Module 6: Intelligent Devices based on Smart Materials

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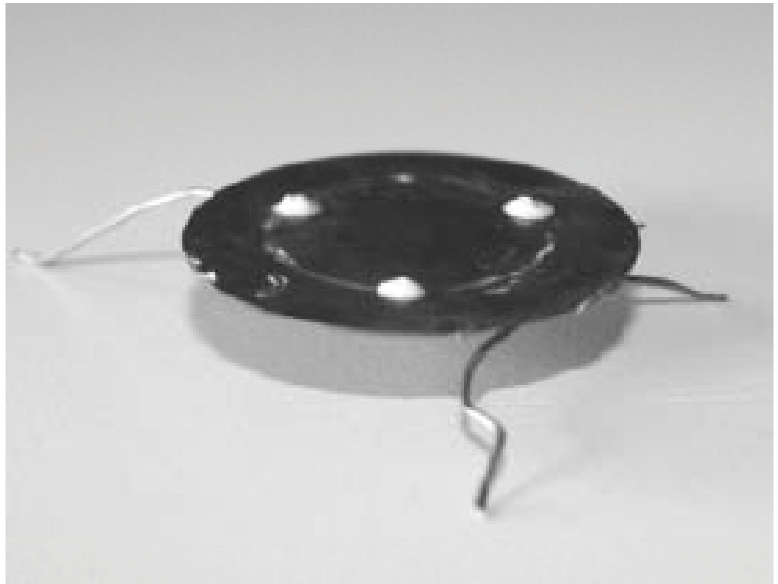


LECTURE 39
Intelligent Devices (Part 2)

Organization of this Lecture

- Inchworm Devices for Locomotion
- Unimorph Thunder
- Rainbow Actuators

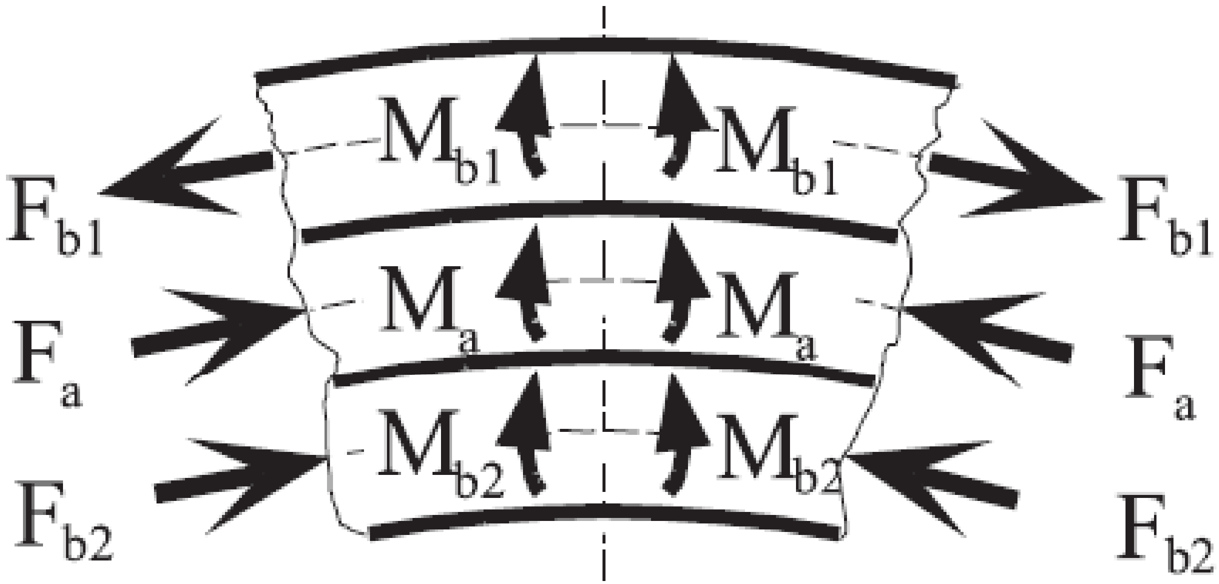
Inchworm Devices for Locomotion

- Such devices are also used to develop small-scale walking systems.
- Electro-chemical batteries are having limited power and hence individual leg motion control is difficult.
- The Inchworm devices are based on resonating a lightly damped elastic-structure activated by stress-based resonator.
- This is also known as elasto-dynamic motion

Unimorph-Thunder

- One of the major devices that is used is known as Thunder [Thin Layer Composite Uniform Ferroelectric Driver]
- It is an unimorph made of PZT at the core and bonded with one/two metallic layers at high temperature.
- The bonding agent is a special high strength thermo-plastic LaRc. At high temperature, this gets melt inside the system and then slowly cooled to develop pre-stress.

Configuration of a Piezo-unimorph



Lobonitu et al, 2001

Major Assumptions

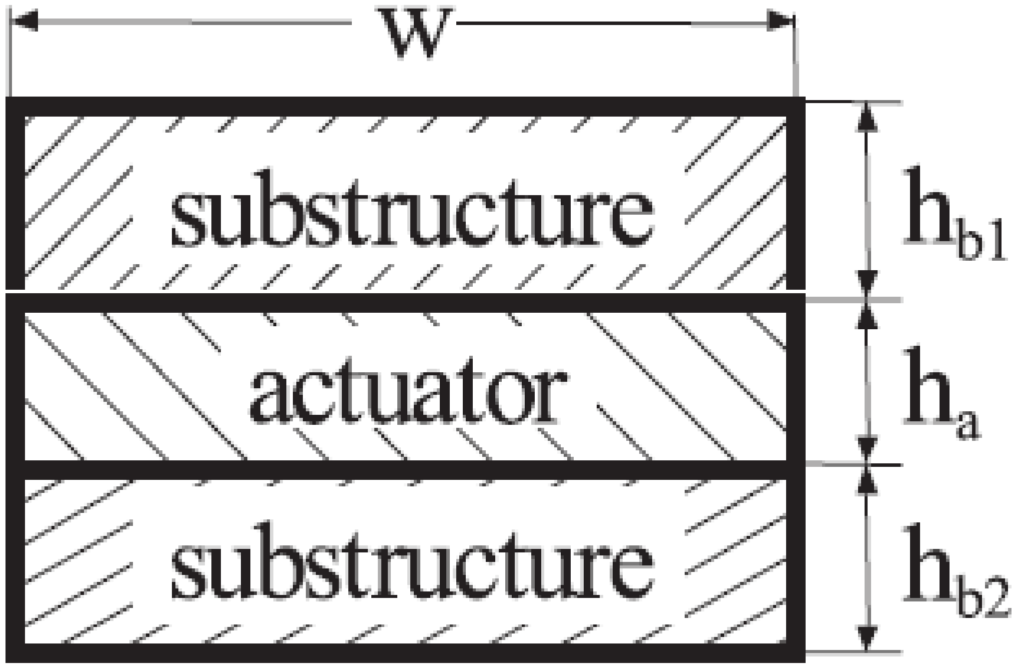
- Formulation based on Euler-Bernoulli Beam Theory

- Ideal Bonding of Layers

- Linear Strain Distribution

- Small Curvature of Unimorph

Geometric Configuration



Governing Equations

$$F_{\mathrm{b1}} = F_{\mathrm{a}} + F_{\mathrm{b2}},$$

$$M_{\mathrm{b1}} + M_{\mathrm{a}} + M_{\mathrm{b2}} = F_{\mathrm{b1}} \left(\frac{h_{\mathrm{a}} + h_{\mathrm{b1}}}{2} + \frac{h_{\mathrm{a}} + h_{\mathrm{b2}}}{2} \frac{F_{\mathrm{b2}}}{F_{\mathrm{b1}}} \right),$$

$$\frac{F_{\mathrm{b1}}}{E_{\mathrm{b}} A_{\mathrm{b1}}} + \frac{M_{\mathrm{b1}} h_{\mathrm{b1}}}{2 E_{\mathrm{b}} I_{\mathrm{b1}}} = - \frac{F_{\mathrm{a}}}{E_{\mathrm{a}} A_{\mathrm{a}}} - \frac{M_{\mathrm{a}} h_{\mathrm{a}}}{2 E_{\mathrm{a}} I_{\mathrm{a}}} + \varepsilon_{\mathrm{a},0},$$

$$- \frac{F_{\mathrm{a}}}{E_{\mathrm{a}} A_{\mathrm{a}}} + \frac{M_{\mathrm{a}} h_{\mathrm{a}}}{2 E_{\mathrm{a}} I_{\mathrm{a}}} + \varepsilon_{\mathrm{a},0} = - \frac{F_{\mathrm{b2}}}{E_{\mathrm{b}} A_{\mathrm{b2}}} - \frac{M_{\mathrm{b2}} h_{\mathrm{b2}}}{2 E_{\mathrm{b}} I_{\mathrm{b2}}},$$

$$\varepsilon_{\mathrm{a},0} = d_{31} \frac{V}{h_{\mathrm{a}}}$$

Assume Equal Curvature

$$\frac{E_{\mathrm{a}} I_{\mathrm{a}}}{M_{\mathrm{a}}} = \frac{E_{\mathrm{b}} I_{\mathrm{b1}}}{M_{\mathrm{b1}}} = \frac{E_{\mathrm{b}} I_{\mathrm{b2}}}{M_{\mathrm{b2}}} \cdot$$

Maximum Moment Generated

$$M_{\mathrm{f}} = M_{\mathrm{b1}} + M_{\mathrm{a}} + M_{\mathrm{b2}} = C_{\mathrm{f}}\varepsilon_{\mathrm{a},0}$$

$$C_{\mathrm{f}} = \frac{C_{\mathrm{f1}}}{E_{\mathrm{a}}C_{\mathrm{f2}} + E_{\mathrm{b}}C_{\mathrm{f3}}},$$

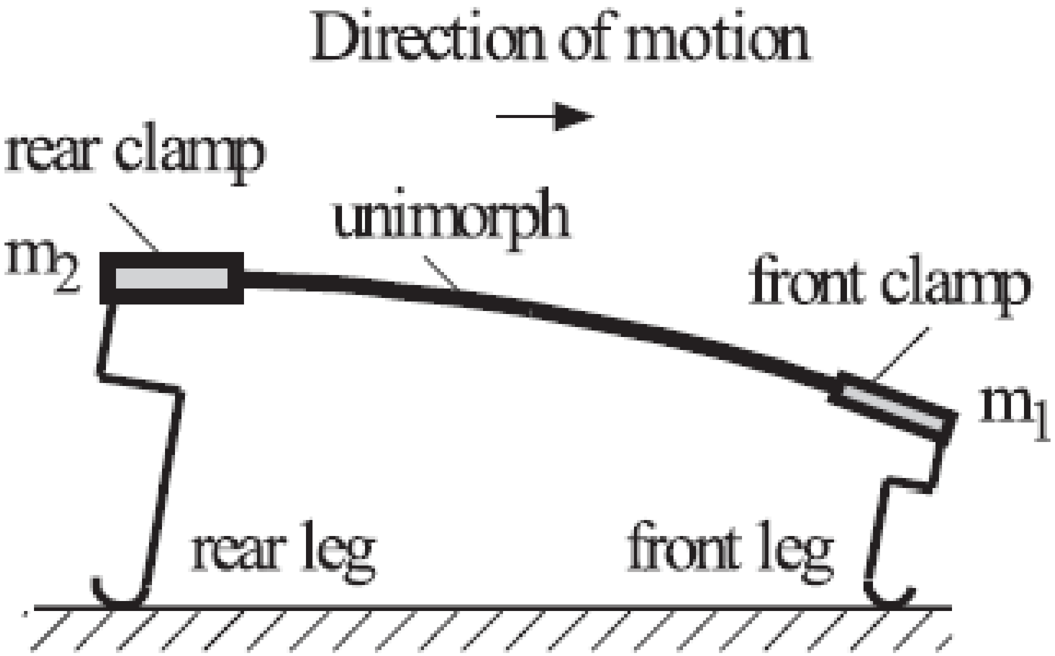
$$C_{\mathrm{f1}} = 28A_{\mathrm{a}}E_{\mathrm{a}}E_{\mathrm{b}}[A_{\mathrm{b1}}(h_{\mathrm{a}} + h_{\mathrm{b1}}) - A_{\mathrm{b2}}(h_{\mathrm{a}} + h_{\mathrm{b2}})]C_{\mathrm{f4}},$$

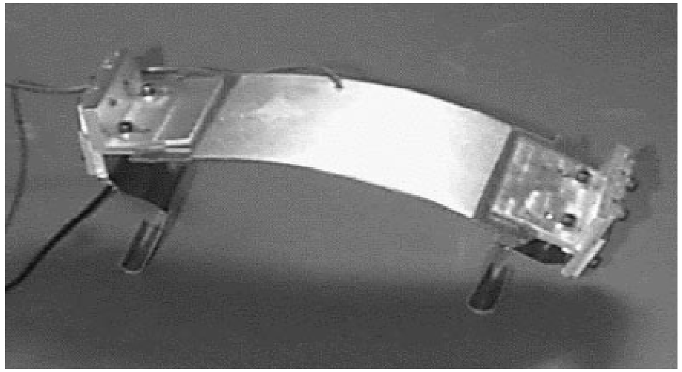
$$C_{\mathrm{f2}} = A_{\mathrm{a}}\left\{A_{\mathrm{b1}}E_{\mathrm{b}}(h_{\mathrm{a}}^2 + 15h_{\mathrm{a}}h_{\mathrm{b1}} + 14h_{\mathrm{b1}}^2) + 14\left[A_{\mathrm{b2}}E_{\mathrm{b}}(h_{\mathrm{a}} + h_{\mathrm{b2}})^2 + 4C_{\mathrm{f4}}\right]\right\},$$

$$C_{\mathrm{f3}} = A_{\mathrm{b1}}\{A_{\mathrm{b2}}E_{\mathrm{b}}(h_{\mathrm{b2}} - h_{\mathrm{b1}})[15h_{\mathrm{a}} + 14(h_{\mathrm{b1}} + h_{\mathrm{b2}})]\} + 56(A_{\mathrm{b1}} - A_{\mathrm{b2}})C_{\mathrm{f4}},$$

$$C_{\mathrm{f4}} = E_{\mathrm{a}}I_{\mathrm{a}} + E_{\mathrm{b}}(I_{\mathrm{b1}} + I_{\mathrm{b2}}),$$

The Complete System

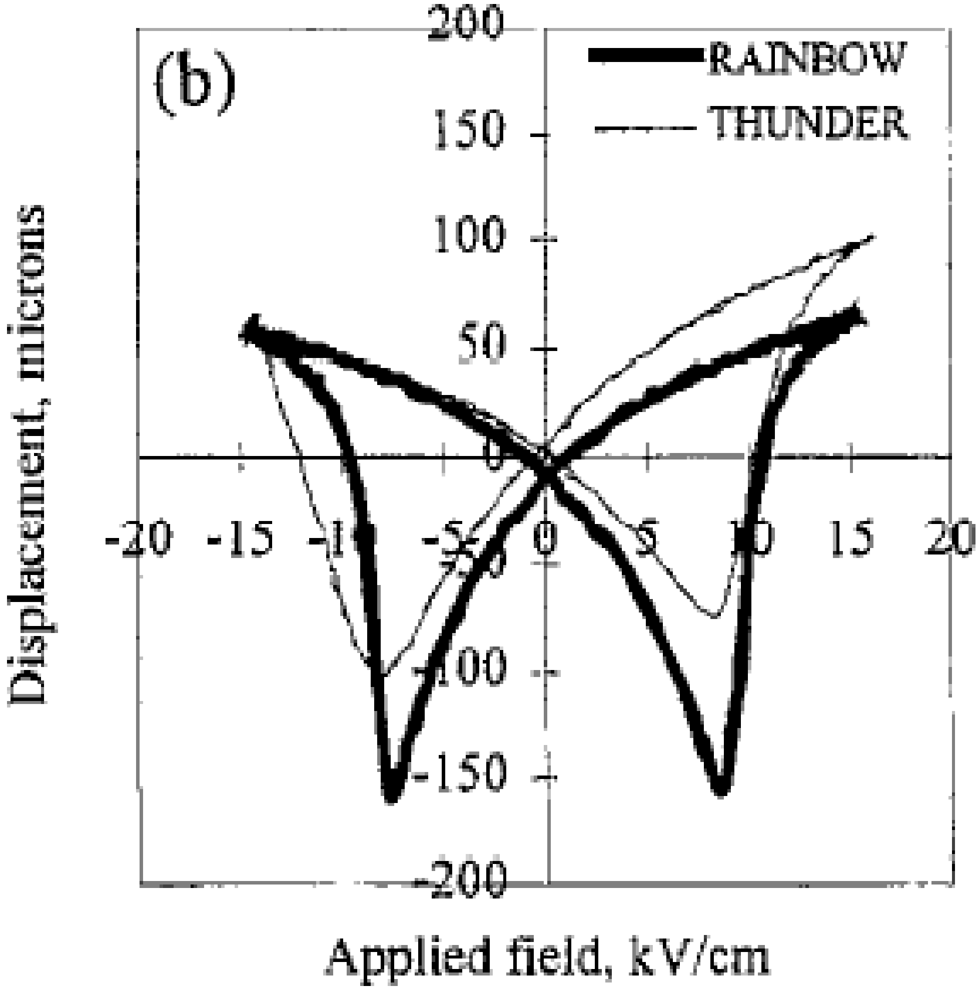




Alternate Rainbow Actuator

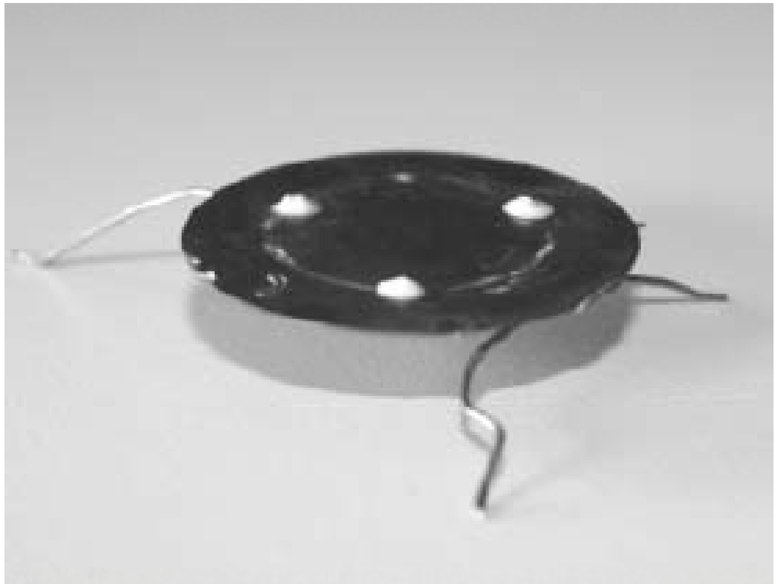
- Rainbow refers to Reduced and Internally Biased Oxide Wafer
- In this case, PZT is placed on a Graphite Block and kept inside a Oven which is preheated at 975^0 C.
- As Oxygen is removed at the interface, a monolithic system gets developed.

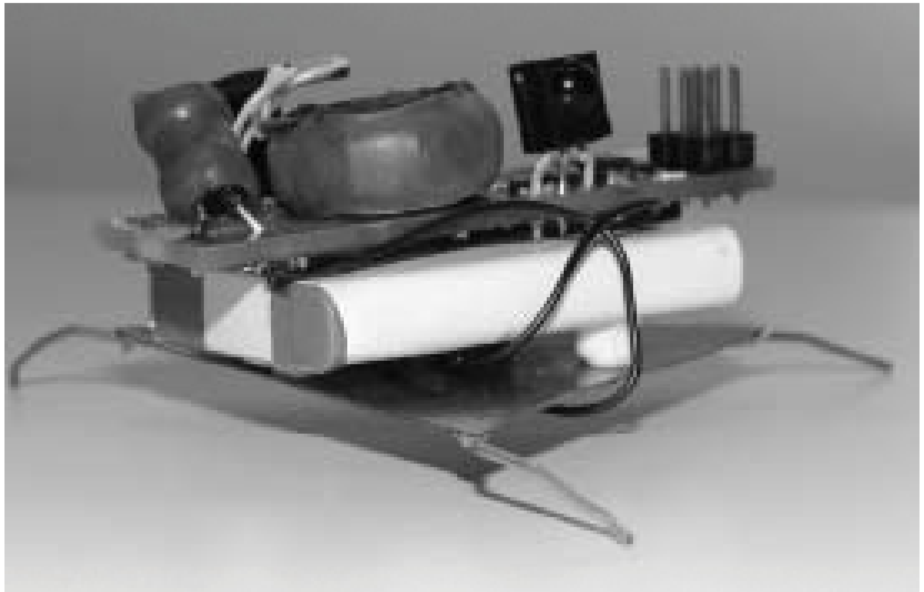
Comparison of Behaviors between Rainbow and Thunder



Stephanie Wise (97)

Vibration Based Plate and Beetle Robots





Becker et al, 2011

Structural Specifications of Becker Devices

	Beetle Robot	Plate Robot
Length x width x height	69 x 80 X 30 mm^3	58 x 42 x 10 mm^3
Mass	31.7g	3.5g
Max Velocity	20 mm/s on glass	150 mm/s (on glass)
Excitation	12-70 kHz	10-60 kHz

Special reference for this lecture

- Micro-mechatronics by Uchino & Giniewicz, Marcel, Dekker
- Modelling and Dynamic Simulation of Vibration driven Robots, Becker *et al*, 2011
- A Piezoelectric driven inchworm locomotion device, Lobonitu *et al*, 2001