International Journal for Ignited Minds (IJIMIINDS)

Design and Material Optimization of Axial Flow Fans

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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. In this thesis, axial flow fan with 10 blades, 9 and 11 blades are designed using theoretical calculations. Unigraphics is used for 3D modeling of the fans. Static, dynamic and CFD analysis is done on the 3 models using the materials steel, S2 Glass Epoxy and Kevlar.

Keywords - *Axial flow fan, unigraphics, ansys, CFD.*

1. INTRODUCTION

The axial flow fans are widely used for providing the required airflow for heat & mass transfer operations in various industrial equipment and processes. These include cooling towers for air-conditioning & ventilation, humidifiers in textile mills, air heat exchangers for various chemical processes, ventilation & exhaust as in mining industry etc. All the major industries of the national economy such as power generation, petroleum refining & petrochemicals, cement, chemicals & pharmaceuticals, fertilizer production, mining activities, textile mills, hotels etc. use large number of axial flow fans for the aforesaid operations.

The axial flow fans are conventionally designed with impellers made of aluminum or mild steel. The grey area today is the inconsistency in proper aero-foil selection & dimensional stability of the metallic impellers. This leads to high power consumption & high noise levels with lesser efficiency

The leading fan manufacturers in the world have been looking at FRP axial flow fans for higher energy efficiency. The improved design of FRP fan is aimed at higher lift to drag ratio and thereby increasing the overall efficiency. The new & improved aerodynamic fan designing, composite development, structural design combined with latest manufacturing process are also expected to result in consistent quality and higher productivity.

Theoretical Calculations

1) Nb = 10 blade Formulas

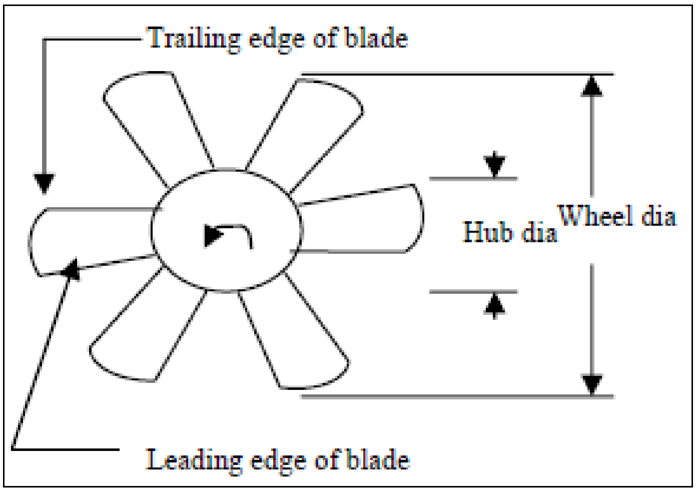

Fig 1: Baisc Dimesion Parameter.

Fan diameter (Df) = 600mm

Fan radius (rf) = 300mm
Hub diameter (Dh) = 150mm
Hub radius (rh) =75mm
Tip radius (rt) = 120mm

2) Hub radius/tip radius (or) hub and tip ratio r = $\frac{rh}{rt}$

3) Number of blades (nb) = $\frac{6r}{(1-r)}$

4) Blades spacing (xp) = $\frac{2*\pi*R}{n*b}$ or $\frac{\pi*R}{3*r}(1-r)$ where R= fan radius

5) Blades width = L ≤ $\frac{3.4*d}{n*b}$

6) Blades length = $\left(\frac{D_{fan}-D_{hub}}{2}\right)$

7) Tip speed (ft/min) = D*S*π

8) Tip clearance = $\frac{\text{Fan diameter}}{100}$

9) Blade passing frequency Fb

10) Number of Blades Effect on Fan Noise

Number of blades varies from 9 to 30,

% flow change = $\left(\frac{N_2-N_1}{N_1+222}\right)*100$

Where,

N1 = New Number of Blades, N2 = Original Number of Blades

11) Fan efficiency = $\left(\frac{\text{total pressure rise+vol}}{\text{Shaft power}}\right)$

12) Axial velocity, V_a = $\frac{Q}{\frac{\pi}{4}*(D_{fan}^2-D_{hub}^2)}$

2. GEOMETRY MODELING

This chapter discusses the geometric creation and computer aided modeling of the model for 9, 10 &11 blades.

2.1 Geometry Details

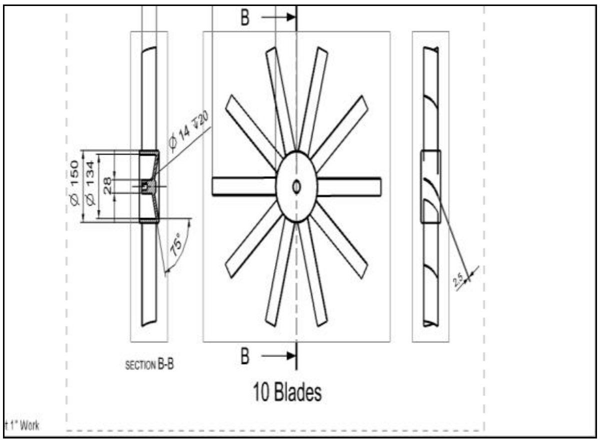

Fig 2: 2D Drafting of 10 Blades

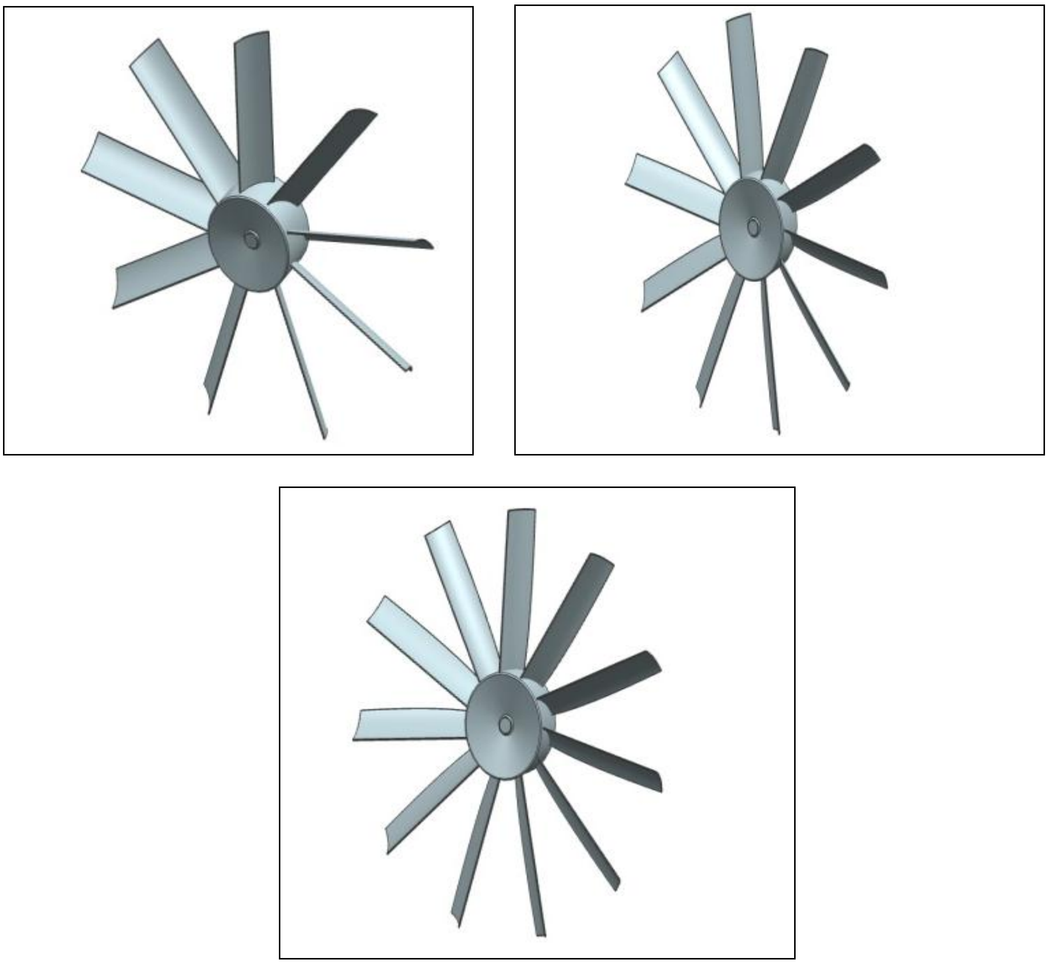

Fig 3: Geometry of Blade with 9, 10 & 11 Blades.

3. RESULTS AND DISCUSSION

CFD, Structural and Dynamic analysis is conducted for all the three blades and conclusions are drawn from. This section discusses about the FE Analysis of the blade.

3.1 CFD Analysis

CFD meshing is carried using the hybrid tet and prism elements and static flow condition is used in the analysis. Below fig 4& 5 shows, the pressure, Velocity and Temperature plots for geometry with 9 Blades. Similar study can be made for remaining model (i.e. 10 & 11 blade model).

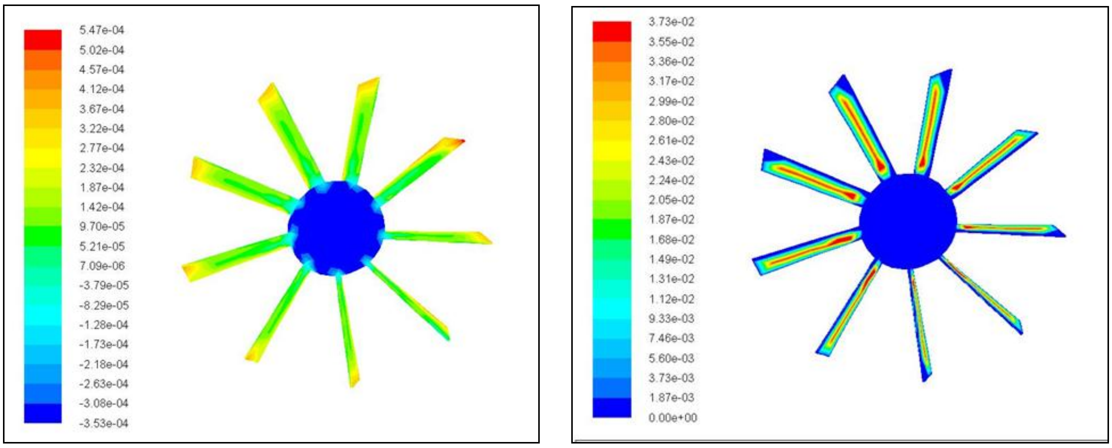

Fig 4: Pressure and velocity Plots obtained from CFD analysis.

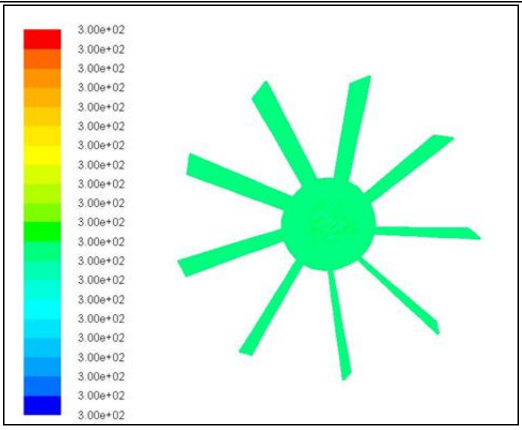

Fig 5: Temperature obtained from CFD analysis.

Below table 1, shows the pressure and velocity variation for geometry with 9, 10 & 11blades.

	9 Blades	10 Blades	11 Blades
Pressure (Pa)	5.47e-04	4.56e-04	2.41e-02
Velocity (m/s)	3.73e-02	3.79e-02	7.93e-02
Temperature (K)	3.00e+02	3.00e+02	3.00e+02

Table 1: Flow parameter for 9, 10 & 11 Blades Geometry.

3.2 Static Structural Analysis

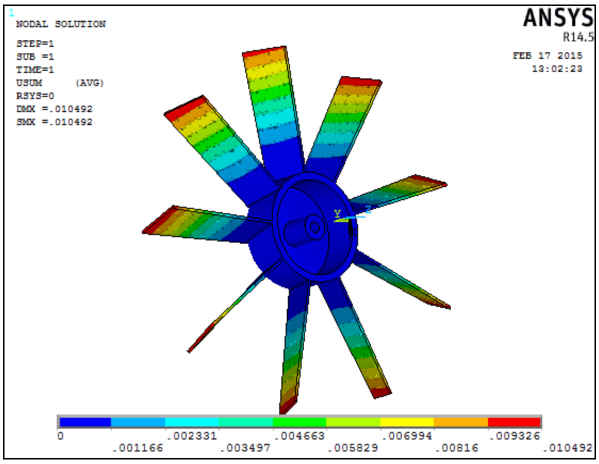

Fig 6: Displacement plots for 9 blade model.

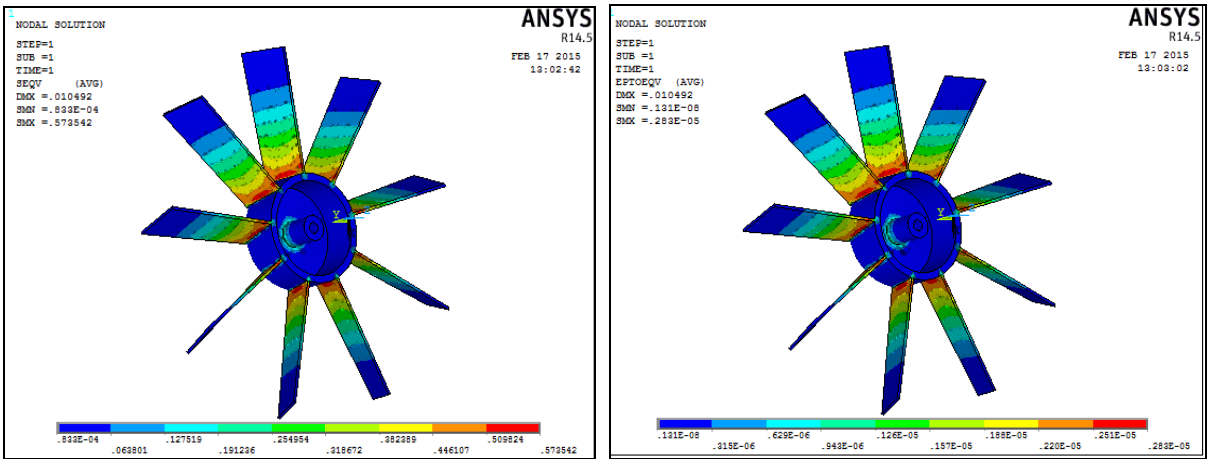

Fig 7: von-Mises Stress and Strain Plots for 9 blade model.

From the above fig 7, it can be noticed the induced stresses are well below the allowable stresses of the given material.

	Material	9 blades	10 blades	11 blades
Displacement (mm)	Stainless Steel	0.010492	0.009981	0.009968
	S2 Glass	0.024909	0.02392	0.022897
	Kevlar	0.079252	0.075747	0.075678
Stress (N/mm^2)	Stainless Steel	0.573542	0.608704	0.5625
	S2 Glass	0.56625	0.616756	0.568041
	Kevlar	0.576926	0.624522	0.586661
Stain	Stainless Steel	2.83E-06	3.00E-06	2.79E-06
	S2 Glass	6.55E-06	7.10E-06	6.54E-06
	Kevlar	2.10E-05	2.31E-05	2.18E-05

Table 2: Structural Analysis Details for 9, 10 & 11 Blades Geometry.

3.3 Dynamic Analysis

Structural and dynamic analysis is carried for the models; initially model is meshed with good quality of second order tetra elements and boundary conditions are applied and solved using the PCG solver to get the high accuracy results

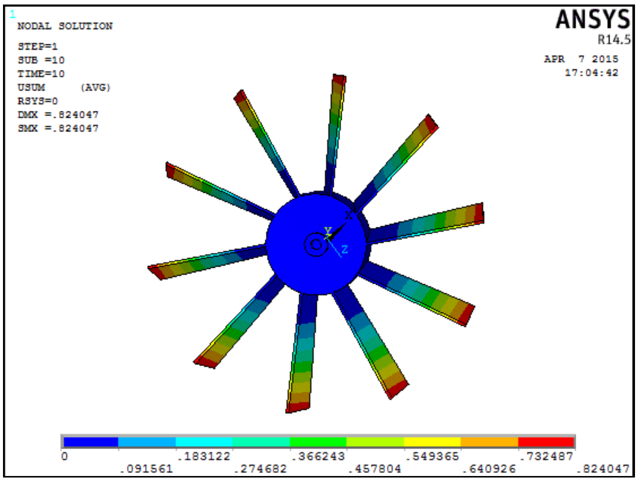

Fig 8: Displacement plots for 10 blade model.

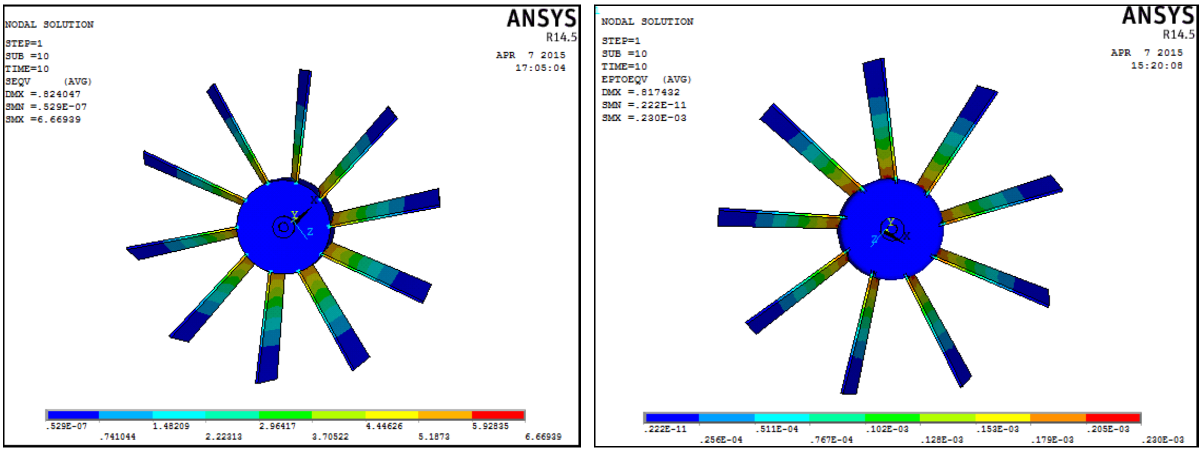

Fig 9: von-Mises Stress and Strain Plots for 10 blade model.

From the above fig 9, it can be noticed the induced stresses are well below the allowable stresses of the given material under the dynamic loading conditions.

	Material	Displacement (mm)	Stress (N/mm^2)	Strain
Set 1	Stainless Steel	0.107587	6.02475	0.297 e-4
	S2 Glass	0.2533571	6.5421	7.53E-05
	Kevlar	0.81743	6.3496	0.23 e-3
Set 2	Stainless Steel	0.222578	12.3782	0.61 e-4
	S2 Glass	0.496788	12.8483	1.48E-04
	Kevlar	1.52878	11.9624	0.433 e-3
Set 3	Stainless Steel	0.418877	23.4331	0.115 e-3
	S2 Glass	0.977312	25.3215	2.92E-04
	Kevlar	3.07369	24.037	0.871 e-3

Table 3: Dynamic Analysis Details for 9 Blades Geometry.

	Material	Displacement (mm)	Stress (N/mm^2)	Strain
Set 1	Stainless Steel	0.107467	6.50114	0.32 e-4
	S2 Glass	0.254846	6.52266	7.51E-05
	Kevlar	0.824047	6.66939	0.242 e-3
Set 2	Stainless Steel	0.206896	12.567	0.619 e-4
	S2 Glass	0.499145	12.8046	1.47E-04
	Kevlar	1.54007	12.5565	0.455 e-3
Set 3	Stainless Steel	0.408082	24.8248	1.22E-04
	S2 Glass	0.98193	25.2349	2.90E-04
	Kevlar	3.09855	25.2478	0.001194

Table 4: Dynamic Analysis Details for 10 Blades Geometry.

	Material	Displacement (mm)	Stress (N/mm^2)	Strain
Set 1	Stainless Steel	0.107336	6.06275	0.299 e-4
	S2 Glass	0.2546	6.07915	0.7 e-4
	Kevlar	0.82334	6.23227	0.226 e-3
Set 2	Stainless Steel	0.206663	11.7185	0.577 e-4
	S2 Glass	0.4987	11.9356	0.137 e-3
	Kevlar	1.53886	11.7367	0.425 e-3
Set 3	Stainless Steel	0.407611	23.1454	0.114 e-3
	S2 Glass	0.98107	23.5233	0.271 e-3
	Kevlar	3.0959	23.5955	1.11E-03

Table 5: Dynamic Analysis Details for 11 Blades Geometry.

The above table 3, 4 & 5, shows the stress, Strain and Displacement induced in the model for all the materials. From the same table it can also noticed that the stress limits are well below the limits.

4. CONCLUSION

In this thesis, an axial flow fan is to be designed and modeled in 3D modeling software called UG. Present available model has 10 no of blades; designed is made for 9 and 11 blades. Material optimization is also carried for all the three blades and the conventional material used for the blade is steel and the study is made for composite materials like S2 Glass Epoxy and Kevlar.

Due to the use of composite materials, the strength to weight ratio increases which is an advantageous than using metallic blades. Static, dynamic and CFD analysis is done on the blades using FEA software Ansys.

By observing the static analysis results, the stress values are less than the respective yield stress values of composite materials, using S2 Glass epoxy and Kevlar yields better results. By observing the dynamic results, the stress values are increasing as compared with that of static results, but the values are within the limits.

By comparing the results for 9, 10 and 11 blades, the stress values for 9 blades are within the limit. So replacing fan with 9 blades instead of 10 blades is better as the weight also decreases.

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