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Optimization of Piezoelectric Fibers in FG Panel with PFRC Layers by Using Genetic Algorithms

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ABSTRACT: In this research, optimization of piezoelectric fibers in a functionally graded cylindrical panel with PFRC layers as sensor and actuator under dynamic load and electrical excitation with various types of supports including simple, clamped and combination of free and clamped supports is provided. The main goal is to obtain volume fraction of piezoelectric fibers in a PFRC layer so that radial displacement in circumferential direction in this layer is equal to that in piezoelectric layer. For the optimization, genetic algorithms were used and in each case, the algorithm parameters are obtained by using parameter tuning method. In order to minimize computational costs, artificial neural networks are trained and employed. Results show that with the introduction of clamped supports, increment for maximum Von Mises stress in the structure and the volume fraction of piezoelectric fibers can be seen.

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1- Introduction

Within various smart materials, piezoceramics have gained more interest, but with some drawbacks. Piezoelectric Fiber Reinforced Composites (PFRCs) are used in order to improve the drawbacks, in which piezoceramic fibers are placed in a polymer matrix.

Piezoceramic optimization problem in functionally graded cylindrical panel can be defined as the best fiber volume fraction within PFRC layer. Genetic algorithm has been selected as the optimization technique. A substantial number of investigations have been done on the piezoelectrics and FGMs. Bahrami et al. [1], presented a three dimensional analysis for a functionally graded cylindrical panel reinforced by PFRC layers subjected to dynamic loading and electrical excitation.

2- Methodology

A schematic view of the problem as well as the geometry parameters, location of the applied electric voltage and panel layers are shown in Figure 1.

The model suggested by Kapuria and Kumari [2] with a little adjustment has been utilized to obtain the effective composite layer properties by considering fibers and matrix properties. Equations governing PFRC layer can be shown in matrix form as Eq. 1.

$$\begin{Bmatrix} \sigma \\ D \end{Bmatrix} = \begin{bmatrix} C & e^T \\ e & \eta \end{bmatrix} \begin{Bmatrix} \varepsilon \\ E \end{Bmatrix} \qquad (1)$$

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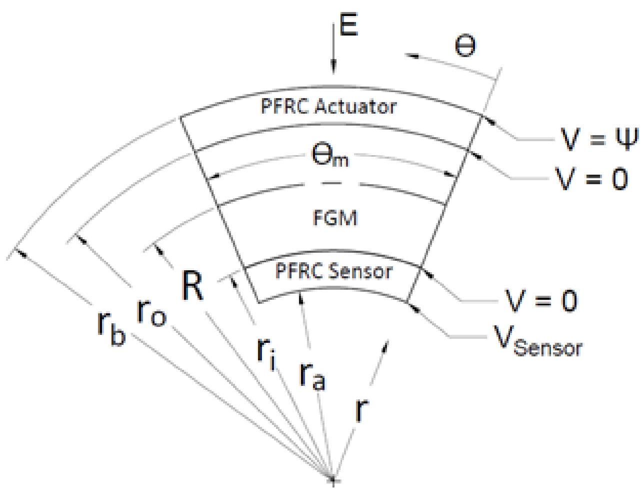

Figure 1. Problem geometry parameters andapplied electric voltage location

2- 1- Derivation of finite element equations for PFRC layer

Finite element algebraic equations for FGMs and smart materials are derived by exploiting Galerkin method and implementing it on the equations of motion (equilibrium equations) and Maxwell's equation. All the equations are written in cylindrical coordinates. Small deformations are regarded in strain-deformation relations. There are also relations for electric field-electric potential.

2- 2- System of governing differential equations

Substituting strain-deformation relations and electric field-electric potential equations in Eq. 1, stresses and electric displacements are derived based on the deformation components and electric potential. Then, the result is substituted in equilibrium and Maxwell's equations, so four equations with four unknowns are obtained for each element.

2- 3- Solving the governing system of differential equations

In order to solve the partial differential equations in the previous section, all the equations are multiplied by an appropriate shape function and integrated over the space domain (based on Bahrami study [3]).

2- 4- FGMs relations

The power law is used for FGM properties, same as Loy and Reddy study [4]. The governing equations general form of FGM is same as the PFRC layer.

2- 5- Assembly

General form of the equations can be shown in Eq. 2. These are linear algebraic equations.

$$[M]\{\ddot{U}\}+[K]\{U\}=\{f\} \tag{2}$$

2- 6- Time domain solution

After assembling [K], [M] and {f} matrices, the equations are solved on time domain by single-step implicit Houbolt method [5].

3- Results and Discussion

For validating the proposed method, the FGM panel with piezoelectric layers is modeled thoroughly in ANSYS commercial finite element package and stresses are compared in t=0.01 s. An acceptable agreement is obtained between two methods (Figure 2).

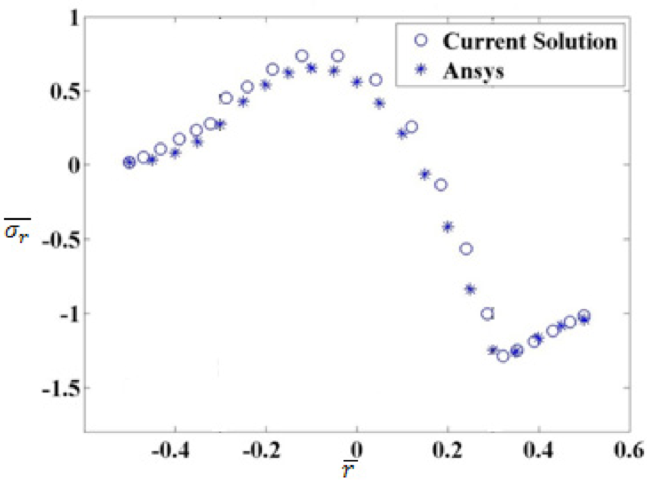

Figure 2. Radial stress distribution along the radial direction

3- 1- FGM cylindrical panel with piezoelectric layers with simply supported boundary conditions at four edges

Cylindrical panel configuration is shown in Figure 1. Parameters related to physical characteristics has been used in Eq. 3.

$$S=10,\quad \theta_m=60^\circ,\ L=1\text{m},\ R=1\text{m} \tag{3}$$

where, S is the average radius to panel overall thickness ratio and L is the length of panel. Furthermore, applied electric load over the outer surface is 0.01 V and the applied mechanical load over the outer surface is compressive and uniform.

3- 2- Equivalent model for panel with four simply supported edges

The objective in this section is radial deformation. Eq. 4 shows the optimization target function.

$$Residual=\sum_{i=1}^{N}\left(u_{r(i)}^{PFRC}-u_{r(i)}^{piezo}\right)^2 \tag{4}$$

where, N is the number of points. Moreover, equivalent modeling has been done for S=5. In order to apply a constraint, a stress should be obtained as the yield stress of the whole structure. After finding structure effective yield stress, this stress is compared by Von Misses stress. For training neural networks, training samples are used. Eventually, piezoelectric fiber volume fraction is obtained 20.48 %. Figure 3 shows the comparison of radial displacement for two panels.

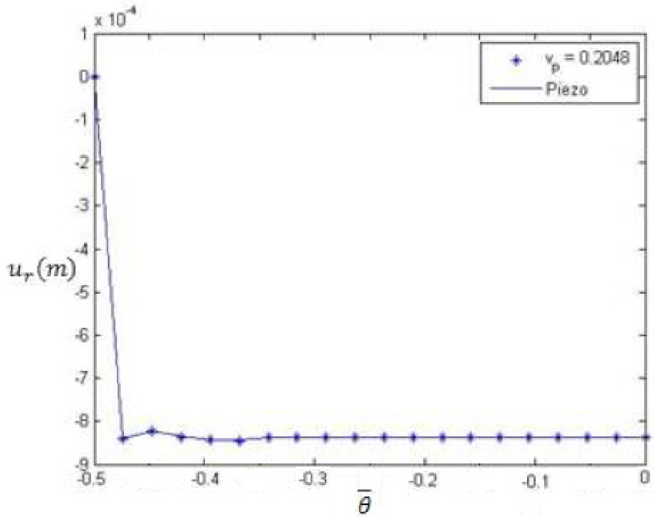

Figure 3. Comparison of panels with piezoelectric layers and with PFRC layers: radial displacement distribution along the circumferential direction

This analysis can be carried out for various boundary conditions. Obtained volume fractions for three types of boundary conditions are given in Table 1. S, C and F are related to simply supported, clamped and free boundary conditions respectively.

Table 1. Comparison of various types of boundary conditions

Boundary condition type	v_p (%)
SSSS	20.48
CCFF	55.43
CCCC	71.20

4- Conclusions

Some important results of this investigation are outlined as follows

- Although PFRC layers have been designed for approaching deformation distribution in the outer surface of the actuator in two panels, radial deformation distributions are almost similar over the whole thickness in the two panels.

- Using artificial neural networks has advantage of low error precision as well as efficient period of processing.
- With suitable design of PFRC layers in very low volume fractions (under 50%), one can achieve piezoelectric response.

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