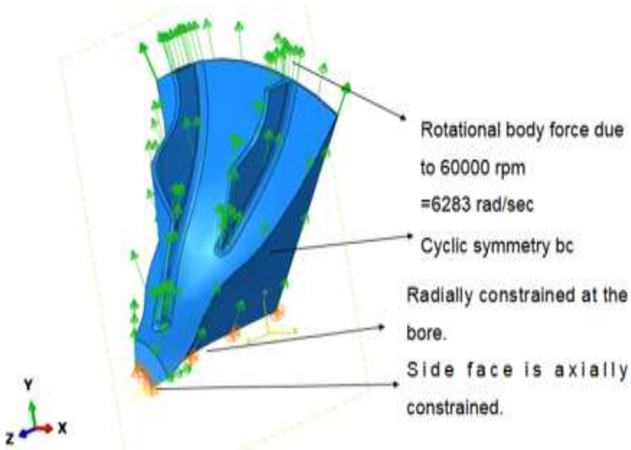

Fig -3: loading conditions

Loading conditions or loads are forces, acceleration or deformations applied to a structure or its components. Rotational body forces are applied on the above component due to 60000 rpm of 6283 rad/sec, cyclic symmetric BC, radially constrained at the bore and the bottom of column are fixed in Z direction.

3. RESULTS

3.1 Stress analysis results

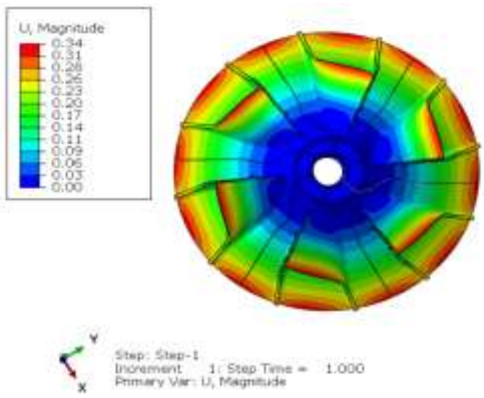

Fig -4: Radial growth plot of complete sector model

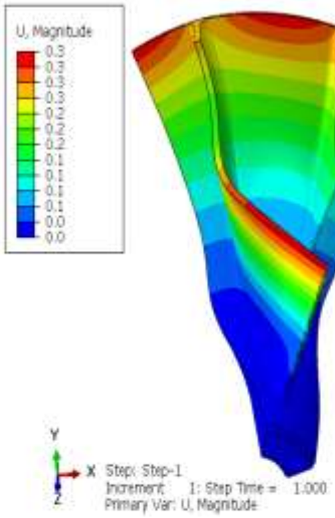

Fig -5: Radial growth plot of 60° sector model

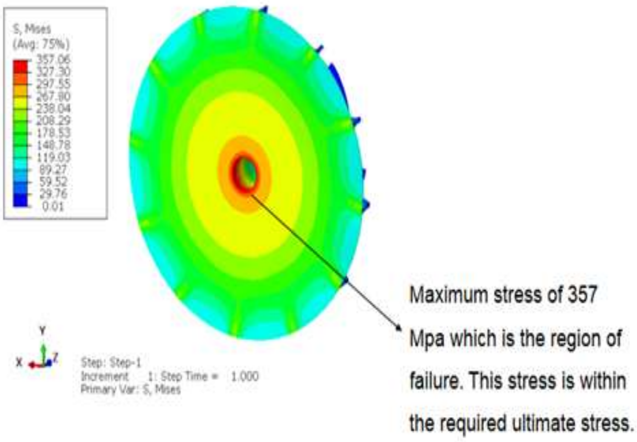

Fig -6: Elemental stress analysis of impeller back/reversed portion

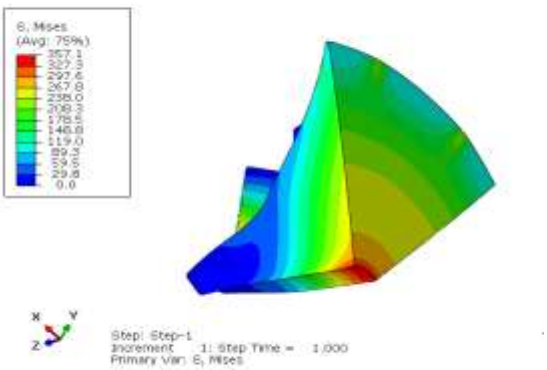

Fig -7: Elemental stress analysis of impeller blade of 60° sector

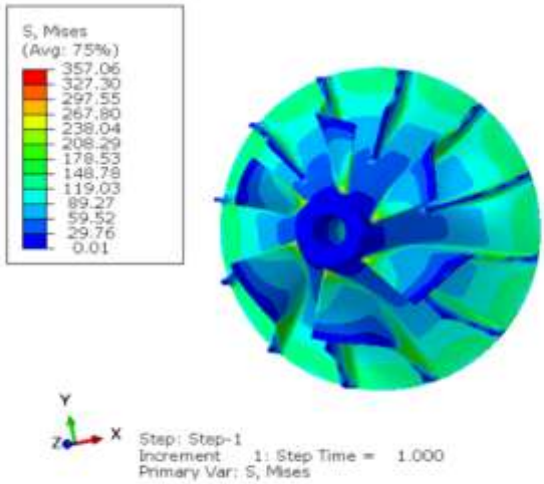

Fig -8: Elemental stress analysis of impeller front portion

By meshing the model in ABAQUS we come to know the total stresses acting on the welding surface. So total no of nodes and elements in the material are 774335 and 541727. Type of element used for meshing is Quadratic tetrahedral elements of type C3D10. The maximum stress is found to be 357Mpa which is the region of failure. This stress is within the required ultimate stress.

3.2 Modal analysis

Experimental model analysis is one of the most important techniques used to determine the mode shape and natural frequency of mechanical system. Here it shows that the four different stages of modes of vibration; in the frequency domain the dynamic properties are studied.

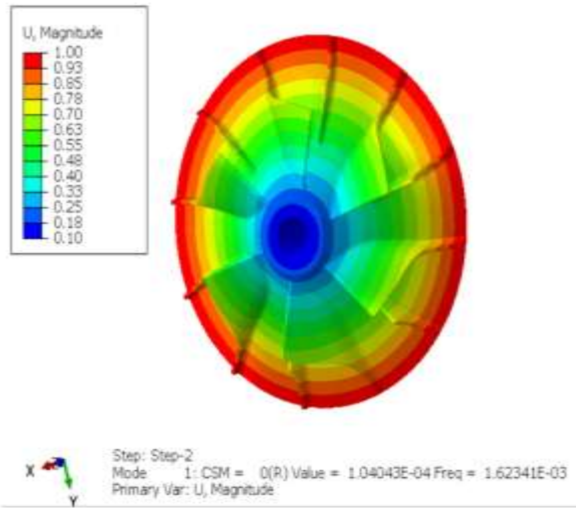

Fig -9: 1st mode of vibration

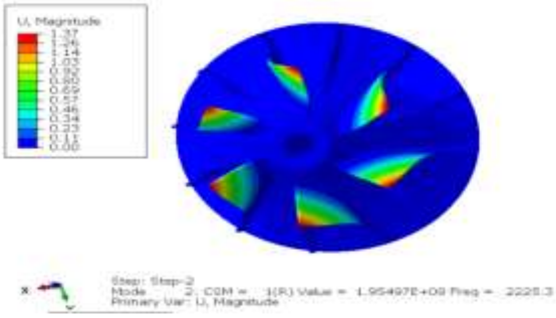

Fig -10: 2nd mode of vibration

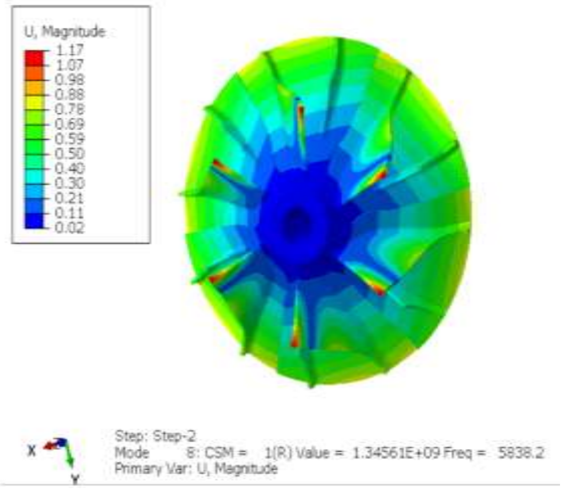

Fig -11: 3rd mode of vibration

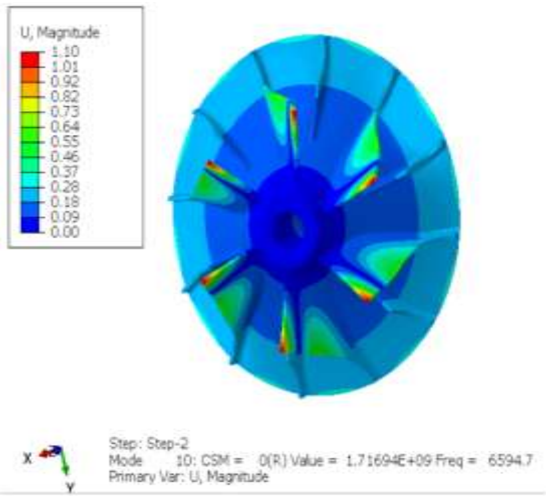

Fig -12: 4th mode of vibration

In the 1st modes of vibration we can observe that the independents from applied load; the nature frequency obtained is 1.62341E^{-3}Hz with corresponding to displacement 1mm, in the 2nd mode of vibration the natural frequency is 2225.3Hz with corresponding displacement of 1.37mm, In the 3rd mode of vibration the displacement is 1.17mm for natural frequency of 5838.2Hz and in the final mode i.e. in the 4th mode of vibration the displacement is 1.10mm for the natural frequency is 6594.7Hz. From the above results, it is concluded that the displacement decreases with increasing natural frequency.

3.3 Fatigue Analysis Results

The SN curve indicates that the life of the impeller under the alternating high cycle stress range. The S-N curve determines the relationship between the number of cycles and cyclic stress amplitude to failure.

As per Goodman equation,

Equivalent stress = Stress Amplitude (1- Ratio of mean stress/ ultimate stress)
Stress amplitude = 613 Mpa (405 Mpa tensile and 208 Mpa in compression)

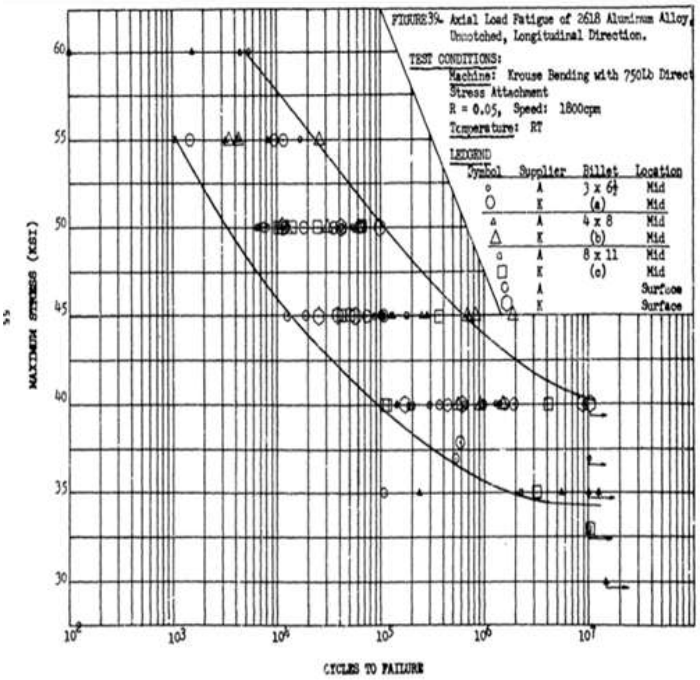

Fig -13: S-N curve of fatigue life

Mean stress = 306.5 Mpa
Ultimate stress = 430 Mpa
Equivalent stress = 176 Mpa
Number of cycles to failure > 10^7 (from the SN Curve)

4. CONCLUSION

The Stress analysis shows a maximum stress of 357 Mpa, which is just above the tensile limits. This will cause permanent deformation and have effect on fatigue life and may cause early failure. The tip deflection is at 0.34 mm which is under the desired range of up to 1 mm tip clearance The modal analysis for the cyclic symmetric model is plotted and the frequencies of up to 10 modes are extracted. The modes are high enough to cause any vibration issues. Fatigue life estimation is done based on the Goodman equation. However as the static analysis does not account for the nonlinear effects some variation in predictions are observed. We could establish a high cycle fatigue more than 10^7 cycles for the impeller.

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