International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 12, December-2013, pp: (100-106), Available online at: www.erpublications.com

Vibration control of a Plate with help of Fuzzy Logic Controller

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Abstract: The purpose of this work is to control the vibration of the plate with the help of fuzzy logic controller. A finite element model of a two-dimensional plate instrumented with a piezoelectric patches sensor-actuator pair is derived. As mesh size (8x8) is found best for the future modeling and analysis of the plate has been taken. The contribution of piezoelectric sensor and actuator layers on the mass and stiffness of the plate is considered. Fuzzy logic optimal control scheme have been designed to study the control effectiveness. Tip displacement and tip velocity are taken as the inputs and the control forces are taken as the output to tune the fuzzy logic controller. The fuzzy logic controller consists of nine rules. It is observed that fuzzy logic controller is found suitable and give effective control to suppress the first three modes of vibration of plate.

Keywords: Fuzzy logic Controller, Smart structure, Finite element model, Active vibration control, Plate.

1. Introduction

In the past era, the heavy machineries and structures are used. But due to their complicated construction, heavy cost and excess uses of the material; the heavy weight machineries and structures are replaced with light weight. The development of high strength to weight ratio of mechanical structures are attracting engineers to build light weight aerospace structures to combine loading capacity and fuel consumption, as well as to build tall buildings and long bridges. However, the flexible light weight structures lead to more complicated vibration problems. Traditionally, vibrations have been controlled using passive techniques. Passive vibration reduction is achieved by adding mass damping and stiffness unsuitable locations on a structure to reduce vibrations. However these techniques lead to increased structure weight and low response. So, the mechanical vibrations induced in light weight aerospace and large-scale flexible structures have attracted engineers to investigate and develop materials to suppress these vibrations.

Varun Kumar and Deepak Chhabra[1] gave a new method of design of fuzzy logic controller for active vibration control of cantilever plate with piezo -patches as sensor /actuator. Kapil Narwal and Deepak Chhabra [2] presented the research at the active vibration control of a flexible structures using piezoelectric material. A simple supported plate structure, which is supported at two opposite ends, is taken as the flexible structure with piezoelectric materials as sensors and actuators. Pardeep Singh and Deepak Chhabra [3] studied the active vibration control of a square cantilever plate with piezo- patch as sensor and actuator bonded on top and bottom surfaces of the plate. The problem is formulated using the finite element method (FEM) by considering square elements with four nodes at its corner and each node is having three degree of freedom.
Different control techniques have been used in the control of flexible structure. M. k. kwak and D. sciulli [4] studied the fuzzy logic based vibration suppression control of active structures equipped with piezoelectric sensors and actuators. Maguid H. M. Hassan [5] introduced the basic forms of smart systems in which the structural system's performance is enhanced by the presence of a closed loop feedback controller that employs observed data, about the system's responses,in evaluating and applying corrective actions in order to improve its performance. Manu Sharma [6] introduced a control law for controlling the vibrations of a cantilevered beam is established using fuzzy logic based independent modal space control and fuzzy logic based modified independent modal space control. H Gu andG Song [7] used Positive position feedback (PPF) control in active vibration control of flexible structures. They used a fuzzy gain tuner is proposed to tune the gain in the positive position feedback control to reduce the initial overshoot while still maintaining quick vibration suppression. Sharma M. [8] presented fuzzy logic based independent modal space control (IMSC) and fuzzy logic based modified independent modal space control (MIMSC) of vibration of a plate. Jing-jun Wei et al. [9] solved the vibration problem using fuzzy logic control laws with different membership function groups are adopted to suppress vibrations of a flexible smart manipulator using collocated piezoelectric sensor/actuator pair and dual-mode controllers combining fuzzy logic and proportional integral control are designed, for suppressing the lower amplitude vibration near the equilibrium point

significantly with help of an experiment. A. Hossain Nezhad Shirazi et al. [10] have been investigated the active vibration control of a simply supported rectangular plate made from functionally graded materials (FGM) with fuzzy logic control (FLC) and compared to the results obtained with the application of PID control. Nemanja Zorić et al. [11] presented the optimized fuzzy logic controller (FLC) with on-line tuning of scaling factors for vibration control of thin-walled composite beams. Abdollah Homaifar et al. [12] studied the methods for achieving active damping on plate structures by use of discrete point piezoelectric sensors and actuators (PZTs). Deepak Chhabra et al. [13] studied the Active Vibration control of beam like structures with distributed piezoelectric actuator and sensor layers bonded on top and bottom surfaces of the beam. Gustavo Luiz C.M. de Abreu and José F. Ribeiro [14] designed an on-line self-organizing fuzzy logic controller (FLC) design applied to the control of vibrations in flexible structures containing distributed piezoelectric actuator patches. J. Lin [15] described how to control actively the vibrations of smart structures by using a decomposed parallel fuzzy control approach. J. Lin et al. [16] presented a novel resonant fuzzy logic controller (FLC) to minimize structural vibration using collocated piezoelectric actuator/sensor pairs. Yaxi Shen et al. [17] designed the multivariable feedback controller fo a a two degrees of freedom model has been constructed for a structural dynamic system consisting of a linear elastic plate bonded with piezoelectric sensors and actuators. Jingjun Zhang et al. [18] studied the active vibration of piezoelectric smart structures, the piezoelectric materials always show nonlinear characteristic, so this paper uses the fuzzy logic to control the smart structures vibration.

2. Methodology

2.1 Properties of The Plate

We considered A plate with a prescribed material and dimensions. The plate is divided into 64 elements (8*8) . The plate possessed the 81 nodes. The plate possess 81 nodes and each node possess 3 degree of freedom (DOF) as shown in fig. 1. So the total degree of freedom becomes 81*3=243 DOF.

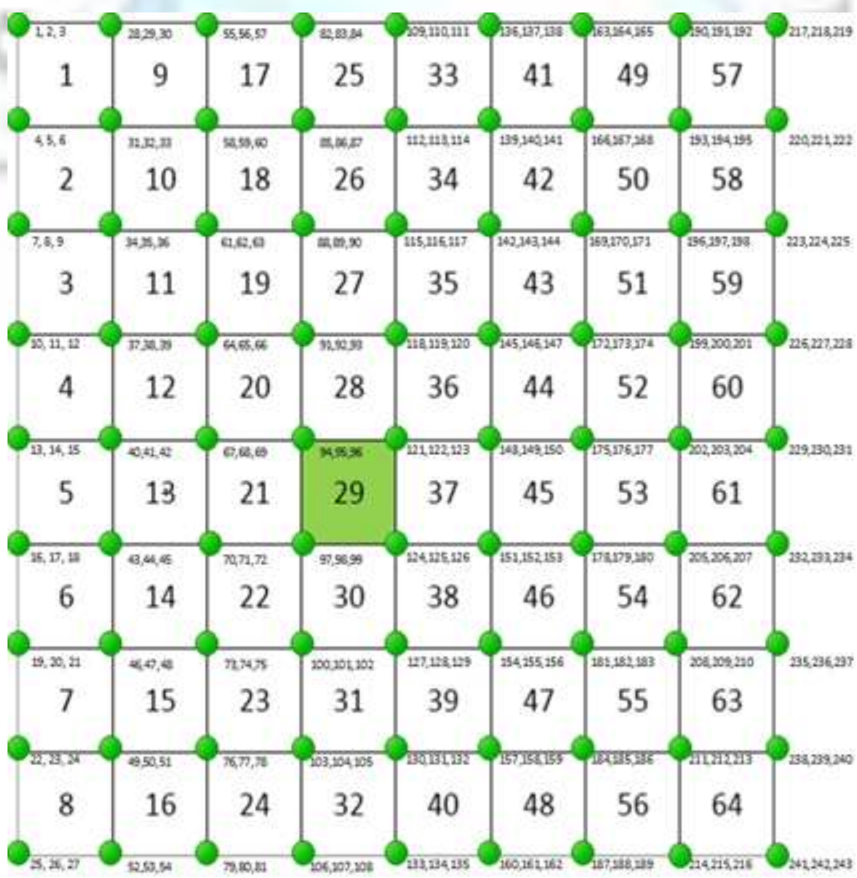

Fig.1: Plate with 64 elements and 243 deegre of freedoms.

The plate properties are shown in table 1. and the piezo-patches properties are shown in table 2.

TABLE 1: Material properties and dimensions for plate

Parameter	Plate
Length (L)	160/1000 M
Breadth (B)	160/1000 M
Height (H)	0.6/1000 M
Density (rho)	7800 Kg./M3
Modulus of Elastisity (E)	207 Gpa
Modulus of Rigidity (v)	0.3 Gpa

TABLE 2: Material Properties and dimensions of Piezo-Patch

Parameter	Piezo-Patch
Length (L)	0.02 M
Breadth (B)	0.02 M
Height (H)	1.06/1000 M
Density (rho)	7500 Kg./M3
Modulus of Elastisity (E)	63 Gpa
Modulus of Rigidity (v)	0.3 Gpa

2.2 FUZZY LOGIC CONTROLLER

The fuzzy logic controller is based on simple human reasoning. The design of fuzzy logic controller is simply based on three steps.

(i) Fuzzification
(ii) Rule base generation
(iii) Defuzzification

(i) Fuzzification

First of all input and output variables for the fuzzy controller are selected. Then the designer has to give the input and output in a suitable range. The range for input variables may be selected by observing the data for input variables, for a considerable length of time. The range for output variables may be selected by looking at specifications which guarantee the safety of the actuator. Fuzzy sets are then constructed over all input variables and output variables.

In the proposed fuzzy controller, the input is the displacement and velocity of the plate taken. The range for both the inputs displacement and velocity is taken from 0 to 200. Nine Triangular membership functions are taken to fuzzify for both displacement and velocity. The range of the output depends on the suitable length of the value of “k” which depend on control force required.

The inputs membership functions are shown in fig 2 and fig 3.

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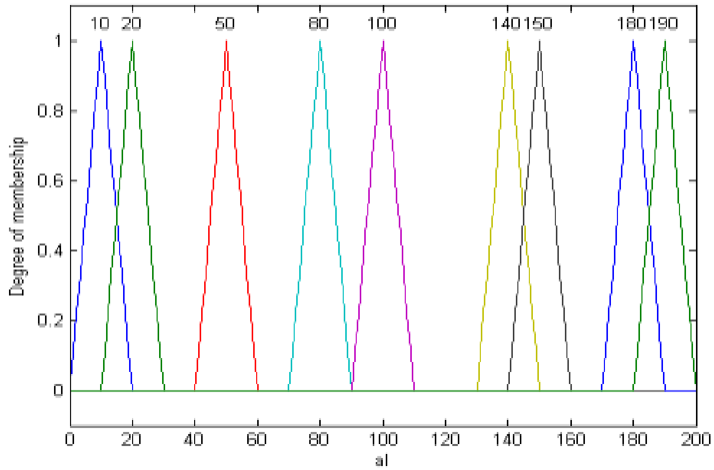

Fig. 2: Membership function of tip displacement

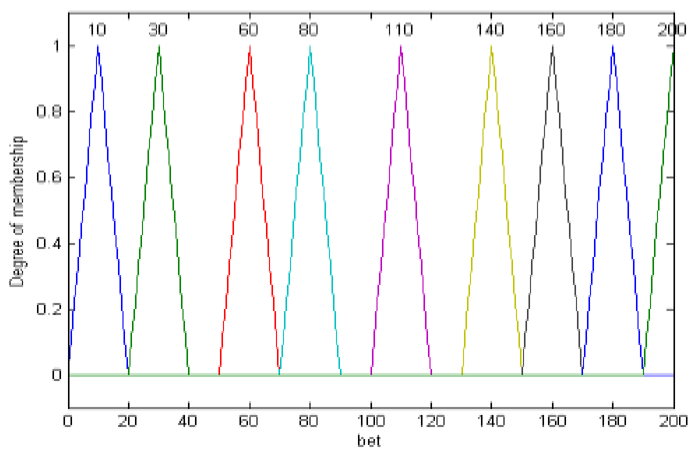

Fig 3: Membership function of tip velocity

(ii) Rule base generation

The rules are designed based on human reasoning. Here the value of two inputs and six outputs are taken to design the fuzzy logic controller. The two inputs are "al" and "bet" which are Tip displacement and tip velocity respectively. The six output are taken as "k1, k2, k3, k4, k5, k6". Nine membership function have been taken for two inputs and six outputs. Now the rule list are generated for two inputs and six outputs by taking "if - then formula."
The rule list is such types as shown in table3.

Table3. Numeric value of two inputs as "al" and "bet" and six outputs "k1, k2, k3, k4, k5 and k6"

Sr. no.	al	bet	K1	K2	K3	K4	K5	K6
1	10	10	0.0202	-3.8604	-1.73	-1.1106	24.7465	-1205.5
2	20	30	0.1363	25.9611	11.6353	-3.33	74.1474	-2705.9
3	50	60	0.43	-81.98	-36.74	-6.66	148.02	-4280.5
4	80	80	0.69	-130.82	-58.63	-8.88	197.11	-5129.4
5	100	110	1.1603	-218.15	-97.79	-12.21	270.54	-6232.6
6	140	140	1.70	-320.11	-143.49	-15.54	343.7	-7198.9
7	150	160	2.11	-395.30	-177.21	-17.76	392.32	-7788.2
8	180	180	2.55	-475.80	-213.30	-19.98	440.83	-8342.7
9	190	200	3.01	-561.27	-251.62	-22.20	489.22	-8868.0

The fuzzy logic controller is designed for active vibration control for a smart structures based on simple human reasoning. And we may show the reasoning for one rule as below:
If al is 10 and bet is 20, then the value of k1 is 0.0202,k2 is -3.8604,k3 is -1.73,k4 is -1.1106,k5 is 24.7465,k6 is -1205.5.

In this way, nine rules are made with help of table 1. The rules are designed with the help of MATLAB programming. The fig.4 shows the rule list for the value of al is 80 and bet is 80.

Fig 4: Rule viewer For the inputs al and bet 80and 80 respectively with fix output k1, k2, k3, k4, k5 and k6.

(iii) Defuzzification

In this step, depending upon the rules which get fired, a crisp value is obtained for the output variables. A centroid method is employed for defuzzification here. The centroid is given by the algebraic expression:

$$q_r = \frac{\int \mu(F_0) F_0 dF_0}{\int \mu(F_0) dF_0}$$

Where F_0 is the fuzzy variable and
$\mu(F_0)$ is the membership value of the fuzzy variable.

3. RESULTS AND DISCUSSIONS

Settling time for each patch placed in the 8X8 mesh under various control laws are as shown in the table4:

Table4. Settling Time at various position of piezoactuator/sensor at different tip displacement and velocity

Sr.No	Piezolocation	Input Displacement	Input Velocity	Settling Time
1	1	80	80	6.9
2	16	80	80	7.3
4	64	80	80	9
5	1	10	20	7.2
6	64	10	20	9
7	1	40	50	7.2
8	50	60	50	7.4
9	64	40	50	9
10	1	100	110	7.4
11	50	100	110	7.6
12	60	140	150	2.31

The Fuzzy Logic Controller is designed based on simple human reasoning. The Rule base of the controller consists of nine rules which have been taken as mentioned in Rule base Generation. Input to the controller consists of tip displacement and velocity of the structure and output of the controller is the force to be applied by the actuator. Fuzzy logic is used in such a way that voltage given to the actuator within breakdown voltage limits and provides stability to the system. The proposed fuzzy logic controller is tested for active vibration control of a plate to suppress first three modes of vibrations. A finite element model of 2D plate instrumented with a piezoelectric patches as sensor/actuator has been taken.. While controlling first three modes simultaneously with a single sensor/actuator pair, effective control is observed with present approach. The position of sensor/actuator has been varied 1 to 64 positions which are available on finite element plate. The value of tip displacement and tip velocity has also been varied from 0 to 200. Thus by varying the sensor/actuator location and value of tip displacement and velocity, we found out the minimum settling time using Fuzzy Logic Controller. Table4. shows the settling of tip vibration using Fuzzy Logic Controller at various locations and values of tip displacement and velocity. The settling time are calculated by changing various position of piezo-patches and both input displacement and velocity on MATLAB software. Some settling time fig. are attached in fig. 5, fig.6. The best time settling is obtained at 60th piezo-patches and tip displacement and tip velocity position is140 and 150 respectively.

Fig.5 shows the controlled and uncontrolled tip displacement, when the piezoelectric sensor/actuator is placed at 60th position and the value of tip displacement and velocity 140 and 150 respectively. Fig.6 shows the controlled and uncontrolled tip displacement, when the piezoelectric sensor/actuator is placed at 10th position and the value of tip displacement and velocity 140 and 150 respectively.

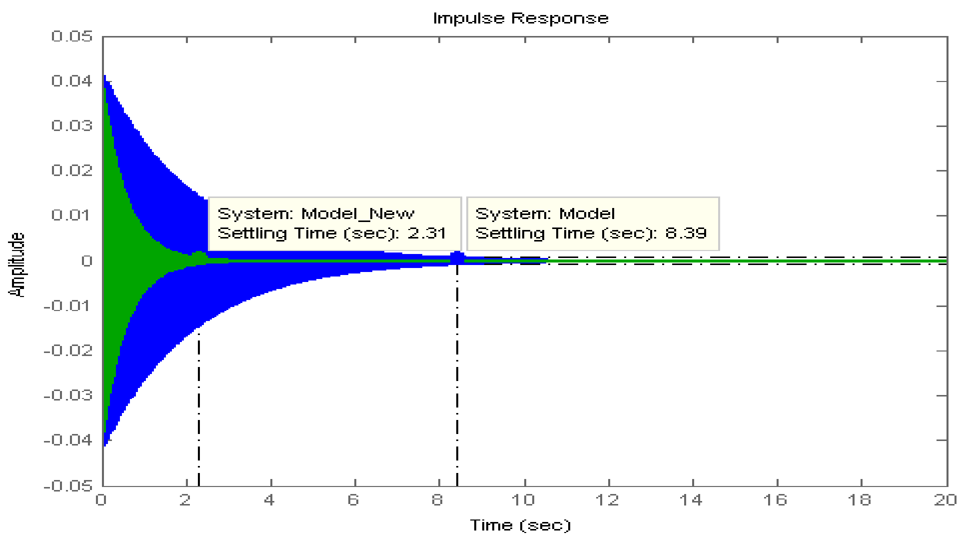

Fig 5: Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 60th position (al=140 and bet=150)

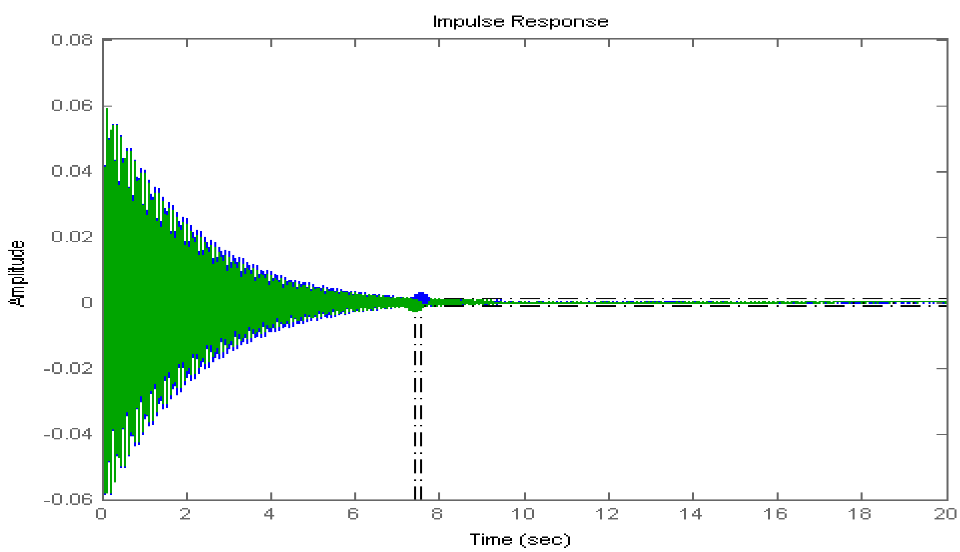

Fig 6: Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 10th position (al=140 and bet=150)

4. CONCLUSION

In this study, the Vibration control of a plate with help of fuzzy logic controller. The present scheme has the flexibility of designing the collocated and non-collocated system. The optimal location of sensor/actuator pair for a plate to suppress first three modes of vibrations and control effectiveness of fuzzy logic controller has been obtained.This work shows the basic techniques for analysis of active vibration control using piezoelectric sensor and actuators. The values of two inputs of the fuzzy logic controller are taken as tip displacement and tip velocity between 0 to 200. The best location of sensor/actuator pair is 60^{th} plate and the optimum value of tip displacement and velocity to get the minimum settling time are 140 and 150 respectively.

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