Modal And Fatigue Analysis Of Industrial Centrifugal Fan Impeller

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Abstract: An appropriate design of centrifugal fan is significant for satisfactory performance of the system. Centrifugal fan has wide applications in industries where the continuous air flow is required for various applications. In this work, the modal and fatigue analysis of centrifugal fan impeller with backward curved vanes are carried out using commercial software ANSYS in order to obtain the natural frequencies and mode shapes of the impeller. Further, fatigue analysis is performed using Gerber stress theory approach with the intention of estimation of the fatigue life, safety factor and damage of impeller.

Index Terms: Centrifugal fan impeller, backward curved blade, vibrations, modal analysis, fatigue analysis, Williams method, tetrahedron mesh

1. INTRODUCTION

Fan is rotating device, transfers the pressurized air through outlet by means of rotating blades. It is classified into two categories; centrifugal fan and axial fan. Centrifugal fan has more advantages over the axial fan because it has high performance and capability to develop relatively high pressure. Hence, it is widely used in dirty airstreams, high moisture, particulate content in material handling applications, and in systems particularly operates at higher temperature like boiler. Boiler is one of the prominent component in process industry, and which fulfils the several functional requirements of industry. The performance of it depends upon several operating parameters. One of the important parameter is the size and type of Forced Draft (FD) and Induced Draft (ID) fans. The FD fan is located at inlet of boiler to provide the pressurized air, whereas ID fan is placed at outlet of boiler to take away the dust, ash particles and smoke through chimney. FD fan develops the positive pressure and ID fan develops the negative pressure. In additions to above applications, the fans are also used in automobiles for cooling of the engines and subsystems. According to the blade geometry, the centrifugal fan is divided into three categories such as; forward curved blade, backward curved blade and radial blade. Backward curved blade is mostly preferred in process and boiler industries, because it has self power controlling characteristics for increasing discharge. Depending upon, the design criteria's such as required flow rate, efficiency, power, specific pressure, the impeller blades are designed. For all the blades configurations of fan, the discharge increases up to certain point (critical point at which maximum power), then after for backward configuration it decreases, however for forward and radial configurations it increases. The benefit of backward curved blade is high efficiency as compared to radial and forward curved blade. The maximum efficiency of backward curved blade is up to 83% and radial has 75% and forward curved blade has 65%. Fan is continuously rotating component, due to rotations of impeller the vibrations and subsequently cyclic stresses are generated in the impeller. Thus, presence of such undesirable effects in system is hazardous for impeller, hence to understand operational behaviour of impeller, it is proposed to carryout modal and fatigue analysis of impeller using commercial software ANSYS.

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S. Sendilvelan et al. [1] have carried out the pre-stress modal analysis of centrifugal pump impeller for various blade thicknesses. For designing of blades they used BLADGEN tool in ANSYS and carried out analysis by varying the blade thickness ranging from 3 mm to 5 mm with increment of 0.5 mm. The influence of thickness of blade on performance of fan has been studied. It was observed that, as thickness of blade increased, the vibration level proportionally reduced. Similarly, Bhope et al. [2] have carried out stress analysis of centrifugal fan with the help of experimental and theoretical stress analysis. Stresses were calculated by considering with and without stiffening rings by using FEA. The FEA results were validated with experimental results. In order to understand the behavior of impeller under running conditions Muhammad Ashri et al. [3] performed the modal analysis of impeller in ANSYS. Continuous rotations of impeller, the cyclic stresses were generated and these were undesirable. Manish Dadhich et al. [4] carried out fatigue and modal analysis of centrifugal fan impeller. For modeling of the impeller CATIA V5 has been used and analysis was performed in ANSYS. There were several materials available for manufacturing of the impeller; nevertheless, Adgale Tushar et al. [5] selected only three materials such as steel, composite and aluminum for analysis. They performed the static structural analysis of impeller. In order to understand the vibrational characteristics, the modal analysis has been carried out. From modal analysis the natural frequencies and corresponding mode shapes have been obtained and observed that, the natural frequency for composite material was very low as compared to steel and aluminum, however the deformation was more as compared to steel and aluminum. In this work, the modal and fatigue analysis of centrifugal fan impeller having backward curved vanes is carried out using commercial software ANSYS. The purpose of analysis is to obtain the natural frequencies and mode shapes of impeller and estimate the fatigue life, safety factor and damage for given operating conditions.

2 ANALYSIS OF CENTRIFUGAL FAN IMPELLER

In this work for designing of impeller, we use the SolidWorks and for analysis ANSYS 16 software is used. The material selected for impeller is structural steel corresponding properties are given in Table 1.

TABLE 1
PROPERTIES OF STRUCTURAL STEEL

Property	Value
Density (Kg/m³)	7850
Young's Modulus (MPa)	2×10^5
Yield strength (MPa)	250
Ultimate tensile strength (MPa)	460
Poisson's ratio	0.3

2.1 Modeling of Impeller

Impeller is significant component in the fan and the performance of fan depends upon the impeller parameters, such as number of blades, blade angle and blade width. In this analysis we focus on number of blades in order to decide the optimal number of blades for satisfactorily performance. Initial CAD model of impeller was developed in SolidWorks using calculated dimensions as per customer requirement shown in Fig.1. There are three methods to design the fan such as fundamental method, Austin Church method and William Osborne method. In this analysis the Williams method is used [6]. After modeling the impeller, it is imported in ANSYS for further process. The solid tetrahedron coarse mesh is used for meshing the impeller model; as solid elements give the precise results as compared to other types of mesh.

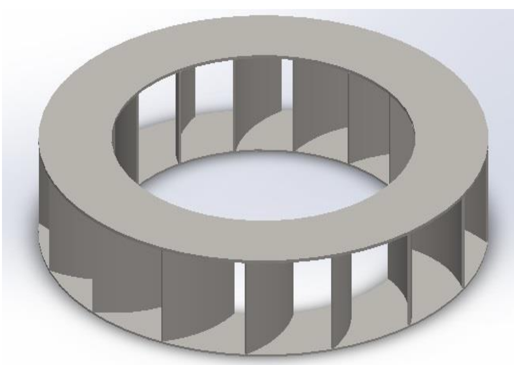

Fig. 1*.CAD model of impeller with 16 blades*

2.2 Modal Analysis

Modal analysis is the study of the dynamic properties of the system in frequency domain and it determines the vibration characteristics such as the natural frequencies, mode shapes and deformation of the component. The mode shapes are important parameter in design of structure of dynamic loading condition. In order to decide the operating frequency range and to avoid the resonance condition, the modal analysis has been carried out for impeller using ANSYS software. The mode shapes of the component presents, how the structure deforms at various frequencies. The analysis consists of three steps, pre-processing, processing and post processing. In pre-processing we use the input data such as import the geometry, defining the material properties, meshing, applying loading and boundary conditions. The developed CAD model is imported in ANSYS software for analysis. Meshing is used to discritize the geometry into number of small elements. The geometry is meshed in mechanical model using ANSYS 16. The automatic mesh method is used for analysis because it covers all complex points on the impeller. The total numbers of elements are 954 and total numbers of nodes are 845. In processing it solves the problem by using applied loading and boundary conditions. Post processing is most important step to view the results. Particularly in modal analysis the part of interest is mode shapes and natural frequencies of the impeller. The analysis results are presented in Fig.2 (a) – (d).

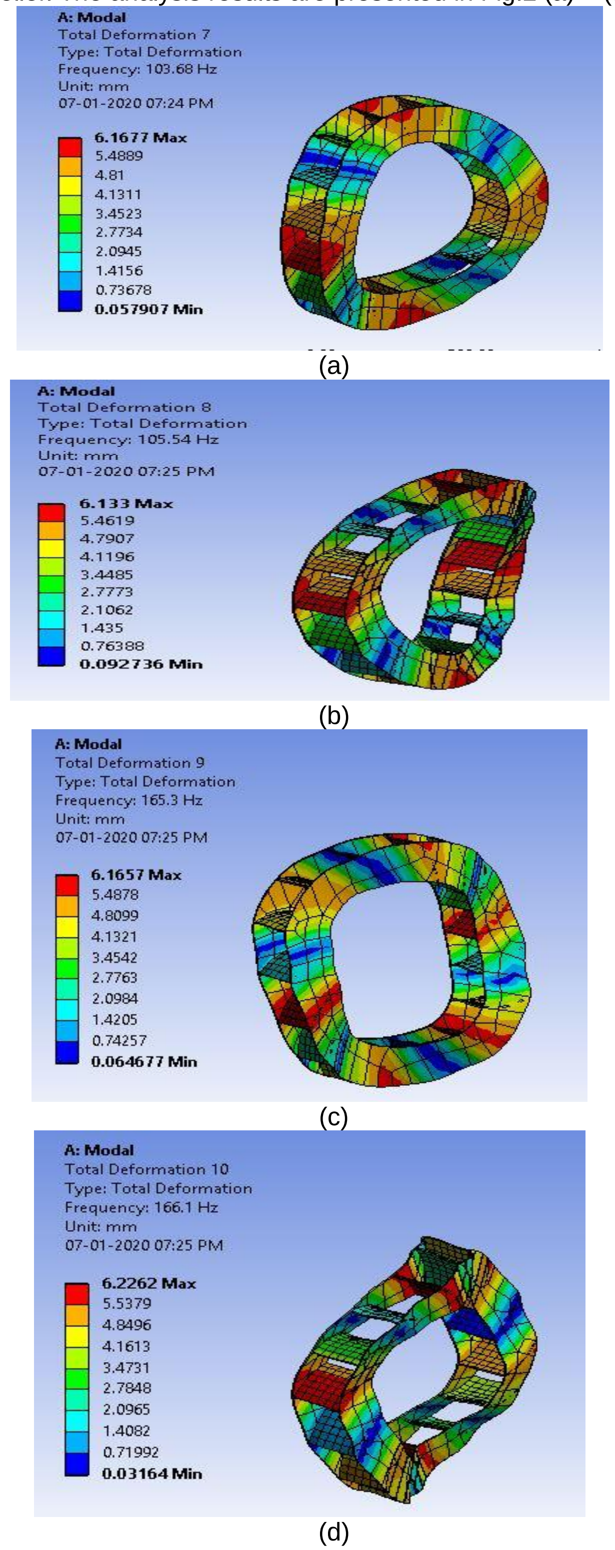

Fig. 2*. Mode shapes of impeller a) Seventh mode shape, b) Eighth mode shape, c) Ninth mode shape, d) Tenth mode shape*

Total ten numbers of mode shapes are obtained to understand the behavior of the impeller. In modal analysis due to rigid body motion first six modes have zero frequency, hence not presented in this analysis. From seventh mode shape onwards there is change in the shape and deformation of the impeller. The maximum natural frequency observed as 166.1 Hz for mode shape number 10 and corresponding deformation is 6.2262 mm.
Table 2 presents the modal analysis result.

TABLE 2
MODAL ANALYSIS RESULTS

Mode Shape Number	Frequency (Hz)	Deformation (max) (mm)
7	103.68	6.1677
8	105.54	6.133
9	165.3	6.1657
10	166.1	6.2262

2.3 Fatigue Analysis
Fatigue is the failure of a component after several repetitive load cycles, and is time delayed fracture under cyclic loading [7]. Fluctuating stresses is the main characteristic of fatigue failure. Most of the structural components fails under the fluctuating stresses, at a stress magnitude, that is less than the ultimate tensile strength of the material. When a ductile material is subjected to cyclic loading, there are basic structural changes occurs, such as crack initiation, localized crack growth, crack growth on planes of high tensile stress and ultimate ductile failure. However, the brittle material when loaded to cyclic loading there is sudden failure of component. Fatigue analysis provides the life, damage and factor of safety of component using a stress-life or strain-life approach. To carry fatigue analysis in ANSYS, three components are required such as Fatigue Material Properties, Fatigue Analysis and Loading Options and Reviewing Fatigue Results. Fatigue material properties contains the materials, include fatigue curves for specific material. The fatigue tool will use the information from these curves for each material in the model when calculating life, damage, safety factors etc. Each material has its own stress- strain life curve. For the strain-life approach, the materials must have strain-life parameters defined. For the stress-life approach, the materials must have alternating stress defined. In Fatigue Analysis, for loading the structure, it is required to select various parameters such as fatigue strength factor (K_f), loading type, scale factor, analysis type, mean stress theory, stress component, units name, infinite life and maximum data points to plot as input data. To perform fatigue analysis, we use first the static structural tool in ANSYS. Fatigue analysis performed in three steps, pre-processing in that we import the geometry in ANSYS with suitable format such as .igs format. After importing the geometry meshing of impeller was done. The purpose of meshing is converting the whole geometry into small number of elements. The total numbers of elements are 954 and total numbers of nodes are 845. The boundary conditions applied are, torque 3.1912 Nm and rotational speed is 1440 rpm and Gerber stress theory is used in analysis. In processing it solves the problem with given boundary conditions. The post processing gives the results such as fatigue life, damage and safety factor of the impeller.

The results fatigue analysis is presented in Fig 3 to Fig.5.

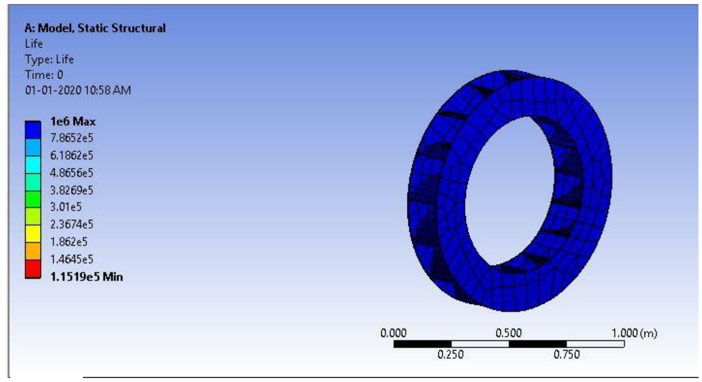

Fig. 3. *Life of impeller*

Fig. 3 shows the fatigue life contour of the impeller of fan. From the above contour plot it is observed that the minimum life of impeller is 1.1519×10^5 cycles. As life of impeller is below 10^6 cycles, the similar triangle principle with finite life fatigue approach is used to estimate the life of impeller.

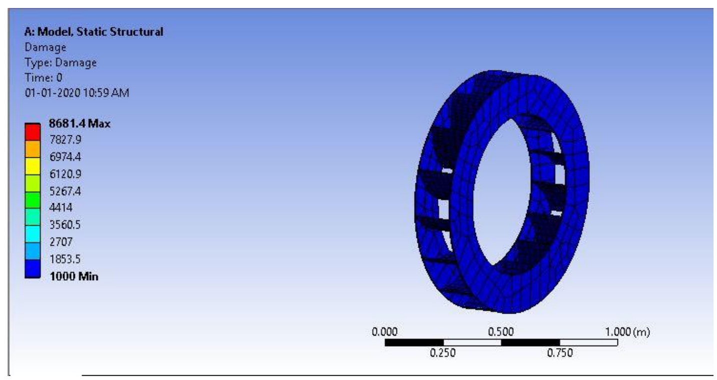

Fig. 4. *Damage of impeller*

Fig. 4 shows damage contour plot for a given design life cycles of 10^6. Damage is the ratio of designed life to the minimum life of component. The maximum damage is 8681.4 is for 10^6 cycles.

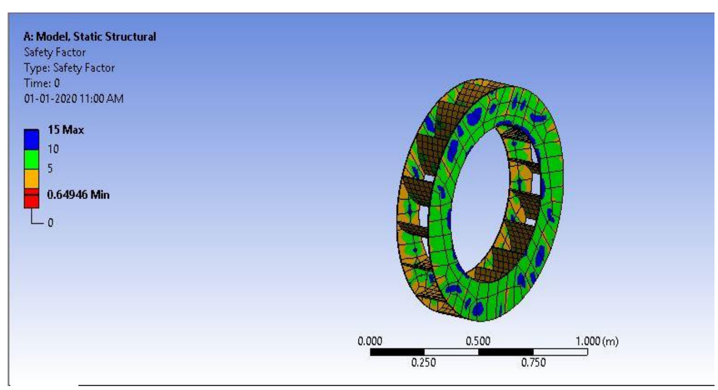

Fig. 5. Safety factor of impeller

Fig. 5 shows safety factor contour plot for a given design life cycles of 10^6. The maximum fatigue safety factor is 15 and minimum is 0.64946. For fatigue safety factor values less than one indicates the failure before design life is reached.

3 CONCLUSION

This paper represents the modal and fatigue analysis of centrifugal fan impeller. For modeling and analysis of an impeller SolidWorks and ANSYS software's are used respectively. From modal analysis the frequency and deformation of impeller corresponding to tenth mode is 166.1 Hz and 6.2262 mm. These results are quite in safe region. Further fatigue analysis of impeller is carried out. It is observed that, the life of impeller is 1.1519×10^5 cycles and maximum damage corresponding to 10^6 cycles is 8681.4.

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