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# Vibrational Analysis of Conducting Nanocomposite Actuator

**Narendra Gariya[1]*, Brijesh Prasad[2], Varij Panwar[3], Pushpendra Kumar[4]**

[1,2,4]Department of Mechanical Engineering,
[3]Department of Electronics and Communication Engineering,
Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India.
*Corresponding author: navigk05@gmail.com

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**Abstract**
The focus of this study is on flexible actuators which act as soft muscles and can produce large amount of deflection (bending) on the application low voltage less than 4V, which can be applied for various applications of robotic arms, manipulators, medical devices, aerospace applications and for structural health monitoring. In this study, vibration analysis of beam structure of polymer composite of (PVDF/CNF) material is carried out using Finite element analysis. The vibration analysis is carried out for six modes with one end fixed and both end fixed boundary conditions. The obtained results from the analysis showed the minimum failure frequency with different mode shapes at different boundary conditions. The analysis can be very much helpful in prediction of the safe working conditions for the complex structures.

**Keywords-** Vibration, Modal Analysis, Composite, Soft Material.

## 1. Introduction

Electroactive polymers (EAPs) showing piezoelectric behavior are increase in demand for the actuator application because of their versatile properties of low power consumption, light weight, ease of fabrication, larger displacement and tailorable properties (Sebastian et al., 2016, Prasad et al., 2019). EAPs are used for various applications of soft robotic arm, conducting substrate, conducting skin, manipulators, biomedical devices, electronic devices for structural and human health monitoring (Prasad et al., 2018). EAPs are developed making use of piezoelectric polymers such as Polyvinylidene Fluoride (PVDF). The EAPs are used as sandwiched structure (conductive membrane is sandwiched in between the conductive electrodes of platinum, silver, copper etc.) and in other way the membrane itself act as the soft actuator without sandwiching (Costa et al., 2014). These EAP actuators can produce deformation on the application of low voltage below 5V. When potential is applied across the composite membrane dipole moment takes place which realign the molecules in the sample. This rearrangement tends to produce the mechanical deformation in the form of actuation. During actuation due to realignment of molecules vibrational energy is produced which is very much important for obtaining the required actuation (Prasad et al., 2019).

In robotics it becomes very much important to understand the design and functioning of the movable part. These movable parts can be used for holding the object, or to move in particular direction for performing some operation. Lots of efforts have been done by providing significant progress in the field of soft robotics (Galea et al., 2019; Kagawa et al., 1979). Finite element analysis (FEA) is being used as designing tool to obtain optimum designing parameters including the safety features for safe operations (Galea et al., 2019; Sahoo et al., 2018). Wang et al. (2006) in his work described about the PVDF sensors theoretical analysis using the FEM software. A point load was applied to perform the experimental modal analysis. Li et al. (2002) studied the vibrational frequencies of all trans arrangement of the PVDF.

PVDF has been majorly used for the actuator application because of its high piezoelectric behavior. The $(CH)_2$ and $(CF)_2$ bonds present in the PVDF are realigned due to the dipole moment producing the disturbance in the polymer chain hence producing some vibrational energy. The energy produced during the deformation and the applied energy can produce the resonance effect which can hinder the actuator performance (Pradeep et al., 2018; Zhu et al., 2013). Therefore, it becomes important to study the vibrational effect of the polymer composite membrane. Here, the study focusses on the fiber reinforced soft polymer actuators. Where PVDF has been used as the polymer matrix and carbon nano fibers (CNF) have been used as the conductive fillers to provide mechanical strength to the polymer composite. The fibers supported the membrane during deformation and helped in maintaining the original state. In this paper, we have performed the vibration analysis of PVDF/CNF material and obtained the natural frequencies at different mode shapes using boundary conditions. For each boundary condition, six modes shapes have been developed and studied.

The rest of the paper is organized in the following sections. In Section 2, the theory of vibration analysis is presented for the considered PVDF/CNF nanocomposite. The results of FEM simulation is presented and described in Section 3. Finally, the paper is concluded in Section 4.

## 2. Vibration Analysis

The vibrational analysis of PVDF/CNF nanocomposite has been done by modal analysis by making use of FEM 14.5 software. For analysis, six modes are selected for each boundary condition and the natural frequencies are obtained for all modes.

### 2.1 Modeling and Analysis

The modal analysis is carried out to determine the dynamic properties of the system in the specific frequency domain which are known as modes. Each mode is defined by a resonant frequency. The analysis is carried out using FEM tool. The equations utilized for the analysis are provided in (Kumar et al., 2017):

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = 0 \tag{1}$$

where,

($M$), ($C$), ($K$), and $\{x\}$ are mass matrix, damping co-efficient matrix, stiffness matrix, and position vector, respectively. For undamped free vibration, ($C$) = 0, hence the resultant equation will be

$$\{x\} = \{A\}e^{i\omega t} \tag{2}$$

where, vector $\{A\}$ shows the respected amplitude of masses, and $\omega$ represents the corresponding frequency of each Eigen vector. Finally, the governing equation is given by

$$\big[[K] - \omega^2[M]\big]\{A\} = 0 \tag{3}$$

Finally, the natural frequency of vibration is calculated using the following governing equation

$$\omega = \sqrt{\frac{K}{M}} \tag{4}$$

## 2.2 3D Modeling

An actuator model having rectangular cross-section is modeled using New Modeler Geometry in ANSYS 14.5 having dimensions (60X30X4) mm and the vibration analysis is carried out in Modal module of ANSYS 14.5. The mesh model consists of 45798 nodes and 9610 elements as shown in Figure 1.

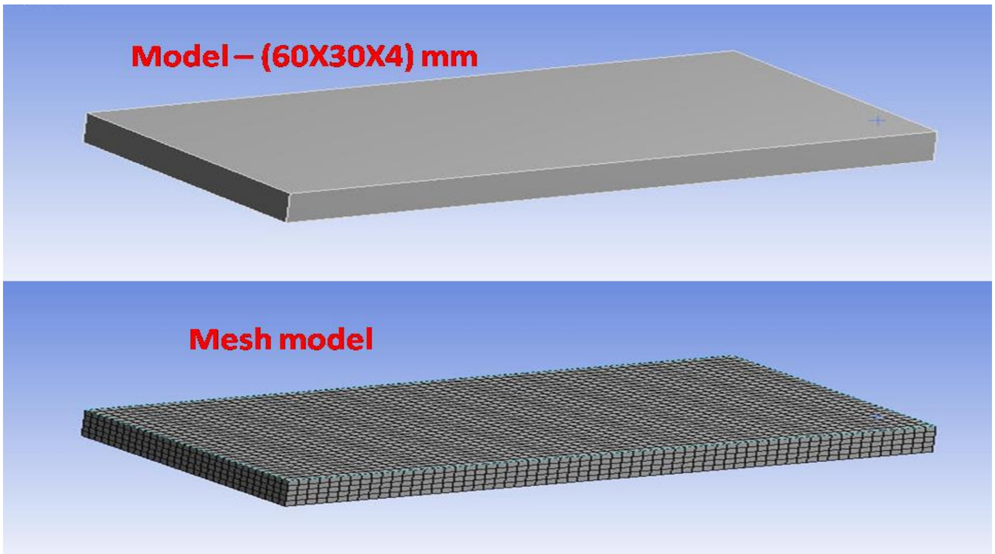

**Figure 1. Actuator geometry and mesh model**

The modal analysis is carried out for first six modes to determine the natural frequencies and mode shapes of the actuator. The analysis is carried out for two cases. In the first case, actuator’s one end is kept fixed while the other end remains free. In the second case, both the ends of the actuator remain fixed.

The material properties of the PVDF/CNF nanocomposite material are taken from previous work and experimental data (Prasad et al., 2019). Young's modulus, Poisson's ratio and density of PVDF/CNF are taken for vibration analysis and shown in Table 1.

**Table 1. Mechanical properties of PVDF/CNF material**

| Material | Young's Modulus | Poisson's ratio | Density |
|---|---|---|---|
| PVDF/CNF | 48 MPa | 0.3 | 2 g/cm$^3$ |

## 3. Results and Discussion

For the first case, where one end of the actuator kept fixed while the other end remains free, natural frequencies and mode shapes are shown in Figure 2.

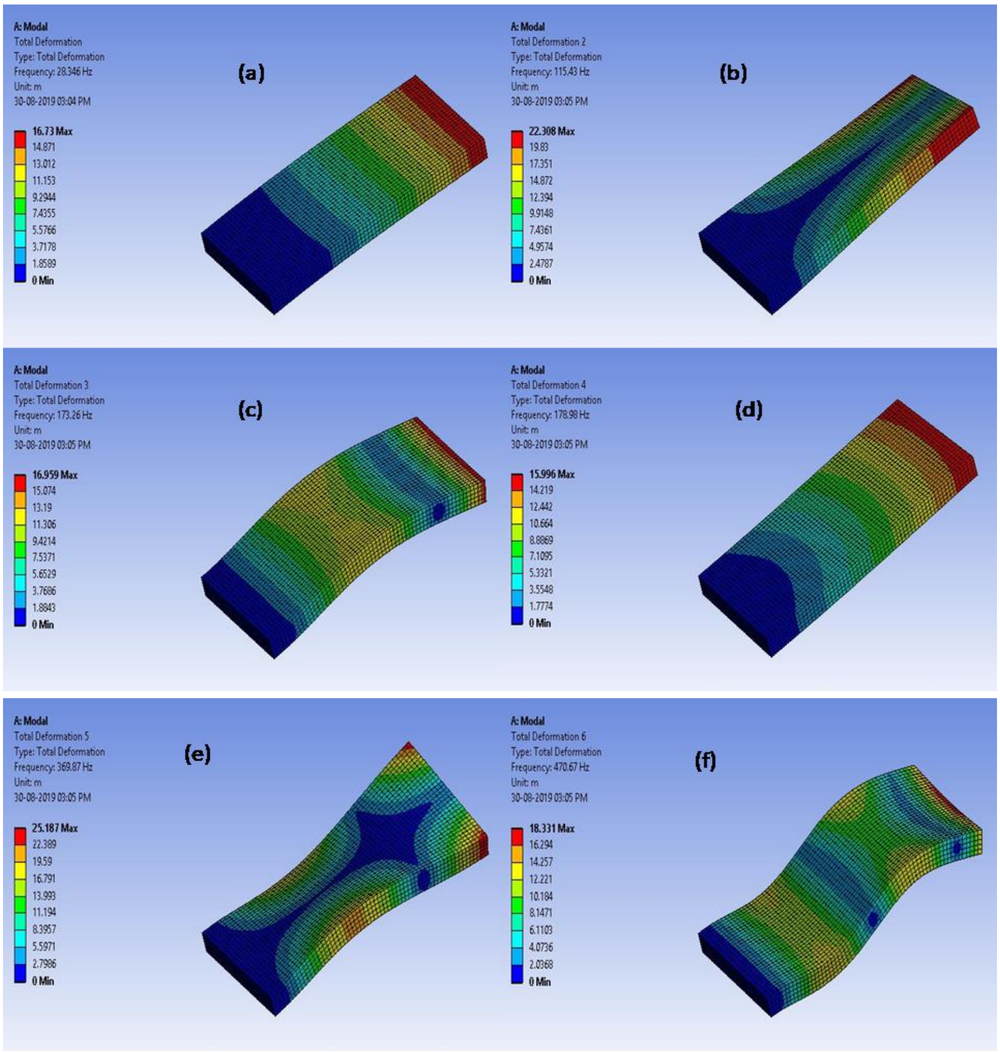

**Figure 2. (a), (b), (c), (d), (e) and (f) mode shapes for first six modes**

For the second case, where both ends of the actuator are kept fixed, natural frequencies and mode shapes are shown in Figure 3.

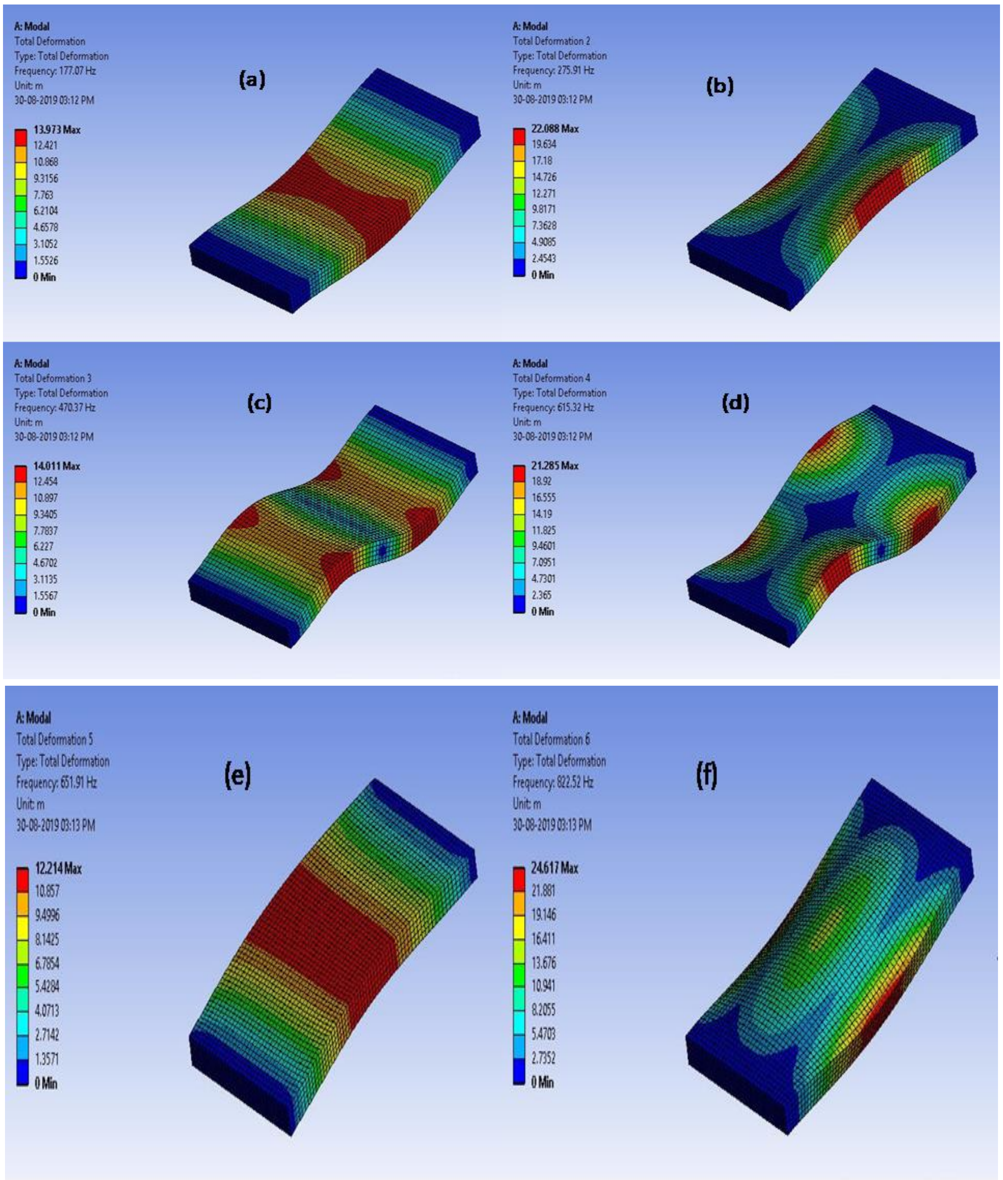

**Figure 3. (a), (b), (c), (d), (e) and (f) mode shapes for first six modes (both ends fixed)**

The obtained results are summarized in Table 2 for both the considered boundary conditions.

**Table 2. Frequency table for both the boundary condition are shown below**

| Material | Modes | Frequencies | |
|---|---|---|---|
| | | Fix-Free condition | Fix-Fix condition |
| **PVDF/CNF** | 1 | 28.346 | 177.07 |
| | 2 | 115.43 | 275.91 |
| | 3 | 173.26 | 470.37 |
| | 4 | 178.98 | 615.32 |
| | 5 | 369.87 | 651.91 |
| | 6 | 470.67 | 822.52 |

Refer to Table 2, it can be observed that the range of natural frequencies is lower (from 28.346 to 470.67 Hz) for the one end fixed boundary condition compared to the both end fixed (from 177.07to 822.52 Hz) boundary condition.

## 4. Conclusion

The present study includes analytical model for studying the fiber reinforced polymer nanocomposite of PVDF/CNF. The values of modulus, poison ratio and density of the material are taken as per the experimental data published previously. To perform the study, a rectangular beam model is designed using the FEM software for the PVDF/CNF nanocomposite. The vibration analysis has been performed for six different modes by applying the boundary conditions with one end fixed and both end fixed. It is found that PVDF/CNF natural frequency vary from 28.346 to 470.67 for one end fix-one end free condition and vary from 177.07 to 822.52 for both end fixed condition. From the study, it can be concluded that minimum failure frequency of PVDF/CNF is 28.346.

For the future work, it will be interesting to analyze the PVDF/CNF membrane considering some imperfections such as crack and porosity; in addition, more boundary conditions can be considered for the analysis. Further, the PVDF/CNF nanocomposite can be analyzed for real application i.e., the soft actuator application with the electromechanical behavior.

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