

An Experimental Investigation of Aerofoil Blade Naca-63415 Vibration Suppression by Using PZT Actuator Under Dynamic Condition in Absence of Aerodynamic Damping

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ABSTRACT:

An experimental study along with numerical simulation to be able to analyse Reynolds numbers impact on vibrating air foil blade. Aerofoil blade vibrates at lower Reynolds number of flows i.e., $Re = 4 \times 10^6$ and above this range the damping effect is caused by Aerodynamic damping. To counterbalance the vibration below certain range of $Re = 2 \times 10^6$ to $Re = 4 \times 10^6$ of flow, so an aerofoil blade that function as cantilever beam with and without PZT patches is subject of an experimental study. Free vibration of aerofoil blade with 45° , 60° & 90° fiber orientation is conducted by varying the initial voltage supply of surface attached PZT Actuator. The actuator (Lead Zirconium Titanate) is used to mitigate the vibration levels to determine damping factor along with blade settling time. As PZT actuator added to blade surface, stiffness and mass of an experimental material increases which is leading to alterations in its natural frequency and the optimization of the patch position on the blades surface. GFRP material structure gives efficient vibration suppression smart with advanced, reliable composite system and PZT actuator acts as a smart damping device, in extended application to turboprop engines. This will be improving reliability and reduce fatigue failures in blades.

Keywords: Reynolds number, Aerodynamic Damping Aerofoil, Blade shapes, PZT, natural frequency, FEA.

1. Introduction

Because of the extremely long and flexible blade design, the modern wind turbine blade has a lower structural tapering value resulting instability in the structure when excavated by external aerodynamics loads [1]. As a result, blades structural stability is focused of numerous research investigations which is to be improved. [2].

Aerodynamic damping is necessary for the blade design in addition to structural damping whether blade is caused by aerodynamic forces dampened by depends on aerodynamic damping [3]. The aero foil stall characteristics creates force within structure of blade, causing blade to vibration. An external aerodynamics loads increase blades vibrations energy if it lacks adequate structural and

aerodynamic dampening elements. Stall induced vibrations in wind turbines includes [4-7]. When there is vibration, the blades vibrate at frequency that is similar to the blade structure inherent frequencies [8]. Materials that react quickly to their surroundings are called smart materials. The substances that take in send or process a stimulus and react by creating a beneficial result, which could include a signal that the substance is working upon it [09]. Because of their perfect characteristics light weight, high bandwidths, effective energy conversion and simple integration- piezoelectric materials have been widely exploited as smart materials for vibration control sensors and actuators [10]. Piezoelectric offer a novel method for reducing Turbomachinery blade vibration and can be create damping or control features [11]. sandwich composites blades with tailored stiffener alignments outperform conventional solid blades in vibration control and efficiency, providing a solution for more robust and cost-effective wind turbine blades [12]. An optimized Aerofoil blade design must balance aerodynamic efficiency with structural loads. It includes geometry, tip speed ratio, wind velocity, blade number, and shape, which influence lift, drag, and overall performance. Combination helps to reduce noise, control stall during dynamic response, and maintain stability under distorted airflow. The outcome is a blade captures maximum wind while remaining robust and efficient.[13] By raising Reynolds number, the flow separation is decreased. An Aerodynamic damping is predicted to be relatively low at low Reynolds numbers because of increased flow unsteadiness, which may have an impact on blade stability. An aerodynamic damping acts like a natural control on blade vibration. $Re\ 4 \times 10^5$ damping reaches its maximum offering the suppression of vibration. at lower Reynolds number vortex generation increases flow unsteadiness, causing stronger pressure fluctuations and aerodynamic forces on the blade. Insufficient damping allows vibrations to grow. As Reynolds number rises flow

separation decreases and aerodynamic damping improves.[14]

2. Frequency Response & Actuation

$$\omega_n = \frac{1}{2\pi} (\beta l)^2 \sqrt{\frac{EI}{\rho A l^4}} \quad \dots\dots\dots I$$

$$\beta l = \text{constant.}$$

L = Length of Blade

A = Area of the cross Section.

Characterization of smart material is its better damping strength. Depending on material's properties and test method, several decomposition parameters such as composition, loss factors and loss tangent which are used separately or composed in metal, ceramics, and rubbers etc. In advanced material logarithmic Attenuation coefficient are apply and evaluated by measuring vibration level such as amplitudes and frequency in the experiment

$$\Delta = \frac{\ln X_n}{X_{n+1}} \quad \dots\dots\dots II$$

X_n, X_{n+1} = Successive

oscillation

$$\epsilon = \frac{\Delta}{\sqrt{(2\pi)^2 - \Delta^2}} \quad \dots\dots\dots III$$

Table I.: Natural Frequencies of an aerofoil blade.

Mode Shape	GFRP	βl
I	6.643	1.86406
II	41.563	4.70092
III	116.556	7.864960
IV	228.403	11.000046

3. Experimental Setup

An experimental setup for the work is shown in Fig.- 01, it takes into account an aerofoil blade with clamped or fixed end and that is fixed horizontally throughout its width.

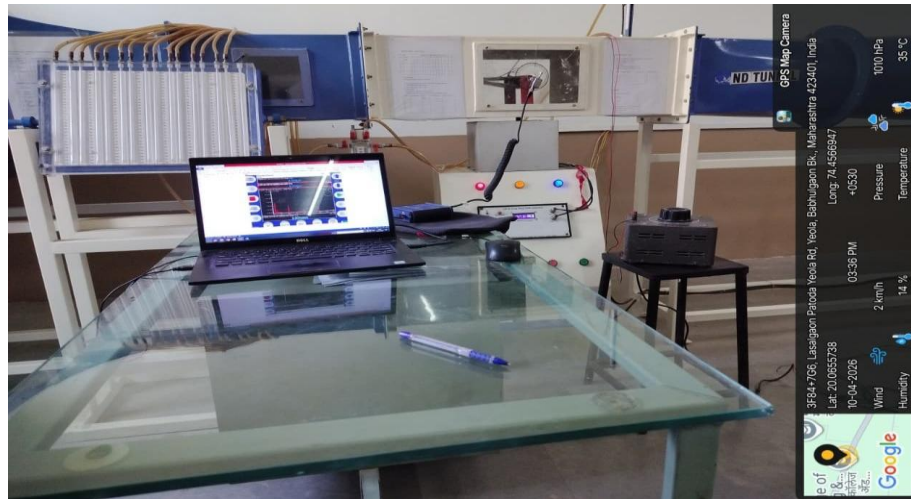


Fig.1. an experimental framework with real time data acquisition.

Damping performance with along without PZT actuator is evaluated and compared to the measured material damping using the calculated and measured frequency Response functions (FRF). The GFRP composite blade size and material characteristics as Table I & II respectively, list PZT actuators. An experimental setup uses Lead Zirconium Titanate (PZT) kind of

SP5H from Sparkler Ceramics, Pune. Piezoelectric actuator is bonded to aerofoil blade on surface simultaneously it is to fixture. Then, FFT analyzer, time and actuation circuit, an accelerometer, Reynolds number flow control regulator with a controller and a computer system with interfaced lab view software makes up this system as shown in Fig.1.

Table II: Cross section of the Aerofoil Blade material.

Cross Sectional Dimension				
1.	Fiber Orientation	30°	45°	60°
2.	Length [metre]	0.4	0.4	0.4
3.	Width [metre]	0.05	0.05	0.05
4.	Thick. [metre]	0.006	0.006	0.006
5.	Youngs Modulus (GPa)	52.36	52.36	52.36
6.	Density (Kg/m ³) ρ	1980	1980	1980
7.	Glass Fiber Volume Fraction (V-glass)	0.6	0.6	0.6

A series of experiments with readings taken at each position is performing using aerofoil blade open end as shown in Fig.1. The choice of acceleration sensor along with its quantitative measure and extent. Air movement within the range activates system along a steady force over chosen range of frequency window with bandwidth initial delayed.

4. Results & Discussion:

Both frequency-domain and time domain approaches are used to compute aerodynamic

damping values. The conventional time domain solution and the frequency domain solution yields results that, closely match. Regarding the impact of Reynolds number, it is observed that while aerodynamic damping is relatively low at $Re = 4 \times 10^5$ and $Re = 6 \times 10^5$, it gradually increases as the Reynolds number increases as seen in Table-III & IV. Aerodynamic damping at $Re = 4 \times 10^5$ is 56 percent and 88 percent greater than that of $Re = 4 \times 10^5$. Free vibrations of GFRP composite material blade are achieved by changing the initial displacement and supply voltage to PZT Actuator.

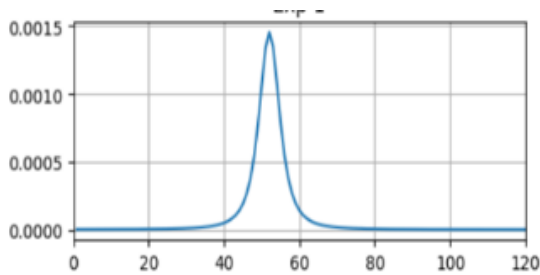
To ensure maximum efficiency, actuators are placed in areas of high voltage and far from areas of low voltage. The results are analyzed using FFT analyzers for a post-analysis process based on predetermined displacement value. Validate the signals and output results acquired followed by Post-Analysis Process and Settling time of individual airfoil blade.

4.1. Aerofoil blade without PZT Actuator

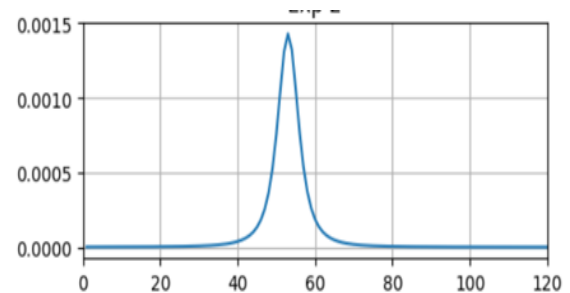
Experimentation without PZT actuator is carried out for all fiber orientation of blade, it is observed that, at 30° fiber orientation has better damping properties for the selected air flow range in absence of Aerodynamic damping as shown in the as seen in Table-III & IV.

Table III: Natural frequency of Aerofoil blade.

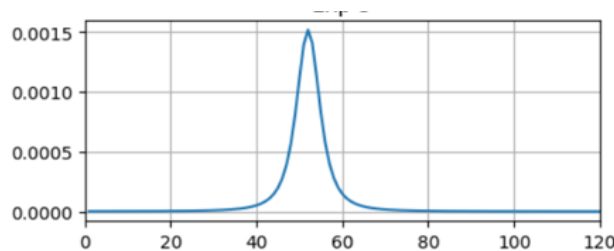
Sr. No.	Flow (Re)	Orientation of Fiber	Sampling Frequency (Hz)	f_1 (hz)	f_2 (hz)	f_n (hz)
1	2×10^5	30°	50	48	56	52
2	2×10^5	30°	120	49	57	53
3	2×10^5	30°	200	48	56	52



(a) SF= 50 Hz



(b) SF= 120 Hz



(c) SF= 200 Hz

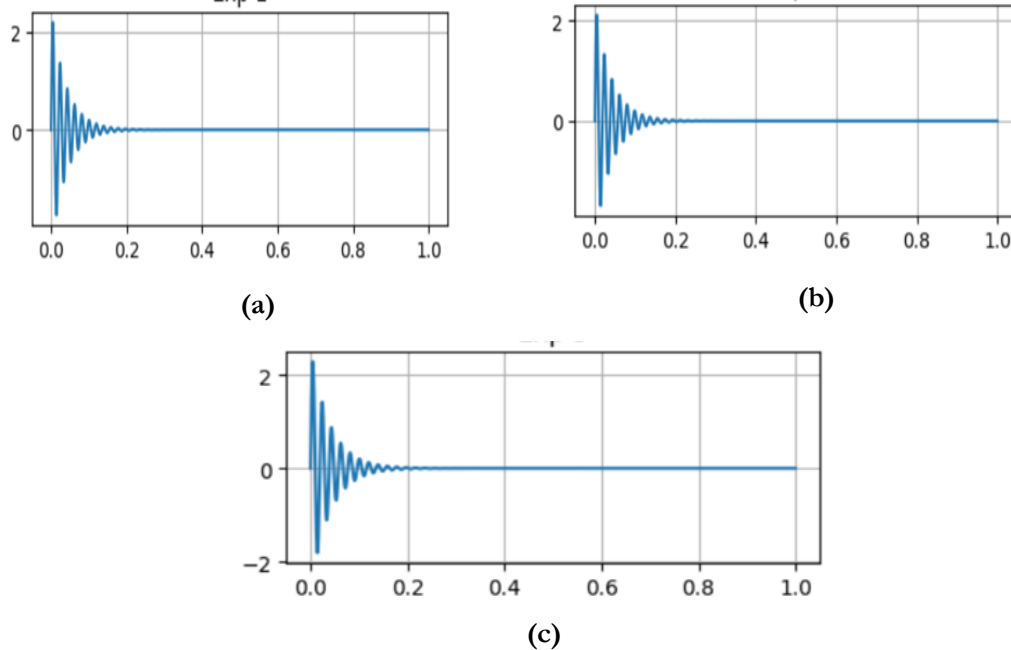
Fig.2. Peak value frequency of Aerofoil Blade fiber with 30° orientation without PZT Actuator (a,b,c)

Table IV: Displacement of blade due dynamic loading condition.

Sr. No.	Flow(Re)	Orientation of Fiber	Amplitude (mm)	Damping ratio (ζ)
1	2×10^5	30°	2.5	0.077
2	2×10^5	30°	2.4	0.075
3	2×10^5	30°	2.6	0.077

The settling time for aerofoil blade is shown in table no-04. It is observed that, amplitude decays rapidly for 30° fiber orientation, as compared to other fiber orientation configuration. Further

suppression of amplitude is shown in Fig.-02 (a, b, c),

**Fig.3. Displacement of Aerofoil Blade fiber 30° orientation (a,b,c)**

4.2. Composite Aerofoil Blade with PZT Actuator.

After application of PZT actuator to blade fiber orientation, it is observed that, there is

considerable reduction in vibration frequency of blade from the peak value as shown in Fig.-04 (a, b, c), comparatively rapid as shown in Table-III & IV.

Table V: Natural frequency of Aerofoil blade with PZT actuator.

Sr. No	Flow (Re)	Orientation	Sampling Freq. (Hz)	(f_1) (Hz)	(f_2) (Hz)	(f_n) (Hz)
1	2×10^5	30°	50	40	54	49
2	2×10^5	30°	120	70	56	50
3	2×10^5	30°	200	100	58	50

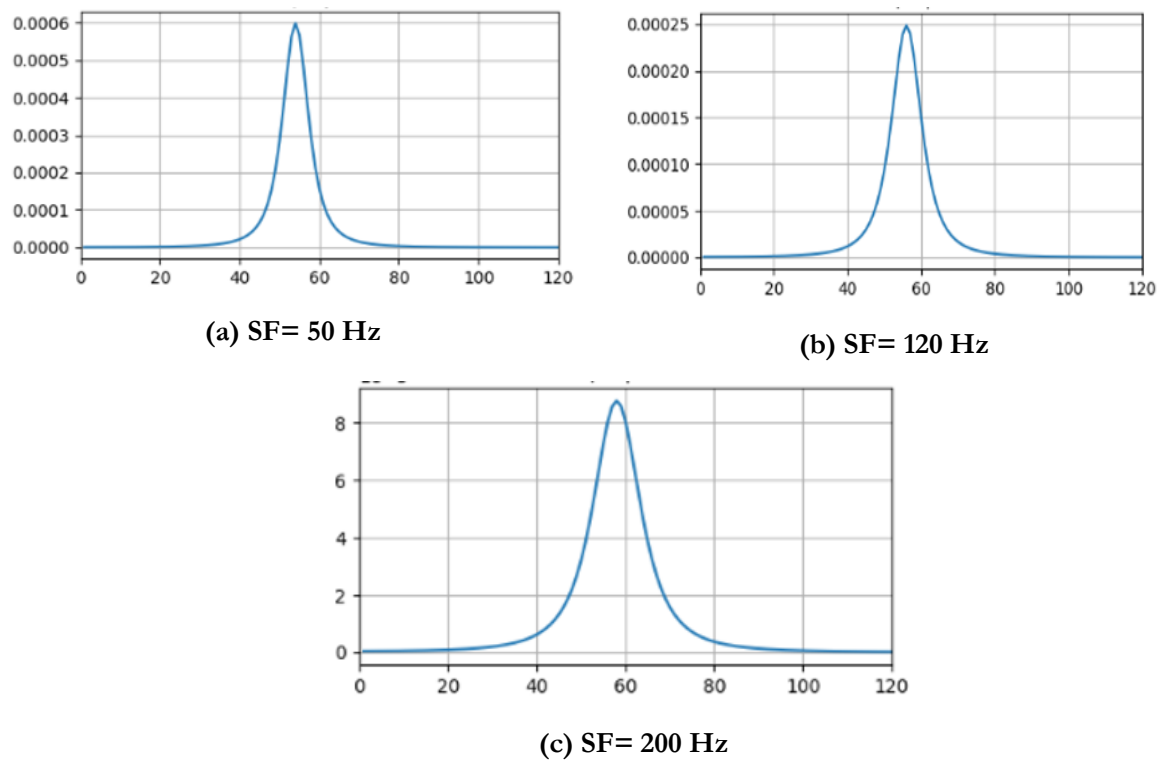
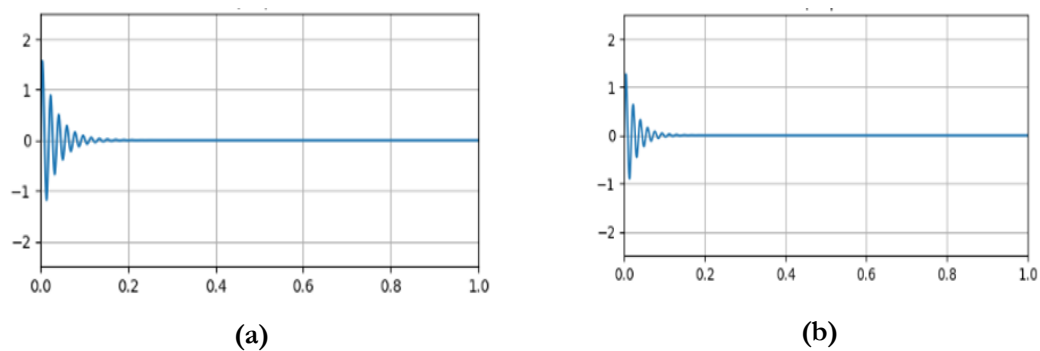


Fig.4. Peak value frequency of Aerofoil Blade fiber with 30° orientation with SF= 50, 120 & 200Hz (a, b, c)

Table VI : Displacement of blade due dynamic loading condition.

Sr. No.	Flow (Re)	Orientation of Fiber	AC supply (Volt)	Amp. (mm)	Damp. ratio (ζ)
1	2×10^5	30°	40	1.8	0.093
2	2×10^5	30°	70	1.5	0.107
3	2×10^5	30°	100	1.2	0.138

Further decrement of amplitude of vibration of blade is increase with voltage supply to PZT Actuator as shown in Fig.-05 (a, b, c). Settling time blade vibration significantly observed in Table-V & VI.



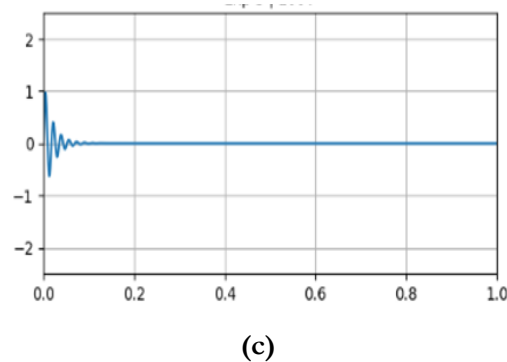


Fig.5. Displacement of Aerofoil Blade fiber 30° orientation (a,b,c)

5. Conclusion

The results of both methods i.e. Frequency and Time domain are in better agreement, while ensuring that the solution of the frequency domain is accurate. The frequency domain method is faster than the conventional time domain method and reduces the computational cost by 90%. An experimental mode analysis without PZT actuator shows good agreement with numerical simulations, with a deviation of about 1-2%. In the closed circuit, the PZT actuator increases natural

frequency and reduces vibration response, while reducing vibration in a less elastic strain area. Comparing natural frequencies with and without piezoelectric transducer indicates that the use of a piezoelectric transducer increases natural frequency while it reduces sampling frequency and displacement of the blade. The results show that, the maximum elastic strain reduced by 24.6 % using a non-rotating propeller piezoelectric transducer. It is effective between the airflow ranges, which is widely applied for productive output.

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