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Free Vibration Analysis of Shape Memory Alloys Used In Wind Turbine Blade Root Connection

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Abstract:- In this work, the free vibration analysis is done on a blade of AIR X- 400W horizontal axis wind turbine. Turbine blade length is designed as 66.5 cm and 4140 steel, shape memory alloys (Ni-Ti, Cu-Zn-Al and Cu-Al-Ni) are used in blade root connection. In this project vibration analysis has been used to determine the natural frequencies and the mode shapes of wind turbine blades for each materials. The total deformation in the wind blade are determined using the finite element method with ANSYS in which the skin and the core of the blade are modeled using solid elements, respectively. The rotor that blades are connected is rotating 400 rpm in 8m/s wind speed. Accordingly, resonance frequencies will be occurred were determined for each materials. As a result of the analysis; the maximum total deformation was observed in 5. mode of natural frequency that blade root connection is Cu-Zn-Al. Generally total deformation values appeared close to each other. The performance of blade was evaluated for each materials were used in blade root connection.

Keywords:- Wind energy, wind turbine blade, vibration analysis, shape memory alloys.

I. INTRODUCTION

Energy is required to achieving sustainable development among societies. Unlike fossil energies, such as gas and coal, which contain high percentages of carbon, renewable energies consist of sources that are naturally inexhaustible - water, sun, biomass, geothermal heat, and wind [1]. Wind energy is the most common energy production method among renewable energy sources. World total installed capacity is 196,630 MW in 2010 [2]. Therefore, availability and reliability of wind turbines is essential. Although damage can occur to any component or part of the wind turbine, the most common type is rotor or blade damage and tower damage [3]. Most wind turbine machines are three-blade units comprising the major components illustrated in Fig. 1 [4].

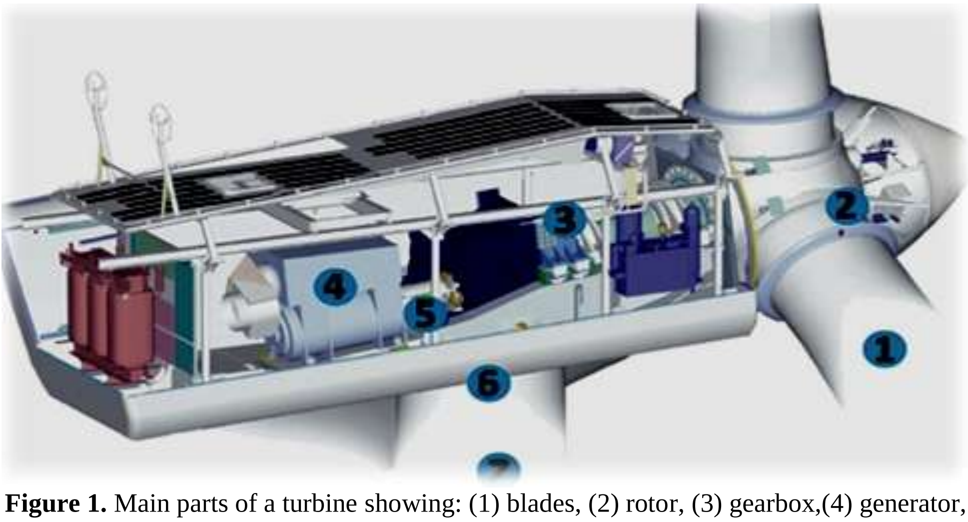


Figure 1. Main parts of a turbine showing: (1) blades, (2) rotor, (3) gearbox,(4) generator, (5) bearings, (6) yaw system and (7) tower [4]

Driven by the wind, the blades and rotor transmit energy via the main shaft through the gearbox to the generator, the main shaft being supported by the bearings, and the gearbox being such that the generator speed is as near as possible to optimal for the generation of electricity [5]. Blades are the main components that differentiate wind turbines from other machinery, acting as the “respiratory centre” of a wind turbine [6]. In engineering structures, a condition of resonance is encountered, when the frequency of the exciting force coincides with one of the natural frequencies of the system [7].

Blades are exposed during their service life to severe conditions of stimulation and vibration, which may have negative effect on their dynamic behaviour and this may lead to structural damages. Consequently, it is necessary to achieve vibrational analysis, so that stimulation of the natural frequencies and therefore resonance case can be avoided. Park et al. [8] have studied a rotating wind turbine blade to obtainits vibratory characteristics, they derived a computational algorithm based on blade stiffness variation due to centrifugal inertia forces. Ghoshal et al. [9] studied four different algorithms for detecting damage on a wind turbine blade based on the vibration response of the blade: transmittance function, resonant comparison, operational deflection shape and wave propagation. Abouhnik et al. [10] presented a new and sensitive approach, to detect faults in rotating machines; based on principal component techniques and residual matrix analysis (PCRMA) of the vibration measured signals.

The amplitude of the generated vibrations of a wind turbine blade depends on the stiffness of the blade which is a function of material, design and size [11]. Glass fiber or carbon fiber reinforced polymer composites are the most popular materials used for the wind turbine blade due to their lightness and superior mechanical properties. Due to the increasing size of the composite wind turbine blade, it is an important issue to arrange the composite materials in a sufficient way to reach the optimal utilization of the material strength [12]. Nowadays there is an increased interest in the use of shape memory alloy (SMA).The technology of SMAs and structures has given a new face of development to the fields of aerospace, robotics and structural engineering due to which the demand for less weight stand-alone systems is growing. Shape memory alloys (SMA) used along with composites are regarded as promising candidates of the so-called ‘‘smart materials” [13]. In the aerospace industry, shape memory alloys have been used in adaptive aircraft wings and smart helicopter blades for increased efficiency and reduced noise and vibration [14, 15]. However there is not a lot of information available on the properties of SMA composites since it is still a relatively new area. Recent research has determined the transformational behavior of SMA composites [16,17], the vibrational behavior [18, 19].

In this study, Shape memory alloys and 4140 steel were used in blade root connection. Wind turbine blade was modeled and analyzed with Ansys 13. Natural frequencies were determined for each material. The total deformations of blade were compared for each materials. Resonance points were determined for each materials when blade is connect to rotor that is rotating 400 rpm in 8m/s wind speed.

II. BLADE STRUCTURE, CHARACTERIZATION AND MATERIAL

Solid model of blade plotted with ANSYS. Turbine blade consists of two parts as shown in Fig. 2. One of them is the blade itself, the other one is blade root connection. In order to provide data for the finite element model, a geometrical model was created based on cross section profiles of shell and spar using SolidWorks software. Then the blade model, which is the fundamental geometrical model, was transferred to ANSYS finite element Software. In the meshing process, second order shell elements were employed to increase accuracy of the modeling. In addition the selected element type is compatible with composites and, in order to not having any triangular elements, a manual meshing method was employed [20]. The finite element model of the blade is shown in Fig.3 and mesh properties are shown Table 1.

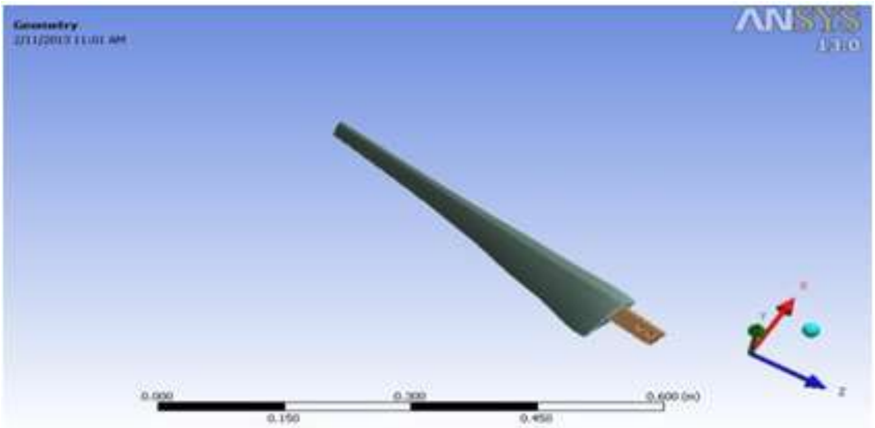


Figure 2. Solid model of blade

Mechanical properties of the materials used in the analysis of wind turbine blade are shown Table 2 [21,22]. 4140 steel, Ni-Ti, Cu-Al-Ni and Cu-Zn-Al materials were selected for structural analysis of blade root connection. And also four-axis composite material made of glass fiber fabric and vinylester material selected for the blade

Figure 3. Finite element model of blade

Table 1. Mesh properties

Mesh properties	
Use Advanced Size Function	On: Proximity and Curvature
Curvature Normal Angle	Default (18.0 °)
Proximity Accuracy	0.5
Min Size	Default (1.0586e-004 m)
Max Size	Default (2.1173e-002 m)
Inflation Option	Smooth Transition
Transition Ratio	0.272
Nodes	503432
Elements	291314
Method	Tetrahedrons
Algorithm	Patch Conforming

Table 2. Mechanical properties of the materials used in the analysis of wind turbine blade

Mechanical Properties	4140 steel	Ni-Ti	Cu-Zn-Al	Cu-Al-Ni
Density (gr/cm^3)	7.85	6.45	7.64	7.12
Young Modulus (GPa)	200	83	72	85
Yield Strength (MPa)	417.1	690	350	400
Ultimate Tensile Strength (MPa)	655	895	600	800
Poisson Ratio	0.3	0.34	0.33	0.33

III. RESULTS

The natural frequencies were obtained for each materials. Frequency values were found to be close to each other. Differences resulted from the materials used in blade root connection. Analysis were performed and evaluated for six natural frequency mode. Natural frequencies were obtained for each materials are shown in the table 3. Table 3 was examined, the natural frequencies are close to each other.

Table 3. Natural frequencies for each materials

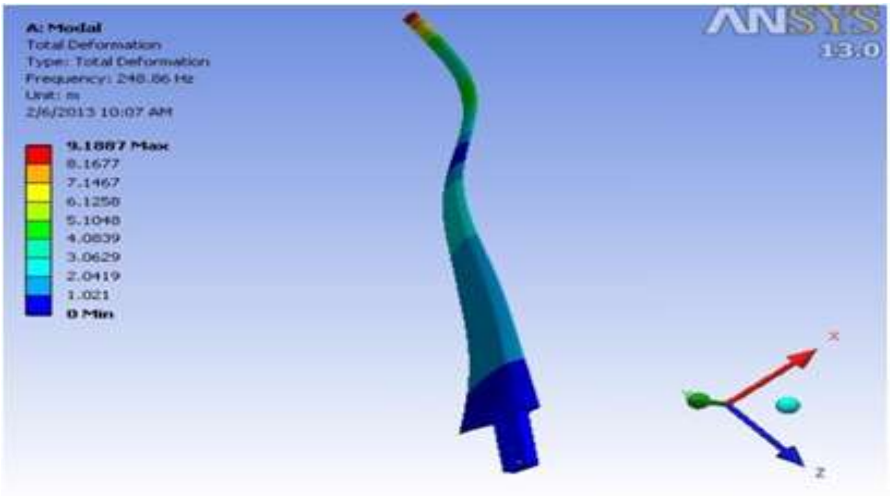
Mode	Frequency (Hz) 4140 Steel	Frequency (Hz) Ni-Ti	Frequency (Hz) Cu-Zn-Al	Frequency (Hz) Cu-Al-Ni
1.	23.249	22.657	22.265	22.45
2.	60.299	55.946	53.546	54.633
3.	102.82	95.747	92.157	93.776
4.	156.16	150.19	146.87	148.38
5.	248.86	238.59	234.4	236.2
6.	311.38	296.07	288.53	291.9

Total deformation values of blade for each mode and for each materials are shown in the table 4. The maximum value of the total deformation was observed in 5. mode when blade root connection is Cu-Zn-Al. Table 4 was examined the total deformation values were demonstrated close to each other. However blade will be less destroyed because of the super elastic properties of shape memory alloys. Generally total deformation values were appeared higher for blade root connection is 4140 steel than the others. In our previous study the stress analysis for the blade shape memory alloys exhibited better performance than 4140 steel [20]. Total deformations for 5.mod of the selected materials are shown in figure 4.

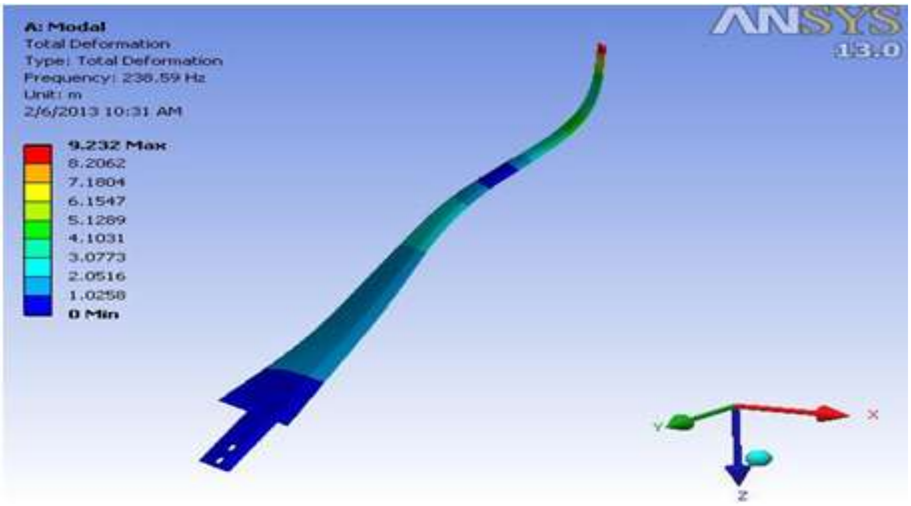
Table 4. Total deformation values

Mode	Total Deformation (m) 4140 Steel	Total Deformation (m) Ni-Ti	Total Deformation (m) Cu-Zn-Al	Total Deformation (m) Cu-Al-Ni
1.	7.9828	7.7966	7.6727	7.731
2.	8.0979	7.8728	7.7791	7.8186
3.	7.6624	7.5303	7.459	7.4923
4.	8.9067	8.7845	8.7375	8.7566
5.	9.1887	9.232	9.2524	9.2471
6.	8.8223	8.7685	8.7552	8.7593

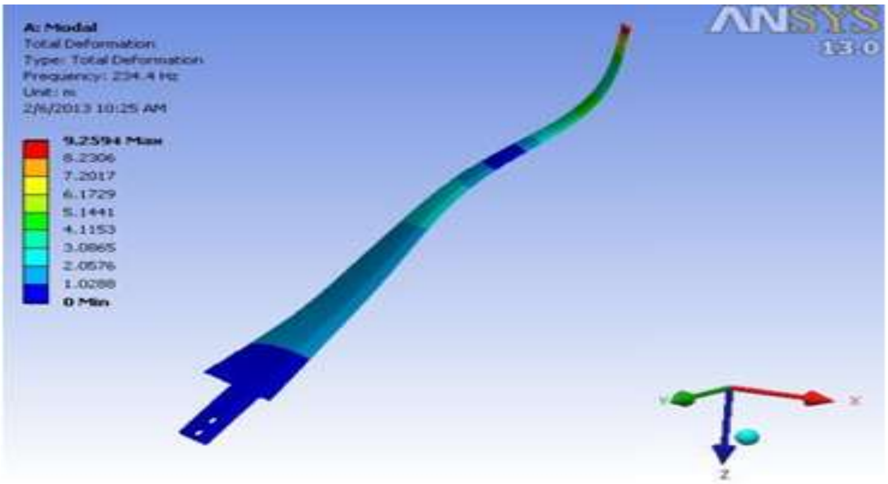
The rotor that blades are connected is rotating 400 rpm in 8m/s wind speed. Rotor frequencies were calculated from 5 m/s wind speed to 60 m/s wind speed. Rotor frequencies are shown in Table 5 and Fig.5.



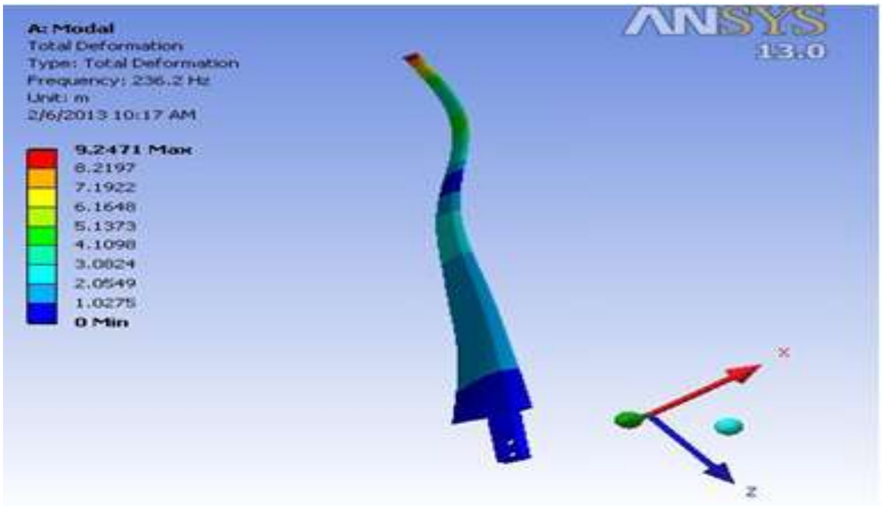
a)



b)



c)



d)

Figure 4. a) Blade root connection is 4140 steel
b) Blade root connection is Ni-Ti
c) Blade root connection is Cu-Zn-Al
d) Blade root connection is Cu-Al-Ni

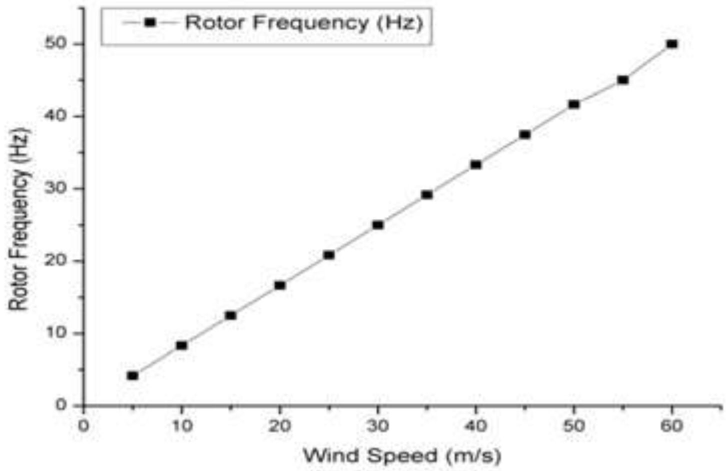


Figure 5. Rotor frequency variation of the wind speeds

Table 5. Rotor frequency variation of the wind speeds

Wind Speed (m/s)	Rotor Frequency (Hz)
5	4.165
10	8.331
15	12.497
20	16.663
25	20.828
30	24.994
35	29.158
40	33.325
45	37.491
50	41.657
55	45.026
60	49.988

The natural frequencies were compared with the rotor frequencies and intersection was observed with only 1. mode of the natural frequency. Because natural frequencies were larger than the rotor frequencies for the other modes. Therefore resonance will be expected in 30 m/s wind speed.

IV. CONCLUSION

Results are evaluated for total deformation and resonance of wind turbine blade**.** The maximum value of the total deformation was observed in 5. mode when blade root connection is Cu-Zn-Al. Generally the total deformation values were demonstrated close to each other. total deformation values were appeared higher for blade root connection is 4140 steel than the others. Natural frequencies were larger than the rotor frequencies except 1. mode. Accordingly resonance situation of this was observed in 30 m/s wind speed. However there is not a lot of information available on the properties of SMA since it is still a relatively new area. SMA demonstrated superior behaviors than conventional materials in our studies. Following studies examining pre-stressed vibration is considered to consolidate conclusions.

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