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Vibration Reduction in a Helicopter Using Active Twist Rotor Blade Method

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Abstract

In this paper, method of vibration reduction using Macro Fiber Composite (MFC) actuator under pressure loading obtained by flow analysis is presented. The model used in analysis contains of D-spar made of GFRP, skin made of $+45^0/-45^0$ GFRP and foam core located inside of the blade. MFC actuators are embedded on the top and bottom skin and optimum placement of MFC chips for twist motion is determined. 3D model is created by Solidworks and finite element analyses are conducted by using the ANSYS® mechanical (workbench). The results show that application of piezoelectric actuators to obtain active twist method can reduce the vibration on a rotor blade and the amount of reduction increase with applied voltage.

1. Introduction

Helicopters are subject of complex unsteady aerodynamic conditions during the take-off, landing, climb and descend. Especially, the main rotor experiences highly unsteady aerodynamic loads, which cause the vibrations and noise. In forward flight, main rotor is exposed to asymmetric loading and flow condition around the rotor region can be divided two parts such as: advancing side and retreating side. Figure 1 shows unsteady aerodynamics phenomena on the main rotor blade. Due to different wind flow velocity across each half, unbalanced lift occurs between advancing and retreating halves of the rotor disk. This condition named as dissymmetry of lift which leads to a vibratory response happens on a flexible blade structure. Vibration phenomena are one of the most critical issues because they lead to passenger/pilot discomfort, fatigue and it also affects fatigue/ operational life of the components. That is why vibration reduction studies are important by applying passive and active techniques to influence aerodynamic conditions. Passive approach is a traditional vibration reduction technique by applying vibration isolators and absorbers, however; these structural component also have a limited operational life and expensive to replace By using active technique, the source of vibratory loads can be directly influenced so it is more effective solution for vibration reduction. Active control approach can be divided by four different methods which are named as; higher harmonic control (HHC), Individual Blade Control (IBC), active trailing-edge flap and active-twist rotor. Moreover, HHC and IBC can be categorized as vibration reduction with blade pitch actuation. However, HHC and IBC have some disadvantages such as they are limited to reduce vibration; because conventional swash plates have limited actuation frequencies and application of these methods are difficult due to complex and heavy hydraulic system. In addition, vibration reduction in rotor which controls with on-blade actuators is also widespread method. This type of reduction can give more safety and less energy consumption for the aircraft. On blade actuator’s failure would not affect the flight safety as much as HHC and IBC and also consume less energy, because of on-blade actuators has not many motion part. These are collecting in two main type; discrete actuators and continuous / embedded actuation. Active-twist rotor system is one of the continuous / embedded actuation methods. In continuous / embedded actuation concept, active material is implemented in the cross section of the rotor blade.

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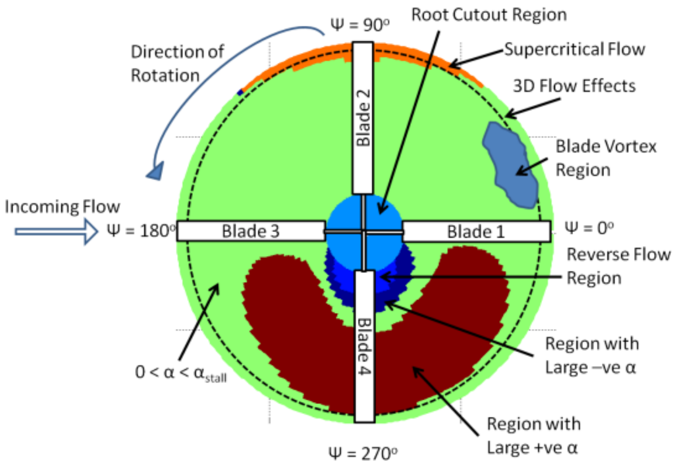

Figure 1: Unsteady Aerodynamics on the Main Rotor Disk [1]

In this paper, implementation of morphing technologies to reduce vibration levels due to rotor aerodynamics at vertical take-off landing unmanned aerial systems are observed. Helicopters are mainly selected to investigate as a vertical take-off unmanned system. The effects due to the disadvantages of vibration are believed to be reduced by the employment of a twist morphing technology on the helicopter blades. Active twist rotor method is used to reduce vibration under aerodynamic loads using piezoelectric actuators. Shark-120 model developed by Oneseen Skytech is used as a UAV in this study. [2] Rotor blade is designed with NACA 23012 airfoil and has a rectangular shape. Detailed dimensions of rotor blade can be seen in Figure 2. It includes D-spar which is made of unidirectional Glass Fiber Reinforced Polymer and $+45^0/–45^0$ GFRP skin. Foam is added inside of the blade to increase the strength of the structure. Figure 3 shows cross section of the rotor blade.

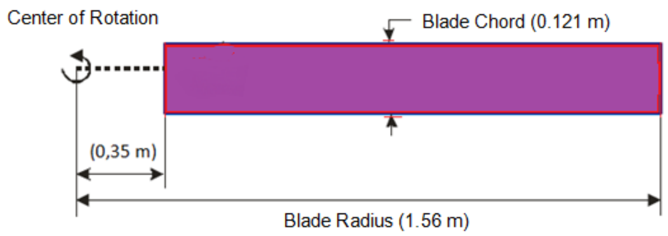

Figure 2: Dimensions of the helicopter rotor blade

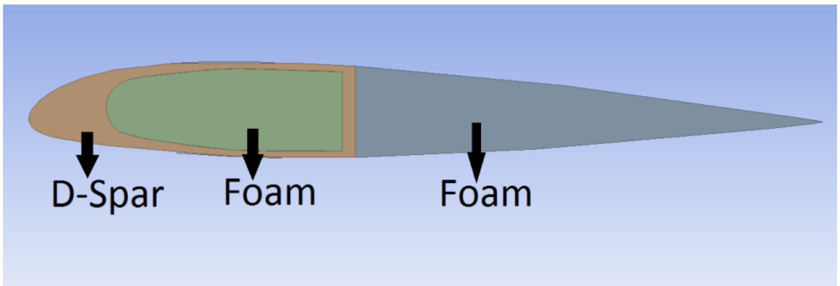

Figure 3: Cross-section of the helicopter rotor blade

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Since skin and MFC are modelled as shell elements, they cannot be seen from cross-section. Therefore, skin and MFC can be seen at figure 4 separately.

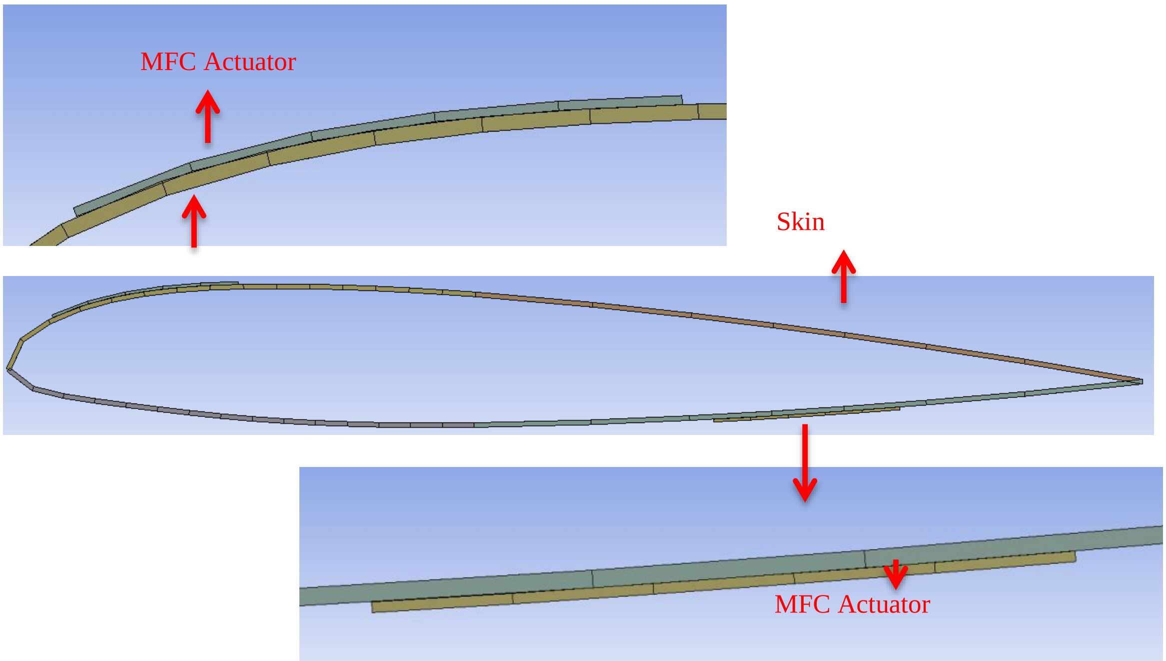

Figure 4: Cross-section of skin and MFC

Mechanic properties of rotor blade component can be seen as follow:

Table 1: Properties of materials used in the cross-section. [3]

	Glas Fiber Reinforced Polymer (GFRP)	Foam	MFC
E_X	45.166 GPa	0.035 GPa	15.5 GPa
E_Y	11.981 GPa	0.035 GPa	15.5 GPa
E_Z	11.981 GPa	0.035 GPa	30.0 GPa
Gxz	4.583 GPa	0.014 GPa	5.7 GPa,
Gyz	1.289 GPa	0.014 GPa	10.7 GPa,
Gxy	1.289 GPa	0.014 GPa	10.7 GPa
υyz	0.325	0.25	0.35
υxz	0.238	0.25	0.4
υxy	0.238	0.25	0.4
ρ	2008 kg/m3	52 kg/m3	4700 kg/m3

Also structure includes Macro-Fiber Composite (MFC) consists of piezoceramic fibre and sandwiched between polyamide films that have attached interdigitated electrode patterns. MFC actuator developed at NASA's Langley Research Center in 1996 is used as smart material. It can be operate between -500 V and +1500 V by helping of particular electrode design.[4] They produce strain-induced twisting motions of the blade when using electrical voltage. The proposed actuation concepts are based on piezoelectric actuation with focus on d33-mode.To decrease the amplitude in the resonance frequency range; piezoelectric actuators are set on both top and bottom of the blade. Location of the MFC patches are indicated according to twist motion and the optimum place is selected.

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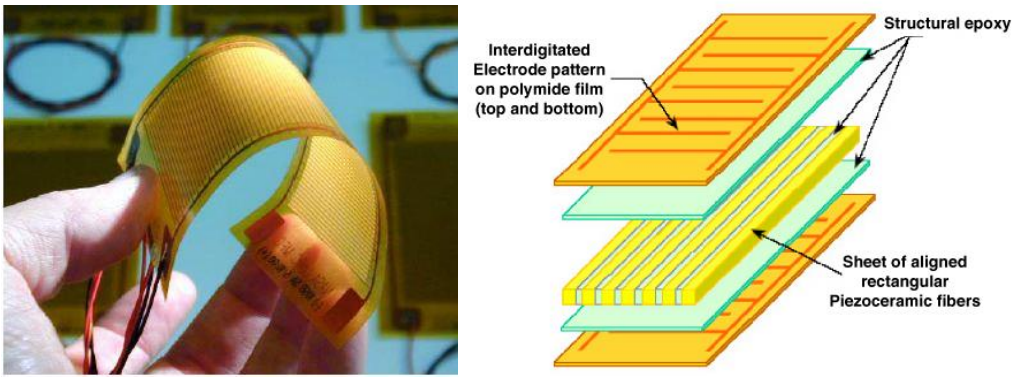

Figure 5: NASA-ARL Macro-Fiber Composite actuator [5]

2. Method

The results were obtained by using applications of different area and different voltages. These arrangements and analyses performed using ANSYS® mechanical (workbench) program. To simulate the aerodynamic loads on blade structure, ANSYS® Fluent tool is used. Harmonic and modal analyses are conducted after structural, thermal and Fluent analysis are performed. All aerodynamic forces are directly transferred to harmonic and modal analysis. Ergo, the real twist effect of MFC chips on blade after applying voltage can be shown. In structural analysis, 62000 cell is used and in Fluent ® analysis the number of mesh equals to 3200000. Triangle mesh is used for skin size and for other sides hexa (quad) mesh is used. Mesh structure for skin and inner side of the rotor includes foam and D spar can be seen in figure 6.

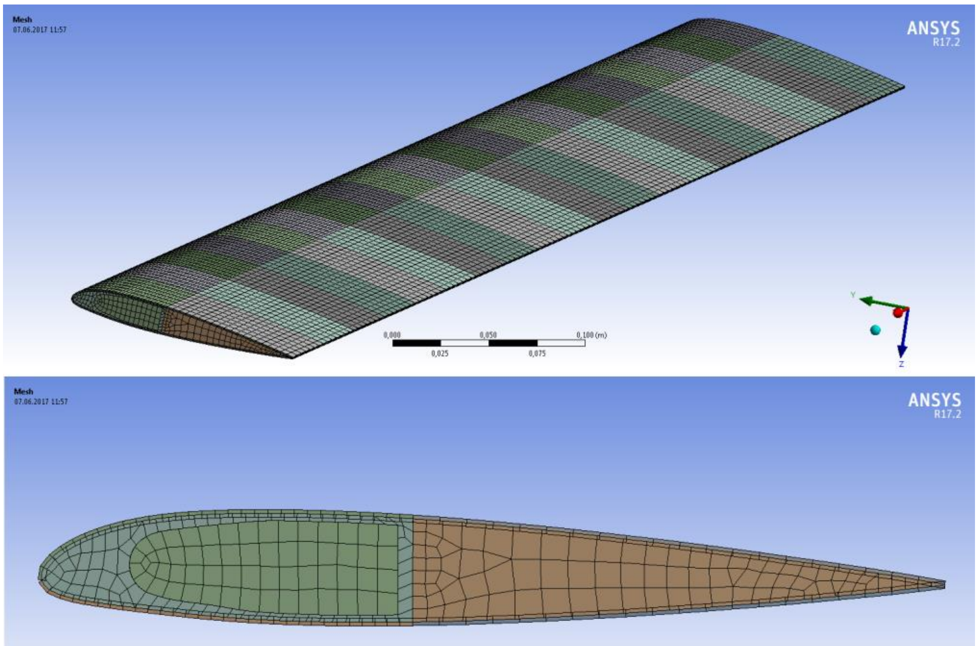

Figure 6: Finite Element Model of Rotor Blade

To observe the voltage effect on piezoelectric actuator in Ansys, thermal analogy method is used. According to this analogy, the strain caused by the voltage difference is modelled analogous toa strain as a result of temperature difference so voltage effect on model can be simulate with thermal effect without using

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piezoelectric modelling. Thermal expansion coefficients are used to input to represent piezoelectric strain effect. The relationship between piezoelectric strains and thermal strains is obtained as following:

$$\propto_{ij} = \frac{d_{ij}}{t} \qquad [6]$$

where t indicates thickness.

D_{33} mode for piezoelectric is used for twist motion. Applied voltage difference in real case equals to temperature change.

$$\Delta V \sim \Delta T \qquad [7]$$

To create fluent domain, the blade geometry is generated, fluid domain is generated on top blade geometry and blade geometry is suppressed in FLUENT before mesh operation. Two fluid domains are constructed during CFD analysis. First one is near blade region with fine mesh and second one is far from blade with coarser mesh considering solving time, CPU and GPU limitations. Blade inside domains and both domain can be seen on Figure 7 to 8.

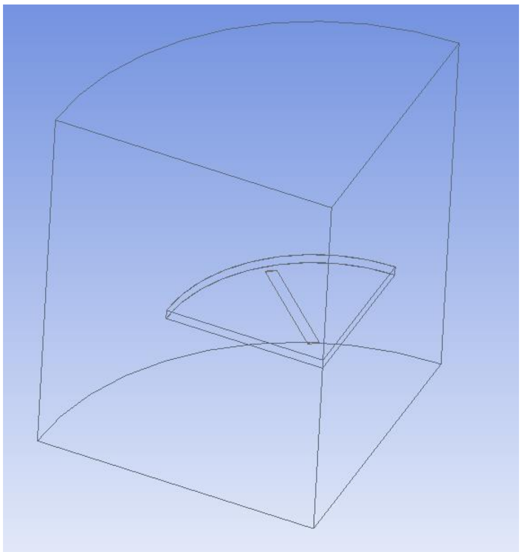

Figure 7: Full CFD Domain

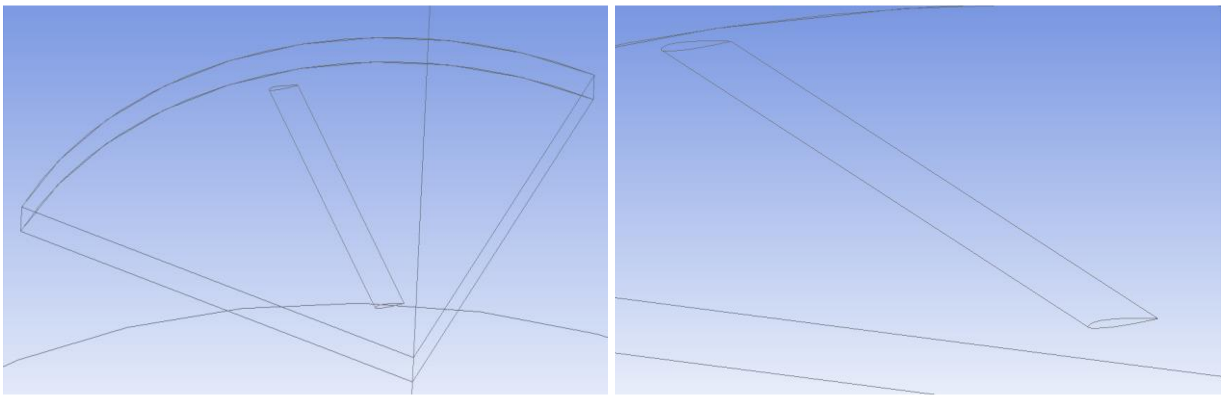

Figure 8: Near Blade CFD Domain (left), Blade Inside Fluid Domains (right)

In order to save computational resources and to simplify the CFD analysis, the domain was designed as a 90° circular model. Symmetry boundary conditions assumed on the left and right sides of the domain. Thus, due to this an external flow problem, the surface of the rotor blade geometry that is part of the rotor blade defined as wall conditions,

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and then the rest of the geometry domains is specified as an enclosure. General view of flow mesh can be seen at Figure 9.

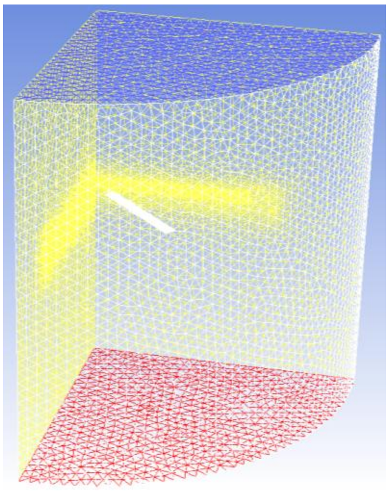

Figure 9: General view of CFD mesh

3. Results and Discussion

For different application areas and different voltages, rotor blade parameters are conducted. At first, blade analyses are obtained without any piezoelectric effect. The applied location of MFC materials is shown in figure 10 to obtained optimum twist motion. MFC material is embedded both upper and lower skin. Application area of MFC is divided by 10 equal parts and vibration reduction rate for each location are shown. Also, the results for different voltage differences by applying MFC material implemented from end to end of blade shown in figure 14 are presented.

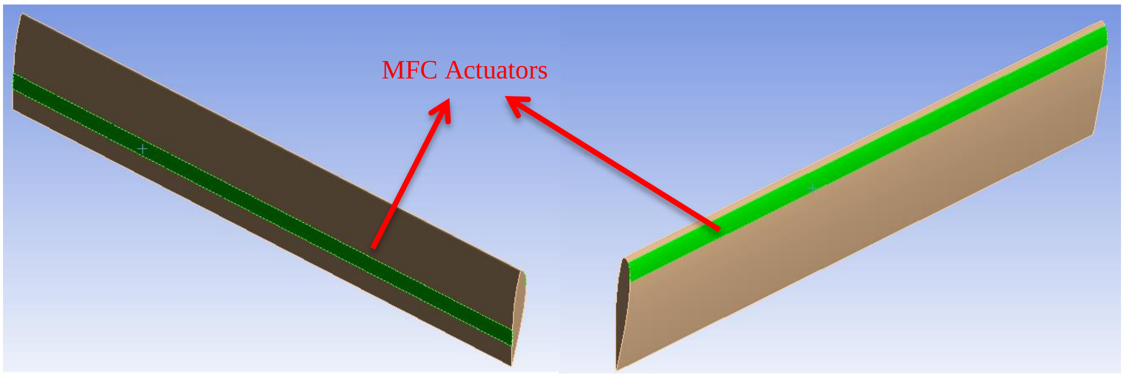

Figure 10: Application of Piezoelectric Actuators

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3.1. Modal Analysis

Table 2 shows first ten natural frequencies of blade. Fifth mode indicates the first twist mode. Also, Figure 11 is shown first three twist mode shapes with corresponding frequencies *f* of 69.01, 293.89 and 411.93.

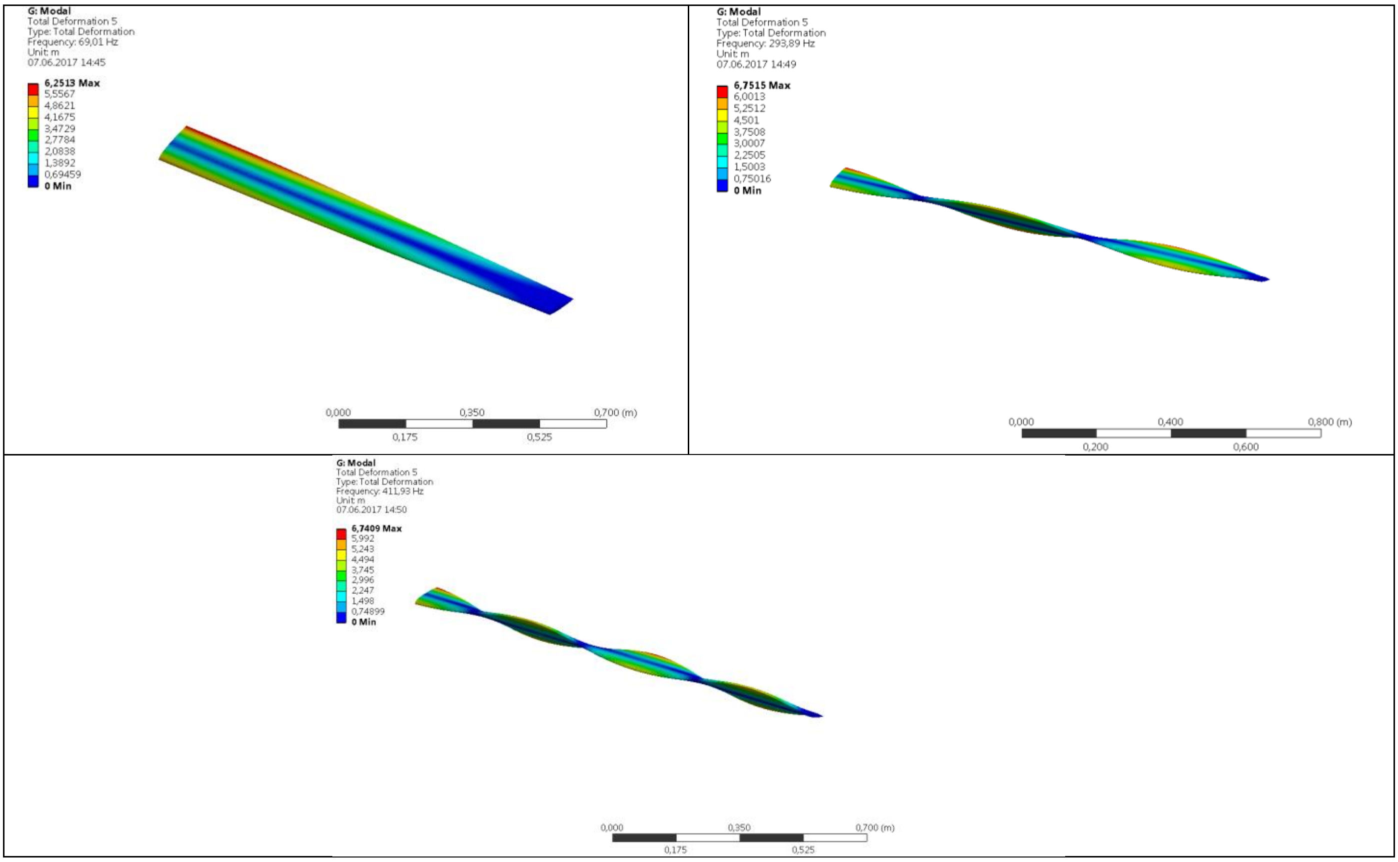

Figure 11: Twist mode shapes of rotor blade without MFC

First twist mode with 69,01 hz frequency is taken into consideration during changing other parameters.

Table 2: Natural Frequency of Rotor Blade without MFC

Mode Number	Frequecny [Hz]
1	3,6427
2	20,571
3	23,388
4	56,17
5	69,01
6	108,23
7	138,44
8	174,93
9	179,13
10	256,77

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3.2. Harmonic analysis

For different voltage inputs, voltages are set from 100 to 1500 with 200 increments. It can be seen from figure 12 and 13 that there is a %80 decrease of amplitude at critical twist mode frequency (69.01) in comparison with without MFC application. Also, twist modes frequency decreases 69.01 hz to 60.29 hz by application of 1500. The decrease of vibration is calculated by given formula:

$$R = \left(1 - \frac{A}{A_0}\right) * 100^{\%} \qquad [8]$$

where A_0 is amplitude when V=0 and A equals to amplitude when V≠0.

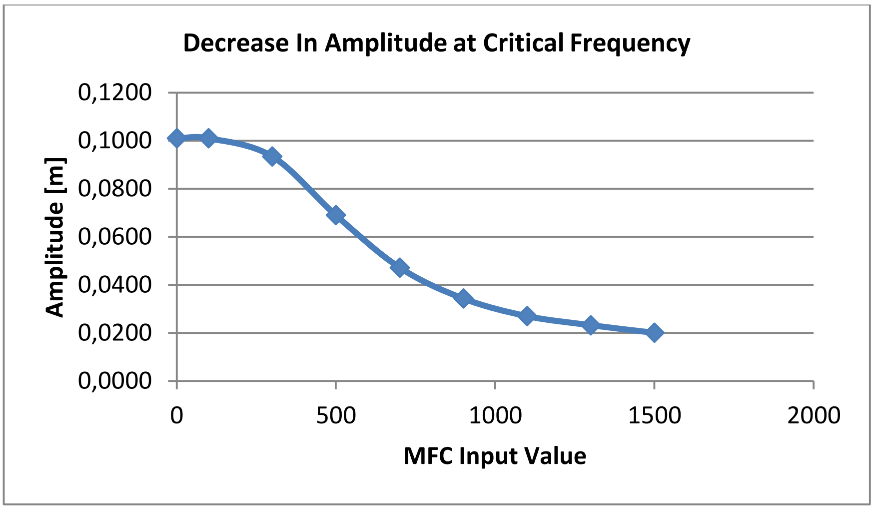

Figure 12: Amplitude Values for for Different Voltage at 69.01 Hz.

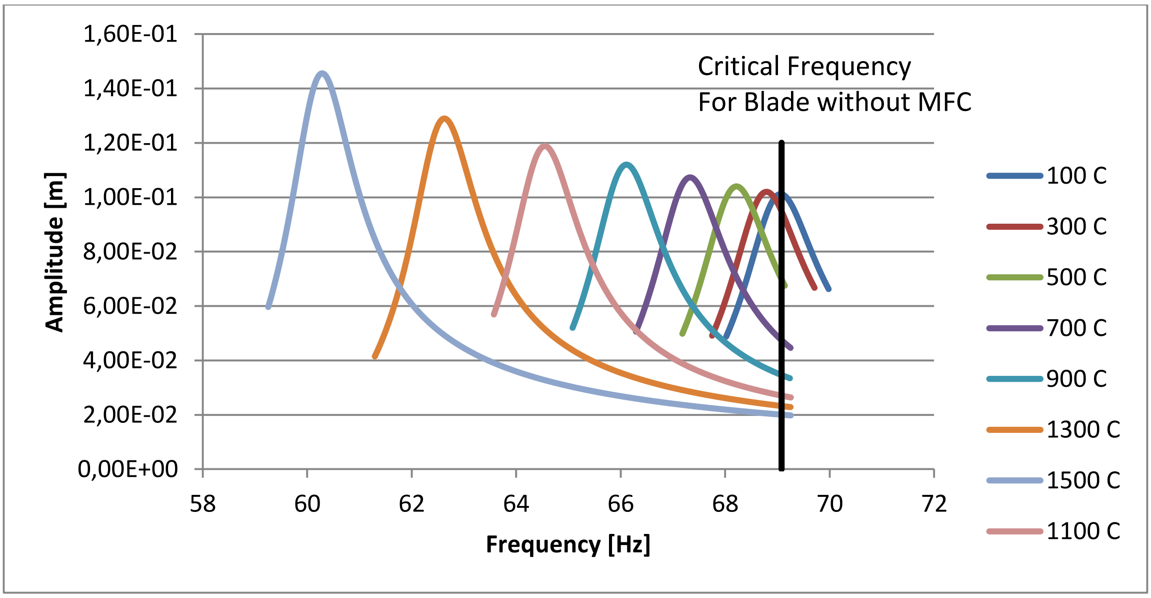

Figure 13: Decrease in Amplitude with Different Voltage

For full application of MFC patch, maximum vibration reduction occurs at 1500 V and equals to % 80.1

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Secondly, effectiveness of MFC is investigated on the blade. To investigate this, patch model is divided into 10 equal parts as it can be seen at figure 14. Both front and back side patch are investigated separately. Analyses started with only %10 of blade increased with %10 increments and effects on vibration reduction are investigated. Figure for front patch is can be seen below. Note that during these analyses, one MFC patch is divided and increased by %10, however, there is no changes applied to other MFC patch located at bottom side of skin.

Figure 14: Patch divisions and increment direction

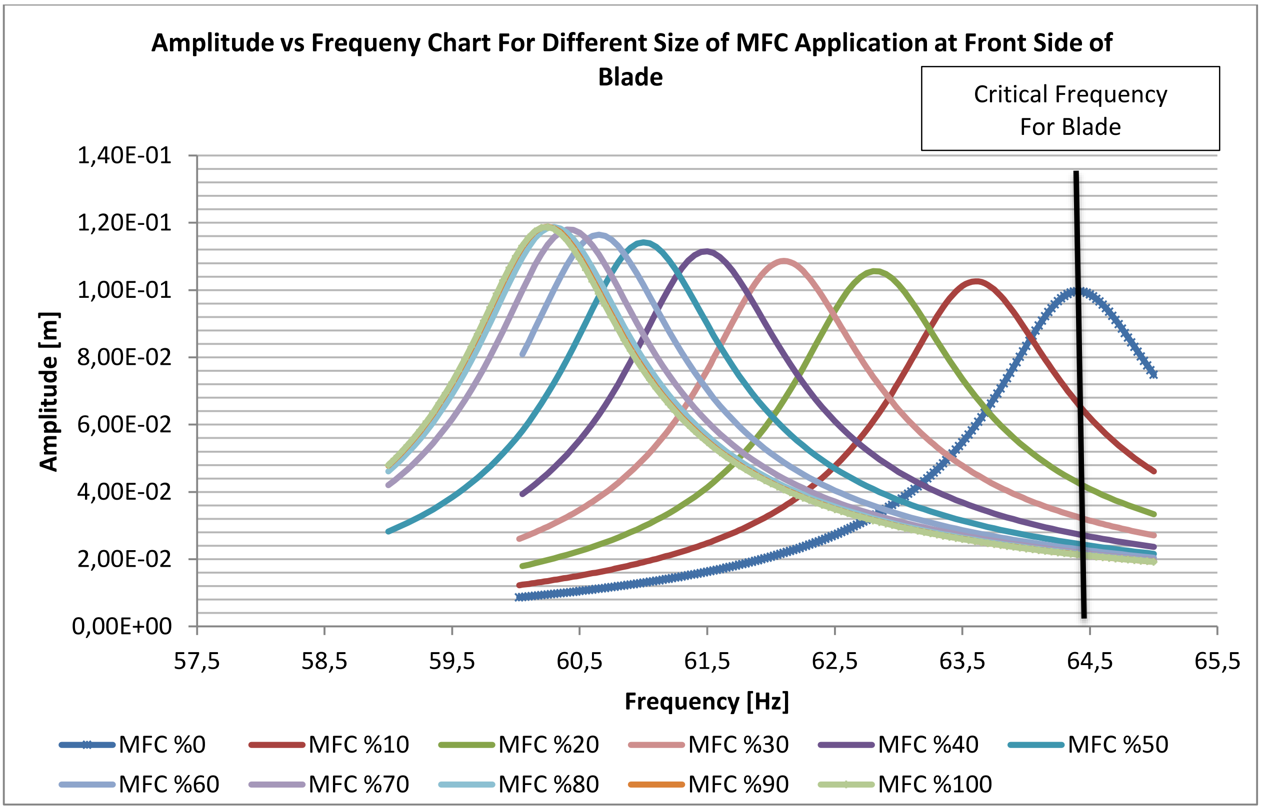

Figure 15: Amplitude vs Frequency for Different Size of MFC Application at Front Side of Blade

It can be seen in Figure 15 that the amplitude decreases with increase of MFC area at 64,4 Hz which is a critical torsion frequency for MFC application only rear side of the blade. Vibration reduction equals to % 78,5 when compare the %0 and %100 MFC application of front side. Also, with increasing MFC area critical frequency is shifting to left due to a change in the MFC size of the whole system.

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4. Conclusions

Vibration reduction on helicopter rotor blade under aerodynamic loads by using active twist rotor blade method helping MFC actuator is studied. Results are obtained by ANSYS packages. Applied voltage is modeled as a thermal analogy and thermal load is used instead of voltage. The study shows that using piezoelectric actuator in active twist rotor method to reduce vibration of helicopter blade is highly efficient. Also, different piezoelectric arrangements and optimum voltages are determined. According to study, results conclude that torsion mode is used to determine the optimum placement of MFC actuators. Also, the length of the MFC actuator and the voltage used in actuators affect rate of reduction in vibration. It would be sufficient to add that the application area of the MFC should be optimized considering the additional mass to the system and this can be considered as a future study.

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