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Dynamic Analysis and Testing of Micro Wind Turbine

Jagadish[1], P.R. Venkatesh[2]

[1]*Department of Mechanical Engineering,R. V. College of Engineering, Bangalore*
E-mail: jagadishgunde17@gmail.com
[2]*Department of Mechanical Engineering, R. V. College of Engineering, Bangalore*
E-mail: venkateshpr@rvce.edu.in

Abstract: Large scale wind turbines have been broadly examined for decades but only few studies conducted on the small scale wind turbines. This study on micro wind turbine provides the analytical and experimental results on dynamic characteristics of 'Glass Filled Nylon' blades. Then we determine the parameters such as natural frequency and mode shapes of micro wind turbine for a domestic application. These dynamic characters are important to know for the further studies on its performance and life of the wind turbine and it provides the information to set a safe rotational speed of the turbine blades. A detailed 3D finite-element model of the Micro wind turbine is created using Creo parametric for the simulation and the material properties of Glass filled nylon.Numerical results obtained by using Ansys work bench and experimental results obtained by using DSA setup for the first four modesare validated and are within the limit.

Key Words: Dynamic analysis, Glass filled nylon, Horizontal axis micro wind turbine, vibration.

I. INTRODUCTION

A micro-wind turbine uses the wind to turn a small generator, which produces electricity. An inverter conditions this electricity to ensure that it is compatible with appliances in the home and can be safely fed into the electricity grid. Globally research is focused on dynamic analysis and testing of the high power generating wind turbine which is usually placed in the remote rural areas. The high power generating wind turbines undergo a high amount of vibration due to the high speed of wind from the environment. The small turbine for residential scale use is available. They are approximately 7 to 25 feet (2.1 to 7.6 m) in diameter and produce electricity at a rate of 300 to 10,000 watts at their tested wind speed.The aim of the dynamic analysis is to determine the predominant natural frequencies and mode shapes of a structure in a static condition of the turbine.
The organization of this paper is as follows, section II presents related work. Geometrical modeling of the turbine is explained in section III. Section IVdescribes analysis of Finite Element Method (FEM) to determine natural frequencies and mode shapes. In section Vexperimental analysis by marking points on the turbine and dynamic vibration testing method is described. Section VI describes results obtained in terms of dynamic characteristic of a micro wind turbine and compared the frequencies obtained from the experimental and FEA methods. Section VII draws conclusion.

A.Description of wind turbine

The turbine is horizontal axis type, which consists of three blades mounted horizontally on a rotating shaft as shown in Fig.1. The blades are made of glass filled nylon and blade span is 2.4m. The turbine consists of a vertical structure for the support to the body and that structure is attached to the ground by four guy pipes. For micro wind turbine – optimal blades are twisted and they have a non-uniform cross section so they are quite difficult to manufacture.
The vertical structure provides the 5m gap from the ground to the axis of the blade. One shaft is provided at the axis of rotation for positioning the blades to the direction of the wind, the shaft is of 1m length and the wing shape is made at the other end of the shaft.

The top portion of the turbine (Blades and generator) is free to rotate around the vertical axis to position the blades at the right direction of the wind.

Fig. 1.Micro wind turbine structure.

II. RELATED WORK

There are many studies has been done on the wind turbines. In [1], the effect of vibration at extreme power production and the natural frequency for parked rotor conditions is proposed. The essential dynamic properties of wind turbine blades, like natural frequencies, damping characteristics and mode shapes, can be experimentally determined by use of the modal analysis technique is demonstrated in [2]. In [3] the behavior of the coupled systems in various wind and wave environments is studied and redesigned the turbine blades. In [4] authors adopted three approaches, the predictor importance analysis, global sensitivity analysis and correlation coefficient analysisto conduct quantitative analysis of the importance of parameters to wind turbine vibrations. In [5] author related the rotational effects affecting the flow on a wind turbine, as well as dynamic effects experienced by the blades. In [6] authors made an analytical study on the structure of the wind turbine blades and the effect of vibration on the blade structures after changing their design. The resolution of bending stress in the blades to find the natural frequency of the blade is proposed in [7]. In [8] the excitation frequencies and the natural frequency of the wind turbineis compared.
However above methods studied on the dynamic characterization of the high power wind turbines, but it is not economical to place the high power wind turbines in the urban areas, due to large buildings the velocity of wind will get reduce till it reach to the turbine. Thus we use micro wind turbines, which can be placed on the terrace, as the size of the turbine will be small and the wind velocity required is less to turn the blade.

III. GEOMETRICAL MODELING

CAD is mainly used for detailed engineering of 3D models of physical components. In this study the micro wind turbine dimensions are taken from model, with respect to those dimensions geometrical models were created in Creo parametric Cad software. Initially all the individual part modeling is done then parts are assembled. The modeling of the turbine is shown in Fig. 2.

Fig.2.Geometrical modeling.

IV. FINITE ELEMENT ANALYSIS

In this section, we describe modal analysis using Finite Element Method (FEM) to determine natural frequencies and mode shapes. In this study, the modal analysis has been accomplished by the commercial finite element packaged Ansys. After constructing finite element model of micro wind turbine, the appropriate meshing with shell elements, model has been analyzed.

A.Material Selection

Wind turbine blades are made of glass filled nylonand other parts of the body made of steel. Modal analysis of blades is done by ANSYS, because blades are the main functional parts of the turbine. Density and young’s modulus are the properties affecting the frequency and mode shapes in modal analysis. The properties of these materials are in Table I.

Table I
Properties of Materials

material	young's modulus (GPa)	poisson's ratio	density (g/cc)
Glass Filled Nylon	14.5	0.35	1.6

B.Mesh Generation

The model was meshed using hexagonal elements with elemental size of 5mm. Fine mesh was required in order to improve solution accuracy. The meshed pattern of the model is as shown in Fig.3.Shell element has been used for analysis and is more disciplined meshing in comparison with other elements and has the capability of gaining more accurate results.

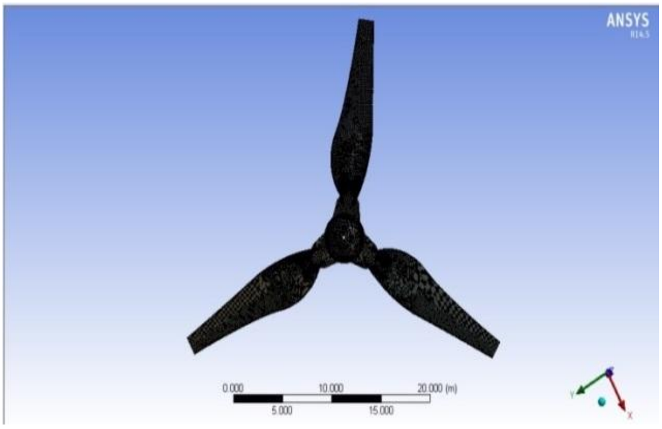

Fig. 3. Mesh generation.

C.Boundary Conditions

Modal analysis has been performed after creating the turbine blades finite element model and meshing in free-free state with no constraints. The results are calculated for the first 4 frequency modes. In this analysis we have made use of subspace method in ANSYS, hence not considered the effect of dynamic vibration on the other parts of the turbine. We concentrated mainly on the vibration effect on blades, because blades are the main functional parts of the turbine.

V. EXPERIMENTAL ANALYSIS

Section IV presents finite element analysis; here we showed experimental analysis by marking points on the turbine through ME-scope software and dynamic vibration testing using DSA (Dynamic Signal Analyzer).

A.Marking the points on the turbine

In this method of testing, we generated points through the ME-Scope software from the CAD model, the CAD model is converted in the STL (Standard Tessellation Language) format.

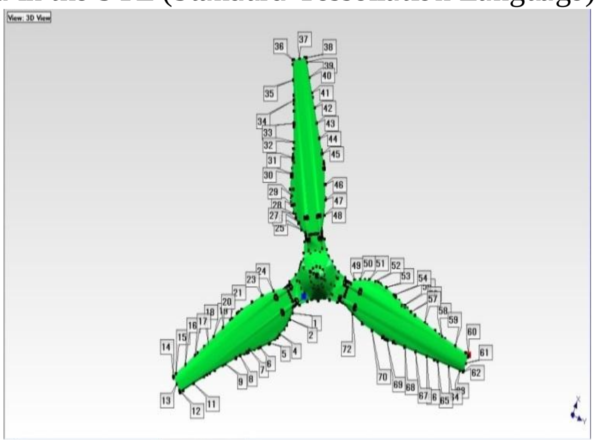

Fig.4. Generated points in ME-Scope software.

STL is a file format native to the stereo lithographyCAD software created by 3D Systems. This file is read in ME-Scope software and that generates the points on the model as shown in Fig.4. With reference to the ME-Scope software marking is done on the turbine blades as shown in Fig.5. We have marked the points as many as possible to get the more accurate results.

Fig. 5.Marking on the turbine.

5.2 Dynamic vibration testing by using DSA/Modal (Dynamic Signal Analyzer)

After marking points, the accelerometer is fixed on one particular point on the turbine blade. We have marked 24 points on each blade total points on three blades are 72.Fixedthe accelerometer on the point number 14 at the end corner of the first blade.The other end of accelerometer is connected to DSA. DSA is a device which converts the dynamic forces into electrical signals, the dynamic force is generated by the hammer and that signals transferred to the DSA through accelerometer which is mounted on a particular point on the physical model. Then the dynamic force is exerted by the hammer on the marked pointsstarting from the first point. Each point undergoes four times of excitation and immediately after finishing one point, the hammer to be tapped on the next point sequentially. The accelerometer must be fixed only on the point number 14 of the first blade. When the vibration produced by excitation of the hammer, that vibration signals transferred to the DSA through accelerometer, then the DSA will converts the vibration signals into electrical signals and that signals display in ME-scope software in the form of graphs. Fig.6 shows graphs of ME-scope software.

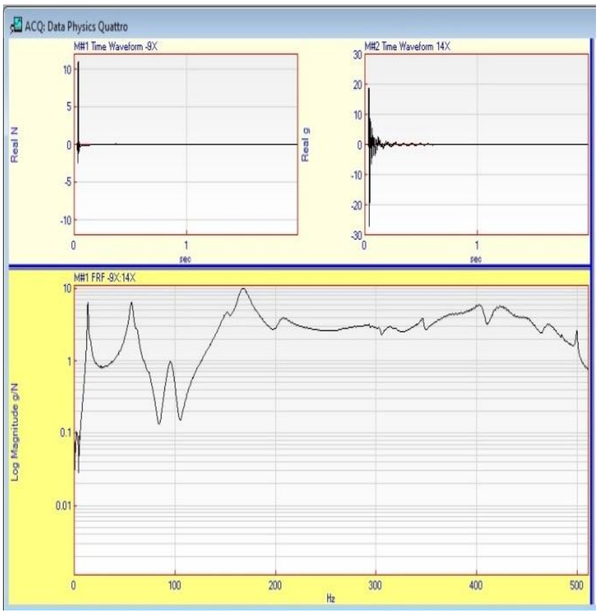

Fig.6. (From top left) First graph shows response from the hammer in Newton (N), second graph shows the response from accelerometer in gravity (g), third graph is ratio of 'g' to 'N' (g/N).

VI. RESULTS AND DISCUSSION

The study proposes a critical comparison of results obtained in terms of dynamic characteristic of a micro wind turbine. Table II gives the frequencies of the turbine blade at a static condition in all the 4 modes.The experimental mode shapes of blades are as shown in Fig.7.

Table II
Experimental Results

Mode no	FrequencyIn Hz
1	12.0094604
2	13.5940619
3	15.3005562
4	16.5475178

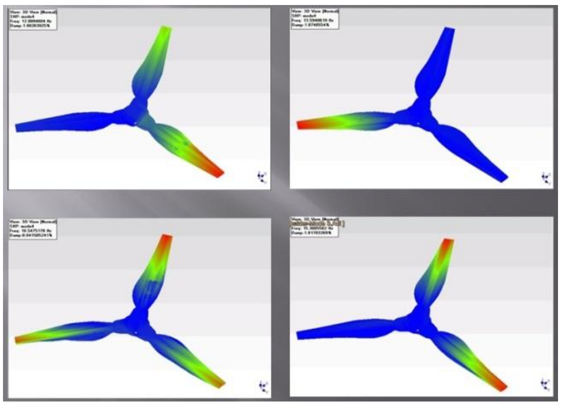

Fig.7.Experimental mode shapes.

The complete details of all the 72 points frequency results are as shown in Fig.8.

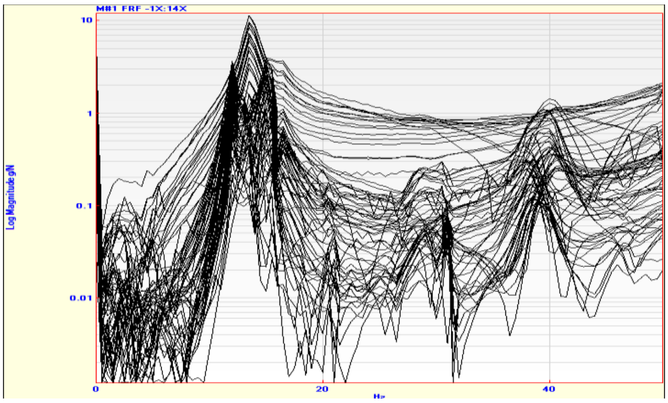

Fig.8. Frequency results of all 72 points of the blades.

It has been observed that due to various approximations made in finite element model the predicted values of the dynamic characteristics of micro wind turbine quite often differs from that of the actual structure. Experimented results from DSA and ME scope is one of the accurate methods of testing.Table III gives the results obtained from the analytical method.

Table III
FEA Results

Mode no	FrequencyIn Hz
1	12.740
2	13.841
3	16.006
4	20.055

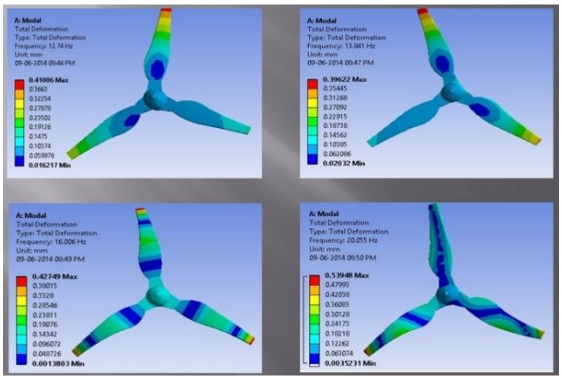

Fig.9 FEA mode shapes.

Frequencies obtained from the experimental and FEA methods are compared and the error is within the desired limit i.e., 8.2%. Fig.10 shows the comparison between analytical and experimental method.

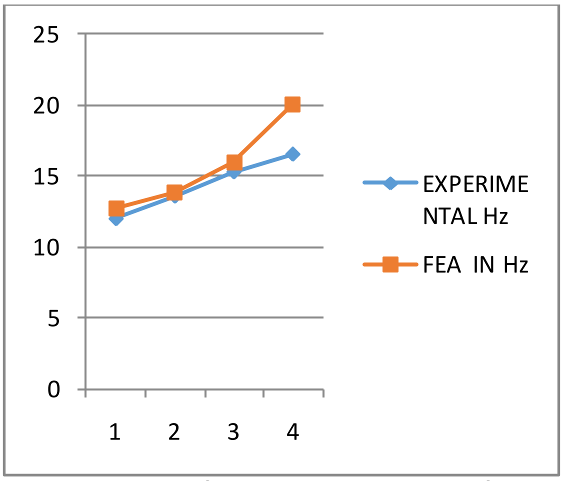

Fig. 10. Comparison of FEA and experimental frequencies.

VII. CONCLUSION

We have looked into the determination of the dynamic characteristic of micro wind turbine, natural frequency and mode shapes.The dynamic characteristics of the Micro wind turbine are tested experimentally by using the DSA setup and obtained the natural frequency of the blades for the four modes.Simulation of the micro wind turbine blade is done by using ANSYS work bench analytically. Frequencies obtained from the experimental and FEA methods are compared and the error is within the desired limit i.e., 8.2%.

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