ACTIVE VIBRATION CONTROL OF CANTILEVER PLATE WITH PIEZOELECTRIC PATCHES

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ABSTRACT

In this study, a fuzzy logic controller is used for active vibration control of smart cantilever plate. The smart cantilever plate is assembled with piezo-electric patches. The piezoelectric material used for patches is a smart material that act as an actuators/sensors. The finite element method (FEM) is used with this smart structure for effective vibration control. For this study we used the (10×10) size cantilever plate which is rectangular in shape. The plate is divided into small size of elements that have equal sizes and shapes.The design of FLC depended on simple human reasoning. MATLAB is used for simulation and analysis of results. From this research it is found that the basic methods of research and design of piezo-electric smart plate with FLC is successfully implemented and give sufficient active vibration control.

Keywords: Piezo-electic Patches, Active vibration control, Fuzzy logic controller (FLC), Smart Cantilever Plate.

1. INTRODUCTION

In past times, engineers used very heavy machineries and structures but these heavy machineries had high cost and complex construction, and heavy weight. So the light weight machineries were invented. The new invented light weight machineries are compatible for various engineer applications aerospace structure and to build the tall buildings and bridges because the flexible light weight structure solve the more complicated vibrations problems. Passive technique can use for vibration control but now a day active technique is more compatible for the control purpose. The piezoelectric material has been introduced as sensors and actuators to reduce the vibrations. The smart piezoelectric material has fast response, smaller mass, and very high accuracy. The branch of vibration engineering becomes more popular due to higher speed, compact and light weight designs and engineered materials. Thus we admit the need of reliable machines and equipment. The main focus in automobile and machineries are on vibration control and sound characteristics.

Many research works had been done on Active vibration control. Peter Dorato [1987] presented the research paper on a Historical Review of Robust Control. In this paper the history was given of the Robust Control system and described the application of the Robust Control. Variable-Structured Robust Controller for Servomotors also invented with the help of Fuzzy Logic [1]. Amin Suyitno, J. Fujikawa, H. Kobayashi, and Yasuhiko Dote [1993] proposed a variable-structured robust controller. The structure was constantly changed by fuzzy logic in such a way that the controller respond fastly if the error was large and to get a robust controller that was insensitive in both plant noise and the observation noise. Several delay-independent and delay-dependent were enough conditions which derived to certify the global asymptotical stability for the uncertain stochastic recurrent neural networks [2].Reza Shahnazi and Mohammad R. [2008] PI Adaptive Fuzzy Control with very high disturbance rejection for unknown Nonlinear Systems described by in their research paper [3]. PMayhan and G Washington [1998] other application of Fuzzy Model system is presented by this paper. This was the new control paradigm for smart structures with the help of Fuzzy system. This was the fuzzy-logic based vibration suppression controlled active structures [4]. M.k. kwakand D.SCIULLI[2004]presented vibration suppression control application of active structures which was based on the fuzzy logics. The controller also used piezoelectric sensors and actuators [5]. Sadri, Wynne and Wright [1999] studied robust active vibration control of plate-like structures. They also studied the theoretical modeling of the vibration of active structure including piezoelectric actuators. These actuators was represented by using the Rayleigh–Ritz method and used to design multi-variable controllers for a cantilever plate by two piezoelectric actuators which providing the controlled strain input and two non-collocated sensors providing the feedback signals [6]. Chen, Yang, Mou and Lu [2002] studied the quality based design approach for a single crystal silicon micro actuator with the help of response surface model and design of experiments [DOE] technique. He discussed the application of response surface model and DOE technique [7]. Anthony and Keane [2008] examined the robust design of lightweight space structure and used a genetic algorithm for this structure. He defined the optimization of a structure using genetic algorithms for which the robustness and performance of the structure also considered. In this paper one of genetic algorithm efficient method was used to estimate local variation about the current design point [8]. Q. Song, J. C. Spall and Y.C. Soh[2003]described robust neural network tracking controller. They assumed the difficulty for robust tracking controller design. They used the neural network in the closed-loop system to estimate the nonlinear system function. They introduced the conic sector theory for providing guaranteed bounded for both the input-output signals and the weights of the neural network. The neural network was trained by the simultaneous per-turbation stochastic approximation [SPSA] method. The suggested neural control system guaranteed the closed-loop stability and a good tracking performance [9]. YuandJinde Cao [2007] researched uncertain recurrent neural networks ofrobust control with time varying delay [10]. Chun-Fei Hsu [2007] studied Adaptive recurrent neural network control [ARNNC] and structure adaptation algorithm used for uncertain nonlinear systems. The ARNNC system was the combination of a neural controller and a robust controller. The neural controller was the principal controller used a self-structuring recurrent neural network (SRNN) and the robust controller was designed to attain tracking performance [11]. Alkhatib and Golnaraghi [2008] studied the active vibration control of a structure. They discussed the essential aspects which involved in the model of an active vibration control system. They presented a generic procedure to the design process and give selective example from the literature on relevant material [12]. J. Fernandez de Canete, Perez Saz-Orozco and I. Garcia-Moral [2007] studied robust stability in multi-variable neural networks control. They described that robust performance and stability were two basic characteristics of feedback control systems. They developed ways to describe uncertainty and harmonics for the controller and plant [13]. Mei, Wu and Jiang [2010] They studied time delay uncertain nonlinear systems of neural network robust adaptive control. They described a robust adaptive control scheme which was based on neural network recommended for time delay uncertain nonlinear systems. The system possessed nonlinear time-delayed input uncertainties and function uncertainties. The radial basis function (RBF) neural networks were introduced to calculate the unknown bounded continuous input uncertainties [14]. M. Adhyaru, I. N. Kar, M. Gopal [2010] analysis bounded robust control of nonlinear systems by neural network based HJB (Hamilton–Jacobi–Bellman) equation. The optimal control algorithm for robust controller design was proposed for nonlinear systems. The HJB equation was defined to tackle constraints on the control input. Utilizing the direct method of Lyapunov stability, the controller included the maximum bound on system uncertainty. [15]. Stavroulakis, Georgios E., [2005] The vibration control mechanism with piezoelectric sensor and actuators and its application was represented by the paper. This paper set on Hamilton's principle and classical engineering theory. They considered two control scheme that is LQR and H_2.sufficient vibration suppression could be achieved with the help of numerical simulation [16]. Zhang, Wenfeng, JinhaoQiu, and JunjiTani.[[2004] They used vibration/position/shape control devices with Piezoelectric actuators and sensor. The robust control of a clamped plate based on the self-sensing actuator (SSA). *A* μ-synthesis controller was studied to squash multi-mode vibrations of plates. Results of the paper proved that the both modes (symmetrical and asymmetrical) could be squashed with feedback control by piezo- patches [17]. Smyser, C. P., and K.Chandrashekhara [1997] Linear quadratic Gaussian with loop transfer recovery method was applied to plan a robust vibration controller based on state space model. The coupled finite-element equations of motion reduced uncoupled equations with the help of mode superposition method. The back propagation algorithm was used to train the neural network and used neural network used to control the vibration of composite beam [18]. Chang, W., [2004] Low-order robust controller was proposed for suppression of smart panel vibrations by that paper. A smart panel was designed using solid, shell finite elements and transition. To minimize panel vibrations robust controller was designed. Balanced controllability and observability of each resonance mode was measured by Modal Hankel Singular values (MHSV).These type of controller was designed in analog circuit [19]. Dong, Xing-Jian, GuangMeng, and Juan-Chun Peng.[2006] The main purpose of this paper was to know the efficiency of identification technique called as observer/Kalman filter identification (OKID)technique in study of vibration control of piezoelectric structures .The linear quadratic Gaussian (LQG) algorithm was used to design the controller . The experimental results founded by using the active vibration control system [20].

Kumar, Varun [2013] They used the fuzzy logic controller to control the vibration of the plate. He used two dimensional plate of mesh size (8x8) with piezoelectric patches. Control effectiveness was studied with the help of Fuzzy logic optimal control scheme. They used two input and one output. Tip displacement and tip velocity used as the inputs and control forces used as output. It is concluded that effective control to suppress the first modes of vibration could be done by fuzzy logic controller [21]. Kumar, Varun and Deepak Chhabra. [2013] In the paper the vibration was managed by fuzzy logic controller (FLC). A FEM was derived with help of piezo-pathes. They used in their research (8x8) mesh size object. It is designed for make more effective of control system by the help FLC. They used tip displacement and tip velocity as a input. And they used the control forces as a output in their research. They divided in nine rules. With the help of MATLAB they found their results. They found in the research for the first three modes of vibration, cantilever plate is best suitable for fuzzy logic controller [22]. Jiang, Jian-Ping, and Dong-Xu Li [2011] The model of the solar array pattern was made by finite element techniques. Modal Hankel Singular Value method was used to reduce the system. The results represented that the vibration could be suppressed with the help of controller [23]. Aridogan, Ugur, and IpekBasdogan [2015] The main reasons of structural vibrations were mechanical failures and noise problems. The main reason of this article was to analysis the current situation of active vibration and noise suppression systems. They categorized the controller based on their architecture, performance in vibrations and noise. These classifications could be used by controller designer [24]. Varun Kumar [2015] The requirement of green energy increased day by day. In present, Govt. also encouraged the green energy. The Govt. gave the 'green certificate' who encourage the green energy. Sun, wind Tides, Geothermal energy are the resources of green energy. The researchers developed the smart materials for generating green energy. Mostly used smart materials are Piezo-electric Material, Thermo-electric, electrostatic etc. [25]

The main aim of this research is to design a cantilever plate structure by using piezoelectric sensors and actuators. These are on the top and bottom of the plate and research using FL controller.

2. METHODOLOGY

Plate

A plate of homogeneous material is studied and this is isotropic elastic rectangular cantilever plate. We studied rectangular plate that has L length, B breadth and T thickness. This plate is divided into small finite number of elements that have similar sizes and shapes. The structure of plate is designed with the help of FEM (finite element method). It is assumed that piezo-electric patches are also attached with structure of plate as an actuators or sensors. These sensors or actuators are mounted on the surface area of the element.

The rectangular plate together with L length is assuming the M number of elements and together with B breadth assuming the N number of elements. We assumed each element is in the rectangular shape with j, k, l or m and with 2a length dimensions, breadth with 2b dimensions and thickness is T.

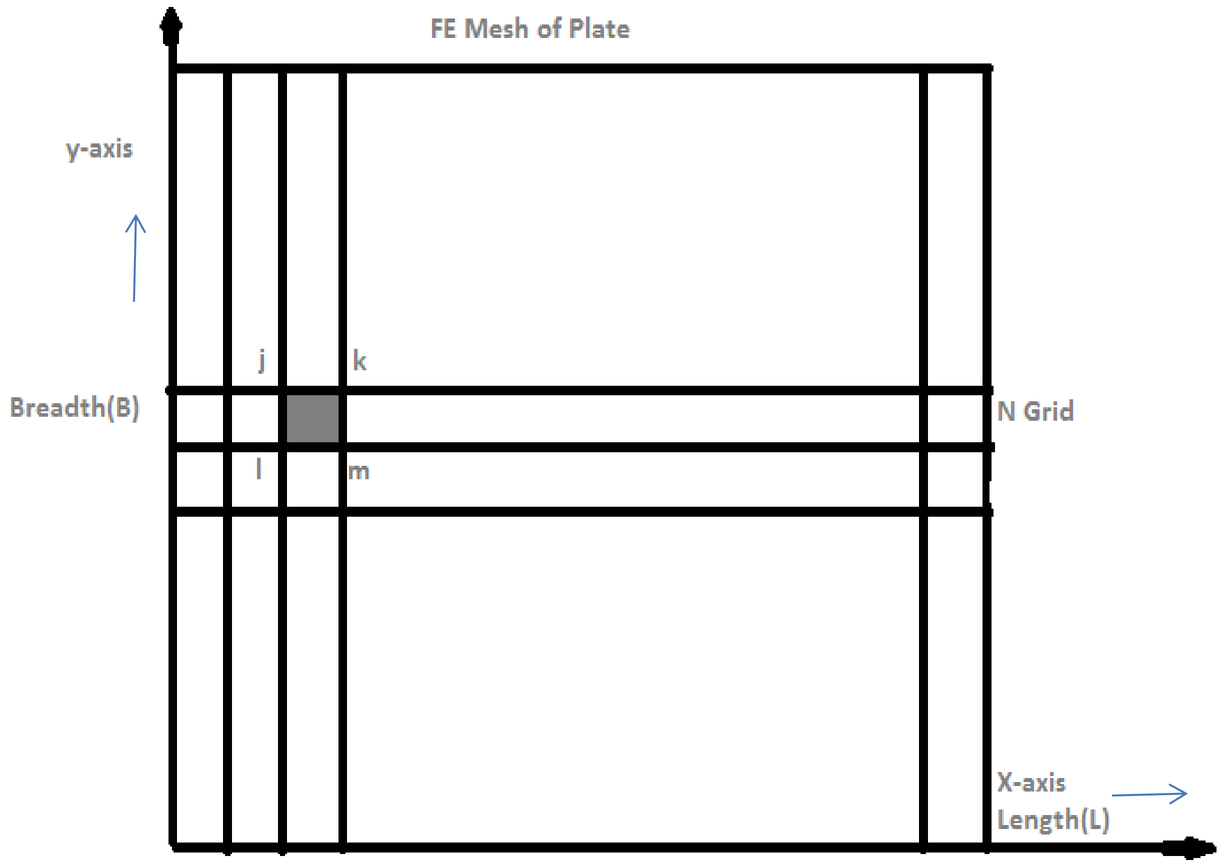

Figure 2.1: FE Mesh of Plate

The plate is implemented with piezo-patch parallel with sensor-actuator pair which is polarized in the direction of thickness. Each piezo electric patch at both top and bottom surfaces are covered by electrodes. The structure of plate combined with two piezo-patches and elastic layer is in the direction thickness at piezo-location.

Properties of Plate

We assumed a rectangular cantilever plate and this plate is partitioned into 100 elements (10*10) as shown in figure. This plate has 121 nodes. Without cantilever position of plate has 121 nodes and each node has 3 degree of freedom (DOF). The total number of DOF in the plate is 121*3=363. But if we assumed the plate, the first 11*3=33 DOF that attached to cantilever plate becomes zero. So DOF is assumed 363-33= 330 DOF.

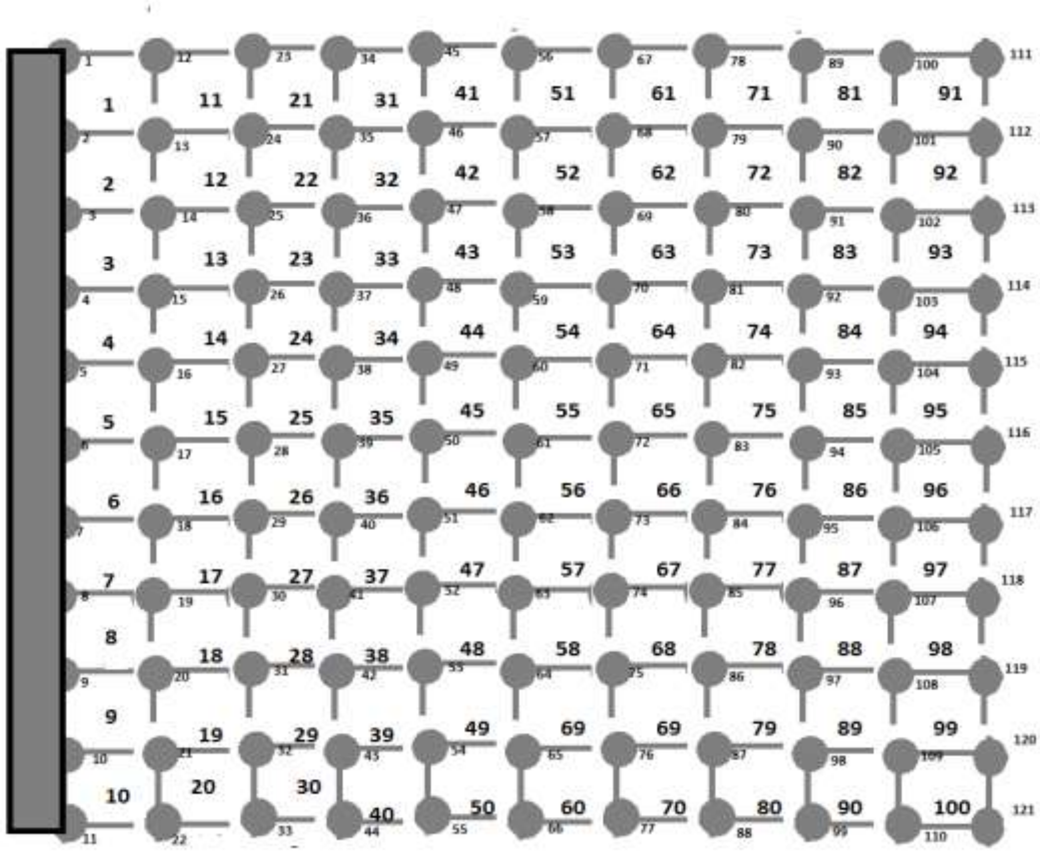

Figure 2.2: cantilever plate with 100 elements and 121 nodes

Table 2.1 Material properties and dimension of cantilever plate

Parameter	Plate
Length(L)	200/1000M
Breadth(B)	200/1000M
Thickness(T)	1/1000M
Modulus of Elasticity(E)	207Gpa
Modulus of rigidity(V)	0.3Gpa

Table 2.2 Material properties and dimension of Piezo-electric patch

Parameter	Plate
Length(L)	0.02M
Breadth(B)	0.02M
Thickness(T)	2/1000M
Modulus of Elasticity(E)	63Gpa
Modulus of rigidity(V)	0.3Gpa

Observer for Tip Displacement

The identification of modal quantitiesin developing any modal control is one of the challenges. In this work, the Kalman observer is follow for identification of modal displacements and velocities of first two modes. Assuming only the first two modes of the plate, the equation of motion of the smart plate in state space is given by[2.1]:

$$\dot{s} = A \times s + B \times V_0 \qquad (2.1)$$

$$y = c \times s \qquad (2.2)$$

$$s = \begin{cases} \eta_1 \\ \eta_2 \\ \dot{\eta_3} \\ \dot{\eta_4} \end{cases} \qquad (2.3)$$

Here $\boldsymbol{y}$is sensor signal and so vector $\boldsymbol{c}$can be got from the sensor equation.

The state equation for a system with external noise can be written as follows:

$$\dot{s} = A \times s + B \times V_0 + G \times v \qquad (2.4)$$

$$y = c \times s + w \qquad (2.4)$$

Where $G = [\begin{smallmatrix} 1 \\ 1 \\ 1 \\ 1 \end{smallmatrix}]$

The Kalman filter dynamics can be written as:

$$s_e = A \times \dot{s}_e + B \times V_0 + K_e \times (y - c \times s_e) \qquad (2.5)$$

Where$\boldsymbol{s_e}$ = estimated state and $\boldsymbol{K_e}$ = Kalman filter gain to minimize the expected value is

$$E\{(s-s_e)^T(s-s_e)\}$$

In discrete time Kalman's equations take the form: Time update:

$$s_e(K+1) = Fs_e(K) + gV_0 \qquad (2.6)$$

Measurement update:

$$s_e(K+1) = s_e(K+1) + M[y - cs_e(k+1)] \qquad (2.7)$$

F and *g* are distinct versions of matrices *A* and *B*, respectively. *M* is the Kalman innovation gain, *k* is a time instant and *s*e is state vector considered by theKalman observer. Use the Kalman observer the entire state vector of the system can be calculated. The estimated state vector can be used to find the control output.

3. DESIGN OF FUZZY LOGIC CONTROLLER

FLC simply based on the human thinking. The design of FLC divided into two main steps:

1. Fuzzification.
2. Defuzzification.

Fuzzification

The input and output variables are chosen for FLC. It gives the input in a specific range. The specific range for input variables can be chosen through noticing the data for input variables, for assumed length of time. The specific range of output variables can be chosen by noticing specifications that give the safety of actuators. Overall input and output variables made the fuzzy sets.

In the suggested FL controller, tip displacement and velocity are used as input. Both tip velocity and displacement are lie in the range of 0-200. We take nine triangular memory functions to fuzzify the input. The specific range of output based on length of 'k'.

Defuzzification

In the defuzzification, based on rules a crisp value is attained for the output variables. A centroid method is used for defuzzification. In the form of algebraic expression for centroid:

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

Where

F_0:- fuzzy variable

$\mu(F_0)$:-membership value of the fuzzy variable.

4. RESULTS

The design of FLC depended on simple human reasoning. The rule base of FLC (fuzzy logic controller) has 9 rules. FLC inputs made up of structure's velocity and displacement and output is force applied through the actuators. The breakdown voltage provided to the actuator and give stability the suggested FLC is checked for active vibration control of cantilever plate to minimize the vibrations. A FE (finite element) model is installed with piezo-electric patches which are used as sensor/actuators. The Kalman observer is used for selecting the tip velocity and displacement.

Settling time for each patch placed in the 10X10 mesh under various control laws are as shown in the table4.1:

Table4.1. 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	5	80	80	5
3	10	80	80	7.3
4	50	80	80	7.6
5	80	80	80	2.2
6	100	80	80	9
7	1	10	20	7.2
8	10	10	20	4.8
9	25	10	20	7.2
10	50	10	20	7.2
11	75	10	20	7.9

12	100	10	20	9
13	1	40	50	7.2
14	10	40	50	7.6
15	20	40	50	5
16	50	40	50	7.4
17	80	40	50	2.2
18	100	40	50	9
19	1	100	110	7.4
20	10	100	110	7.6
21	20	100	110	5
22	50	100	110	7.6
23	5	100	110	1.9
24	70	140	150	2.31
25	90	180	190	2.4

The position of sensor/actuator has been varied 1 to 100 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 find out the minimum settling time using Fuzzy Logic Controller. Table 4.1.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. The best time settling is obtained at 5th piezo-patches and tip displacement and tip velocity position is100 and 110 respectively.

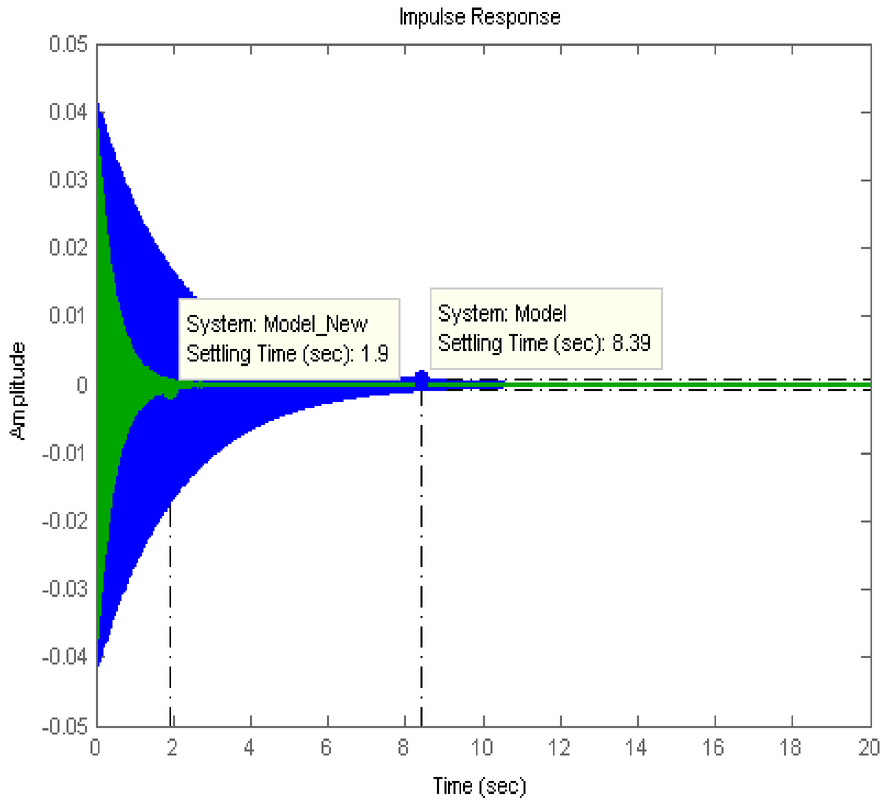

Fig 4.1.Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 5th position (al=100 and bet=110)

Fig.4.1 shows the controlled and uncontrolled tip displacement, when the piezoelectric sensor/actuator is placed at 5th position and the value of tip displacement and velocity 100 and 100 respectively.

5. CONCLUSION

This study provide the active vibration control (AVC) of smart cantilever plate with the help of piezo-patches that are worked as a piezo-electric sensors or actuators. This cantilever plate in size (10*10) is divided into small finite number of elements which are equal in size and shape. The position of sensor/actuator has been varied 1-100 positions which are available on finite element plate.The structure of plate is designed with the help of FEM.

The input (tip velocity and tip displacement) of FLC used with cantilever plate was taken in range of 0-200. By varying the sensor/actuator location and value of tip displacement and velocity, we found out the minimum settling time using Fuzzy Logic Controller. We see that the best vibration control of the plate is achieved at fifth position of plate. At the fifth position value of tip velocity and tip displacement is 100 and 110 with 1.9 value of settling time.

REFERENCE

1. Peter Dorato, 1987, 'A Historical Review of Robust Control', IEEE Control system magazine; 0272-1706,87:0600-30, 44-47.
2. Amin Suyitno, J. Fujikawa, H. Kobayashi, and Yasuhiko Dote,1993, 'Variable-Structured Robust Controller by Fuzzy Logic for Servomotors' IEEE transactions on industrial electronics, VOL. 40, NO. 1, FEBRUARY 1993, 80-88.
3. Reza Shahnazi and Mohammad-R., 2008, 'PI Adaptive Fuzzy Control wiith Large and Fast Disturbance Rejection for a Class of Uncertain Nonlinear Systems', IEEE transactions on fuzzy systems, VOL. 16, NO. 1, FEBRUARY 2008, 187-197.
4. P.Mayhan and G. Washington,1998,'Fuzzy model reference learning control: a new control paradigm for smart structures',IOP SCIENCE, Smart Mater. Struct. **7** (1998) 874–884.
5. M. K.Kwak and D.Sciulli, 'fuzzy-logic based vibration suppression control experiments on active structures, Journal of Sound and Vibration "0885# 080"0#\ 04_17
6. AM Sadri, R J Wynne and J R Wright, 1999, "Robust strategies for active vibration control of plate-like structures" I00599 © IMechE 1999
7. S. Chen, J. Yang, J. Mou, Y. Lu, 2002," Quality based design approach for a single crystal silicon micro actuator using DOE technique and response surface model" Springer-Verlag 10.1007/ soo542-001-0128-8
8. D. K. Anthony and A.J. Keane,2003, "Robust optimal design of a lightweight space structure using a genetic algorithm" AIAA Inc. 0001-1452
9. Q. Song, J. C. Spall and Y.C. Soh, 2003, "Robust neural network tracking controller using simultaneous perturbation stochastic approximation" IEEE 0-7803-7924-1
10. Wenwu Yu and Jinde Cao, 2007, "Robust Control of Uncertain Stochastic Recurrent Networks with Time-varying Delay" Springer Science Business Media, 26:101–119
11. Chun-Fei Hsu , 2007, " Adaptive recurrent neural network control using a structure adaptation algorithm" Springer-verlag18:115–125
12. RabihAlkhatib and M. F. Golnaraghi, 2008, "Active Structural Vibration Control" sage publication 2003; 35; 367
13. J. Fernandez de Canete, S. Gonzalez-Perez, P. del Saz-Orozco, and I. Garcia-Moral, 2009,"Robust stability in multivariable neural network control using harmonic analysis" IJIE 3:1
14. Rong Mei, Qing-Xian WuandChng-Sheng Jiang, 2010, "Neural network robust adaptive control for a class of time delay uncertain nonlinear systems" ICIC 1349-4198
15. Deepak M. Adhyaru, I. N. Kar, M. Gopal ,2010,"Bounded robust control of nonlinear systems using neural network–based HJB solution" Springer-Verlag 20:91–103
16. Stavroulakis, Georgios E., et al. "Design and robust optimal control of smart beams with application on vibrations suppression." *Advances in Engineering Software* 36.11-12 (2005): 806-813.
17. Zhang, Wenfeng, JinhaoQiu, and JunjiTani. "Robust vibration control of a plate using self-sensing actuators of piezoelectric patches." *Journal of intelligent material systems and structures* 15.12 (2004): 923-931.
18. Smyser, C. P., and K. Chandrashekhara. "Robust vibration control of composite beams using piezoelectric devices and neural networks." *Smart Materials and Structures* 6.2 (1997): 178.
19. Chang, W., et al. "Design of robust vibration controller for a smart panel using finite element model." *J. Vib. Acoust.* 124.2 (2002): 265-276.
20. Dong, Xing-Jian, GuangMeng, and Juan-Chun Peng. "Vibration control of piezoelectric smart structures based on system identification technique: Numerical simulation and experimental study." *Journal of sound and vibration* 297.3-5 (2006): 680-693.
21. Kumar, Varun. "Vibration control of a plate with help of fuzzy logic controller." *International Journal of Enhanced Research in Science Technology and Engineering* 2 (2013): 100-106.

22. Kumar, Varun, and Deepak Chhabra. "Design of fuzzy logic controller for active vibration control of cantilever plate with Piezo-Patches as sensor/actuator." *International Journal of Emerging Research in Management &Technology* 2 (2013): 34-44.
23. Jiang, Jian-Ping, and Dong-Xu Li. "Robust H∞ vibration control for smart solar array structure." *Journal of Vibration and Control* 17.4 (2011): 505-515.
24. Aridogan, Ugur, and IpekBasdogan. "A review of active vibration and noise suppression of plate-like structures with piezoelectric transducers." *Journal of Intelligent Material Systems and Structures* 26.12 (2015): 1455-1476.
25. VarunKumar "The Emerging Resource of Renewable Energy: Smart Materials." *National Conference on Recent Development in Mechanical Engineering,UIET, MDU,ROHTAK.20-21 Nov.2015*