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Fabrication Methodology of Small Scale Horizontal Axis Wind Turbine

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Abstract : Due to the increasing environmental and economic cost of fossil fuels, alternative sources of energy are needed. One such source is wind energy. Much of the current wind turbine research focuses on large-scale wind turbines. An alternative approach is small-scale wind turbines designed specifically to produce power at low wind speeds. The mechanism is that the wind drives the blades, which in turn drive the compound gear train, which eventually is coupled to a generator. The DC power from the generator can either be used directly or converted to AC power and then used or stored in a battery for future use.

While these results provide valuable information for the design of small-scale wind turbines, further study into the design process would result in an improved performance using CFD techniques as well as experimentation. This paper includes design and analysis of a light weight and small size turbine without compromising its performance.

Key words : DC Generator, Horizontal Axis Wind Turbine.

1. INTRODUCTION

Wind is the motion of air masses produced by the irregular heating of the earth’s surface by sun. Wind energy is not a constant source of energy. It varies continuously and gives energy in sudden bursts. About 50% of the entire energy is given out in just 15% of the operating time. Wind strengths vary and thus cannot guarantee continuous power.
The power extracted from the wind can be calculated by the given formula:

$$P_W = 0.5\,\rho\,\pi R^2\, V_w^{\,3}\, C_P(\lambda, \beta)$$

Where,
P_W = extracted power from the wind,
ρ = air density,
R = blade radius (in m),
V_W = wind velocity (m/s)
C_P = the power coefficient which is a function of both tip speed ratio (λ), and blade pitch angle, (β)(deg.)
Tip speed ratio (λ) can be defined as the ratio of blade velocity at the tip to the velocity of wind.

Paul Gipe [1] has written extensively about renewable energy for both popular and trade press. He has also lectured widely on wind energy and how to minimize its impact on the environment.

James Edward Hansen [2] research is in the field of climatology is unparalleled and provides a guidance for us for development of novel technologies. Johnson [3] knowledge on wind energy is commendable and it provides us a reference for calculating the wind energy that is available at any location based upon the latitude and longitude.

Frank Travanty [4] has carried out his work in tower and antenna wind loading as a function of height and determines the maximum safe height of installing the freestanding tower. Karam Maalawi [5] has studied about aerodynamics of the wind turbines blades, thereby he provides us the basic concept of selection of wind turbine blades profiles that will be best suited for the power requirement based upon the wind velocity available in that location.

In wind turbines, the blade speed is usually affected by several factors namely

- Velocity of wind
- Blade Profile
- Angle of attack
- Back pressure created by nacelle.

Our main aim is to increase the blade velocity in order to increase the power generated by the wind turbine. Of the aforementioned factors, we assume input wind velocity to be constant as it is an uncontrollable factor.

In any wind turbine blade design, it is necessary to consider the surrounding environmental conditions. The reason for this is simply because there is no perfect blade for every single location. The blades are responsible for taking a force moving along the surface of the earth and converting that force into a rotational one capable of spinning the generator shaft.

For a desirable wind turbine, lift force should be maximum and drag force should be minimum. These limits are governed by the Angle of attack. Lift force is the component of force which acts perpendicular to the direction of wind flow and is responsible for rotation of blades. Drag force, on the other hand, acts in the same direction as that of the wind and is considered a nuisance.

Back-pressure created on the downstream side of the blade is proportional to the cross sectional area of the nacelle. In any case, the backpressure cannot be completely eliminated. However, the design of the nacelle can be carefully selected so as to minimize the backpressure created.

2. METHODOLOGY

Nacelle is basically a housing which supports the major components of the wind turbine. Various shapes were considered for the design of nacelle. Cuboid was not considered because of the large volume it occupies. Cylindrical was not chosen so as to reduce the turbulent air contact with nacelle covering as it flows towards its rear end, thereby reducing the amount of back pressure created. So, the nacelle is tapered from front end to rear end with circular cross section. Base is flattened in order to easily mount it on the Yaw mechanism.

Blade was designed considering the factors namely available wind velocity, cut-in speed (minimum wind velocity at which the turbine starts generating power). In the scenario considered, the minimum available wind velocity being 3m/s, blade profile NACA 4412 (Figure 1) was selected with an angle of attack of 10 degrees.

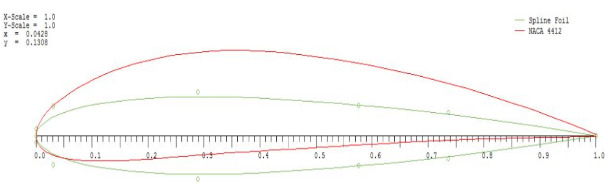

Figure 1: NACA 4412 blade profile section

A gear is a component having number of cut portions over it surface internally or externally called teeth. In case of wind turbines, the gears used are usually external gears. They are used to transmit torque from driver end to the driven end. A gear is a component having number of cut portions over it surface internally or externally called teeth. In case of wind turbines, the gears used are usually external gears. They are used to transmit torque from driver end to the driven end.

The compound gear train, for the gear box of the wind turbine, was designed with the sole motive of achieving an overall gear reduction of 20. The dimensions of the gears were so chosen that the different gear loads, namely tangential load, static load and dynamic load, are well within the limits to avoid any instances of failure.

Module was considered as 2mm to aid fabrication process.
m = 2mm
a = addendum = 1*m = 2 mm
Dedendum = 1.25*m =2.5 mm
Hole depth = 2*a = 4 mm
Circular pitch = Π*m = 6.28 mm
Minimum total depth = 2.25*m = 4.5 mm
Tooth thickness = 1.5708*m = 3.14 mm
Minimum clearance = 0.25*m = 0.5 mm.

A Shaft is a component that transfers force from one end to the other through rotation due to incoming forces. They are subjected to shear stress and torsion and therefore should be strong enough to withstand those. The weight must be considered because it increases the inertia. The shaft was designed for combined bending and torsional moments. The shaft and hub assembly is shown in the Figure 2.

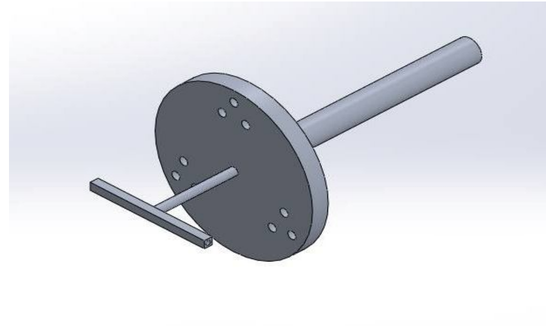

Figure 2: Shaft and hub assembly

$$P = \frac{2*\pi*N*T}{60}$$

$$M = \frac{W_N L}{4}$$

$$T_e = \sqrt{T^2 + M^2}$$

$$T_e = \frac{\pi}{16}\tau_s d^3$$

Where P = Power (W)
M = Bending moment (N-m)
T = Torsional moment (N-m)
T_e = Equivalent Torsion (N-m)
d = Diameter of shaft (m)

Using the above calculations we obtained diameter of desired shaft as 0.03m.

Hub is usually a circular component that rides blades over it in simple horizontal axis wind turbines. In advanced level the blades are mounted over the pitch mechanism that automates the angle of attack and indeed the pitch mechanism is fixed to the hub. To this hub is the driver shaft attached that transfer rotational power to generator using mating gears mechanism to produce energy. In first hand, the entire aerodynamic force acts over the hub. Therefore hub should be strong enough to withstand the weight, drag and harmonic forces from blades and self-weight of shaft.

Bearing were selected for the shafts and yaw mechanism to suit the requirements. A roller bearing was used for yaw mechanism and ball bearings were used for shafts.

Once the design specifications were obtained, simulations were carried out using ANSYS, to ascertain that the components were safe for operation.

Boundary conditions considered for simulations performance are

- Nacelle – Flat base was fixed and axial and rotational loads were applied at the points where shafts are being passed (Figures 3and 4).
- Blade – Stem was fixed and centrifugal force was applied at the tip.

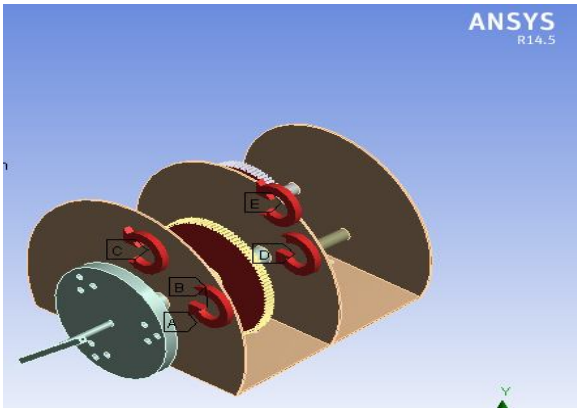

Figure 3: Rotational loads on nacelle

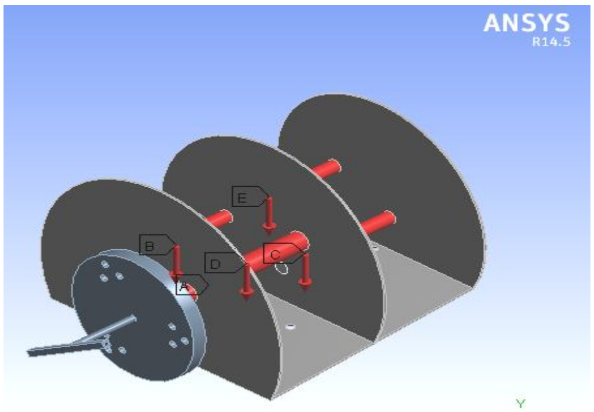

Figure 4: Point loads on nacelle

- Shaft and hub assembly - shaft is fixed and load corresponding to weight of blades is applied on hub (Figure 5).

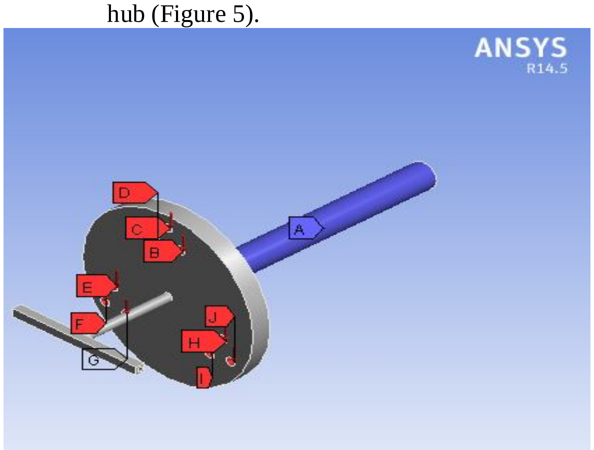

Figure 5: Loads on shaft and hub assembly

3. RESULTS AND DISCUSSIONS

The nacelle was meticulously designed so as to achieve minimum weight of 23 Kg's.

Structural analysis was performed on the nacelle and results for total deformation, elastic strain and Von-misses stress are shown in Figure 6, Figure 7 and Figure 8.

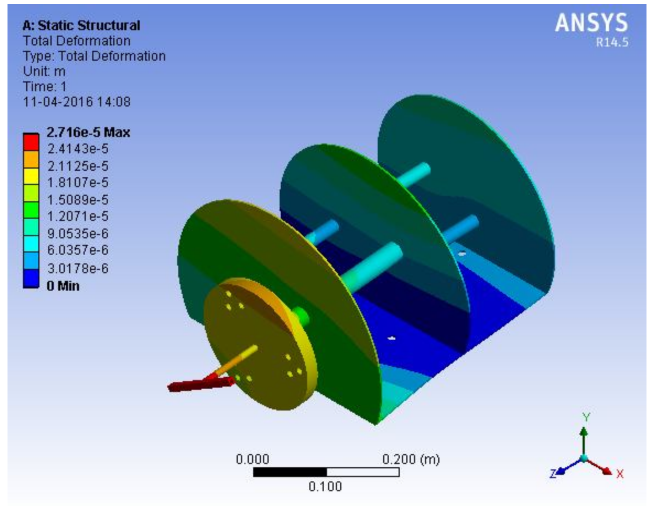

Figure 6: Total deformation of nacelle

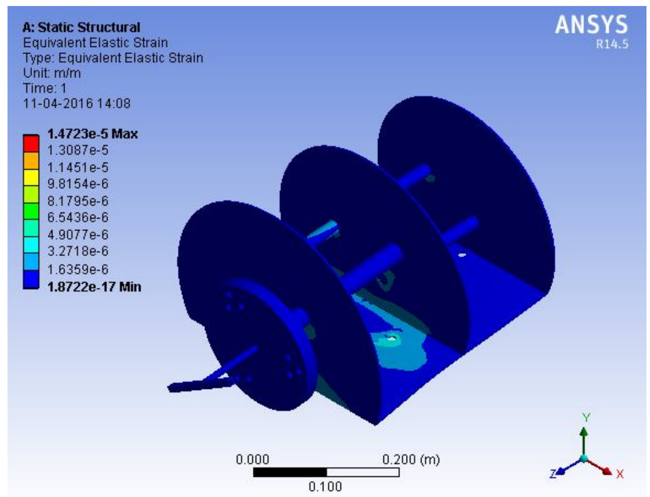

Figure 7: Elastic strain distribution on nacelle

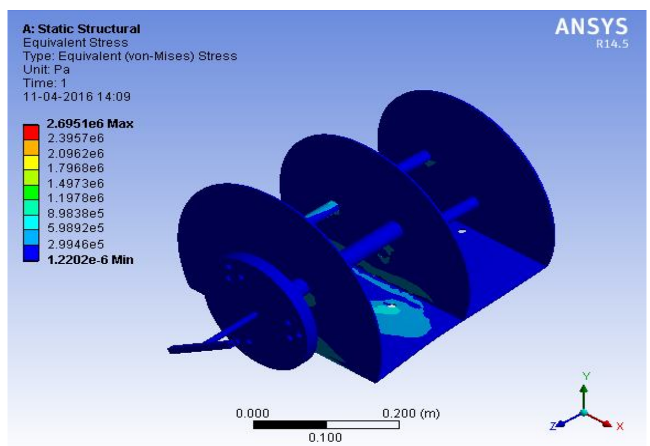

Figure 8: Von-Misses stress on nacelle

The results obtained were 2.716e-005 m as Maximum deformation, 1.8722e-017 and 1.4723e-005 as Minimum and Maximum strain respectively and 1.2202e-006 N/m^2 and 2.6951e+006 N/m^2 as Minimum and Maximum stresses developed respectively.

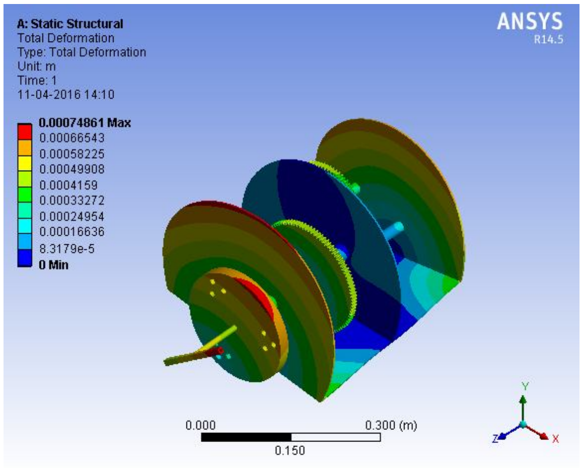

Figure 9: Nacelle deformation when gears rotate

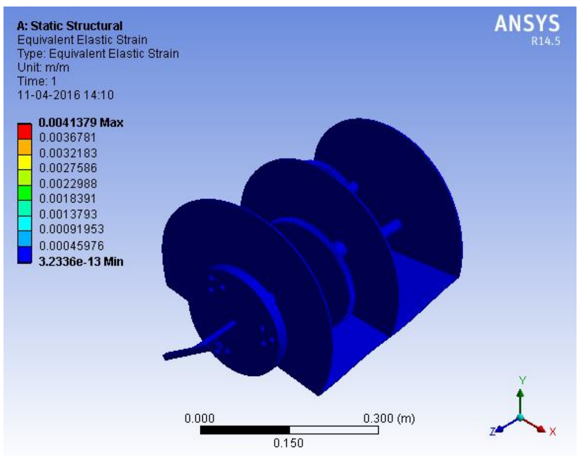

Figure 10: Nacelle strain when gears rotate

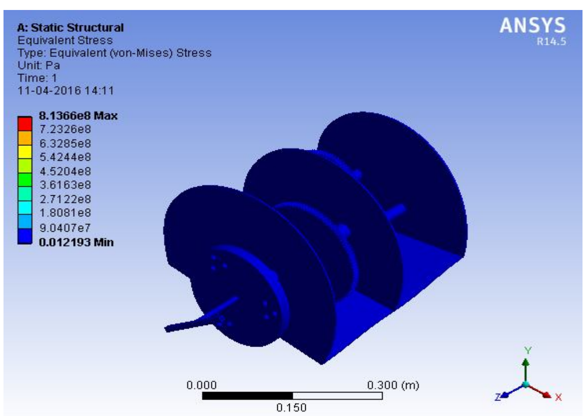

Figure 11: Nacelle stresses when gears rotate

Figure 9, Figure 10 and Figure 11 indicate the deformation, strain and stresses induced in the Nacelle assembly when the gears are rotating.

Hub should withstand the dynamic loads acting on it due to blades in the form of their self weight, centrifugal forces and the pressure from the incoming wind. Analysis of the shaft and hub assembly is carried out based on the above mentioned loads.

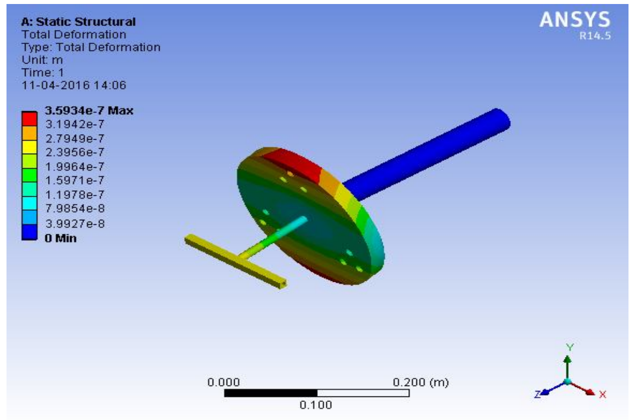

Figure 12: Total deformation of hub and shaft

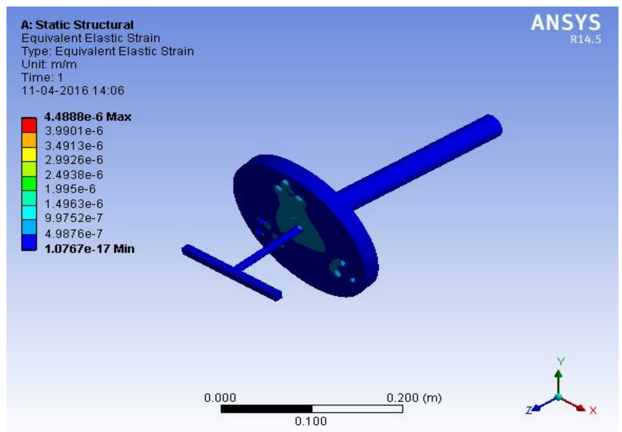

Figure 13: Elastic strain of hub and shaft

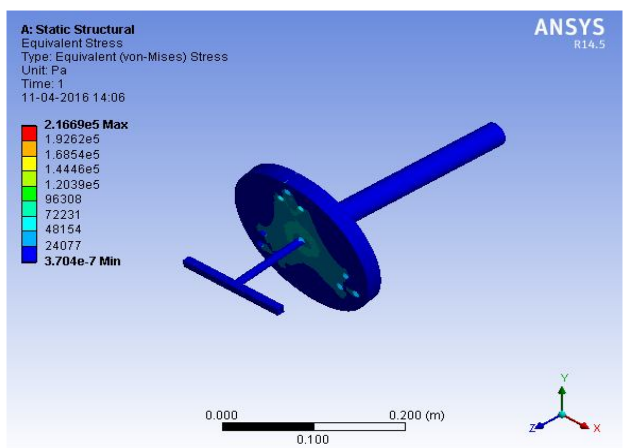

Figure 14: Von-Misses stress on hub and shaft

Figure 12, Figure 13 and Figure 14 represent the deformation, strain and von-misses stresses induced on the hub and shaft assembly after applying the constraints based upon the total assembly of the wind turbine set up.

The Maximum deformation obtained is 3.5934e-007 m. The Minimum and Maximum strain obtained are 1.0767e-017 and 4.4888e-006 respectively and Minimum and Maximum stresses are 3.704e-007 N/m^2 and 2.1669e+005 N/m^2 respectively.

To optimize on minimum cost of energy requires a multi-disciplinary method that includes an aerodynamic model, a structural model for the blades, along with cost models for the blades and all the major wind turbine components. The blade of profile NACA 4412 is made up of Fiber glass. Fiber glass is the material which was zeroed in taking into consideration all the above points. Sharp edges are avoided to reduce stress concentration and to increase the life of the blades. Length of each blade is 1 meter thereby producing a blade sweep diameter of around 2 meters.

As the forces were applied on the outer edge of blade, the results obtained are as shown in Figure 15, Figure 16 and Figure17.

Figure 15 indicates the total deformation of the blade based upon the dynamic loads and static loads acting on the blade. Figure 16 and figure 17 indicate the strain and stress induced in the blade respectively.

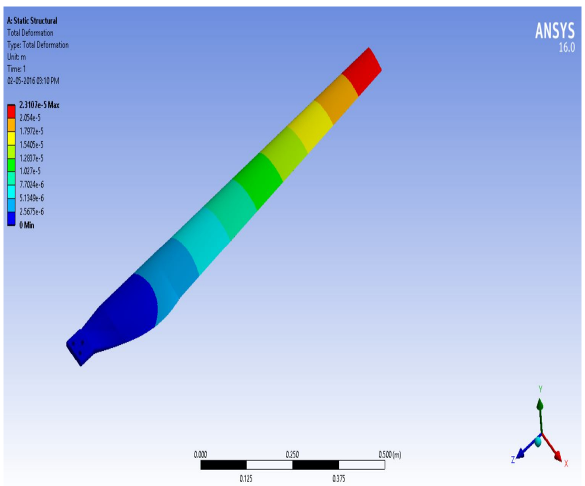

Figure 15: Total deformation of blade

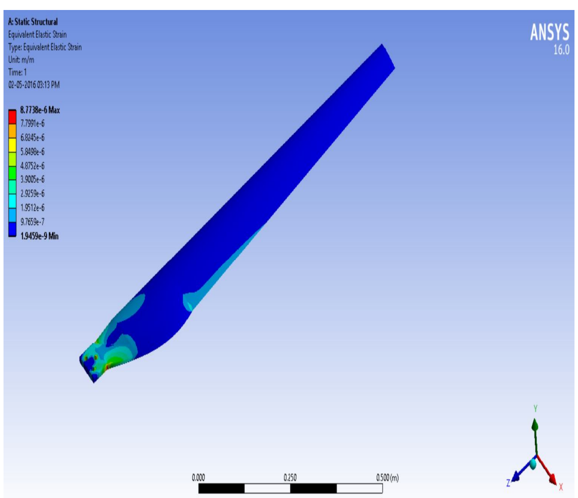

Figure 16: Elastic strain of blade

Self weight of 25 N and Centrifugal force of 50 N is acting on the blade. The Maximum deformation was 2.3107e-5 m. The Minimum and Maximum strains developed are 1.9459e-9 and 8.7738e-6 respectively. The Minimum and Maximum stresses produced are 384.25 N/m^2 and 1.7464e+6 N/m^2 respectively.

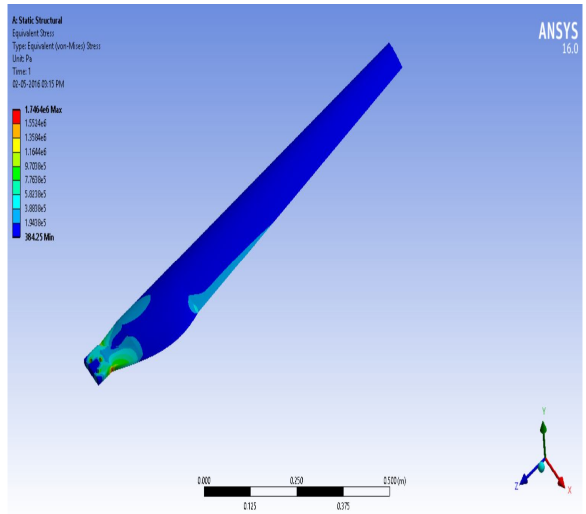

Figure 17: Equivalent stress of blade

4. CONCLUSIONS

The assembly of all the components of the Horizontal Axis Wind Turbine is done successfully. The analysis was done by keeping factor of safety as 3.

Loading values on nacelle where 0.45 N, 15 N and 9 N. The results obtained were 2.716e-005 m as maximum deformation, 1.8722e-017 and 1.4723e-005 as minimum and maximum strain respectively and 1.2202e-006 N/m^2 and 2.6951e+006 N/m^2 as minimum and maximum stresses developed respectively.

Figure 18: The hub assembly with gear system

Loading values on hub were 21810 N/m^2 acting on each set of three holes with the shaft being fixed. The Maximum deformation obtained is 3.5934e-007 m. The Minimum and Maximum strain obtained are 1.0767e-017 and 4.4888e-006 respectively and Minimum and Maximum stresses are 3.704e-007 N/m^2 and 2.1669e+005 N/m^2 respectively.

Figure 18 indicates the assembly of the hub with the gear system for obtaining desired speeds of the system. Figure 19 shows the assembly of the wind turbine with the blade assembly.

Figure 19: The complete assembly of wind turbine

Thus, a small scale Horizontal Axis Wind Turbine is developed which can generate a maximum of 1 kW power. This turbine was built taking into consideration all the difficulties that would be experienced while it is being erected and put into use.

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