Smart Materials, Actuator and Sensor Concepts

Department of Mechanical Engineering
440B Baldwin Hall, Cincinnati, Ohio 45221-0072
August 22, 2002
(Mark Schulz, Ph. 513-556-4132)
Smart Materials, Actuator and Sensor Concepts
(Active materials with higher strain are needed to make these concepts easier to build and to improve performance)

• Linear Actuators, Wireless Motor
• Vibration Attenuation, Flutter Suppression
• Micro-power Generation
• Semi-active Vibration Isolation
• Sensor Development
• Bio-Nanotechnology
• Nanotube Actuators
• Structural Health Monitoring Techniques
A Camless Valve System for IC Engines  
(M. Schulz, D. Klett, M. Sundaresan, J. Sankar)  

OBJECTIVE: Develop a valve actuator using smart materials
HIGH POWER DENSITY ACTUATORS RESEARCH

(M. Schulz, M. Sundaresan)

OBJECTIVE: Develop high power density actuators using smart materials

AFC harmonic drive motor with no wires

An AFC strut actuator

A hybrid AFC-hydraulic actuator
Comparison of Electromagnetic, Solid State, and Harmonic Drive Motors

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Stall Torque (Ncm)</th>
<th>No-load Speed (RPM)</th>
<th>Power Density (W/kg)</th>
<th>Torque Density (Nm/kg)</th>
<th>Peak Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>DC, brushless</td>
<td>Aeroflex</td>
<td>0.33</td>
<td>13,500</td>
<td>106</td>
<td>0.29</td>
<td>71%</td>
</tr>
<tr>
<td>EM</td>
<td>DC, brushless</td>
<td>Micro Mo</td>
<td>0.99</td>
<td>4,000</td>
<td>-</td>
<td>0.04</td>
<td>~20%</td>
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<tr>
<td>EM</td>
<td>DC, brushless</td>
<td>Maxon</td>
<td>1.27</td>
<td>5,200</td>
<td>-</td>
<td>1.13</td>
<td>70%</td>
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<tr>
<td>EM</td>
<td>DC, brushless</td>
<td>Mabuchi</td>
<td>1.60</td>
<td>14,500</td>
<td>-</td>
<td>0.42</td>
<td>53%</td>
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<tr>
<td>USS</td>
<td>SW, ET</td>
<td>Kumada</td>
<td>133</td>
<td>120</td>
<td>80</td>
<td>8.8</td>
<td>80%</td>
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<tr>
<td>USS</td>
<td>TW, D</td>
<td>Shinsei</td>
<td>60</td>
<td>100</td>
<td>18</td>
<td>2.6</td>
<td>27%</td>
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<tr>
<td>USS</td>
<td>TW, D</td>
<td>MIT</td>
<td>170</td>
<td>40</td>
<td>12</td>
<td>5.2</td>
<td>15%</td>
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<tr>
<td>USS</td>
<td>TW, R</td>
<td>MIT</td>
<td>0.54</td>
<td>1750</td>
<td>108</td>
<td>2.1</td>
<td>-</td>
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<tr>
<td>EMHD</td>
<td>FHA-17A-6006</td>
<td>HD Inc.</td>
<td>1,400</td>
<td>80</td>
<td>21.4</td>
<td>11.7</td>
<td>56%</td>
</tr>
<tr>
<td>SSHD</td>
<td>TW, HD</td>
<td>NCA&amp;T</td>
<td>~2,635</td>
<td>~12</td>
<td>~234</td>
<td>~186</td>
<td>~29%</td>
</tr>
</tbody>
</table>

Notes: Table data from MIT, last row data based on estimates at NCA&TSU, EM=electromagnetic, SW=standing wave, SS=solid state, TW=traveling wave, D=disk, R=ring, ET=extension/twist, HD=harmonic Drive
OBJECTIVE: Develop a vibration suppression technique using smart materials.
FLUTTER SUPPRESSION RESEARCH

OBJECTIVE: Develop a flutter suppression technique using PZT’s and a laser sensor (Ed Shackleford, Anindya Ghoshal, Mannur Sundaresan, M. Schulz)

View of the wing tip in the low speed wind tunnel controlled using a laser vibrometer sensor and piezoceramic patches

Experimental Setup for flutter suppression using PZT patches & laser vibrometer sensor
MICRO-POWER GENERATION
(M. Schulz, M. Sundaresan)

OBJECTIVE: Generate power for autonomous structural health monitoring

Approach: Power generation devices; (a) the Strain Power Pack; (b) two Series Power Mounts; (c) the parallel power mount with frequency spreader

![Diagram of power generation devices]
Objective: A semi-active magnetorheologic damper is used to attenuate vibration and noise of operating automotive components. An enhanced sky-hook control algorithm is used. Two factors are to be optimized: relative displacement and transmitted force from the component.

Figure 1. Semi-active control system for vibration attenuation of automotive components.
ACTIVE FIBER COMPOSITE SENSOR DEVELOPMENT

**OBJECTIVE:** Develop an AFC sensor for structural health monitoring

(Saurabh Datta, Mark Schulz, Mannur Sundaresan)

Problem: AFC’s are designed primarily for actuation

Approach: Develop new electrode for sensing

Teaming: UC, NCA&T & CeraNova Corporation

![Piezoceramic fiber preforms (figure from CeraNova Corp.)](image1)

![Piezoceramic fiber sensor built at the UC](image2)

Parallel connectivity for actuation

Series connectivity for sensing

(+)

(-)

(+)

(-)
ARRAY PROCESSING FOR SMART STRUCTURES

OBJECTIVE: Develop a smart sensor array and new sensor materials

A Continuous Sensor Array

(Mannur Sundaresan, William N. Martin, Mark Schulz)
WAVELETS AND PIEZOCERAMIC SENSORS
(D. Hughes, A. Ghoshal, M. Sundaresan, M. Schulz)

OBJECTIVE: Develop wavelet analysis techniques for smart sensors

- The Wavelet Transmittance Function (WTF) of piezoceramic sensor data is used for crack detection in structures

\[ W_{\psi}(a,u) = \int_{-\infty}^{\infty} f(t)\psi_{a,u}^*(t)dt \]
\[ \psi(t) = e^{i\omega_0|t|} e^{-\frac{|t|^2}{2}} \]
\[ WT_{12} = \frac{WT_2}{WT_1} \]

No crack:  \( \text{WTF} \sim 1.0 \)

With crack:  \( \text{WTF} \sim 0.75 \)
The Wavelet Transform indicating damage in a helicopter flexbeam, (a) input, (b) response of healthy leg, (c) response of damaged leg.
A CONTINUOUS PIEZOCERAMIC SENSOR

OBJECTIVE: Develop neural composite materials for SHM, BHM
(with Mannur Sundaresan at NCA&TSU)

Voltage response for the single PZT sensor and the continuous sensor with nine PZT nodes

Comparison of the energy of the continuous sensor (DS) and a single PZT sensor (SS)
BIO-NANOTECHNOLOGY:

THE NEW FRONTIER

IN MATERIALS AND STRUCTURES
• The Biological Neural System

The generalized neuron.  The visual cortex.  Levels of information processing in man.
Skin is a multifunctional and layered material that can inspire the design of structures.
Diamond
Each carbon atom is bonded to four others in a tetrahedral fashion.

Graphite
The ball and stick model (a) of graphite indicates the closely-packed nature of the carbon atoms. The layers of carbon in graphite are 335 pm apart, approximately twice as long as the C-C bond distance of 142 pm (b).

Carbon Nanotube
The molecules vary in length from a few nanometers to a micrometer or more.

FORMS OF CARBON
(figures from General Chemistry, 3rd Edition, Hill and Petrucci, Prentice Hall)
Developing Piezoelectric Nanotube Actuators and Sensors
(Mark Schulz)

Boron nitride nanotubes for piezoelectric actuation
Developing Carbon Nanotube Electro-chemical Actuators
(Mark Schulz)

CNTs coated with polymer electrolyte (black) form unidirectional ropes and a fiber that is actuated by setting up an electric field using interdigitated electrodes (red/blue)

Concept for using carbon nanotubes and double-layer charge injection for actuation