

Wind Mill Shaft Design and Optimization Using Composite Materials

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ABSTRACT:This contribution deals with the possibility of simulation of complex parts made from polymer-composites with CAD/CAM/CAE software. First part of contribution is aimed on describing the basis of fiber composites and its behavior under load. Main reason of choosing carbon fibers as material for innovative parts depends on low density and high tensile strength. Thus carbon fiber composites are frequently used at automotive and sporting goods production, parts from these industries were selected. Along with this work design of Shaft is done for said application. Second part of work will lead to different studies performed in Simulations and describes the stress and weight comparisons made from Steel, Carbon fiber/Glass Fiber composites. The optimization for weight and strength of the shaft based on Fiber orientations and thickness of fiber's will be done.

KEYWORDS: FEA, MODAL FEA , NATURAL FREQUENCY, FORCE COMING ON SHAFT ETC.

I. INTRODUCTION

A windmill is a mill that converts the energy of wind into rotational energy by means of vanes called sails or blades. Centuries ago, windmills usually were used to mill grain, pump water, or both. Thus they often were gristmills, wind pumps, or both. The majority of modern windmills take the form of wind turbines used to generate electricity, or wind pumps used to pump water, either for land drainage or to extract groundwater.

II. ESIGN OF SHAFT VALUES

Power = 2000 kW
Rotor assembly Weight = 215746.30 N
 $S_{yt} = 450 \text{ N/mm}^2$
Blade & Hub weight = 22000 kg
Tower Weight = 125 to 150 tonnes
Rotor Diameter = 88 m (288 feet)
Shaft Material as,

Rotor Speed: 16 rpm
Shaft Material as: 25 CrMo4
 $S_{ut} = 700 \text{ N/mm}^2$
Nacelle & generator weight = 52000 kg
 $D_i = 250 \text{ mm}$ $D_o = 418 \text{ mm}$

Wind speed = 12 m/s
Tower Height = 80 m (260 feet)
Torque = $1193.66 \times 10^6 \text{ N-mm}$

Sr.No.	Material	S_{yt}	S_{ut}
1	Steel (25CrMo4)	450 N/mm ²	700 N/mm ²
2	Carbon epoxy	670 N/mm ²	825 N/mm ²

Table Material tensile strength value

III.FINITE ELEMENT ANALYSIS OF SHAFT

3.1 Analysis of existing Shaft

Structural steel/Alloy steel is used as existing materials. By using the existing material the analysis is performed in ANSYS.

3.1.1 Static Structural Analysis

A static analysis calculates the effect of steady loading condition on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however, include steady inertia load (such as gravity and rotational).

Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

3.1.2 Modal Analysis of shaft for finding Natural Frequencies

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It also serves as a starting point for another, more detailed analysis, such as a transient dynamic analysis a harmonic response analysis, or a spectrum analysis. Modal analysis also used to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameter in the design of a structure for dynamic loading condition.

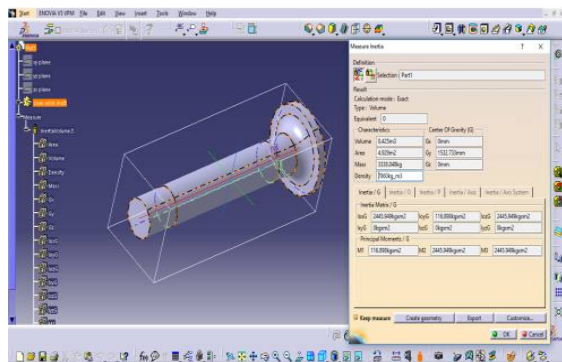


Fig Weight of solid shaft

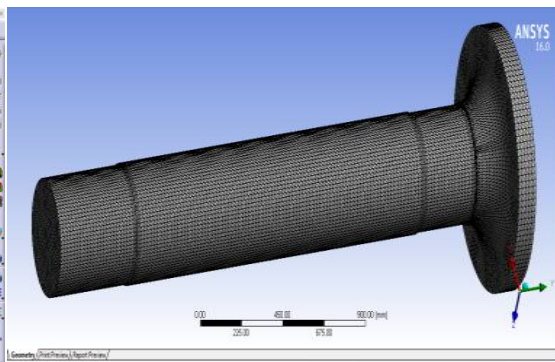


Fig Meshing of wind mill shaft

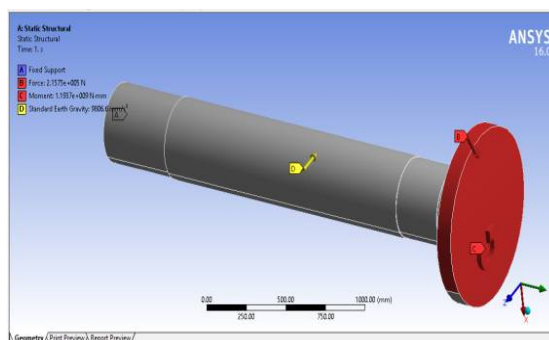


Fig Combine Boundary condition

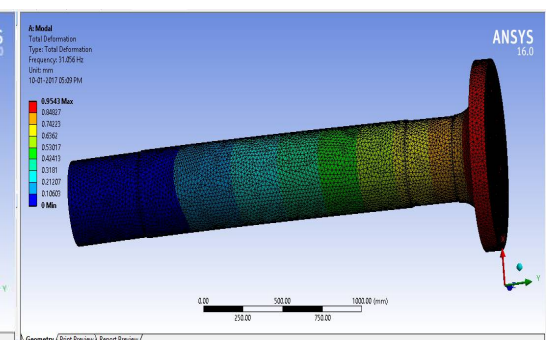


Fig Modal analysis of Steel Solid shaft ($d_o = 418$)

3.2 Optimization Analysis for Shaft at Different Thicknesses (Hollow) with Carbon Epoxy fiber

Solid shaft is over safe and further can be considering for Hollow shape (for weight reduction). For the same, dimension of hollow shaft is to be determined. Considering various thicknesses and further Analysis of the same Starting from $d_i/d_o = 0.6$, So $d_o = 418$ mm, hence $d_i = 250$ mm

3.2.1 Property of materials

Material	25CRMO4 Steel	carbon Fiber/Epoxy fibers
Young's Modulus 'E'	210×10^3 MPa	70 Gpa
Poisson's ratio	0.3	0.3
Density	7860 kg/m^3	1600 kg/m^3
yield tensile strength,	450 MPa	670 MPa
Ultimate tensile strength	700 MPa	825 MPa

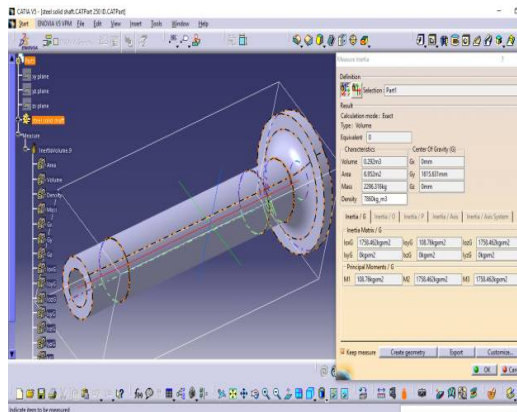


Fig Weight of shaft (ID 250 mm)

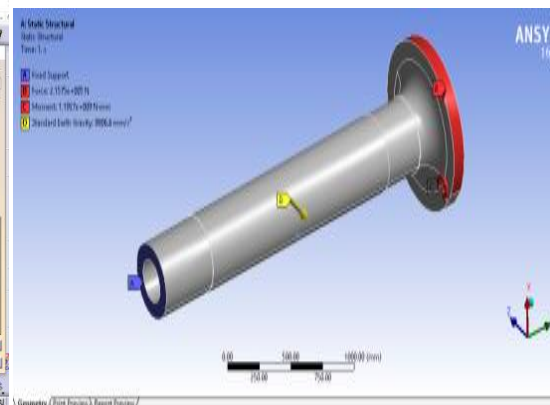


Fig Combined boundary condition

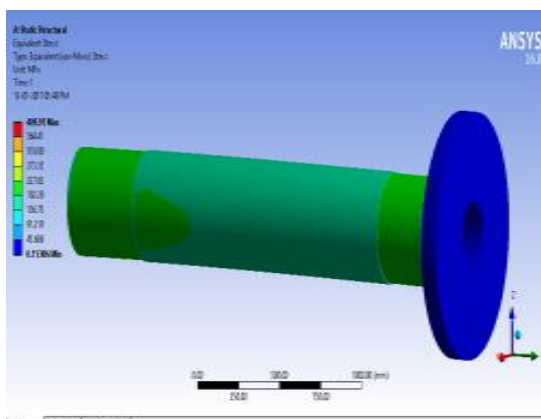


Fig 1st Mode Shape result of Steel hollow shaft

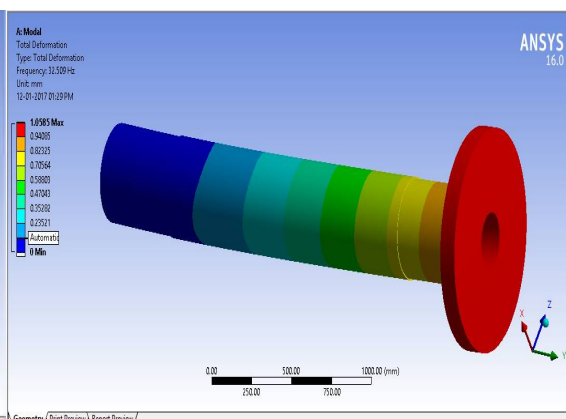


Fig Stress in Shaft (ID=250 mm)

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3.2.2 Modal analysis of Epoxy hollow shaft

After finalising the suitable thickness modal analysis are done and frequency tabulated in following table

From the static structural analysis of hollow shaft with the carbon fiber/epoxy fiber as a material, it is found out that the ID = 250 mm shows better result, because stress are within limit as compared to allowable stress for the carbon fiber/Epoxy fiber. Carbon fiber/Epoxy fiber has low density and high strength. Selected diameter shows good result as compared to other diameter also the deformation is considerable limit i.e. 13.66 %

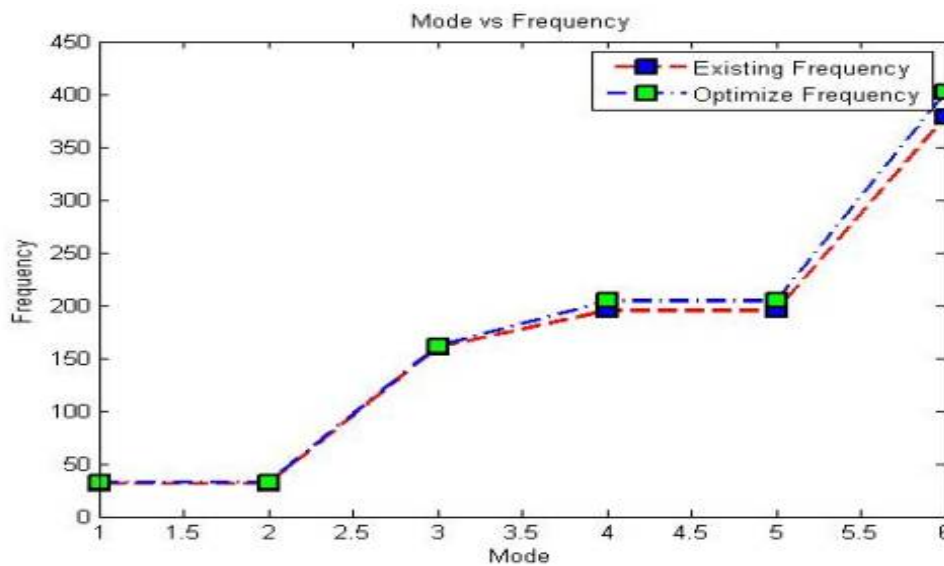
Weight of the shaft is to be reducing up to 31.20 % so overall cost is to be minimized.

Trial	ID, mm	Thickness, mm	Stress, MPa	Deformation, mm	Weight, kg
0	Solid	--	244.17	11.139	3338.048
1	230	94	374.75	12.363	2456.32
2	240	89	385.56	12.611	2377.988
3	250	84	409.95	12.903	2296.316
4	260	79	425.49	13.251	2211.31
5	270	74	470.45	13.662	2122.97

Table Result for Modal Analysis (Existing and Optimized)

Mode	Frequency [Hz] Existing Shaft	Frequency [Hz] Optimized Shaft
1.	31.056	32.50
2.	31.057	32.51
3.	160.49	161.60
4.	195.12	204.16
5.	195.13	204.17
6.	378.85	401.4

Table Result Frequency (Existing and Optimized)



From results of normal mode analysis, it is seen that the natural frequency of existing design is 31.056 Hz and proposed design is 32.50 Hz. So there is rise in natural frequency of proposed design. Further the second and onwards the frequencies of proposed design are increased compared to existing design. So overall the dynamic performance of the Shaft is being improved.

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3.2.3 Result Comparison For Existing And Optimized Shaft

Parameters	Existing	Optimized
Material	Steel- 25CrMo4 (Solid)	CarbenFiber/Epoxy fiber (Hollow- ID – 250mm)
Weight	3338.048 kg	2296.316 kg
% Change in Weight	Hollow Shaft is 31.20 % lighter than Steel	
Stress	244.17 MPa	409.95 MPa
% Change in Stress	Hollow Shaft has 40.44 % more Stress than Steel but its within allowable limit	
Deformation	11.14 mm	12.903 mm
% Change in Deformation	Hollow shaft has 13.66 % More deformation than Steel but it's not big issue	

Table:- Result comparison for existing and optimized shaft

IV. CONCLUSION

4.1 Conclusion

- It has been observed that all the stresses were within the allowable limit.
- Shaft with hollow ID- 250 mm shows safe results.
- Hollow shaft at 250 mm ID shows very less weight (31.20 %) compare to solid and hence finally suggested for shaft improvement for weight reduction application.
- Hollow shaft at 250 mm ID shows high Stress (40.44 %) and deformation (13.66 %) values compare to steel-25CrMo4 but those are within limit while considering.

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