MODAL ANALYSIS OF VERTICAL AXIS WIND TURBINE BLADE

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Abstract

The present work is carried out on modelling and analysis of vertical axis wind turbine The behaviour of the Vertical Axis Wind Turbine (VAWT), present technological state, new finding through modelling work and future direction of VAWTs were reviewed. It was observed that VAWT plays a vital role in the present energy crisis. Vertical axis wind turbine (VAWT) is used to generating green electric power and is becoming more popular. It needs less space and operates at low wind speed when compared with horizontal axis wind turbine (HAWT). It can be located at ground level for easy maintenance. It is also omni-directional which means that they do not need to be pointed in the direction of the wind. HAWT is popular for its efficiency. The modeling of spring is carried out by SOLIDWORKS 2019 and analysis it with finite element analyzer **ANSYS 18.1** and further is to check the utilizing this wind energy in most effective manner to get maximum output.

Keywords: Vertical Axis Wind Turbine, horizontal axis wind turbine, wind turbine blade.

1. Introduction

A Horizontal axis machine has its blades rotating on an axis parallel to the ground. Horizontal axis wind turbines are the most common type used. All of the components (blades, shaft, generator) are on top of a tall tower, and the blades face into the wind. The shaft is horizontal to the ground. The wind hits the blades of the turbine that are connected to a shaft causing rotation. The shaft has a gear on the end which turns a generator. The generator produces electricity and sends the electricity into the power grid. The wind turbine also has some key elements that adds to efficiency. Inside the Nacelle (or head) is an anemometer, wind vane, and controller that read the speed and direction of the wind. As the wind changes direction, a motor (yaw motor) turns the nacelle so the blades are always facing the wind. The power source also comes with a safety feature. In case of extreme wind, the turbine has a break that can slow the shaft speed. This is to inhibit any damage to the turbine in extreme conditions.

Vertical axis wind turbine (VAWTs) have the main rotor shaft arranged vertically. VAWTs run in any direction. In vertical axis turbines the shaft the blades are connected to is vertical to the ground. All of the main components are close to the ground. Also, the wind turbine itself is near the ground, unlike horizontal where everything is on a tower. There are two types of vertical axis wind turbines; lift based and drag based. Lift based designs are generally much more efficient than drag, or 'paddle' designs.

2. Literature Review

Fatemeh Afzali, Onur Kapucu, Brian F Feeny ASME in year 2016 International Design Engineering Technical Conference and Computers and Information in Engineering Conference. Derivation of a vibration model for an H-rotor/ GIROMILL blade is investigated. The blade is treated as uniform straight elastic Euler-Bernoulli beam under transverse bending and twisting deformation. The behaviour of the linearized equation for bend only is examined.

Gunner C. Larsen, Morten H. Hansen, Andreas Baumgart, Ingermar Carlen Riso National

Laboratory, Roskilde, Denmark February 2002. This investigation has demonstrated that essential properties of wind turbine blades, like natural frequency, damping characteristics and mode shapes, can be done experimentally use of modal analysis technique.

Gronman et al. [2018] suggested that the circulating flow system inside the vane ring can be beneficial from the rotor's performance point of view. There are three reported benefits that a vane system around a SAVONIUS turbine can produce: the first is that the possible flicker caused annoyance is expected to decrease, the second is the improved self-starting capability and the third is the improved performance. The lower flicker-related annoyance is explained by restricting or closing visual access to the rotating blade.

Douak M, Aouachria Z, Rabehi R, Allam N. [2018], Due to SAVONIUS turbines most significant qualities, a higher self-starting torque than other VAWT, they can be use not only for power generation at low wind speeds but as a starter for lift-type VAWT with poor starting performance. Even so, the situation has not been studied extensively, authors have proposed the addition of SAVONIUS rotor to lend its self-starting proficiency to a Darrius rotor expecting to achieve better operating conditions.

KH Wong et.al [2018] designed a flat plate deflector where the deflector was being placed too near to the VAWT. From the simulation, averaged CP obtained was about 33% increment whereas from the experiment the maximum CP was increased about 7.3%. The other examined parameters are the tilt angle, size, aspect ratio and shape of the deflector.

Naccache et.al [2018] analysed D-VAWT has low sensitivity to the change of TSR comparing VAWTs with a design with high efficiency and low TSR sensitivity. It maintains high efficiency of TSRs. High efficiency turbine DVAWT is an innovation.

A Damak et.al [2018] Helical Batch Rotor (HBR) had a higher power coefficient and a higher static torque when designed, built from resin and glass fibre, finally analysed in an open wind tunnel. The main objective was generation of more power from wind. Therefore, this work is green source of energy and has no bad effect on the life of earth.

Rudi H., et al. [2016] have also compared experimental results with numerical results. Maximum efficiency of ventilated Savonius is 25% better than conventional Savonius. Ventilation on the blade are also able to eliminate a critical position at 165o rotation angle of the conventional Savonius rotor.

Wenehenubun F, Saputra A, Sutanto H. [2015], Savonius turbines have a robust body, their mechanical systems can be installed close to ground level. They generally consist of a semi-circular "S" shaped cross segment pair of blades with a characteristic overlap in between; since less drag is involved moving along the wind, then the drag variance assists the turbines to spin.

Singh MA, Biswas A, Misra RD. [2015] made a computational simulation to check the effect on the performance of a coupled rotor to a truncated cone located in the end plate and analysed its self- starting increment at the beginning of the movement. After adding a Savonius device to a SB-VAWT rotor to increase starting performance, found that while the self-starting improvement was obvious, at high rotational speed, Cp was greatly affected.

3. Methodology

THEORITICAL CALCULATION OF WIND TURBINE BLADE

Design Calculation:

ρ = density of air (1.23 kg/m^3)

A = area of the wind blade that is experienced the force of wind = D*H

D = diameter of the turbine blade (in m)

H = height of the turbine blade (in m)

V = wind speed in (m/s) = π*D*N/60

R = radius of the rotor

ω = angular speed/second = 2 π N/60

N = rotational speed = 60*ω/2π

Theoretically,

$$(P_w)_{theoretical} = \tfrac{1}{2}\, \rho\, A\, V^3 \text{ watt}$$

$$(P_w)_{actual} = M*W$$

$$M = 60*P/2\,\pi\,N$$

Therefore, area of blade is taken as rectangular cross-section because of blade that is experiencing force of wind is a rectangular formed by diameter of blade and height of the blade.

Maximum power obtained from a rotor is given by $P_{max} = 16/27 \ (1/2 \ \rho \ h \ d \ v^3)$
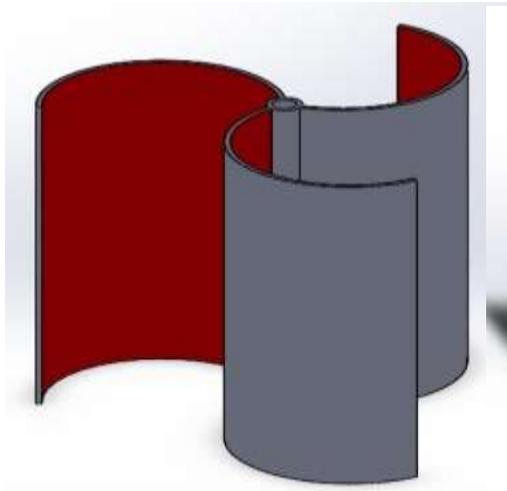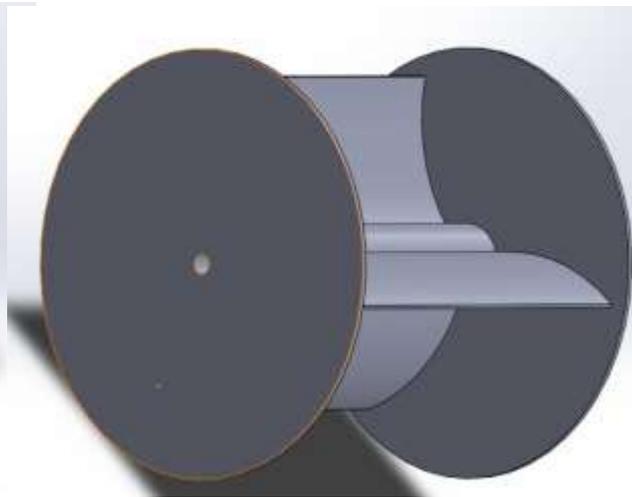

Fig. 1 Blades of three   fig .2 Rotor with blades

Velocity of turbine mainly depends on the density of air and area of the blade.

Model Calculations:

For calculating the natural frequency, we have a formula,

$$f = \omega/2\pi$$

where,

      f = frequency
      ω = angular velocity
      f = 501.28 Hz

$\omega = 2 \ \pi \ f$
      = 2*π*501.28
      ω = 3149.635 rad/sec

Rotational speed in RPM = 60 *3149.635/2 π
             = 60*f
             = 60*501.28
           N = 30076 rpm

Radius of the turbine blade = 0.4m

$V = d*\omega$

Where,

      v = velocity
      d = diameter

Velocity of blade (v) = π D N/60
            = π*0.4*30076/60
         V = 629.91m/sec.

Deformation of the wind turbine blade for different materials is calculated as follows:
1. Aluminium 6061:

Frequency f_1 = 501.28 Hz

$\omega_1 = 2\,\pi\,f_1$

$= 2 * \pi * 501.28$

$\omega_1 = 3149.63513$ rad/sec.

Rotational speed in rpm = $60 * f_1$

$= 60 * 501.28$

$N_1 = 30076$ rpm

Velocity of turbine blade = $\pi\,D\,N_1/60$

$= \pi * 0.4 * 30076/60$

$V_1 = 629.91$ m/sec

2. Aluminium 7075:

Frequency f_2 = 500.89 Hz

$\omega_2 = 2\,\pi\,f_2$

$= 2 * \pi * 500.89$

$\omega_2 = 3147.184$ rad/sec.

Rotational speed in rpm = $60 * f_2$

$= 60 * 500.89$

$N_2 = 30053$ rpm

Velocity of turbine blade = $\pi\,D\,N_2/60$

$= \pi * 0.4 * 30053/60$

$V_2 = 629.43$ m/sec

3. Inconel:

Frequency f_3 = 487.87 Hz

$\omega_3 = 2\,\pi\,f_3$

$= 2 * \pi * 487.87$

$\omega_3 = 3065.377$ rad/sec.

Rotational speed in rpm = $60 * f_3$

$= 60 * 487.87$

$N_3 = 29272$ rpm

Velocity of turbine blade = $\pi\,D\,N_3/60$

$= \pi * 0.4 * 29272/60$

$V_3 = 613$ m/sec

4. Aluminium Alloy:

Frequency f_4 = 502.03 Hz

$\omega_4 = 2\,\pi\,f_4$

$= 2 * \pi * 502.03$

$\omega_4 = 3154.34$ rad/sec.

Rotational speed in rpm = $60 * f_4$

$= 60 * 502.03$

$N_4 = 30121$ rpm

Velocity of turbine blade = $\pi\,D\,N_4/60$

$= \pi * 0.4 * 30121/60$

$V_4 = 630.85$ m/sec

4. MODAL ANALYSIS

It is the study of the dynamic properties of systems in the frequency domain. In physics, electronics, control systems engineering, and statistics, the frequency domain refers to analysis of mathematical functions or signals with respect to frequency, rather than time. Simple graph will show signal changes over time, whereas a frequency-domain graph shows how much of the signal lies within each given frequency band over a range of frequencies.

MODAL ANALYSIS IN ANSYS
Step by step procedure for modal analysis:
> **Step 1:**

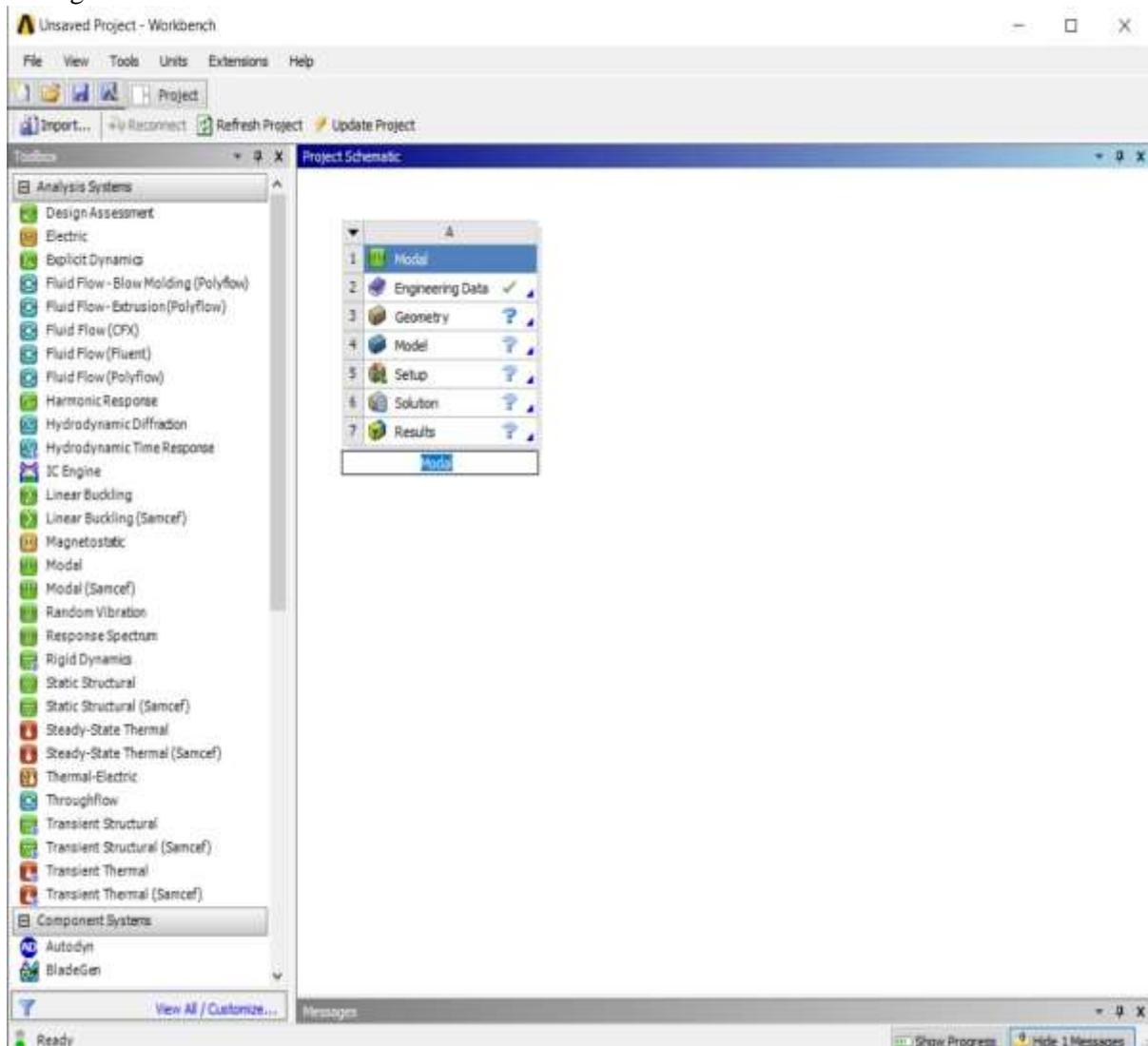ANSYS Workbench is opened. The interface of the ANSYS appears as shown in the figure 3.

Fig .3 Ansys Interface

Step 2: Creation of analysis system: To create an analysis system, expand the standard Analyses folder in the Toolbox and drag an analysis type object "template" onto the Project Schematic as shown in the figure 4.2. The analysis system is displayed as a vertical array of cells where each cell represents a component of the analysis system. Address each cell by right clicking on the cell and choosing an editing option.

Fig .4 Tool box

> ➢ **Step 3: Engineering data:**

The engineering data option is selected. A window appears where the mechanical properties of the material of the turbine blade can be given as shown in the figure 5.
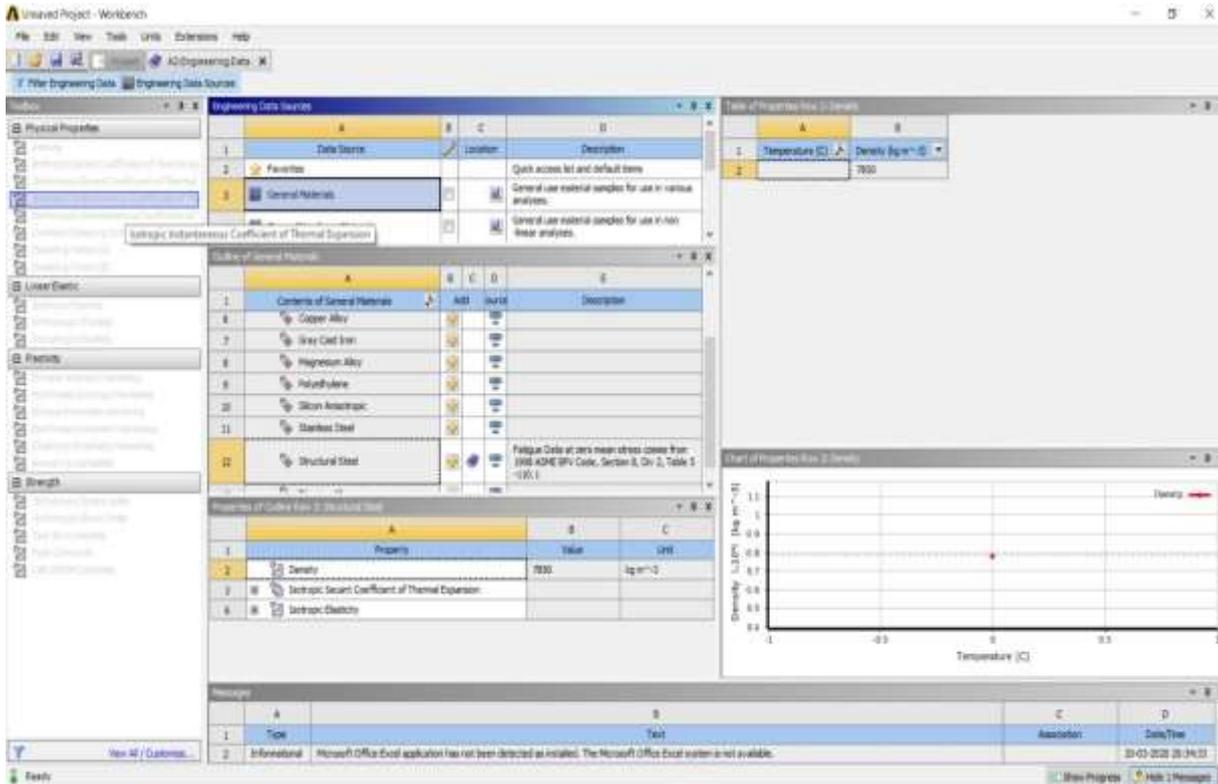

Fig .5 Selecting general materials from engineering data

> ➢ **Step 4: Apply geometry:** Attach geometry to the system or build a new geometry in Design Modeler. Right click on the Geometry cell and select Import Geometry to attach an existing model or select New Geometry to launch Design Modeler. For an existing model, the geometry is imported in IGES format as shown in the figure 6.
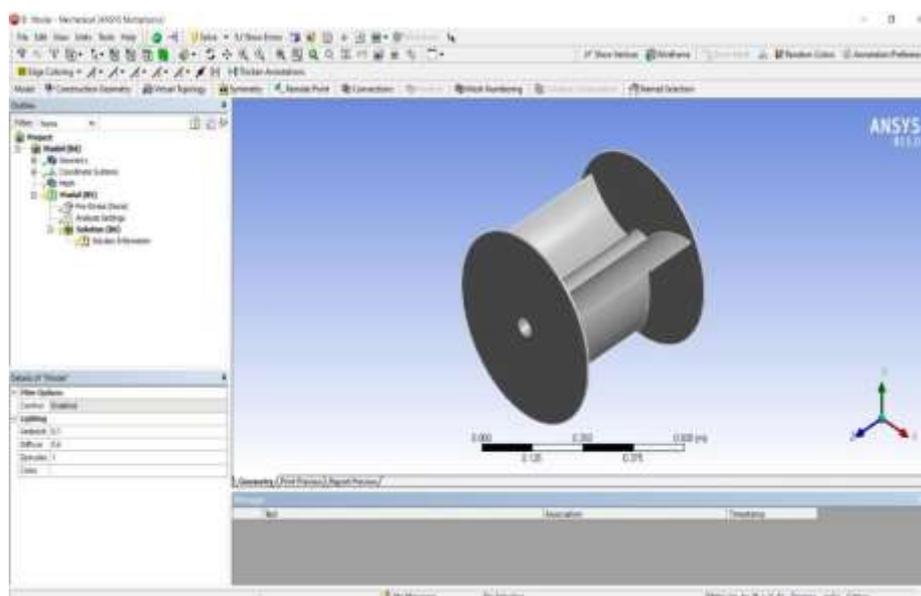

Fig .6 Geometry of model

➢ **Step 5: Apply mesh controls and preview mesh:**

Meshing is the process in which the geometry is spatially discretized into elements and nodes. This mesh along with the material properties is used to mathematically represent stiffness and the mass distribution of the structure. The default element size is determined based on a number
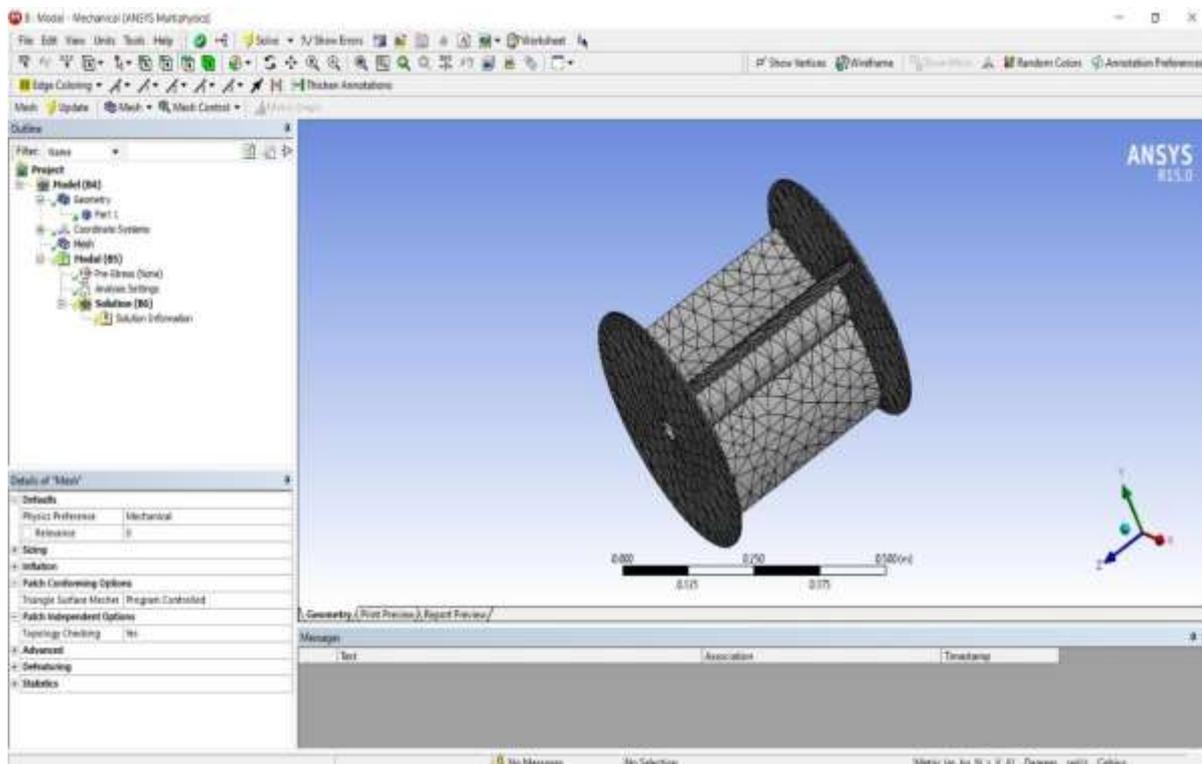

Fig .7 wind turbine blade after mesh

of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. If necessary, the fineness of the mesh is adjusted up to four times to and eight times for an assembly to achieve a successful mesh.

the option mesh is selected and fine meshing is selected. Wind turbine blade is divided into the five elements as shown in the figure no.7.

➢ **Step 6: Apply fixed supports:**

For a modal analysis applicable loads are all inertial, structural, imported, interaction loads and applicable supports are all structural supports.
Fixed support is applied to the both faces top and bottom side of the face there is no force is applied on the both the faces of the wind turbine blade.
Fixed supports are given on the model both sides of wind turbine blade.
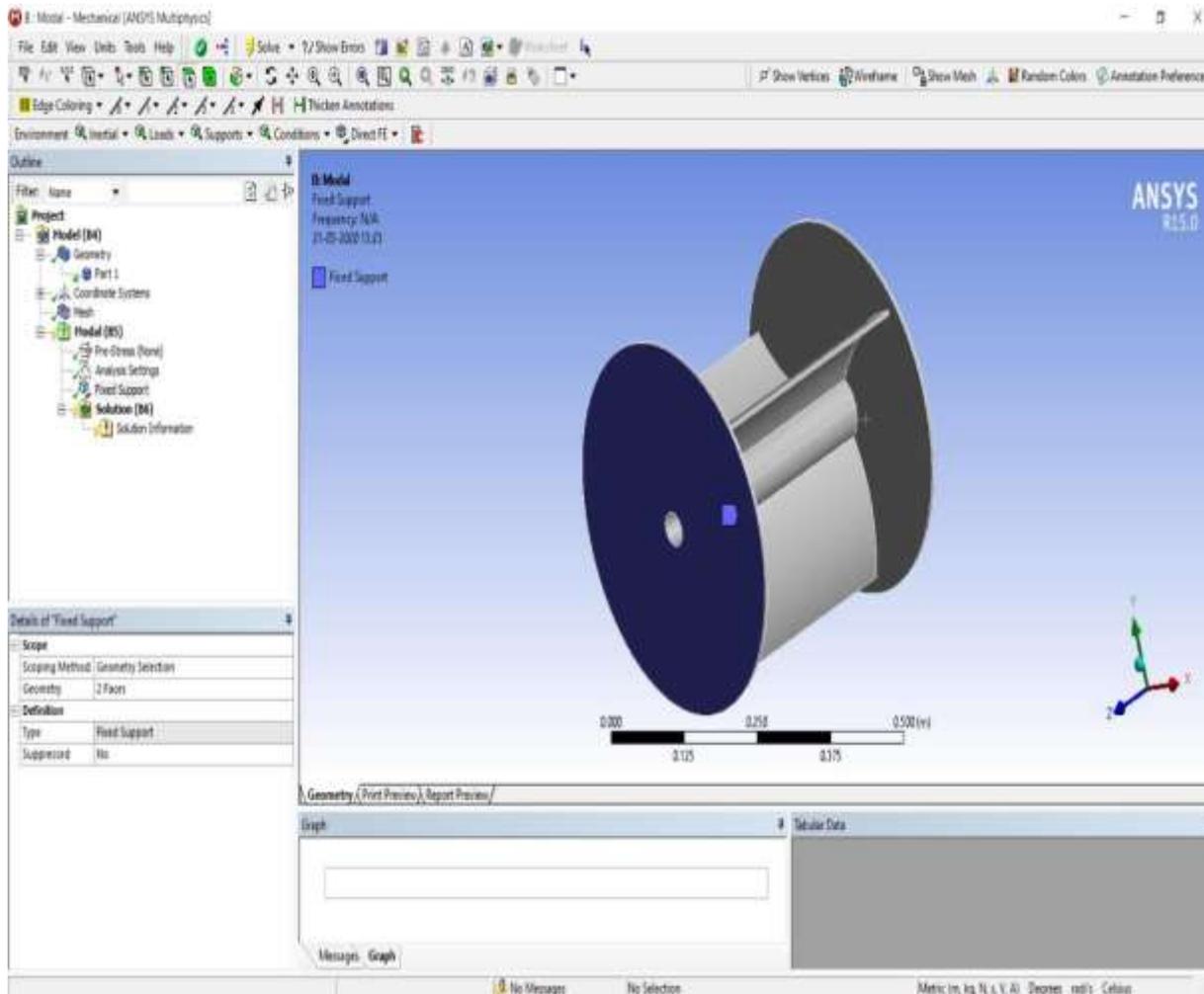
Fig .8 Fixed supports on blade rotor

> ➢ **Step 7: Solve the problem:**

Select the solution tab Right-Click on it then dialog box will open in that insert then go to deformation which is applied to the total body. Then the solve option is selected and the solution status as shown in the figure 9.
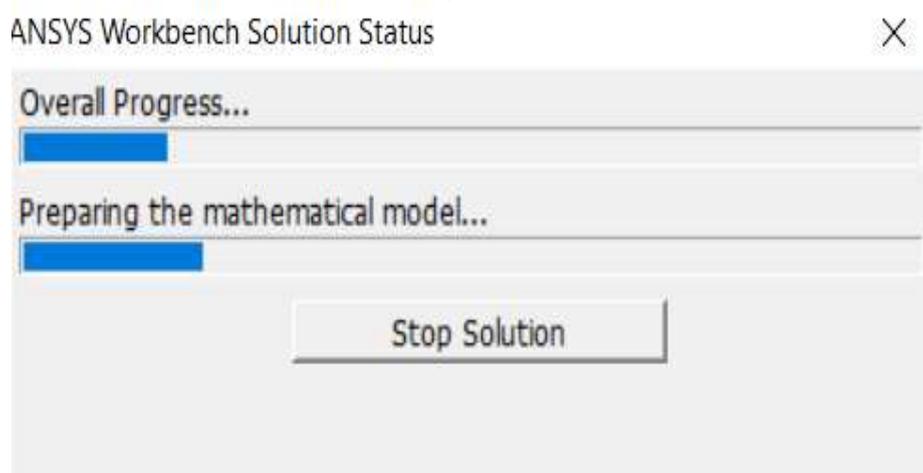

Fig .9 status of the solution

5. RESULTS AND DISCUSSIONS
ANALYSIS ON DIFFERENT WIND TURBINE BLADE MATERIALS
Aluminium 6061:

The usage of aluminium 6061 has increased due to it has following properties:

1. High strength.
2. Light weight.
3. High corrosion resistance.
4. Less cracks susceptibility.
5. Low coefficient of thermal expansion

The below properties are taken from standard machinery's handbook.

Table .1 Chemical composition of Al 6061   **Table . 2 Mechanical properties of Al 6061**

S. No.	ELEMENT	CONTENT (%)
1.	Al	95.85-98.56
2.	Mg	0.8-1.2
3.	Si	0.40-0.8
4.	Fe	0.0-0.7
5.	Cu	0.15-0.40
6.	Cr	0.04-0.35
7.	Zn	0.0-0.25
8.	Ti	0.0-0.25
9.	Mn	0.0-0.15

S. NO	PARAMETER	VALUE
1.	Density	2700 kg/m^3
2.	Young's Modulus	68.9 GPa
3.	Poison's ratio	0.33
4.	Shear Modulus	26 GPa
5.	Tensile strength	124-290 MPa

The natural frequency of Al 6061 at mode shape 1 is obtained as 501.28 Hz as shown in figure no. 10.
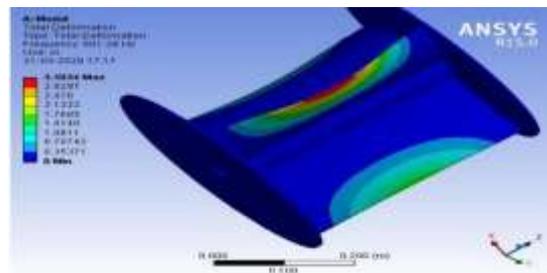

Fig . 10 Total Deformation 1 of Al 6061

Aluminium 7075:

It consists of an aluminium alloy, with zinc as primary alloying element. It has excellent mechanical properties and exhibits good ductility, high strength, toughness and good resistance to fatigue. It is often used in construction and commonly used to extrude aluminium bars, pipes, rods, and tubes.

Table . 3 Chemical composition of Al 7075   **Table .4 Mechanical properties of Al 7075**

S. No.	ELEMENT	CONTENT (%)
1.	Si	0.4
2.	Fe	0.5
3.	Cu	1.2-1.6
4.	Mn	2.1-2.5
5.	Mg	2.5
6.	Cr	0.15
7.	Zn	5.6-6.1
8.	Ti	0.2
9.	Al	remaining

S. NO	PARAMETER	VALUE
1.	Density	2810 kg/m^3
2.	Young's Modulus	71.7 GPa
3.	Poison's ratio	0.33
4.	Shear Modulus	331 MPa
5.	Tensile strength	280 MPa

The natural frequency of the Al 7075 at mode shape 1 is obtained as 500.89 Hz as shown in the figure no.11
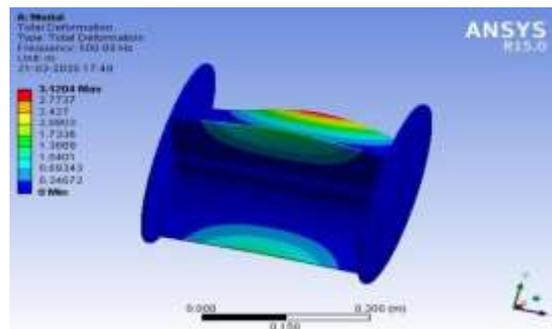

Fig .11 Total Deformation 1 of Al 7075

Inconel 625:

Inconel nickel-chromium alloy 625 is used for its high strength, excellent fabricability including joining and out standing corrosion resistance. Service temperatures range from cryogenic to 1800ºF. It possesses high strength properties and resistance to elevated temperatures and protect against corrosion and oxidation. Its ability to withstand high stress and wide range of temperatures, both in and out of the water.

The below properties are taken from standard machinery's handbook.

Table .5 Chemical composition of Al 6061

S. No.	ELEMENT	CONTENT (%)
1	C	0.058
2	Si	0.283
3	Mn	0.36
4	P	0.008
5	S	0.011
6	Fe	4.451
7	Mo	8.195
8	W	0.1
9	Al	0.005
10	Co	0.114
11	Nb	3.4
12	Ti	0.22
13	V	0.005
14	Cr	21.407
15	Ni	Remaining

Table .6 Mechanical properties of Al 7075

S. NO	PARAMETER	VALUE
1.	Density	8440 kg/m^3
2.	Young's Modulus	204.86 GPa
3.	Poison's ratio	0.3
4.	Shear Modulus	442 MPa
5.	Tensile strength	896 MPa

The natural frequency of the Inconel 625 at mode shape 1 is obtained as 487.87 Hz as shown in the figure no.12
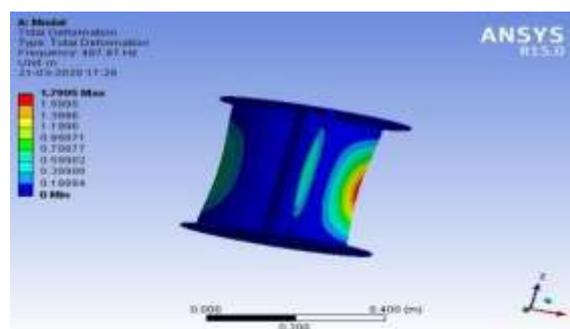

Fig .12 Total Deformation 1 of Inconel 625

6. CONCLUSIONS

The objective of the work is to study the behaviour of vertical axis wind turbine blade is adopted for knowing the frequency for a particular material and design modifications.
For this analysis four different materials are carried out which include Aluminium 6061, Aluminium 7075, Inconel 625 and Aluminium Alloy and the following conclusions are drawn from this work.

1. The modelling was done in SOLIDWORKS and analysis in ANSYS 15.0 and it is observed that aluminium alloy is the material which causes the blade to break at ease and does not suitable for using this material can cause serious destructions no frequency is obtained.
2. The values of the deformation of various blade materials obtained at fixed supports to give total deformation.
3. It is observed that the minimum deformation with speed (29272) is obtained for a material used is Inconel.
4. The maximum deformation (30121) is observed for Aluminium Alloy at the specified mode conditions.
5. Among all this four materials Inconel 625 has very small deformation but has failure conditions also.

Taking, the results of analysis into consideration it can be finally concluded that Inconel 625 has some what less deformation compared to other three materials but it is not optimum material to be selected. This Inconel 625 material also has deformation compared to the materials which are already used. So those which I have used are not suitable for the preparing the vertical axis wind turbine blade.

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