Numerical and Experimental Study on Dynamic and Static Behavior of Cantilever Beam using PZT Actuators

Dr. R. B. Barjibhe [1], Mr. P .V. Fegade[2]

[1]Professor, Dept. of Mechanical Engineering, S.S.G.B.C.O.E.T., Bhusawal. (INDIA)

[2]Assistant Professor, Dept. of Mechanical Engineering, S.S.G.B.C.O.E.T., Bhusawal. (INDIA)

---***---

Abstract – *In this present scenario deformation is the major problem in structural design. In Aerospace and satellite objects, faces a major problem of static deformation due to many parameter uncertainties and environmental disturbances. Piezoelectric materials allow the transformation of electricity constraints into mechanical constraints and vice versa. They are used as controllers or sensors in the industry field. The objectives of this work are the modeling of smart structures and study on dynamic and static behavior of the beam, also the effect of the number and location of the actuators in the control system. In this work we consider a cantilever beam under static loading condition and tried to reduce the deflection of that beam using piezoelectric actuator. The study uses ANSYS software to derive the finite element model of the beam. Experimentation was also conducted to verify numerical results. The effect of the number and locations of the actuators on the control system are also investigated. Results are presented to show the dynamic and static behavior of aluminium beams with piezoelectric (PZT) actuators. The work displayed the role of piezoelectric actuators for the active control of the beam which is utilized to control the different beam like structure like aerospace component, the tail of the aircraft, Arial reflectors etc.*

Key Words: ANSYS, Cantilever Beam, Mode shape, Natural Frequency, Piezoelectric (PZT) Actuators.

1. INTRODUCTION

Engineers from civil, electrical, aerospace and mechanical engineering fields are all involved in some part of the development of smart materials and structural systems. One reason for this activity is that it may be possible to create structures and systems that are capable of adapting or correcting in response to changing operating conditions without human intervention. The advantage of incorporating these special types of materials into a structure is that the sensing and actuating mechanisms become a part of the structure and can directly sense and actuate strains. Smart materials are defined as materials that are capable of automatically and inherently sensing or detecting changes in their environment and responding to those changes with some kind of actuation or actions. These characteristics provide several possible applications for these materials in aerospace, manufacturing, civil infrastructure systems, and biomechanics. Active vibration and acoustic transmission control, active shape control, and active damage control are some of the areas that have found innovative applications for smart materials and structures. Examples of specific applications is micro positioning, vibration isolation, fast acting valves and nozzles, transducers, luxury car shock absorbers, and active engine mounts in aircraft. Some of the benefits of using smart materials are system integration, reduction of mass and energy requirements, elimination of moving parts in actuators, and collocation between actuator and sensor. Piezoelectric materials like (lead-Zirconium-Titanate) can be used effectively in the development of smart systems. So far a large amount of work has been devoted exploring smart plates with piezoelectric actuation. Some of them suggested strategies have already found in practical applications in vibration control. Materials with piezoelectric properties have been found to exhibit pyroelectric and electro caloric properties for the possible conversion of thermal energy into electrical energy, and vice versa. Conversion of thermal in to mechanical energy and vice-versa by means of thermal expansion together with piezoelectric effect can be observed in piezo-thermoelectric materials. These effects can be used to increase the efficiency of the control actuation. K.B.Waghulde, Dr. Bimlesh Kumar, Prof. T.D. Garse, Prof. M.M. Patil studied on vibrations induced in flexible structures such as beam have been researched through various optimization functions and control theories to optimize transient response dynamic characteristics. Piezoelectric materials sensors/actuators have been used to reduce and control these vibrations.[1]
J.J. Liu and B.M. Liaw have aimed to explore efficiency problems of using PZT actuators in active vibration control of beams and Stepped beam model is then derived to describe the beam-actuator structure when the effect of actuators is taken into consideration. Modal expansion method is used to determine the efficiency index of PZT actuators in each mode.[2] Waleed Khalid and Al Ashtari, describes the governing equation of the thin smart beam transverse deflection was derived by the same procedure that the Bernoulli-Euler equation derived but with some additional mathematical terms to be valid for describing the smart beam.[3] K. Venkata Rao S. Raja T. Munikenche Gowda, presented partially debonded actuators affect stiffness and vibration characteristics of the piezoelectric beam and thus leading to degradation in actuation authority and active vibration control system. It is carried out to understand the bending behaviour of the piezoelectric beam in the presence of edge debonded actuators. Furthermore, the effect of debonding of actuators on the natural frequencies of the

beam is investigated.[4] The primary goal of this work is the modelling of smart structures. Static and dynamic analytic models will be derived for segmented piezoelectric actuators that bonded to an aluminium beam. These models lead to the ability to predict:

1. The natural frequencies and mode shapes of this smart beam.
2. The deflection and the response of a beam induced by external forces or both piezoelectric actuators and external forces.
3. The effects of the number and location of the actuators on the control system.

2. MODELING OF CANTILEVER BEAM WITH PZT ACTUATOR USING ANSYS

2.1 Modal Analysis

The natural frequency of the aluminium beam is found by the well known Finite Element (FEA) Software ANSYS. Modal analysis is carried out using the Block Lanczos method for finding the natural frequencies. The fixed free boundary condition was applied by constraining the nodal displacement in both x and y direction.

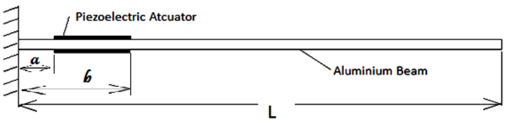


Fig.1 Schematic of Cantilever Beam With PZT

Table-1: Material Properties and Dimensions of Aluminium Beam and Piezoelectric Actuator

Dimensions/Properties	Aluminium	PZT actuator
Length	0.4 m	0.0762 m
Width	0.03 m	0.0254 m
Thickness	0.005 m	0.5x10-3 m
Density	2700 Kg/m3	7600 kg/m3
Young modulus	70 Gpa	76 GPa
Poisson's ratio	0.3	0.25
PZT Stain Constant	----	-247 x 10-12 m/V

The first two mode shapes of aluminium beam with and without PZT are shown in following Fig.2 and Fig.3

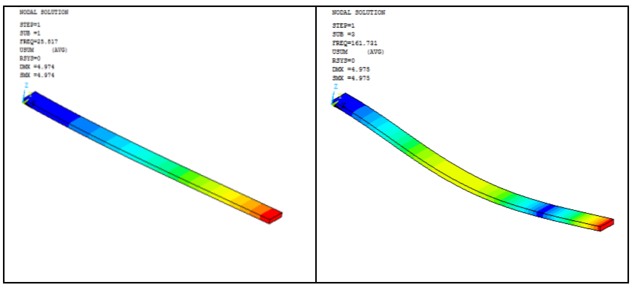


Fig.2 1st and 2nd Mode Shape of Cantilever Beam without PZT Actuator

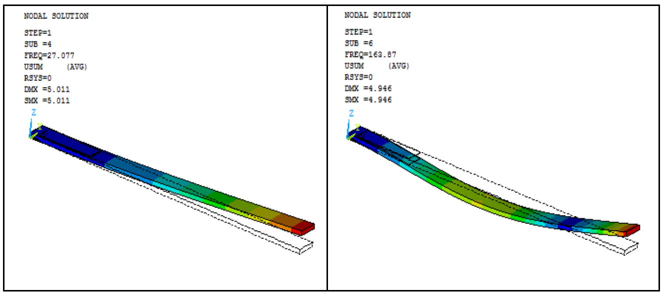


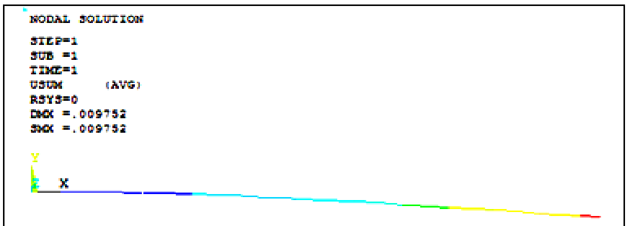
Fig.3 1st and 2nd Mode Shape of Cantilever Beam with PZT Actuators

Table 2: First Two Natural Frequencies of Beam

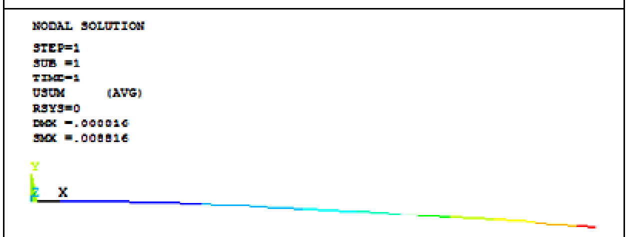
Mode	f_n (Hz) Without PZT Actuators	f_n (Hz) With PZT Actuators
1	25.817	27.07
2	161.731	163.87

2.2 Static Analysis

The deflection model is an approximate since the only control action is considered. Several examples of beam had been studied under same external action and various actuation boundary conditions to illustrate how deflection control can be achieved with use of PZT actuators. So the cantilever beam under point load at free end is considered and the response of the beam external action and actuation is superimposed. The results are shown in Fig. 4 to Fig.6.



Deflection of beam at 0 volt



Deflection of beam at 25 volt

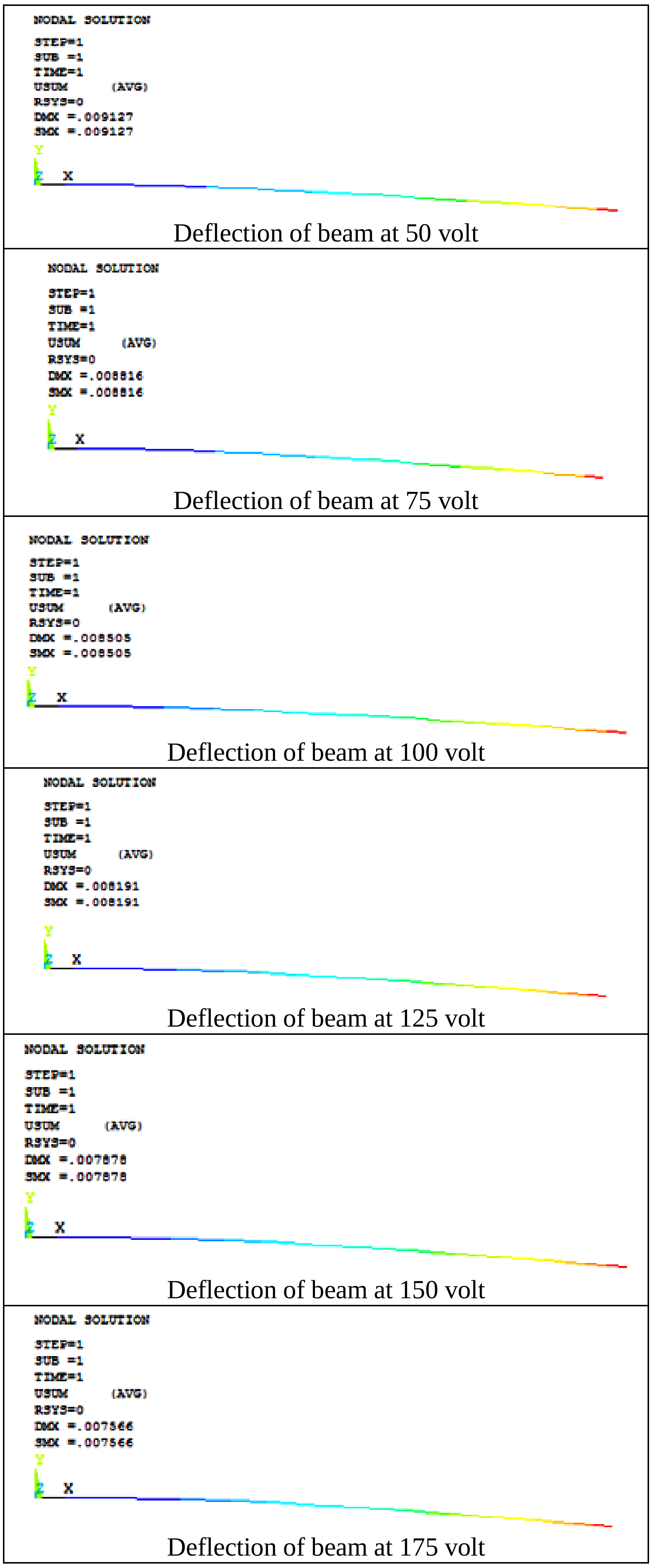


Fig.4 Deflection Control of Beam When PZT Actuators is Placed Near Fixed End and Various Voltages Applied to it.

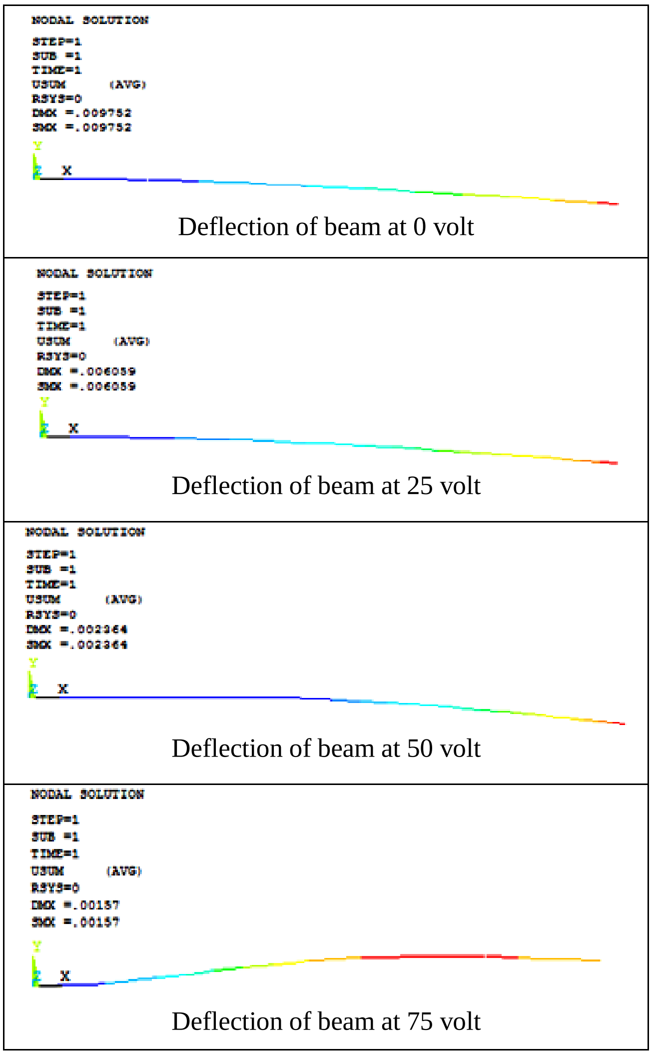
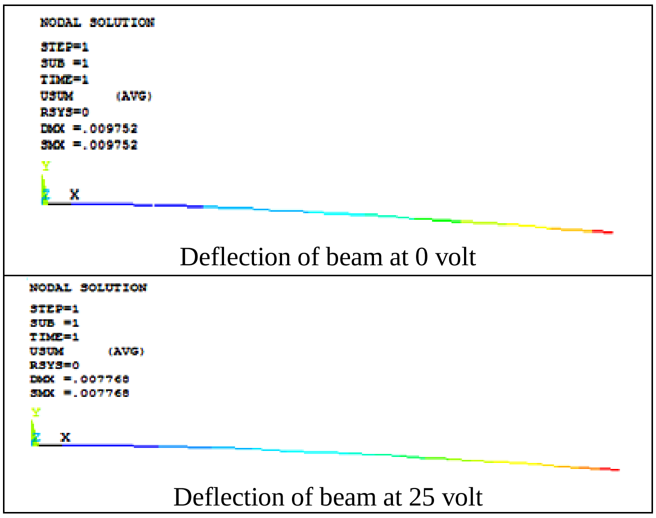


Fig.5 Deflection Control of Beam When PZT Actuators is Placed at Middle of the Beam and Various Voltages Applied to it.



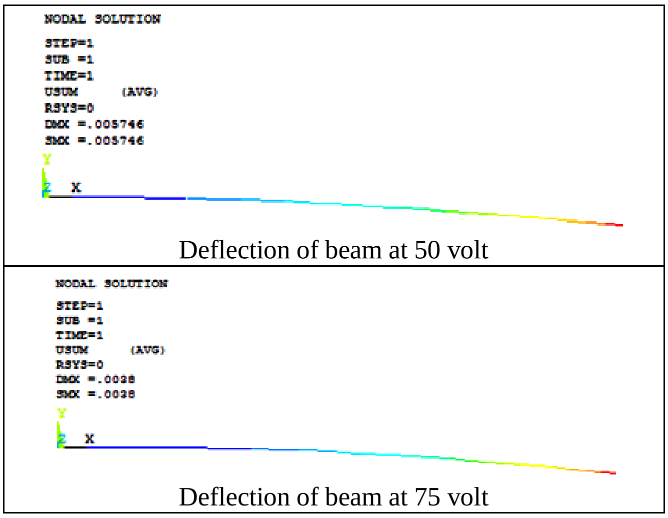


Fig.6 Deflection Control of Beam when PZT Actuators is Placed Near Fixed End and at Middle of the Beam and Various Voltage Applied to it.

3. EXPERIMENTAL SETUP

As explained previously, the natural frequencies and mode shapes of a cantilever beam bonded with piezoelectric actuator can be predicted numerically (ANSYS). Experimental analysis has been conducted to verify the numerical approach. Among piezoelectric materials, lead zirconate titanate (PZT) has high coupling coefficients and piezoelectric charge coefficients. PZT-5H of Sparkler Ceramics Company is used for actuators. They are thin, unobtrusive, self-powered, adaptable to complex contours, and available in a variety of configurations. Fig. 7 represents the experimental setup. The experimental setup consists of a cantilever aluminium beam with piezoelectric actuators. A sensor, it was used to measure the displacement at the tip. A control panel instrument and a personal computer, acquired the output data from the sensor at the same time. A function generator was used to provide a harmonic signal to an amplifier which supplied voltage to the piezoelectric actuator.

4. RESULT AND DISCUSSION

Numerical and Experimental results are presented to show the dynamic and static behavior of aluminium beams with PZT actuator. The adhesive layers are neglected. A constant voltage with an opposite sign was applied to the PZT actuator on each side of the beam. Due to the converse piezoelectric effect, the distributed PZT actuator contract or expand depending on negative or positive active voltage. In general, for an upward displacement, the upper actuators need a negative voltage and the lower actuators need a positive one. The control of static deflection and modal analysis of the beam under the distribution of PZT actuator are analyzed. The natural frequencies for aluminium beam without and with PZT actuator are listed in Table 2.

Fig. 7 Experimental Setup

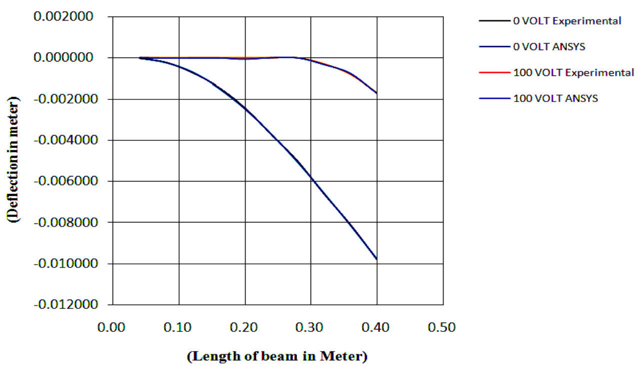


Fig.8 Comparison of Deflection Control Result When 100 Volt Applied to Actuators Placed Near Fixed End and Middle of the Beam

After that a 10 N load is applied to the tip of the beam. It is clear that the structure reverts as the specified voltages are increased. To investigate the effect of the number and placement of the PZT actuator on the deflection control, Two sets of the PZT actuator pairs are considered: (near fixed end and at the middle of the beam); one PZT actuator (near fixed end and the middle ones, near fixed end and near free end) located on the beam. When one pair of PZT actuator is used, a very high active voltage is needed to reduce the deflection, and the beam is also not smoothly flattened. In next when we placed one PZT near fixed end and near free end then the structure goes to reverts. It can be observed that there is a better agreement of numerical results and experimental results for 100 volts applied to PZT when placed near fixed end and at middle of the beam (shown in Fig.8). Also it shows that below a certain active voltage, the beam can be flattened quite smoothly by PZT actuator placed near fixed end and the middle positions of the beam for 100 volts applied to the PZT. And we observed that it is not necessary to cover the whole beam with piezoelectric actuators.

5. CONCLUSIONS

A simple but efficient approach was proposed to simulate the action of the PZT actuators placed on cantilever beam. The solutions of the transverse displacement induced by actuation have been written in such form that explicitly accounts for the position of the actuator. Finite element verification of the proposed model is presented. Through the use of those solutions, the deflection control in a beam subjected to static external action can be achieved. Experimentation was also conducted in order to verify the numerical results. Finally, the effect of the number and locations of the actuators on the control system are also investigated. When we placed one pair of PZT near fixed end then the deflection of the beam is controlled as about 28% also it required more voltage. When we placed PZT actuator near fixed end and at middle of the beam then the deflection of the beam controlled as about 82% also it required less voltage and we observed that beam flattened quite smoothly. The investigation shows that designing smart structures with distributed PZT actuators, the number and location of the actuators must be given careful consideration

REFERENCES

1. K.B.Waghulde, Dr. Bimlesh Kumar, Prof. T. D. Garse and Prof. M.M.Patil, “Smart Materials and Structures used for Vibration Control”, Journal of Information Knowledge and Research in Mechanical Engineering, Nov. 10- Oct. 11, Vol.1 pp.26-30.

2. J.J. Liu and B.M. Liaw, “Efficiency of Active Control of Beam Vibration Using PZT Patches” International Congress & Exposition on Experimental and Applied Mechanics Costa Mesa, CA, June 7-10, 2004

3. Waleed Khalid and Al Ashtari, “The Deflection Control of a Thin Cantilever Beam by Using a Piezoelectric Actuator / Sensor” 1st Regional Conference of Eng. Sci. NUCEJ Special Issue Vol.11,No.1, 2008, pp. 43-51

4. K. Venkata Rao, S. Raja and T. Munikenche Gowda, “Bending Behavior and Vibration of Piezoelectric Beam with Debonded Actuators: Coupled Finite Element Analysis”, International Journal of Applied Engineering Research, (2012), ISSN 0973-4562, Vol.7, No.11

5. Yuvaraja .M, Senthilkumar.M and I. Balaguru, “Study on Vibration Characteristics of PZT Actuated Mild steel and Aluminium Cantilever Beams”, Annals of Faculty Engineering Hunedoara, International Journal of Engineering, (2011), pp. 177-182

6. Action Nechibvute, Albert Chawanda, and Pearson Luhanga, “Finite Element Modeling of a Piezoelectric Composite Beam and Comparative Performance Study of Piezoelectric Materials for Voltage Generation”, International Scholarly Research Network,(2012), pp. 1-11

7. Dongchang Sun, Liyong Tong and Satya N. Atluri, “ Effects of Piezoelectric Sensor/Actuator Debonding on Vibration Control of Smart Beam” International journal of Solid and Structures, (2001) pp. 9033-9051

8. Pushkar V. Fegade, Prof. A. V. Patil, Prof. L. K. Toke “Study on Optimal location and Optimal Voltage for PZT Actuator on Aluminium Cantilever Plate ”,International J. of Engg. Research & Indu. Appls. (IJERIA), Vol.6, No. 4, Nov 2013, pp 119-126.