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Study and Analysis on Bladeless Wind Turbine

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Abstract - *The method of generating the wind energy to generate electricity is modernizing with the development of technology .The new method to harness the wind energy is growing in various forms .One of it is studied in the paper and analysis is done on various parameters .The bladeless wind turbine utilize vortex formation to extract energy from the wind and the design is made to oscillate within the wind range and generate electricity from the vibration .The transportation and installation are cheaper as compared to conventional wind turbine. This bladeless technology consists of a cylindrical shape like structure mounted vertically on an elastic rod, instead of tower, foundation, nacelle and blades which are the crucial parts of conventional turbine. In this paper the fluent analysis is performed on von Karman effect to understand the vortex shedding effect around the blunt bodies. Also the bladeless wind turbine is designed with certain existing parameters of dimension in CATIA V5 and the same is analyzed for different material and dimension of mast. The various performance parameter like displacement, frequency etc. The Model is designed with two material which are carbon fibre and glass fibre as they are most suitable to this bladeless turbine.*

***Key Words*: Bladeless Wind Turbine, CATIA V5, Fluent Analysis, Vortex Shedding .**

1. INTRODUCTION

The demand for the energy is increased due to the growing population and developing countries. The requirement to meet the need of industry, power plant and homes are growing rapidly. The non-renewable energy-producing resources are globally limited. The field of energy production from the renewable resource such as hydropower, geothermal, biomass, solar energy and wind energy is advancing [1]. So the ways to produce this energy through various methods are also developing. Wind energy is a renewable source of energy which is used to generate the electricity using wind turbine .The conventional wind turbine that are used to produce the electricity are horizontal axis turbine and vertical axis turbine. Surprisingly, Conventional wind turbines are somehow unpopular because of several drawbacks directly related to their large size. The visual impact, along with the noise pollution and transportation, poses a great treat to installing wind turbines in densely populated areas or near important natural features. Conversely, miniaturization makes wind turbine unprofitable compared to other energy sources or other uses of land, making them generally suitable for distribution of small-scale power generation. Due to the larger growth of the wind power industry, many wind turbine design exist in development .The variety of design reflects ongoing commercial, technological and inventive interest in harvesting wind resources more efficiently and in greater volume. Bladeless wind turbine is an alternative and innovative way to harness energy from wind, with different and exciting characteristics which makes it a revolution in wind power generation. The Operation of Bladeless Wind Turbine is based on VIV (Vortex Induced Vibration) phenomenon. When the wind flows the mast starts to oscillate .The vibration may be the result of a vortex vibration with the force applied to the mast. Then the kinetic energy of the oscillating cylinder is converted to electricity through a linear generator similar to that used for harnessing wave energy [2]. The purpose of this study is to analyze the behavior of bladeless wind turbine when placed in a fluid (air) stream and to examine the various parameters related to it. Experimental testing of the bladeless wind turbine would to be expensive. Given the manufacturing of the modified, since the operation takes a long time. So the best way to estimate the performance of bladeless wind turbine is through the use of analysis software (ANSYS). Our area of focus is to observe frequency and displacement and can have better stress distribution since it's prone to high fatigue stresses due to resonance that will be required in its operation.

2. LITERATURE REVIEW

Bladeless wind turbine technology is developing at faster rate considering the importance of renewable energy. Many Research and study are under the experimental and small scale commercialization are taking place. The journal paper [3] studied that Today, India is stepping towards becoming a global super power. This means that it leads the list of developing countries in terms of economic development .As a result, energy demand will increase many times over the next few decades. Coal cannot be the main energy source to meet their energy needs. This is because coal is depleting very fast. Coal is estimated to be depleted in a few decades. The next clean energy source is solar energy, but it is expensive because of its low concentration per unit area. In terms of installed wind power capacity, India is ranked fifth in the world. The papers [4] describe the vortex induced vibration used for harvesting energy. Various physical phenomena and concepts related to this realm are discussed in detail. Various problems that arise from conventional windmills are highlighted. The possibility of using piezoelectric material to maximize the vibration amplitude of vertical windmills is highlighted. The paper describes various terms related to bladeless wind power and various applications are noted down in this paper.

Briefly describe the history of bladeless wind energy. Paper[5] studies the taper ratio of a conical cylinder to maximize vorticity. Various tests on tapered cylinders are also carried out to investigate the effects of taper ratios. In comparison to uniform cylinders, tapered cylinders have a wider range of lock in ranges. By adding the fluid forces, vortex produced vibration is seen as an one degree of freedom model. Other factors that influence vorticity, such as mechanical damping and mass ratio, are investigated in a journal study [6]. In study [7], a staggered multi-code was employed for dynamic simulation of a uniform cylinder, with one code dealing with fluid charge and another analyzing fluid structure interaction. Vortex shedding varies over a small band of frequencies and amplitudes at higher Reynolds Numbers. As a result, severe flow oscillations are formed, resulting in the so-called Von Karman Vortex effects [8].

3. MATERIAL AND METHOD

Following are the component that bladeless wind turbine consist of- Components

1. Mast

2. Rod

3. Generating system

4. Foundation

5. Tuning passive system

6. Piezoelectric material

7. Inverter

The basic principle of the bladeless wind power generation is on transform the linear motion of mast to rotational motion. As the taper cylindrical structure (mast) experiences wind, it vibrate due to the formation of vortices around the mast, which are then converted to rotating power to generate electricity. With flawless wind power the mast is fasten to the ground and a rib structure is attached at the upper part of the mast that holds the string arrangement. Power can be obtained by continuous mast rotation. Thread is pulled by the mast utilizing the wind power along with chain clamped to sprockets driving the shaft, which in turn rotates the alternator to produce power [9]. Depending on the direction the wind blowing, the mast oscillates in either direction. The rib structure on the top of the mast is usually attached to five or six filaments (threads) to absorb energy from the air. The filament is designed in such a way that power is generated in all directions of vibration. After the maximum amplitude of oscillation it reached both sides, the mast returns to the original position and oscillate in turned to the other side.

3.1 Vortex Shedding Phenomenon

Naturally, for any bluff body placed in uniform flow with changing velocity, it will form a thin boundary layer near its body due to the viscosity of the liquid. This boundary layer grows until it reaches a critical point called the separation point, where the fluid particles overlap resulting in a wake region behind the body. This waking region is often referred to as the 'Kármán Vortex Street' where periodic shedding of these vortices from the surface of the body induces periodic pressure differentials on the structure [10]. The relationship between the vortex shedding frequency, diameter of the cylinder and ambient flow velocity has been discovered by Strohaul nearly 100 years ago regarding his work in a special way of creating noise[11]. The strohaul number, like the Reynold's number, is a dimensionless quantity that represents the ratio of inertial forces to viscous forces in a fluid. As a function of Strouhal number, which is dependent on fluid stream velocity and structure diameter, Vortex Shedding can cause high vibration on flexible structures at a given frequency.

The Strouhal number is defined as

$$St=fD/U \qquad (1)$$

where, f is the frequency of vortex shedding, D denotes the length or diameter of the bluff body and U is fluid stream velocity [12]. At higher Reynolds Number, vortex shedding varies with a smaller band of frequencies and amplitudes. For this reason, strong flow oscillations have been created, leading to the so-called Von Karman Vortex effects [8]. Graebel stated that when a fluid flows over a blunt body, vortices are formed and spilled alternately at top and bottom of the body [13]. In addition, repeated, alternating scattering of vortices creates a normal energy in normal flow of flow over the body. This load alternates with the direction in which each vortex is dissipated. This type of vibration effect is called as vortex induced vibration.

The resonance velocity of the vibration generated by the vortex is given by

$$Vr=Nb/St \quad (2)$$

where, N is the natural body frequency, b is reference crosswind width and St is Straouhl number [14]. Bluff body structure is an important factor in attracting proper frequency and energy from vibration. Different types of bluff bodies are available, including cylinders, spheres, and cones. The bladeless turbine structure is proposed in a circular hole, supported by a ground cylinder pipe or rod. Two parts of the vortex wind generator are denoted in figure 1. The main components of this turbine are the mast, rod, stand and base. The air flows directly to the normal area to the exact point of the vortex wind generator. The whole structure support the von Karman effect due to the air flow. As the whole structure is immersed in the airway, the effect of von Karman varies widely from the top to bottom of the mast. To facilitate the analysis of von Karman effect, the whole mast is divided into a series of small discs with different diameters throughout the cross section. The Reynolds number, air velocity, diameter of the submerged object or disc, and air flow direction all play a role in the von Karman effect. In Figure 2, it shows the von Karman effect for 2d discs of diameter. The vortex shedding is clearly a sinusoidal process, as indicated by the von Karman effect. Therefore it is possible to represent the lifting force generated from the vortex induced vibrations as a sinusoid,

$$F_t=1/2\rho u^2DC_L\sin(\omega_s t-\phi) \quad (3)$$

where, ρ is air density, u is air velocity, D is diameter of the cross- section of mast, CL is coefficient of lift, ω_s is vortex shedding frequency and t is time [8]. When the entire conical structure is divided into smaller parts, each of them can be treated as small cylinder with irregular lengths like a circular disc. The Figure 3 shows the plot of the lift coefficient vs. the function of time. The variation of the drag coefficient with time is plotted in Figure 4.When the vortex shedding frequency synchronizes with the cylinder's vibration frequency, the most substantial reaction occurs. The vortex shedding frequency approaches the body's normal frequency as the air flow is adjusted. This will set a significant amount of vibration energy to the body [8]. The entire vortex structure is placed into a fluid domain for the Fluid-Structure Interaction study after the von Karman analysis and dimension fixation. Figure 5 depicts the velocity flow field. When air travels over the mast's cross section disc, a velocity reduction happens in the middle of the downstream and close to its place. Air velocity, on the other hand, increases on both sides of the disc. Subsequent distribution of pressure is shown in Figure, 6 which is opposite to the velocity distribution.

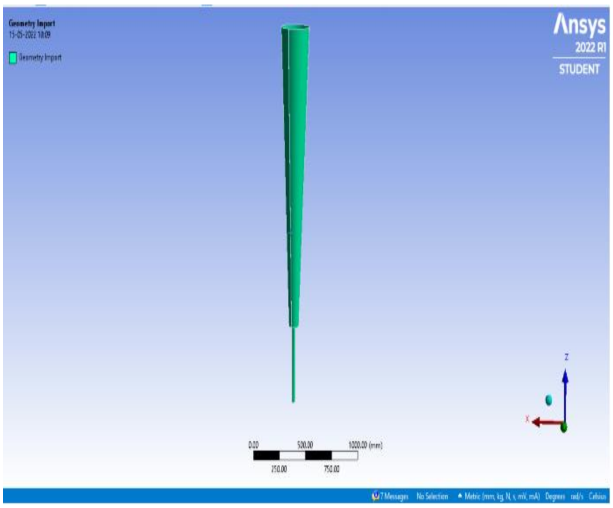


Figure 1: Model of bladeless wind turbine

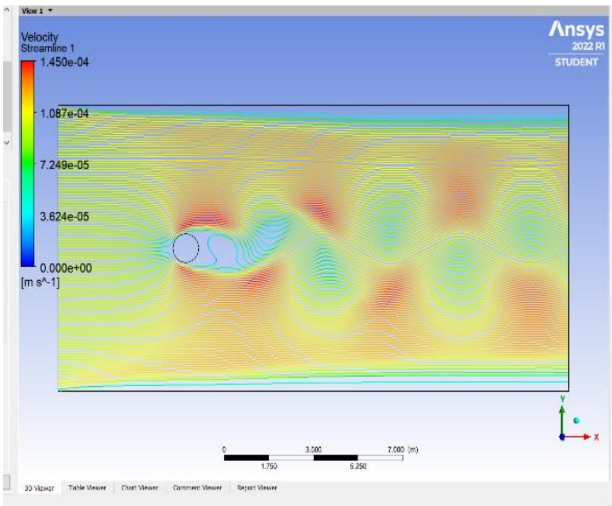


Figure 2: Von Karman effect on 2d disc diameter.

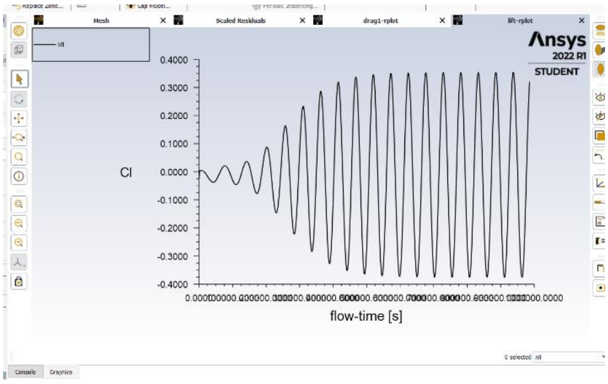


Figure 3: The plot of the lift coefficient vs the function of time.

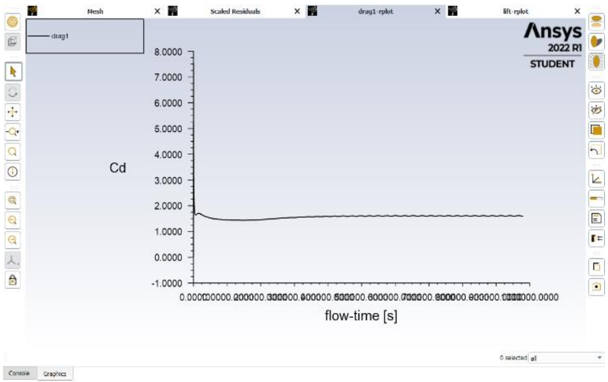


Figure 4: The plot of coefficient of drag vs the function of time.

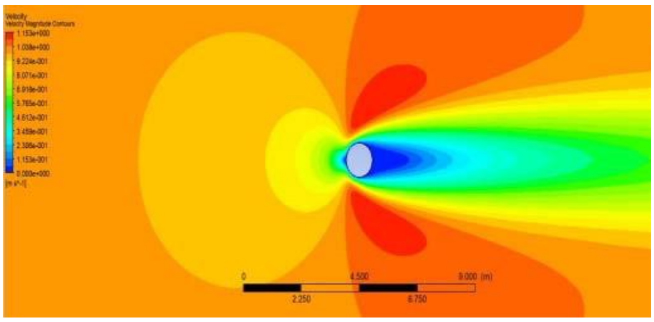


Figure 5: Contour Velocity flow field.

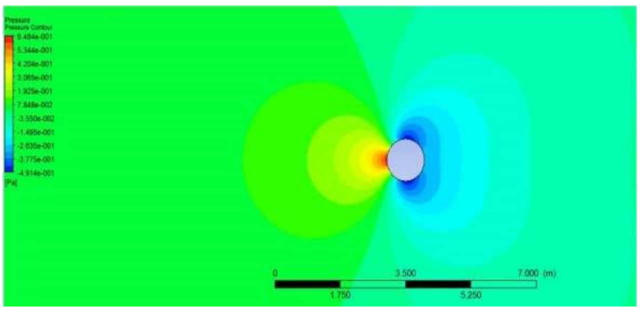


Figure 6: Contour distribution of pressure.

3. Structural design and Analysis

The model is designed in the CATIA V5 software and stp.file is imported in ANSYS 2022 as shown in Fig 1.This structure is designed in a cylindrical cone tapering down from top .A tapered or non-tapered cylindrical construction can be used to represent the vortex bladeless turbine. But the tapered cylindrical structure is the most suitable alternative to supply the vortex shedding property of fluid flow and therefore the oscillation is produced due to its simple aerodynamic shapes[11].

Static analysis and CFD analysis of vortex bladeless wind turbine is carried out in ANSYS software version 22 to determine the deflection values of the windmill. The finite element analysis (FEA) method consist of CAD modelling, pre-processing, solution and post processing steps. The finite element analysis approach is used to calculate natural frequency. During the modelling and analysis process the input parameter inserted are load conditions, materials, meshing size etc. The pressure value calculated by the Eq(3).It comes approximately 120Pa. And taking the velocity of air passing around the bluff body at 8m/s. The two materials carbon fibre and glass fibre are taken in Ansys engineering data library with their defined parametric values. The motive of selecting this material is that they are most suitable for the bladeless wind turbine and the use of this material in wind power generation industry is common.

Glass fiber consist of mechanical properties to other fibers such as polymers and carbon fiber. Glass fiber is a composite material composed of fiberglass and polyester resin. It need less lift force since the load of the glass fiber is less, allowing for reaching natural frequency oscillations at lower velocity. When comparing the two materials, fiberglass can withstand both compressive and tensile forces. The easy availability and affordability of glass fiber makes good choice than carbon fiber. Various machining procedures can be avoided, and it can be produced in a variety of geometric shapes, enhancing its suitability as an airfoil material. For these reasons fiber material is selected for the mast design and nylon is selected as rod material due to its flexibility, light weight and easy availability [11]. Ansys' finite element method is a numerical method for solving engineering problems. In the finite element method, the description of the problem leads to a system of algebraic equations. This method approximates an unknown value from a discrete number of points in the region. Break large tasks into simpler parts called finite elements. FEM employs variational method from the calculus of variations by minimizing the error function to approximate the solution of a problem. The boundary condition and meshing is applied on the models. The boundary condition for the model is setting the known values for displacement or load. The total deformation values of models with their maximum and minimum deflection are noted in the table [2].Meshing is performed on the model with element size of 20 mm[15]. The different length size of mast and rod are mention in table [1].Along with the parameter like maximum diameter(Dmax),minimum diameter (Dmin),diameter of rod (d) are also mentioned. The range of modal frequency performed in modal Analysis is given in table 3.The range of frequency was set between 1 to 1000Hz for 10 modes. The displacement of bottom end of rod is fixed in all directions and the above portion of the mast is kept free to move in all direction to have maximum displacement at the mast.

Pressure value is obtained using equation,

$$P=F/A \quad (3)$$

Where, P= Pressure acting on the surface of the mast

F=Force acting

A= Area of the frustum

Force is calculated using the equation

$$F=0.5\rho u^3 DLC \quad (4)$$

Where, ρ=Density of air (1.225Kg/m^3)

D=Average diameter

L=Total length of BWT

C= Coefficient of lift force (0.6)

U= Velocity of air taken as 8m/s

Substituting the above value in Eq(4)

$$F=0.5\times1.225\times8^3\times0.12\times2.70\times0.6$$

$$=60.96N$$

Area of frustum $=\pi\times r\times L_1$

Where, r= Average radius of frustum

L_1= Length of mast,

Substituting the values area is obtained approx.(0.508m^2).

Substituting the values of F and A in Eq(3) Gives the pressure as approximately 120 Pa.

4. RESULT AND DISCUSSION

From the study and analysis performed in the Ansys software on the both material carbon fiber and glass fiber of different length and parameter input the output we get through this is that glass fiber is the suitable material for fabricating the bladeless wind turbine as is shows the maximum deflection among both materials. We also found that as the length of the turbine increased the deflection increased producing maximum power. The pressure applied on the mast structure is calculated with the help of Eq(3). Deflection are obtained from the structural analysis by the application of pressure 120 Pa across the frustum surface by considering air velocity as 8 m/s. Bladeless windmill produces the electricity for household where less amount of electricity is required. It has a simple structure, simple design, easy manufacturing, and small installation space, making it a suitable solution compared to existing windmills. An added benefits is lower maintenance costs due to fewer moving parts .The result show that bladeless wind turbine are the good option for wind power generation because of their advantages over traditional giant wind turbine. The phenomena of vortex shedding is performed in Fluent analysis applying the boundary condition in the fluid flow. The frequency of the model is obtained by modal analysis in the ANSYS software. The various frequencies produced by the different models are shown in Modal Analysis Fig (A-F).

The bladeless turbine has immense potential to harness the wind energy and generate electricity and small scale which can be used to supplied the electricity in rural areas. As compared to the conventional wind turbine the efficiency to produce energy is less but still for small scale energy generation it is a good option to implement. The challenge of the bladeless turbine technology is the orientation and integration of the generators. A piezoelectric material or linear energy collector may be a suitable solution for theses generators. Also the linear alternator are used to generate the electricity.

Table 1: Dimensions for the model. [16]

Sr.no	Parameter	Dimensions(mm)		
		1	2	3
1.	D_{max}	150	210	270
2.	D_{min}	90	90	90

3.	d	30	30	30
4.	L_1	2400	2100	1800
5.	L_2	350	400	450
6.	L	2750	2500	2250

Table 2: Total deflection of carbon fiber and glass fiber.

Sr.no	Material	Maximun Deflection(mm)	Minimun Deflection(mm)
1	Carbon FiberL2750	0.0015052	0
2	Carbon FiberL2500	0.0011173	0
3	Carbon FiberL2250	0.0017478	0
4	Glass Fiber L2750	258.08	0
5	Glass Fiber L2500	370.42	0
6	Glass Fiber L2250	421.38	0

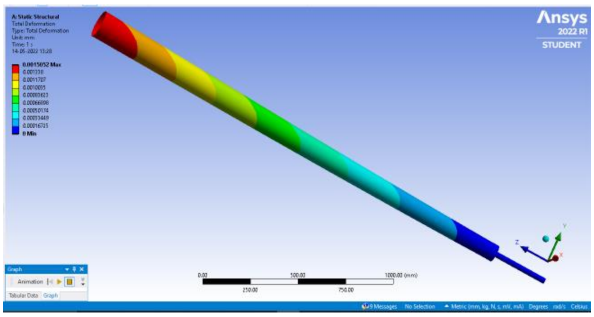
Table 3: Frequency range variations

Sr.no	Model	Model Frequency(Hz) Maximum	Model Frequency(Hz) Maximum
1	Carbon FiberL2750	358.75	7.188
2	Carbon FiberL2500	407.91	7.082
3	Carbon FiberL2250	330.07	6.135
4	Glass Fiber L2750	1.12	0
5	Glass Fiber L2500	1.64	0
6	Glass Fiber L2250	1.72	0

5. CONCLUSION

In a developing country like India, having more rural population and condition suiting for electricity generation through bladeless wind turbine is the best solution. India is focusing on increasing the percentage of renewable energy for electrical power and provides energy more economically. In this study the static structural and modal analysis is performed on the various different length of mast and two different material that are carbon fiber and glass fiber are taken in consideration .From the observation it is found that the displacement value obtained under the static analysis in glass fiber material is greater compared to the carbon fiber .The length of mast and rod also plays an important role in extracting the power at good frequency. Among both material glass fiber is superior to carbon fiber in terms of amplitude of oscillation and therefore fiberglass material is best choice for bladeless turbine .The von Karman effect is also studied. The forces required to generate power in bladeless turbine is different from that of a conventional wind turbines. This device traps the energy of vorticity. As the wind travels through a structure, the flow direction reverses, forming cyclical vortices.

Static Structural Analysis



(A) Carbon fiber L2750

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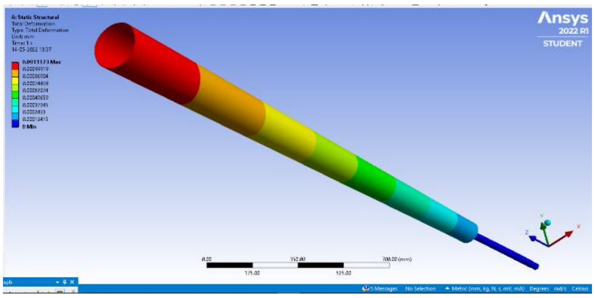
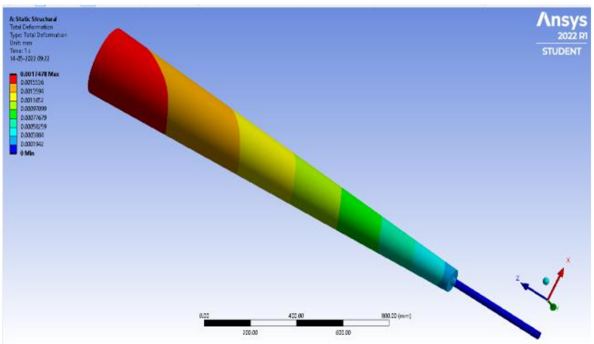
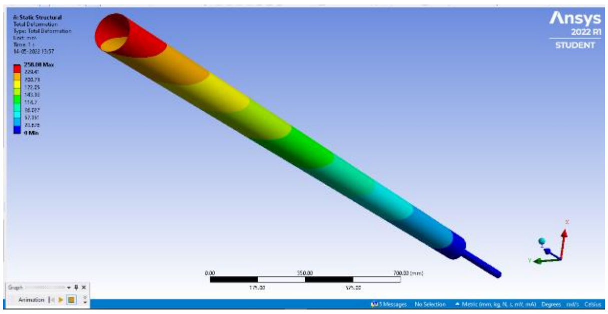


(B) Carbon fiber L2500

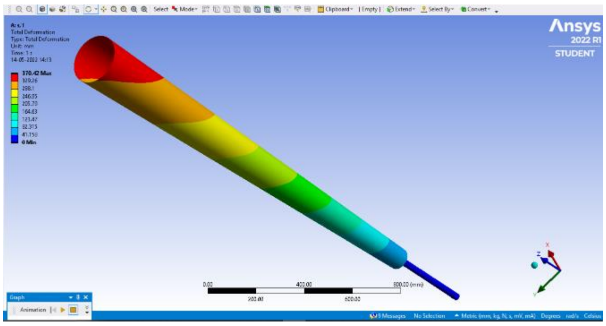


(C) Carbon fiber L2250

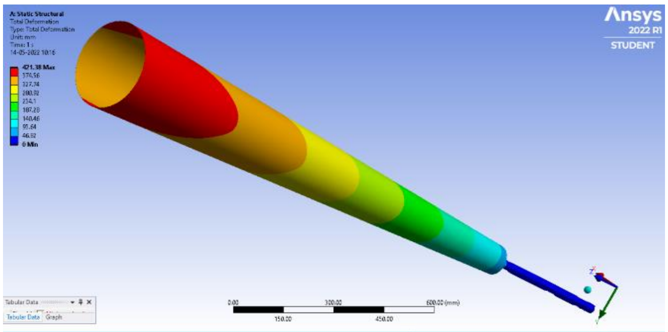
It is never practicable to use a traditional wind turbine in a smaller area or at a cheaper cost. Therefore the main advantage of this turbine is that it require less space, cost efficient and hence most suitable for rural area electrification in India.



(D) Glass fiber L2750

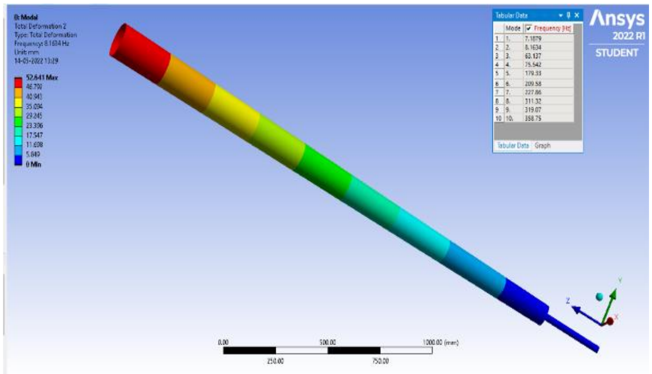


(E) Glass fiber L2500

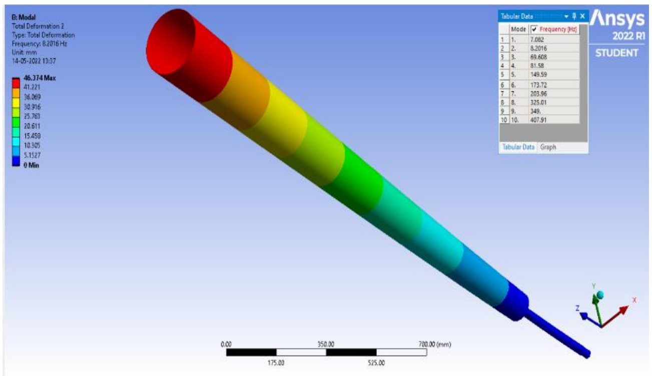


(F) Glass fiber L2250

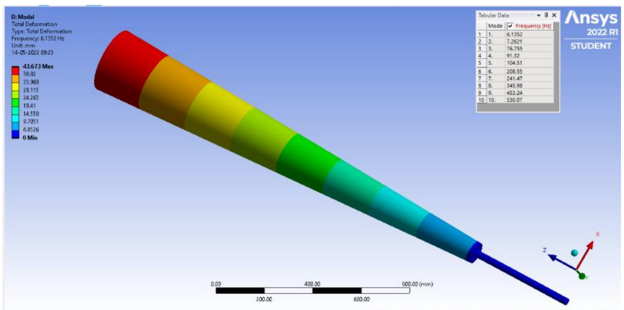
Modal Analysis



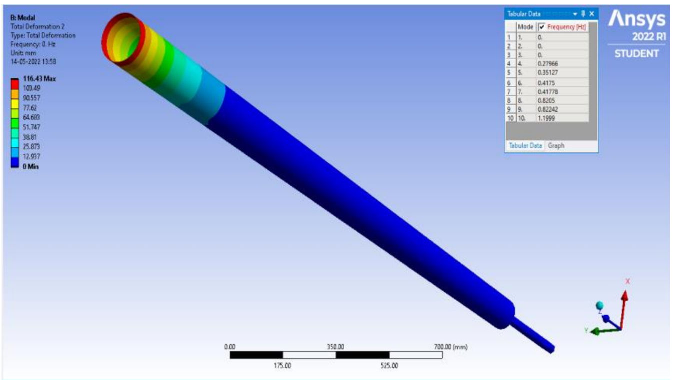
(A) Carbon fiber L2750



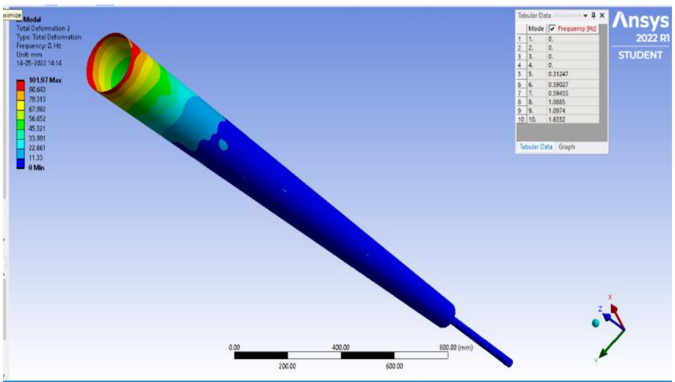
(B) Carbon fiber L2500



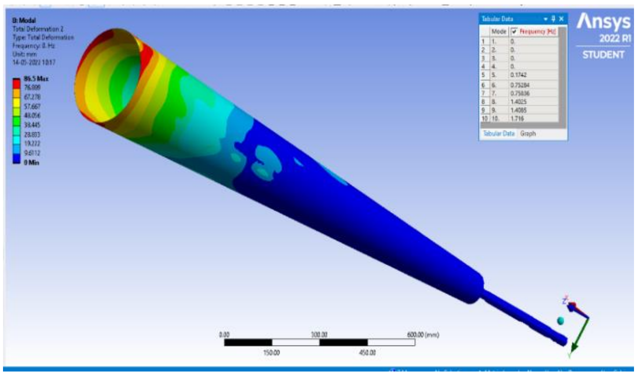
(C) Carbon fiber L2250



(D) Glass fiber L2750



(E) Glass fiber L2500



(F) Glass fiber L2250

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