DESIGN AND MODAL ANALYSIS OF SAVONIUS TYPE VERTICAL AXIS WIND TURBINE BLADE MADE OF STEEL, ALUMINUM AND GFRP

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ABSTRACT

Wind Turbine is used to generating electric power. This paper studies modal analysis of savonius type vertical axis wind turbine systems with different materials. The efficiency of the wind turbine depends on the material, shape, angle of the blade and wind velocity. So material plays important role in the design of wind turbine. In this paper, Stainless Steel, aluminum and Glass Fiber Reinforced Polymer (GFRP) materials have been used to design wind blades of 1000 mm height and 500 mm chord length with 4 different arc radius.

For this purpose, modeling software Solid Works is used to design wind blades of three different materials and modal analysis of the same blades were done by using ANSYS WORKBENCH software. Modal analysis is used to determine the natural frequency and mode shape of vibration of any structure. It is used to determine the response of structure for dynamic loading.

Key Words : VAWT, Savonius, Stainless Steel, Aluminum, GFRP, Modal Analysis, Ansys.

DESIGN CALCULATION

The power of the wind is proportional to air density, area of the segment of wind being considered and the wind speed. The relationships between the above variables are provided in equation below.

$$P_w = \frac{1}{2} \rho A V^3$$

where P_w = Power of the wind (W)

ρ = Air density = 1.23 kg/m^3

A = Area of a segment of the wind being considered (m^2)

= D x H = 1 x 1 = 1 m^2

D = Diameter of the turbine in meter

H = Height of the Turbine in meter

V = Wind speed in m/s

The angular velocity of a rotor is given by

$$\omega = \lambda . V / R$$

Where λ = Dimensionless factor called the tip speed ratio.

λ is a characteristic of each specific wind mill and for a savonius rotor λ is typically around unity

R = Radius of the rotor

The output of a rotating body is obtained from the product of torque and angular speed.

$$P = M * \omega$$

P = Output in N-m/s (1 N.m/s = 1W)

M = Torque in N-m

ω = Angular speed / s = $2 \pi n / 60$

n = Rotational speed in rpm = $(60 \omega) / 2\pi$

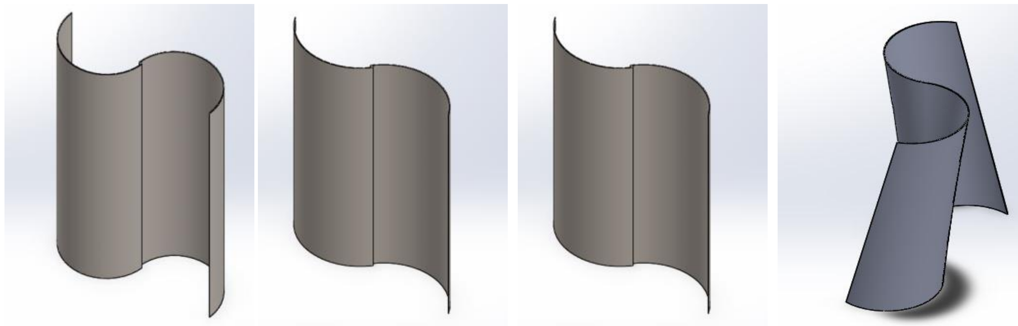
$$M = 60 P / 2 \pi n$$

According to Betz's law, the maximum power that is possible to extract from a rotor is

$$P_{max} = 16/27 * 1/2 * \rho * d * h * v^3$$

The power of wind depends on the swept area of wind turbine and velocity of wind.

DESIGN OF SAVONIUS BLADE WITH FOUR DIFFERENT SHAPES



R250 mm R300mm R350 mm Twisted blade

Fig.1 : Different shapes of Wind blades

Dimension : Height : 1000 mm, Rotor Diameter : 1000 mm, Thickness : 3 mm

Each Blade has same chord length of 500 mm with different arc radius.

MODAL ANALYSIS OF STAINLESS STEEL AND ALUMINUM WIND BLADE

All the four different shapes of Stainless Steel(SS), Aluminum(Al) and Glass Fiber Reinforced Polymer (GFRP) material blades are analyzed. The results are tabulated and compared with each other.

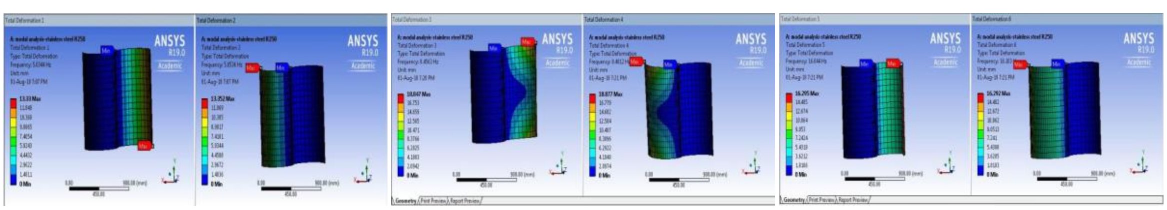


Fig.2 : Natural Frequency and Total Deformation for SS R250

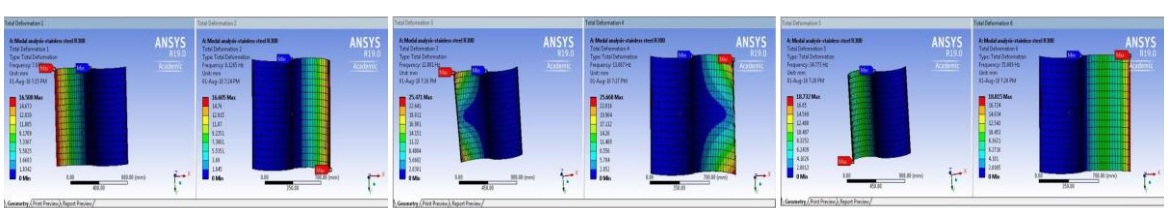


Fig.3 : Natural Frequency and Total Deformation for SS R300

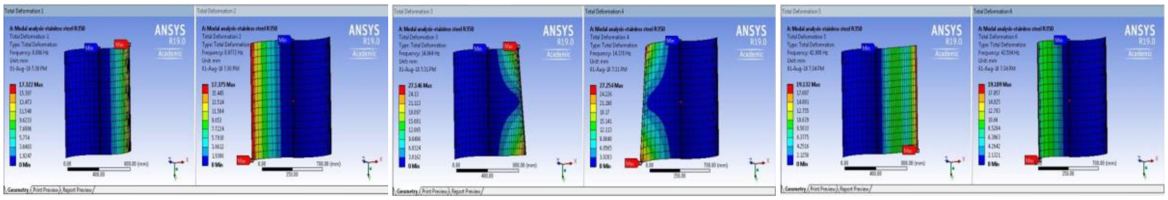


Fig.4 : Natural Frequency and Total Deformation for SS R350

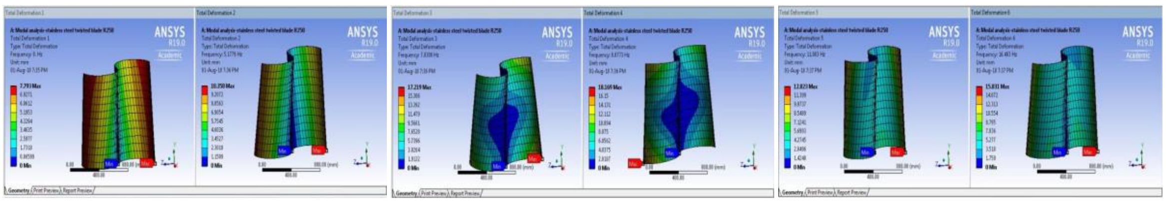


Fig.5 : Natural Frequency and Total Deformation for SS Twisted blade

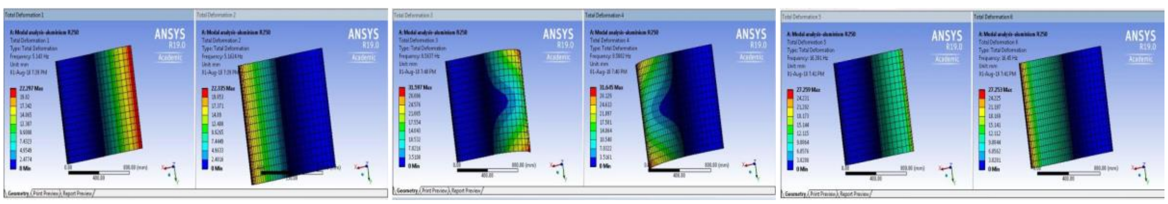


Fig.6 : Natural Frequency and Total Deformation for Al R250

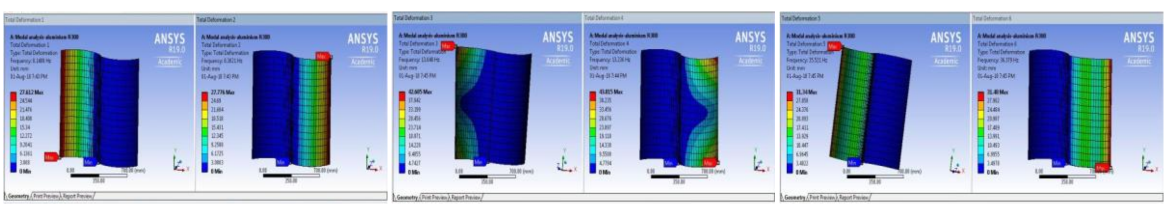


Fig.7 : Natural Frequency and Total Deformation for Al R300

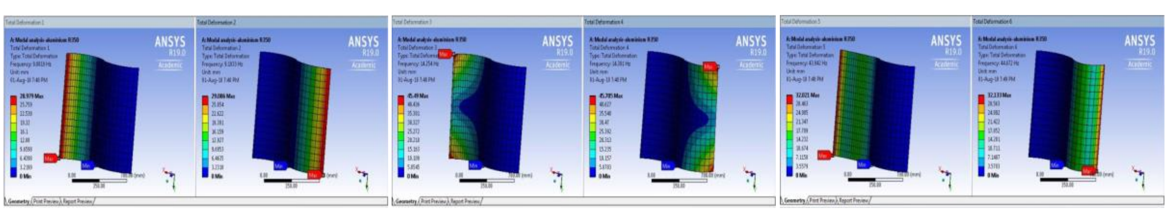


Fig.8 : Natural Frequency and Total Deformation for Al R350

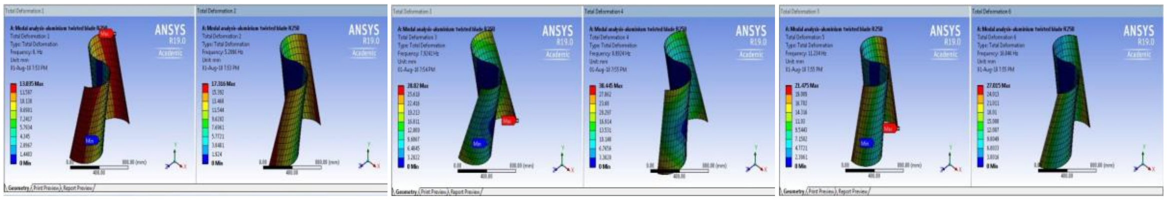


Fig.9: Natural Frequency and Total Deformation for Al Twisted blade

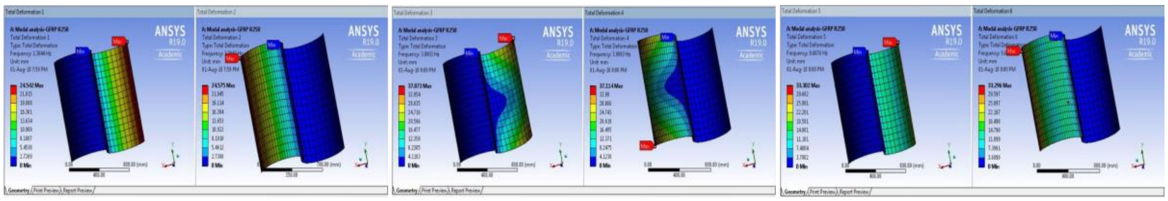


Fig.10 : Natural Frequency and Total Deformation for GFRP R250

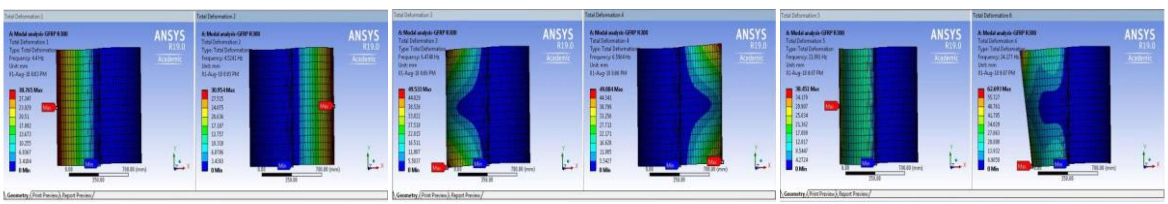


Fig.11 : Natural Frequency and Total Deformation for GFRP R300

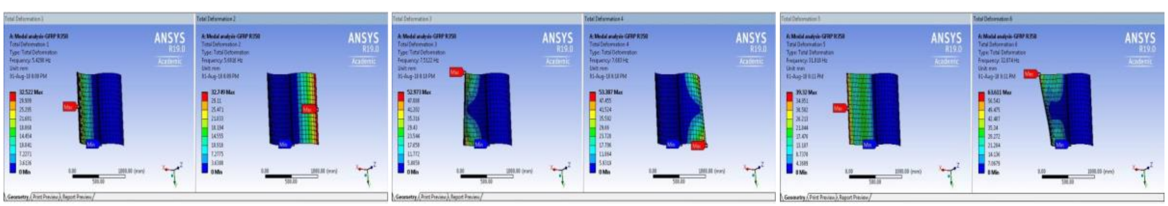


Fig.12 : Natural Frequency and Total Deformation for GFRP R350

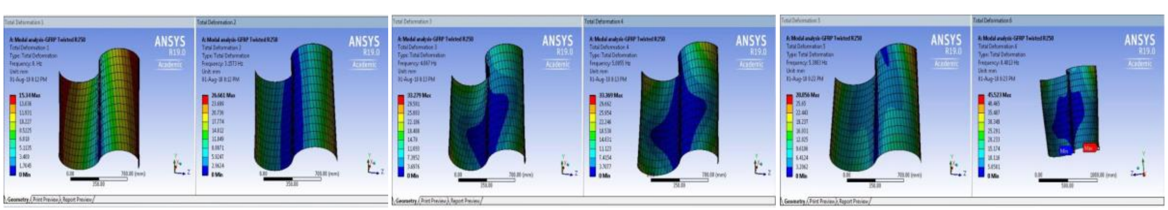


Fig.13 : Natural Frequency and Total Deformation for GFRP Twisted blade

RESULT AND DISCUSSION

Table 1 : POWER AND FORCING FREQUENCY FOR VARIOUS WIND SPEEDS

SL. NO	WIND SPEED (m/s)	ANGULAR SPEED (rad/sec)	ROTATIONAL SPEED (RPM)	FORCING FREQUECY OF ROTOR(Hz)= (RPM/60)	P_{max} (Watts)	Torque (N-M)
1	1	2	19	0.32	0.36	0.18
2	2	4	38	0.64	2.90	0.73
3	3	6	57	0.96	9.80	1.63
4	4	8	76	1.27	23.22	2.90
5	5	10	96	1.59	45.36	4.54
6	6	12	115	1.91	78.38	6.53
7	7	14	134	2.23	124.46	8.89
8	8	16	153	2.55	185.78	11.61
9	9	18	172	2.87	264.52	14.70
10	10	20	191	3.18	362.85	18.14
11	11	22	210	3.50	482.95	21.95
12	12	24	229	3.82	627.00	26.13
13	13	26	248	4.14	797.18	30.66
14	14	28	267	4.46	995.66	35.56
15	15	30	287	4.78	1224.62	40.82

NATURAL FREQUENCIES AND MODE SHAPES

Natural frequency is the frequency of the structure at which it tends to vibrate when it is disturbed. Mode shape is specific pattern of vibration of a structure to a specific frequency. Due to various rotational speeds (RPM) of the rotor, we obtain various forcing frequency which has been tabulated.

Forcing Frequency (Hz) = Rotational Speed in Revolution/Second

The natural frequency of the rotor should not be equal to forcing frequency. If both the frequency match, the structure of rotor is going to be resonate. This resonance will cause the increased amplitude of vibration and this increased amplitude may lead to the failure of structure.

Table 2 : NATURAL FREQUENCY AND DEFORMATION OF STAINLESS STEEL

	SS R250		SS R300		SS R350		SS- TWISTED BLADE	
MODE	FREQ.(Hz)	DEFOR(mm)	FREQ. (Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)
1	5.0344	13.33	7.933	16.508	8.886	17.322	0.002	7.793
2	5.0536	13.352	8.1265	16.605	8.9772	17.375	5.1779	10.358
3	8.4563	18.847	12.88	25.471	14.064	27.146	7.8308	17.219
4	8.4812	18.877	13.067	25.668	14.178	27.254	8.8773	18.169
5	16.044	16.295	34.773	18.732	42.989	19.132	11.003	12.823
6	16.103	16.292	35.609	18.815	43.594	19.189	16.493	15.831

Table 3 : NATURAL FREQUENCY AND DEFORMATION OF ALUMINUM

	Aluminum R250		Aluminum R300		Aluminum R350		Aluminum TWISTED BLADE	
MODE	FREQ.(Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)
1	5.143	22.297	8.1499	27.612	9.0819	28.979	0.001	13.035
2	5.1624	22.335	8.3621	27.776	9.1933	29.006	5.2896	17.316
3	8.5637	31.597	13.048	42.685	14.254	45.49	7.9241	28.82
4	8.5882	31.645	13.236	43.015	14.391	45.705	8.9924	30.445
5	16.391	27.259	35.521	31.34	43.942	32.021	11.234	21.475
6	16.45	27.253	36.379	31.48	44.133	32.133	16.846	27.015

Table 4 : NATURAL FREQUENCY AND DEFORMATION OF GFRP

	GFRP R250		GFRP R300		GFRP R350		GFRP TWISTED BLADE	
MODE	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR
1	2.3844	24.542	4.4	30.765	5.4298	32.522	0	15.34
2	2.3943	24.575	4.5241	30.954	5.6016	32.749	3.1573	26.661
3	3.9803	37.073	6.4748	49.533	7.5122	52.973	4.067	33.279
4	3.9893	37.114	6.5964	49.884	7.683	53.387	5.0055	33.369
5	9.6076	33.302	23.993	38.451	31.818	39.32	5.3983	28.856
6	9.6309	33.296	24.177	62.693	32.074	63.611	8.4013	45.523

CONCLUSION

Here the natural frequencies of four different wind blades made of stainless steel, aluminum and GFRP at different wind speed were compared with forcing frequency of table 1 and no natural frequencies of Stainless Steel and aluminum match with forcing frequencies. So failure of structure will not occur in Stainless Steel and Aluminum. So both the materials are suitable for fabrication of wind blades of that dimensions.

In Glass Fiber Reinforced Polymer material, the natural frequencies of GFRP R250 mm at mode 1, 2, 3 and 4 are same at wind speed from 7 m/s to 12 m/s. In GFRP R300 mm, the natural frequency at mode 1 and 2 are same at wind speed from 13 m/s to 15 m/s. In twisted blade, the natural frequency at mode 2 and 3 are same at wind speed from 10 m/s to 13 m/s. Hence there is a possibility for resonance. So failure of structure will occur in R250, R300 and twisted blades. But natural frequency of GFRP R350 mm at all modes differs from forcing frequency. In this case no natural frequencies match with forcing frequencies. So failure of structure will not occur. So GFRP R350 mm is suitable for fabrication of wind blades with less weight and low cost without affecting its performance and stability.

It is suitable for houses in urban areas to produce green energy. It can produce electric power of 363 Watts and 1225 Watts at wind speed of 10 m/s and 15 m/s respectively. We can reduce the weight of the material by $1/4^{th}$ of steel and manufacturing cost by 50% when compared with steel.

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