Design and Analysis of Axial Fan Rotor Parts

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Abstract – An axial fan is a type of a compressor that increases the pressure of the air, flowing through it. The blades of the axial flow fans, force air to move parallel to the shaft about which the blades rotate. Aim of the present work is to design parts of axial fan rotor and to determine stresses acting in various section of blade, blade shaft of axial fan rotor by static analysis. Stresses obtained through finite element analysis are compared with the analytical calculation performed in the handbook for the size of fan blade assembly. The values of both the analytical and finite element method are approximately the same; another objective is to determine Stresses acting at various section of the aerofoil blade. Thereby, performing a modal analysis and to determine the Blade shaft assembly natural frequency modes from the finite element method. Then natural frequency modes are to be compared with the excitation frequency at 1x.2x and 16x (blade pass frequency). Design safe is checked based on the obtained results.

I. INTRODUCTION

An **axial fan** is a type of a compressor that increases the pressure of the air flowing through it. The blades of the **axial flow** fans force air to move parallel to the shaft about which the blades rotate. In other words, the flow is axially in and axially out, linearly, hence their name. The design priorities in an axial fan revolve around the design of the propeller that creates the pressure difference and hence the suction force that retains the flow across the fan. The main components that need to be studied in the designing of the propeller include the number of blades and the design of each blade. Their applications include propellers in aircraft, helicopters, hovercrafts, ships and hydrofoils. They are also used in wind tunnels and cooling towers. If the propeller is exercising propulsion, then efficiency is the only parameter of interest and other parameters like power required and flow rate are considered of no interest. In case the propeller is used as a fan, the parameters of interest include power, flow rate, pressure rise and efficiency. An axial fan consists of much fewer blades i.e., two to six, as compared to ducted fans. Axial fans operate at high specific speed i.e., high flow rate and low head and hence adding more blades will restrict the high flow rate required for its operation. Due to fewer blades, they are unable to impose their geometry on the flow, making the rotor geometry and the inlet and outlet velocity triangles meaningless. Also, the blades are made very long with varying blade sections along the radius.

A. *Parameters Of Fans*

The various parameters of fans are as follows

- Volume
- Differential pressure
- Temperature
- Density of the medium handled

B. *Fan Law*

- Flow α N.D3
- Pressure α N2.D2
- Power α N3.D5

Where,

N – Speed of fan

D – Diameter of fan

C. *Fields Of Application*

Axial-flow fans in thermal power stations are used as fresh-air (forced-draft), induced draft and pulverize air Fans (primary air Fans); in recent years they have also become more widespread in a flue-gas de- sulphurizing (FGD). Their use is not contingent on the fuel type employed (coal, oil, gas, peat), although fuel type is naturally a design determinant, specifically with induced draft units. Regarding the installation of Fans downstream of electrostatic precipitators, today's flue gas desulphurizing plants support various circuit configurations and hence, different arrangement of induced draft and FGD Fans. In recent years, axial fans operating as "booster fans" on the wet-gas side downstream of the scrubber have gained particular importance. With these units, the choice of material, surface protection considerations and sealing towards then conveyed-medium circuit require particular attention.

D. *Objective Of The Product*

- To study the stresses acting on various sections of blade and blade shaft

- To study the structural behavior of aero foil blade and blade shaft at a rotational speed of 1000 RPM.

- Modal analysis of Blade.

II. PRINCIPLE OF AEROFOIL BLADE

Axial fan Impellers with Aero foil blades provide uniform, high volume airflow with low power consumption for optimum efficiency using the same aerodynamics that create flight. Airfoil impellers have a round leading & trailing edge, and profile cross section, that looks similar to a teardrop. As air approaches the blade's leading edge, the stream splits and travels above and below the blade. Air is deflected across the convex curve along the top of the blade and along the concave curve on the bottom of the blade, and flows downward over the trailing edge as it leaves the blade.According to Bernoulli's Principle, the faster moving air across the top of the blade creates less pressure than the slower moving air on the bottom of the blade.

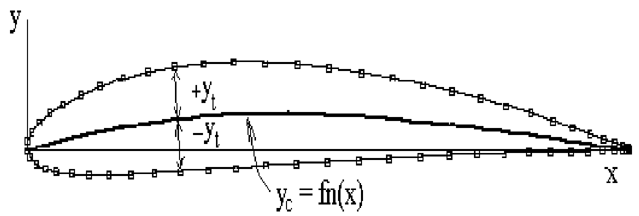


Figure 1 Aerofoil

This creates lift in an airplane wing or airflow in an impeller. Aero foil impellers function just like a series of small airplane wings attached to a hub, with one notable exception. In axial fans, the airfoil's twisted design ensures that the incident angle between the airfoil and the airflow is constant along the blade length, giving a uniform blade loading for high efficiency, low noise fans.

A. *Project Methodology*

1. Identification of suitable blade and blade shaft assembly
2. 3D modeling of Blade
3. Extraction of coordinates of aero foil profile
4. Importing coordinates in ANSYS
5. Complete modeling, meshing and trial run of blade
6. Blade shaft modeling, meshing and trial run in ANSYS
7. Assembly of blade and blade shaft in ANSYS
8. Application of boundary conditions
9. Static analysis and post processing
10. Result evaluation and conclusion

III. MODELLING

A. *Modeling Of Fan Blade.*

Fan blade is created by 12 profiles of spline curves using the keypoints as per the give calculations

Figure 2 Fan Blade

B. *Modeling Of Blade Shaft*

The given design of blade shaft has been first sketched in NX software using sketch option and revolve command has been used to model the blade shaft. Fillets and chamfers were made at the required positions and at the center a hole has been made as per the diagram

Figure 3 Modeling of Blade Shaft

C. *Modeling Of Impeller Hub*

using the 'sketch' option in the NX software and revolved about an axis such that whole impeller hub has been modelled. The required holes and bushes are made and they are patterned to 16 numbers at an angle of 22.5 degrees.

Figure 4 Modeling of Impeller Hub

D. Final Assembly Of Axial Fan Rotor

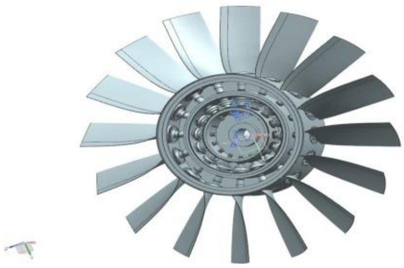


Figure 5 Final Assembly of Axial Fan Rotor

The modelled blade has been made to assemble to the impeller hub using 'touch align' and 'Centre axis' align options. The same previous procedure was carried out for patterning the blades. The blade is positioned at an angle of 52.1 degrees on the hub as per the given design.

IV. DESIGN AND ANALYSIS

A. FAN BLADE

Key points for each spline were found from NX model and 12 spline curves were imported in ANSYS software using 'Read input from' option.Then Lines were created using key points and curves and splines were created using key points. Areas were created by selecting the required splines, lines and curves. From the areas created the volume has been made by selecting the areas in sequential order. The total number of volume created are 21. Fan blade were sized as a uniform elements which is the first step for meshing. Moderate number of elements were created such that moderate meshing could be obtained. Whole splines were sized by uniform numbers and lines and arcs were also uniformly sized.

Figure 6 Meshing of Fan Blade

As per the elements created meshing of blade were done. A moderate and uniform meshing were created as per the requirement.

B. Blade Shaft

Figure 7 Blade Shaft

Blade shaft modelling process is similar to a modelling of fan blade. Lines were created by join the nodes and areas have been developed using the lines. Volume of shaft have been created using the areas and the volume is being made to create mesh. Blade shaft were sized as a uniform elements which is the first step for meshing. Moderate number of elements were created such that moderate meshing could be obtained. As per the elements created meshing of the blade shaft was done. A moderate and uniform meshing was created as per the requirement. After meshing had done the shaft has been rotated to get the solid part and six holes in the shaft were marked as per the requirement given in the design.

C. Assembly Of Blade And Blade Shaf

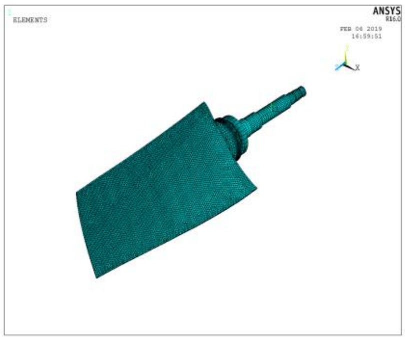


Figure 8 Assembly

V. STATIC ANALYSIS

A. Boundary Conditions Applied To Test Run The Blade

Constraints applied to the blade boss to arrest all the degrees of freedom. Gravity applied along Z –direction

Real constants considered: (Aluminium)

Density 2.65 gm/cc

Young's modulus: 0.69 e+05 N/mm2

Poission's ratio: 0.3

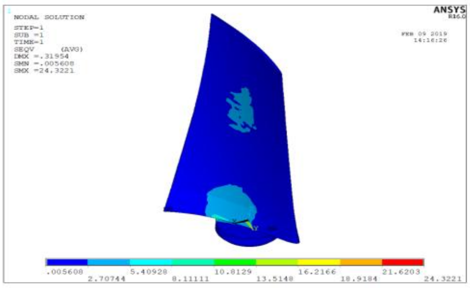


Figure 9 Blade Von Mises stress

B. Boundary Conditions Applied To Test Run The Blade Shaft

Constraints applied to the shaft edge to arrest all the degrees of freedom. Gravity applied along Z –direction.

Real constants considered: (Steel)

Density 7.85 gm/cc

Young's moduls: 2.1 e+05 N/mm2

Poission's ratio: 0.3

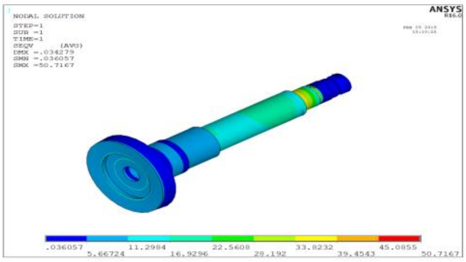


Figure 10 Shaft Von Mises Stress

C. Boundary Conditions Applied To Run The Blade Shaft Assembly

Constraints applied to the axial thrust bearing and radial bearing to arrest the degrees of freedom. Gravity applied along Z –direction. Balancing force at C.G (FBA)= 1495N (along y direction)

Torsional force at C.G (FTA)= 1272.28N (along –z direction).Reaction force at 281mm from blade edge= 1683.27N.

Real constants considered :

FOR MATERIAL 1 (BLADE)

Density 2.65 gm/cc

Young's moduls : 0.69 e+05 N/mm2

Poission's ratio : 0.3

FOR MATERIAL 2 (BLADE SHAFT)

Density 7.85 gm/cc

Young's moduls : 2.1 e+05 N/mm2

Poission's ratio : 0.3

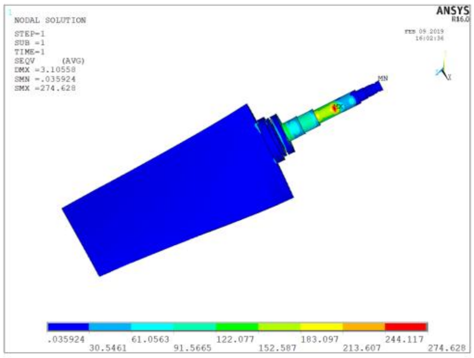


Figure 11 Assembly Von Misses Stress

D. Deformed Shape Of Blade-Shaft Assembly

The figure shows the original shape of blade and blade shaft assembly before applying boundary conditions and the deformed shape of blade and blade shaft assembly after applying the boundary conditions.

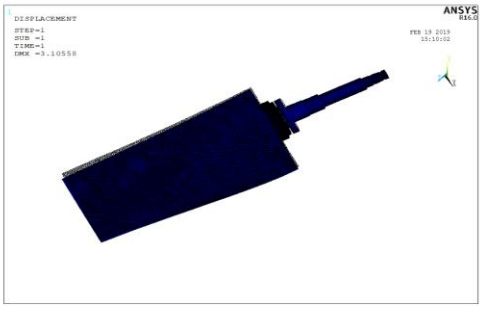


Figure 12 Deformed Assembly

VI. MODAL ANALYSIS

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The results can also be used to correlate with finite element analysis normal mode solutions. In structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. These periods of vibration are very important to note in earthquake engineering, as it is imperative that a building's natural frequency does not match the frequency of expected earthquakes in the region in which the building is to be constructed. . Engineers tend to learn from such examples (at least in the short term) and more modern suspension bridges take account of the potential influence of wind through the shape of the deck, which might be designed in aerodynamic terms to pull the deck down against the support of the structure rather than allow it to lift.

A. Mode1 At 60 Hz Frequency

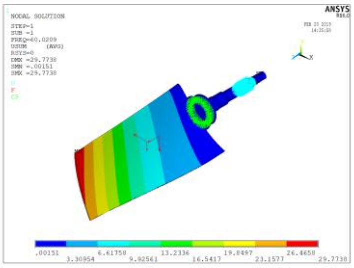


Figure 13 at Node 1

B. Mode 10 At 1025 Hz Frequency

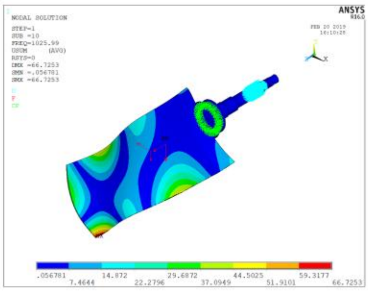


Figure 14 at Node 10

	Von Misses stress (N/mm^2)	
Section	**Handbook**	**ANSYS**
A-A	30.25	35.64
B-B	17.43	17.28
C-C	20.28	17.33
D-D	18.95	12.21
E-E	18.67	15.04
F-F	18.9	13.78
G-G	18.49	12.33
H-H	16.53	11.09
J-J	14.02	8.22
K-K	10.99	5.43
L-L	5.26	2.83

VII. RESULTS

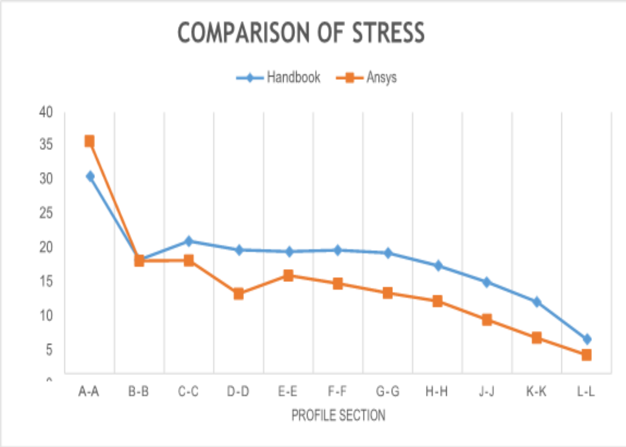
A. RESULTS FROM STATIC ANALYSIS

Table 1 von misses stress

From Static Analysis, Von Misses stress at blade and the shaft are found and they lie under the safe zone. Also the mass of blade is found as 10 kg and mass of blade shaft is found as 7 kg in ANSYS which is very near exact given Handbook values of BHEL. It is also found that stress concentration is maximum in Blade Shaft at the places where they are supported and are in contact with the impeller hub and blade.

- Stresses acting on the Blade and the blade shaft were determined using the Static analysis
- Stresses obtained through Finite element method is compared with the Analytical calculation performed in the handbook for this size of Fan blade assembly. The values of both the analytical and finite element method are approximately the same.
- Stress across the section of the aero foil blade decreases from the section AA to MM.
- Stress variation across each section of the Aero foil Blade were determined.
- In case of Blade, Stress is more at the section AA (blade root), which is about 30 N/mm2 approximately
- Maximum Stress across the blade shaft is about 270 N/mm2 with the factor of safety 2.0.
- The maximum displacement of the Blade shaft assembly is 3 mm and it is located at the section MM (blade tip) of the Blade.

B. Comparison Of Stress



Von Mises stress Graph

The above graph shows the comparative results of Von Mises stress as given by BHEL handbook and ANSYS results at the blade

C. Results From Modal Analysis

Table 2: Mass participation

SI.NO	freq(HZ)	Mass participation(kg)		
		X	Y	Z
1	60	4.42	1.81	0.00
2	76	2.62	6.20	0.00
3	121	0.07	0.03	0.00
4	169	3.64	1.06	0.00
5	324	0.21	0.68	0.01
6	393	0.49	0.93	0.00
7	541	2.05	3.28	0.00
8	646	0.78	0.00	0.01
9	721	0.40	0.17	0.03
10	1026	0.09	0.07	0.03

Table 3 Excitation Frequency Vs Natural Frequency

Excitation frequency		Margin over natural frequency
1X	17	252 %
2X	33	81 %
16X (blade pass)	267	21 %

- Blade shaft Assembly Natural frequency modes were determined from the Finite Element Method.
- The Natural frequency modes were compared with the Excitation Frequency at 1x, 2x and 16x (Blade pass frequency) and they are found to be safe with the good margin as shown in the Table

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