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Wind Mill Shaft Design and Optimization Using Composites Materials Using CAD/CAM

Saket S. Patil[1], Ajitabh Pateriya[2]
[1] *Lecturer in Mechanical Engineering Department, Amravati University, Maharashtra, India*
[2] *Assistant Professor of Mechanical Engineering Department, Amravati University, Maharashtra, India*

ABSTRACT

This contribution deals with the possibility of simulation of complex parts made from polymer composites with CAD/CAM/CAE software. First part of contribution is aimed on describing the basis of fiber composites and its behavior under load. Main reason of choosing carbon fiber as material for innovative parts depends on low density and high tensile strength. Thus carbon fiber composites are frequently used at automotive and sporting goods production parts from these industries were selected. Second part will lead to different studies performed in Simulations and describes the stress and weight comparisons made from Steel, Carbon fiber, Glass Fiber composites. The optimization for weight and strength of the shaft based on Fiber orientations and thickness of fibers will be done.

1. INTRODUCTION

A windmill is a mill that converts the energy of wind into rotational energy by means of vanes called sails or blades. Centuries ago, windmills usually were used to mill grain, pump water, or both. Thus they often were gristmills, wind pumps, or both. The majority of modern windmills take the form of wind turbines used to generate electricity, or wind pumps used to pump water, either for land drainage or to extract groundwater.

1.1 Major Parts of Wind Turbine

1.1.1 Tower of Wind Turbine

Tower is very crucial part of wind turbine that supports all the other parts. It is not only support the parts but raise the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. The height of tower depends upon the power capacity of wind turbines. Larger turbines usually mounted on tower ranging from 40 meter to 100 meter.

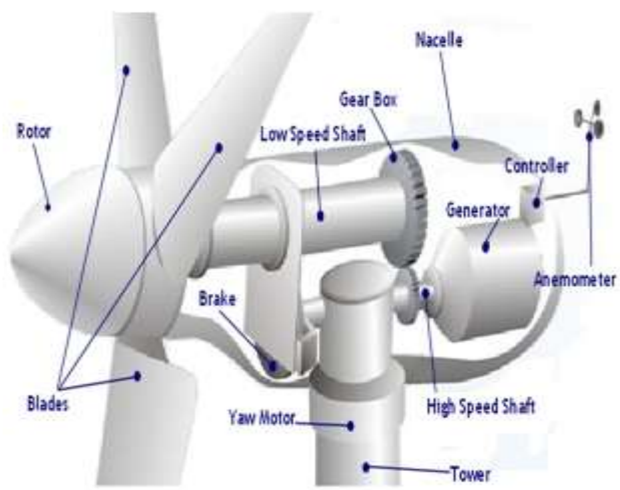

Fig 1 Wind Mill components

1.1.2 Nacelle of Wind Turbine

Nacelle is big box that sits on the tower and house all the components in a wind turbine. It houses Power Converter, Shaft, Gearbox, Generator, Turbine controller, Cables, Yaw drive.

1.1.3Rotor Blades of Wind turbine

Blades are the mechanical part of wind turbine that converts wind kinetic energy into mechanical energy. When the wind forces the blades to move, it transfers some of its energy to the shaft. Blades are shaped like airplane wings blades can be as long as 150 feet.

1.1.4 Shaft of Wind Turbine

The shaft is connected to the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to shaft which enters to an electrical generator on the other end.

1.1.5 Gearbox

The rotor turns the shaft at low speed ex. 20 rpm but for generator to generate electricity we need higher speed. Gearbox increases the speed to much higher value required by most generators to produce electricity. For example, if Gearbox ratio is 1:80 and if rotor speed is 15 rpm then gearbox will increase the speed to $15 \times 80 = 1200$ rpm that is given to generator shaft.

1.1.6 Generator

Generator is electrical device that converts mechanical energy received from shaft into electrical energy. It works on electromagnetic induction to produce electrical voltage or electrical current. A simple generator consists of magnets and a conductor. The conductor is typically a coiled wire. Inside the generator shaft connects to an assembly of permanent magnets that surrounded by magnets and one of those parts is rotating relative to the other, it induce the voltage in the conductor. When the rotor spins to the shaft, the shaft spins the assembly of magnets and generates voltage in the coil of wire.

1.1.7 Power Converter

Because wind is not always constant so electrical potential generated from generator is not constant but we need a very stable voltage to feed the grid. Power converter is an electrical device that stabilizes the output alternating voltage transferred to the grid.

1.2 Composite Materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties.

Composite materials (composites for short, distribution shown on Figure 1) are made simultaneously by two or more materials with vastly different mechanical and / or chemical properties which remain separate and are clearly observable in macroscopic or microscopic scale inside the finished part. There are two categories of materials involved: reinforce and filler. At least one piece from each category must necessarily be present. Filler surrounds and supports the reinforcement to maintain mutual relative position. Reinforcement is adding its special mechanical properties in order to improve the mechanical properties of filler. Synergy produces mechanical properties unattainable by individual participating materials and a wide range of fillers and reinforcement allows the designer to select the most appropriate product mix.

Laminates are composite materials consisting of fillers and reinforcements in the form of fibres / fabrics. Fillers are used as resins of different types depending on application and desired properties. The most famous of them are polyester, vinyl ester, epoxy, phenol formaldehyde (PF), polyimide (PI), polyamide, polypropylene (PP), polyether ether ketone (PEEK). They have different mechanical properties, different terms of use, thermal expansion and resistance. As reinforcement fabrics are used weaves cloth, twill or satin or single-shift and bi-axial or mat with binder (powder, emulsion).

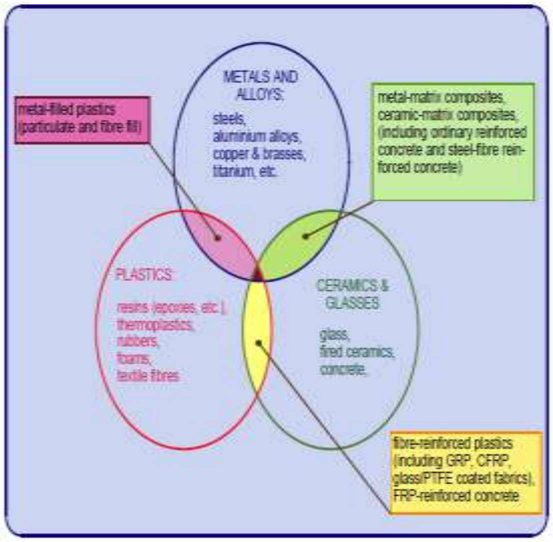

Fig. 2 Relationships between Classes of Engineering Materials, Showing the Evolution of Composites

Carbon fiber composites, particularly those with polymeric matrices, have become the dominant advanced composite materials for aerospace, auto-mobile, sporting goods, and other applications due to their high strength, high modulus, low density, and reasonable cost. For applications requiring high temperature resistance, as required by spacecraft, carbon fiber carbon-matrix composites (or carbon-carbon composites) have become dominant. As the price of carbon fibres decreases, their applications have even broadened to the construction industry, which uses carbon fibres to reinforce concrete.

Design of composite parts in the past consisted of many trials, prototyping and testing, resulting in increased production costs. With the advances of technology and performance of personal computers came on the analytical range of 3D CAD software to enable the design and analysis in a virtual environment. This eliminates the tedious and expensive, often limiting the design process: test - mistake. Often the designer neglects the preparatory phase in order to reduce costs and propose over equipped components, which today is highly inappropriate.

1.3 Benefits of Composites

In comparison to common materials used today such as metal and wood, composites can provide a distinct advantage. The primary driver and advantage in the adoption of composites is the lightweight properties. In transportation, less weight equates to more fuel savings and improved acceleration. In sporting equipment, lightweight composites allow for longer drives in golf, faster swings in tennis, and straighter shots in archery. While in wind energy, the less a blade weighs the more power the turbine can produce. Besides weight savings, the most important benefits of composites include:

- Non-corrosive
- Non-conductive
- Flexible, will not dent
- Low maintenance
- Long life
- Design flexibility

1.4 Objectives

- ✓ Design of Hollow Shaft for selected application.
- ✓ Modeling and Analysis of shaft for designed dimensions.
- ✓ Study of composite materials used through literature.
- ✓ Analysis of Shaft based on composite materials with different fiber angle orientations and thicknesses and selection of the best from it.
- ✓ Validation of the results

2. LITERATURE SURVEY

Chris J. Burgoyne,[1]studied the different applications of composite materials in the area of construction. Where the materials used for structures are all characterised by low creep, as would be expected when the structures must resist significant permanent loads. For most applications, the higher stiffness fibres, i.e. carbon, glass and polyester, are used. The use of GFRP composites for complete structures is proving to be economic when there are access difficulties for building conventional heavy structures. The use of polyesters as soil reinforcement is also commercially successful, due to their résistance to corrosion in potentially aggressive soil conditions. Other applications have not yet taken off commercially. It also concluded that there is some scope for the use of composite reinforcement, but only in areas where rapid corrosion of steel is to be expected and only when deflections are not the limiting factor.

Branislav Duleba[2]in his paper describes the possibilities of use of carbon fiber composite in wide range of application. Carbon fiber composites, particularly those with polymeric matrices, have become the dominant advanced composite material for many industries due to their high strength and low density. He First tested model was design of rear upper arm from complex model of roadster, made with cooperation with students. This study shows, that use of normal carbon fiber composite at this part is not advisable, because possible faults of material can occur at area connected to bushings and chassis. As the goal of his whole study was to make the chassis as light as possible, simulation shows that there is the need of changing the material of composite or apply more layers of composite. At the end of paper the technique of production of test model was described. Technique called core wrapping was used by him, where the core made of Styrofoam was wrapped by layers of carbon fiber and epoxy resin.

The paper of **Darren A. Baker [3]** discusses about recent advancements in carbon fiber materials. Review of the authors provide the context of subject matter importance, a cost comparison of potential low-cost carbon fibres, a brief review of historical work, a review of more recent work, and a limited technical discussion followed by recommendations for future directions. As the available material for review is limited, the author includes many references to publicly available government documents and reviewed proceedings that are generally difficult to locate.

Luiz Claudio Pardini and Maria Luisa Gregori[4] in their work present ab-initio predictions of elastic constants and thermal properties for 2.5D carbon fiber reinforced carbon-silicon carbide hybrid matrix composites, by using the homogenization technique. The homogenization technique takes properties of individual components of the composites (fiber and matrix) and characteristics of the geometrical architecture of the perform to perform calculations. Ab-initio modelling of mechanical and thermal properties is very attractive, especially during the material development stage, when larger samples may be prohibitively expensive or impossible to fabricate. The modeling of properties by this simple method allows avoiding costly testing and reducing time consuming specimen preparation.

It also concluded that the Z-direction reinforcement allows higher delamination resistance and endurance on thermal stresses generated by heat treatment processing, and also the inter laminar fracture toughness is improved. An increase in the carbon fiber volume fraction, results in higher elastic properties, but nevertheless decreases the thermal conductivity.

The aim of this work was to investigate the development and mechanical characterization of new polymer composites consisting of glass fibre reinforcement, epoxy resin and filler materials such as TiO2 and ZnS. The newly developed composites are characterized for their mechanical properties. Experiments like tensile test, three point bending and impact test were conducted to find the significant influence of filler material on mechanical characteristics of GFRP composites. The tests result have shown that higher the filler material volume percentage greater the strength for both TiO2 and ZnS filled glass epoxy composites, ZnS filled composite show more sustaining values than TiO2.

Tensile, Bending and Impact strength increases with addition of filler material, ZnS filled composite shows significantly good results than TiO2 filled composites, Impact toughness value for unfilled glass composite is more than filled composite is concluded in the paperby **Patil Deogonda et. al. [5]**

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H. Kim [6]proposed that the out-of-plane properties can still be increased further by using CNMs via effective processing techniques. It is also time to consider scale-up processing more seriously 20 years after the first discovery of CNTs. So far, aligned CNTs on carbon fibres have shown most promising results in mechanical property enhancement for carbon fiber composites, but this may be the most expensive method to incorporate CNTs into carbon fiber composites and has a limitation for scale-up processing. Hence, economical and effective processing methods should be devised further to see more real life applications of CNMs for carbon fiber composites.

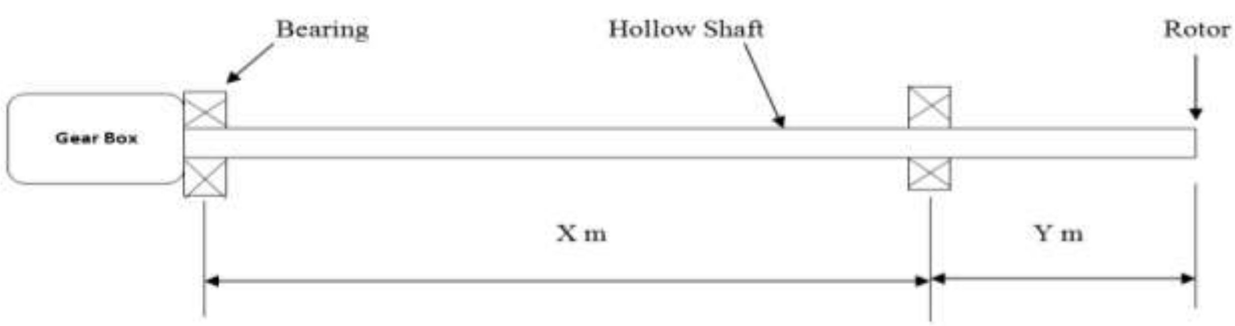
Mark Bruderick [7] discusses about the carbon fiber origin and applications of the same in Automobile industry. The design and analysis, materials, process, and performance of these innovative composite structures are discussed. This work presents the three Viper structural systems that employ the high modulus of carbon fiber SMC to achieve exceptional stiffness in lightweight structures. Mass reductions and stiffness improvements are recorded by carbon fiber over glass fiber.

3. DESIGN OF SHAFT

Sample Calculation

Power = 1 kW
Max Rotor Speed: 720 rpm
Wind speed = Max. 16 m/s
Rotor assembly Weight = 11.2 kg = 110 N
Shaft Material as: 40C8
S_{yt}= 380 N/mm^2
S_{ut}= 650 N/mm^2
X = 0.5 m

Y= 0.1 m



Nature of load	K_m	K_t
1. Stationary shafts		
(*a*) Gradually applied load	1.0	1.0
(*b*) Suddenly applied load	1.5 to 2.0	1.5 to 2.0
2. Rotating shafts		
(*a*) Gradually applied or steady load	1.5	1.0
(*b*) Suddenly applied load with minor shocks only	1.5 to 2.0	1.5 to 2.0
(*c*) Suddenly applied load	2.0 to 3.0	1.5 to 3.0

Table 1. Value of Km & Kt

For Suddenly applied load (Given)

$K_m = 2.0 \quad K_t = 1.5$

$d_i/d_o = C = 0.6$

According to ASME Standard:

$0.30\ S_{yt} = 0.3 * 380 = 114$ MPa

$0.18\ S_{ut} = 0.18 * 650 = 117$ MPa

Selecting lower of the two is 114 MPa, and there are no key ways on the shaft

So, $\tau_{max} = 114$ MPa

Torque:

$$\text{Power} = \frac{2\pi N T}{60}$$

$$1000 = \frac{2\pi * 720\ T}{60}$$

$T = M_t = 13.263$ N-m $= 13.263 \times 10^3$ N-mm

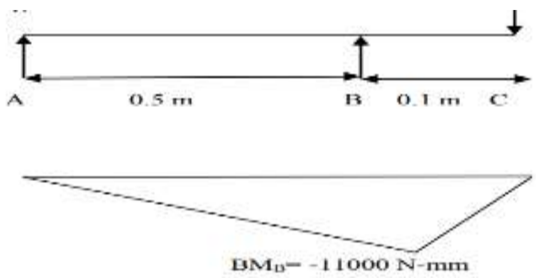
OR

$$M_t = \frac{60 \times 10^6\ (kW)}{2\pi\ N}$$

$$= \frac{60 \times 10^6\ (1)}{2\pi * 720}$$

$= 13.263 \times 10^3$ N-mm

Bending Moment:



$BM_B = -11000$ N-mm

$R_A + R_B = 110$ ------------- (a)

Taking moment @ A,

$R_B \times 500 - 110 \times 600 = 0$

$$R_B = \frac{110 \times 600}{500}$$

$R_B = 132$ N

Using equation (a),

$R_A = -22$ N

BM at A = 0

BM at B = -110 x 100 = -11000 N

BM at C = 0

Net BM at B = -11000 N-mm

Using maximum shear stress theory,

For Solid Shaft,

$$\tau = \frac{16}{\pi d^3} \sqrt{(Km * Mb)^2 + (Kt * Mt)^2}$$

$$114 = \frac{16}{\pi d^3} \sqrt{(2 * -11000)^2 + (1.5 * 13.263 x 10^3)^2}$$

d = 10.98 mm = 12 mm

For Hollow Shaft,

$$\tau = \frac{16}{\pi do^{3}(1 - C^{4})} \sqrt{(Km * Mb)^{2} + (Kt * Mt)^{2}}$$

$$114 = \frac{16}{\pi do^{3}(1 - 0.6^{4})} \sqrt{(2 * -11000)^{2} + (1.5 * 13.263 x10^{3})^{2}}$$

d_o= 11.50 mm = 12 mm **d_i = 7.2 mm**

4. SUMMARY AND FUTURE WORK

Summary:-

- Wind mill and its operating details are studied in detail which will be useful in further part of work.
- Wind mill and its components basics and composite materials are studied in detail which will be useful in further part of work.
- Composite materials in detail are studied.
- Design of shaft is done based on given specifications with Model of Shaft is done using CATIA 3-D Modeling Software.
- Torsion testing machine details are studied with testing process and parameters to be studied.

Future Work:-

- Analyse the Shaft using ANSYS as the tool. Structural analyses are to be performed on the shaft.
- Optimization of shaft based on composite material and ply angle orientations is to be performed.
  Testing and validation of the results

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