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Research Paper

Design of Adaptive neuro-fuzzy inference system (ANFIS) Controller for Active Vibration control of Cantilever Plate with Piezo -Patches as sensor /actuator.

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ABSTRACT

The aim of this work is to optimise the vibration of the plate with the help of Adaptive neuro-fuzzy inference system (ANFIS) controller. The contribution of piezoelectric sensor and actuator layers on the mass and stiffness of the plate is considered. As the plate is square so we get total 64 squares. To validate the present code, frequency response has been compared with exact solution as well as experimental results already published in the previous papers. Adaptive neuro-fuzzy inference system (ANFIS)optimal control scheme have been applied to study the control effectiveness and tip displacement-settling time graph are plotted using piezoelectric patches at various locations to find out the optimal location to suppress the first three modes. It is observed that Adaptive neuro-fuzzy inference system (ANFIS) controller is found suitable and give effective control to suppress the first three modes of vibration of cantilever plate. Tip displacement and tip velocity are taken as the inputs and the control force are taken as the outputs at different nine points. The controller consists of nine rules which are based on simple human reasoning. Using augmented equations, a finite element model of a two-dimensional cantilever plate instrumented with a piezoelectric patches sensor-actuator pair is derived.

Key words: Smart structure, Finite element model, Active vibration control, Adaptive neuro-fuzzy inference system (ANFIS) Controller.

1. Introduction

A vibration control strategy in which an external source of energy is used to control structural vibrations is called active vibration control (AVC). It essentially consists of sensors to capture the structural dynamics, a processor to manipulate the sensor signals, actuators and a source of energy to actuate the actuators. [1].
Different control techniques have been used in the control of flexible structure.
Varun Kumar designed the Fuzzy Logic Controller for Active Vibration Control of Cantilever Plate with Piezo -Patches as Sensor /Actuator. M. k. kwak and D. sciulli [3] studied the fuzzy logic based vibration suppression control of active structures equipped with piezoelectric sensors and actuators.
Manu Sharma [4] 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 [5] used Positive position feedback (PPF) control in active vibration control of flexible structures. Maguid H. M. Hassan [6] presented the basic forms of smart systems in which the structural system's

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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.

Sharma M. [7] introduced 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. [8] 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. [9] have been investigated the active vibration control of a simply supported rectangular plate made from functionally graded materials with fuzzy logic control and compared to the results obtained with the application of PID control. Nemanja Zorić et al. [10] presented the optimized fuzzy logic controller with on-line tuning of scaling factors for vibration control of thin-walled composite beams.

Liu, Lin and Lee [11] studied a novel neural network approach for the identification and control of a thin simply supported plate. The motion behaviour of a two dimensional model of piezoelectric materials bounded to the surface of the plate is analytically investigated. Yu and Jinde Cao [12] proposed robust control of uncertain stochastic recurrent neural networks with time varying delay. They consider a novel control method which is given by using the Lyapunov Functional method and linear matrix inequality approach. Chun-Fei Hsu [13] introduced an adaptive recurrent neural network control system with structure adaptation algorithm for the uncertain nonlinear systems. The developed ARNNC system is composed of a neural controller and a robust controller. Roy and chakraborty [14] purposed genetic algorithm based linear quadratic regulator control scheme has been proposed for active vibration control of smart Fiber Reinforced Polymer composite shell structures under combined mechanical and thermal loading.

Gupta, Sharma, Thakur and S P singh [15] introduced A new scheme for active structural vibration control using piezoelectric patches at elevated temperatures is analytically derived and experimentally verified. Amit Kumar and Deepak Chhabra [16] Designed the Nural Network Controller for Active Vibration Control of Cantilever Plate with Piezo -Patches As Sensor /Actuator.

Prof. Sandip R Panchal et al. [17] Designed the ANFIS Controller for Overhead Crane. Akhil V. Gite et al. [18] described ANFIS CONTROLLER and its applications. Sefer Kurnaz et al.[19] described an ANFIS based autonomous flight controller for UAVs (unmanned aerial vehicles). To control the position of the UAV in three dimensional space as altitude and longitude–latitude location, three fuzzy logic modules are developed.

2. Methodology

2.1 Plate

An isotropic elastic rectangular plate of homogenous material is considered with its dimensions length L, breadth B, and thickness H. The plate is cantilever at two opposite sides and is subjected to vibrations. The vibration of the boundaries will be uniform and synchronous. The remaining degrees of freedom along the sides of the structure will be locked. The plate is discretized into some finite number of smaller elements of identical shapes and sizes. The structure will be modeled by means of the FEM. It is supposed that the pair of piezoelectric patches can be added to the structure as sensor and actuator in piece coinciding with the surface area of each element.

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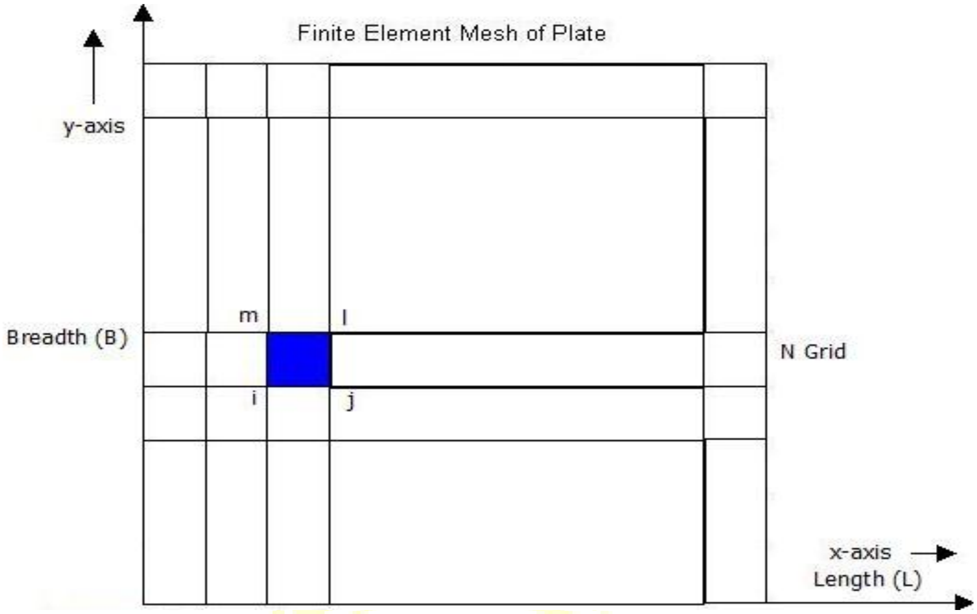

Figure 1: Problem Formulation

Considering M is the number of elements along the length of the plate and N are the number of elements along the breadth. Each element is considered to be rectangular in shape with nodes i, j, l and m; and with dimensions length 2a and breadth 2b and thickness h.

2.2 Finite Element Method

Consider an elastic plate structure. The plate is instrumented with a piezo-patches collocated sensor and actuator pair polarized in the thickness direction. Electrodes is covered on the top and bottom surface of each piezo-patches. The plate is divided into discrete finite elements where 'ζ' and 'η' are the natural coordinates of the finite element and they are related to global coordinates *(x, y)* as:

$$\zeta = \frac{\boldsymbol{x}}{\boldsymbol{a}}$$

And

$$\eta = \frac{y}{b}$$

Each finite element has four nodes and each node has three degrees of freedom: one translational w and two rotational θ_x and θ_y . If $\{u_e\}$ is the displacement vector of an element then displacement in the *z*-direction can be interpolated as:

$$w = [N]_{1\times 12}\{u_e\}_{12\times 1}$$

Where $[N]_{1\times 12}$ is Hermite's interpolation function .

Ignoring shear deformations in the plate and using Kirchhoff's classical plate theory, strains produced in the plate can be written as:

$$\{\boldsymbol{\varepsilon}\} = \{\frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}}\ \frac{\partial \boldsymbol{v}'}{\partial \boldsymbol{y}}\ \frac{\partial \boldsymbol{v}'}{\partial \boldsymbol{x}} + \frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}}\}^{\boldsymbol{T}}$$

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Where $u = -z\frac{\partial\omega}{\partial x}$ and $\boldsymbol{v}' = -z\frac{\partial\omega}{\partial y}$

After substituting values of 'u' and '$\boldsymbol{v}'$' in the above equation, we get:

$$\{\boldsymbol{\varepsilon}\}_{3\times1} = \boldsymbol{z}[\boldsymbol{B_u}]_{3\times12}\{\boldsymbol{u_e}\}_{12\times1}$$

Where $[\boldsymbol{B_u}]_{3\times12} = [-\frac{z\partial^2}{\partial x^2} - \frac{z\partial^2}{\partial y^2} - \frac{2z\partial^2}{\partial x\partial y}]^T_{3\times1}[\boldsymbol{N}]_{1\times12}$

Kinetic energy of one finite element:

$$T_e = \frac{1}{2}\int_s \rho_{s\dot{w}^2} d\boldsymbol{\tau} + \frac{1}{2}\int_p \rho_{p\dot{w}^2} d\boldsymbol{\tau}$$

Potential energy of one finite element:

$$V_e = \frac{1}{2}\int_s \{\boldsymbol{\varepsilon}\}^T\{\boldsymbol{\sigma}\}d\boldsymbol{\tau} + \frac{1}{2}\int_v \{\boldsymbol{\varepsilon}\}^T\{\boldsymbol{\sigma}\}\boldsymbol{d\tau}$$

Electric energy stored in one finite element:

$$W_{elect} = \frac{1}{2}\int_P \{E\}^T\{D\}d\boldsymbol{\tau}$$

External surface traction or a point force can act on a smart structure. These forces would do work on the smart structure and as a result, energy stored per element is:

$$W_{ext(1)} = \int_{A_s}\{w\}^T\{f_s^e\}dA_s$$

Work required to apply external charge on the surface of a piezoelectric is:

$$W_{ext(11)} = -\int_{A_P} qv dA_P$$

Now, the Lagrangian for one finite element of the smart structure can be obtained as:

$$L = T_e - V_e + \left(W_{elect} + W_{ext(1)} + W_{ext(11)}\right)$$

The Lagrangian can be calculated using finite element relations and augmented constitutive equations . The equation of motion of one finite element is derived using Hamilton's principle:

$$\delta\int_{t1}^{t2} L dt = 0$$

The resulting variational contains two variables namely '$\{u_e\}$' and 'v'. Taking variation with respect to $\{u_e\}$,we get:

$$([m_S^e] + [m_P^e])\{\ddot{u_e}\} + ([k_S^e] + [k_P^e])\{u_e\} + \left([k_{uv}^e] + [\overline{k_{uv}}]\right)v = \{F_S^e\} + \{F_{T,S}^e\} + \{F_{T,P}^e\}$$

and taking variation with respect to 'v', we get:

$$v = ([k_{vv}^e] + [\overline{k_{vv}^e}])^{-1}(Q_{ext}^e + Q_{pyro}^e + ([k_{vu}^e] + [\overline{k_{vu}^e}])\{u_e\})$$

Where

$$[m_S^e] = \int_s \rho_s [N]^T[N]d\boldsymbol{\tau}$$

is the substrate element mass matrix,

$$[m_P^e] = \int_P \rho_P [N]^T[N]d\boldsymbol{\tau}$$

is the piezoelectric element mass matrix,

$$[k_S^e] = \int_s z^2[B_u]^T[c_s][B_u]d\boldsymbol{\tau}$$

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is the substrate element stiffness matrix,

$$[k_P^e] = \int_P z^2 [B_u]^T [c_s][B_u] d\boldsymbol{\tau}$$

is the piezoelectric element stiffness matrix,

$$[\boldsymbol{k}_{uv}^e] = [\boldsymbol{k}_{uv}^e]^T = \int_P \boldsymbol{z}\{\boldsymbol{B}_u\}^T [\boldsymbol{e}^t][\boldsymbol{B}_v] \boldsymbol{d\tau}$$

is the electromechanical interaction matrix.

2.3 Design of Adaptive Neuro-Fuzzy Inference System (ANFIS)

The Design of ANFIS controller consists two controller. Neural Network and Fuzzy Logic Controller. The ANFIS controller is shown in fig1. ANFIS is a five layered feed-forward neural network structure, as shown in FIG 1. In ANFIS controller the special architecture based on Sugeno type of inference system enables the use of hybrid learning algorithms. The approach used in this work for updating the ANFIS network parameters is a hybrid learning algorithm which is a two level learning algorithm. In this approach, the parameters of ANFIS network are evaluated in two parts as input and output parameters.

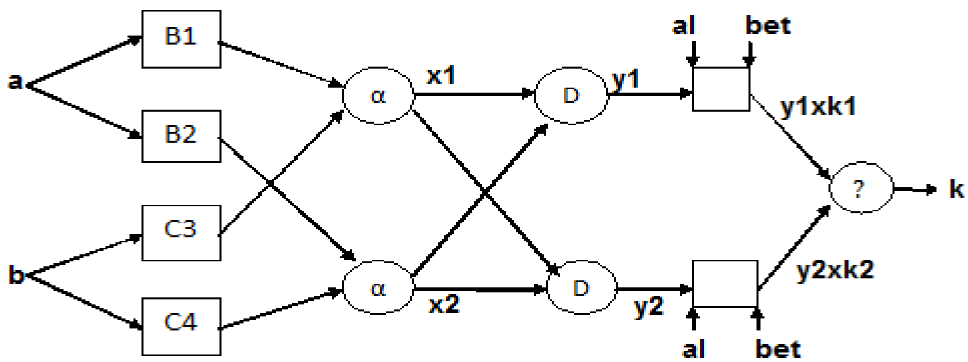

FIG.1 ANFIS CONTROLLER

3. RESULT

By using ANFIS controller, settling time for each patch placed in the 8X8 mesh are as shown in the table1:

Table 1. Settling Time at various position of piezoactuator at different tip displacement and velocity

al	bet	Piezolocation	settling time
10	20	35	2.14
10	20	25	2.58
20	30	35	1.79
30	40	35	1.6
40	50	35	1.41
50	60	35	1.34
60	70	35	1.34

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70	80	35	1.15
80	90	35	1.12
90	100	35	1.12
100	110	35	1.12
110	120	35	1.09
120	130	35	1.09
130	140	35	0.94
140	150	35	0.94
150	160	35	0.94
150	160	25	1.27
160	170	35	0.94
170	180	35	0.894
180	190	35	0.94
190	200	35	0.94

The value of tip displacement and tip velocity has also been varied from 0 to 200. The position of sensor/actuator has been lies between 1 to 64 positions which are available on finite element plate. By varying the actuator location and value of tip displacement and velocity, we observed the minimum settling time using ANFIS Controller. Table1. shows the settling of tip vibration using ANFIS Controller at various locations and values of tip displacement and velocity. The settling time are calculated with help of MATLAB software by changing various position of piezo-patches and both input displacement and velocity. Fig.3.1-Fig.3.4 shows the various controlled and uncontrolled tip displacement, when the piezoelectric sensor/actuator is placed at different positions.

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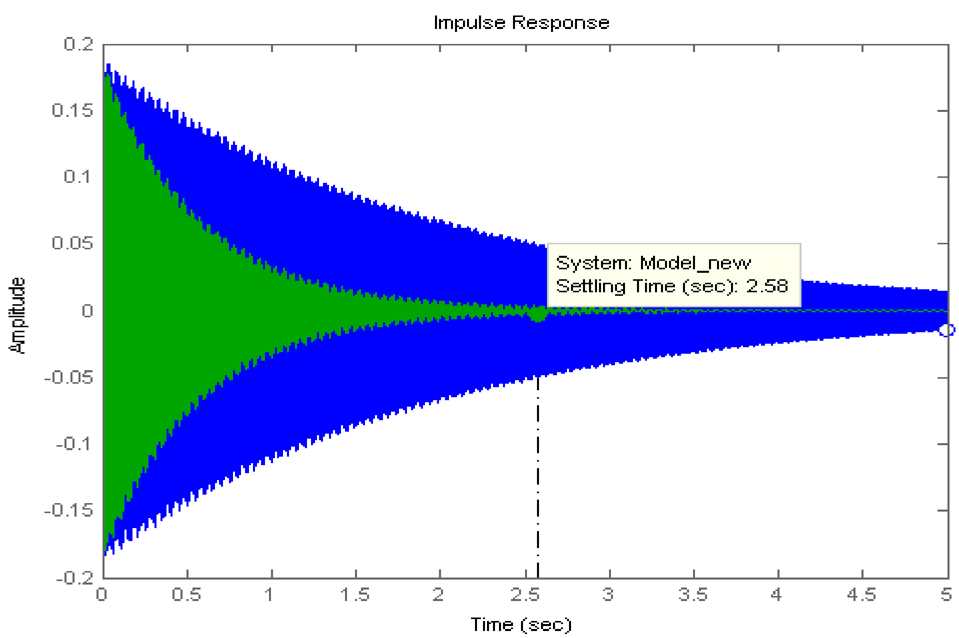

Fig 3.1.Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 25th position (al=10 and bet=20)

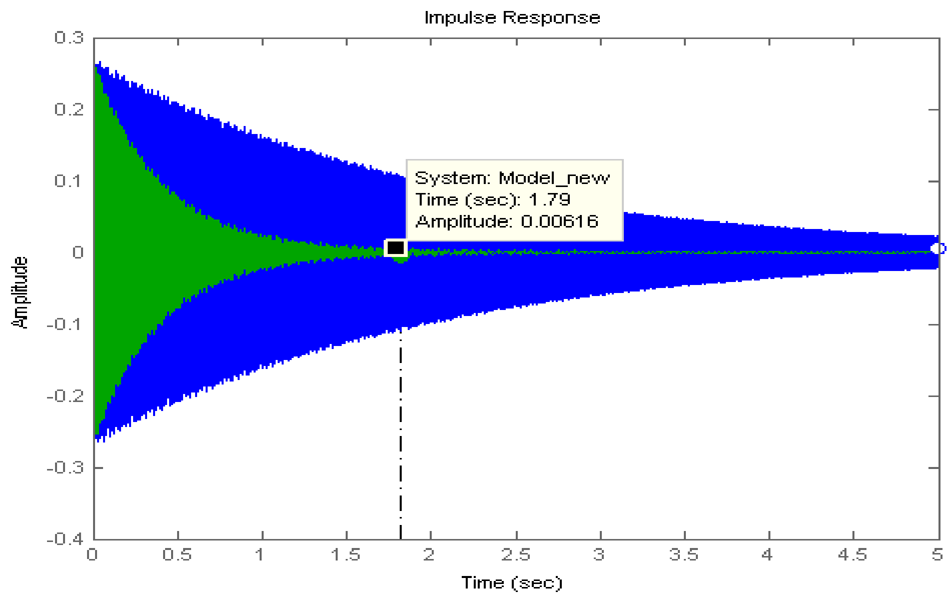

Fig 3.2.Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 35th position (al=20 and bet=30)

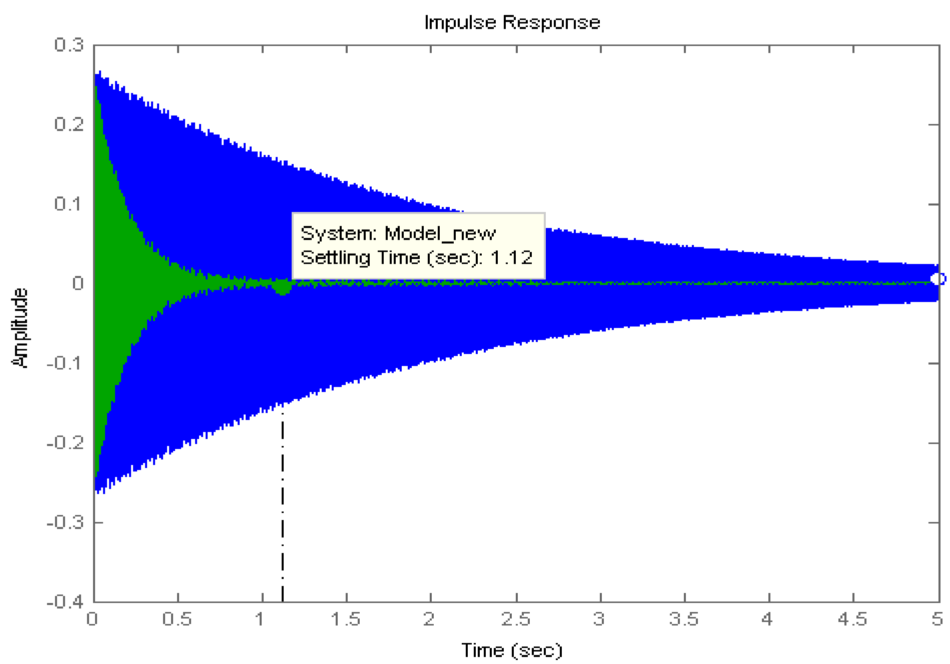

Fig 3.3.Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 35th position (al=100 and bet=110)

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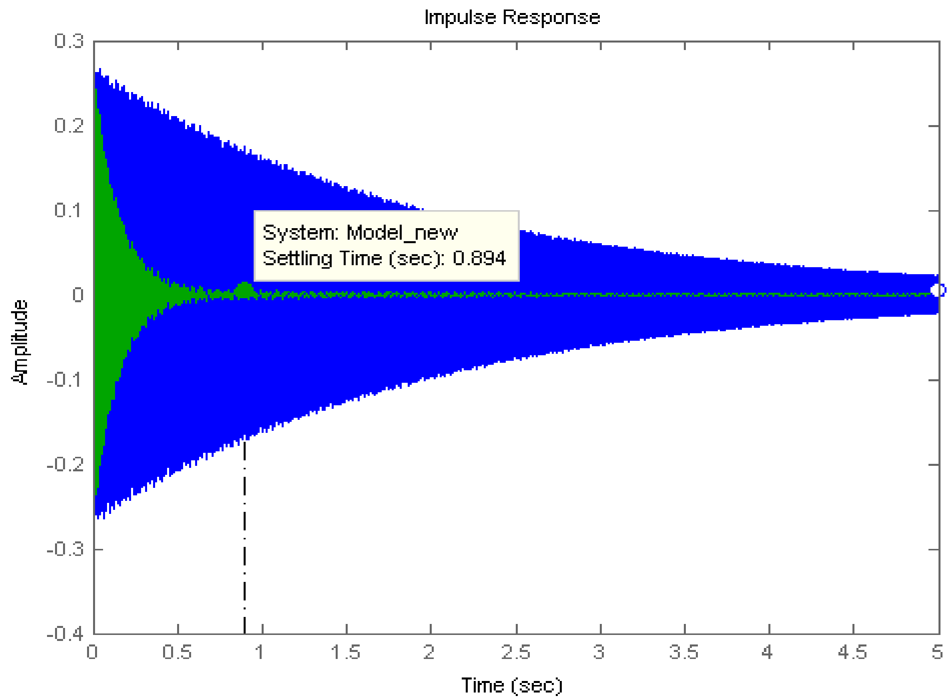

Fig 3.4.Controlled and Uncontrolled Tip Displacement When piezoactuator is placed at 35th position (al=170 and bet=180)

4. CONCLUSION

This work describes the basic techniques for analysis of active vibration control using piezoelectric actuators. The optimal location of sensor pair for a cantilever plate to suppress first three modes of vibrations and control effectiveness of ANFIS controller has been obtained. A general scheme of analyzing and designing piezoelectric smart cantilever plate with ANFIS control is successfully developed in this study. The values of two inputs of the ANFIS controller are taken as tip displacement and tip velocity between 0 to 200. The best location of sensor/actuator pair is 35th. The optimum value of tip displacement and velocity to get the minimum settling time are 170 and 180 respectively. The minimum settling time is obtained is 0.894sec.

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