Examination of Structural and Dynamic Properties for Vertical Axis Wind Turbine Blade Made of Stainless Steel using Ansys

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Abstract: This study investigates the potential for installing Savonius type Vertical Axis Wind Turbine systems with the goal of maximizing efficiency and reducing the cost. The wind turbine efficiency depends on the material of the blade, angle of the blade and shape of the blade. So material of the wind turbine blade plays an important role in the design of wind turbine. In this paper, Stainless Steel is used to design Savonius wind blades of 1 m height and 0.5 m chord length with 4 different arc radii. For this purpose, CAD modeling software Solid Works is used to model Savonius wind blade and static structural and modal analysis of the Stainless Steel blade is done by using ANSYS Workbench software. Static structural analysis is used to determine stress, strain, deformation and displacement under static loading condition. The response of structure for dynamic loading is determined by modal analysis. It is used to determine the natural frequency and mode shape of vibration of any structure. This wind turbine is suitable to install in small houses in urban areas.

Key Words: Solid Works, Stainless Steel, ANSYS, Structural Analysis, Modal Analysis.

I. INTRODUCTION

Savonius wind turbine is one type of vertical axis wind turbine used for converting the wind force into torque on a rotating shaft and electric power. The turbine consists of a number of blades vertically mounted on a rotating shaft. It is low cost and reliable, but efficiency is poor. This turbine is self starting and no pointing mechanism is required to allow for shifting wind direction. Sigurd Johannes Savonius invented this wind turbine in 1922. It was not widely used for many years. Its popularity is increasing recently due to increase of urbanized areas, which have specific demands. The Savonius rotor blade seems to satisfy these particular needs.

II. DESIGN CALCULATION

The relationships between wind power, swept area, air density and wind speed are given by below equation [Asis Sarkar 2012],

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

Where \( P_w \) = Power of the wind (W)
\( \rho \) = Air density = 1.23 kg/m\(^3\)
\( A \) = \( D \times H = 1 \times 1 = 1 \) m\(^2\)
\( V \) = Wind speed in m/s

The angular velocity of a rotor is given by
\[ \Omega = \lambda \cdot \frac{V}{R} \]

Where \( \lambda \) = Dimensionless factor called the tip speed ratio.

\( \lambda \) is a characteristic of each specific wind mill and for a Savonius rotor \( \lambda \) 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.

\[ P = M \times \omega \]

\( P \) = Output in N-m/s (1 N.m/s = 1W)
\( M \) = Torque in N-m
\( \omega \) = Angular speed / s = \( 2 \pi n / 60 \)
\( n \) = Rotational speed in rpm = \( (60 \omega) / 2\pi \)

According to Betz’s law [Albert Betz 1919], the maximum power that is possible to extract from a rotor is

\[ P_{max} = 16/27 \times \frac{1}{2} \rho A V^3 \]

III. METHODOLOGY

- The detailed study of wind turbine
- Find out the existing problem
- Scope and objective of the project
- Material selection
- Design and modeling of Wind turbine
- Structural & Modal analysis of turbine blade
- Conclusion

The savonius wind turbine made of Stainless Steel with one meter height and one meter diameter with four different shapes by changing arc radius of blade is designed by Solidworks software.
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Then this design is exported to Ansys Workbench software for doing structural and modal analysis. Finally the results are tabulated and graphed for easy understanding.

Table 1 Power and Torque of the proposed wind turbine for various wind speeds

| S. No | Wind Speed (m/s) | Angular Speed (rad/sec) | Rotational Speed (rpm) | P_{max} (watts) | Torque (n-m) |
|-------|------------------|-------------------------|------------------------|-----------------|-------------|
| 1     | 5                | 10                      | 96                     | 45.36           | 4.54        |
| 2     | 6                | 12                      | 115                    | 78.38           | 6.53        |
| 3     | 7                | 14                      | 134                    | 124.46          | 8.89        |
| 4     | 8                | 16                      | 153                    | 185.78          | 11.61       |
| 5     | 9                | 18                      | 172                    | 264.32          | 14.70       |
| 6     | 10               | 20                      | 191                    | 362.85          | 18.14       |
| 7     | 11               | 22                      | 210                    | 482.95          | 21.95       |
| 8     | 12               | 24                      | 229                    | 627.00          | 26.13       |
| 9     | 13               | 26                      | 248                    | 797.18          | 30.66       |
| 10    | 14               | 28                      | 267                    | 995.66          | 35.56       |
| 11    | 15               | 30                      | 287                    | 1224.62         | 40.82       |

Figure 1 Wind Speed Vs Wind Power

IV. DESIGN OF SAVONIUS BLADE WITH FOUR DIFFERENT SHAPES

| Shape          | Dimension: Height : 1000 mm, Rotor Diameter : 1000 mm, Thickness : 3 mm |
|----------------|---------------------------------------------------------------------|
| R250 mm        | Each Blade has same chord length of 500 mm with different arc radius. |
| R300 mm        |                                                                      |
| R350 mm        |                                                                      |
| Twisted blade  |                                                                      |

V. STATIC STRUCTURAL ANALYSIS OF WIND BLADE

All the four different shapes of stainless steel blades are analyzed with different loads of 500N, 1000N, 1500N and 2000N. The results are tabulated and the comparisons of the results are plotted.
VI. MODAL ANALYSIS OF WIND BLADE

All the four different shapes of SS material blades are analyzed. The results are tabulated and the comparisons of the results are plotted.
VII. RESULT AND DISCUSSION

Table 2 Load and Stress (MPa)

| LOAD (N) | SS R250 | SS R300 | SS R350 | SS TWISTED |
|----------|---------|---------|---------|------------|
| 500      | 87.203  | 94.033  | 273.93  | 95.898     |
| 1000     | 174.41  | 188.07  | 547.85  | 191.8      |
| 1500     | 261.61  | 282.1   | 821.78  | 287.69     |
| 2000     | 348.81  | 376.13  | 1095.7  | 383.59     |

![Figure 12 Natural Frequency and Total Deformation for R300](image1)

![Figure 13 Natural Frequency and Total Deformation for R350](image2)

![Figure 14 Natural Frequency and Total Deformation for Twisted blade](image3)

![Figure 15 Load Vs Stress](image4)

Table 3 Load and Strain

| Load (N) | SS R250 | SS R300 | SS R350 | SS TWISTED |
|----------|---------|---------|---------|------------|
| 500      | 0.000452| 0.0004884| 0.001478| 0.00049706|
| 1000     | 0.000905| 0.0009769| 0.002956| 0.00099411|
| 1500     | 0.001358| 0.0014654| 0.004434| 0.0014912|
| 2000     | 0.001811| 0.0019539| 0.005913| 0.0019882|

![Figure 16 Load Vs Strain](image5)

Table 4 Load and Deformation (mm)

| LOAD (N) | SS R250 | SS R300 | SS R350 | SS TWISTED |
|----------|---------|---------|---------|------------|
| 500      | 35.867  | 21.057  | 23.041  | 37.75      |
| 1000     | 71.735  | 42.114  | 46.081  | 75.5       |
| 1500     | 107.6   | 63.172  | 69.122  | 113.25     |
| 2000     | 143.47  | 84.229  | 92.163  | 151        |
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 speed (RPM) of the rotor, we obtain various forcing frequency [Domenico Lombardi 2017] 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.

Resonance

Resonance is the tendency of a system to oscillate with high amplitude when excited by energy at a certain frequency. This frequency is known as the system’s natural frequency of vibration or resonant frequency. For a wind turbine, this means that the rotational speed during normal operations should never be the same as the natural frequency of its component The maximum stress of 1095.7 MPa and strain of 0.0059131 is realized in SS R350 blades at 2000N loads. In modal analysis the natural frequencies of different blades made of stainless steel at different wind speed were compared with forcing frequency and no natural frequencies match with forcing frequencies. So failure of structure will not occur.

VIII. CONCLUSION

The result of static structural analysis to evaluate displacement, stress and strain is good and result shows that Stainless Steel is better choice to fabricate wind turbine blades. Modal analysis result also shows that the failure of structure will not happen. After comparing the analysis result of all the four different shapes, it is decided that SS R350 mm blade is the better choice. It is suitable for houses in urban areas to produce electricity. It is capable of producing electric power of 363 Watts and 1225 Watts at wind speed of 10m/s and 15 m/s respectively.

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