Active Vibration Control of Cantilever Beam by using PZT Patches: A Review

Vidur V. Gundage[1] Prof. Dr. Rupesh J. Patil[2]
[1]Student [2]Principal
[1,2]DYPIET, Pune

Abstract— This paper reviews work done in the area of Active Vibration Control of Beam by Using PZT patches. Active vibration control deals with the vibration of a structure by using opposite directional force of same magnitude for suppression of cantilever beam. In this paper a cantilever beam is used to study the active vibration control using PZT patches. The smart beam consists of rectangular aluminum beam fixed at one end and PZT patches are used as sensor and actuator. ANSYS 14.2 software is used to derive the finite element model of beam and to find out the optimum position and size. Optimization of position will be carried out by theoretically and experimentally. Then experimental study will be carried out for the various control methodologies for maximum vibration control at optimized position using neural network controller or its Simulink. The experiment should be carried out to place the sensor at top and actuator below the beam and actuator placed above the beam and sensor below the beam using serial plotter or Arduino 1.6.7 software.

Key words: Active Vibration Control, PZT Patches, Cantilevered Beam, PZT Sensor, PZT Actuator, Finite Element Model, Optimization For Placement Of Sensor & Actuator

I. INTRODUCTION

The control of mechanical and structural vibrations is important in many fields. In manufacturing, where mechanical vibration degrades both the production rate and the quality of the end products; in civil engineering, where structural vibration affect human comfort; in automotive and aerospace field, where vibrations reduce component life and generate annoying noise. Generally, isolators and passive dampers are used to reduce mechanical vibration called as passive vibration control. The Passive methods are limited due to little effectiveness of reducing vibration in the range of low frequencies, sensibility to changes in operating condition. Better results can be achieved using the active methods. An Active vibration control system is integration of mechanical and electronic components with computer control. The main components of active vibration control system are mechanical structure introduced by the disturbance, the sensors, the controller (to intelligently make use of signal from the sensor and to generate the appropriate control signal, and the actuator (to counter act the effect of disturbance on the structure). Arduino 1.6.7 software is used to plot the graphs using baud rate 9600 or serial plotter can be used to get the required graphs.

II. LITERATURE REVIEW

Qinglei Hu and Guangfu Ma has studied that the vibration reduction is critical problem related to manufacture of floatable spacecraft, which often employs large flexible structures are generally light weight and have relatively low damping for the fundamental and initial model. Further, the frequency associated with these models are low, the vibration control of nodes become an important issue in satellites and other large spacecraft structure. Active vibration control has been used as a solution for flexible spacecraft's to achieve the degree of vibration or suspension for required precision painting accuracy.

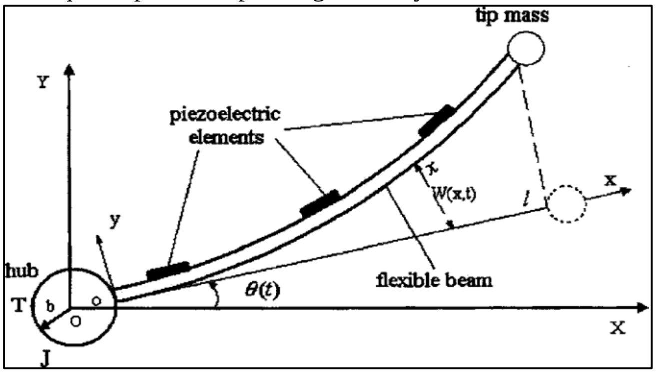

Fig. 1: Model of spacecraft with flexible appendages with bonded PZT material

Negative feedback control is an effective method for active damping which is the greatest immunity against the destabilizing effects of spillover. A second critical problem arises that model uncertainties of the flexible spacecraft is governed by partial differential equation as a system of distributed parameters and therefore possesses an infinite number of dimensions , which make it difficult to control. The paper explores the availability of the variable structure output feedback control (VSOFC) approach to flexible spacecraft for large angle rotational moments with active vibration control using piezo-ceramics. There are three control algorithm viz. constant gain negative velocity feedback controls, positive position feedback, linear quadratic Gaussian control. The goal of design is to achieve good robustness and distribution rejection, which can be achieved during sliding phase. Therefore, the sliding surface should be large as possible, the reaching time should be small and the boundary should also be small A generalized scheme bound or variable structure output feedback control and altitude controller VSOFC acting on hub and design of independent flexible control system using piezoceramics. Three different algorithms namely GNUF, PPF & LOG control are designed acting on flexible appendage and both simple and multimode vibrations are studied. [1]

Deepak Chhabra et.al. studied the active Vibration control of beam like structures with distributed PZT actuator and sensor layers bonded on top and bottom surfaces of the beam. The patches are located at the different positions to determine the better control effect. The PZT patches are placed on the free end, middle end and fixed end. The study is demonstrated through simulation in MATLAB for various controllers like Proportional Controller by Output Feedback, Proportional Integral Derivative controller (PID) and Pole Placement technique. A smart cantilever beam is modeled with SISO system. The entire structure is modeled using the concept of PZT theory, Euler-Bernoulli beam theory, Finite Element Method (FEM) and the State Space techniques. The numerical simulation shows that the sufficient vibration control can be achieved by the pro-posed method. Present work deals with the mathematical formulation and the computational model for the active vibration control of a beam with PZT smart structure. A general scheme of analyzing and designing PZT smart structures with control laws is successfully developed in this study. It has been observed that without control the transient response is predominant and with control laws, sufficient vibrations attenuation can be achieved. Numerical simulation showed that modeling a smart structure by including the sensor / actuator mass and stiffness and by varying its location on the beam from the free end to the fixed end introduced a considerable change in the system's structural vibration characteristics. From the responses of the various locations of sensor/actuator on beam, it has been observed that best performance of control is obtained, when the PZT element is placed at fixed end position. [2]

Yavuz Yaman etal. studied the smart plate which consists of a rectangular aluminium plate modelled in cantilever configuration with surface bonded PZT sensor and electric patches. The patches are symmetrically bonded on the top and bottom surface now using ANSYS, a model is prepared and experiments are conducted with it to find out the influences of actuator placement and size on the response of smart plate and determine the maximum admissible PZT voltage. Now the various parameters are discussed which will be affecting the response of the smart plate.Effect of actuator placement ?The actuators used is BM 500 and HS dimensions are (25*25*0.5), it is used on aluminum plate, the actuators are placed using modal analysis and identically polarized patches are assumed to be bonded symmetrically on top and bottom. Now to find the influence two cases are considered, the positioning of the patches is in x-y co-ordinate system and they are changed while keeping the distance between them constant. As the patches are placed near the root (y=0), response increases. But when the patches are moved in x-direction then there is no noticeable change in response. Influences of actuator sizes- The effect of increase in size of actuator on the response are investigated in terms of change in convergent ratio, which is defined by the ratio of the area converged by PZT sensors. The PZT actuator of 300 V is provided and found out that increase in size increases the energy transmitted to the smart plate giving rise to the response for the specified PZT actuation value. It also increases the stiffness of the plate.

Maximum admissible PZT actuation-PZT materials are bitter and have tensile strength in order of 63 MPa. Therefore the stress in the actuators can be critical in adverse applications. In order to determine the maximum possible PZT actuation valve, the von mises stresses developed in the actuator should be investigated prior to the operation. It was found to be of the order of 1 MPa. For normal operation (200-300 V), the PZT is not expected to fail. [3]

S.Raja et.al. searched the shear actuator induce distributed force/moments in the sandwich beam in contrast to the extension-bending actuators, which develop only concentrated force/moment and is found more efficient in actively controlling vibration. Actuator thickness & position play an important role in deciding the performance. The extension-bending actuator produces more transverse deflection than the shear actuator. We can observe that moderately thin shear actuators is found to be more efficient and also the face laminated thickness has a significant effect on the efficiency of shear actuator. [4]

R. Setola studied the reconstructor uses a spline shaped function to interpolate the available measurements and to take into account the boundary condition. The spline functions introduce a sort of spatial filtering on the high frequency mode and thus increase the robustness of the control scheme against spill over. Reconstructor joined to a suitable controller is able to reduce vibration of beam subjected to persistent multi-frequency disturbance acting at unknown beam abscissa. Thus by using this we can reduce the noise generated by the flexible structure when they are excited by external pseudo-periodic cause. [5]

Te̋o Lenquist da Rocha studied the active Vibration control by smart material technology is increasing day by day. To obtain optimized control performance, actuator and sensor must be placed at locations to excite the desired mode more effectively. It may be modelled by finite element method using MATLAB, ANSYS etc. H norm each sensor and actuator position is determined for selected modes of plate and computed using linear matrix inequalities technique. PZT elements are positioned at the optimal position using two first mode of structure. [6]

Zeki KIRAL etal. studied the dynamic response of the beam is calculated by using the finite element method in order to design a suitable control technique and numerical results are verified by vibration measurements.Two laser displacement sensors are used to measure the dynamic response of the beam The moving load is obtained by pressured air directed to the beam vi nozzle. In this case the suppression of the residual vibration that occurs after the moving load has left the beam is considered as main subject. Active vibration control of a cantilever smart beam is considered both experimentally and numerically. The simulation of closed loop vibration control with displacement feedback is achieved by using a commercial finite element package. [7]

C Mei searched that due to demand for mechanical structures to be lighter and faster, there has been increasing interest in Active vibration control in recent years. In this paper, a hybrid approach consisting of complementary wave and mode-based control is described on Timoshenko theory. In modal Active Vibration Control, the aim is to control the characteristics of modes of vibration i.e. their damping factors, natural frequency or mode shapes. Active wave control aims to control the distribution of energy in structure by either reducing the transmission of waves from one part of the structure to another or by absorbing the energy carried by other waves. In proposed hybrid approach, wave control is first designed and is targeted at higher frequencies. Two control strategies there, one optimally absorbs the vibrational energy and the other adds optimal damping to structure. Modal control is then designed for the lower modes of structure based on modified equation of motion of structure-plus-wave-controller. After the implementation of wave control, the equation of motion of the system is modified. Hybrid approach exhibits better broadband active vibration control performance than the cases with either modal or wave control alone. While control design based on the classical Euler-Bernoulli model theory is only applicable to slim beams, the present design based on the advanced Timoshenko model is suitable for deep as well as slim beam elements.[8]

Chih-Liang Chu et.al. investigated the active vibration control of a flexible beam mounted on an elastic base. Beam system is analysed using a finite element approach. The study utilizes the independent modal space control (IMSC) method for active control of a flexible beam supported on elastic base. Basic principle of IMSC method is that it transforms the coupled system dynamic equations into the decoupled modal space and thereafter applies a process of feedback control to each decoupled mode. In order to improve analysis accuracy the study considers Timoshenko beam theory for system analysed. The system equation are first expressed as state-space equations then decoupled. The IMSC method uses the characteristics of left/right modal matrices, R & L, to decouple a coupled system. The modal control force is obtained from control design in modal space. The analysis using the Timoshenko beam theory is examined with a total of 32 finite elements being used. Numerical results are compared with those obtained using ANSYS. The proposed control strategy is not only capable of controlling a single vibration mode, but also two modes while using one actuator. [9]

Jacques Lottin et.al. worked in which deals with the problem of efficient location of sensors and actuators encountered in the domain of active control of flexible structure. It appears that the optimal solution depends upon the type of control scheme that is used as well as the kinds of sensors and actuators that are implemented, and on the criterion that is considered. This paper recalls and discusses some approaches that are presented in the literature and presents some results that are obtained with a mock-up equipped with PZT sensors and actuators. The main conclusion of this study is the necessity to manage several sensors and actuators in order to guarantee global quality of vibration rejection along the beam. More precisely, according to the variety of measurements and actions, it will be more or less easy to build the corresponding control scheme. Another aspect of this study concerns the level of the attainable vibration reduction. Indeed, if disturbances come from the basis, it is not possible to eliminate its influence at the clamped end of the beam. In this case, the use of several actuators may lead to an acceptable compensation of their effect along a large section of the beam. Let us recall that the requirement is the vibration amplitude of a few nanometres. This involves very accurate sensors, already available in the seismic domain, as well as very sensitive actuators. [10]

K. B. Waghulde et. al. studied the vibration of a smart beam is being controlled. This smart beam setup is comprised of actuators and sensors placed at the root of a cantilever beam. Vibrations can be caused by various sources including human activity and nearby motorized equipment. In this case, disturbance is produced using a white noise signal to the actuator.

The PZT sensors are used to detect the vibration. Simultaneously, feedback controller sends correction information to the actuator that minimizes the vibration. To optimize results, controllers were designed using Linear Quadratic Gaussian (LQG) theory. This theory generally results in high-order controllers. Additionally, optimal control theory is being used to directly optimize low-order controllers. A smart beam was constructed using a Lucite beam, PZT actuator, and PVDF sensor. A dSPACE controller card was installed and integrated with related electronics to create an active control setup. Experiments were conducted to control the Vibration response to broadband disturbance. A 30% reduction in 1st -mode vibration response was achieved. Results in this experiment can be further improved. Additional focus onto the first mode is one way to improve results. Further focus on the first mode will allow the creation of better controllers through more accurate models of best fit. As this experiment has come to an end, various opportunities for expansion have been identified. This experiment leads well into many applications of aerospace and structural engineering. Whether used in airplane wings, helicopter propellers, or any type of slender beam where vibration is an obstacle that has to be overcome active vibration control using smart material is everywhere. [11]

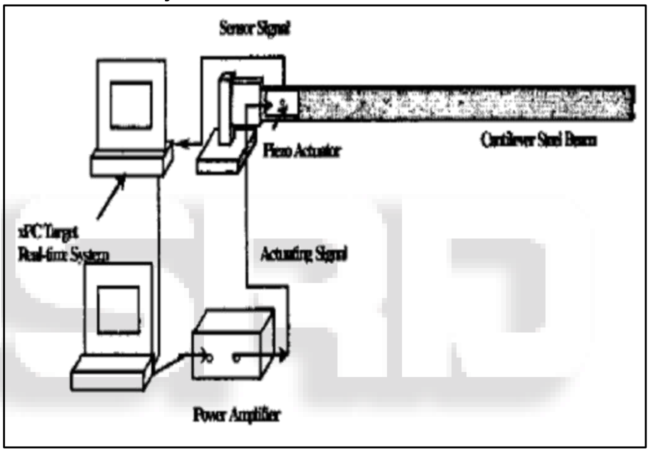

Fig. 2: Schematic of real-time experiment setup for active Control

Pradeep Kumar Sharma and Sankha Bhaduri told that the purpose of this study is to focus on the application of PZT material to control the vibration of the structures. Piezoceramics are low cost, light weight and easy to implement materials which can be applied to minimize the amplitude of structural vibration. The basic principle of PZT actuation is also discussed in this study. Piezoceramics are applied as sensor or actuators or in both form of sensor and actuators by different authors. It is available in various forms such as rigid patch, flexible patch, stack etc. In this study an attempt has been taken to discuss the application of various forms of piezoceramics for active control of structural vibration.The vibration control of beam is considered as an important engineering problem because it will enhance the stability of the system. In this paper a review is conducted on the active vibration control method of beam using smart material. As PZT materials are low cost, light weight and easy to implement materials therefore many authors attempted to control the vibration of structures using PZT smart materials. They studied the behavior of PZT materials under the influence of externally applied forces and electric current as well. Different methods of active vibration control using PZT patches are discussed in this paper. Introduction of analytical software package

(ANSYS) is also discussed here for the modeling of smart beam structure. This survey will give an introduction to a new researcher in this field to different published papers at a single glance. [12]

Juntao Fei Yunmei Fang, and Chunyan Yan presented results on active control schemes for vibration suppression of flexible steel cantilever beam with bonded PZT actuators. The PZT patches were surface bonded near the fixed end of flexible steel cantilever beam. The dynamic model of the flexible steel cantilever beam is derived. They have investigated Active vibration control methods: optimal PID control, strain rate feedback control (SRF), and positive position feedback control (PPF) and implemented using xPC Target real-time system. Their Experimental results demonstrate that the SRF and PPF controls have better performance in suppressing the vibration of cantilever steel beam than the optimal PID control. Suppression of the single dominant mode vibration is carried out and the best result is obtained using SRF-controller. [13]

A.P. Parameswaran et.al studied all the mechanical systems which suffer from undesirable vibrations during their operations. Their occurrence is uncontrollable as it depends on various factors. However, for efficient operation of the system, these vibrations have to be controlled within the specified limits. Light weight, rapid and multi-mode control of the vibrating structure is possible by the use of piezoelectric sensors and actuators and feedback control algorithms. In this paper, direct output feedback based active vibration control has been implemented on a cantilever beam using Lead Zirconate-Titanate (PZT) sensors and actuators. Three PZT patches were used, one as the sensor, one as the exciter providing the forced vibrations and the third acting as the actuator that provides an equal but opposite phase vibration/force signal to that of sensed so as to damp out the vibrations. The designed algorithm is implemented on Lab VIEW 2010 on Windows 7 Platform. From this experiment work, it was concluded that though active vibration control of the smart system was achieved, it was non-deterministic as well as non-sustained. This was attributed to the time-multiplexed nature of the GPOS (LABVIEW was run on a Windows 7 platform) where in the internal as well as external interrupts are serviced sequentially, Hence, the processor was unable to devote its complete processing time as well as capabilities towards achieving satisfactory vibration control. Thus even though active vibration control was achieved, the results showed inconsistent transient as well as steady state characteristics in the dynamics of the beam. Hence, it was concluded that experimental control of the vibrating smart beam needed to be performed on a real time operating system (RTOS) platform wherein deterministic and reliable control could be achieved. [14]

III. Experimental Setup

Active vibration control is defined as a technique in which the vibration of a structure is reduced or controlled by applying opposite force to the structure that is appropriately out of phase but equal in amplitude to the original vibration. As a result two opposite force cancel each other and structure stops vibrating. Techniques like use of springs, pads, dampers, etc have been used previously to control vibration. These techniques are known as "Passive vibration control technique". They have limitations of versatility and can control the frequencies only within a particular rage of bandwidth hence there is a requirement for active vibration control. Active vibration control is a modern approach towards vibration control at various places; classic control techniques are becoming too big for modern machines where space is limited and regular maintenance is not possible and if possible, it's too expensive, at such conditions AVC techniques comes handy, it is very cheap requires no manual maintenance and the life expectancy is also much more than the passive controllers. Active vibration control makes use of smart structure. The system mainly requires actuators, sensors, source of power and a compensator that performs well when vibration occurs. Smart structure are used in the bridges, trusses, buildings, mechanical systems etc. analysis of a basic structure can help in improving the performance of structure under poor working conditions involving beam vibrations.

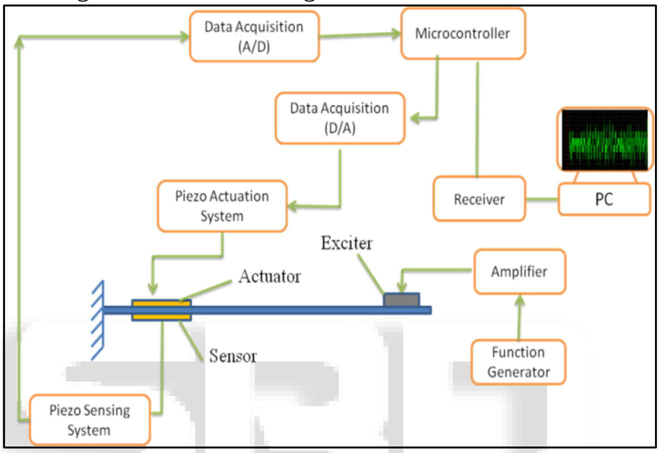

Fig. 3: Experimental setup for Active Vibration Control

The Major components are:

A. Sensor Patch

It is bonded to the host structure (beam). It is generally made up of PZT crystals. It senses the disturbance of the beam and generates a charge which is directly proportionally to the strain. Direct PZT of 50V capacity is used.

B. Controller

The charge developed by the sensor is given to the controller, the controller lines are charged according to the suitable control gain and charge is fed to the actuator. Controller also forms the feedback functions for the system. PID and SRF controller are used.

C. Actuator Patch

the lined up charge from the controller is fed to the actuator causes pinching action (Or generates shear force) along the surface of the host which acts as a damping forces and helps in the alternating vibration motion of the beam. Converse PZT is used.

The beam is clamped at one end using the set table hence making it a cantilever beam, the excitation is given from the other end, the free end using an exciter, excitation of which can be controlled using a function generator (Producing a wave form of sinusoidal, triangle, Square) and an amplifier. The excitation produces vibrations in the beam which results in the formation of shear stress in the beam, the sensor patch present at the fixed end acts to this shear stress and produces proportional electrical signals which is fed to the computer through the D/A system and finally from the computer the signal is fed to the actuator and it produces opposite shear in the beam and the entire beam is balanced. Active vibration control finds its application in all the modern day machines, Engineering structures, automobiles, gadgets, sports equipment's, ceramics, electronics etc. As it needs only a little actuation voltage hence it does not requires any external power source, the power can be directly derived from the host machine itself. As the electronics is also developing at a very fast rate hence the size of a processor is also reducing, which is very useful in the design of the control system. In this work a smart plate (aluminum plate) with one pair of PZT lamination is used to study the active vibration control. The smart plate consists of rectangular aluminum beam modeled in cantilever configuration with surface bonded PZT patches. The study uses ANSYS-14.2 software to derive the finite element model of the smart plate. Based on this model, the optimal sensor locations are found and actual smart beam is produced. In this experiment we can find a suitable control methodology by which we optimize the controller gain to get more effective vibration control with minimum control input.

IV. Conclusion

The active vibration control study of cantilever beam by piezoelectric effect is done in the papers. It is concluded that active vibration control is very effective using PZT patches. The study between the different effective controllers like neural networks or its Simulink is not yet done which is important to get effective suppression. Also the optimization is required when sensor is placed above the beam and actuator below the beam and vice versa. This system can be used at airplane wings, helicopter propellers, etc.

Acknowledgment

I would like to extend my gratitude to acknowledge those guiding lights imbibed in me the right ingredient and helped me to accomplish this task. I sincerely, acknowledge with deep sense of gratitude to my respected guide Dr. R. J. Patil, Principal, Dr. D. Y. Patil Institute of Engineering and Technology, Pune for his guidance and encouragement.

References

[1] Qinglei Hu, Guangfu Ma "Spacecraft vibration suspension using variable structure output feedback control and smart material." Transactions of the ASME Vol. 128, APRIL 2006.
[2] Deepak Chhabra, Kapil, Narwal, Pardeep, Singh "Design and Analysis of PZT Smart Beam for Active Vibration Control" International Journal of Advancements in Research & Technology, Volume 1, Issue1, June-2012.
[3] Yavuz Yaman, Tarkan Callskan, Volkan Nalbantonglu "Active vibration control of smart plate" ICAS2002 CONGRESS.
[4] S.Raja, G.Prathap, P.K.Sinha "Active Vibration Control of composite sandwich beams with distributed PZT extension-bending and shear actuator" Article in Smart Materials and Structures February 2002.
[5] R. Setola "A spline based Reconstruction for active vibration control of a flexible beam" Journal of Sound and Vibration (1998) 213(5), 777–790
[6] Te˝o Lenquist da Rocha, Samuel da Silva, Vicent lopes Jr "Optimal location PZT sensor and actuator for flexible structure" Eleventh International Congress on sound and Vibration July 2004.
[7] Zeki KIRAL, Levent MALGACA, Murat AKDA˘G "Active Vibration Control of Residual Vibrations of a cantilever smart beam." Turkish J. Eng. Env. Sci. 32 (2008)
[8] C Mei, "Hybrid wave/mode active control of bending vibrations in beams based on the advanced Timoshenko theory." (Journal of Sound and Vibration 322 (2009) 29–38)
[9] Chih-Liang Chu, Bing-SongWu, Yih-Hwang Lin, "Active vibration control of a flexible beam mounted on an elastic base." doi:10.1016/j.finel.2006.07.001.
[10] Jaques Lottin, Fabian Formosa, Mihal Virtosu, Laurent Brunett "Optimum location of sensors and actuators for the control of flexible structure." Research and Education in Mechatronics KTH, Stockholm, Sweden June 15-16, 2006
[11] K. B. Waghulde, Dr. Bimleshkumar Sinha, M. M. Patil, Dr. S. Mishra "Vibration Control of Cantilever Smart Beam by using PZT Actuators and Sensors" International Journal of Engineering and Technology Vol.2(4), 2010, 259-262
[12] Pradeep Kumar Sharma, Sankha Bhaduri, "Active Vibration Control Structures Using PZT Materials: A Review" International Journal of Emerging Research in Management &Technology ISSN: 2278-9359 (Volume-4, Issue-11) November 2015
[13] Juntao Fei "Active Vibration Control of Flexible Steel Cantilever Beam Using PZT Actuators" 2012.
[14] A.P. Parameswaran*, A.B. Pai, P.K. Tripathi, and K.V. Gangadharan, "Active Vibration Control of a Smart Cantilever beam on General Purpose operating System", Defence Science Journal, Vol. 63, No. 4, July 2013, pp. 413-417, DOI: 10.14429/dsj.63.4865.