Structural Health Monitoring Applications Using Piezo-Dielectric Effects

Jeffrey S. Vipperman

University of Pittsburgh
Department of Mechanical Engineering
Sound, Systems, and Structures Laboratory
531 Benedum Engineering Hall
Pittsburgh, PA 15261

Outline

- ➢ Overview of Current Health Monitoring Systems
- ➢ Linear Piezoelectricity
- ➢ Adaptive Piezoelectric Sensoriactuator (APSA)
- ➢ Experimental Demonstration
- ➢ Conclusions and Future Work

What do we Want in a Health Monitoring System?

- Real-Time Operation
- In-Situ Operation
- Self-monitoring or autonomous
- Quantify "damage"
- Locate damage
- Scalable
- Cheap, simple, easy-to install, amenable to retrofit market

- No method provides the complete answer

Brief Overview of Some Previous Methods and [Strengths] and (Weaknesses)

- Ultrasound: [detailed 3-d view of internal structure, portable], (surface delams, tedious, no measure of structural degradation)
- X-ray and Thermography [Excellent, 2-d view of defects, easy], (bulky, expensive, no *in-situ* or real-time)
- Acoustic Emission [can determine distance to failure, real-time, *in-situ*, can tell failure is imminent], (little quantification)
- Fiber Optic Array [Can pinpoint damage, *in-situ*, real-time], (have to create grid with adequate structural resolution, only finds cracks that break fiber-optic cables)
- Modal (Frequency) Analysis [well understood], (model based, temperature effects, eigenanalysis required to pinpoint damage - complex, computationally-intensive)

Features of Proposed Method

- Monitors Electrical Behavior of Piezoelectrics to determine mechanical properties of the structure to which it is attached
- PZT "sees" structure as a distributed elastic foundation
- Real-Time Operation
- In-Situ Operation
- Very Cheap and Simple
- Easy to Retrofit
- Can use APSA simultaneously as a transducer for active control

Linear Piezoelectric Equations

$$T_{ij} = c^E_{ijkl} S_{kl} + e_{kij} E_k$$ (Actuator)

$$D_i = e_{ikl} S_{kl} + \varepsilon^S_{ik} E_j$$ (Sensor)

$()^S$ - Blocked Value

$()^E$ - Short Circuit Value

Monitor Permittivity (Capacitance)

- "Blocked" vs. "Free" Capacitance

$$\varepsilon^S = \varepsilon^T \left(1 - k^2\right)$$

- PZT-5A, *k*=0.7, so

$$\frac{\varepsilon^T}{\varepsilon^S} \approx 2$$

- Capacitance of an Electroded Piezoelectric Patch

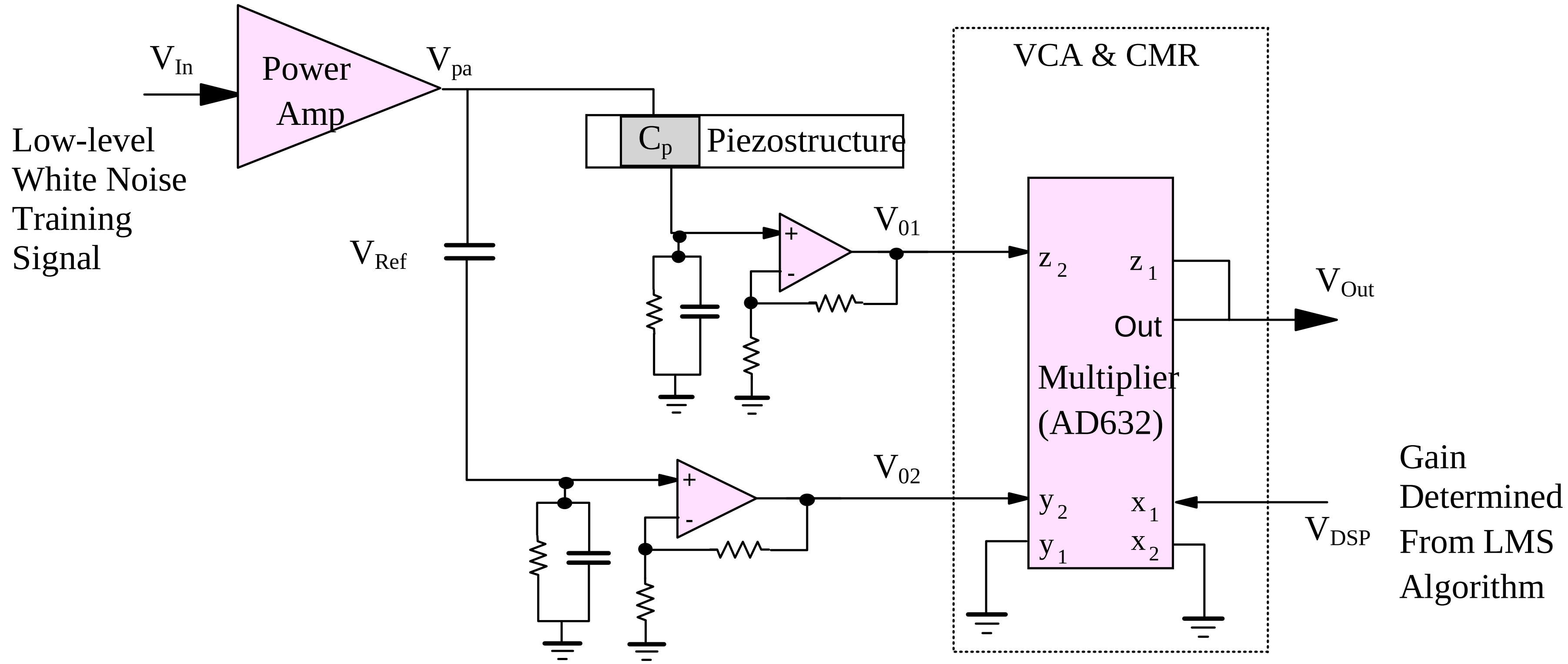
$$C_p = \frac{\varepsilon A}{t}$$

Adaptive Piezoelectric Sensoriactuator (APSA)

- Self-sensing piezoelectric transducer
- Provides truly collocated sensor/actuator pair
- Separates mechanical and electrical charges
- Inherently monitors capacitance of piezoelectric patch in real-time
- Health monitoring operation independent of control
- Dual-technology opportunity

➡ Vipperman, J. S., and R. L. Clark", "Implementation of an Adaptive Piezoelectric Sensoriactuator," AIAA Journal, 34(10), 1996, pp. 2102-2109.

Adaptive Piezoelectric Sensoriactuator (APSA) - Schematic



- Sets Gain Across Analog Network

$$w(k+1) = w(k) - \mu e(k)x(k)$$ (LMS)

- Adaptive Filter Coefficient Prop. to Capacitance

$$C_p \propto w(k)$$

- Looks for "abrupt" changes in capacitance

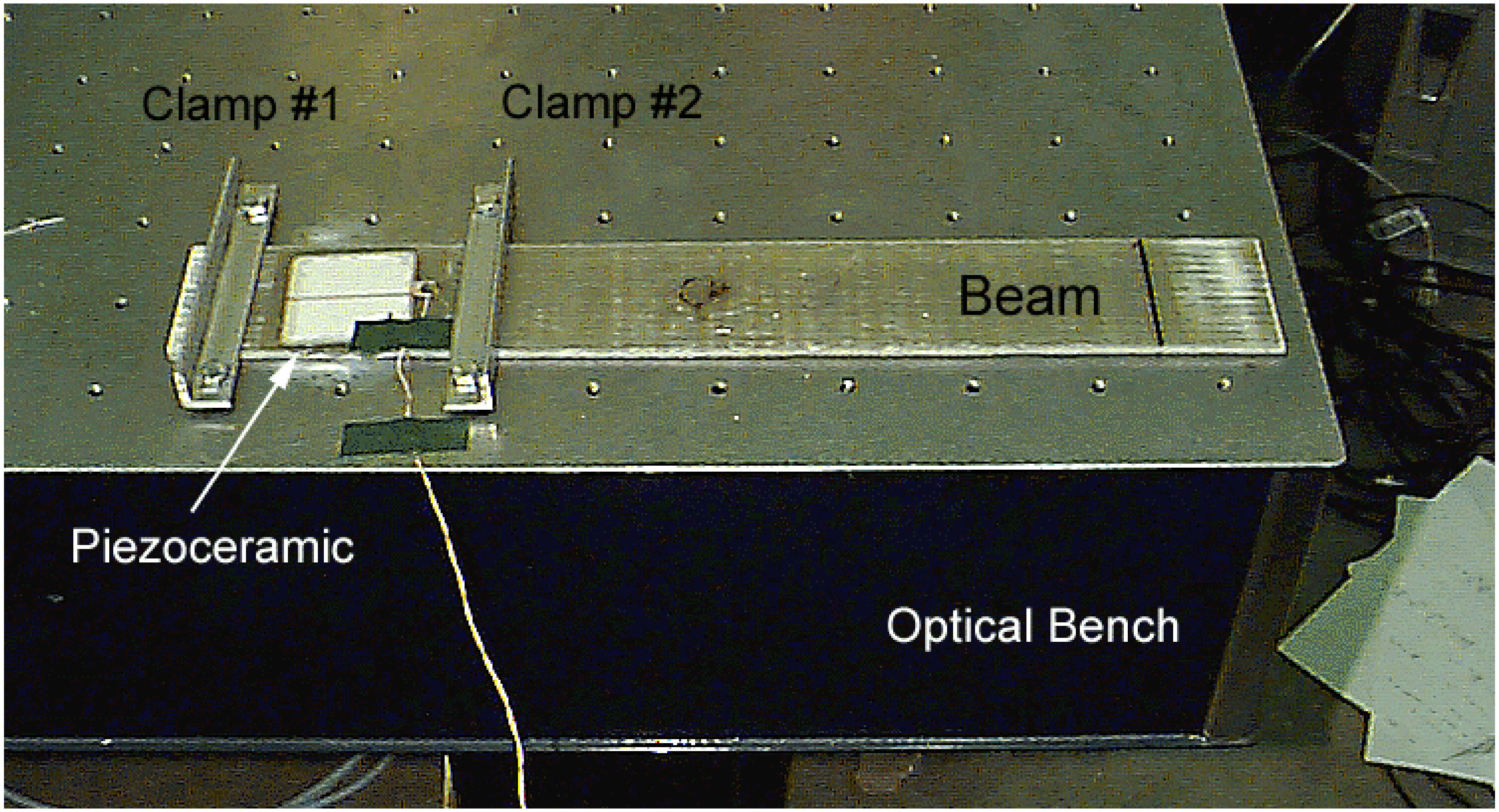
$$y(k) = w(k) - w(k-1)$$ (Edge Detector)

Events that can effect the strain field, Causing a change in PZT Capacitance

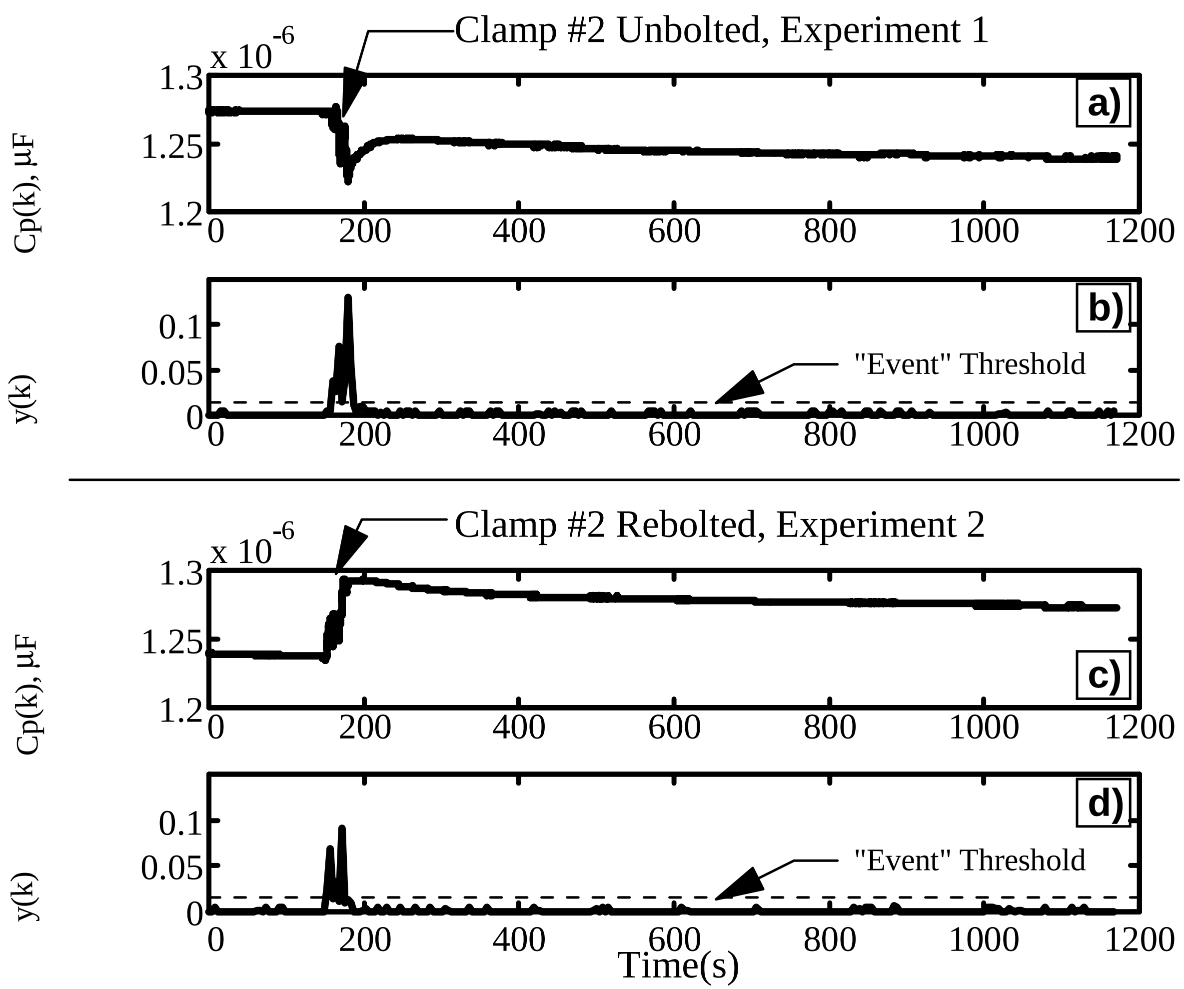
- Structural boundary condition change
  - Fastener Failures

- Change in Stiffness (*EI*, *EA*)
  - Impact Damage
  - Fatigue Cracking

Picture of Test Setup



Experimental Results For Structural Boundary Condition Change



Conclusions

- A novel method of structural health monitoring using the Adaptive Piezoelectric Sensoriactuator is presented
- The electrical properties of the piezoceramic change with varying mechanical conditions of the structure
- The structure forms a varying elastic foundation for the piezoceramic patch
- Capacitance of the piezoceramic transducer can be monitored in real-time using the Adaptive Piezoelectric Sensoriactuator
- A digital edge detector (differentiator) watches for "abrupt" capacitance changes
- The method is simple, cheap, works in-situ, works in real-time, amenable to retro-fit

Future Work

- Ability to localization damage
- Ability to quantify damage or events
- Temperature insensitivity (electro-mechano-thermal coupling)