metis design

mechanical design
composites engineering
structural health monitoring

PACKAGING OF STRUCTURAL HEALTH MONITORING COMPONENTS

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Background

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- Structural Health Monitoring (SHM) denotes a system with the ability to detect and interpret adverse “changes” in a structure in order to reduce life-cycle costs and improve reliability

- Most new vehicles utilize advanced composite materials due to their high specific strength and stiffness

- Different areas of concern for NDE
  - metals: corrosion and fatigue vs composites: delamination and impact
  - damage below the visible surface is most important for composites

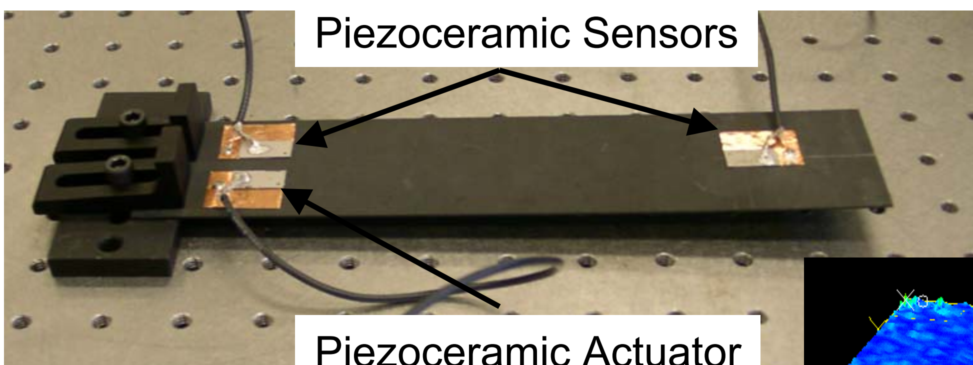
- Integration issues
  - retrofit SHM systems into existing vehicles to monitor damage growth
  - integrate SHM networks into new vehicle designs to guide inspections and dictate need-based maintenance and repair

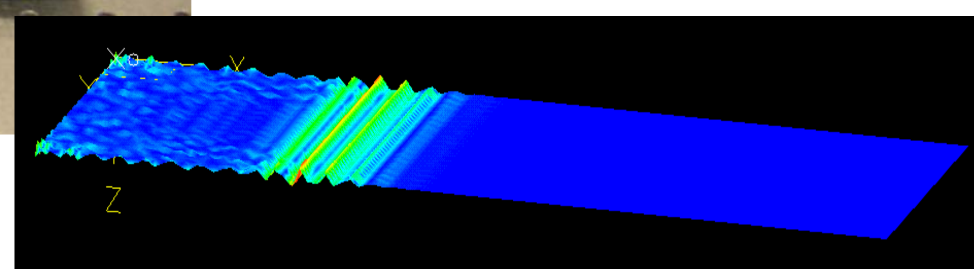
Sensor Study Conclusions

- Piezoelectric materials are ideal for SHM applications
  - can be used as actuators and sensors for a variety of NDE methods
  - light, low cost, low power, flexible, can be deposited
- Frequency response methods
  - useful detection sensitivity to global damage
  - can be used for first or last line of defense
- Lamb wave methods
  - sensitive to local presence of many types of damage
  - potential for triangulation of damage location and shape
- Recommendations for SHM system architecture
  - design based upon analytical results and experimental tuning
  - use of multiple detection methods to gain maximum information

Lamb Wave Methods

- Form of elastic perturbation that propagates in a solid medium
  - actuation parameters determined from governing equations
  - excite A_o wave for long travel distances and to minimize clutter
- Damage can be identified in several ways
  - group velocity approximately $\propto (E/\rho)^{1/2}$, damage slows down waves
  - reflected wave from damage can be used to determine locations
- Present research utilizes piezoelectric actuators/sensors to detect energy present in transmitted and reflected waves

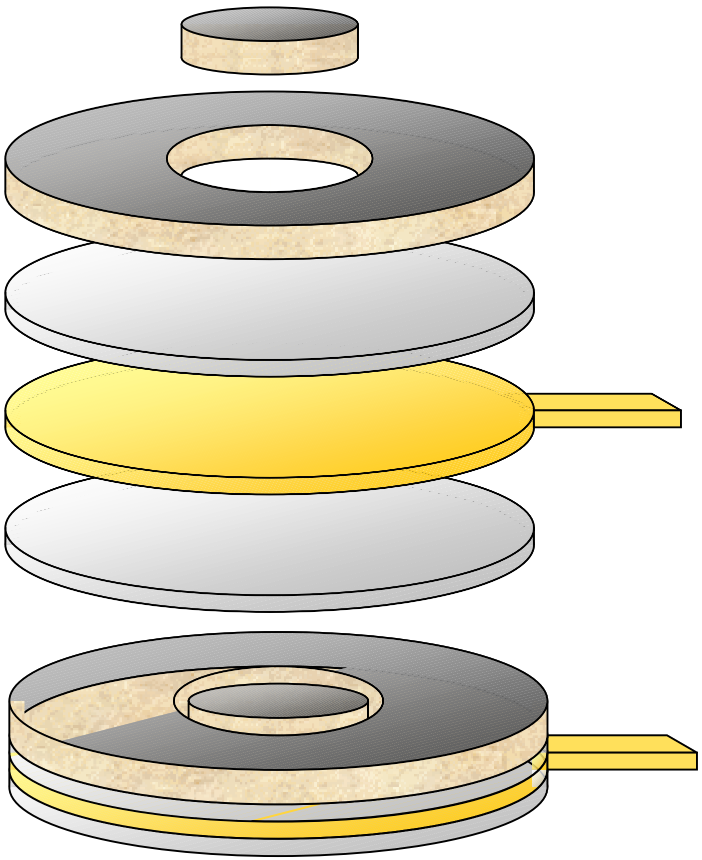




Recent Lamb Wave Research

- Optimization of Lamb wave testing procedure
  - selection of best actuating/sensing materials, adhesives, electrodes
  - more efficient actuating/sensing scheme for transmission and reflection
  - increased reliability, robustness and signal strength by 4x
- Algorithm development
  - damage evaluation algorithms in MATLAB using filters and wavelets
  - tuned and validated by a large set of simple test results
  - current software yields report on presence, location, and type of damage
- Test specimen database
  - testing sensors/algorithms on composite plates and sandwich structures
  - several combinations of small and controlled damage still yields measurable effect, the more damage, the more dramatic the results
  - exhibits 83% accuracy, nearly 100% for delamination (over 200 tests)

Original Actuator/Sensor Package



PZT Sensor

PZT Actuator

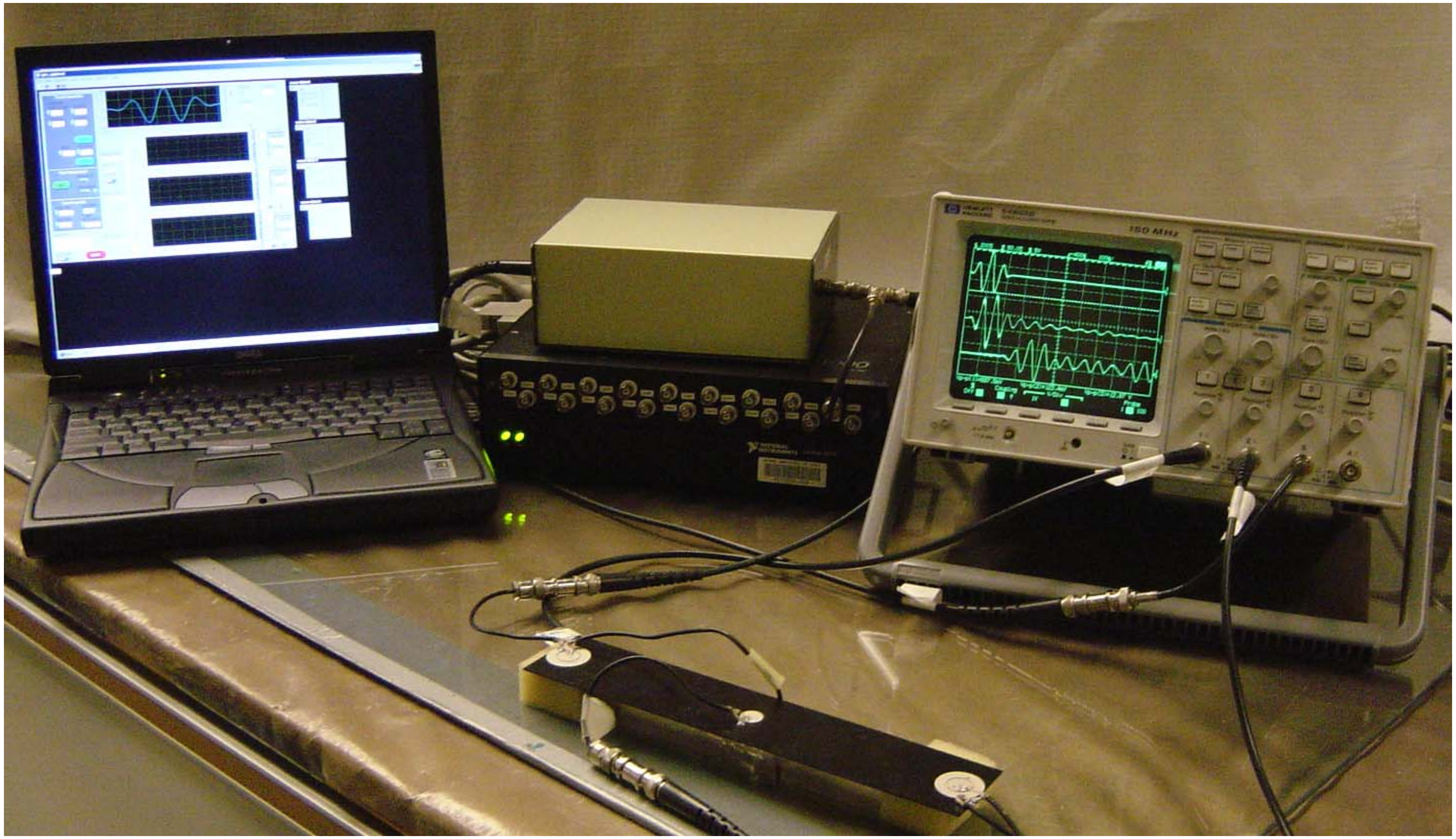
Electrically conductive adhesive

Brass shim stock

Electrically insulative adhesive

Complete sensor/actuator

Lamb Wave Test Setup



- Tests have been executed via variety of acquisition methods
- Completely portable, simple to use and automated results
- Presently use TDS oscilloscope and Agilent function generator

Introduction

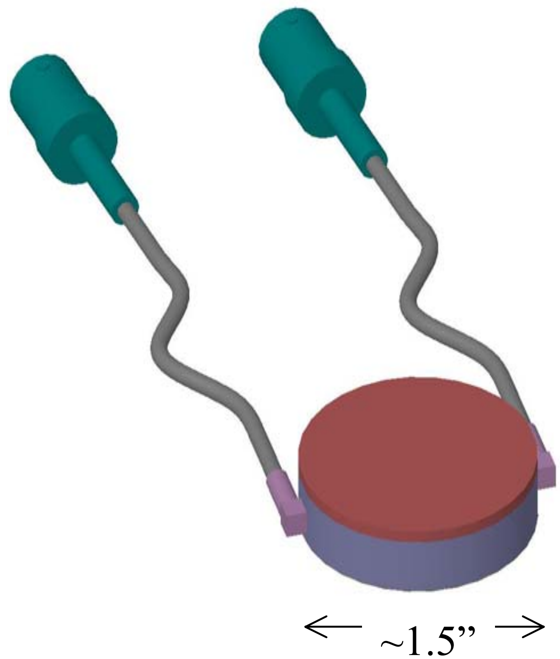
- SHM is predicated on the ability to integrate sensors
  - system reliability must be increased (sensors do not initiate damage)
  - sensors are sufficiently reliable so that they do not require replacement at intervals less than the economic lifetime of the part being monitoring
  - packaging of sensors is a major consideration

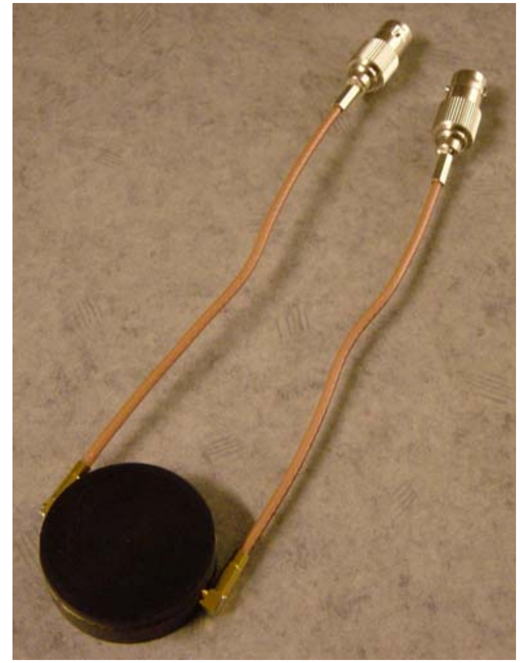
- Packaging must perform multiple functions
  - provide an interface between sensors and structure (eg. to ensure that Lamb waves generated can be transmitted with minimal power loss)
  - guarantee power and data connections to and from actuators/sensors
  - protect sensors from natural, mechanical and electrical environments, including temperature, moisture, EMI, vibration, strain and impact
  - avoid durability issues for sensors, fatigue and creep

Design Requirements

- Geometric constraints
  - maximum height: ~0.5” (greater tolerance inside, less on aerosurface)
  - maximum diameter: ~1.6” (total volume not to exceed 1 in^3)
- Mechanical constraints
  - strain: 2000 microstrain
  - vibration: resonance must be above 66 Hz
  - incidental impact protection
- Environmental constraints
  - moisture: assume always in hot/wet/salty environment
  - temperature: -20°F to 180°F
  - chemical: resistant to fuel, oil, paint, acetone, etc.
  - constant EMI exposure

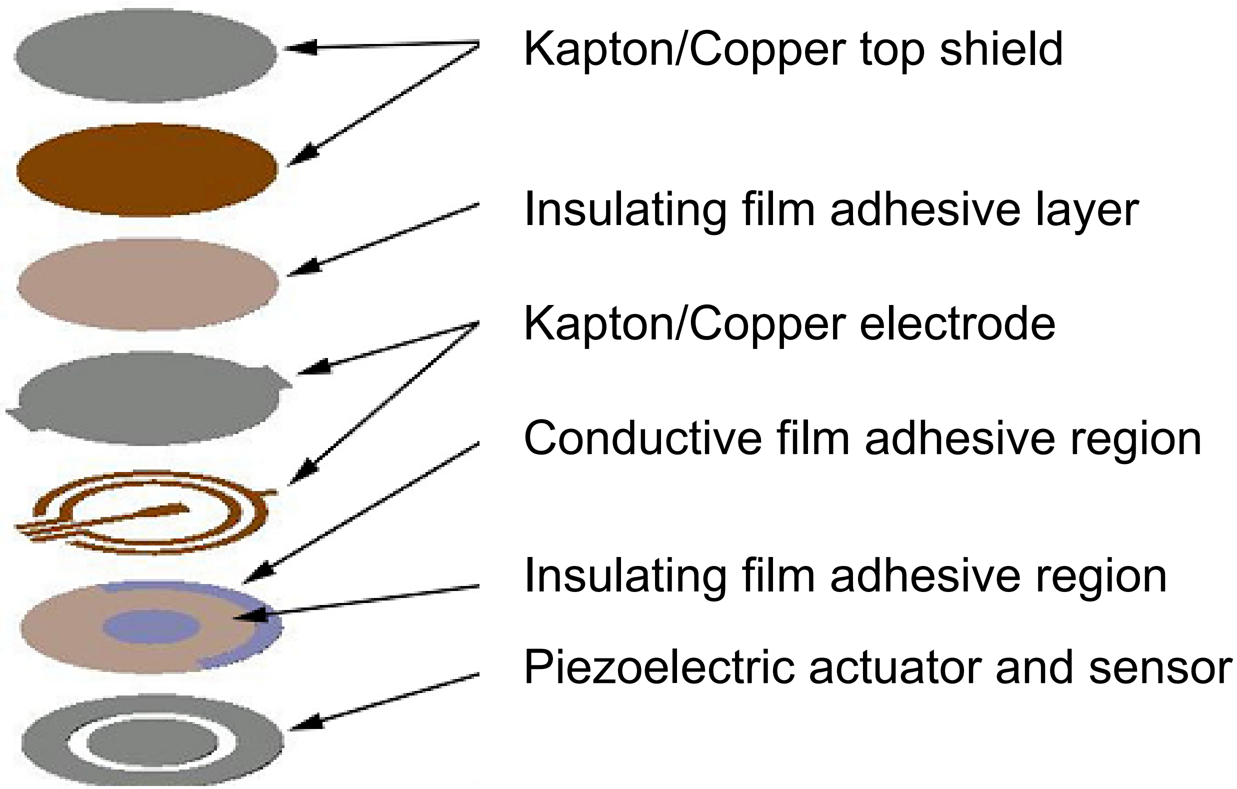
Device Design





- Packaging challenges broken down into subcomponents
  - electrode design – improve robustness, eliminate solder, reduce EMI
  - encapsulation – impact protection, thermal and moisture resistance
  - mounting scheme – improve durability, strain resistance
  - connection scheme – improve signal strength, strain resistance

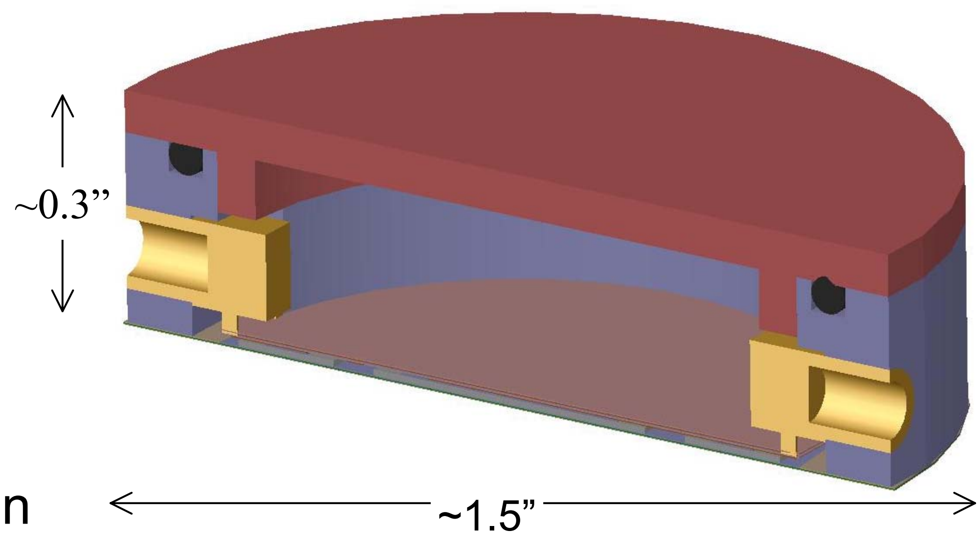
Electrode Design



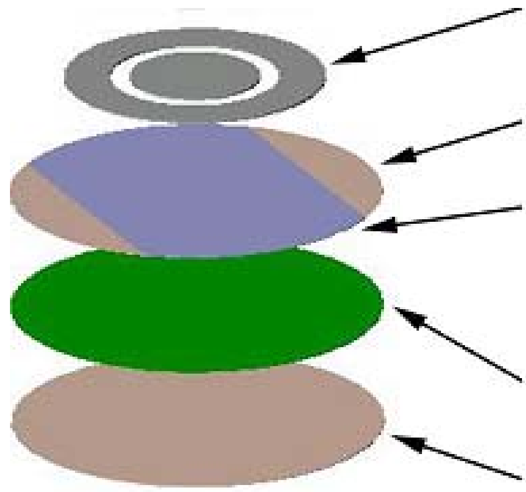
- Original design used direct solder connections
  - exposed wires were susceptible to EMI
  - mechanically and electrically weak joints (pull out, cold-solders)
  - soldering temperatures could depole piezoelectric wafers
- New copper coated Kapton design eliminates these issues

Encapsulation

- Original design called for epoxy encapsulation
- New “cap” design allows for more flexibility
  - impact resistance
  - moisture sealed
  - space for micro-connectors for wired design
  - space for other electronic components for wireless design
- Environmental protection
  - low absorptivity
  - some thermal protection
  - global EMI protection
- Delrin two-piece design
  - low weight, low cost
  - machined in prototypes
  - injection molded in production
  - removable top for integration, repair

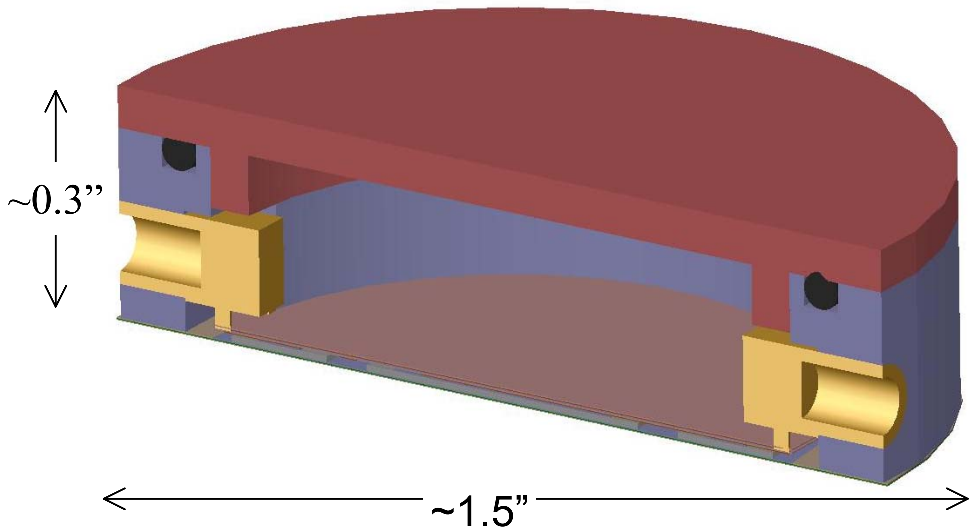


Mounting Scheme



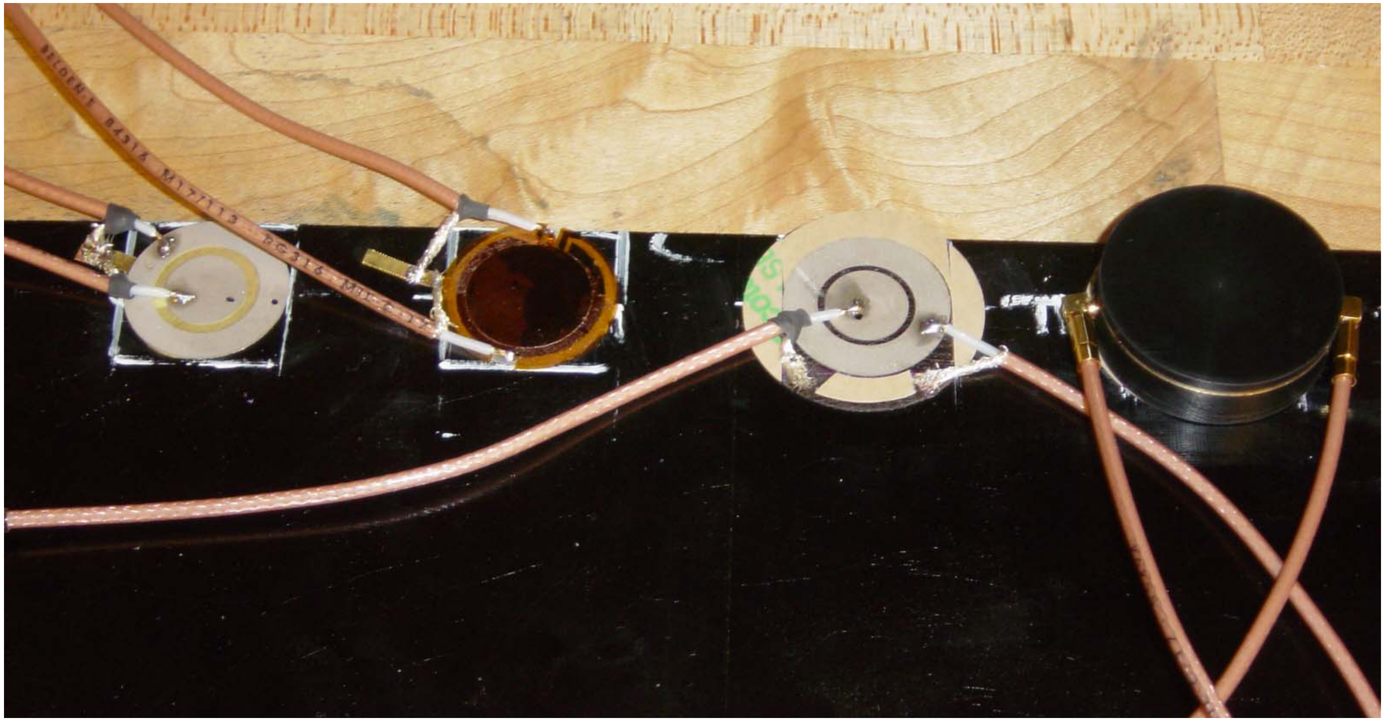
- Original design used thin brass shim with conductive adhesive
- Eliminated conductive path to the structure
- Optimized force imparted to the specimen by the actuator
  - FE model created with parametric values for polyester thickness
  - selected a particular combination of material stiffness and layer thickness
- Bottom layer of insulating adhesive
  - strong, durable
  - cures at room temperature with low pressure

Connection Scheme



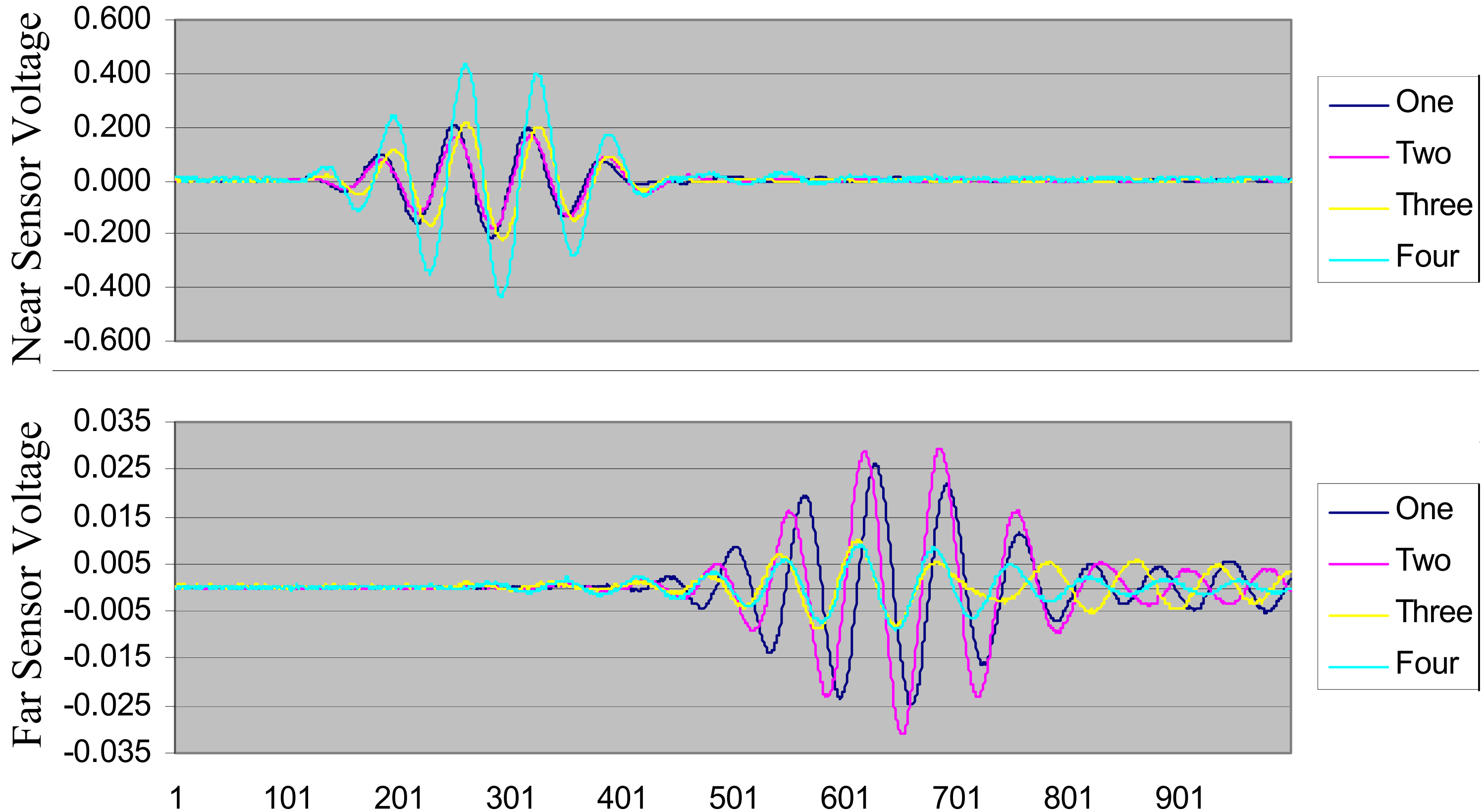
- Original design used BNC cables directly soldered to PZT
- New design employs micro-connectors attached to electrodes
  - better conduction of data signal
  - provides cleaner shielding and ground attachments
- Mechanical advantages
  - flanged micro-connector provides strain relief
  - external adaptor provides standard BNC connection

Experimental Testing



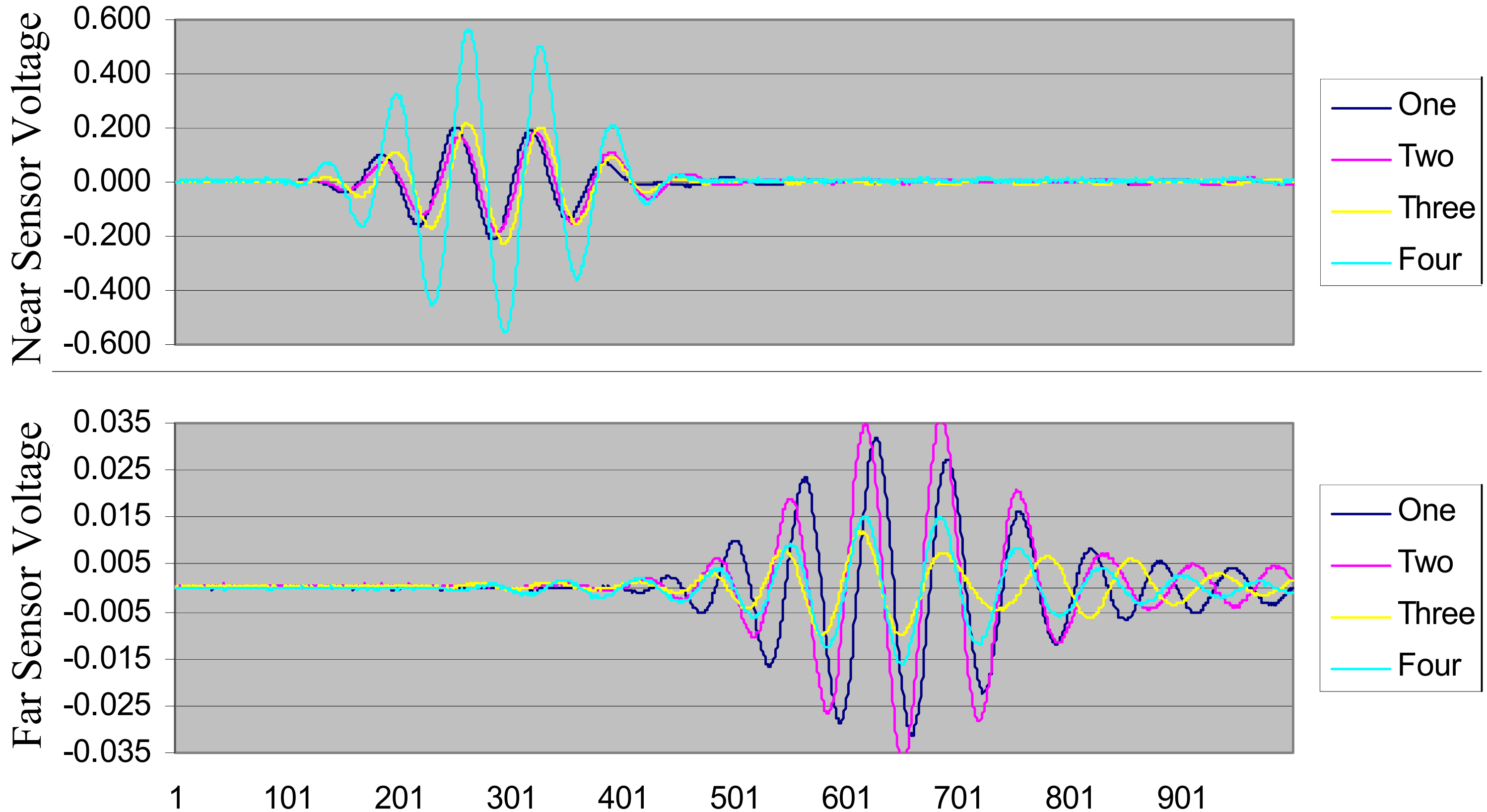
- Four levels of configurations tested
  - original design with no modifications
  - new electrode used with original mounting, no cap
  - new mounting scheme used with old soldering method, no cap
  - entire new design, including electrode, mounting and cap
- Tests performed on 10x10” composite plate, original procedure

Baseline Test Results



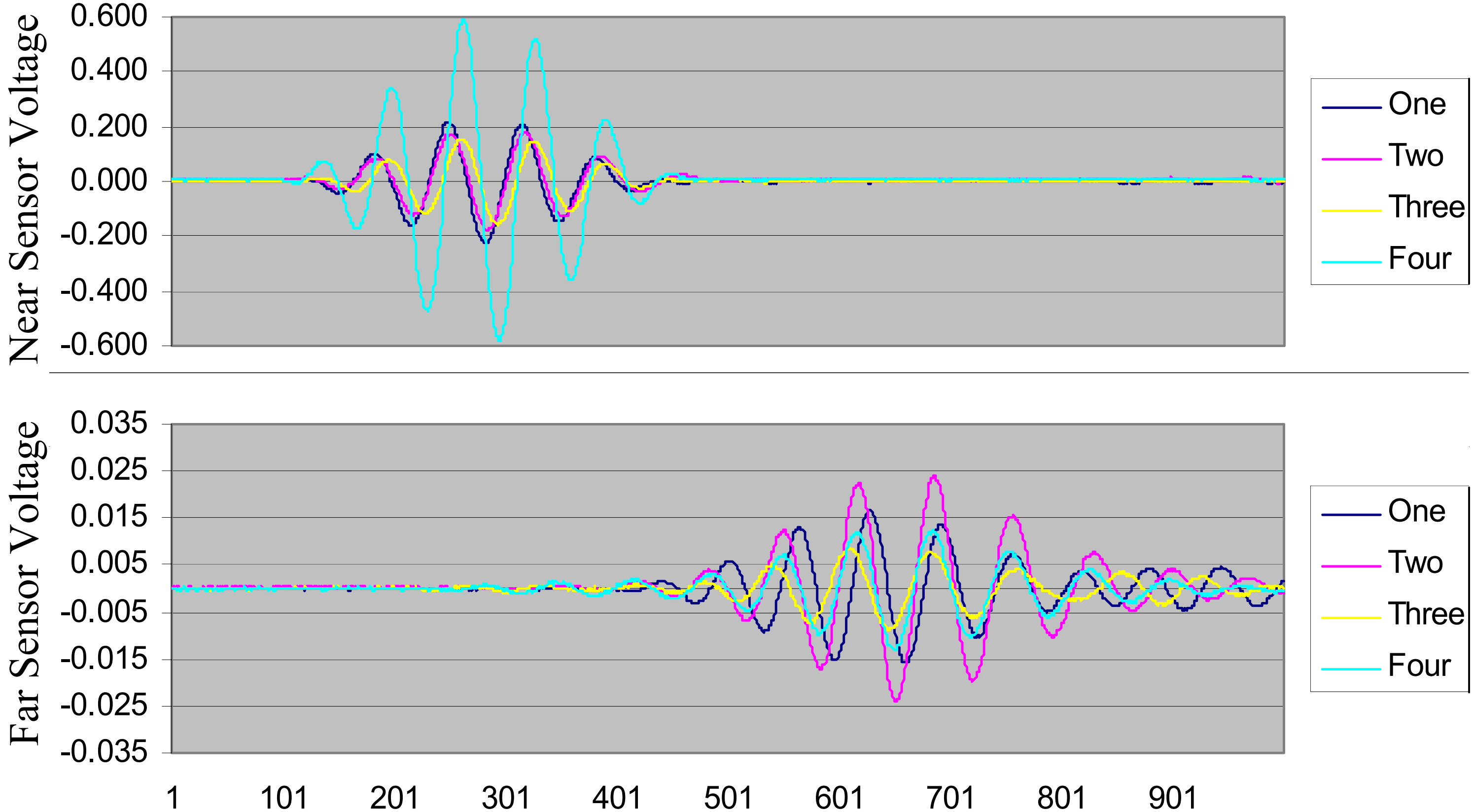
- Voltage at the near sensor show little difference between the first three configurations, however signal is more than doubled by cap configuration
- Voltages damped by ~50% at far sensor by configurations that employed the new mounting; far sensor data not as useful anyhow

Thermal Test Results



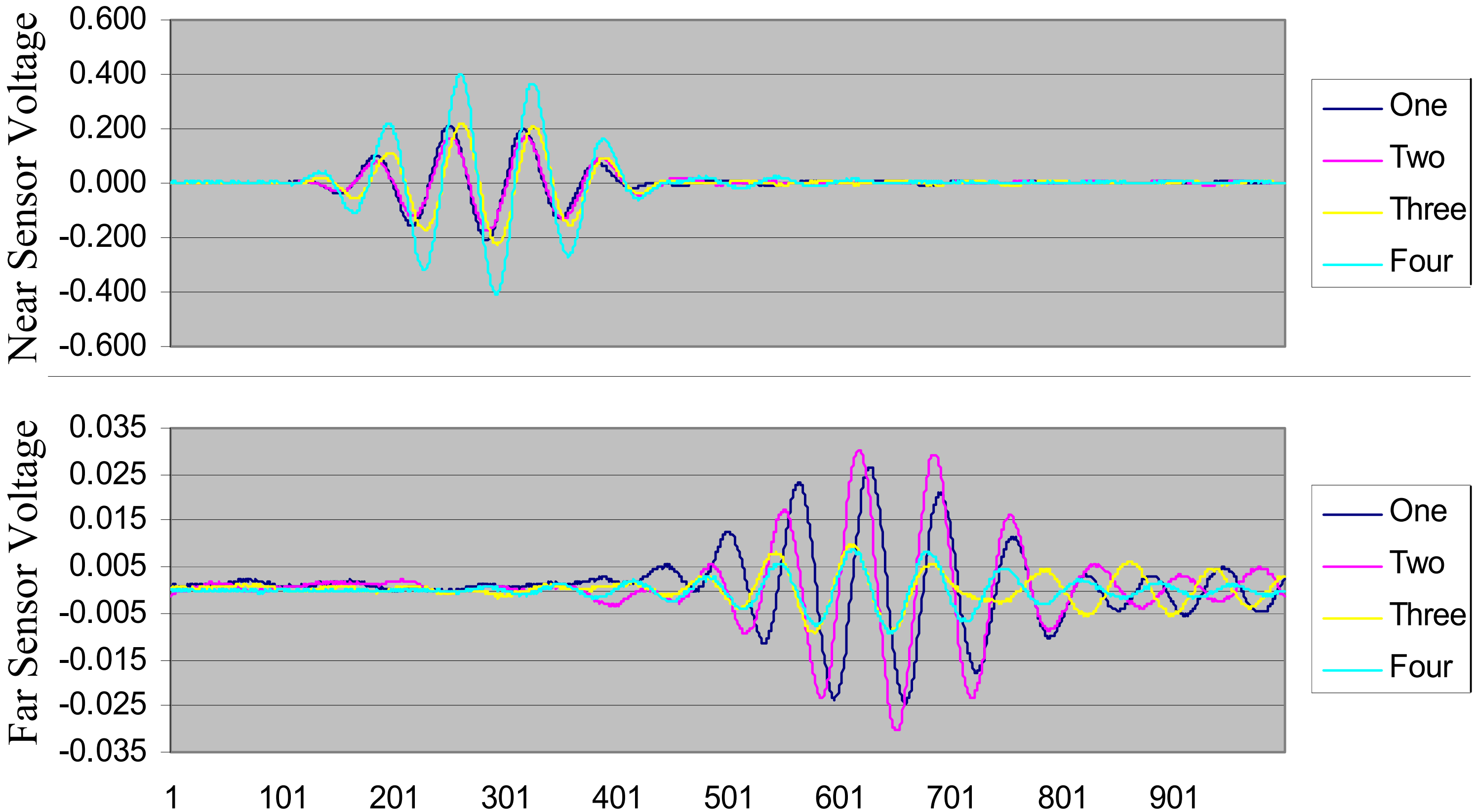
- Plate placed in a post-cure oven at 180°F for a period of 24 hours
- Voltage levels for the near sensor generally remained the same, however great increase for the cap configuration, resistivity of micro-connectors
- Signal strength at far sensor slightly increased for all, cap results best

Humidity Test Results



- Plate and sensors placed in chamber, held at 100% humidity for 24 hours
- Little effect from the moisture was observed for any of the configurations
- First three configurations experienced a slight decay in signal at near and far
- The cap configurations experienced a slight increase in signal strength

Electrical Noise Test Results



- Old “brush-style” electric hand drill to simulate electrical noise
- All voltage levels measured remained consistent with the baseline results
- Configurations that used solder method experienced high levels of electrical noise seen as jumps in the signals, new electrode showed reduced noise
- Cap completely eliminated all electrical noise from the sensors

Conclusions

- Overall packaging scheme meets or exceeds requirements
  - new electrode scheme successfully eliminates electrical noise
  - encapsulation protects from moisture, incidental impact, thermal barrier
  - new mounting scheme can tolerate variety of temperatures, high strain
  - micro-connectors provide strain relief, better conduction
- Testing demonstrated features of new design
  - improved baseline results at near sensor for more accuracy, lower power
  - far sensor results lower due to damping by adhesive, not as important
  - tolerant of harsh environmental conditions
  - easier to integrate with structures, more durable
- Volume remaining in cap sufficient to package remaining electronic components for future wireless design

Future Recommended Research

- Currently researching other relevant SHM components
  - thin-film battery
  - recharging system
  - wireless transceiver
  - microprocessor
- Improved algorithms
  - enhanced reliability, reduce number of empirical constants
  - encryption for software distribution
  - testing on more complex aerospace structures
- Commercialize products in near future
  - wired version for low cost implementation
  - wireless version for increased flexibility, reduce complexity

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