Utilizing the Finite Element Method to Analyze the Active Vibration Suppression of Structural Systems

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Introduction:

The use of piezoelectric materials in smart/adaptive structures has been studied intensely for more than a decade. Engineering applications using this technology have been proposed and conceived experimentally, such as for active vibration suppression, noise cancellation, and shape control.

In this work, a distinctly different piezoelectric transduction mode is utilized where the electric field is applied perpendicular to the poling direction. In this case, a piezoelectric rectangular element that is poled in the longitudinal direction and subjected to an electric field *E*3 in the thickness direction will undergo shear deformation as shown in Figure 1(b). This is referred to as the piezoelectric *shear* actuation mechanism.

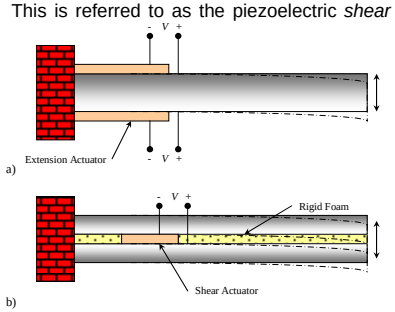


Figure 1. Piezoelectric extension and shear actuators

The finite element method is utilized to replicate experimental results of the active vibration suppression of a cantilever beam with embedded piezoelectric shear actuators. The commercial finite element package **ABAQUS** is utilized for the numerical modeling. The feedback control is implemented using FORTRAN subroutines coupled to the ABAQUS analysis. It is shown that the numerical model accurately predicts the influence of the feedback control system on the dynamic response of the beam.

Feedback control:

In this study, active vibration suppression is implemented using a feedback control system. The controller design is that of the Positive Position Feedback (PPF) algorithm. The structure and the compensator are coupled using the following relationships:

$$\ddot{\xi} + 2\zeta\omega_n \dot{\xi} + \omega_n^2 \xi = g\omega_c^2 \eta \qquad \ddot{\eta} + 2\zeta_c \omega_c \dot{\eta} + \omega_c^2 \eta = \omega_c^2 \xi$$

Structure Compensator

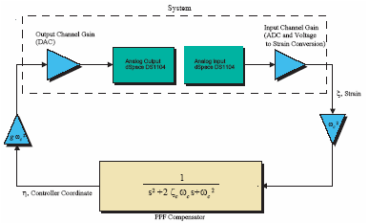


Figure 2. Experimental implementation of PPF control

Cantilever Beam:

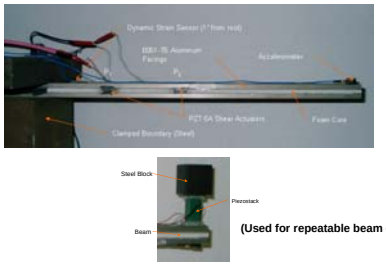
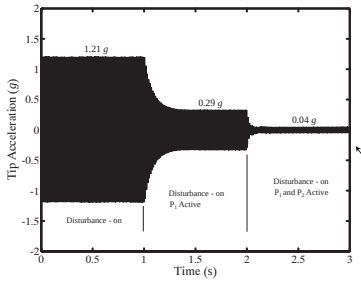


Figure 3. Cantilever beam configuration

Results:

Table 1. Natural frequency comparison

Mode	Experimental Natural Frequency (Hz)	Finite Element Natural Frequency (Hz)	% Diff.
1	123.0625	126.85	2.9858
2	495.7125	495.12	0.11967
3	1098.275	1094.6	0.33574
4	1538.200	1558.3	1.2899



96.7% reduction in Amplitude!!!

Figure 5. Cantilever beam tip acceleration with various feedback control options

Finite element model:

- A two dimension plane stress implicit dynamic **ABAQUS** model is utilized to characterize the structural response of the cantilever beam. The model consisted of 2754 CPS8R and CPS8RE elements (8893 nodes).
- The mathematic representation of the compensator is that of a spring-mass-damper system. A spring-mass-damper system is included in the model to act as a physical representation of the compensator.
- The two systems (beam and compensator) are coupled using user subroutines intrinsic to **ABAQUS**. In the experiment, the strain at the root of the beam is used as the sensor input to the control system. The numerical model is consistent, in that the strain at the root of the beam applies a force to the compensator. In turn, the value of the compensator displacement, multiplied by a scalar gain, is applied as an electric potential to the piezoelectric shear actuators.

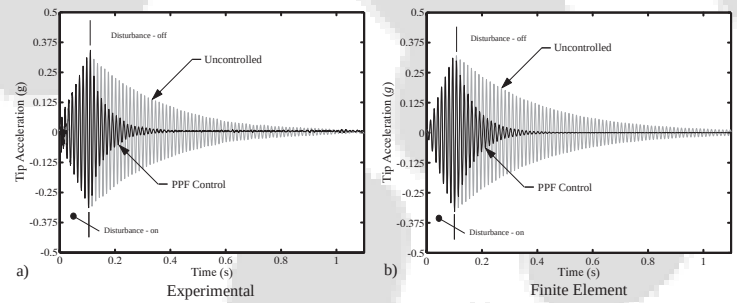


Figure 4. Experimental and finite element comparison of settling time of the cantilever beam

Table 2. Results of the settling time comparison

	Experimental	Finite Element
Damping Ratio PPF	3.4 %	3.2 %
Damping Ratio Uncontrolled	0.78 %	0.74%
Settling Time Decrease	69.8 %	73.3 %

Conclusion:

The goal of this study was to accurately reproduce the observed experimental response of the vibration suppression of a cantilever beam using the finite element method. The control algorithm utilized was Positive Position Feedback. It is shown that the dynamic characteristics of the cantilever beam are accurately represented utilizing the finite element method with the active vibration suppression active and inactive.

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