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DESIGN AND ANALYSIS OF A VERTICAL AXIS WIND TURBINE BLADE

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ABSTRACT

One of the most important design parameters for cost-effective VAWT is selection of blade material. VAWT blades must be produced at moderate cost for the resulting energy to be competitive in price and the blade should last during the predicted lifetime (usually between 20 and 30 years). At present, Aluminum blades fabricated by extrusion and bending are the most common type of VAWT materials.

Then available prospective materials are shortlisted and assessed. Subsequently, comparisons are made between the available materials based on their mechanical properties and costs. Finally, comparisons have been made between the design features of a VAWT with Aluminum and the alternative material blades using one of the prospective airfoils. The results of the design analyses demonstrate the superiority of the alternative blade material over conventionally used Aluminum. Structural and modal analyses have been conducted using advanced finite element methods.

INTRODUCTION

1.1 Introduction of Vertical Axis Wind Turbine

Today, the wind energy market is dominated by horizontal axis wind turbines (HAWTS). AWTS tend to work best in more open settings, offshore or on land in rural areas where the wind is not disturbed by buildings or trees. In contrast, vertical axis wind turbines (VAWTS) are more suited for built-up urban areas. They have lower wind start-up speeds, can be located nearer to the ground making maintenance easier, work in any wind direction and are relatively quiet.

At present, Aluminium blades fabricated by extrusion and bending are the most common type of VAWT materials. The major problem with Aluminium alloy for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decrease quite markedly at increasing numbers of cyclic stress applications. Under this backdrop, an attempt has been made in this paper to investigate alternative materials as VAWT blade material.

1.2 Horizontal versus Vertical Axis Wind Turbines

The HAWT is the most common turbine configuration. The propellers and turbine mechanisms are mounted high above the ground on a huge pedestal. It is a matter of taste as to whether they enhance the landscape. However, there is no denying that the height at which their mechanisms are located is a disadvantage when servicing is required. Also, they require a mechanical yaw system to orient them such that their horizontal axis is perpendicular to and facing the wind. As potential power generation is related to the swept area (diameter) of the rotor, more power requires a larger diameter. The blades experience large thrust and torque forces, so size is limited by blade strength. Figure 1.0 shows GE Wind Energy’s 3.6 Megawatt HAWT. Larger wind turbines are more efficient and cost effective.

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Figure 1.0. GE Wind Energy's 3.6 Megawatt HAWT.

A VAWT does not need to be oriented into the wind and the power transition mechanisms can be mounted at ground level for easy access. Figure 1.1 shows a picture of an H-Darrius Rotor VAWT.

Figure 1.1. An H-Darrius rotor VAWT.

The perceived disadvantage of the VAWT is that they are not self-starting. However, it could be argued that the HAWT is also not self-starting since it requires a yaw mechanism for orientation. Currently, VAWT are usually rotated automatically until they reach the ratio between blade speed and undisturbed wind speed (Tip Speed Ratio or TSR) that produces a torque large enough to do useful work. Through the use of drag devices and/or variable pitch blade designs, it is hoped that a VAWT will be able to reach the required TSR without the use of a starter.

Prospective Materials

The smaller wind turbine blades are usually made of aluminum, or laminated wood. Metals were initially a popular material because they yield a low-cost blade and can be manufactured with a high degree of reliability, however most metallic blades (like steel) proved to be relatively heavy which limits their application in commercial turbines.

1.6 INTRODUCTION TO UNI-GRAPHICS

Overview of Solid Modeling

The Unigraphics NX Modeling application provides a solid modeling system to enable rapid conceptual design. Engineers can incorporate their requirements and design restrictions by defining mathematical relationships between different parts of the design.

PROBLEM DEFINITION AND METHODOLOGY

VAWT blades are exposed to diversified load conditions and dynamic stresses are considerably more severe than many mechanical applications. Based on the operational parameters and the surrounding conditions of a typical VAWT for delivering electrical or mechanical energy, the selection of proper materials for the VAWT blade materials are required. If proper material not choose, it causes to failure.

METHODOLOGY

- Design the vertical axis turbine blade by using Unigraphics software based on 2D dimensions.
- Export .prt file into parasolid (.xt) file and import into Ansys software for analysis.
- Perform static analysis of VATB blade by using Aluminium material to calculate deformation and stresses.
- Perform modal analysis of VATB blade by using Aluminium material to calculate natural frequency.

- Perform static analysis of VATB blade by using E-GLASS/EPOXY material to calculate deformation and stresses.
- Perform modal analysis of VATB blade by using E-GLASS/EPOXY material to calculate natural frequency.
- From analysis results, best material proposed for VATB blade.

3D MODELING OF VERTICAL AXIS WIND TURBINE BLADE

4.1 DESIGN PROCEDURE

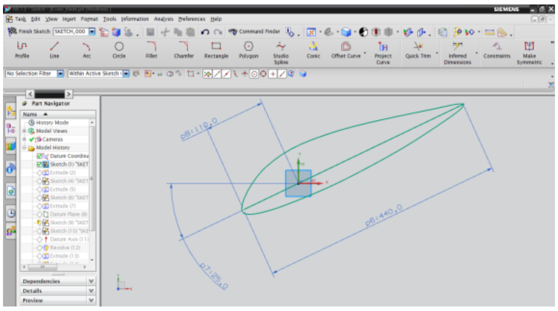

Fig.4.1 2D sketch of blade

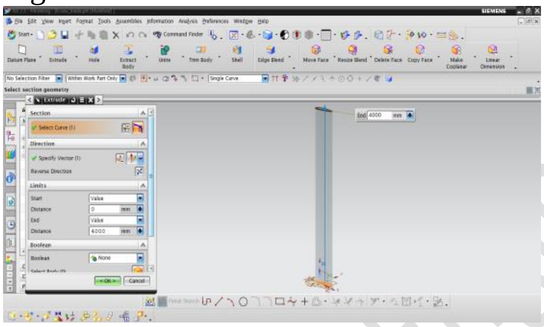

Fig.4.2 Extrude of 2D sketch of blade

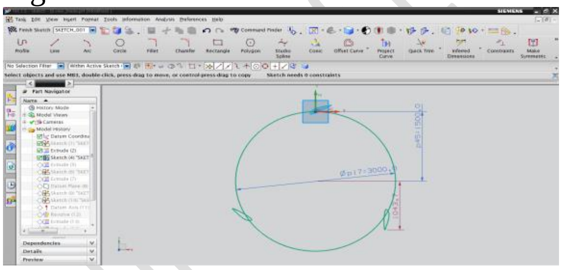

Fig.4.3 2D sketch of blade

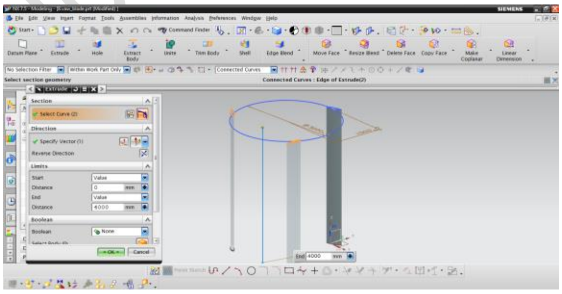

Fig.4.4 Extrude of 2D sketch of blade

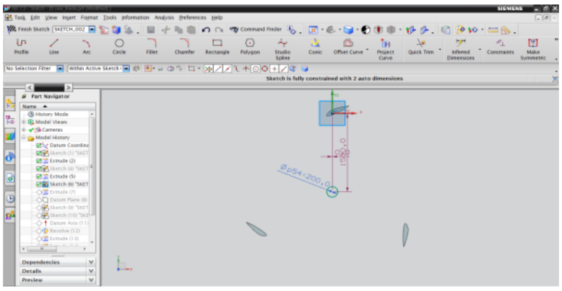

Fig.4.5 2D sketch of blade

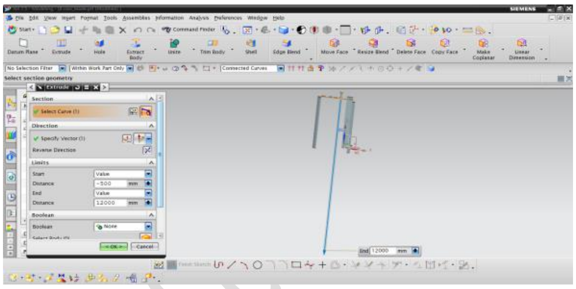

Fig.4.6 Extrude of 2D sketch of blade

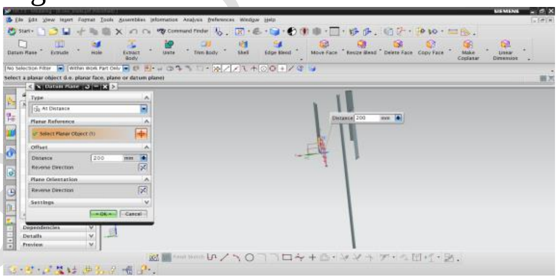

Fig.4.7 Creating datum plane blade

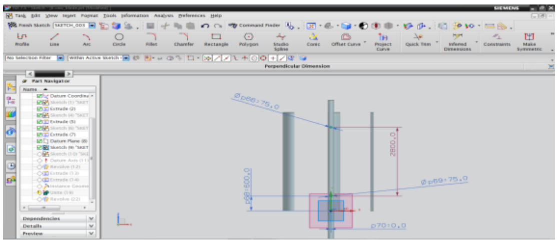

Fig.4.8 2D sketch of blade

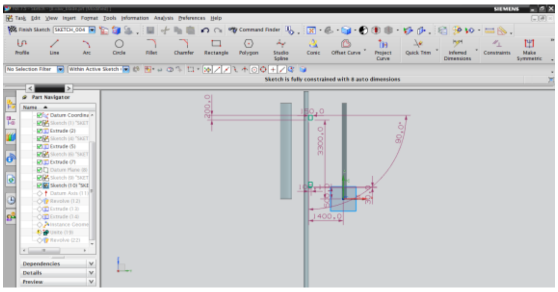

Fig.4.9 2D sketch of blade

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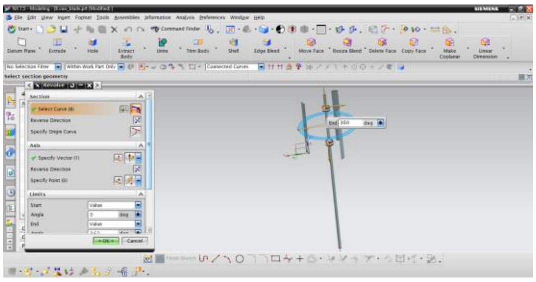


Fig.4.10 Extrude of 2D sketch of blade

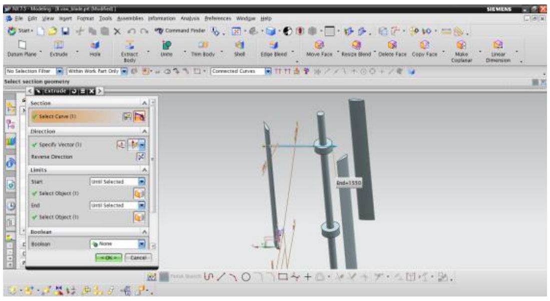


Fig.4.11 Extrude of 2D sketch of blade

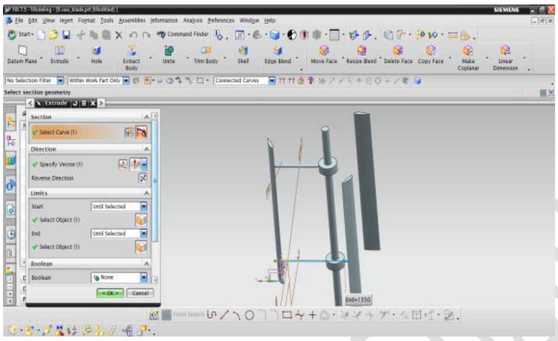


Fig.4.12 Extrude of 2D sketch of blade

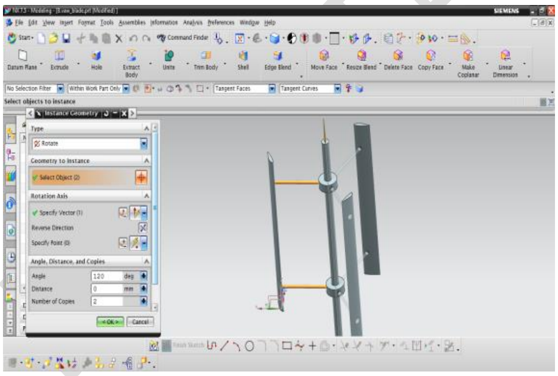


Fig.4.13 Making pattern of blades

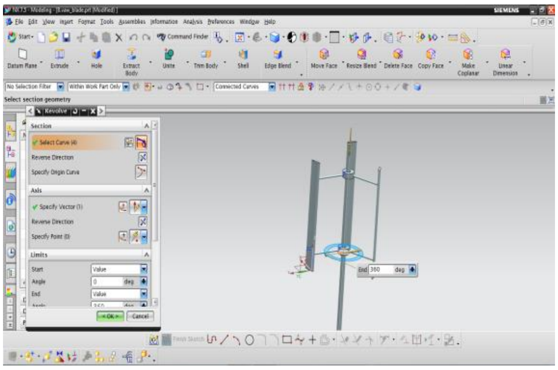


Fig.4.14 Extrude of 2D sketch of blade

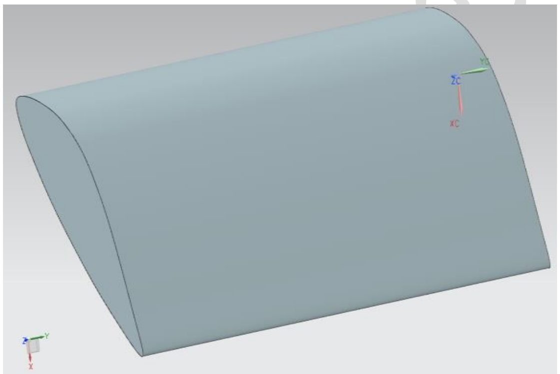


Fig.4.15: 3D model of the vertical axis wind turbine blade

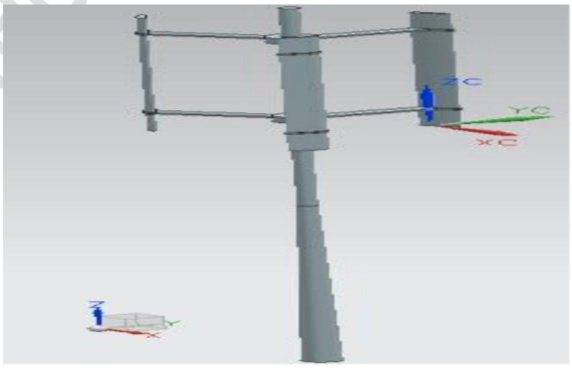


Fig.4.16: 3D model of the vertical axis wind turbine

FINITE ELEMENT METHOD

5.1 INTRODUCTION

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal Points”. Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement within the element in terms of the displacement at the nodes of the element.

ANSYS INTRODUCTION

The ANSYS program is self contained general purpose finite element program developed and maintained by Swason Analysis Systems Inc. The program contain many routines, all inter related, and all for main purpose of achieving a solution to an an engineering problem by finite element method.

The kinds of loading that can be applied in static analysis include:

- Externally applied forces and pressures.
- Steady state inertial forces
- Imposed displacement
- Temperatures
- Fluences (for nuclear swelling)

ANALYSES OF A VERTICAL AXIS WIND TURBINE

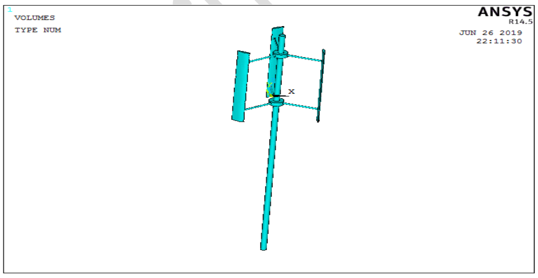
7.1 STATIC ANALYSIS OF VERTIAL AXIS WIND TURBINE USING ALUMINIUM

Element type: Solid187
No. of nodes: 8
Degrees of freedom: 3 (UX, UY, UZ)

ALUMINUM:

Mechanical properties:

Young’s modulus, E (Gpa)	:	71
Poisson’s ratio, υ	:	0.35
Density (g/cm^3)	:	2.65



Imported model

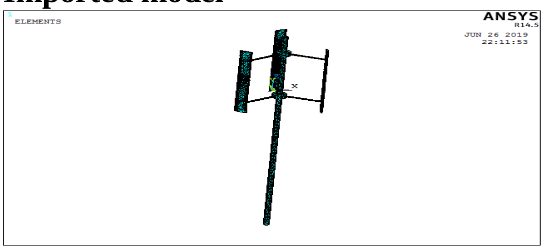


Figure: Finite element model

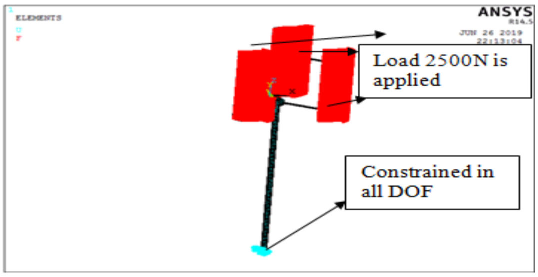
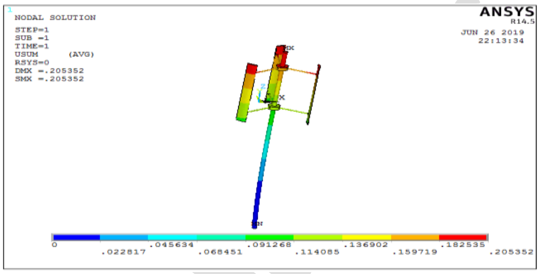
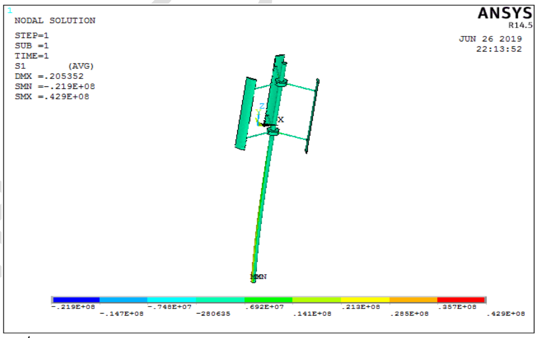


Figure: Loading conditions

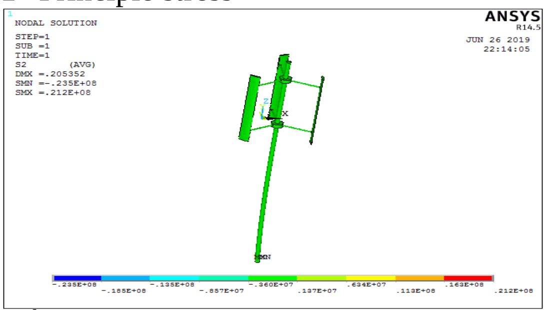
Results:



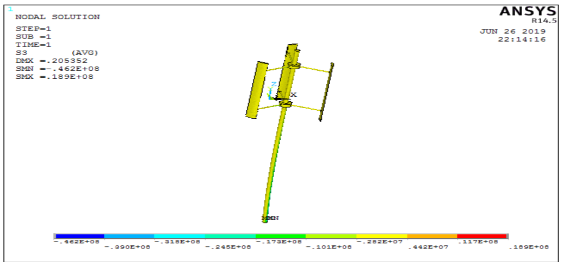
Resultant deformation



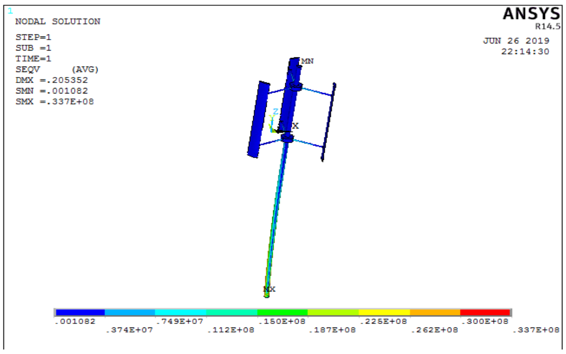
1st Principle stress



2nd Principle stress



3rd Principle stress



Vonmises stress

From above static analysis results, Vonmises stress formed on VAWT is 33.7MPa. Yield strength of Aluminium is 180MPa.

Factor of safety = yield strength/Vonmises stress =180/33.7 = 5.34

7.2MODAL ANALYSIS OF VERTICAL AXIS WIND TURBINE USING ALUMINIUM:

Methodology:

- Develop a 3D model.
- The 3D model is created using UNIGRAPHICS-NX software.
- The 3D model is converted into parasolid and imported into ANSYS to do modal analysis.
- Calculate natural frequencies and plot their mode shapes.

Natural Frequency:

Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position, if there is no outside interference.

Fundamental Natural Frequency

The fundamental frequency, often referred to simply as the fundamental, is defined as the lowest frequency of a periodic waveform. In terms of a superposition of sinusoids (e.g. Fourier series), the fundamental frequency is the lowest frequency sinusoidal in the sum.

Resonance:

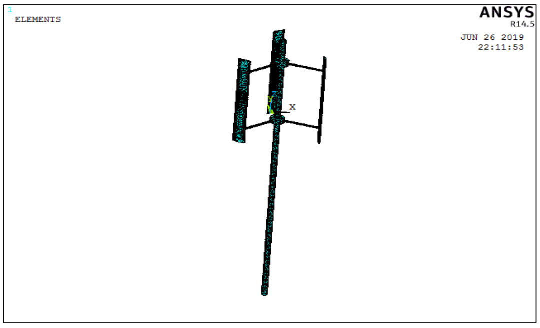
In physics, resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others. Frequencies at which the response amplitude is a relative maximum are known as the system's resonant frequencies, or resonance frequencies. At these frequencies, even small periodic driving forces can produce large amplitude oscillations, because the system stores vibration energy.

Mode Shapes:

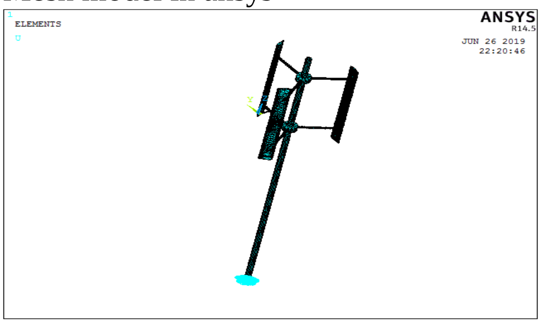
For every natural frequency there is a corresponding vibration mode shape. Most mode shapes can generally be described as being an axial mode, torsional mode, bending mode, or general modes.

Modal Analysis:

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 can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.



Mesh model in ansys



Applied fixed loads at end of VAWT

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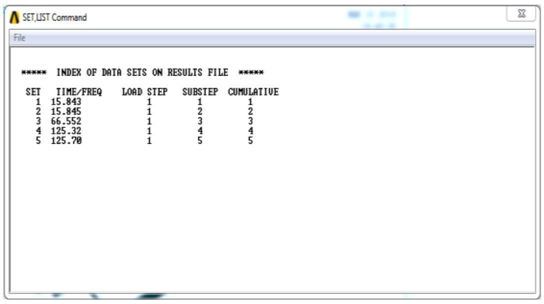
Results



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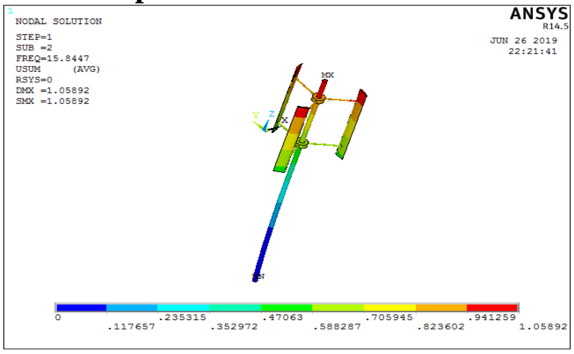
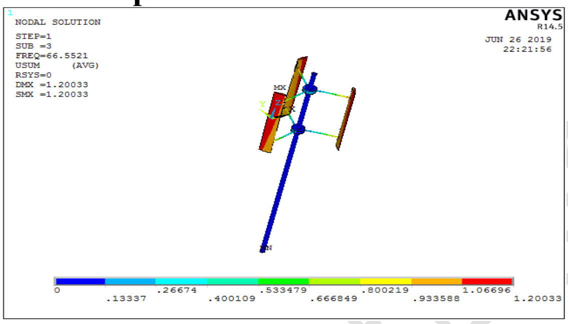
Five natural frequencies

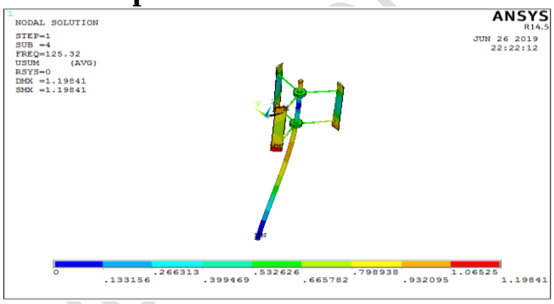
Mode shape-1



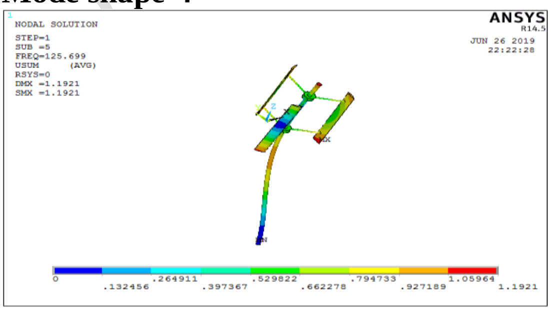
Mode shape-2



Mode shape-3



Mode shape-4



Mode shape-5

7.3 STATIC ANALYSIS OF VERTIAL AXIS WIND TURBINE USING E-GLASS/EPOXY

Element type: Solid185

No. of nodes: 20

Degrees of freedom: 3 (UX, UY, UZ)

EGLASS/EPOXY

Mechanical Properties:

Young's modulus in fiber direction E1 (GPa) : 53.8

Young's modulus in transverse direction, E2 (GPa) : 17.9

Shear modulus, G12 (GPa) : 8.96

Major Poisson's ratio, υ12 : 0.25

Minor Poisson's ration, υ21 : 0.08

Strength in the fiber direction, XL (MPa) : 1.03 X 103

Strength in the transverse direction, XT (MPa) : 27.58

Shear strength, S (MPa) : 41.37

Density (g/cm3) : 2.60

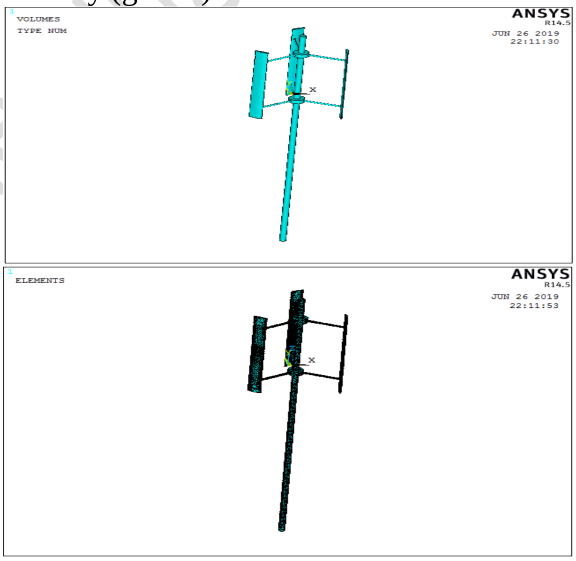


Figure: Finite element model

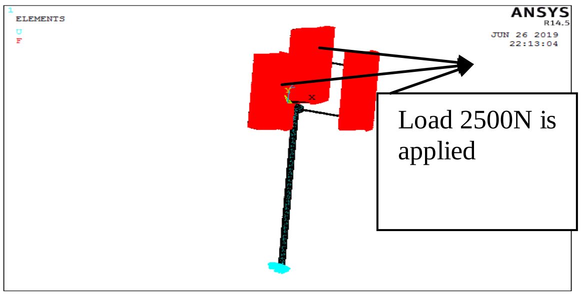


Figure: Loading conditions

Results:

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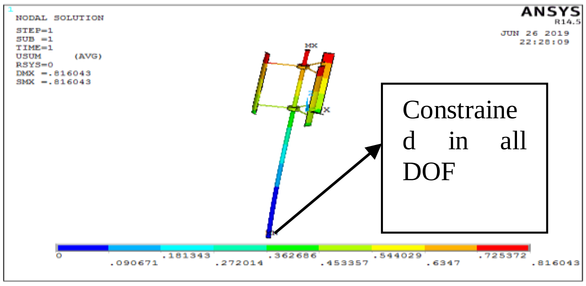
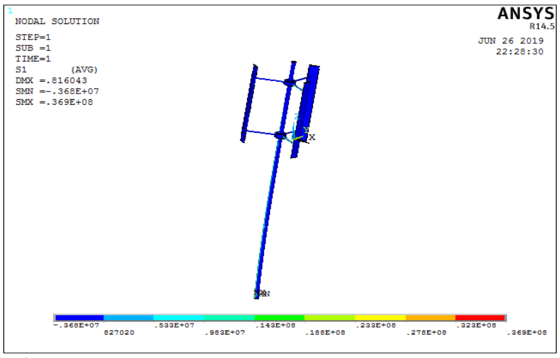
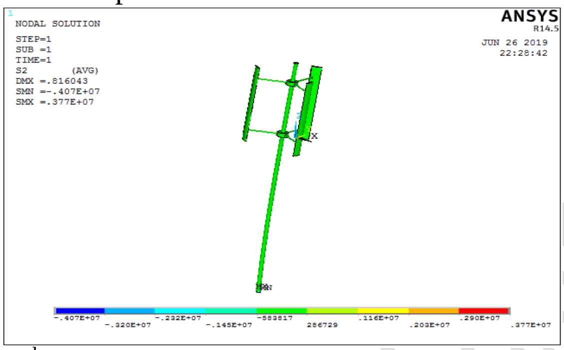


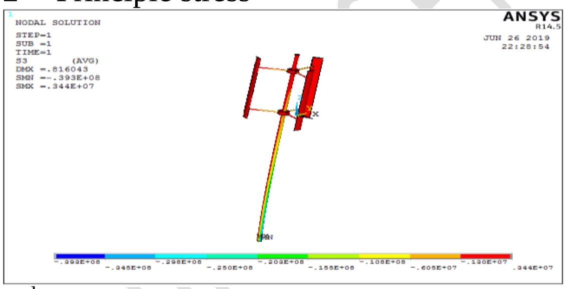
Resultant deformation



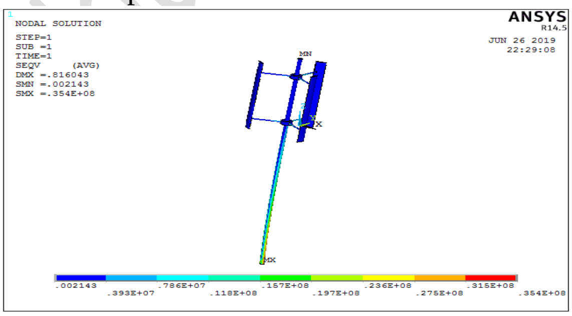
1st Principle stress



2nd Principle stress



3rd Principle stress



Vonmises stress

From above static analysis results, Vonmises stress formed on VAWT is 35.4MPa. Yield strength of E-Glass/Epoxy is 800MPa.

Factor of safety = yield strength/Vonmises stress =800/35.4 = 22.6

7.4MODAL ANALYSIS OF VERTICAL AXIS WIND TURBINE USING E-GLASS/EPOXY:

Methodology:

- Develop a 3D model.
- The 3D model is created using UNIGRAPHICS-NX software.
- The 3D model is converted into parasolid and imported into ANSYS to do modal analysis.
- Calculate natural frequencies and plot their mode shapes.

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Mode Shapes:

For every natural frequency there is a corresponding vibration mode shape. Most

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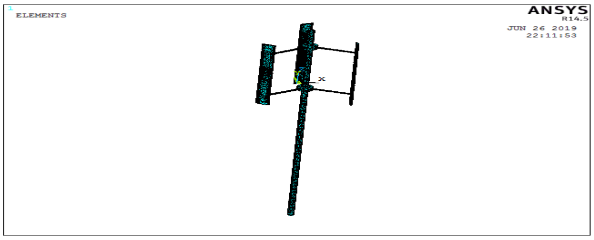
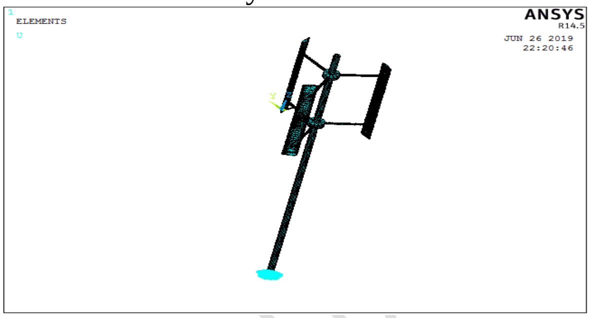
mode shapes can generally be described as being an axial mode, torsional mode, bending mode, or general modes. A crude mesh will give accurate frequency values, but not accurate stress values.

Modal Analysis:

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 can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

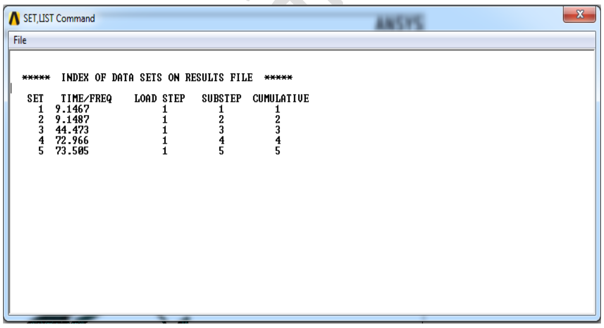


Mesh model in ansys



Applied fixed loads at end of VAWT

Results



SET,LIST Command

File

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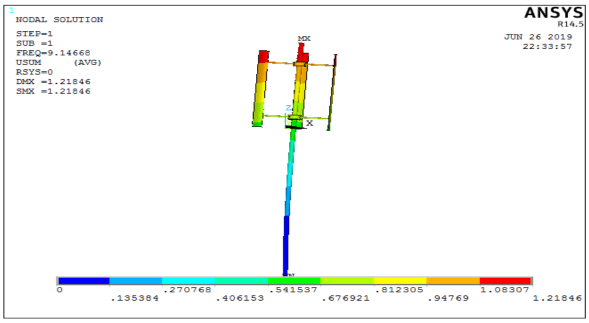
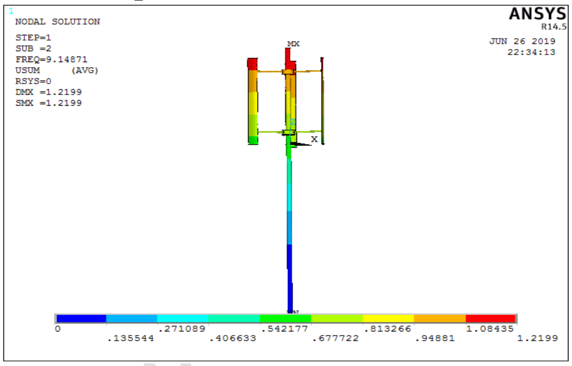
5	73.505	1	5	5

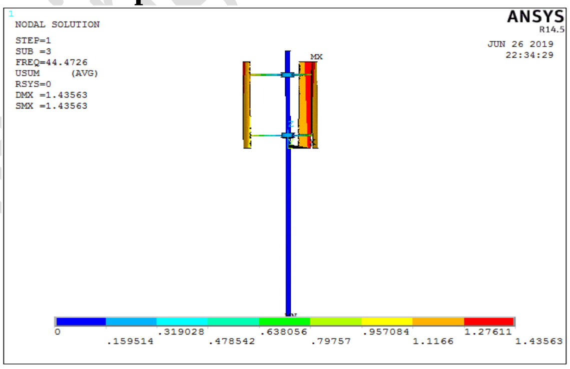
Five natural frequencies



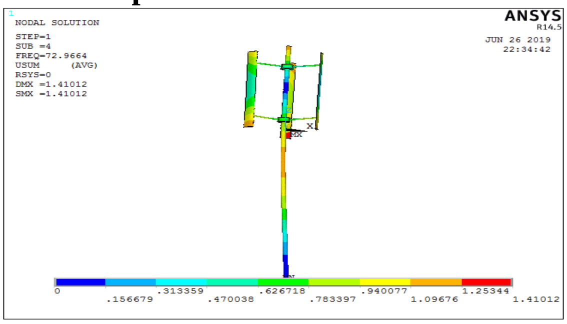
Mode shape-1



Mode shape-2



Mode shape-3



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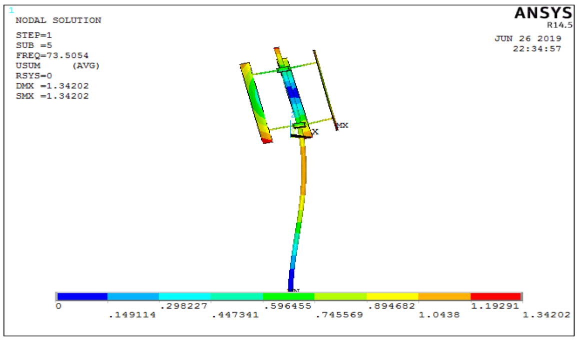

Mode shape-5

RESULTS AND CONCLUSION

	USUM	VON MISES STRESS	NATURAL FRQEUNCYRANGE(Hz)	WEIGHT (kg)
ALUMINUM	0.63	5.32	45.65 - 80	284
E-GLASS/EPOXY	2.42	5.28	28.95	179

CONCLUSION:

Vertical axis wind turbine blade has been analyzed and compared at wind speed (2500N approximately), for the different materials. By comparing the results, stresses developed in the blade are almost same in both materials, and these stresses are within the yield strength. E-glass/epoxy blade has very less weight comparing with Aluminum. So, we can conclude that E-glass/epoxy is the best material for the wind turbine blade.

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