IOP Conf. Series: Materials Science and Engineering **197** (2017) 012044 doi:10.1088/1757-899X/197/1/012044

Design and Analysis of Wind Turbine Blade Hub using Aluminium Alloy AA 6061-T6

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Abstract: This work presents the design and analysis of horizontal axis wind turbine blade hub using different material. The hub is very crucial part of the wind turbine, which experience the loads from the blades and the loads were transmitted to the main shaft. At present wind turbine is more expensive and weights more than a million pounds, with the nacelle, rotor hub and blades accounting for most of the weight. In this work Spheroidal graphite cast iron GGG 40.3 is replaced by aluminium alloy 6061-T6 to enhance the casting properties and also to improve the strength-weight ratio. This transition of material leads to reduction in weight of the wind turbine. All the loads caused by wind and extreme loads on the blades are transferred to the hub. Considering the IEC 61400-1 standard for defining extreme loads on the hub the stress and deflection were calculated on the hub by using Finite element Analysis. Result obtained from ANSYS is compared and discussed with the existing design.
Key words: Cast iron GGG 40.3, Aluminium alloy 6061 T-6, IEC 61400-1 standards, Extreme loads, Finite element analysis, ANSYS.

1. Introduction

A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy; a process known as wind power. If the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Similarly, it may be referred to as a wind charger when used for charging batteries. The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types.Fig.1 represents the image of Horizontal Axis Wind Turbine components.

Ali Muhammad et al [1] explained about Modern mega watt class wind turbines are exposed to high and complex loads. The influence of the manufacturing process on material properties is investigated includes the simulation of fatigue life and refining the existing material models lead to a more efficient utilization of the material. Arvind singh rathore et al [2] discussed an optimization model for rotor design of 750 kW horizontal axis wind turbine. In this work a blade of length 21.0 m is taken and airfoil for the blade is S809.The airfoil taken is same from root to tip. All the loads caused by wind and inertia on the blades are transferred to the hub. The stress and deflection were calculated on blades and hub by Finite element analysis method. The maximum stress in the model is less than maximum allowable stress. Tony Burton et al [3] give the information about wind resources, various theories, co-ordinates, performances related to wind turbine. It also describes about various type of geometries of turbine, different loads acting on the wind turbine and all the fundamentals of wind turbine.

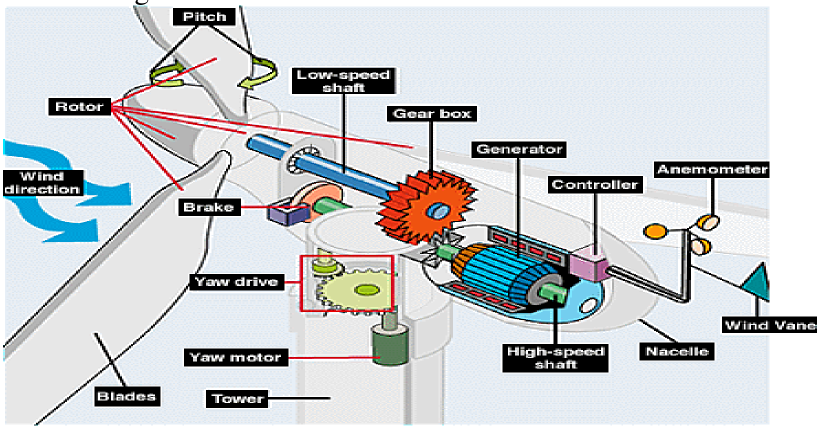

Figure.1 Components of Horizontal Axis Wind Turbine

Vinay V. Kuppast et al [6] study of effect of vibration characteristics of aluminium alloys of different compositions. The modeling and analysis is carried out using ANSYS software. Young's Modulus and the ultimate tensile strength of the 380 alloys increase with the increase in copper and silicon content. Deformation is least in case of 380 alloys and is recommended for low vibration applications.IEC-61400 [7] is an international standard published by the international Electro technical Commission regarding wind turbines. It is a set of design requirements made to ensure that wind turbines are appropriately engineered against damage from hazards within the planned lifetime. Wind classes determine which turbine is suitable for the normal wind conditions of a particular site. Turbine classes are determined by three parameters - the average wind speed, extreme 50-year gust, and turbulence. In this work aluminium alloy 6061-T6 is chosen as an alternativefor the wind turbine hub to reduce the strength-weight ratio and gradual decrease in cost of production.In ANSYS both the materials existing and proposed material are analysed under IEC 61400-1 load cases and the results of total deformation and equivalent stress is taken for comparison.

2.Experimental Set Up

The aim of the project is to reduce strength-weight ratio and decrease in cost by changing material of hub. A 3D model is designed in Pro-E and it analysed in ANSYS for both existing material and an aluminium alloy. After analyzing both the results are compared and fatigue analysis is made for aluminium alloy in order to determine whether it is capable in environmental conditions.

2.1 Mechanical properties and chemical composition of materials for study

Table 1 and 2 represents the mechanical properties and the chemical composition of the materials to study.

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Table 1 Mechanical property of materials for study

Properties	Aluminium alloy 6061 T6	Cast Iron
Density	2700kg/m³	7100 Kg/m³
Tensile Strength	310Mpa	370Mpa
Yield Strength	218Mpa	250Mpa
Poisson's Ratio	0.32	0.27
Young's Modulus	69000Mpa	169000Mpa

Table 2 Chemical composition of materials for study

Aluminium alloy 6061 T6		Cast Iron	
Mg	0.937	C	3.4
Si	0.535	P	0.1
Fe	0.139	Mn	0.4
Ti	0.012	Ni	1.0
Mn	0.022	Mg	0.06
Zn	0.0983	-	-
Cr	0.022	-	-
Ni	0.005	-	-
Al	98.096	-	-

2.2Model of hub

The 3D model of the hub is modelled using the software PRO/E. PRO/E is widely used software to model the three dimensional model due to its user friendly options compared to other similar software's. The 3D model is imported to ANSYS for analysis. In order to import the model is converted into global file format namely .stp format. After converting the file into .stp format the file is imported into ANSYS. Fig. 2 (a) and (b) represents 3D model of wind turbine rotor hub and meshing of wind turbine rotor hub.

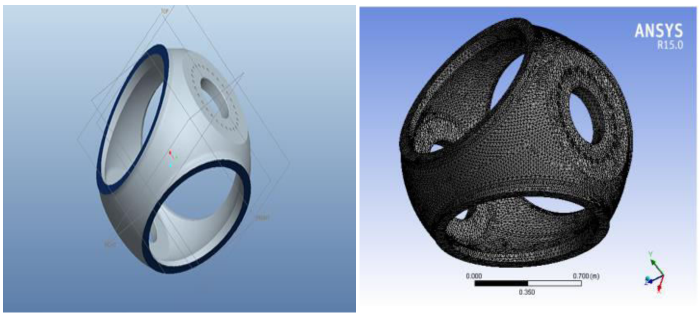

Figure. 2(a) 3D model of wind turbine rotor hub (b) Meshing of wind turbine rotor hub

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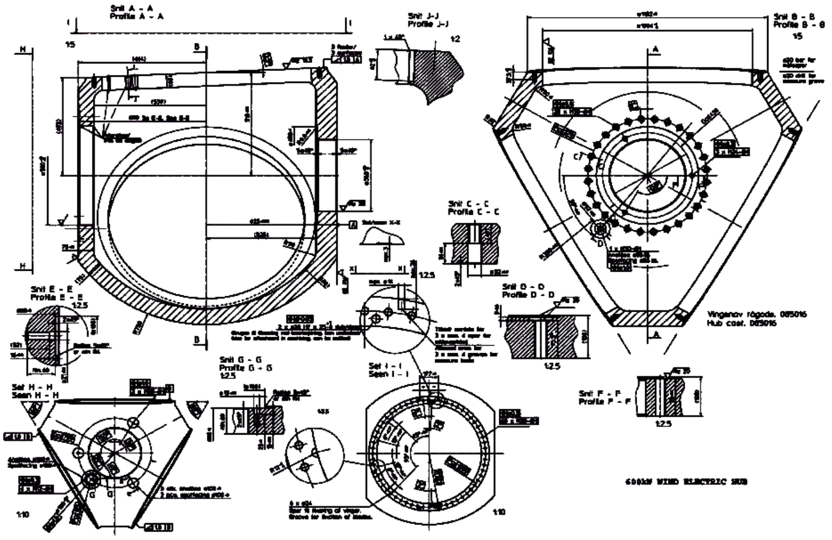


Figure. 3 2D Dimensions of 600KW Horizontal Axis Wind Turbine (SUZLON Energy)

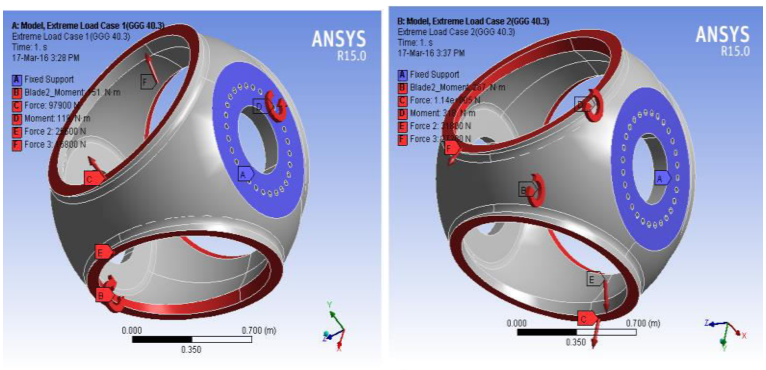
2.3Extreme load cases on hub from IEC 61400-1

Moments and forces on the hub can then be determined from the blade forces. For a rigid rotor turbine, both flapping and lead lag moments are transmitted to hub, usually flapping is the predominant one. The blade root bending moment for each blade is $M_\beta = K_\beta * \beta$

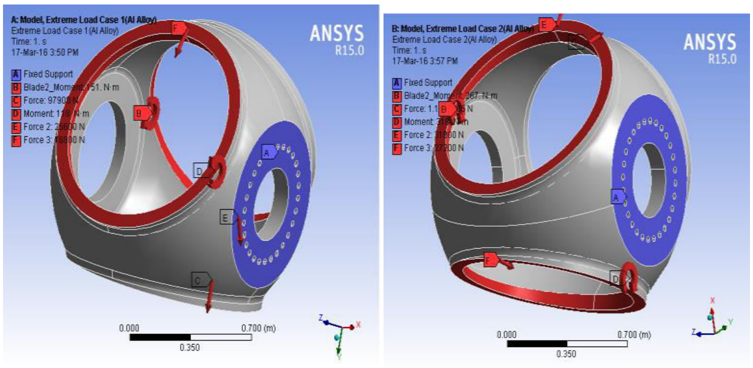
Table 3 Extreme loads on hub from IEC 61400-1

B.M & Forces	Load Case-1	Load Case-2
301 Hub1 Mx KNm	118	-318
302 Hub1 My KNm	151	267
303 Hub1 Fx KN	25.6	31.8
304 Hub1 Fy KN	16.8	27.2
305 Hub1 Fz KN	97.9	114

2.4Analysis of materials for study



(a) (b)



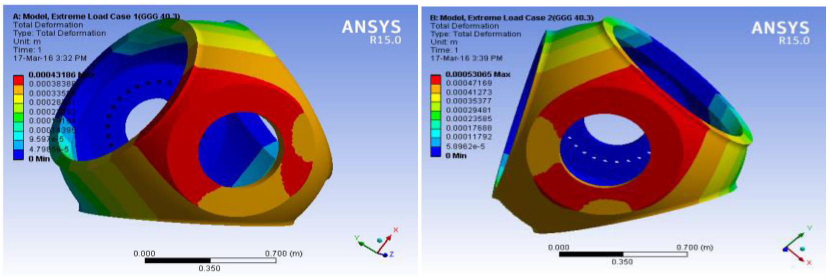
(c) (d)

Figure. 4 (a), (b) Load case 1&2 for GGG 40.3 (c), (d) Load case 1&2 for aluminium alloy materials

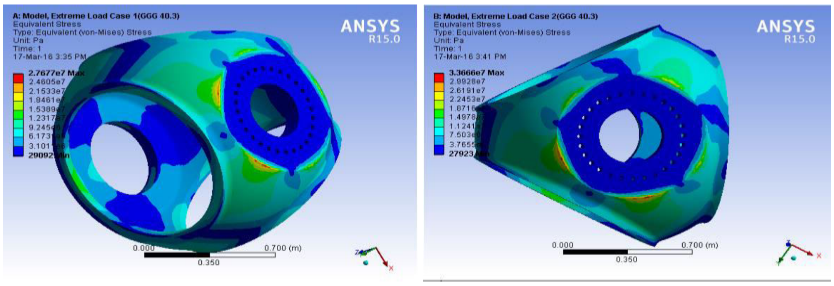
3.Results and Discussion

3.1Results of cast iron (GGG 40.3) for load case1and 2

GGG 40.3 is a german standard from DIN 1693 which is also called spheroidal graphite cast iron. Due to the spherical formation of the graphite, The ductile cast iron acquires special properties compared to the flake graphite; tensile strength, yield strength are improved, expansion and impact strength are increased. Deformation describes the transformation from initial to final geometry. The collective displacement of points in a body relative to an external reference frame is known as deformation. Fig 5(a) represents the total deformation change in the existing material i.e cast iron GGG 40.3 for 1 sec. The blue indicates the minimum value of 0m and red indicates the maximum value of 0.00043186m. Fig 5 (b) represents the total deformation change in the existing material i.e cast iron GGG 40.3 for 1 sec. The blue indicates the minimum value of 0m and red indicates the maximum value of 0.00053065m.The von-mises stress is often used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition.Fig 5(c) represents the equivalent stress change in the existing material i.e cast iron GGG 40.3 for 1 sec. The blue indicates the minimum value of 29092 Pa and the red indicates the maximum value of 2.7677e7 Pa. Fig 5(d) represents the equivalent stress change in the existing material i.e cast iron GGG 40.3 for 1 sec. The blue indicates the minimum value of 27923 Pa and the red indicates the maximum value of 3.3666e7 Pa.



(a) (b)

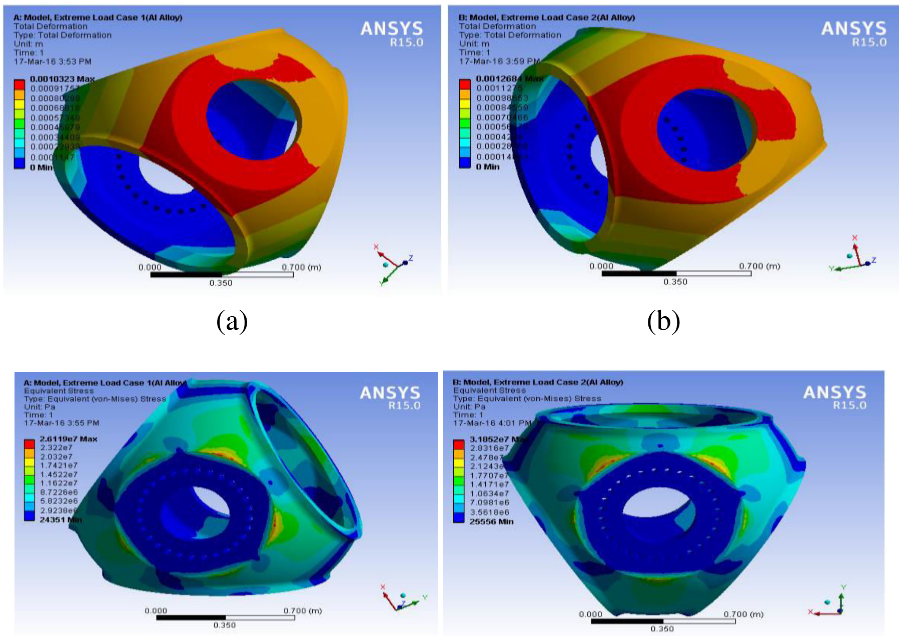


(c) (d)

Figure. 5(a), (b) Deformation for Load case 1&2 for GGG 40.3,
(c), (d) Stress for Load case 1&2 for GGG 40.3

3.2Results of Aluminium alloy for load case1and 2

Aluminium alloy6061 is a precipitation –hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. T6 temper 6061 has an ultimate tensile strength of at least 3000 MPa and yield strength.Change in the shape of a body caused by the application of a force (stress). Deformation is proportional to the stress applied within the elastic limits of the material. A deformation may be caused by external loads, body forces (such as gravity or electromagnetic forces), or changes in temperature, moisture content, or chemical reactions, etc.Fig 6(a) represents the total deformation change in the existing material i.e Aluminium alloy 6061 T-6 for 1 sec. The blue indicates the minimum value of 0m and red indicates the maximum value of 0.0010323m. Fig 6(b) represents the total deformation change in the existing material i.e Aluminium alloy 6061 T-6 for 1 sec. The blue indicates the minimum value of 0m and red indicates the maximum value of 0.001268m. Equivalent stress is used to predict yielding of materials under multiaxial loading conditions using results from simple uniaxial tensile tests.Fig 6(c) represents the equivalent stress change in the existing material i.e Aluminium alloy 6061 T-6 for 1 sec. The blue indicates the minimum value of 24351 Pa and the red indicates the maximum value of 2.699e7 Pa.Fig 6(d) represents the equivalent stress change in the existing material i.e Aluminium alloy 6061 T-6 for 1 sec. The blue indicates the minimum value of 25556 Pa and the red indicates the maximum value of 3.1852e7 Pa.

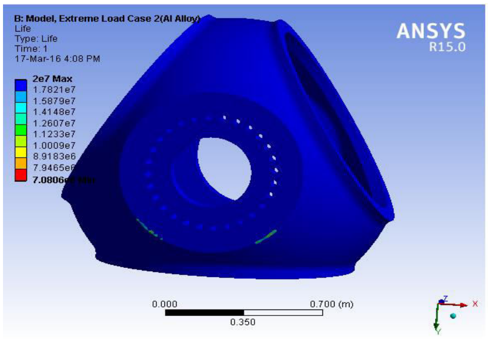


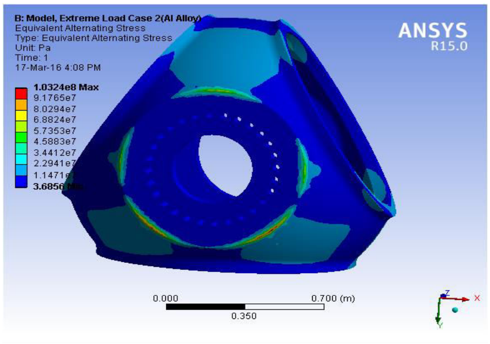
(a) (b)

(c) (d)

Figure. 6 (a), (b) Deformation for Load case 1&2 for Aluminium alloy,
(c), (d) Stress for Load case 1&2 for Aluminium alloy

3.3Fatigue analysis of Aluminium alloy





(a) (b)

Figure. 7(a) Fatigue life for Aluminium alloy hub
(b), Equivalent alternating stresses for Aluminium alloy hub

Table 4 Comparison of materials study analysis

Material	Load cases	Deformation (m)	Stress (Pa)
Cast iron	Case - 1	0.00043186 Max, 0 Min	2.7677e7 Max, 29092 Min
Cast iron	Case - 2	0.00053065 Max, 0Min	3.3666e7 Max, 27923 Min
Aluminium alloy	Case - 1	0.0010323 Max,0 Min	2.6119e7 Max, 24351 Min
Aluminium alloy	Case - 2	0.0012684 Max,0 Min	3.1852e7 Max, 25556 Min

Table 5 Fatigue analysis

Material	Safety factor	Biaxiality	Alternating stress	Life
Aluminium alloy	Max 15	Max 0.99136	Max 1.0324e8	Max 2e7
Aluminium alloy	Min 0	Min -1	Min 3.6856	Min 7.0806e6

Factor of safety (FOS), also known as (and used interchangeably with) safety factor (SF), is a term describing the capacity of a system beyond the expected loads or actual loads.N_f, as the number of stress cycles of a specified character that a specimen sustains before failure of a specified nature occurs. For some materials, notably steel and titanium, there is a theoretical value for stress amplitude below which the material will not fail for any number of cycles, called a fatigue limit, endurance limit or fatigue strength. Fig. 7 represents (a) Fatigue life for Aluminium alloy hub (b), Equivalent alternating stresses for Aluminium alloy hub. Table 4 gives the comparison of materials study analysis. Table 5 gives the results of fatigue analysis.

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4.Conclusions

- Wind turbine Rotor Hub has been analyzed for two extreme load conditions as per the most important load cases according to IEC 61400-1 (wind turbine loads)
- Existing material is used for analysis (GGG40.3). Stress levels are high. Factor of safety of the analysis shows 7.6 and required is 3. This shows that the current design is much higher in safety.
- So we can use aluminum alloy for reducing material cost and total weight reduction. The stress (32MPa) and deflection (1.2mm) a value from the analysis. Further Fatigue analysis is carried out and alternating stress for the aluminum alloy is 103.2MPa which is less than the allowable yield limit(170MPa).
- The fatigue life of aluminum alloy rotor hub is safe for 20 years time of wind turbine life time. Hence using aluminum alloy rotor hub will be beneficial to the industries in cost wise.

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