

Vibration Control of Smart Cantilever Beam Using LQR Control

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Abstract

In this paper vibration of beam are controlled using LQR controls. Smart beam is modeled using piezoelectric patches. Harmonic and modal analysis is done in a finite element tool (ANSYS 14.5). The dynamic behavior of smart beam is obtained using a system identification technique. The feedback control algorithm is implemented using National Instrument CRIO 9022 controller. It is observed that with this controller of 30% reductions are obtained in vibration amplitude. The presented control method is effective to suppress the vibration of the beam smart beam.

Keywords: *Smart Beam, Active Vibration Control, LQR control.*

1. INTRODUCTION

Vibration control by using piezoelectric ceramic materials has received much attention to recent years. A smart structure consists of a host structure incorporated into sensors and actuators. The piezoelectric smart structure is used to control and suppression of unwanted structural vibration [1]. The finite element method is a powerful tool for analyzing complex structures and capable of dealing with integration of smart components and

classic structural parts [2]. Special finite elements have been developed to account for piezoelectric effect [3]. Tzou and Tseng [4] developed a finite element code with feedback control design to study the vibration suppression of a flexible shell. Smart structure can be modeled by using system identification techniques using the experimental data [5]. Allik and Hughes [6] applied the finite element method to analyze the three dimensional piezoelectric vibration modes.

The feedback control algorithm is implemented to suppress vibration amplitude. Lim et al. [7] employed the output feedback control law to study the vibration control of a plate structure. Xing Jian Dong et al presented a system identification technique based on measured input and output data of a smart plate using kalman filter identification technique in numerical simulation and experimental study based on Linear Quadratic Guassian (LQG) control algorithm. Yaman et al [8] showed the effect of H^∞ controller of suppressing the vibration of smart beam due to its first two flexural modes. Similar work is done for active vibration control of a smart plate, and usage of piezoelectric actuators on vibration suppression with H^∞ controller is successfully presented [9]. Halim [13] studied the implementation of spatial H_2 and H^∞ controllers on active vibration control and presented quite successful results. However these works were limited to a beam with simply supported boundary condition. Fanson et al [10] demonstrated active vibration control of a beam with piezoelectric patches using positive position feedback investigated both strain feedback and optimized PID compensator methods of active vibration control of cantilever beam bonded piezoelectric

actuator. Fanson and Caughy [12] proposed the PPF control method based on the model displacement signal. The PPF controller is very effective against suppressing the specific vibration mode, thus, maximizing the damping in target frequency band without destabilizing other mode.

V. Sethi and G song [14] have designed a full state linear quadratic regulator (LQR) controller by using the identified model. To achieve the full state feedback, an observer is designed based on the identified model.

Riessom Weldegiorgis et al [15] derived mathematical model using system identification technique for both vibration modes is successfully simulated for controller design and shows respectively 49.29% and 52.84% percentage reduction in vibration amplitude for first and second modes. Therefore the objective of this study is to evaluate the performance of LQR control law as applied to smart beam to suppress vibration.

2. MATHEMATICAL MODELING

Mathematical model of a system is an important component for control system design. The first two modes of vibration are considered in this analysis. In this

study, the system model is derived using MATLAB system identification toolbox. In this paper dominant mode of the beam vibration are identified experimentally using an impact hammer test. A simple smart system containing a beam instrumented with a PZT sensor and a PZT actuator is tested for vibration control. An LQR controller is added to the system as shown in figure1. The output voltage of the sensor is fed to the LQR controller then to the actuator. The sensor location is fixed throughout the simulations to ensure that the same output voltage fed to the actuator. As per premount [16], for the system with LQR controller, the closed loop state equation is written as follows.

$$\dot{Z} = (A - BK)Z + Bf$$

Where k is the optimum gain matrix.

$$K = BTSc$$

To minimize the performance index

$$J = \int_0^{\infty} (x^T Qx + u^T Ru) dt$$

Where Q and R the state and input weight matrices respectively. So to minimize the performance index, the feedback is obtained as

$$U = -kx$$

In equation 2 Sc is the solution of the controller algebraic Riiccati equation

$$A^T Sc + Sc A - Sc BB^T Sc + Q = 0$$

The closed loop eigen values of the system, i.e. the eigen values of the close loop state matrix $(A - Bk)$ in equation 1 are computed and the damping matrix Cuu is taken as zero matrix in numerical computations.

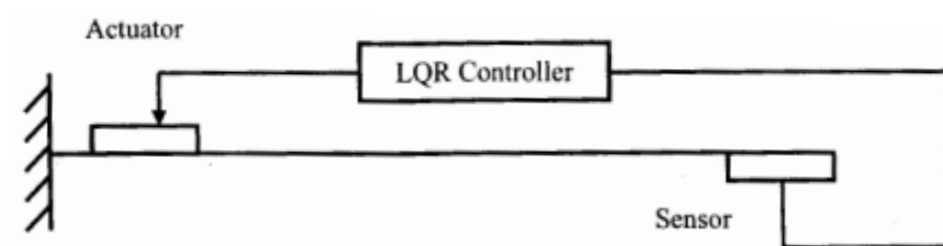


Figure.1 Smart Beam with LQR Controller for Cantilever

3. HARMONIC ANALYSIS

For the purpose of identifying the optimum location of the piezoelectric patches used as a sensor and actuator, Harmonic analysis is carried out for the frequencies of 0 to 200Hz in ANSYS. In ANSYS, the smart beam is modeled and a sinusoidal force is applied to its tip. This force compels the beam in pure bending modes and the entire strain distribution of the beam can easily be analyzed. Harmonic analyses to smart beam with different locations of piezoelectric actuators are analyzed. The results show that location of maximum strain is near the

fixed end of the beam for those modes of vibration as shown in fig. 2. The maximum strain induced in piezoelectric due to mechanical vibration of the beam can be effectively sensed for both modes at this particular location. Moreover, at the same location maximum strain can be imposed on the beam using PZT actuator with less input voltage in case of actuation. Hence, the sensor and actuator piezoelectric patches are fixed on the both faces of the beam at this particular location for better performance. The frequency response to identified FFT plot as shown in fig.3.

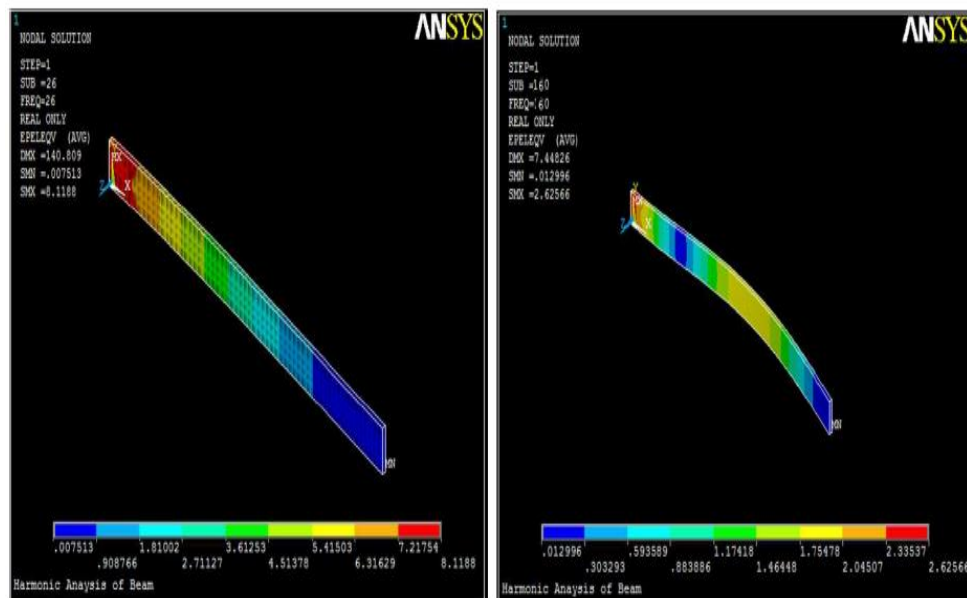


Fig. 2 Harmonic Analysis of Beam

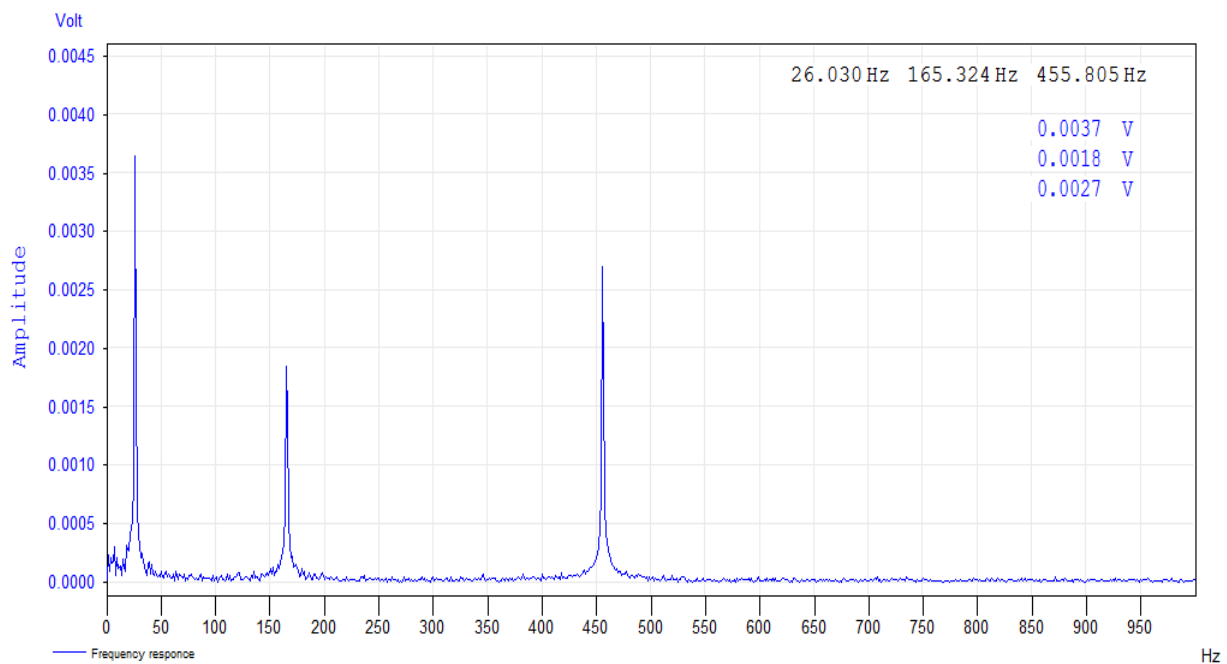


Fig.3 Frequency Response- Identified FFT Model Plot

4. EXPERIMENTAL SETUP

In order to verify the effectiveness of vibration control strategies, the experimental set up shown in figure is designing and built. The set up consists of a (0.5x0.03x0.005m) beam in fixed configuration with a pair of piezoelectric patches as a sensor and actuator mounted on both sides of the beam.

The third PZT are used for exciting the beam and vibrations picked up using an accelerometer and the values are given to the Labview software. The real time control algorithm is coded on national instruments CRIO9022 processor using

Labview graphical programming language. DAS is used to acquire the sensor data onto the charge amplifier. This conditioned strain signals is then used as input to the controller.

The actuating signal generated by the controller is sent to the voltage amplifier and supplied to the PZT after amplification to actuate the beam. The experimental set up is as shown in fig.4.

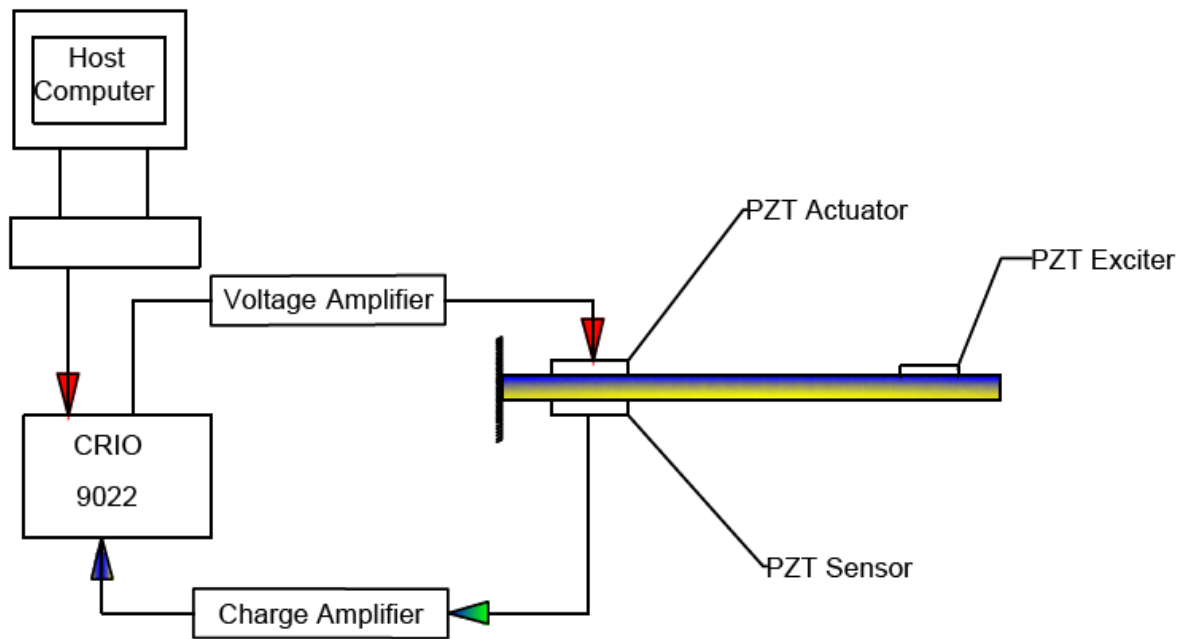


Figure: 4

5. RESULT AND DISCUSSIONS

Vibration characteristics of beam are investigated by bonding PZT patches at near fixed end. The frequency response from two dominant modes of vibration of the beam is identified experimentally using Impact Hammer test. The actuator location is varied from three locations and the effect of the actuator placement of the controlling vibration of the beam is studied. Fig. 5 to Fig.7 shows the sensor voltage outputs for the three different locations of the actuator.

The output voltage measured from the sensor. The settling time, placing the actuator closer to the fixed end of the beam performs better in attenuating structural vibrations of the system. Also vibration magnitude, placing the actuator far from the fixed end of the beam gives better results.

From the results it is observed that LQR control law showed relatively low system stability through it significantly reduces the amplitude of vibration and less settling times.

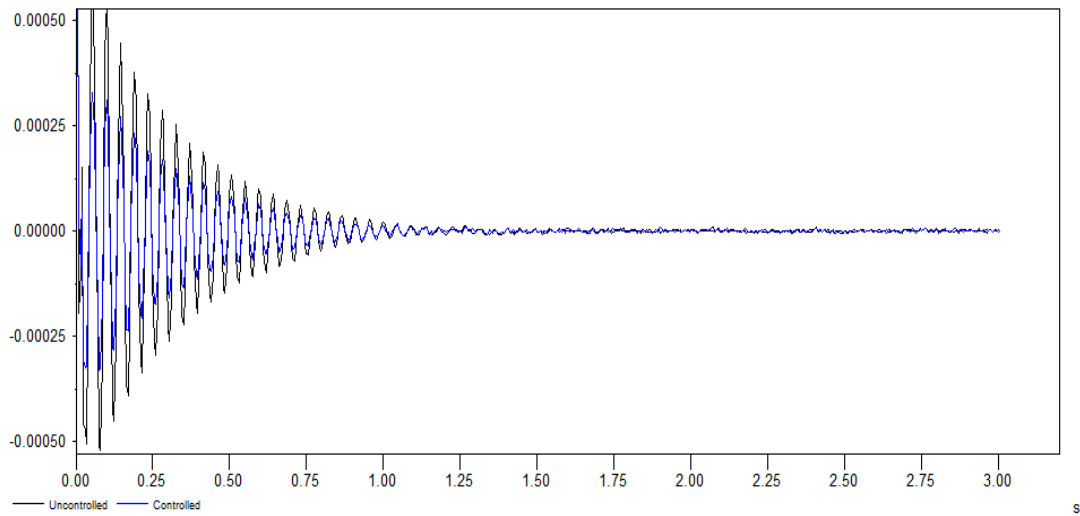


Fig. 5: Closed Loop Sensor Voltages with an LQR Controller (PZT Actuator Placed at 0.1 m for fixed end of cantilever beam)

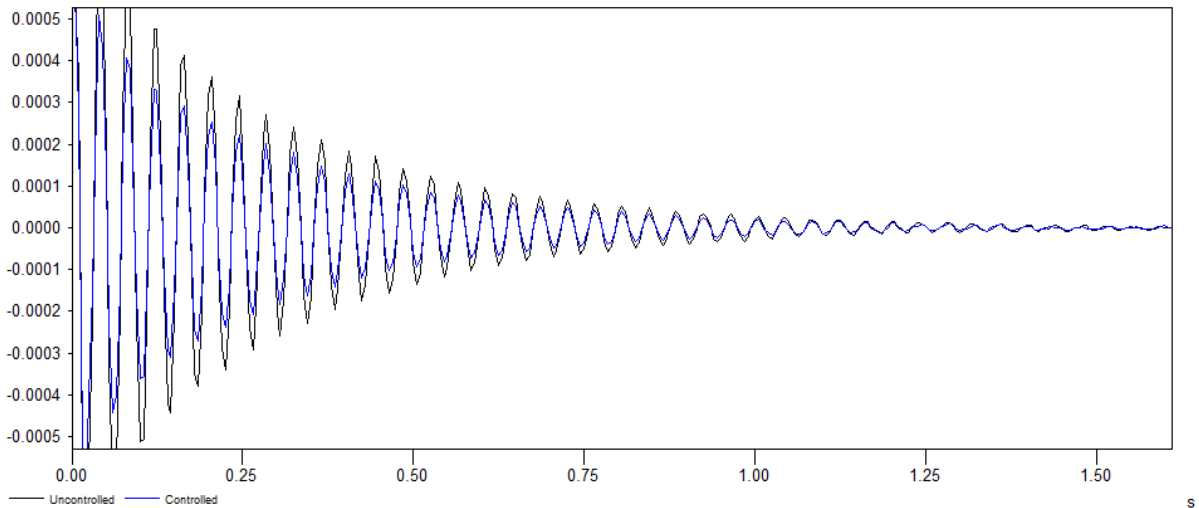


Fig. 6 Closed Loop Sensor Voltages with an LQR Controller (PZT Actuator Placed at 0.2 m for fixed end of cantilever beam)

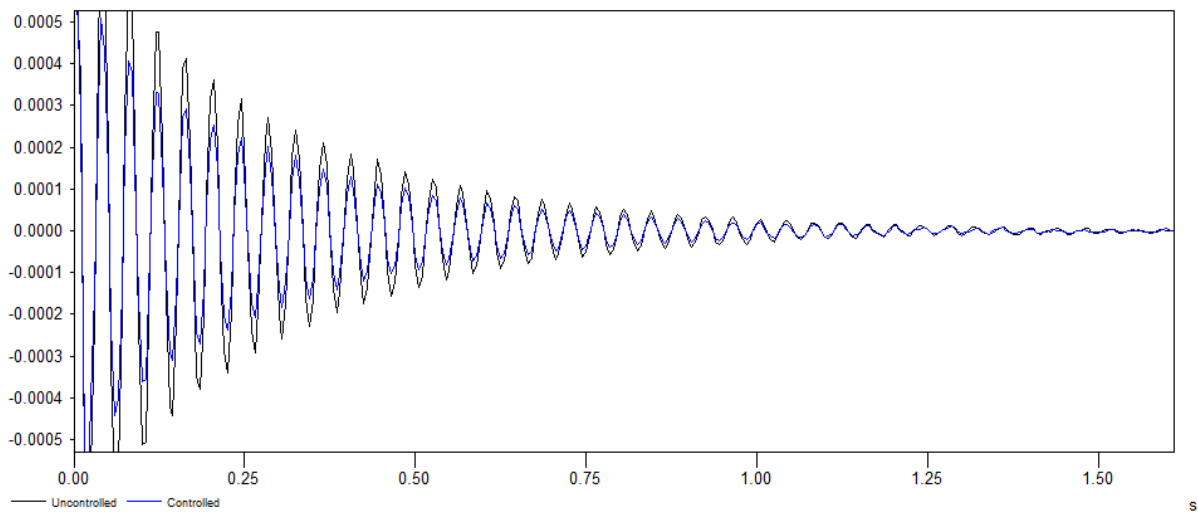


Fig.7 Closed Loop Sensor Voltages with an LQR Controller (PZT Actuator Placed at 0.3 m for fixed end of cantilever beam)

CONCLUSION

Frequency response from cantilever smart beam with actuators as a controller of fixed and free end is obtained. In terms of the settling time, placing the actuator closer to the fixed end of the beam performs better in attenuating structural vibrations of the system. Whereas, in terms of the vibration magnitude, placing the actuator far from the fixed end of the beam gives better results. Hence, it is better to place the actuator close to the beam support for better vibration management in case of cantilever beams system.

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