Modeling and Active Control of a Deformed Smart Structure Using Piezoelectric Elements

A. Lebied
Mechanical Engineering Department, Faculty of Engineering Sciences
University Mentouri Constantine, Algeria
lebied.aziz@yahoo.fr

B. Necib
Mechanical Engineering Department, Faculty of Engineering Sciences
University Mentouri Constantine, Algeria

M. Sahli
Departement de Mécanique Appliquée, ENSMM
24 chemin de l’Epitaphe, 25030 Besançon, France
mohamed.sahli@ens2m.fr

Copyright © 2013 A. Lebied, B. Necib and M. Sahli. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

The vibration reduction and health control of structures have become issues of an essential interest in many sectors of innovative industries, particularly in the fields of aeronautics, aerospace, biomechanics, transportation and others. The insertion techniques of new materials and smart structures in the mechanical systems allow getting gains in cost, maintenance and more accurate monitoring for smaller design margins and a reduction in weight of these structures. In this context, our study revolves around the control of health and deformation of smart structures, taking into account the mechanical and piezoelectric behaviour of sensors and PZT actuators, mechanical contact as well as the initial conditions and the imposed boundary conditions. In this work, an approach for modelling of an
intelligent structure by the finite element method was presented. This structure is of aluminium type beam with elastic behaviour where piezoelectric rectangular pellets discreetly spread on the surface of the beam are instrumented. The realised numerical simulations were carried out and compared with experimental resultants from the literature and the results show the effectiveness of these PZT elements, depending on their positions, and to control the deformed structure and good agreement has been found between the experimental data and numerical predictions.

**Keywords:** smart structure, piezoelectricity, sensors, finite elements modelling

1 Introduction

These recent years have seen the emergence of many developments in the field of so-called smart structures, which means structures containing sensors and actuators coupled to a computer and able to respond to external stimuli [1,2]. Among the many types of materials that can be found in nature, piezoelectric materials exhibit remarkable characteristics [3,4]. Due to their electromechanical conversion ability and their small footprint, the use of piezoelectric transducers open the door to a wide range of applications in active control of structures in the fields of aero spatial, civil engineering, land and air transport domain. Compared to a classic mechanical structure, the phenomena related to the behavior of piezoelectric materials induce a coupling relationship between the mechanical displacement and electrical variables that must be taken into account in numerical modeling.

Piezoelectric materials have the property of to focus electrically under the action of a mechanical force, and vice versa, and to deform when we applied to them an electric field [5, 6]. This phenomenon is reversible which allows using the piezoelectric elements indifferently either as actuators or sensors or even the two functions combined (Fig. 1).

![Figure1. Piezoelectric effect at a microscopic scale.](image-url)
Many works have been carried out these past ten years in the field of the supervision structures. Some of these studies are qualitative [7], while others offer simplified models to determine the size and the position of the defect [8], in order to detect cracks [9] to control the polymerization during the composite manufacturing [10] and to control the change in the shape of the structures. All of these works have allowed of developing different measurement systems and some surveillance systems which are already used in the aerospace industry or in the field of civil engineering [11, 12]. It should be noted that most of the work on control of health of adaptable structures are especially focused on experimental analyses [13-15]. Ling et al, [16] conducted a study to measure the electro-mechanical impedance of piezoelectric sensor coupled to a structure in order to obtain information on its dynamic frequency response. These same transducers were used by Grondel et al. [17] to generate and receive of Lamb waves in plates and shells. Modeling and health monitoring of smart structures by the finite element method has been the subject of particular attention [18,19]. The interest for piezoelectric materials as well as their applications in the design of smart structures, the detection of impacts, delamination or cracks using the reflection of waves and the conversion of the modes to the passage of a defect, has led many researchers to formulate new elements [20-22]. Using only the velocities of each mode, Osmont et al. [23] have managed also to locate a hole in a sandwich structure. Grondel et al. [24] have developed models for detecting defects in shape using piezoelectric transducers. Finally, Naillon et al. [25] synthesize the different methods of resolution of the problem to the eigenvalues (calculation of resonances and the ant resonances) of piezoelectric structures modeled by tridimensional volume elements. In this study we are interested on the study of structural monitoring over time, using piezoelectric elements as rectangular patches for the preservation of their state of health.

2 Numerical simulations

2.1 Boundary conditions

Considering flush-free aluminum beams, the thickness, width and length are 2, 10 and 100 mm, respectively. The Al-beams control form is made possible by equipping them of a piezoelectric actuator of ceramic type PZT - 5A actuator which can generate distortions when it is applied to them an electric field.
These last will cause changes in shape so as to obtain a gradual overall increase of the deformed system (beam Al/PZT). For this, a voltage from 5 to 30 volts has been applied on the upper and lower surface of the piezoelectric side placed on the top side of the beam, inducing bending efforts. These efforts allowed finally deflecting the beam. And the other hand, the second ceramic piezoelectric sensor of type (PZT - 5A) allows to measure the deformations generated on the beam. All PZT patches are supposed perfectly bonded. The elastic properties and electrical characteristic of the piezoelectric actuator (PZT - 5A) are presented in table 1.

![Diagram of beam actuation](image)

Figure 2. Active control of beams actuated by extension PZT elements bonded on both surfaces (dimensions in mm).

<table>
<thead>
<tr>
<th>designation</th>
<th>materials</th>
<th>Al</th>
<th>PZT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td></td>
<td>2.7</td>
<td>7750</td>
</tr>
<tr>
<td>Young's modulus E₁</td>
<td></td>
<td>69GPa</td>
<td>69GPa</td>
</tr>
<tr>
<td>Young's modulus E₂</td>
<td></td>
<td>69GPa</td>
<td>55GPa</td>
</tr>
<tr>
<td>Shear modulus G₁₂</td>
<td></td>
<td>26</td>
<td>25GPa</td>
</tr>
<tr>
<td>Poisson's Coefficient</td>
<td></td>
<td>0.33</td>
<td>0.384</td>
</tr>
<tr>
<td>Piezoelectric Coefficient d₃₁</td>
<td></td>
<td>-171 pm/V</td>
<td></td>
</tr>
<tr>
<td>Piezoelectric Coefficient d₃₃</td>
<td></td>
<td>374pm/V</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td>100mm</td>
<td>10mm</td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td>10mm</td>
<td>10mm</td>
</tr>
<tr>
<td>Thickness</td>
<td></td>
<td>2mm</td>
<td>100µm</td>
</tr>
</tbody>
</table>

### 2.2 Construction of the model

The numerical simulations were performed using the LsDyna® software and comforted with those find in the literature [26, 27]. The structure is meshed with quadratic planar eight-node type Plane180 with degrees of freedom are the displacements along x and y.
The piezoelectric material is mesh with elements type Plane223 whose degrees of freedom are the displacements along x and y and the electric potential. The complete structure is discretized using 185 elements with two layers of elements in the thickness of the PZT elements and three in the thickness of the beam Al. Certain hypotheses for modeling of the boundary conditions have been proposed. First structure is supposed fixed at one of the two ends, while the other end is free. In this model, varying the position of the center of the actuator in the range of 10 to 90mm. The applied voltage is of the order of 5 to 30Volts. The geometry and boundary conditions are shown on Figure 3.

![Figure 3. Mesh finite elements and boundary conditions of the structure.](image)

### 3 Results and discussion

The deflected beams generated by piezoelectric elements PZT-5A is calculated for different voltages whose values are varying between 5 to 30Volts. The simulation results are shown on Figures 4 and 5.

The response in terms of change in displacement in function of the applied voltage (see Fig.4), that allows to see the deformation of the bending beam follows the increase of the voltage. The evolution of the arrow at the free end of the beam is also shown on Figure 5. It is observed that its value increases as a function of one part of the actuator position retained until reaching a maximum near the recess, and secondly depending on the field applied to the piezoelectric element.

![Figure 4. Deformation of the extension beam actuated by piezoelectric element.](image)
Simulating the deformation of Al beam by piezoelectric element is shown on Figure 6. The test duration is 15s. It tells the elastic energy in the structure for a voltage applied equal to 20volts.

4 Experimental Validation

The configuration of Figure 3 with two piezoelectric patches has been studied analytically by Sun and Zhang [25] and experimentally Gevarter and al., [26]. Our model FE proposed in this study was valid by comparison with these two studies (analytical and experimental). The comparisons were shown on Figure 7, showing a good correlation between the results. They also highlight the effectiveness of PZT actuators used to precisely detect the deformed beams. Note also that the three types of analysis yield similar results.
Figure 7. Variation of the arrow from the free end of the beam according to the position of the actuator.

5 Conclusion

Numerical modeling by finite elements model for the measurement of the deformation and the change in shape of a clamped-free structure composed of both elastic and piezoelectric materials have been given by using the LsDyna® software. The numerical results were valid by comparisons with analytical and experimental results find in the literature. The numerical results showing a good correlation and agree very well. It was also concluded that the actuator and the sensor will be better placed at the housing because it is the position or the actuator has the greatest impact and where the sensor gives the greatest signal. They are said to co-located as glues one below the other on either side of the beam.

References


the sensing capability of a piezoceramic inertial actuator, Sensors and Actuators A
Physical, 93 (2001) 243-249.

[16] S. Grondel, et al., The propagation of Lamb waves in multilayered plates:
phasevelocity measurement, Measurement science & technology, 10 (1999) 348-
353.

[17] A. Benjeddou, Advances in piezoelectric finite element modeling of
adaptative structural elements: a survey, Computers & Structures, 76 (2000) 347-
363.

[18] A. Zallo, P. Gaudenzi, Finite element models for laminated shells with

[19] T. Monnier, Ondes de Lamb dans les milieux stratifies. Application a la
surveillance in situ et en temps réel de l'endommagement de structures

composite plate/shell structures and its application to the study of active vibration

[21] S. Tliba, Contrôle actif des vibrations dans des structures mécaniques minces
instrumentées de transducteurs piezoélectriques, Thèse à l'ENS de Cachan,
Cachan (94), décembre 2004.

[22] D. Osmont, Health monitoring of Sandwich plates based on the analysis of
the interaction of Lamb waves with damages, Proceedings of Conference on
Structural Health Monitoring, These de doctrotat a l'Ecole Normale Superieure de
Cachan, France, 2002.

[23] S. Grondel, et al., Design of optimal configuration for generating A0 Lamb
mode in a composite plate using piezoceramic transducers », Journal of the


[26] W. Gevarter, Basic Relations for Control of Flexibles Structures, AIAA
Received: September 23, 2013