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Composite Material Tapered Beam Design and Optimization for the Application of Wind Mill Blade

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ABSTRACT

Beams are very common types of structural components and it can be classified according to their geometric configuration as uniform or taper and slender or thick. If practically analysed, the non-uniform beams provide a better distribution of mass and strength than uniform beams and can meet special functional requirements in architecture, aeronautics, robotics, and other innovative engineering applications. Design of such structures is important to resist dynamic forces, such as wind and earthquakes. It requires the basic knowledge of natural frequencies and mode shapes of those structures. The main of objectives of this project are to study and analyse vibration frequencies of conventional tapered beam designed as per design requirements and to design a composite tapered beam to replace conventional design and record its natural frequencies. After analysis of steel tapered beam and GFRP, the best angled lay-up tapered beam design from the different options of GFRP designs selected as per FEA modal analysis results will be manufactured.
Keywords-GFRP, Layup angles, Analysis, FEA, Optimization.

1. INTRODUCTION

Lightweight for materials and for design have always been a critical topic in product design in several industries. This concept has been most critical in the aviation industry and also in industries where huge rotating parts (e.g., blades of wind turbine) are important elements of product design and in automobile industry, where driving dynamics are of major consideration. The universal trends toward CO2 reduction and improving resource efficiency have significantly increased the importance of this topic over the last years.Composite materials are becoming an important part of today's materials as they offer advantages like low weight, corrosion resistance, high fatigue strength, faster assembly, etc. They are used as materials to manufacture from aircraft structures to golf clubs, electronic packaging to medical equipment, and space vehicles to home building. Composites are generating curiosity and interest in students all over the world.

1.1 Overview Composite Material:

A composite material is a structural material which consist two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One of the constituents is called as the reinforcing phase and the one constituent in which it is embedded is called the matrix. The reinforcing phase material can be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc.

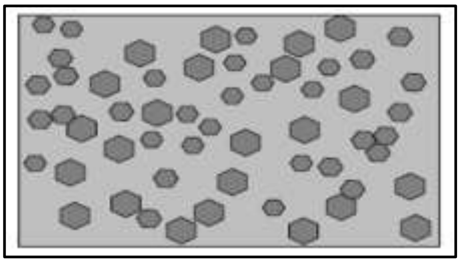


Fig. 1: Composite Material Cross section

1.2 History of Composite Material

You are no longer to supply the people with straw for making bricks; let them go and gather their own straw [Exodus].The Israelites used bricks which were made of clay and were reinforced with straw is an early example of application of composites. The constituents individually, clay and straw, were not capable of serving the function by them but they did when put together. Some believers believe that the straw was used to keep the clay safe from cracking, but the others suggest that it would blunt the sharp cracks in the dry clay. There are abundant historical examples of composites in the literature. Significant examples of the use of composites include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500 B.C.), and laminated metals in forging swords (A.D. 1800).

In the 20th century, there were modern composites used in the 1930s with glass fibers reinforced resins. Boats and aircraft were made out of these glass composites, commonly called as fiberglass. Since the 1970s, the application of composite materials has widely increased due to the development of new fibers such as carbon, boron, and aramids and new composite systems with matrices made of metals and ceramics.

1.3 Naturally Found Composites

There are some composites which can be found in nature from inside the human body to trees around us are made up of different composite materials. Examples of the same are wood, where the lignin matrix is reinforced with cellulose fibers and bones in which the bone-salt plates made of calcium and phosphate ions reinforce soft collagen.

1.4 Advanced Composite Materials

Advanced composites are composite materials that are traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminium. Examples are graphite/epoxy, Kevlar/epoxy, and boron/ aluminium composites. These materials have now found applications in commercial industries as well.

2. LITERATURE REVIEW

[1]Rajamohan Ganesan &Abolghassem Zabihollah presented a paper “Vibration analysis of tapered composite beams using a higher-order finite element” The objective of the present work is to conduct an investigation of the free undamped vibration response of such tapered composite beams, using the finite element method. Conventional cubic Hermitian finite element formulation requires a large number of elements to obtain reasonably accurate results in the analysis of tapered laminated beams. Since the continuity of curvature at element interfaces cannot be guaranteed with the use of conventional formulation, the stress distribution across the thickness is not continuous at element interfaces. The material and geometric discontinuities at ply drop-off locations leads to additional discontinuities in stress distributions. As a result, efficient and accurate calculation of natural frequencies becomes very difficult. In order to overcome these limitations, a higher-order finite element formulation is developed in Part I of the present work. The stiffness coefficients of the tapered laminated beam are determined based on the stress and strain transformations and classical laminate theory. In Part II of the present work, the developed formulation is used for the free undamped vibration analysis of various types of tapered composite beams and a parametric study is conducted.

[2]R. Ghayoura, M. Ghayoura and S Ziaei-Rada presented a case on “Vibration analysis of tapered rotating composite beams using the hierarchical finite element” in which a hierarchical finite element model is presented for the flapwise bending vibration analysis of a tapered rotating multi-layered composite beam. The shear and rotary inertia effects are considered based on the higher shear deformation theory to derive the stiffness and mass matrices of a tapered-twisted rotating and composite beam element. Certain non-composite beams for which comparative results are available in the literature are used to illustrate the application of the proposed technique. Dimensionless parameters are identified from the equations of motion and the combined effects of the dimensionless parameters on the modal characteristics of the rotating composite beams are investigated through numerical studies. The results indicate that, compared with the conventionalities element method, the hierarchical finite element has the advantage of using fewer elements to obtain a better accuracy in the calculation of the vibration characteristics of rotating beams such as natural frequencies and mode shapes. Based on the proposed formulation, the mass and stiffness matrices of a tapered composite rotating beam element were developed for the eigenvalue analysis of rotating, doubly tapered beams. The element was found to give reasonably accurate results. The consideration of shear deformation was found to reduce the values of the higher natural frequencies of beam vibration. The results indicate that the hieratical finite element formulation uses fewer elements to obtain accurate results, which, in turn, leads to less costly computational processes. Comparison with available data reveals that the method is accurate and can be used for a large class of rotating beams.

[3]R. Vasudevan & B. Parthasaradhi In this study, free vibration responses of a rotating tapered composite beam with tip mass are investigated. The energy expressions for the kinetic and potential energies of a rotating composite beam with tip mass have been formulated. The energy expressions are then applied in Lagrange’s equations to develop the equation of motion of a composite beam with tip mass. The stiffness and mass matrices for a standard composite beam element with two end nodes with two degrees of freedom at each node are derived. Various parametric studies are performed to investigate the effect of tip mass and the

rotational speed on the variation of natural frequencies of the composite beam. The investigations are also done to study the effect of hub radius on the natural frequencies. It is shown that the addition of tip mass increases the stiffness of the structure and consequently increases the natural frequencies.

[4]Deepanshu Bhatt, Yogesh Mishra &Dr. P. K. Sharma presented a paper “Static and Free Vibration Analysis of Laminated Composite Plate by using Finite Element Method” in which Finite Element Method is used to solved Static and free vibration analysis. The Static analysis and free vibration analysis of orthotropic laminated composite plates are different materials are use. The ANSYS model is used to obtain the static and free vibration responses for laminated plates with different aspect ratios, thickness ratios and boundary condition under different support condition for different modes. In this work, a finite element model is being developed in ANSYS using APDL code.

[5]Le Wang, Ning Guo, Zhichun Yang presented a paper on “Boundary condition identification of tapered beam with flexible supports using static flexibility measurements” This paper investigates a boundary condition identification method for tapered beam with the specific flexible boundaries using static flexibility measurements. The specific flexible Received in revised form boundaries are modelled by two translational springs with a particular interval which are connected at one end of the tapered beam, and the purpose of this paper is just to identifythe stiffness’s of the two translational springs. According to the static equilibrium equation, it is proved that the static flexibility of the beam is a function of the flexural rigidity of the beam at its constrained end and the stiffness’s of the two translational boundary condition identification springs. Then, using three different measurements, a set of linear equations are established to identify the stiffness’s of the two translational springs. Finally, the flexible boundary feasibility and effectiveness of the proposed method are demonstrated using both simulative and experimental examples.

3. PROBLEM STATEMENT

Beams are very common types of structural components and it can be classified according to their geometric configuration as uniform or taper and slender or thick. If practically analysed, the non-uniform beams provide a better distribution of mass and strength than uniform beams and can meet special functional requirements in architecture, aeronautics, robotics, and other innovative engineering applications. Design of such structures is important to resist dynamic forces, such as wind and earthquakes. It requires the basic knowledge of natural frequencies and mode shapes of those structures. The main of objectives of this project are to study and analyse vibration frequencies of conventional tapered beam designed as per design requirements and to design a composite tapered beam to replace conventional design and record its natural frequencies

4. TAPERED BEAM MODEL AND ITS ANALYSIS

The finite element analysis (FEA) is a computational technique used to obtain approximate solution of boundary value problems in engineering. Simply stated, a boundary value problem is mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. The static structural analysis of tapered beam is done by finite element analysis using ANSYS 16.2 software.

4.1. FEA Results Steel Blade

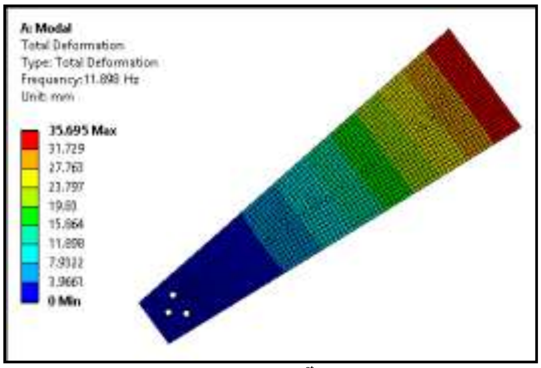


Fig. 2: Total Deformation plot for 1st mode shape of steel beam

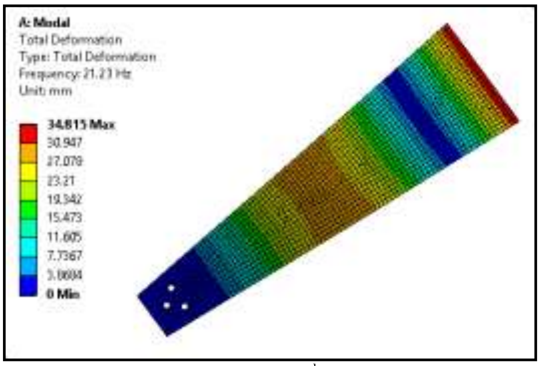


Fig. 3: Total Deformation plot for 2nd mode shape of steel beam

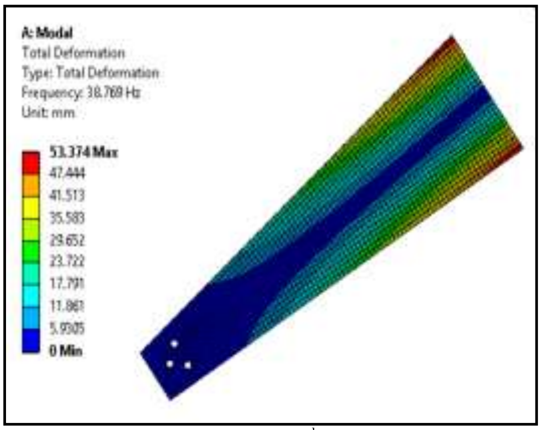


Fig. 4: Total Deformation plot for 3rd mode shape of steel beam

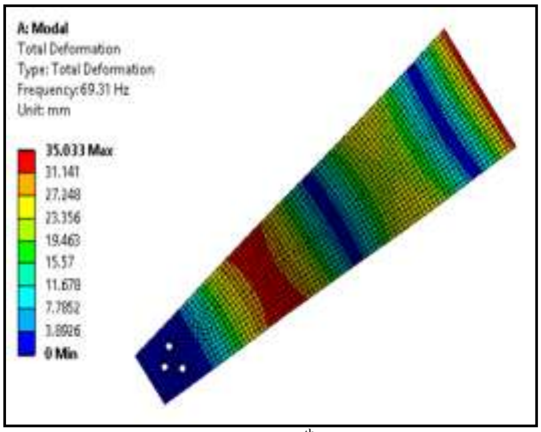


Fig. 5: Total Deformation plot for 4th mode shape of steel beam

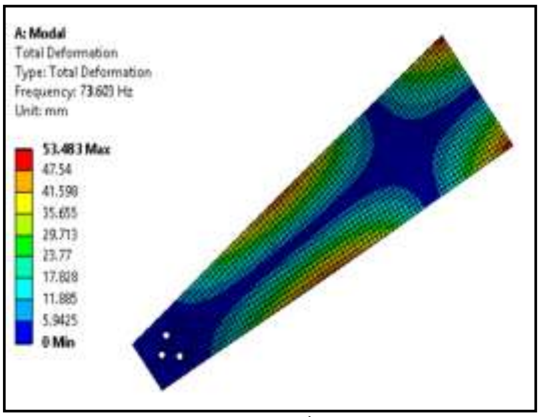


Fig. 6: Total Deformation plot for 5th mode shape of steel beam

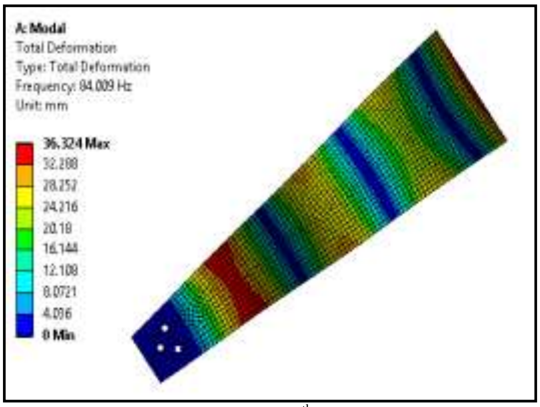


Fig.7: Total Deformation plot for 6th mode shape of steel beam

From the FEA results obtained, we get the natural frequencies of the Steel Tapered Beam as shown in the below table:

Table 1:- Natural frequencies for steel tapered beam

Mode Shape	Natural Frequency
1	11.898
2	21.23
3	38.769
4	69.31
5	73.603
6	84.009

4.2. FEA Results GFRP Blades:

4.2.1 Experiment1 (0-90,0-90,0-90)

Material properties and ply setting used in the ANSYS Advance Composite module is shown in the image below.

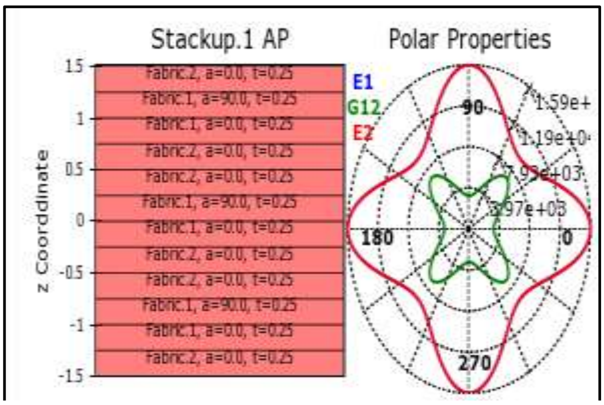


Fig. 8: Properties of the GFRP plies 0-90 glass fiber as fabric1 with fabric 2 as resin epoxy

Figure shows that alternate layers of epoxy resin are applied on the Glass fiber woven cloth. Angle of the cloth is such that fibre orientations are kept 0-90 in all three layers of the cloth. Results for mode shapes and frequencies for this experiment are given below.

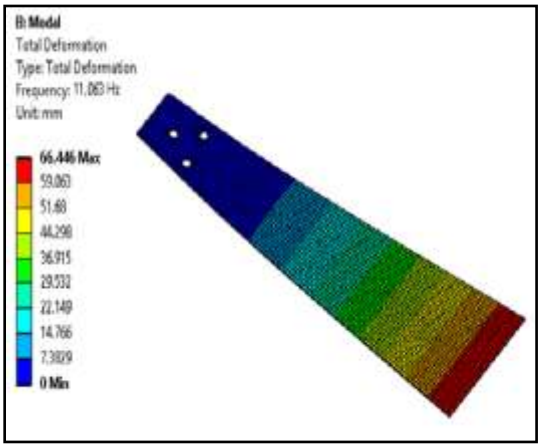


Fig. 9: Mode shape plot 1 frequency 11.063 Hz

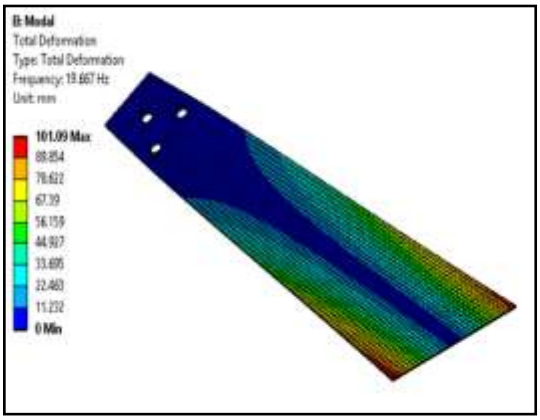


Fig. 10: Mode shape plot 2 frequency 19.67 Hz

Table 2: – Modal frequency Summary Experiment 1

Mode Shape	Natural Frequency
1	11.063
2	19.667
3	38.02
4	66.52
5	69.64
6	86.09

Finite Element Analysis results for the all 9 experiments performed are to be compared to find out the best suitable combination to replace steel.

Table 3:- FEA summary

Material	Natural Frequency					
Mode Shape No	1	2	3	4	5	6
Steel	11.898	21.23	38.769	69.31	73.603	84.01
GFRP Exp. 1	11.063	19.667	38.02	66.52	69.64	86.09
GFRP Exp. 2	10.81	19.527	37.89	66.36	68.93	88.23
GFRP Exp. 3	10.8086	19.67	37.96	66.44	69.38	87.89
GFRP Exp. 4	10.601	19.58	37.84	66.32	68.84	87.74
GFRP Exp. 5	10.93	19.452	38.36	66.48	69.59	88.23
GFRP Exp. 6	10.7042	19.323	38.22	66.56	68.96	87.49
GFRP Exp. 7	10.66	19.946	37.84	65.96	69.43	87.34
GFRP Exp. 8	10.76	19.952	38.59	65.68	69.32	87.33
GFRP Exp. 9	10.65	19.048	38.49	66.37	68.54	88.23

It can be clearly seen that only experiment 1 has the first natural frequency as good as steel and all the other are lagging in the first natural frequency of the blade at the least by 9.72%. So it will be clear choice to choose first experiment combination as a replacement to the steel. As from the other natural frequencies of the first experiment are lagging from the steel , most important property in the dynamic frequency analysis is to find out and compare lowest natural frequency for the given free boundary condition and which is matching in the case of first experimental combination. So same should be manufactured and tested with FFT analyser to compare frequencies with the analysis.

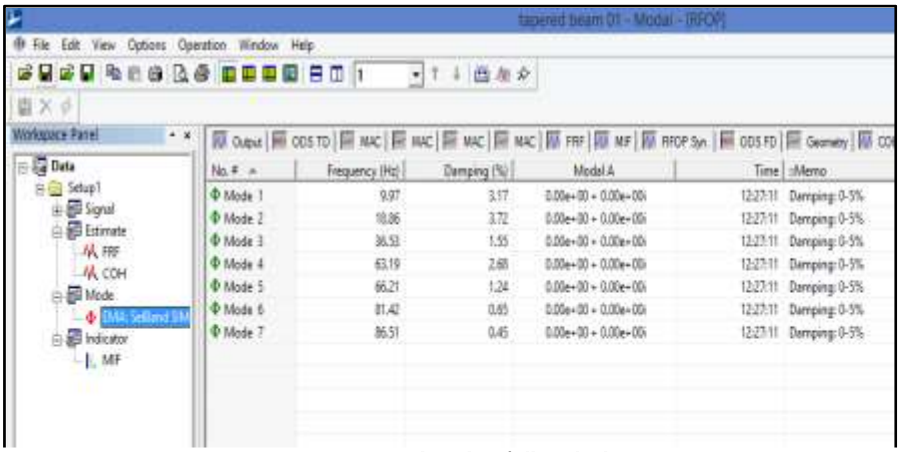
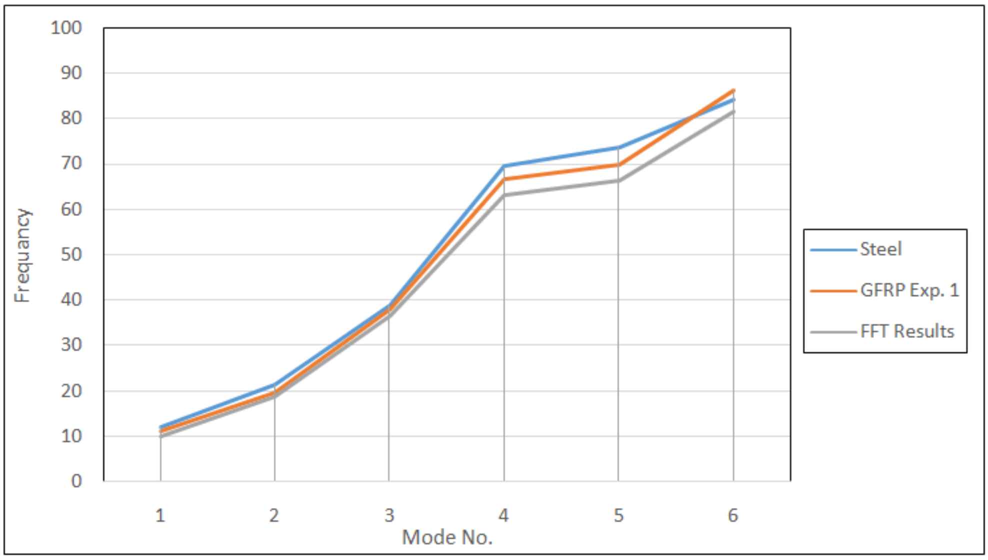


Fig.11: Experimental results of all mode shape

Table 4: Natural Frequency

Material	Natural Frequency					
Mode Shape No	1	2	3	4	5	6
FFT	9.97	18.86	36.53	63.19	66.21	81.42

Fig. 12: Graph of comparison of Steel, GFRP and FFT results



5. CONCLUSION

1. Steel and GFRP blade for the wind pump is successfully designed and simulated in FEA and results are within the acceptance criteria for both.
2. It can be clearly concluded from the design and FEA chapter that conventional blade for the turbine can be replaced with the GFRP design by saving weight without affecting the structural performance in terms of material failure.
3. From FEA analysis performed of taguchi matrix layup combinations it can be safely concluded that cloth angle of 0-90 for all three layers will provide best results of the first modal natural frequency which is comparable with the steel.
4. This mean modal frequency performance of the blade design is also not changing if we replace the steel blade with the 0-90 layup angled GFRP blade.
5. GFRP blade successfully manufactured and tested for finding out modal frequencies.

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