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Teaching Learning Based Optimization (TLBO) for Optimal Placement of Piezo-Patches

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Abstract

Active vibration control using piezopatches has been active field for the past few years. Various methods like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) etc. had been used for optimal placement of piezopatches to control vibration of a cantilever beam. In the present study an attempt is made to find optimal location for placement of both single and multiple (i.e. 5 patches) piezo-patches on the cantilever beam. An advanced optimization technique known as Teaching Learning Based Optimization (TLBO) algorithm is used. The objective function used in this study is based on the strain equation of the cantilever beam. It is found that both the advanced optimization techniques i.e. TLBO and GA has given the maximum strain value at the root of the cantilever beam for the first six modes in case of single patch. Also for multiple patches the optimal locations obtained by TLBO is almost the same as that obtained by GA.

Keywords: Advanced Optimization Technique, Active Vibration Control, Optimal Placement, Piezopatches, Teaching Learning Based Optimization (TLBO)

1. Introduction

In the past, many research work has been carried out in this field and the research is still going on to find the ultimate solution by which vibration can be actively dissipated in shorter span of time. In order to dissipate the vibration of cantilever beam in shorter span of time, it is necessary that the piezo patches are placed on such location where the maximum deformation or strain is produced. Position of actuator and sensor play a very important role in controlling the vibration in an effective way. Problems like lack of observability and controllability can arise when actuator and sensors are misplaced. Hence, this is one of the reason why lot of research has been carried out in this field.

The first researcher to work on this field[1]. In their study, they had derived the static and dynamic analytic model for segmented piezoelectric actuator. The model used in their study had the ability to predict the response of structural element to a command voltage applied to the patch which indirectly helped the author to find the optimal location of piezopatches. In[2] formulated an optimization problem for a general beam that has arbitrary boundary condition and can have as many piezo patches as desired. The optimization criterion is based on the modal cost and controllability index. The optimal size and location for beam with various boundary conditions are determined for single pair and for two pairs of actuator and then their performance is compared. Recent advances in optimization of smart structure and actuator was studied[3]. The objective of this paper is to give a glimpse of the work that has been done till today in the field of active vibration control. In[4] studied about the optimal position of actuator and sensor for the control of flexible structure[5] studied vibration control of beams with piezoelectric actuator and sensors by using Particle Swarm Optimization (PSO). In [6] studied piezoelectric material and has also given few examples where the piezoelectric can either be used as sensor or actuator. The author has further described on energy harvesting, structural health monitoring, etc[7]., In proposed a new technique for identifying and control of a piezoelectric patch actuator. This paper mainly focuses on determining the transfer function of a highly nonlinear and hysteretic piezoelectric actuator and its inverse by System Identification (SI) techniques. Optimal placement

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of piezoelectric patches for multimode active vibration control of beam structure by using genetic algorithm was studied[8]. The author has used genetic algorithm (GA) to find the optimal location of piezo-patches on the cantilever beam for both single as well as for multiple piezo-patches. The objective function used in this study is based on the maximum strain equation of the cantilever beam. There are many different optimization techniques that can be used. Some of the most significant optimization techniques are listed in table[9]. Teaching Learning Based Optimization algorithm for dealing with real parameter optimization problems was developed[10–13] and studied[14]. The authors had explained the working of TLBO and also given its advantages and disadvantag[15] studied the generation of alternative process plans using TLBO for machining operations, machining parameters (speed, feeds and depth of cuts), machine tools, setup, etc. The author then ended this paper with a conclusion that TLBO is one of the few algorithms that gives better results as compared to other algorithm. Application of TLBO was studied[16]. In this paper, TLBO was used to solve clustering problem type and the obtained results were comparable with other algorithm that was used in this study. In [17] studied high dimensional real parameter optimization with TLBO. The author had used TLBO to solve high dimensional function optimization problems and the results were then compared with other optimization techniques like PSO and Differential Evolution (DE).

In the earlier study GA is used to find the optimal location but in the present study a newly developed algorithm is used i.e. TLBO to find the optimal location of the piezo-patches. After obtaining the optimal location, both the results are compared to find the effectiveness of the new method in optimal placement of piezo-patches.

2. Methodology

The criterion, material properties and its parameter used for determining the optimal location of piezo-patches is kept the same as it was in the previous study but the algorithm to obtain the optimal location for single and multiple piezo-patches has been changed. The criterion is based on maximum strain location of the cantilever beam which is obtained by double differentiating the displacement eigen function which is given in equation (1).

$$Wn(x) = C_n\{[\cosh(\beta_n * x) - \cos(\beta_n * x)] - \alpha_n[\sinh(\beta_n * x) - \sin(\beta_n * x)]\} \quad (1)$$

where, $\alpha_n = \left[\dfrac{\cos(\beta_n * l) + \cosh(\beta_n * l)}{\sin(\beta_n * l) + \sinh(\beta_n * l)}\right]$; $C_n = \dfrac{1}{\sqrt{\rho AL}}$

After double differentiating the above equation (1), strain equation of the cantilever beam is obtained which is shown in equation (2).

$$W_n(x)'' = (C_n * \beta_n^2)\{[\cosh(\beta_n * x) + \cos(\beta_n * x)] - \alpha_n[\sinh(\beta_n * x) + \sin(\beta_n * x)]\} \quad (2)$$

where,

$$\alpha_n = \left[\frac{\cos(\beta_n * l) + \cosh(\beta_n * l)}{\sin(\beta_n * l) + \sinh(\beta_n * l)}\right]; \ C_n = \frac{1}{\sqrt{\rho AL}}$$

By using equation (1), first six modes of the cantilever beam can be plotted as shown in Figure 1.

By using equation (2), the strain shape of first six modes of the cantilever beam can be obtained which is shown in Figure 2.

The formulation of objective function is explained in brief in the next section.

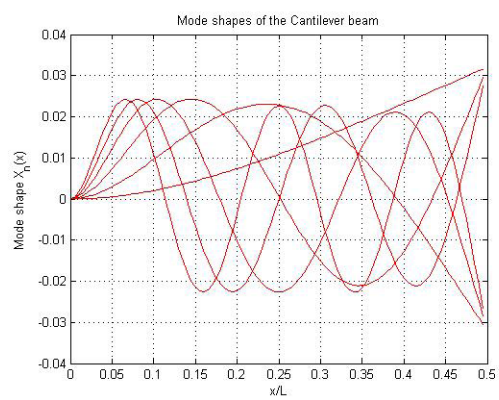

Figure 1. Mode shape of first six modes.

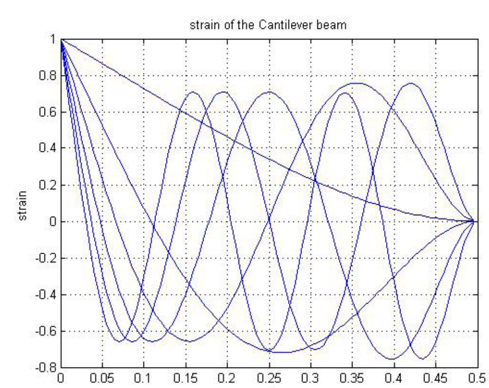

Figure 2. Strain shape of first six modes.

3. Formulation of Objective Function and its Constraint

In order to determine the optimal location for single and multiple piezo-patches on the cantilever beam, TLBO algorithm is used which is considered as one of the advanced optimization technique. It is a newly developed algorithm which is based on the concept of a classroom with n number of students and one teacher. In order to obtain the optimal location for both the cases by using TLBO, it is very important first to form the objective function. Since there are two cases in this present study, so the formulation of objective function is discussed in two corresponding cases given.

Case 1: Determining the optimal location for single patch.

In order to dissipate the vibration in shorter span of time it is very important to place the piezo-patch on that location where maximum strain of the cantilever beam is detected. And hence the objective for case I is to maximize the strain equation of the cantilever beam so that maximum strain location on the cantilever beam is obtained. The constraint for this case will only be the length of the beam, since it will be useless if the optimal location obtained is beyond the length of the beam. Hence the objective function and the constraints are

Maximize

$$W_n(x)'' = (C_n * \beta_n^2)\{[\cosh(\beta_n * x) + \cos(\beta_n * x)] - \alpha_n[\sinh(\beta_n * x) + \sin(\beta_n * x)]\} \quad (3)$$

where,

$$\alpha_n = \left[\frac{\cos(\beta_n * l) + \cosh(\beta_n * l)}{\sin(\beta_n * l) + \sinh(\beta_n * l)}\right] ; \; C_n = \frac{1}{\sqrt{\rho AL}}$$

Subject to: $0 \le x \le l$

Case 2: Determining the optimal location for multiple piezo-patches (i.e. 5 piezo-patches).

In extreme cases where the vibration has to be dissipated in real short time, one piezo-patch won't be sufficient to control the vibration. Increasing the input voltage of that piezoelectric patch also won't help, since there are some limitation while supplying the input voltage to the piezo-patches. And hence to overcome this difficulty, case 2 has been considered. Now, the objective function of case 2 has been developed by assuming the present system to be a linear system, and also the maximum strain value of all the six modes are at the root of the cantilever beam and therefore adding all the six strain function of six modes algebraically, the objective function becomes,

Maximize

$$W_n'' = W_1'' + W_2'' + W_3'' + W_4'' + W_5'' + W_6'' \quad (4)$$

Where

$$W_1(x)'' = (C_1 * \beta_1^2)\{[\cosh(\beta_1 * x) + \cos(\beta_1 * x)] - \alpha_1[\sinh(\beta_1 * x) + \sin(\beta_1 * x)]\} \quad (5)$$

$$W_2(x)'' = (C_2 * \beta_2^2)\{[\cosh(\beta_2 * x) + \cos(\beta_2 * x)] - \alpha_2[\sinh(\beta_2 * x) + \sin(\beta_2 * x)]\} \quad (6)$$

Subject to:

$$1)\, 0 \le x \le l$$

$$2)\, loc2 - loc1 \ge 0.05$$

Now, in case 2 there are two constraints, first is the length of the beam and the second constraint is used to avoid overlapping of location of two piezo-patches on the beam. The optimal location is determined by TLBO algorithm which is discussed below in detail.

A. Teaching Learning Based Optimization (TLBO)

To solve the above two cases TLBO algorithm is used, unlike the previous study where the author had used GA to obtain the optimal location for the two cases. But before going ahead with the optimal location obtained by TLBO, a brief explanation of this algorithm is given.

TLBO is a population based method as it uses population (i.e. students) to reach the optimal solution (i.e. Teacher). It is divided into two parts i.e. "Teacher phase" and the "Learner's phase". In "Teacher phase" the student learns from the teacher and in the "Student phase" the student learns from other classmate. The job of the teacher is to increase the knowledge level of each and every student, so that the best student will act as the teacher in the next iteration. TLBO can be implemented by following the steps given:

1) Generate random population as per the population size and the constraints.
2) Calculate the mean of the population and also the corresponding value of f(x), so that the best solution (i.e. Teacher) can be identified for that particular iteration.
3) Teacher phase begins, where student 1 is selected to increase its knowledge level.

4) Student phase begins where the student 1 will be compared with other student and the best student will be kept.
5) Step 3 and Step 4 will continue till the teacher selects each and every student and increase their knowledge level.

A binary coded TLBO algorithm is generated by using above steps and the functions obtained in case 1 and case 2. The details of cantilever beam, piezo-patch selected for the present study and the optimal location obtained by TLBO algorithm for both the cases is discussed in the next section.

4. Numerical Results and Discussion

The properties and the parameters of beam used in this study was kept same as it was in the previous study [12], so that it would be easy to compare the performance of two different algorithm (GA & TLBO) and make a conclusion on it. The properties of the cantilever beam and the piezo-patch are given in Table 1.

Case 1: Optimal location for single patch by using TLBO
One of the advantage of using TLBO is, it doesn't require any controlling parameter unlike other algorithms like GA, PSO, DE and so on. The results obtained when TLBO was implemented with the objective function and its constraint for case I is shown in Table 2. It can be seen that the maximum strain value for each and every mode is at the root of the cantilever beam. Table 2 also gives the comparison between theoretical maximum strain value for each mode, the results obtained through GA for single patch and that obtained by using TLBO.

Table 1. Material properties and parameter of beam and piezo-patch

	L (m)	W (m)	T (m)	ρ kg / m^3	Young's Modulus (Pa)
Beam	0.5	0.03	0.002	7810	21e10
Patch	0.033	0.03	0.0005	7500	139e9

Table 2. Maximum strain location for each mode for single patch

Methods	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Theoretical	0	0	0	0	0	0
GA[8]	7.06E-5	0.000108	6.47E-5	0.00104	0.0015	0.00091
TLBO	8.5E-10	1.0E-6	1.4E-6	2.6E-7	7.5E-6	2.6E-6

Table 3. Optimal Location for five patches

Methods	Location 1	Location 2	Location 3	Location 4	Location 5
Theoretical	0	0.4250	0.0800	0.3360	0.1640
GA[8]	0.000009	0.4249	0.07983	0.3362	0.164
TLBO	0	0.4249	0.0798	0.3362	0.1640

From Table 2, it can be seen that both advanced optimization techniques (i.e. TLBO and GA) has given the maximum strain value at the root of the cantilever beam for the first six modes in case of single patch. Further, both this algorithm results are compared for the case of multiple patches.

Case 2: Optimal location obtained for multiple patch by using TLBO.
As mentioned earlier, the objective function of case 2 has been formed by adding algebraically all the strain equation of first six modes. It should be noted that it's a single variable problem and so TLBO will give only one best solution. In order to overcome this difficulty, TLBO was executed in parts over the entire length of the beam. When TLBO was executed first time, it gave the first maximum strain value at the root of the cantilever beam. Now to find the next maximum strain value, TLBO is executed over that length of the beam which is left after occupying the first location and some intermediate distance in order to avoid overlapping of piezo-patches i.e. (patch size + intermediate distance = 0.05). In a similar manner, the next maximum strain value of the beams is determined. The maximum strain value obtained by theoretical method, GA and by using TLBO for five patches is given in Table 3.

From Table 3, it can be seen that both advanced optimization techniques (i.e. TLBO and GA) has given almost the same optimal location for the five piezo-patches.

5. Conclusion

In the present study, one of the latest optimization technique was used (i.e. TLBO) to find the optimal location of both single and multiple patches which has already been found by using GA. So that a comparison as well a conclusion can be made on the performance of this two advanced optimization techniques. By comparing the result, it can be clearly seen that the optimal location obtained through TLBO as well as GA for single patch is at the root of the cantilever beam. Even in case of multiple patches, the optimal location obtained by both this technique is almost the same. And hence it can be said that even algorithm like TLBO can be used to solve such type of problems. TLBO can be further explored in the field of Vibration and Vibration Control and Measurement.

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