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Polymer Actuators Based on Maxwell Forces

by

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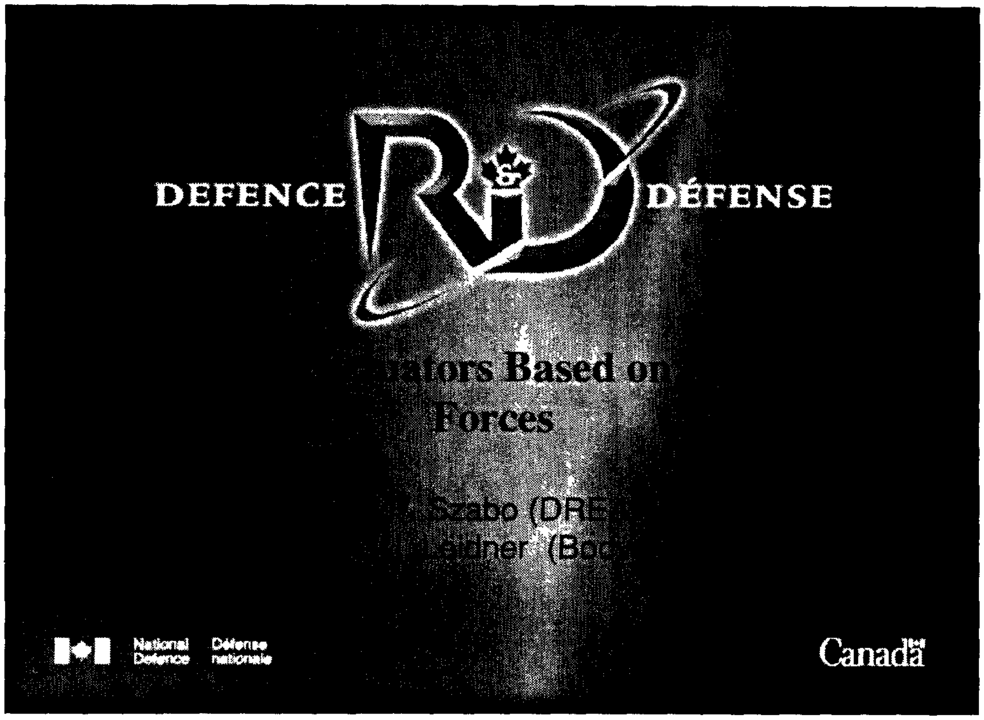
Abstract

There are currently two main classes of actuating materials - piezoelectric materials, characterized by high frequency response but very small movements, and shape memory alloys, characterized by very slow response but relatively large movements. Polymeric actuators are an emerging class of materials, which offer the potential to fill the performance gap between piezoelectric materials and shape memory alloys. There are four main classes of polymeric actuators: (i) piezoelectric, (ii) hydrated membranes and hydrogels, (iii) electrostrictive, and (iv) dielectric. In this presentation, the possible applications of dielectric polymers to active noise and vibration control will be presented, along with results of preliminary work to fabricate and characterize these materials. Dielectric actuators based on cast thermoplastic polyurethane films were prepared with brushed-on graphite powder as electrodes. Strains of up to around two percent were measured. This strain corresponds to a stress of approximately 150 kPa. The voltage/strain relationship followed a parabolic relationship as predicted by theoretical considerations. Actuators with similar strain values were prepared by forming longer films and rolling them into tubes.



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Outline

- Background
- Theory
- Actuator fabrication
- Quasi-static properties
- Summary
- Future Work

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Types of Actuator Materials

Fast response, low strain
  - Piezoelectric
  - Electrostrictive
  - Magnetostrictive

Slow response, high strain
  - Shape memory alloys

Fast response, high strain
  - Dielectric actuators

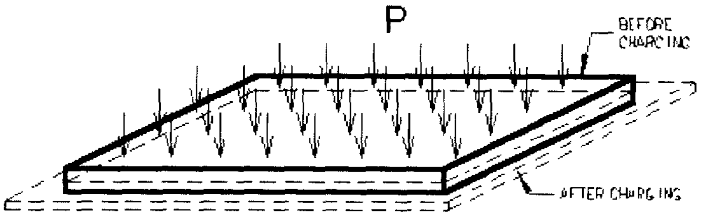
Background

- Dielectric actuator technology is at a point where the basic phenomenon has been observed and demonstrated.
- Most of the research in the field has been published since 1998, and the bulk of the work has been carried out at SRI, and more recently in Denmark
- Strains of > 100% have been observed in stretched acrylic and silicone films. Frequency response for silicone flat up to 400 Hz.
- Much of the work is directed at "artificial muscles" for robotics.

Dielectric Actuators

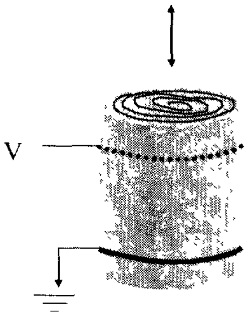
Maxwell Stress Effect

A voltage potential applied across a thin, non-conducting, elastomeric membrane results in the attraction of two charged surfaces, compression of the elastomer, and a resulting increase in its length.



- If a thin film actuator is rolled into a rod then actuation force is along the cylinder axis.
- Elastomeric actuator would be ideal for active vibration isolation.

"Rolled" actuator



Combined Active/ Passive Vibration Isolation

- Active and passive isolation are complementary
- Works as passive isolator if power fails
- Robust control

Objectives

- Develop simple static models for film actuators
- Select an appropriate dielectric elastomer
- Fabricate a number of film and rod shaped actuators
- Characterize the static strain as a function of applied voltage and film thickness
- This was intended to be preliminary study
- Work was carried out at Bodycote Ortech under contract to DREA

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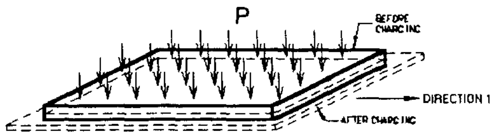
Single Layer Model

Strain	$\varepsilon_1 = \mu e_0 e V^2/2Yd^2$
Stress	$P_1 = \mu e_0 e V^2/2d^2$

Assumptions:
- No constraints on dielectric
- Dielectric is perfectly elastic
- Electrode has no stiffness
- Deformation due only to Maxwell forces

Maximum effects are proportional to
- dielectric permittivity of polymer
- square of the dielectric strength (max voltage per unit thickness)

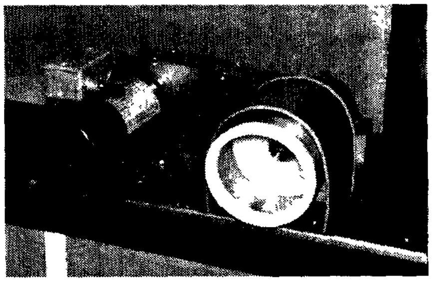


Material Selection

- Graphite electrodes - low stiffness, electrically conductive.
- Elastomer - non-conductive, no pinholes, high dielectric breakdown strength, high dielectric constant, low hardness
- Preliminary film casting experiments were carried out on:

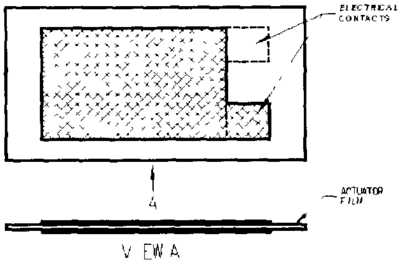
	Manufacturer	**Type**	**Hardness (Shore A)**	**Dielectric Constant**	**Dielectric Strength (kV/mm)**
FC2123	Dyneon	Fluorinated rubber	71	5.7	40
THV 220	Dyneon	Fluorinated rubber	44	5.7	62
Elastosil RT 601	Wacker	2 component silicone	45	3.1	23
Pellethane 2103-70A	Dow	Thermoplastic polyurethane	[illegible]	[illegible]	25
PLV 6034	Pelseal	2 component fluoroelastomer		3.1	40
SIFEL 5701	Shin Etsu MicroSi	2 component fluorosilicone	71	3.1	23

Film Preparation



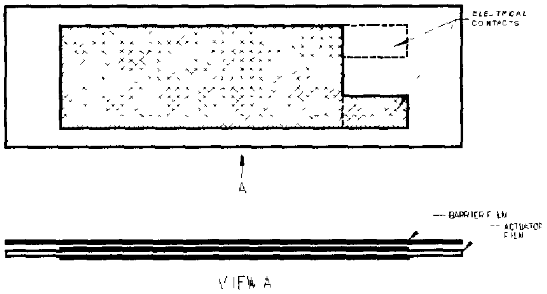
- A centrifugal spin caster was designed and built
- Idea was that gas bubbles would be removed under centrifugal force.
- Initial experiments indicated that dimensional accuracy of the drum was inadequate, resulting in non-uniform films.

Decided to use a simple casting procedure, selecting defect free areas:
- Dissolved PU in 8% DMF solution
- Cast films onto glass plates buffed with wax
- Dried films at 60°C for > 8 hours
- Film thicknesses were in the range 25-150 μm



Film Actuator

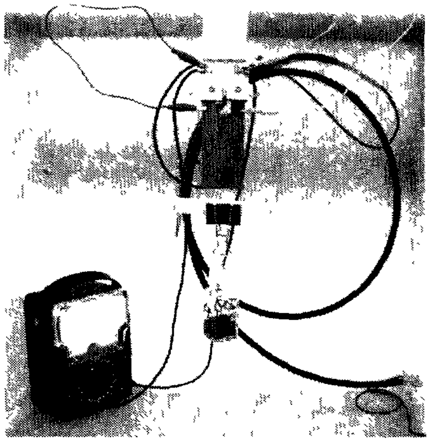
- Graphite powder applied to both sides using a mylar mask



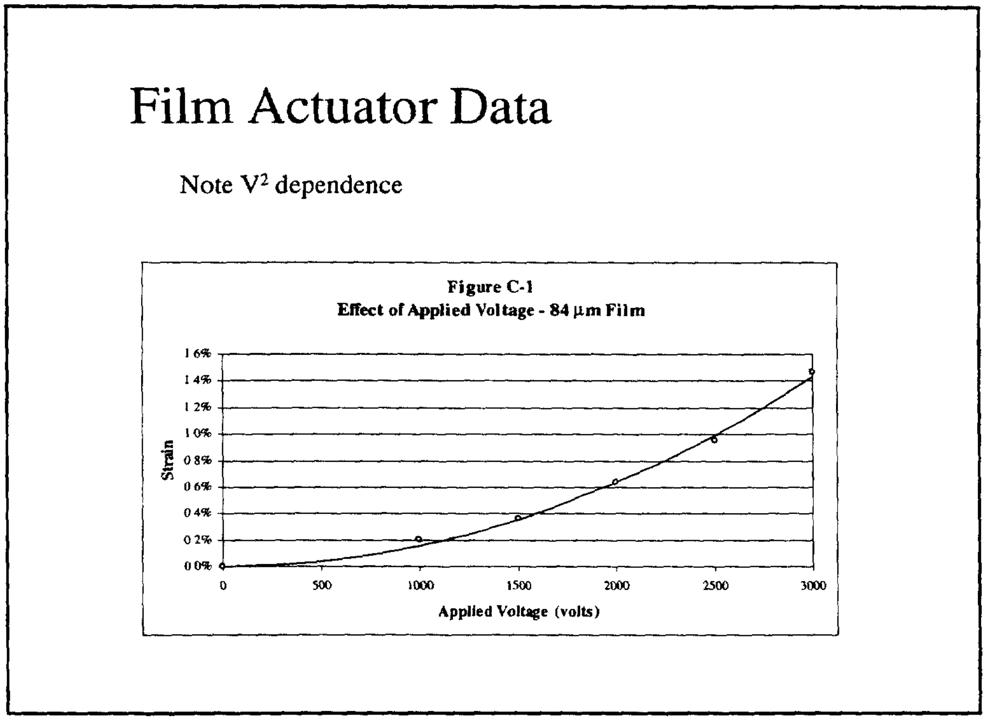
Rod Actuator

- Barrier film applied to one side of film actuator
- Laminated film rolled onto steel mandrel.
- Mandrel removed and replaced with plastic cylinder.

Actuation Experiments



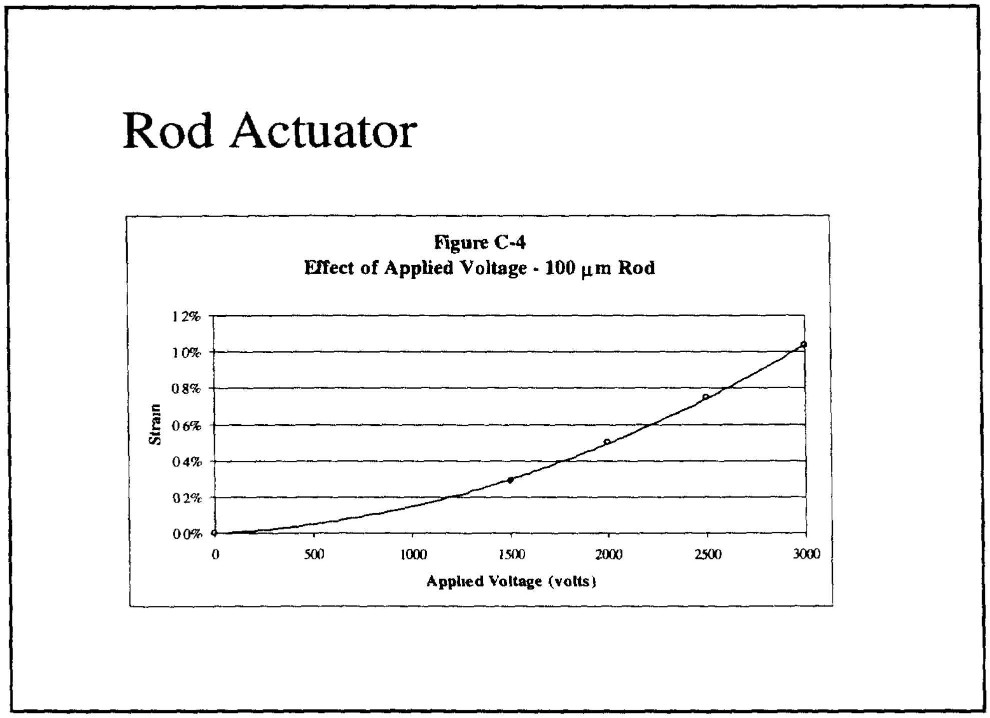
- Actuation chamber built for safety
- High voltage power supply connected to two electrodes
- Elongation measured as a function of voltage up to dielectric breakdown. Used cathetometer.
- Films of <50 µm were destroyed by arcing at low voltages before any measurements could be made.
- Film thicknesses in the range of ~100µm arced at ~3500 - 4500 V.



Film Actuator Data

Note V^2 dependence

Figure C-1
Effect of Applied Voltage - 84 μm Film



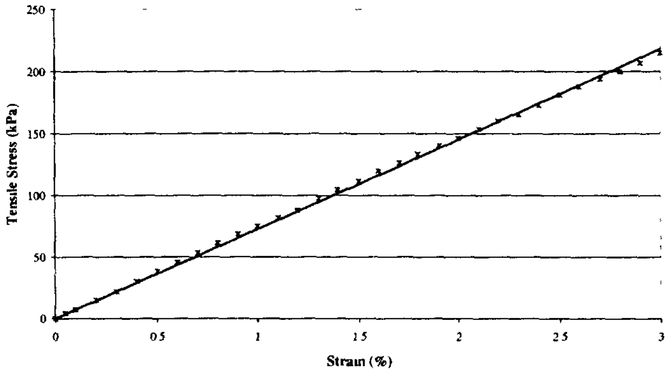
Rod Actuator

Figure C-4
Effect of Applied Voltage - 100 μm Rod

Instron Stress-Strain Data

ASTM D882-97 Quasi-static Young's modulus = 7.275 MPa

Figure D-1
Stress/Strain Behaviour of Pellethane 2103-70A

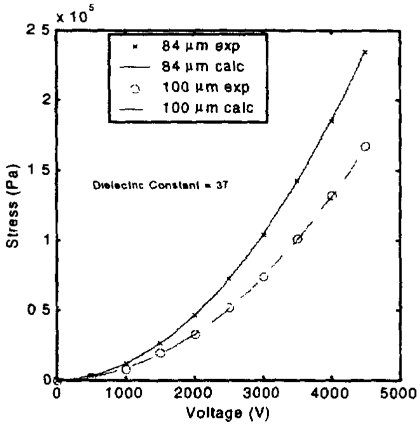


Summary Table

Up to 234 kPa stress observed
Thickness dependence not in accordance with the model
Non-uniformity of film thickness possibly an issue

	Stress (kPa)			
Applied Voltage	**84 µm Film** **01-05-8518-107**	**100 µm Film** **01-05-8660-7-3**	**135 µm Film** **01-05-8660-9/12**	**100 µm Rod** **01-05-8518-111**
0	0	0	0	0
500	3	2	2	
1000	12	8	8	
1500	26	19	19	20
2000	46	33	33	36
2500	72	52	52	56
3000	104	74	75	80
3500	142	101	102	
4000	185	132	133	
4500	234	167	169	

Comparison with Model



Stress $P_1 = \mu e_0 e V^2/2d^2$

For 84 µm and 100 µm films:
- Model fits data very well using a value of e = 37 for the dielectric constant
- Manufacturer's reported value of e = 7.3
- Difference could be explained by frequency dependence of e.
- Need to measure e(ω)

Summary

- Dielectric actuators based on cast thermoplastic polyurethane films were prepared with brushed-on graphite powder as electrodes.
- Strains of up 2% were measured, which corresponds to a stress of approximately 230 kPa for an 84 µm film.
- The voltage/strain relationship followed a parabolic relationship as predicted by theoretical considerations. Actuators with similar strain values were prepared by forming longer films and rolling them into tubes.
- Experimental data was in accordance with a simple parallel plate capacitor model for two different film thicknesses, using a value of 37 for the dielectric constant of the polyurethane film.

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Future Work

- This was a preliminary study.
- Have applied for TIF funding to further explore the potential of these actuator materials
  - Focus will be on active/ passive vibration isolation mounts
  - Materials formulation and characterization
  - Fabrication methods for multi-layers and rolled geometries
  - Actuator characterization (RMC)
  - Modelling (MAVART)

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