International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 12, December-2013, Impact Factor: 1.252, pp: (144-151), Available online at: www.erpublications.com

An Emerging Controlling Process of Vibration with help of Fuzzy Logic Controller for a Cantilever Plate

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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 cantilever plate instrumented with a piezoelectric patches sensor-actuator pair is derived. 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. Rule base of 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 cantilever plate. With the help of MATLAB simulation the frequency and peak gain values are obtained.

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

INTRODUCTION

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection.

Different control techniques have been used in the control of flexible structure. M. k. kwak and D. sciulli [1] studied the fuzzy logic based vibration suppression control of active structures equipped with piezoelectric sensors and actuators. Maguid H. M. Hassan [2] 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 [3] 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 [4] 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. [5] 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. [6] 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. [7] 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. [8] 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. [9] studied the methods for achieving active damping on plate structures by use of discrete point piezoelectric sensors and actuators (PZTs). Deepak Chhabra et al. [10] 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 [11] 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 [12] described how to control actively the vibrations of smart structures by using a decomposed parallel fuzzy control approach. J. Lin et al. [13] presented a novel resonant fuzzy logic controller (FLC) to minimize structural vibration using collocated piezoelectric actuator/sensor pairs. Yaxi Shen et al. [14] 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. [15] 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. Varun Kumar and Deepak Chhabra [16] gave a new method of design of fuzzy logic controller for active vibration control of cantilever plate with piezo -patches as sensor /actuator.

In this research paper we study the properties of the plate and properties of piezo actuator/sensor. This piezo actuator/sensor is mounted on the plate for obtaining the frequency and peak gain values at different positions. After the, properties of the plate, we studied the process of designing the fuzzy logic controller. Further the results and discussions is described for this work with help of MATLAB software on fuzzy logic toolbar. At last, the conclusion and future work given for new researchers.

Properties of the Plate

We considered the cantilever plate. The plate is divided into 64 elements (8*8) as shown in fig. 1. The plate possessed the 81 nodes. When the plate is without cantilever position the plate possess 81 nodes and each node possess 3 degree of freedom (DOF) as shown in fig. 2. So the total degree of freedom becomes 81*3=243 DOF. But when we considered the cantilever plate the first 9*3=27 DOF which attached cantilever edge becomes zero. So in case of cantilever plate the DOF considered is 243-27=216 DOF.

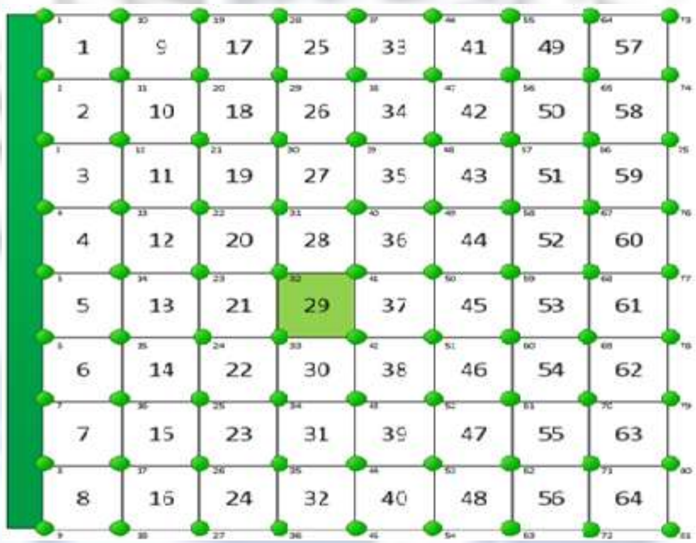

Fig. 1: Cantilever Plate with 64 elements and 81 Nodes

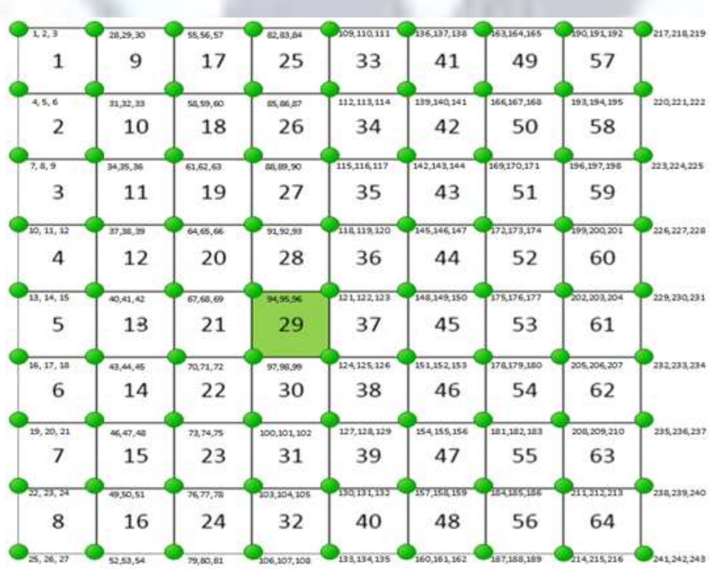

Fig. 2: Plate with 64 elements and 243 deegre of freedoms.

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The plate properties are shown in table1. and the piezo-patches properties are shown in table2.

TABLE 1: Material properties and dimensions for plate

Parameter	Plate
Length (L)	320/1000 M
Breadth (B)	320/1000 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

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.

1. 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.
The inputs membership function are shown in fig3and fig4.

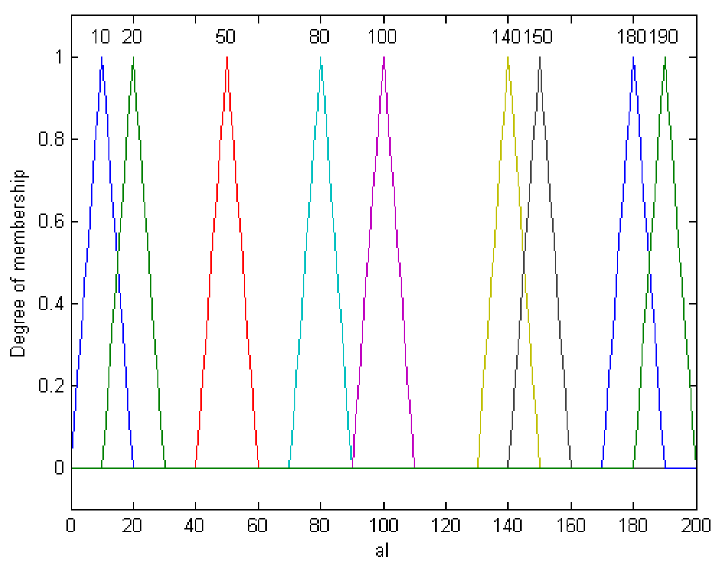

Fig 3: Membership function of tip displacement

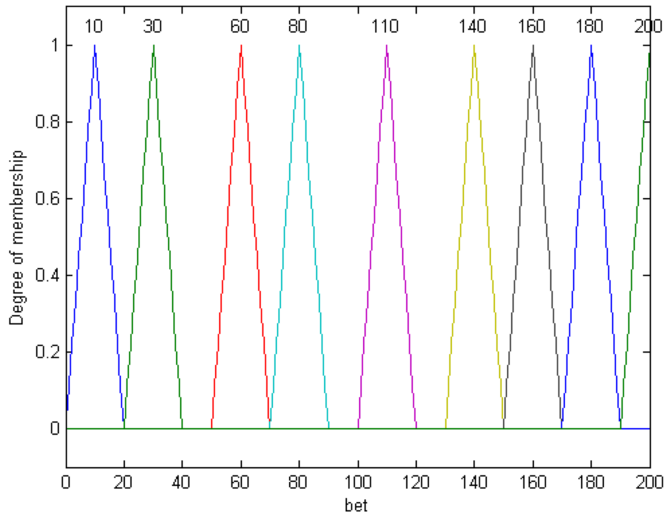

Fig 4: Membership function of tip velocity

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.

2. 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.

Table 3: 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	20	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 3. The rules are designed with the help of MATLAB programming. The fig.5 shows the rule list for the value of al is 80 and bet is 80.

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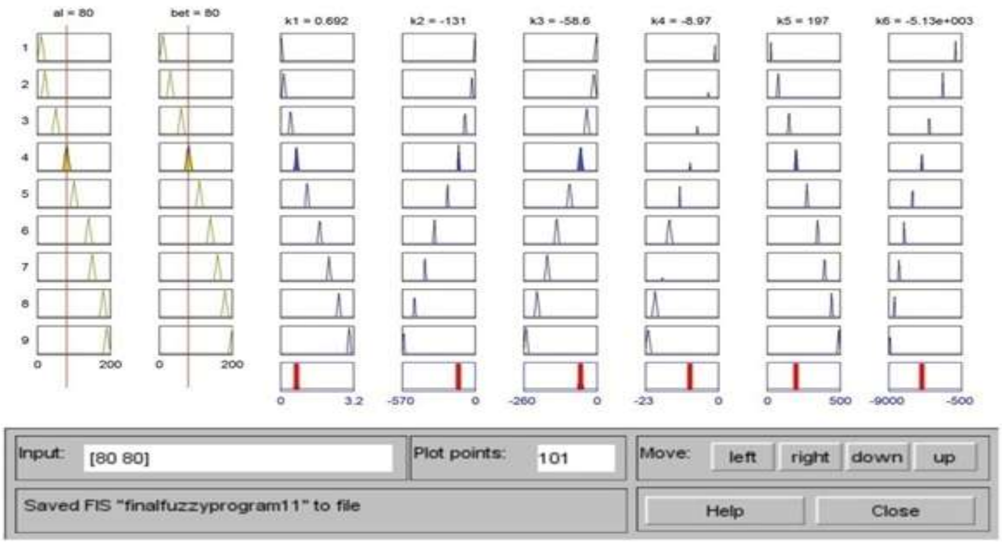

Fig. 5: Rule viewer For the inputs al and bet 80and 80 respectively with fix output k1, k2, k3, k4, k5 and k6.

3. 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.

RESULTS AND DISCUSSIONS

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

Table4. Peak Gain at various position of piezoactuator/sensor on Cantilever Plate

Sr.No	Piezolocation	Modal Frequency (rad/sec)	Modal Peak Gain	New Modal Frequency (rad/sec)	New Modal Peak Gain
1	1	824	1.14	145	-6.41
2	10	824	1.14	146	20.1
3	20	824	1.14	146	26.1
4	30	824	1.14	146	29.6
5	40	824	1.14	146	32.1
6	50	824	1.14	146	34
7	60	824	1.14	146	35.6
8	70	824	1.14	146	36.9
9	80	824	1.14	146	38.1
10	90	824	1.14	146	39.1
11	100	824	1.14	146	40
12	110	824	1.14	146	40.8
13	120	824	1.14	146	41.6
14	130	824	1.14	146	42.3
15	140	824	1.14	146	42.9
16	150	824	1.14	146	43.5
17	160	824	1.14	146	44.1
18	170	824	1.14	146	44.6
19	180	824	1.14	146	45.1
20	190	824	1.14	146	45.6
21	200	824	1.14	146	46

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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. 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 200 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 Peak Gain using Fuzzy Logic Controller. Table4. shows the Peak Gain of tip vibration using Fuzzy Logic Controller at various locations. The Peak Gain are calculated by changing various position of piezo-patches and both input displacement and velocity on MATLAB software. Some Peak Gain fig. are attached in fig. 6, fig.7, fig.8, fig.9 and fig.10. The best time Peak Gain is obtained at 1st piezo-patches, New Modal Frequency is 145rad/sec, New Modal Peak Gain is -6.41 shown in fig.6.

Fig 7. Shows the Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 10th position. Fig 8. Shows the Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 100th position. Fig 9. Shows the Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 150th position. Fig 10. Shows the Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 200th position.

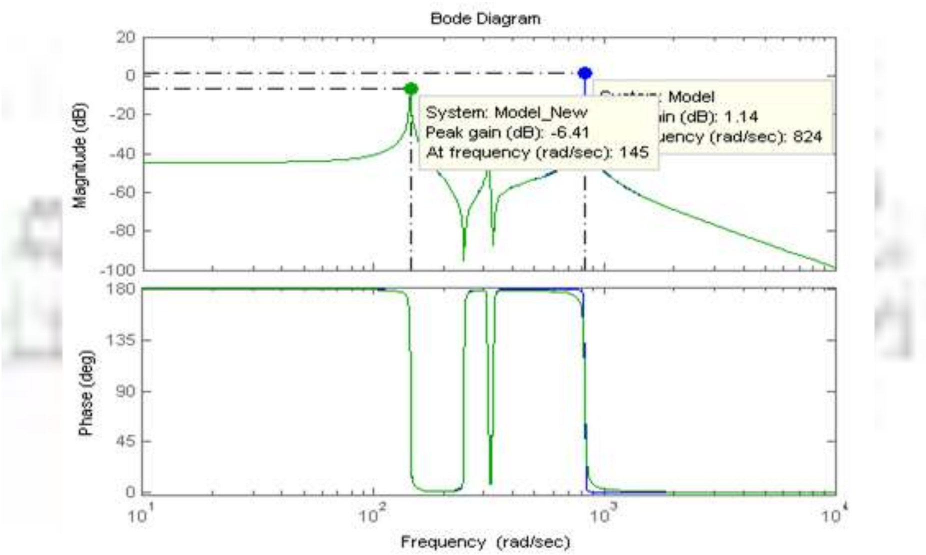

Fig 6: Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 1st position

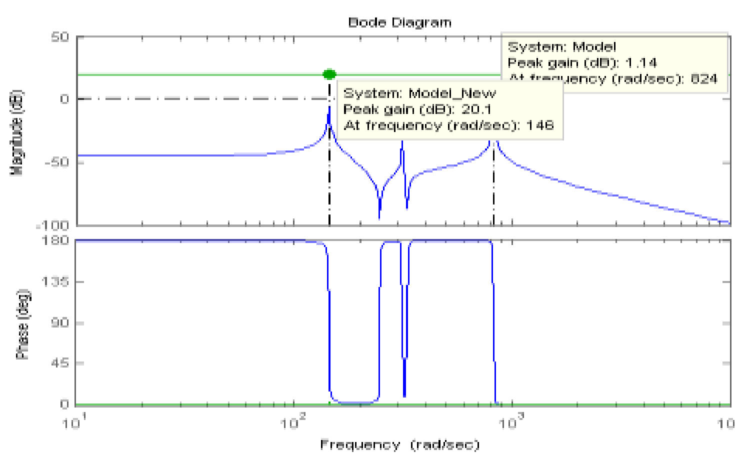

Fig. 7: Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 10th position.

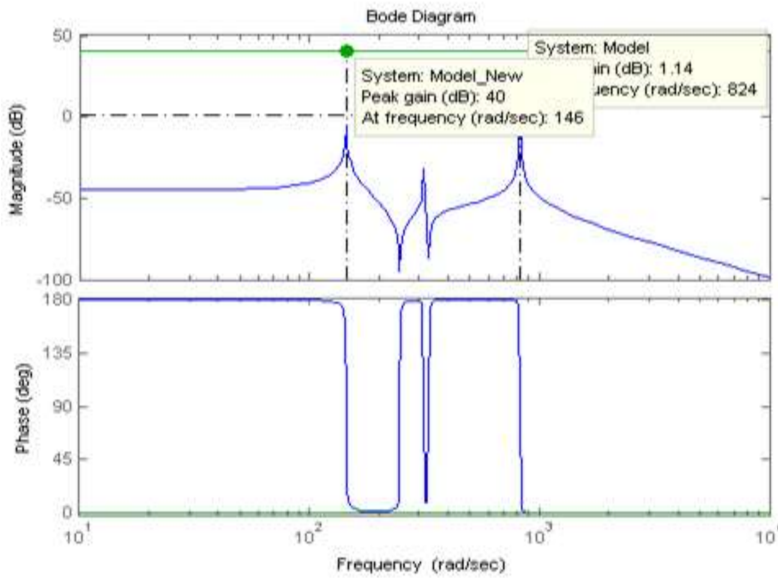

Fig. 8: Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 100th position.

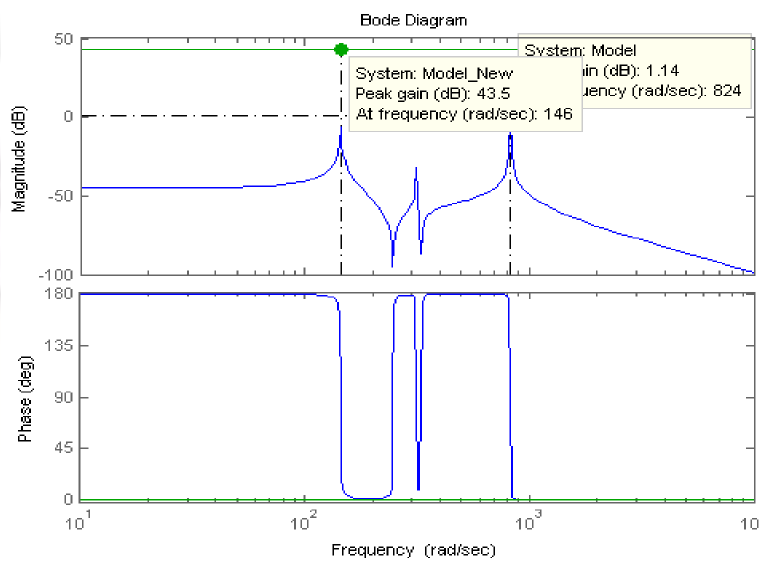

Fig 9: Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 150th position

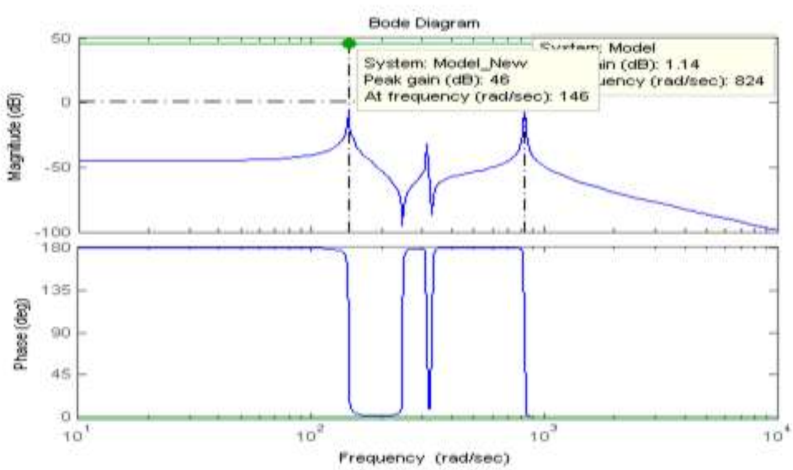

Fig. 10: Controlled and Uncontrolled frequency and peak gain When piezoactuator is placed at 200th position.

CONCLUSION

This work shows the basic techniques for analysis of active vibration control using piezoelectric sensor and actuators. A general scheme of analyzing and designing piezoelectric smart cantilever plate with fuzzy logic control is successfully developed in this study. The present scheme has the flexibility of designing the collocated and non-collocated system. The optimal location of sensor/actuator pair for a cantilever plate to suppress first three modes of vibrations and control effectiveness of fuzzy logic controller has been obtained. The values of two inputs of the fuzzy logic controller are taken as tip displacement and tip velocity between 0 to 200. The best time Peak Gain is obtained at 1st piezo-patches position where New Modal Frequency is 145rad/sec, New Modal Peak Gain is -6.41.

Future Scope

In future the develop design model can also be applied for the analysis of shell, cylinder any complicated shape. Active control of smart structures having complicated geometries can be analyzed with the procedure proposed. The new controller can be designed with help of fuzzy logic controller for example fuzzy and neural network combines a new controller named ANFIS.

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