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INVESTIGATION OF EFFICIENT MODEL BASED VIBRATION MECHANISM FOR HORIZONTAL AXIS WIND TURBINE BLADE

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Abstract

The most common problem in a horizontal axis wind turbine is the flap wise vibration in which the blades vibrate parallel to the shaft axis due to the varying wind speed when it meets its natural frequency causing resonance. In order to avoid that Shape Memory Alloy (SMA) wire is embedded on the blades. SMA which is normally in its twinned martensite state becomes detwinned martensite when load is applied on it. When it is heated it changes to austenite causing it be reform itself to its original orientation .when the SMA wire is cooled it once again becomes twinned martensite. When the amplitude of vibration is high the SMA wire which is embedded on the wind turbine blade is supplied with current supply which heats the SMA and brings it back to its initial position. In this study the optimum frequency at which the vibration is maximum and the amount of current which is to be supplied are experimentally analyzed.

Keywords: Flap wise vibration; detwinned martensite; Resonance; shape memory alloy

1. Introduction

Meeting the world's growing energy demands in line with preserving the environment has led to great progress in the field of renewable energy or so-called green energy. According to the Environmental Impact Assessment International Energy Outlook, the global energy demand is expected to almost double by 2030. Population and income growth are the key drivers behind the growing demand for energy. Considering that conventional energy production is the single largest producer of greenhouse gases, the opportunities for renewable energies have potential for vast renewable energy capabilities. More than 66 countries have renewable energy policy targets to meet. Horizontal-Axis Wind Turbine (HAWT) is a wind turbine in which the axis of the rotor's rotation is parallel to the wind stream and the ground. All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). Most horizontal axis turbines built today are two- or three-bladed, although some have fewer or more blades. The purpose of the rotor is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. Since the blades of a wind turbine are constrained to move in a plane with the hub as its centre, the lift force causes rotation about the hub. In addition to the lift force, a drag force perpendicular to the lift force impedes rotor rotation. A prime objective in wind turbine design is for the blade to have a relatively high lift-to-drag ratio. This ratio can be varied along the length of the blade to optimize the turbine's energy output at various wind speeds. HAWT’s can be subdivided into upwind wind turbines and downwind wind turbines. Shape Memory describes the effect of restoring the original shape of a plastically deformed sample

by heating it. This phenomenon results from a crystalline phase change known as "thermoplastic martensitic transformation".
Metals are characterized by physical qualities as tensile strength, malleability and conductivity. In the case of shape memory alloys, we can add the anthropomorphic qualities of memory and trainability. Shape memory alloys exhibit what is called the shape memory effect. If such alloys are plastically deformed at one temperature, they will completely recover their original shape on being raised to a higher temperature. In recovering their shape the alloys can produce a displacement or a force as a function of temperature. In many alloys combination of both is possible. Key features of shape memory alloys include: high force during shape change, large movement with Small temperature change and a high permanent strength. Because of these properties shape memory alloys are helping to solve a wide variety of problems. Mani and Senthilkumar proposed that a Dynamic Vibration Absorber (DVA) can be used as an effective vibration control device. In this paper, the unique property of SMAs temperature-dependent Young's modulus has been used to change the stiffness of the spring actively to control the vibration. Experiments were carried out with an SMA-based dynamic vibration absorber to study the effect of reduction in amplitude of vibration of a cantilever structure.

A microcontroller-based control system has been developed for timely actuation of SMA. Bhargaw et al suggested that the thermo-electric behavior of shape memory alloy (SMA) wire was presented. When the wire was electrically heated above its transformation temperature by current, a large mechanical force is exerted due to transformation in its phases. In order to make use of SMA wire as an actuator, different parameters and their relationships were investigated. These parameters are recoverable strain (displacement), temperature hysteresis and electrical resistance variation under different stress levels. Optimum safe heating current was assessed and phase transformation temperatures were estimated by heat transfer model. The connections with steel and martensitic nickel-titanium tendons rapidly lost their stiffness after being cycled beyond their elastic drift levels. This novel connection was intended as a proof of concept that can be further developed in terms of practicality, ease of installation, and cost. Tcherniak and Larsen proposed that the presented study continues the work on application of Output Only Modal Analysis (OMA) to operating wind turbines.

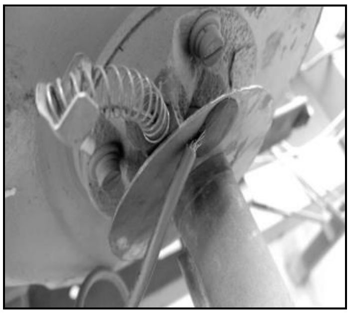
The paper discusses the technical challenges regarding blade instrumentation and data acquisition, data processing applied to eliminate the time-varying nature of an operating wind turbine in the resulting eigenvalue problem and, finally, it presents and discusses the initial results. Barzegari et al proposed that in this study, analytical relations for evaluating the exact solution of natural frequency and mode shape of beams with embedded shape memory alloy wires are presented. The effect of axial load generated by SMA wires with buckling load and frequency jump is accurately studied. Schubel and Crossley recommended that a detailed review of the current state-of-art for wind turbine blade design is presented, including theoretical maximum efficiency, propulsion, practical efficiency, HAWT blade design, and blade loads. A detailed review of design loads on wind turbine blades is offered, describing aerodynamic, gravitational, centrifugal, gyroscopic and operational conditions. Mollasalehi et al. proposed that a major barrier to the acceptance of Small wind turbines is that they are perceived to be noisy. This paper investigates an aspect of noise emission that has not been considered; vibration and noise generation from the tower. It was found that wind itself can only excite the first two bending modes. On the other hand, emitted noise from the tower at large distances can be neglected, as close to the tower, the noise can reach 30 db. Staino and Basu recommended that this paper proposes the modelling and control of vibrations in wind turbines due to change in the rotational speed of the blades. Structural and/or electrical faults occurring in a wind turbine may lead to fluctuations of the angular velocity of the rotor blades a reduced order model is designed for the synthesis of an appropriate control law. Simulations results show that the proposed control scheme is successful in improving the blade response.

Further, under the conditions considered in this study, the numerical investigation reveals that the controller is robust with respect to rotor speed variations under circumstances when grid fault occurs.[8] Williams et al. proposed that The adaptive-passive vibration absorber shows promise for combining the stability and low complexity of passive tuned absorbers with the robust performance of active vibration control schemes Results of the tests indicate that an adaptive absorber incorporating SMA as a tuning element has potential as a simple, high-performance adaptive-passive technique for vibration control. Saadat et al. proposed that The adaptive-passive vibration absorber shows promise for combining the stability and low complexity of passive tuned absorbers with the robust performance of active vibration control schemes. Results of the tests indicate that an adaptive absorber incorporating SMA as a tuning element has potential as a simple, high-performance adaptive-passive technique for vibration control. Tenguria et al. suggested that the wind turbine blade is a very important part of the rotor. Extraction of energy from wind depends on the design of blade. This work is focused on the two segments of blade, root segment and transition segment. Result obtained from ANSYS is compared with the previously done experimental work. Chaudhari proposed that this paper presents a review on the dynamic characteristics of Wind Turbine. One of the most important sources of renewable energy is Wind Power. However, it has the complicated dynamic interaction between different parts of the turbine as motion of the blades interact with aerodynamic forces, electro-magnetic forces in the generator and the structural dynamics of several turbines components like drive train, nacelle and tower, etc.

Park et al proposed that in the wind-turbine design, linear vibration analysis of the wind-turbine blade should be performed to get vibratory characteristics and to avoid structural resonance. Through the numerical problems, this work shows that the proposed method is useful to predict the vibratory behavior of the rotating blade. Furthermore, a numerical problem was solved to check the numerical accuracy of commercial program results within operating region. Qiao et al. suggested that with the increasing size of wind turbine blades, the need for more sophisticated load control techniques has induced the interest for aerodynamic control systems with build-in intelligence on the blades. By using this model, an active vibration method which effectively suppresses the vibrations of the Smart blade is designed. Monner proposed that for active noise and vibration reduction tasks in Smart-structures technology piezoelectric ceramics are first choice. This article gives an overview of commercially available and emerging Smart materials with special focus on active noise and vibration reduction tasks. Tartibu et al. suggested that in this paper, Flap-wise, edge-wise and torsional natural frequencies of a variable length blade have been identified. Concurrence between MATLAB and Unigraphics NX5 results has been found for the frequency range of interest. This means that an effective method to compute natural frequencies of a variable length blade was developed.

2. Experimental Setup

A miniature wind turbine was created in our lab using a motor and wind turbine blade setup and it was assembled. The main parts of the wind turbine are the motor, the collet, copper plates carbon bush aerodynamically designed wind turbine blades of size. The SMA wire is attached to the wind turbine blades using insulation tapes and araldite so that it increases the stiffness of the whole set up and when activated it increases its young's modulus and also corresponds to the rotational centrifugal stiffness. In order to supply electric power to the SMA wire which is rotating along with the blades, a solid contact type set up was made to transfer electric current from the power source to the SMA. The electric supply is given to the carbon bush which is attached to the motor set up. The carbon bush is always in contact with the copper plate which is mounted on the shaft of the motor. Through this solid contact the electric energy is transferred from the power source to the carbon bush, from the carbon bush to the copper plate as shown in Figure 1. This method is called the solid type power transfer. Copper wires are attached to the copper plate as illustrated in Figure 2 using passive admissive and insulation tapes so that the electric current from the copper plate is in turn gets transferred to the SMA wire which is attached to the wind turbine blades.



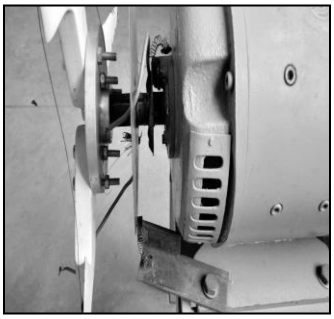


Figure 1. Carbon Bush and Copper Plate **Figure 2. Carbon Bush and Copper Wire**

Figure 3. Experimental Setup Assembly

3. Static and Dynamic Analysis

A current controller is used to vary the speed of rotation of the motor shaft so that various speed of rotation of the motor shaft is achieved. Initially the natural frequency of the motor set up, the collect set up is found using a lab view program and its corresponding first natural

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frequency and second natural frequency are noted. The noted vales are represented in Table 1. Also the motor system and collect system are assembled and the natural frequencies of the whole system are also noted.

4. SMA Coupled Blades

The motor is rotated at 3 various speeds which are 450rpm, 500rpm and 550rpm. This condition is taken for the experimental work as shown in figure 3. The first operating condition is the motor is coupled with SMA wire and without passing electric current the blades are rotated in 450,500 and 550rpm. The natural frequency of the blade system is noted using the Lab VIEW program shown in Figure 4. The different types of electric current supplied to the SMA are

- Constant current 0.5A
- Constant current 1A
- Constant current 1.5A
- Current from controller

The outputs which are to be analyzed are

- Without SMA
- With SMA (Passive)
- With SMA (Active)
- Constant current (0.5A,1A,1.5A)

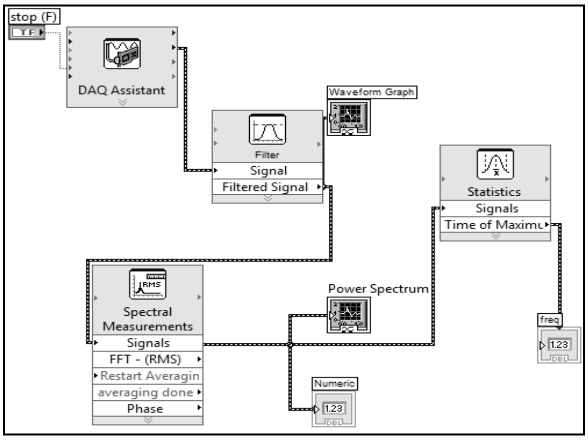

Figure 4. Lab VIEW Program for Natural Frequency

Table 1. First and Second Natural Frequencies

Part name	Targeted frequency (Hz)	Shifted frequency(Hz)		
		450 RPM	500 RPM	550 RPM
Motor	10 ,30	10.6 ,29.3	10.5 ,29	10.5 ,28.3
Blade	32 ,63	29.6 ,59.3	29.1 ,65.5	29 ,50

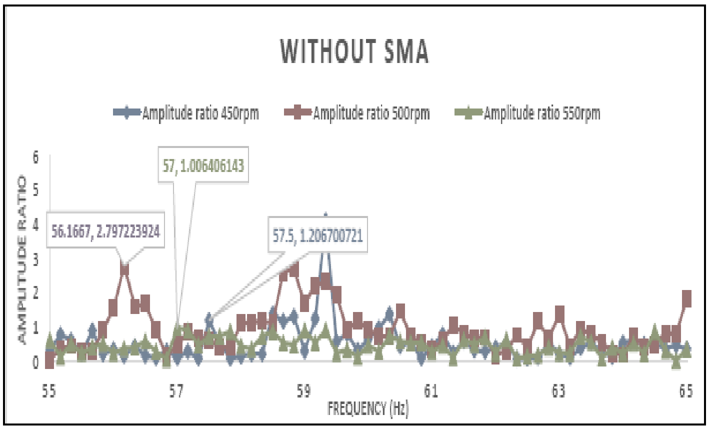

Figure 5. Frequency Vs. Amplitude Ratio at Various Speeds

Again the same process is repeated by giving constant current to the SMA wire of 0.5A, 1A and 1.5A respectively and its corresponding natural frequency is also noted. This is the active condition of the SMA with constant current which is shown in Figure 7. A current controller unit is connected to the SMA wire which replaces the constant power supply unit so that the varying current is supplied to the system known as the controller. Once gain the respective natural frequencies for different speeds of 450,500 and 550rpm are noted. The results are consolidated and a graph is plotted between frequency and amplitude ratio. For the various speed of rotation of the motor the graphs are plotted and are merged together to get an over view of the results in Figure 6 and 7.

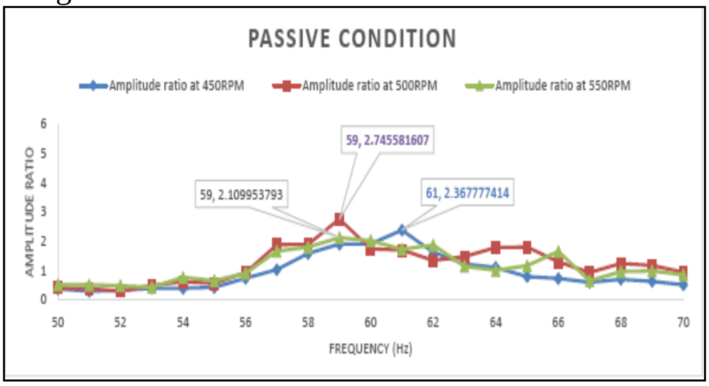

Figure 6. Frequency Vs. Amplitude Ratio for Various Speeds in Passive Condition

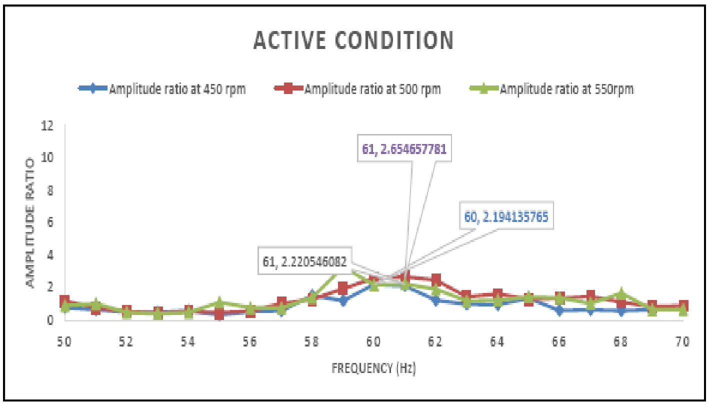

Figure 7. Frequency Vs. Amplitude Ratio for Various Speeds in Active Condition

In order to understand the comparison of the frequency shift and the decrease in the amplitude change of vibration a graph plotted between the amplitude ratio and speed of motor gives a clear picture. Apart from this plot also the graph between frequency and motor speed also helps in understanding the frequency shift after inclusion of SMA wire in blade system. From the Figure 8 we can understand that the amplitude ratio of vibration which was much higher has comparatively decreased when SMA is introduced because of the increase in the stiffness. Also on further supplying the current to SMA, the phase change from Detwinned martensite to austenite makes the SMA wire to take back its original shape and on cooling it becomes twinned martensite once again. Say for example the amplitude ratio of vibration at the speed of 450rpm was nearly about 4.12 times higher than the average amplitude of vibration. But when SMA is introduced in the passive condition the amplitude ratio has decreased to 2.36 and on further supplying the current and making it an active system the amplitude ratio has decreased to 2.19.

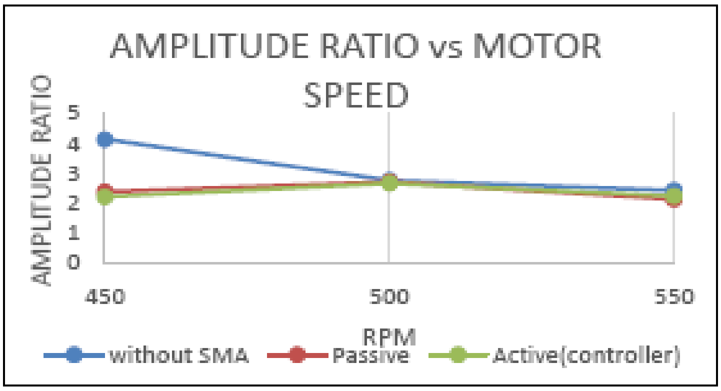

Figure 8. Amplitude Ratio Vs. Motor Speed

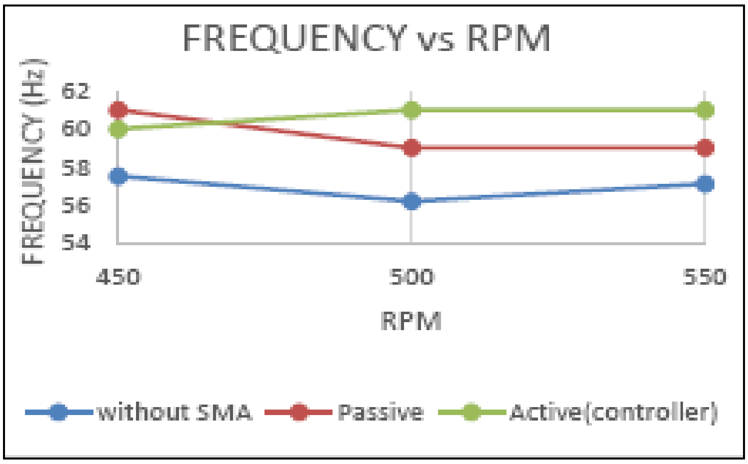

Figure 9. Frequency Vs. Motor Speed

Similarly from the Figure 9 it can be seen that there is a frequency shift. Initially when the system was rotating at 500 rpm the natural frequency of the system was 56Hz and when the SMA wire is coupled with the blade the natural frequency of the blade system increased to 59Hz. By making the deformed SMA in to phase change of austenite the active current is supplied to the SMA and the natural frequency of the system becomes 61Hz.

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5. Directional Stiffness Of Proposed Design

The percentage increase in the frequency and the percentage decrease in the amplitude ratio can be easily understood by the Table 2.

Table 2. Percentage Deviation in Amplitude Ratio

	450rpm	500rpm	550rpm	Average	Deviation (%)
Without SMA	4.1213	2.7455	2.4133	3.0934	-
Passive	2.3677	2.6976	2.1099	2.39178	22.681
1A	3.4114	2.401	2.9919	2.93490	22.708
1.5A	3.4859	2.141	2.3391	2.65553	11.027
Active	2.1941	2.654	2.2205	2.35644	23.823

From the Table 2 it is seen that the percentage decrease in the average amplitude ratio when SMA wire is introduced is 22.68% and when the electric current is supplied the amplitude reduction has further reduced by 23.82 percentages which is the maximum of all.

Table 3. Percentage Deviation in Frequency

	450rpm	500rpm	550rpm	Average	Deviation (%)
without SMA	57.5	56.167	57.1	56.92223	-
Passive	61	59	59	59.66667	4.82
1A	59	59	58	58.6666	1.67
1.5A	59	59	58	58.6666	1.67
Active	60	61	61	60.6666	6.57

Similarly the frequency shift to that of the speed of rotation of motor speed it is seen that the frequency has shifted to the higher scale when SMA is introduced than without it is clearly seen through Table 3. There is a 4.82% of frequency shift when SMA is introduced on the blade system. The frequency has increased from 56.92Hz to 59.66% when a passive SMA is placed. Further it is seen that the frequency has shifted by 6.57% than when SMA was not present when the current is supplied through an active current controller unit.

6. Conclusion

- The result shows that the amplitude ratio without SMA was 3.09 which was very much higher. This is because of the poor damping in the blades.
- In the passive condition SMA wire is introduced in the blades. Due to the super elastic nature of the SMA the damping is increased causing reduction in amplitude ratio and the shape memory effect leads to the shifting of natural frequency because there is variation in young's modulus from table 2 and 3.
- The amplitude ratio was decreased by 22.68%.
- The frequency shift was reduced by 4.82%.
- In the active condition constant current and hardware in-loop unit are used to supply electric current to the SMA which is seen from table 2 and 3.

- ✓ When constant electric current is supplied the amplitude ratio is decreased by 11.02% and the frequency shift is 1.67%.
- ✓ When hardware in-loop unit is connected over all amplitude ratio was decreased by 23.82% and the frequency is shifted by 6.57% which is a much greater results than the passive condition

- Without increase in the mass the overall operating range is increased .the 1KW blade with cut-off velocity of 12m/s can be effectively increased to 13-14 m/s.
- In some of the blade design due to achieve higher blade stability the aerodynamic effect is compromised. There are few blades in which there is a good aerodynamic design but does not enhance a good stability.
- Power can also be increased by increasing the blade tip velocity. With a poor blade structural integrity the achievable power would be 1KW but as the stability is increased by adding SMA the power production can reach up to a level of 1.2KW.
- Once the system meets its natural frequency the controller unit is activated, the natural frequency of the assembled system shifts leading to avoidance of resonance.

7. References

[1]. H.N. Bhargaw, M. Ahmed and P. Sinha, “Thermo-electric behaviour of NiTi shape memory alloy”, Transactions Nonferrous Metals Society of China, 23(8), 2013, 2329-2335

[2]. Y. Mani and M. Senthilkumar, “Shape memory alloy-based adaptive-passive dynamic vibration absorber for vibration control in piping applications,” Journal of Vibrations and Control, 21(9), 2015, 1838-1847

[3]. D. Tcherniak and G. C. Larsen, “Application of OMA to an operating wind turbine: now including vibration data”, 5th International Operational Modal Analysis Conference, 12, 2013, 1-12

[4]. M. Barzegari, M. Dardel and A. Fathi, “Vibration analysis of a beam with embedded shape memory alloy wires,” Acta Mechanica Solida Sinica, 26(5), 2013, pp. 536-550

[5]. P.J. Schubel and R.J. Crossley, “Wind turbine blade design”, Wind Turbine Technology, 13, 2014, 1-34

[6]. E. Mollasalehi, Q. Sun and D. Wood, “Contribution of small wind turbine structural vibration to noise emission”, Energies, 6(8), 2013, 3669-3691

[7]. A. Staino and B. Basu, “Dynamics and control of vibrations in wind turbines with variable rotor speed”, Engineering Structural, 56, 2013, 58-67

[8]. K. Williams, G. Chiu and R. Bernhard, “Adaptive-passive absorbers using shape-memory alloys”, Journal of Sound Vibrations, 249(5), 2003, 835-848

[9]. S. Saadat et al., “An overview of vibration and seismic applications of NiTi shape memory alloy,” Smart Material Structures, 11(2), 2002, 218-229

[10]. N. Tenguria and S. Ahmed, “Design and finite element analysis of horizontal and turbine blade,” International Journal of Applied Engineering Research Dindigul, 1(3), 2010, 500-507

[11]. N.B. Chaudhari, “Dynamic Characteristics of Wind Turbine Blade,” International Journal of Engineering Research and Technology, 3(8), 2014, 168-173

[12]. H. Park, H. Y. Park, S. Y. Jeong, S. Il Lee, Y. H. Shin and J.P. Park, "Linear vibration analysis of rotating wind-turbine blade", Current Applied Physics, 10(2), 2010, 332–338

[13]. Y. H. Qiao, J. Han, C. Y. Zhang and J. P. Chen, "Modeling smart structure of wind turbine blade", Applied Composition Materials, 19(3-4), 2012, 491-498

[14]. L. K. Tartibu, M. Kilfoil and V. Der Merwe, "Vibration analysis of a variable length blade wind turbine", International Journal of Advanced Engineering Technology, 4(1), 2012, 2231-1963

[15]. H. P. Monner, "Smart materials for active noise and vibration reduction", Proceedings Novem-Noise Vibrations Emergency Methods, Saint-Raphael, 2005, 18-21