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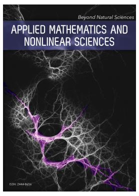

Applied Mathematics and Nonlinear Sciences

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Optimal position of piezoelectric actuators for active vibration reduction of beams

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Submission Info

Communicated by Hacı Mehmet Baskonus
Received April 25th 2019
Accepted May 29th 2019
Available online March 31st 2020

Abstract

This paper investigates the optimal placement of piezoelectric actuators for the active vibration attenuation of beams. The governing equation of the beam is achieved by coupled first order shear deformation theory with two node element. The velocity feedback controller is designed and used to calculate the feedback gain and then apply to the beam. In order to search for the optimal placement of the piezoelectric actuators, a new optimization criterion is considered based on the use of genetic algorithm to reduce the displacement output of the beam. The proposed optimization technique has been tested for two boundary conditions configurations; clamped -free and clamped-clamped beam. Numerical examples have been provided to analyze the effectiveness of the proposed technic.

Keywords: piezoelectric; optimization; genetic algorithm; active vibration control.
AMS 2010 codes: 35J05

1 Introduction

In the last few decades, piezoelectric materials have been grossly used in various industrial sectors due to their great ability of converting energy [1–3]. One of the main sectors that used the piezoelectric materials is the active vibration control. Such technic aims to reduce structures vibration by measuring the output displacement and accordingly a result gain calculated using control algorithms and introduce into the structures by means piezoelectric actuators [4]. The mathematical modeling of the active vibration control of different type of structures has been largely investigated. Theoretical and finite element models have been introduced by the research community. [5] proposed an analytical model based on Kirchhoff-Love thin shell theory to model an intelligent shell with piezoelectric sensor and actuator distribution. [6, 7] introduced a new electromechanical model for plate with piezoelectric layers based on higher order shear deformation theory with the use of finite element method. More studies are provided by the research in the literature reader can refer to [8–12].

However, the miss placement of the piezoelectric patches can significantly reduce the performance of control mechanism and lead to a lack of observability and controllability. Therefore, finding the optimal position of the piezoelectric patches is a main point to increase the system efficiency. A large amount of research papers has been conducted to investigate the issue of optimal location and different cost functions are presented in the literature. [13] used genetic algorithm with two modified optimization criteria based on the minization of the actuators input energy to find the suitable placement, orientation and size of the distributed actuators and sensors. [14] proposed criteria based on the maximizing the controllability gramian. The authors used Ansys for the determination of the required parameters and by mean genetic algorithm the optimization was implemented. [15] introduced a new fitness based on variations in the average closed loop dB gain margin reduction for the determination of the optimal location and numbers of discreet piezoelectric patches. Several approached and optimization technics can be also found in [12, 16–21].

In the present paper a simple fitness function has been proposed based on the minimizing of the displacement output. The fitness function was optimized using a genetic algorithm code special implemented by the authors using an improve crossover and mutation process. The velocity feedback controller is applied to analyze the effectiveness of the proposed technic. Low velocity feedback controller has been implemented using newmark schema to analyze the effectiveness and the performance of the proposed technic.

2 Theoretical

Considering a beam with surface bounded piezoelectric patches. The coupling relationship between the electrical and mechanical behavior of the smart piezoelectric beam [4, 22] can be described as:

$$\begin{Bmatrix} \sigma_{xx} \\ \tau_{xz} \\ D_z \end{Bmatrix} = \begin{bmatrix} Q_{11} & 0 & -e_{31} \\ 0 & Q_{55} & 0 \\ e_{31} & 0 & \in_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_{xx} \\ \gamma_{xz} \\ E_z \end{pmatrix} \tag{1}$$

The dynamic equations of the smart beam can be derived by using Hamilton's principle:

$$\delta \int_{t_1}^{t_2} (\pounds - w_e) dt = 0 \tag{2}$$

Based on the Timoshenko's beam theory, and using Hamilton's principle with two node beam element the governing mechanical equation of motion of the smart beam can be written as (see [22]):

$$[M^e]\{\ddot{\forall}\} + [K^e]\{\forall\} = \{f_{mec}{}^e\} + \{f_{ele}{}^e\} \tag{3}$$

where $[M^e]$ represents the element mass matrix corresponding to the vector of mechanical displacement. $[f_{mec}{}^e]$ and $[f_{ele}{}^e]$ represent the externel mechanical and electric forces. and $[K^e]$ the stiffness matrix which given by:

$$[K^e] = [K^e_{uu}] + [K^e_{uv}][K^e_{vv}][K^e_{vu}]$$

The matrices $[K^e_{vv}]$ *and* $[K^e_{vu}]$ are piezoelectric permittivity and electromechanical coupling matrices.

In the present investigation we proposed the velocity feedback algorithm to be used for the active vibration control. In order to couple the input voltage with the output displacement of the beam the following schema is implanted:

$$V_a = G_v \dot{u} \tag{4}$$

3 Optimization

The objective here is to find actuators locations that ensure the effectiveness to the active vibration control with low input cost, in this regards we chose a the difference of amplitude in different time increment as a fitness function as shown:

$$J = min(x(t) - x(t+dt)) \tag{5}$$

In order to minimize the cost function, the genetic algorithms (GA) is used [23,24]. The GA is global probabilistic search algorithm inspired by Darwinian principle of natural selection. The flowchart of the optimization procedure conducted by the GA is presented in Figure 1. The developed GA is founded on five main process; population, selection crossover and mutation. First the beam is discretized in 12 elements; each element is a possible position of piezoelectric actuator. The population is containing 12 chromosomes. The chromosome contains gen as much as the number of actuators. It must be noted that is, crossover and mutation, specially designed by the authors for the problem under investigation.

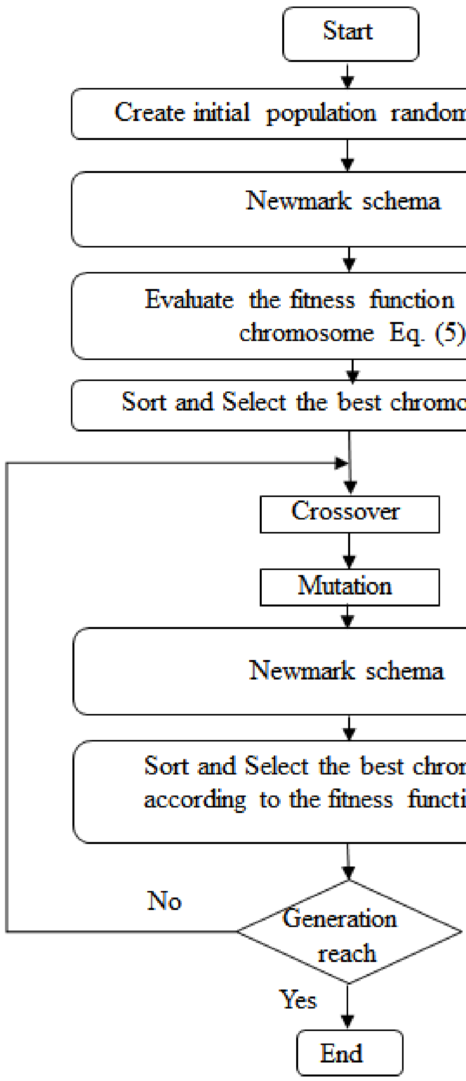

Fig. 1 Flowchart of the genetic algorithm used in the placement strategy.

The GA starts by selecting the best chromosomes and ranked them based on their fitness function to use them in the crossover process. Then, the crossover is implemented and filtered to avoid the repeated gen. Finally one mutation gen is applied at each Childs coupled. The whole process is depicted in Figure 2.

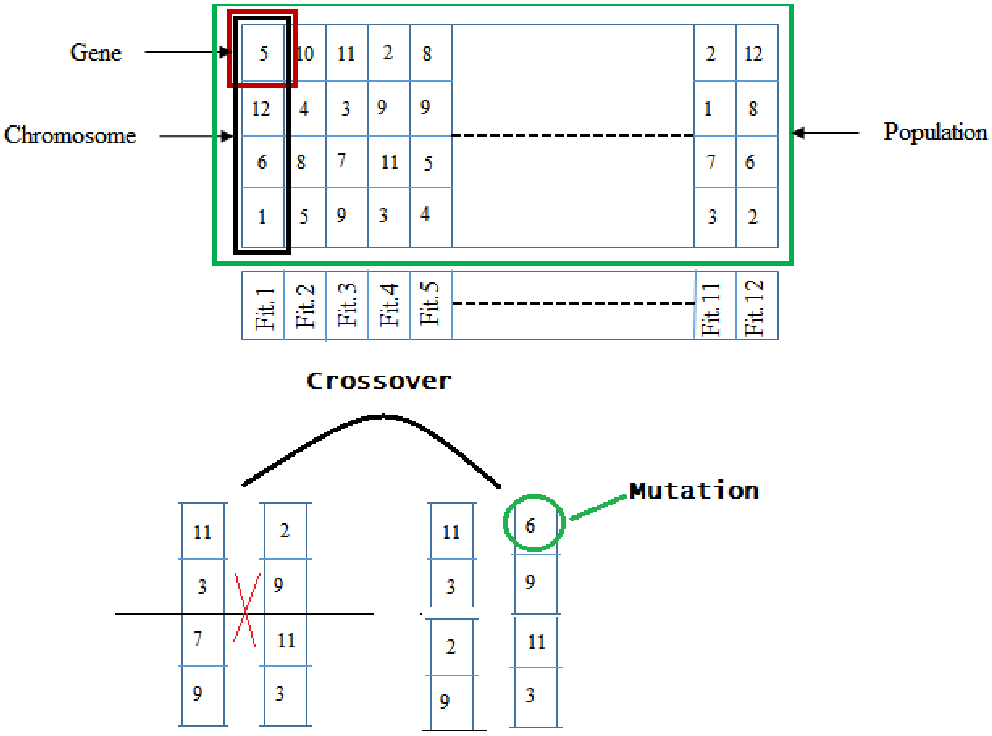

Fig. 2 Genetic algorithm coding process.

4 Results and Discussion

To analyze the accuracy of the present methodology, a composite beam dimensioned 500*x*40*x*10 mm with four surface bounded piezoelectric actuators has been considered. The material properties of the structures under consideration are presented in Table 1.

Table 1 Material proprieties

Proprieties	T300/976 [25]	PZT G-1195
Young's modulus E (N/m2)	150 × 109	63×109
Poisson's ratio	0.3	0.3
Shear modulus G	7.1×109	24.2×109
Density ρ (kgm-3)	1600	7600
Piezoelectric constant e_{31} (cm-2)	-	17.584
Dielectric constant $\in_{33}$ (Fm-2)	-	15.0×10-9

The beam is discretized into 12 elements from the left to the right as shown in Figure 3. A GA code as described in the previous section is implemented to find the optimal location of the piezoelectric actuators; two cases of beam boundary conditions have been analyzed clamped-free and clamped-clamped. The progressive convergence of the piezoelectric actuators location onto an optimal solution is depicted in Figure 3, in which the red points present the best contribution of one piezoelectric actuator for each generation, it's clear from the Fig that concentration of the piezoelectric possible location is find to be in the optimal location that's due to the fact that GA select the best individuals to be used in the next generation.

As explained in the previous section each possible configuration is represented by their fitness function, the convergence of the fitness function for the case of clamped-free beam is shown in Figure 4. For the case of

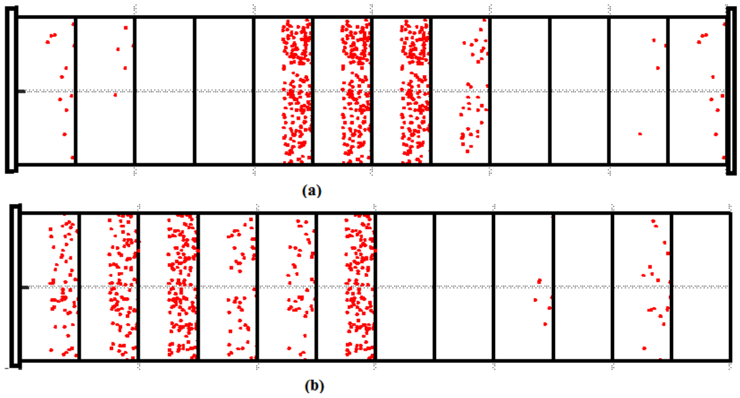

Fig. 3 Optimal distribution for both CC and CF boundary conditions for each generation.

Table 2 Optimal configuration of the piezoelectric actuators

Configuration	fitness	position
CF	9.088e-05	[1,2,3,6]
CC	3.925e-05	[4,5,6,7]

clamped-clamed beam the convergence of the fitness function is presented in Figure 5. It can be seen from both figures that the value of fitness function of the CF beam is much larger than the CC beam which is quite normal since the displacement of the CF is bigger.

In order to investigate the active vibration control of the present structures. The smart beam considering the optimal placement of the piezoelectric actuators has been subjected to an initial displacement of 0.008 mm. As a first case, a clamped-free beam is considered; the time history of the beam displacement is shown in Figure 6 while the second case clamped-free beam is presented in Figure 7. Two low velocity feedback gains for each case have been used. The Figs are clearly shown that the proposed controller is reduce efficiently the vibration of the beam in matter of amplitude and settling time.

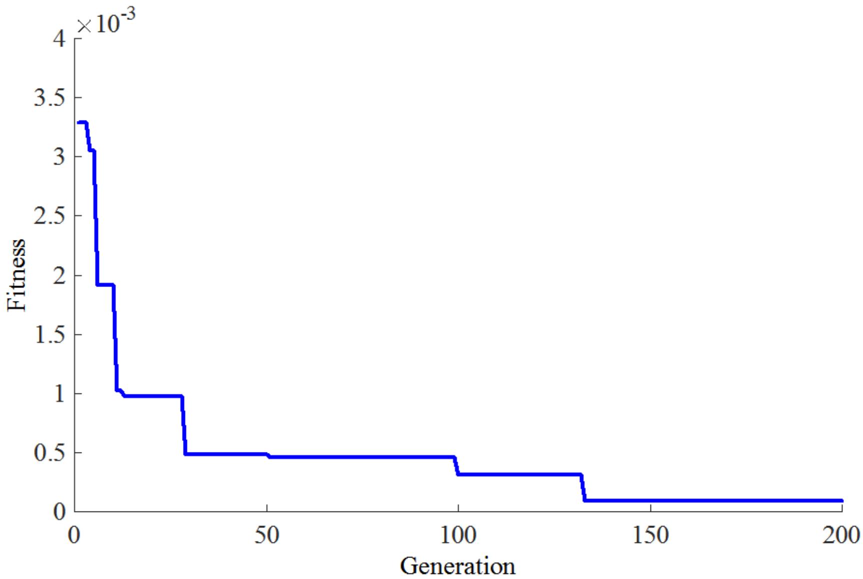

Fig. 4 Variation of fitness index with generation for the clamped-free beam

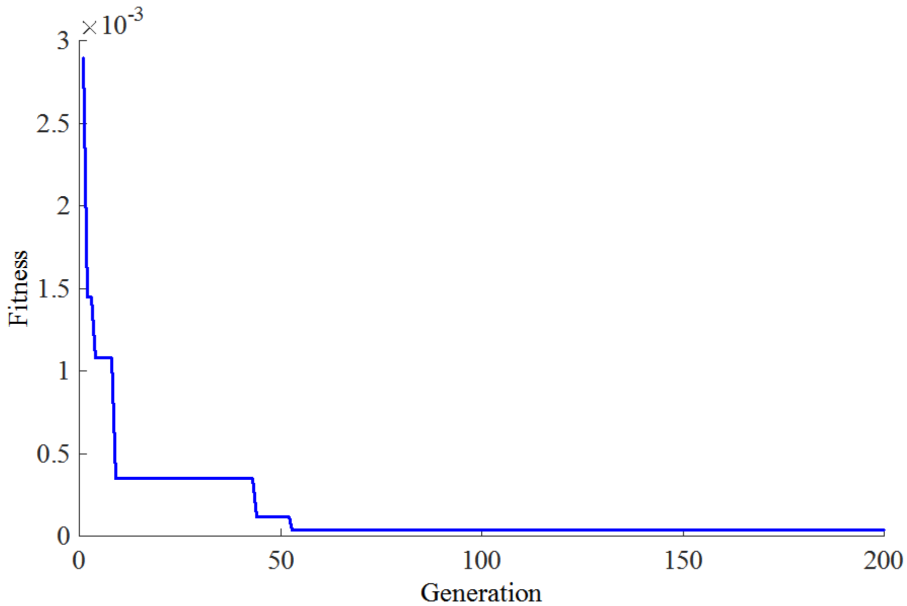

Fig. 5 Variation of fitness index with generation for the clamped-clamped beam

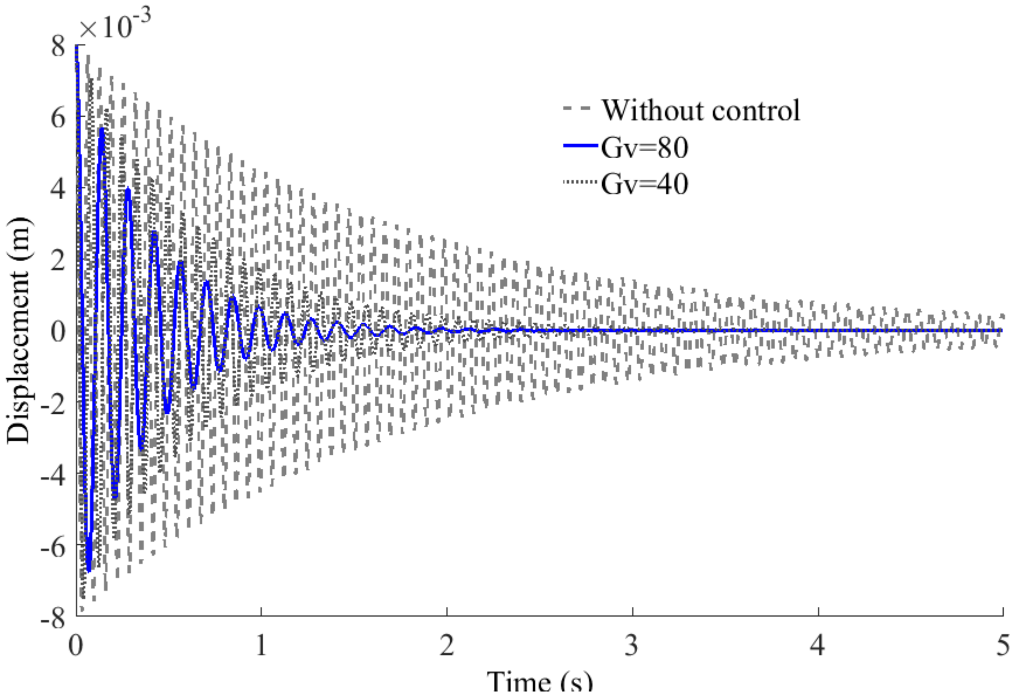

Fig. 6 Tip deflection of clamped-free beam with and without control

5 Conclusions

This work conducts to the active vibration control with optimally placement piezoelectric actuators. A FEM model of a composite beam with four piezoelectric actuators is developed base on the shear deformation theory. The minimizations of output displacements have been used as a fitness function to optimally place the piezo-electric actuators through a GA optimization technic. A low velocity feedback controller is implemented using newmark integration schema to actively reduce the beam vibrations. Two cases of boundary conditions have

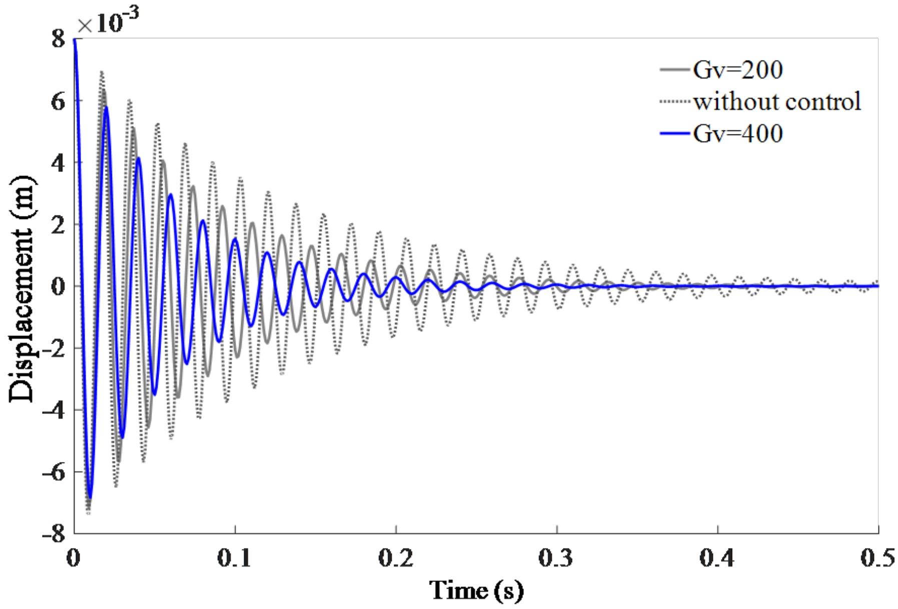

Fig. 7 Tip deflection of clamped-clamped beam with and without control

beam treated and different results were presented. The results show that significant reduction with minimum required actuation has been obtained thanks to the proposed methodology.

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