JES Journal of Engineering Sciences

Vol 13, Issue 04, APRIL/2022
ISSN NO:0377-9254

PERFORMANCE AND QUALITY IMPROVEMENT OF TWO BLADED WIND TURBINE HUB BY FEA ANALYSIS

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ABSTRACT

To better understand the unsteady aerodynamics and structural responses of horizontal-axis wind turbines. The experiment consists of an extensively instrumented, downwind, three-bladed, wind turbine. We are designing a two-bladed hub for the experiment. For this thesis, I present the modules of the mechanical design and analysis of the hub. The hub design must be unique because it runs in rigid, teetering, or independent blade-flapping modes. In addition, the design is unusual because it uses two servomotors to pitch the blades independently. In my thesis, I focus on the analysis of the hub body. I perform solid-mechanical calculations, and a finite element analysis, and investigate the structural integrity of the hub body. The solid model is generated in CATIA then the model is imported to ANSYS. The quality mesh is prepared in ANSYS for converged solution for analysis package with high optimizing results. These features are used to investigate new load reduction, noise reduction, blade pitch optimization, and control techniques for two-bladed turbines. The hub needs to meets all the performance specifications except that it achieves 90% of the specified teeter range.

1.0 INTRODUCTION

A wind turbine is a device that converts the wind's kinetic energy into electrical power. Wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

Fig: 1.1: Wind Turbines

Much like solar PV installations, you can purchase a domestic wind turbine to supply as much or as little electricity as you want. If you are hoping to limit your dependence on the mains as much as possible, you will need a larger turbine, or multiple smaller turbines. If you are simply looking to produce enough electricity for a light in your garden shed, you can get away with a very small turbine.

1.1 Classification of Wind turbines:

Wind turbines can rotate about either a horizontal or a vertical axis, the former being both older and more common. They can also include blades or be bladeless. Vertical designs produce less power and are less common.

a. Horizontal axis

b. vertical axis

A. Horizontal axis

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Any solid object produces a wake behind it, leading to fatigue failures, so the turbine is usually positioned upwind of its supporting tower. Downwind machines have been built, because they don't need an additional mechanism for keeping them in line with the wind. In high winds, the blades can also be allowed to bend which reduces their swept area and thus their wind resistance. In upwind designs, turbine blades must be made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.Turbines used in wind farms for commercial production of electric power are usually three-bladed. These have low torque ripple, which contributes to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from 20 to 80 meters (66 to 262 ft). The size and height of turbines increase year by year. Offshore wind turbines are built up to 8MW today and have a blade length up to 80m. Usual tubular steel towers of multi megawatt turbines have a height of 70 m to 120 m and in extremes up to 160 m.The blades rotate at 10 to 22 revolutions per minute. At 22 rotations per minute the tip speed exceeds 90 meters per second (300 ft/s). Higher tip speeds mean more noise and blade erosion. A gear box is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but more energy can be collected by variable-speed turbines which use a solid-state power converter to interface to the transmission system. All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind which ceases their rotation, supplemented by brakes.

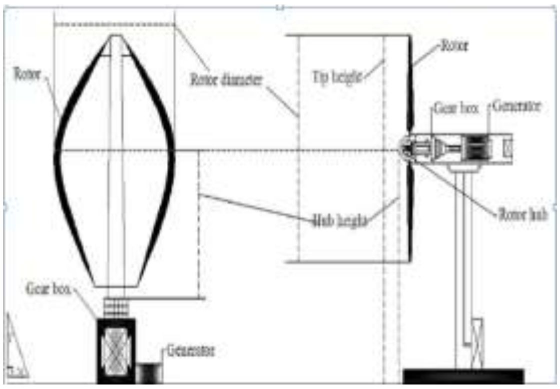


Fig: 1.2: (a).vertical axis wind turbine, (b).horizontal axis wind turbine

B. Vertical axis

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce much less energy averaged over time, which is a major drawback. The key disadvantages include the relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360-degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype.

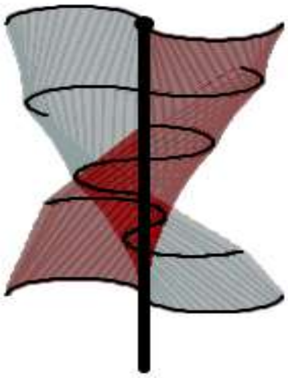


Fig: 1.3: Vertical Wind Turbines.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. Wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

Problem:

Design a two-bladed hub for the Unsteady Aerodynamics Experiment, which features independent blade-pitch adjustment and can be run in the rigid, teetering, or flapping modes.

Scope of Design:

My initial design responsibilities were primarily limited to the design, analysis, and structural bench-testing of the hub. NREL engineer Lee Fingers designed the electrical system components, such as the servomotor, servo controller, and data acquisition equipment. Only the hub was to be modified. The NWTC requested I use the nacelle, pitch shafts, blades, and boom from the three-bladed rotor.

Scope of Testing:

In this project testing is done on structural analysis.

2.0 LITERATURE REVIEW

Apadopoulos et al. (1995) **[1]** analyzed and reported that the parking conditions of wind turbine rotor in upstream and downstream velocities. They have created power coefficient curve and assessed wake features due to variation of wind velocities and at stalled condition. They observed increased turbulent levels near the blade tips and around the hub height for various wind speeds. At the wake zone, they observed that there was no increase in turbulent energy and it was due to flat wake velocity profile and the absence of strong shear layers that produce turbulence. A limitation of this study is the terrain complexity in association with the fact that the prevailing wind velocity was particularly high, leading to a relatively weak wake.

Crespo and Hernandez (1996) [2] studied The evolution of turbulence characteristics in wind turbine wakes**.** They evaluated turbulent kinetic energy (k) and its dissipation rate ( ) by experimental methods and numerical methods using CFD. The characteristic values of turbulence velocity and length were calculated by algebraic combinations of ‘k’. The spectrum of unperturbed basic flow was recovered for increasing turbulent kinetic energy by neglecting the effect of wake. The standard deviation of the axial velocity was used to measure the turbulence in wind turbine wakes. Since turbulence was isotropic neither in the atmospheric surface layer nor in the wake zones, in order to validate the results of the numerical model, it was necessary to make assumptions that relate ‘k’ to the standard deviation in the wind direction. They considered two wake regions one at near the hub and the other away from hub for their analysis leaving the intermediate zone that had turbulence. The region next to the downstream of the rotor, where expansion occurs, was not considered in their analysis.

Collecutt and Flay (1996) [6] developed and tested the understanding and study of design and performance of wind turbines is important in the course of optimization of its performance. The research and finding of the researchers related to the design and performance of wind turbine is briefly presented in this section. The optimum design parameters for horizontal axis wind turbines. They considered the design parameters such as the rotor diameter, rated power and tower height. The results of the study indicated that the cost of energy production reduces by the optimization of the relative combination of rotor diameter and rated power with respect to site mean annual wind speed. They optimized wind turbine for the mean annual wind speed range of 6-8 m/s. The cost of energy generation may be reduced up to 10% by properly choosing the wind turbines to suit the rated wind speed.

Karam Y. Maalawi and Mahdy T.S. Badawy (2001) [7] examined a direct approach for the determination of aerodynamic performance characteristics of horizontal axis wind turbines. They developed analytical equations for optimizing chord and twist distribution for an ideal windmill along with an exact trigonometric function method. The variation of the angle of attack along blade span relative wind velocity was obtained directly from unique equation with specific rotor size and blade geometry. In their case study, the analysis of an existing turbine model was carried out and the results were compared with the findings of other investigators. They used 44 an ideal actuator disk model and obtained the optimum variations of the axial and rotational induction factors. They proposed a method to predict the performance of horizontal-axis wind turbines and applied to the existing machines of ERDA NASA MOD-0, with the capacity of 100 KW. The optimum aerodynamic blade geometry as well as the trimmed-rotor solutions were obtained and investigated in detail. Further, the authors concluded that the proposed method of analysis eliminated the complications of other numerical methods.

Benini and Toffolo (2002) [18] used evolutionary methods to optimize wind turbines. They fix the turbine power and include in the objective function economical costs.

3.0 DESIGN AND ANALYSIS SOFTWARES

3.1 Introduction to CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Cero Elements/Pro and NX (Unigraphics).

The 3D CAD system CATIA V5 was introduced in 1999 by Dassault Systems. Replacing CATIA V4, it represented a completely new design tool showing fundamental differences to its predecessor. The user interface, now featuring MS Windows layout, allows for the easy integration of common software packages such as MS Office, several graphic programs or SAPR3 products (depending on the IT environment).

The concept of CATIA V5 is to digitally include the complete process of product development, comprising the first draft, the Design, the layout and at last the production and the assembly. The workbench Mechanical Design is to be addressed in the Context of this CAE training course.

Sets of workbenches can be composed according to the user's preferences. Therefore Dassault Systems offers three different software installation versions. The platform P1 contains the basic features and is used for training courses or when reduced functionality is needed. For process orientated work the platform P2 is the appropriate one. It enables, apart from the basic design features, analysis tools and production related functions. P3 comprises specific advanced scopes such as the implementation of external software packages.

Fig: 3.1: Catia Menu

CATIA can be applied to a wide variety of industries, from aerospace and defense, automotive, and industrial equipment, to high tech, shipbuilding, consumer goods, plant design, consumer packaged goods, life sciences, architecture and construction, process power and petroleum, and services. CATIA

V4, CATIA V5, Pro/ENGINEER, NX (formerly Unigraphics), and Solid Works are the dominant systems.

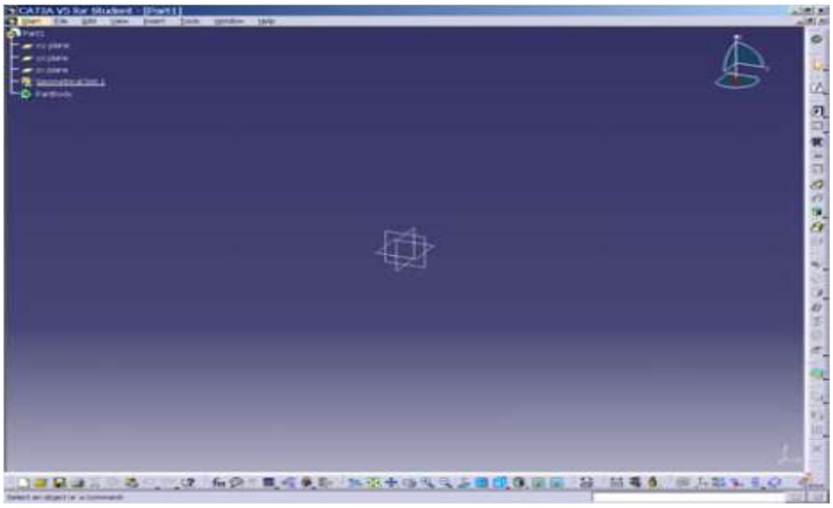


Fig: 3.2: Home Page of CatiaV5

3.2 Finite Element Method:

In mathematics, finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems. It uses variation methods (the Calculus of variations) to minimize an error function and produce a stable solution. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses all the methods for connecting many simple element equations over many small sub-domains, named finite elements, to approximate a more complex equation over a larger domain. Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. In this article, a brief introduction to finite element method is provided. The method is illustrated with the help of the plane stress and plane strain formulation.

4.0 DESIGN METHODLOGY OF 2 BLADED WIND TURBINES

The objective of this project work is to successfully develop a design of a hub mechanism for a 2 Bladed wind turbine Hub. The mechanism is to be reliable, simple, cost-effective and practically feasible. The aim of this rotating mechanism is to provide stability to the product on unbanked curves, so as to enable added threshold speed on curves in comparison to narrow tilting areas. This system is also supposed to enhance comfort as the side force felt taking a turn is comparatively less in Turbine Hub. The methodology adopted to use standard and presently used components in design rather than to design all components from ground up. The advantage of this method is that, you do not have to spend ridiculous amount and time in testing the integrity of each part as they have already proved their worth in real world applications.Initially the frame design was adopted from an already existing hub design and minor changes were made to suite our purpose, the tilting mechanism first devised was based on using power screw driven by motor lifting and lowering each gear rotation. This mechanism was later dropped in testing phase due to following disadvantages.

1. It had a very large response time; this was not suitable for a approaching curve at a very high speed.
2. Wear and tear of hub and contact nut bearing is too high to be satisfactorily used in a turbine.
3. The system used high torque steppers; this along with controls could shoot up the cost of production.

Due to these disadvantages, the hub design was dropped and a fully new design was defined. The hub uses the same rotating mechanism setup. The software to be used in design is Catia V5 and testing of design is Ansys.

4.1 Modeling of 2 Bladed Wind Turbine Hub in CATIA V5

This 2 Bladed Wind Turbine Hub is designed using CATIA V5 software. This software used in automobile, aerospace, consumer goods, heavy engineering etc. it is very powerful software for designing complicated 3d models, applications of CATIA Version 5 like part design, assembly design.

The same CATIA V5 R20 3d model and 2d drawing model is shown below for reference. Dimensions are taken from. The design of 3d model is done in CATIA V5 software, and then to do test we are using below mentioned software’s.

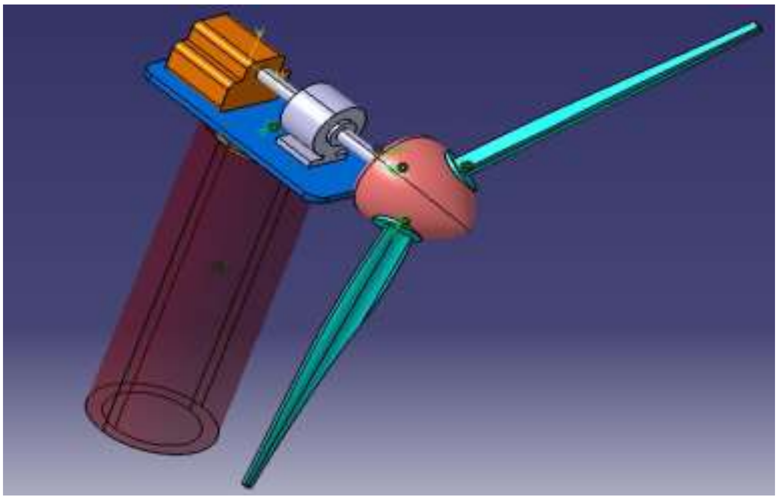


Fig: 4.1: Model design of 2 Bladed Wind Turbine Hub in CATIA-V5

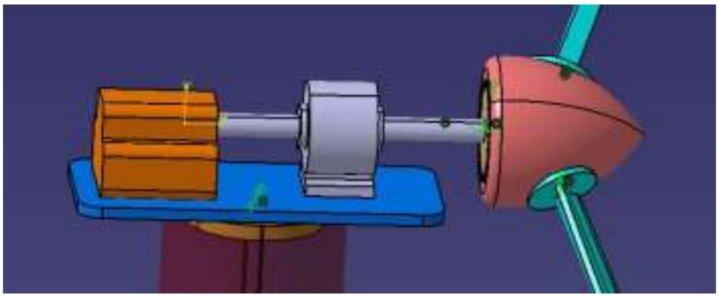
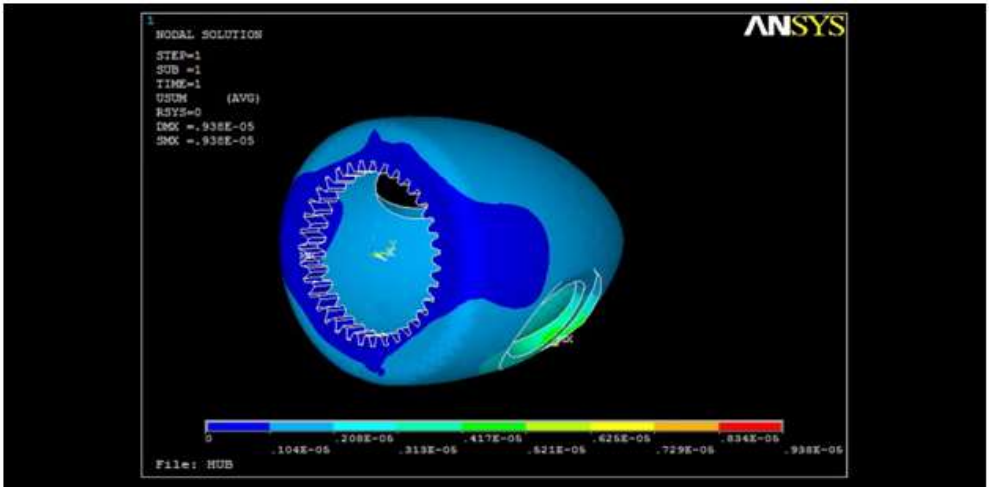


Fig: 4.2: Model arrangement of 2 Bladed Wind Turbine Hub in CATIA-V5

5.0. DISCUSSION ON ANALYSYS RESULT

5.1 Results of Displacement analysis:



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
USUM      (AVG)
RSYS=0
DMX =.938E-05
SMX =.938E-05
```

Fig: 5.1: Displacement of HUB

Minimum displacement of hub:0.104K, Maximum displacement of hub: 0.938K

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ISSN NO:0377-9254

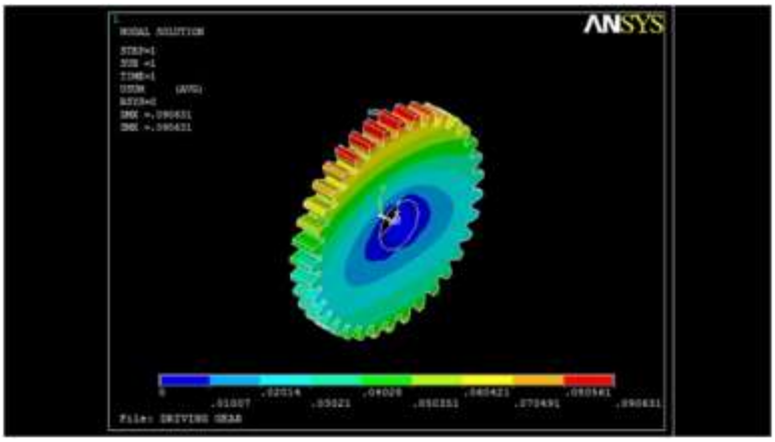

Fig: 5.3: Displacement of DRIVING GEAR

Minimum displacement of driving gear:0.1007, Maximum displacement of driving gear: 0.090631

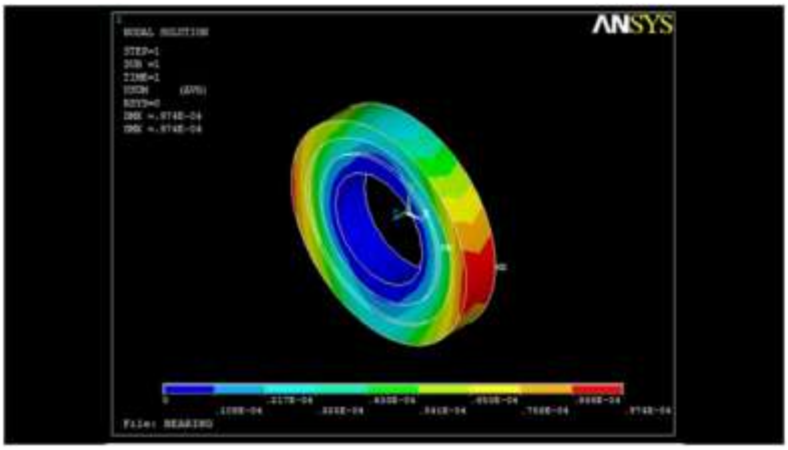

Fig: 5.4: Displacement of BEARING

Minimum displacement of bearing:0.108E, Maximum displacement of bearing:0.974E

S.no.	Description	Standard values	Modified values
1	displacement of hub	0.110E	0.120E
2	displacement of turbine blade	0.126E	0.120E
3	displacement of driving gear	0.090681	0.090631
4	displacement of bearing	0.964E	0.974E

5.2 Results of Stress analysis:

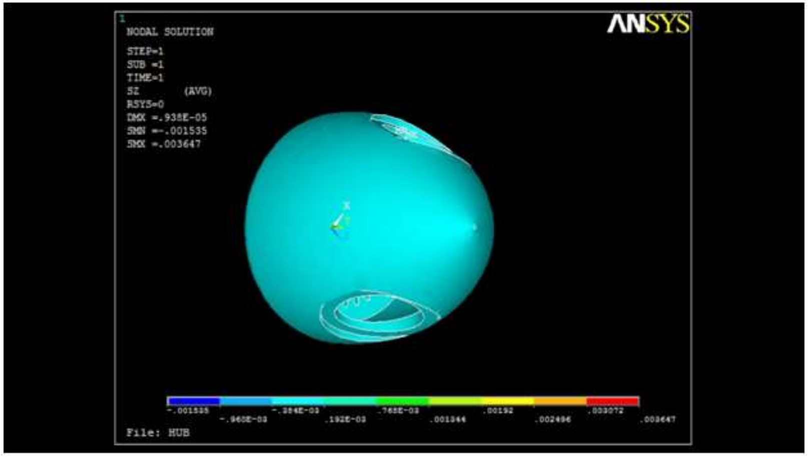

Fig: 5.5: Stress Analysis of *HUB*

Minimum stress of hub:-0.001535, Maximum stress of hub: 0.003647

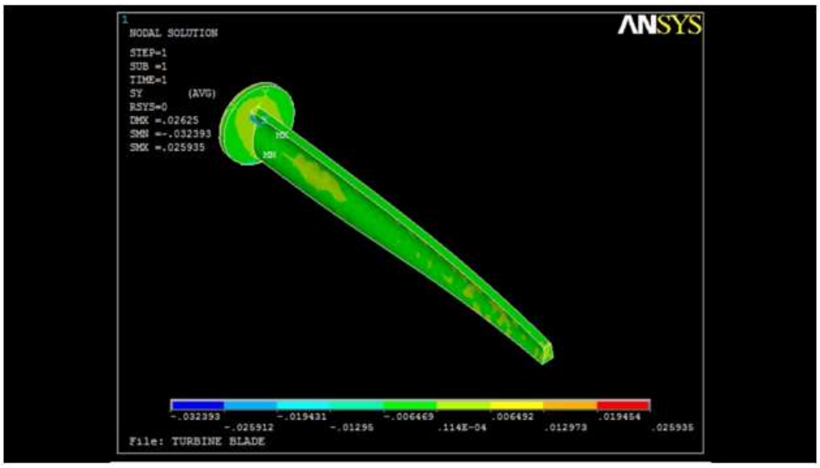

Fig: 5.6: Stress Analysis of *TURBINE BLADE*

Minimum stress of turbine blade:-0.32393, Maximum stress of turbine blade: 0.025935

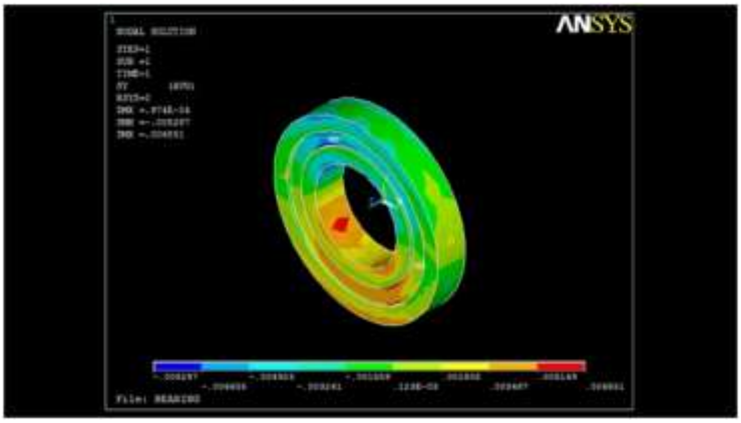

Fig: 5.8: Stress Analysis of *BEARING*

Minimum stress of bearing:-0.008287, Maximum stress of bearing:0.006851

Sl.no	Description	Standard values	Modified values
1	stress of hub	0.003637	0.003647
2	stress of turbine blade	0.025835	0.025935
3	stress of driving gear	13.0744	13.8744
4	stress of bearing	0.006859	0.006851

5.3 Results of Strain analysis:

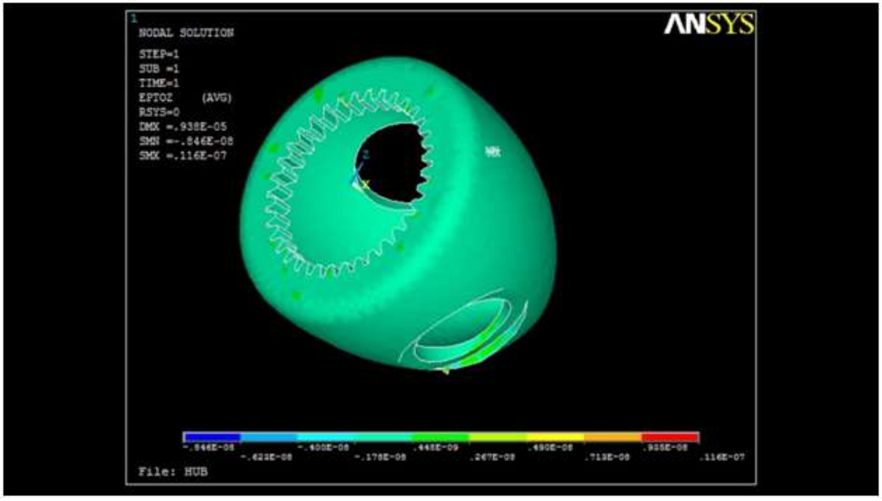

Fig: 5.9: Strain Analysis of HUB

Minimum strain of hub:-0.846E-08, Maximum strain of hub:0.116E-07

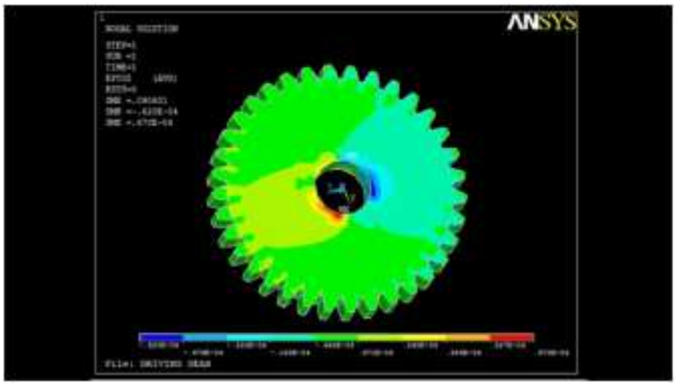

Fig: 5.11: Strain Analysis of DRIVING GEAR

Minimum strain of driving gear:-0.620E-04, Maximum strain of driving gear:0.670E-04

Sl.no	Description	Standard values	Modified values
1	strain of hub	0.115E-08	0.116E-07
2	strain of turbine blade	0.630E-07	0.632E-07
3	strain of driving gear	0.678E-04	0.670E-04
4	strain of bearing	0.362E-07	0.367E-07

CONCLUSION

- It can be seen from the above result that, our objective to increase the velocity of a turbine hub in a curve has been successful. As shown above figures the displacement of the complete design is meshed and solved using Ansys and displacement is very less. This is showing us that clearly each component in assembly is having minor displacement.
- Stress is at the fixing location (Minimum Stress which is acceptable). The value is -0.0015 MPa which is very less compared to yield value; this is below the yield point.
- The maximum stress is coming, this solution solving with the help of Ansys software so that the maximum stress is 0.0036 Mpa which is very less .so we can conclude our design parameters are approximately correct.
- The design of the hub of 2 bladed wind turbine hub rotating mechanism worked flawlessly in analysis as well. To demonstrate tilting is also working successfully, all these facts point to the completion of our objective in high esteem.

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