International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

# A Comparative Study between GFRP Blade, GFRP Blade with Steel Wire Mesh and GFRP Blade with Aluminum Sheet Metal Reinforcement Based on Modal Analysis Technique

Nilesh P. Chandgude
Mechanical engineering dept.
SVPM's COE Malegaon (Bk)
Maharashtra, India.

Prof. Nitin D. Gadhave
Mechanical Engineering Dept.
SVPM's COE Malegaon (Bk)
Maharashtra, India

***Abstract*— Modal analysis is a technique which is used to find natural frequency and mode shape of structure. In wind turbine blade specific weight and specific stiffness ratios must be high so that material selection becomes vital problem. GFRP gives high value of these ratios but some reinforcement of strips of steel wire mesh and aluminum sheet metal in GFRP can improve stiffness of blade without much increase in weight of blade. In this paper three wind blades were manufactured from GFRP, GFRP with steel wire mesh reinforcement and GFRP with Aluminum sheet metal reinforcement and modal analysis was carried out on manufactured blades using finite element analysis (FEA) method by using ANSYS 14.5 software and verification of result by experimental modal analysis by using FFT analyzer. Also we suggest best material for wind turbine rotor blade by comparison based on natural frequencies and weight of blades.**

***Keywords—Modal analysis; specific stiffness; GFRP blade; Finite element analysis (FEA); FFT analyzer.***

## I. INTRODUCTION

Blade is a key element of wind mill which convert wind kinetic energy into mechanical energy. Blade must be stiffer and should have high strength. GFRP is a common composite material for wind turbine rotor blade. S. A. kale and R. N. Varma [1] have developed blade of 800 mm length having NACA 4412 airfoil profile for a horizontal axis micro wind turbine of 600 W power output. Saad Sami et al. [2] have determined fundamental flap-wise and edge-wise modal frequency of 5KW glass reinforced polyester composite wind turbine blade using FEM technique and validate extracted modal frequency by experimental modal analysis. Shun-zhang Chen and Lu-ping LI [3] have determined natural frequency of 15 KW wind turbine rotor blade by using FEM method for rotating and irrotating blade. Nitasha B. Chaudhari [4] Performed modal analysis on 5MW HAWT blade by using Qblade v0.8 software at different rotating speeds. Chi Chen et al. [5] performed modal analysis on 1.2 MW HAWT rotor blade by using ANSYS modeling. Ye Zhiquan et al. [6] studied structural dynamic analysis of HAWT blade of 300 W by experimental and FEA modal analysis. Pabut O et al. [7] have developed 3D model of the blade in ANSYS software and performed modal analysis by using FEA method and verification of result by experimental method. Ashwani Kumar et al. [8] performed dynamic analysis on single wind turbine blade made of Al 2024 by using FEA method. For design of blade solidedge software was used and FEA result were verified with experimental result available in literature. Cui Yanbin et al. [9] they consider wind turbine blade as a composite laminate plate and perform modal analysis on blade by using ANSYS APDL software and calculate the first six natural frequency of the blade. Santhosh A et al. [10] compared wind turbine blade made up of CFRP and Aluminum alloy on the basis of modal analysis and select CFRP material as it saves approximately 20% material weight compared to Aluminum alloy. Tartibu L.K et al. [11] they performed modal analysis on uniform and stepped beam which was a representative of wind turbine blade and determined natural frequency of stepped and uniform beam also they stated that only flap wise natural frequencies are more likely to coincide with excitation frequency. Fangfang Song et al. [12] they adopted a way of combining a solid work and ANSYS to develop blade model so as to describe the actual shape and layer structure of composite blade precisely. The modal analysis was performed on the blade to check whether the resonance occurs or not. Ganesh B. Taware et al. [13] they manufactured two small wind turbine blades and performed free vibration analysis on these two blades and determined natural frequencies of two blades and also observed increase in natural frequency of blade made up of GFRP with steel wire mesh reinforcement. Zhang Lanting [14] he designed and analyzes an E-glass/epoxy composite blade for a 1.2MW HAWT blade. Y.G Li et al. [15] they take a blade of 100 KW as the object of study. They performed finite element analysis to determine natural frequency and mode shapes. Brian J. Schwarz and Mark H. Richardson [16] they reviewed three topics related to experimental modal analysis, that topics were making FRF measurement with a FFT analyzer, modal excitation technique, and modal parameter estimation from a set of FRFs. Tartibu L.K et al. [17] they determined flap-wise, edge-wise and torsional natural frequencies of variable length wind turbine blade.

Also they compare natural frequencies of blade obtained by MATLAB program and finite element program Unigraphics NX5. Khandare R.S et al. [18] have determined natural frequencies of cooling fan blades made up of GFRP material by using ANSYS workbench software and compared these result with experimental result. Cem Emeksiz and Mustafa Tufan Altunok [19] they performed free vibration analysis on a blade of AIR-X400 W horizontal axis wind turbine. C. Amer and M. Sahin [20] they modelled an optimized horizontal axis 5-meter-long wind turbine rotor blade by using the airfoil geometries also they performed modal analysis. They stated that the original configuration can be made stiffer by applying all layers in o-degree direction. In this paper small horizontal axis wind turbine rotor blades of 600 W capacity were considered and modal analysis were performed on GFRP blade, GFPR blade with steel wire mesh reinforcement and GFRP blade with Aluminum sheet metal reinforcement by FEA and experimental modal analysis methods to select suitable blade.

## II. MODAL ANALYSIS USING FEA

### *A. The Rotor Blade*

The horizontal axis wind turbine rotor blades of 600 W capacity were made up of glass fiber reinforced plastic material. Length of blade was 800 mm and maximum chord length was 135mm and maximum twist was 23.66˚, the main characteristics of this rotor are: rotor diameter 1.6 m, rated power 600 W, airfoil NACA 4412 [1]. Blade was modelled using CATIA V5 software and file was saved in IGES file format that file was imported into ANSYS and modal analysis was performed on the blade by using ANSYS 14.5 workbench software. Fig. 1 shows 3D CAD model of the blade. Blades are fixed in turbine hub so fix support was applied at root of the blade in ANSYS modal analysis. Material properties were assigned then geometry was imported into ANSYS 14.5 software then meshing was done on imported model after meshing nodes and elements obtained for GFRP blade was 20730 and 10101 respectively; for GFRP blade with steel wire mesh reinforcement nodes and elements obtained was 20680 and 10054 respectively and for GFRP blade with Aluminum sheet metal reinforcement nodes and elements obtained was 25453 and 12436 respectively. Modal analysis was performed to find out natural frequencies and mode shape of blades. Table II shows the values of natural frequencies obtained by ANSYS 14.5 software for all three blades. Fig. 2 to 10 shows mode shape obtained for three different blades. Maximum deformation occurs at the tip of the blade and at the root section deformation was minimum. Material characteristic of rotor blade is shown in table I.

TABLE I. MATERIAL CHARACTERISTIC OF ROTOR BLADE

| Sr. No | Material Properties | Value |
|---|---|---|
| 1 | Tensile modulus along X direction (MPa) | 14000 |
| 2 | Tensile modulus along Y direction (MPa) | 6530 |
| 3 | Tensile modulus along Z direction (MPa) | 1530 |
| 4 | Shear modulus along XY direction (MPa) | 2433 |
| 5 | Shear modulus along YZ direction (MPa) | 1698 |
| 6 | Shear modulus along ZX direction (MPa) | 2433 |
| 7 | Poisson ratio along XY | 0.217 |
| 8 | Poisson ratio along YZ | 0.366 |
| 9 | Poisson ratio along ZX | 0.217 |
| 10 | Mass Density in kg/m^3 | 2600 |

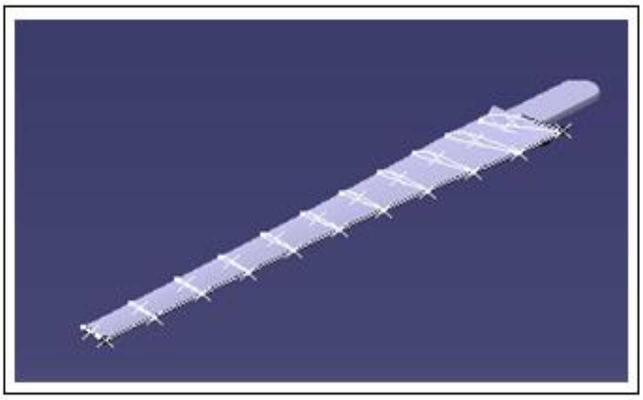


Fig.1.3D CAD model of blade

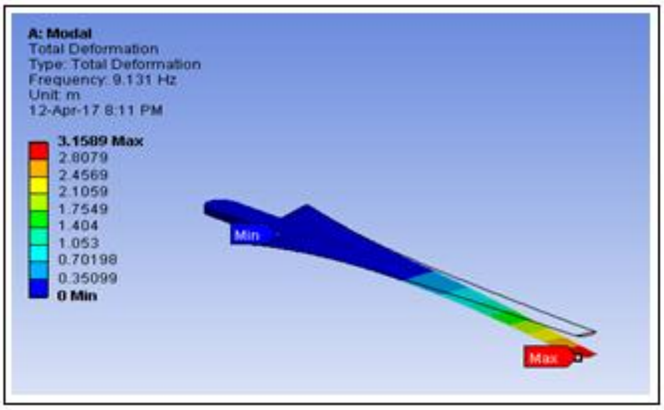


Fig. 2.First Mode shape of GFRP blade with Aluminum sheet metal reinforcement

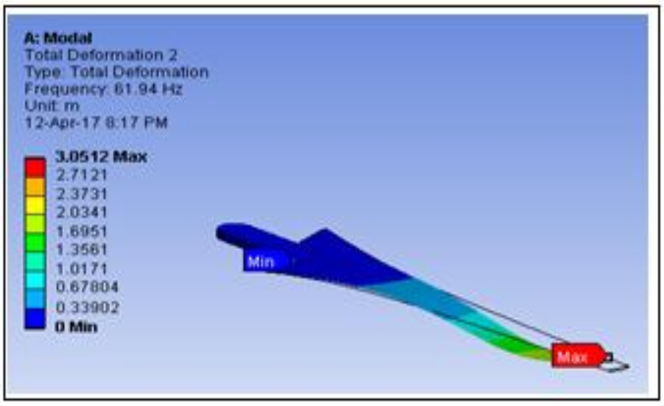


Fig. 3.Second Mode shape of GFRP blade with Aluminum sheet metal reinforcement

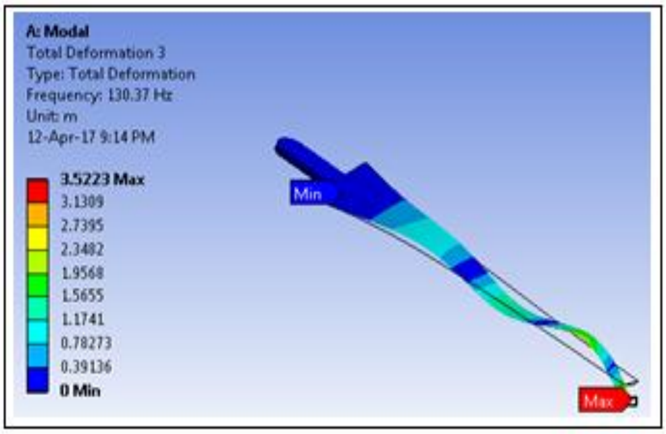

A: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 130.37 Hz
Unit: m
12-Apr-17 9:14 PM

Fig. 4.Third Mode shape of GFRP blade with Aluminum sheet metal reinforcement

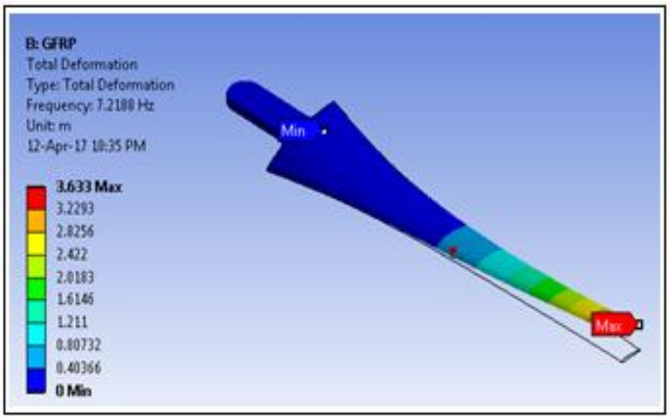

B: GFRP
Total Deformation
Type: Total Deformation
Frequency: 7.2188 Hz
Unit: m
12-Apr-17 10:35 PM

Fig. 5.First Mode shape of GFRP blade

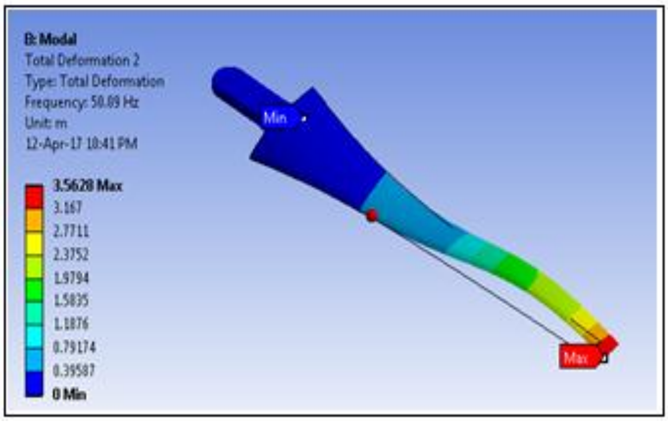

B: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 50.09 Hz
Unit: m
12-Apr-17 10:41 PM

Fig. 6.Second Mode shape of GFRP blade

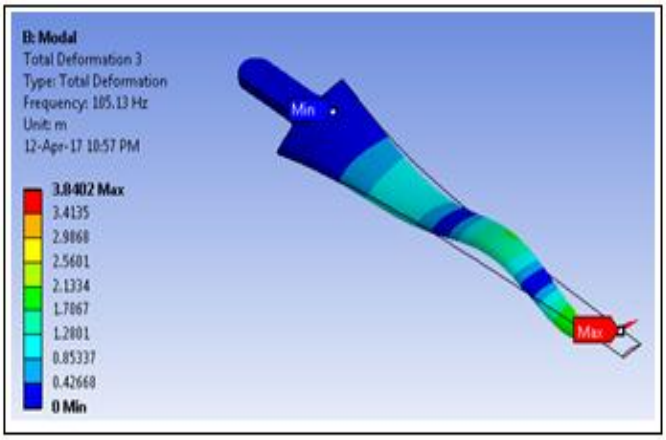

B: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 105.13 Hz
Unit: m
12-Apr-17 10:57 PM

Fig. 7.Third Mode shape of GFRP blade

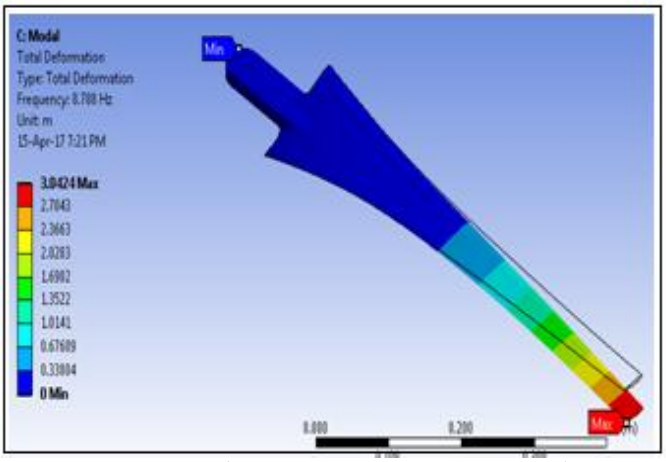

C: Modal
Total Deformation
Type: Total Deformation
Frequency: 8.788 Hz
Unit: m
15-Apr-17 7:21 PM

Fig. 8.First Mode shape of GFRP blade with steel wire mesh reinforcement

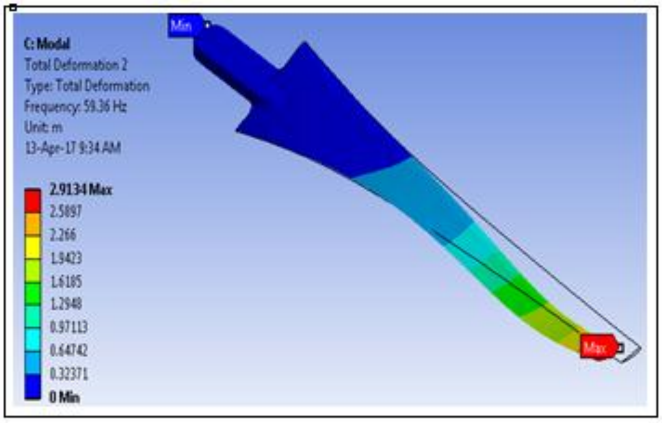

C: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 59.36 Hz
Unit: m
13-Apr-17 9:34 AM

Fig. 9.Second Mode shape of GFRP blade with steel wire mesh reinforcement

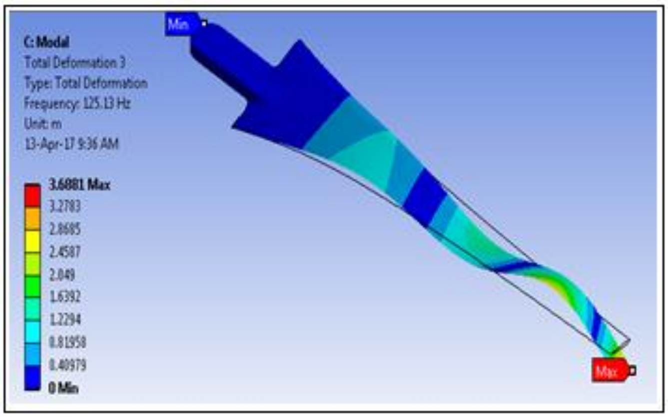

C: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 125.13 Hz
Unit: m
13-Apr-17 9:36 AM

Fig.10.Third Mode shape of GFRP blade with steel wire mesh reinforcement

TABLE II. NATURAL FREQUENCIES BY ANSYS

| | | | |
|---|---|---|---|
| **(a)-GFRP blade with Aluminum sheet metal reinforcement** | | | |
| Modal Frequency (Hz) | 1<br>9.13 | 2<br>61.94 | 3<br>130.37 |
| **(b)-GFRP blade** | | | |
| Modal Frequency (Hz) | 1<br>7.21 | 2<br>50.09 | 3<br>105.13 |
| **(c)-GFRP blade with steel wire mesh reinforcement** | | | |
| Modal Frequency (Hz) | 1<br>8.78 | 2<br>59.36 | 3<br>125.13 |

## III. EXPERIMENTAL MODAL ANALYSIS

In experimental modal analysis the rotor blade natural frequencies are obtained by measuring and analyzing the input and output response signals by using FFT analyzer.

### *A. Experimental Setup*

In this experiment rotor blade is fixed at the root of the blade with the help of C clamp and tip of the blade is free end thus blade act as a cantilever beam. The accelerometer is placed on surface of the blade at different predefined location to sense the response signal. Blade was excited with the help of impact hammer and input and output response was recorded with the help of FFT analyzer. Fig. 11 shows schematic diagram of experimental setup. To measure the frequency response functions of the turbine blade model a single input, single output impact tests with fixed boundary conditions was performed. This method of excitation with Impact hammer is cheap and equipment required for it was readily available. Modal analysis was performed to extract natural frequencies of the blades. Equipments required for the test are as below.

a) *Test Specimen:* Blade of 800 mm length was clamped at the root with the help of C clamp as shown in fig. 12. Blade is made up of GFRP composite.

b) *Impact hammer:* Impact hammer consist of load cell attach to its head to measure input force. Following table shows the specifications of the Impact hammer.

TABLE III. SPECIFICATIONS OF THE IMPACT HAMMER

| | |
|---|---|
| Model No | 086C03 |
| Manufacturer | PCB Piezotronix |
| Description | Impulse force hammer |
| Output bias | 9.7 |
| Temperature | 74 ° |
| 23 ° relative humidity | 55 % |
| Hammer sensitivity | 2.280 |

c) *Accelerometer:* Accelerometer measures the response acceleration at fixed predefined point. Following table shows the specification of the Accelerometer.

TABLE IV. SPECIFICATIONS OF THE ACCELEROMETER

| | |
|---|---|
| Model name | 7105A-0500 |
| Manufacturer | Measurement specialties, Inc |
| Frequency Range | 0.32 Hz-10000 Hz |
| Sensitivity at 100 Hz | 9.749 mV/g |
| Transverse sensitivity | < 5% |

d) *FFT analyzer:* Measurement of the force and acceleration signals was done by using a “DEWE-43 A” 8- channel dynamic signal analyzer. Measurement data may be processed on a computer using DEWESoftX software. DEWESoftX software was used to interpret the data and to evaluate natural frequencies. Table V shows natural frequencies obtained by experimental modal analysis. Fig. 13 to 15 shows graph of frequency verses acceleration for three different blades.

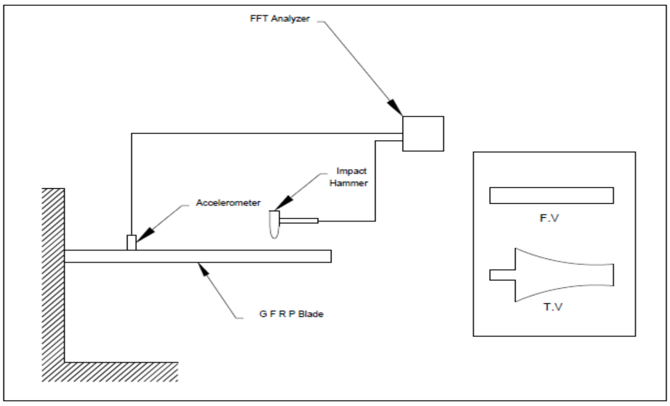


Fig.11. Schematic diagram of experimental setup.

Fig. 12.Experimental Setup

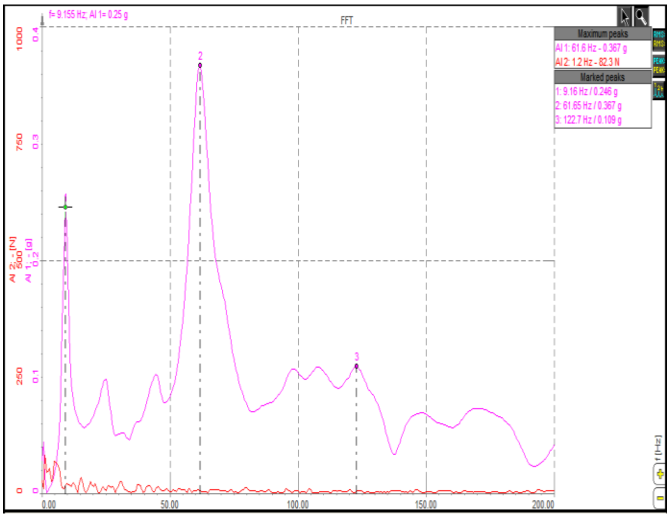


Fig.13. Graph of frequency v/s acceleration of GFRP blade with Aluminum sheet metal reinforcement.

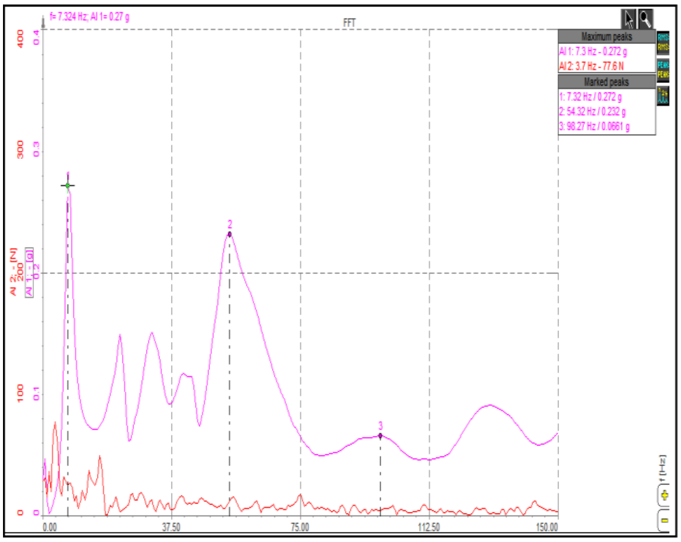


Fig.14. Graph of frequency v/s acceleration of GFRP blade.

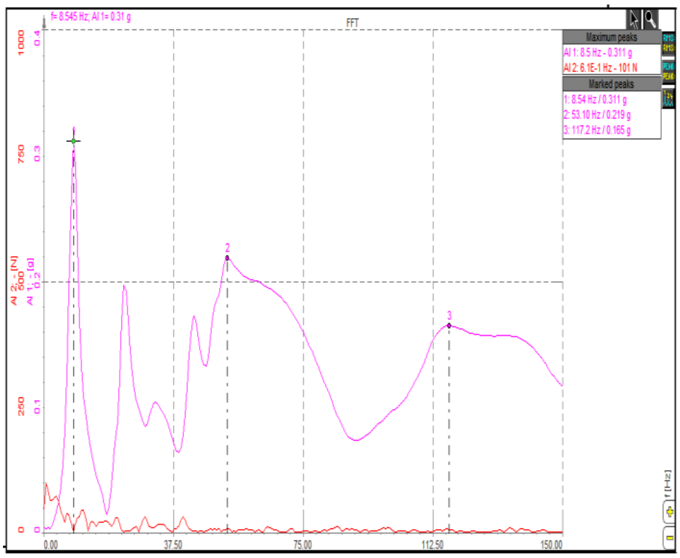


Fig. 15.Graph of frequency v/s acceleration of GFRP blade with steel wire mesh reinforcement

TABLE V. NATURAL FREQUENCIES BY FFT ANALYZER

| (a)-GFRP blade with Aluminum sheet metal reinforcement | | | |
|---|---|---|---|
| Modal Frequency (Hz) | 1<br>9.16 | 2<br>61.65 | 3<br>122.7 |
| (b)-GFRP blade | | | |
| Modal Frequency (Hz) | 1<br>7.32 | 2<br>54.32 | 3<br>98.27 |
| (c)-GFRP blade with steel wire mesh reinforcement | | | |
| Modal Frequency (Hz) | 1<br>8.54 | 2<br>53.10 | 3<br>117.2 |

## IV. RESULTS

The result obtained by FEA and experimental method for modal analysis of three different wind turbine rotor blades are compared as shown in table from table VI to table XII. Also the FEA and experimental results obtained are compared in the form of graphs as shown in fig. 16 and 17. From fig. 16 and 17 it was observed that natural frequency increases for GFRP blade with steel wire mesh and GFRP blade with aluminum sheet metal reinforcement as compared to GFRP blade.

TABLE VI. COMPARISONS OF THE DIFFERENT MODE ANALYSIS RESULTS FOR 600 W GFRP ROTOR BLADE

| Mode No. | Natural frequency by FFT (Hz) | Natural frequency by ANSYS (Hz) | Error (Hz) | % Error |
|---|---|---|---|---|
| 1 | 7.32 | 7.21 | 0.11 | 1.50 % |
| 2 | 54.32 | 50.09 | 4.23 | 7.78% |
| 3 | 98.27 | 105.13 | -6.86 | -6.98% |

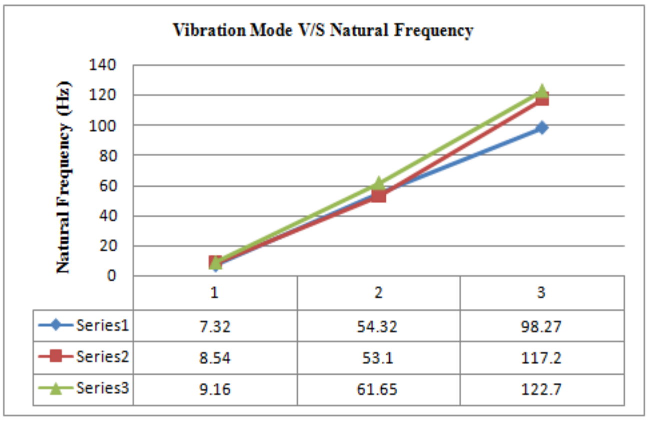
TABLE VII. COMPARISONS OF THE DIFFERENT MODE ANALYSIS RESULTS FOR 600 W GFRP ROTOR BLADE WITH STEEL WIRE MESH REINFORCEMENT

| Mode No. | Natural frequency by FFT (Hz) | Natural frequency by ANSYS (Hz) | Error (Hz) | % Error |
|---|---|---|---|---|
| 1 | 8.54 | 8.78 | -0.24 | -2.81% |
| 2 | 53.10 | 59.36 | -6.26 | -11.78% |
| 3 | 117.2 | 125.13 | -7.93 | -6.76% |

TABLE VIII. COMPARISONS OF THE DIFFERENT MODE ANALYSIS RESULTS FOR 600 W GFRP ROTOR BLADE WITH ALUMINUM SHEET METAL REINFORCEMENT

| Mode No. | Natural frequency by FFT (Hz) | Natural frequency by ANSYS (Hz) | Error (Hz) | % Error |
|---|---|---|---|---|
| 1 | 9.16 | 9.13 | 0.03 | 0.32% |
| 2 | 61.65 | 61.94 | -0.29 | -0.47% |
| 3 | 122.7 | 130.37 | -7.67 | -6.25% |

In fig. 16 and 17 series 1 represent GFRP blade, series 2-represent GFRP blade with steel wire mesh reinforcement and series3-represent GFRP blade with Aluminum sheet metal reinforcement.



| | 1 | 2 | 3 |
|---|---|---|---|
| Series1 | 7.32 | 54.32 | 98.27 |
| Series2 | 8.54 | 53.1 | 117.2 |
| Series3 | 9.16 | 61.65 | 122.7 |

Fig. 16.Vibration Mode V/S Natural Frequency for three different blades of 600 W machine. (By using FFT)

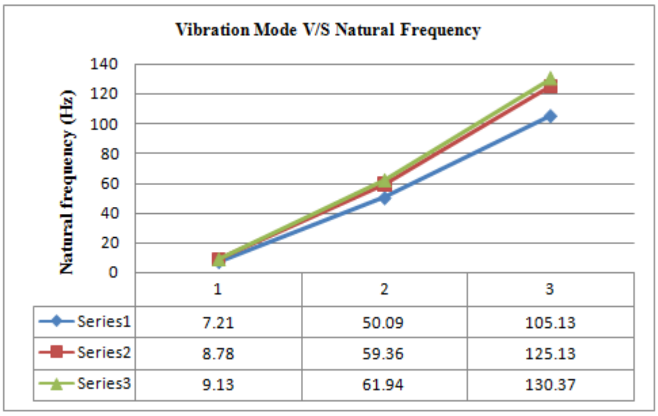


Fig. 17.Vibration Mode V/S Natural Frequency for three different blades of 600 W machine. (By using ANSYS)

TABLE IX. COMPARISON FOR FFT RESULTS OF GFRP BLADE AND GFRP BLADE WITH STEEL WIRE MESH

| Mode No. | GFRP Blade (Hz) | GFRP blade with steel wire mesh (Hz) | Increase in frequency (Hz) | % Increase in frequency |
|---|---|---|---|---|
| 1 | 7.32 | 8.54 | 1.22 | 14.28% |
| 2 | 54.32 | 53.10 | -1.22 | -2.29% |
| 3 | 98.27 | 117.2 | 18.93 | 16.15% |

TABLE X. COMPARISON FOR FFT RESULTS OF GFRP BLADE AND GFRP BLADE WITH ALUMINUM SHEET METAL

| Mode No. | GFRP Blade (Hz) | GFRP blade with Aluminum sheet metal(Hz) | Increase in frequency (Hz) | % Increase in frequency |
|---|---|---|---|---|
| 1 | 7.32 | 9.16 | 1.84 | 20.08% |
| 2 | 54.32 | 61.65 | 7.33 | 11.18% |
| 3 | 98.27 | 122.7 | 24.43 | 19.91% |

TABLE XI. COMPARISON FOR ANSYS RESULTS OF GFRP BLADE AND GFRP BLADE WITH STEEL WIRE MESH

| Mode No. | GFRP Blade (Hz) | GFRP blade with steel wire mesh (Hz) | Increase in frequency (Hz) | % Increase in frequency |
|---|---|---|---|---|
| 1 | 7.21 | 8.78 | 1.57 | 17.88% |
| 2 | 50.09 | 59.36 | 9.27 | 15.61% |
| 3 | 105.13 | 125.13 | 20 | 15.98% |

TABLE XII. COMPARISON FOR ANSYS RESULTS OF GFRP BLADE AND GFRP BLADE WITH ALUMINUM SHEET METAL

| Mode No. | GFRP Blade (Hz) | GFRP blade with Aluminum sheet metal (Hz) | Increase in frequency (Hz) | % Increase in frequency |
|---|---|---|---|---|
| 1 | 7.21 | 9.13 | 1.92 | 21.02% |
| 2 | 50.09 | 61.94 | 11.85 | 19.13% |
| 3 | 105.13 | 130.37 | 25.24 | 19.36% |

TABLE XIII. COMPARISON FOR WEIGHT OF GFRP BLADE AND GFRP BLADE WITH ALUMINUM SHEET METAL

| | GFRP Blade | GFRP blade with Aluminum sheet metal | Increase in Weight (kg) | % Increase in weight |
|---|---|---|---|---|
| Weight of the blade (kg) | 0.8 | 1 | 0.2 | 20% |

TABLE XIV. COMPARISON FOR WEIGHT OF GFRP BLADE AND GFRP BLADE WITH STEEL WIRE MESH

| | GFRP Blade | GFRP blade with steel wire mesh | Increase in Weight (kg) | % Increase in weight |
|---|---|---|---|---|
| Weight of the blade (kg) | 0.8 | 1 | 0.2 | 20% |

## V. CONCLUSION

From comparison it was found that natural frequency of GFRP blade with steel wire mesh increases from 14.28% to16.15% compared with GFRP blade based on FFT results whereas in case of ANSYS results increase in frequency found to be 15.61% to 17.88%. Later from comparison between GFRP blade and GFRP blade with Aluminum sheet metal increase in natural frequency of GFRP blade with Aluminum sheet metal found to be 11.18% to 20.08% based on FFT results whereas in case of ANSYS results increase in frequency found to be 19.13% to 21.02% without much increase in weight of blade. Increase in natural frequency indicate that increase in stiffness of the blade thus by making reinforcement of six number of strips of steel wire mesh and six strips of Aluminum sheet metal into GFRP blade we can improve stiffness of the blade approximately 11% to 21% depending on composition of material of blade. Here increase in weight observed was 20% for GFRP blade with Aluminum sheet metal and GFRP blade with steel wire mesh reinforcement. The FEA results were verified with experimental results; good agreement between FEA results and experimental results was observed. Percentage increment in weight of GFRP blade with steel wire mesh reinforcement and GFRP blade with Aluminum sheet metal reinforcement was observed to be 20 % and percentage increment in natural frequency was high for GFRP blade with Aluminum sheet metal reinforcement as compared with GFRP blade with steel wire mesh reinforcement. So we can select GFRP blade with Aluminum sheet metal reinforcement as a material for wind turbine rotor blade based on weight and natural frequency.

## ACKNOWLEDGMENT

I am very thankful to my department head Prof. S.S. Patil and guide Prof. N. D. Gadhave who has given me an idea about this project. Also I am thankful to Prof. S. H. Kadhane from Malegaon Engineering College and Prof. G. B. Taware from Someshwar polytechnic College who has given me support and guidance throughout this work.

## REFERENCES

[1] Sandip A. Kale and Ravindra N. Varma “Aerodynamic design of horizontal axis micro wind turbine blade using NACA 4412 profile” international journal of renewable energy research Vol. 4, No. 1, 2014, pp. 69-72.

[2] Saad Sami, Behzad Ahmad zai, M. Amir Khan "Dynamic analysis of 5KW wind turbine blade with experimental validation" Journal of Space Technology Vol-4, No-1, July 2014, pp. 82-87.

[3] Shun-zhang Chen and Lu-ping LI "3D Modeling and Finite Element analysis of Dynamic Characteristics for Blades of Wind Turbine" college of power and energy engineering Changsha University of Science & Technology, Changsha, China.

[4] Nitasha B. Chaudhari “Dynamic Characteristics of Wind Turbine Blade” International Journal of Engineering Research &Technology (IJERT ) Vol. 3 Issue 8, August – 2014, pp. 168-173.

[5] Chi Chen, Min Wang, Long Zou "Modal Analysis of Wind Turbine Blades based on ANSYS Modeling" Advanced Materials Research Vol. 790 (2013) , pp 655-658.

[6] Ye Zhiquan, Ma Haomin, Bao Nengsheng, Chen Yan and Ding Kang "Structure Dynamic Analysis of a Horizontal Axis Wind Turbine System Using a Modal Analysis Method" Wind engineering volume 25, no. 4 , 2001, pp 237–248.

[7] Pabut O, Allikas G, Herranen H, Talalaev R, & Vene K "Model validation and structural analysis of a small wind turbine blade" 8th International DAAAM Baltic Conference industrial engineering 19-21 April 2012, Tallinn, Estonia.

[8] Ashwani Kumar, Arpit Dwivedi, Vipul Paliwal, Pravin P Patil “Free Vibration Analysis of Al 2024 Wind Turbine Blade Designed for Uttarakhand Region Based on FEA” Procedia Technology 14 ( 2014 ) 336 – 347.

[9] Cui Yanbin, Shi Lei, Zhao Feng "Modal Analysis of Wind Turbine Blade Made of Composite laminated plates" Pow. And En, Eng. Con. 2010, Asia Pecific, 2010,1-4.

[10] Santhosh. A, Manjunatha Babu. N.S, Mohan Kumar. K "Modal analysis of wind turbine blade using FE modeling” International journal of engineering sciences & research Technology, December 2016, pp. 590-597.

[11] Tartibu L K ., Kilfoil M. and Van der merwe A. J. "Modal testing of simplified wind turbine blade" International Journal of Advances in Engineering & Technology, Vol. 4, Issue 1, July 2012, pp. 649-660

[12] Fangfang Song, Yihua Ni, , Zhiqiang Tan "Optimization Design, Modeling and Dynamic Analysis for composite wind Turbine blade" Procedia Engineering 16 ( 2011 ) 369 – 375.

[13] Ganesh B. Taware, Sham H. Mankar, V. B. Ghagare, G. P. Bharambe, Sandip A. Kale "Vibration Analysis of a Small Wind Turbine blade" International Journal of Engineering and Technology (IJET) Vol 8 No 5 Oct-Nov 2016. pp. 2121-2126.

[14] Zhang Lanting "Research on Structural Lay-up Optimum Design of composite Wind Turbine Blade" Energy Procedia 14 (2012) 637 – 642

[15] Y.G Li and L.Y. Wang & Z wang "modal analysis and three dimensional modeling of 100 KW horizontal axis wind turbine blades" International Conference on Applied Science and Engineering Innovation (ASEI 2015), pp. 1313-1317.

[16] Brian J. Schwarz & Mark H. Richardson "Experimental Modal Analysis" CSI Reliability Week, Orlando, FL October, 1999.

[17] Tartibu L K ., Kilfoil M. and Van der merwe A. J. "Vibration analysis of a variable length blade wind turbine" International Journal of Advances in Engineering & Technology, Vol 4, Issue 1, July 2012, pp. 630-639.

[18] Khandare R.S, Londhe B.C., Ganore D.J. "Vibration Analysis of Fiber Reinforced Plastic Fan Blade" International Research Journal of Engineering and Technology (IRJET) Volume: 02 Issue: 06, Sep-2015, pp. 86-91.

[19] Cem Emeksiz, Mustafa Tufan Altunok "Free Vibration Analysis of Shape Memory Alloys Used In Wind Turbine Blade Root Connection" International Refereed Journal of Engineering and Science (IRJES) Volume 5, Issue 9 (September 2016), PP.11-17.

[20] C. Amer, and M. Sahin “Structural Analysis of a Composite Wind Turbine Blade” World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8, No:7, 2014, pp.1264-1270.