Artificial muscle design based on electroactive polymers

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Introduction

Problem:

- Need for powered human assistive devices to restore mobility of patients.
- Available actuators are heavy and energy inefficient for mobile systems.

Solution:

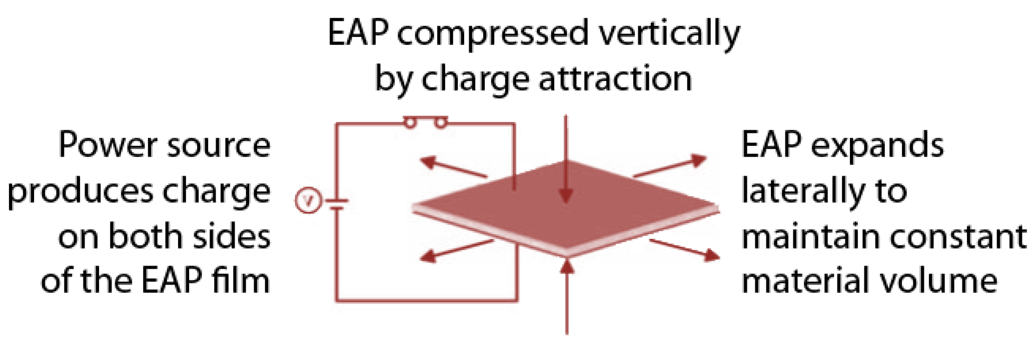
- Electroactive polymers (EAP) are a smart material that change shape when subjected to electric fields.
- EAP are light and inexpensive.
- EAP actuators can be designed as artificial muscles.

Objectives

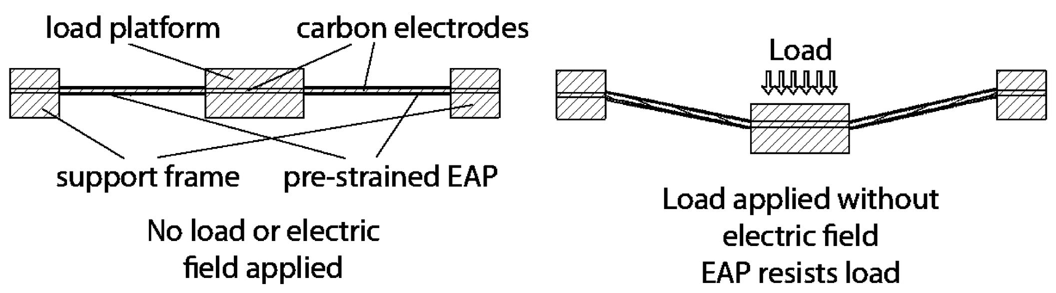
- Examine properties of 3M VHB 4910 EAP.
- Design a proof of concept actuator.
- Test its feasibility to be an actuation solution for human assistive devices.

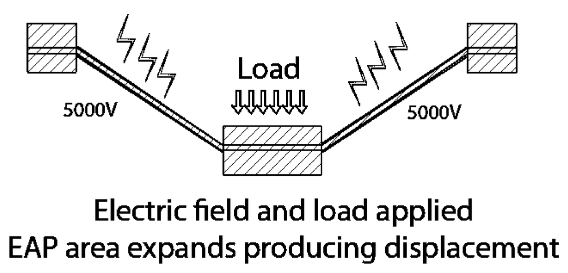
Theoretical background

- 3M VHB 4910 is a dielectric EAP.
- The compression in response to electric field stress (Maxwell stress) induces EAP expansion perpendicular to the field.



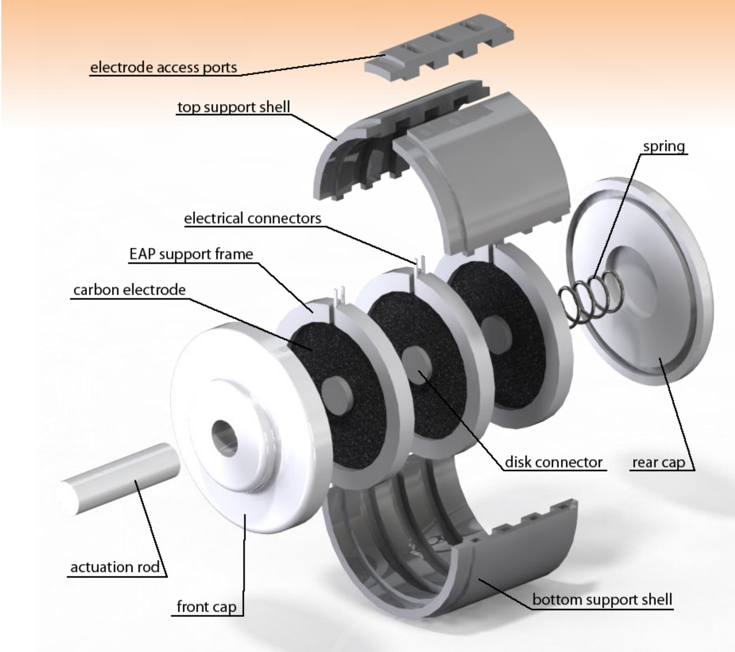
- Lateral expansion of EAP film placed in a rigid frame can be controlled by varying electric field to produce motion.



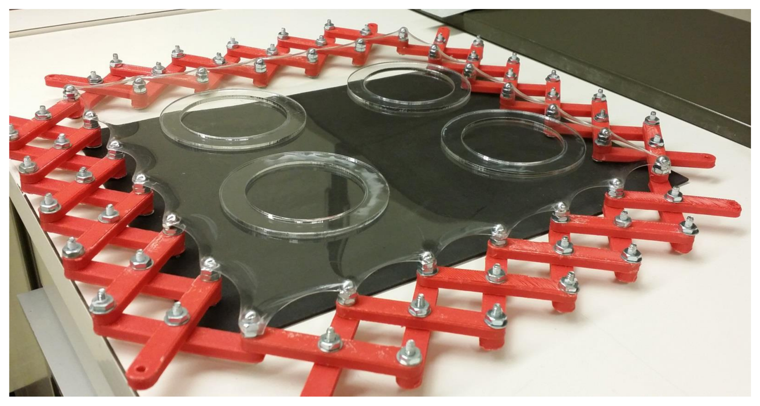


- Pre-strain of the film enhances strain efficiency and reduces the strength of electric field required.

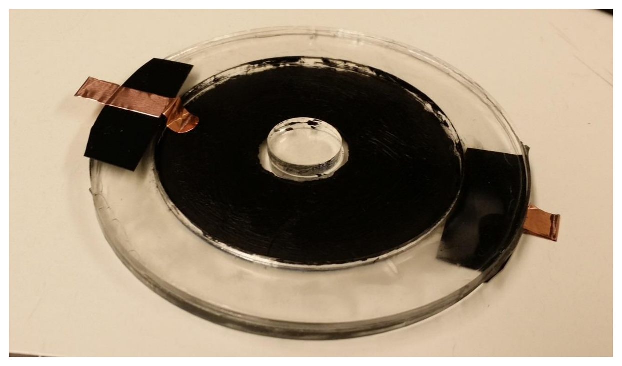
Design and testing methodology



SolidWorks design model.

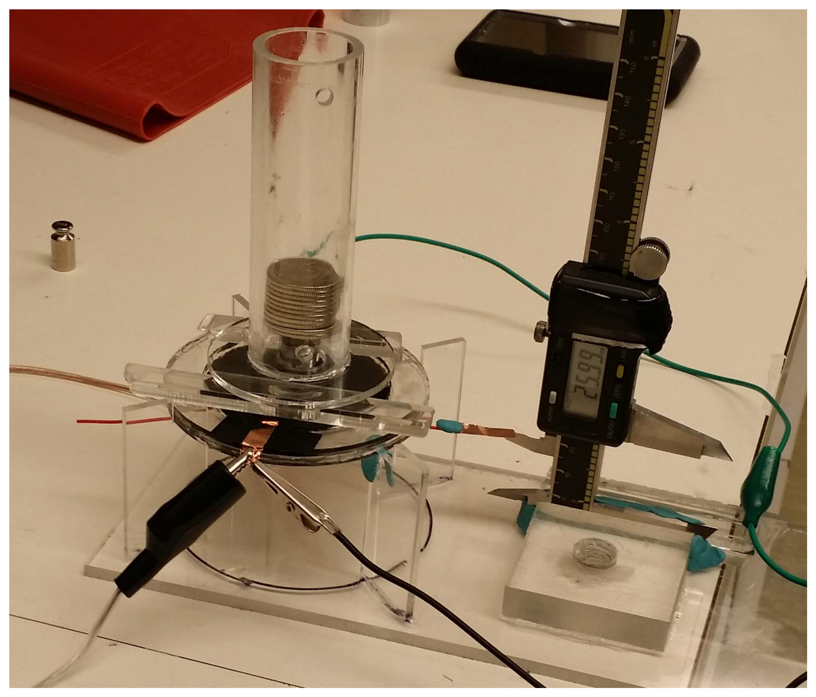


Pre-straining mechanism with acrylic frames attached to fixate the EAP.



Carbon grease electrode coated EAP in a rigid acrylic frame.

- A spring-loaded stacked film actuator was designed in SolidWorks.
- EAP films were modeled using Hooke's elastic equations, relating Maxwell stress, biaxial film strain, and applied voltage.
- A pre-straining mechanism was built and used to apply a 400% biaxial strain to the film.
- EAP disks were constructed using acrylic frames and pre-strained EAP coated with carbon grease electrodes.
- EAP displacement was measured under varying load and electric field conditions.

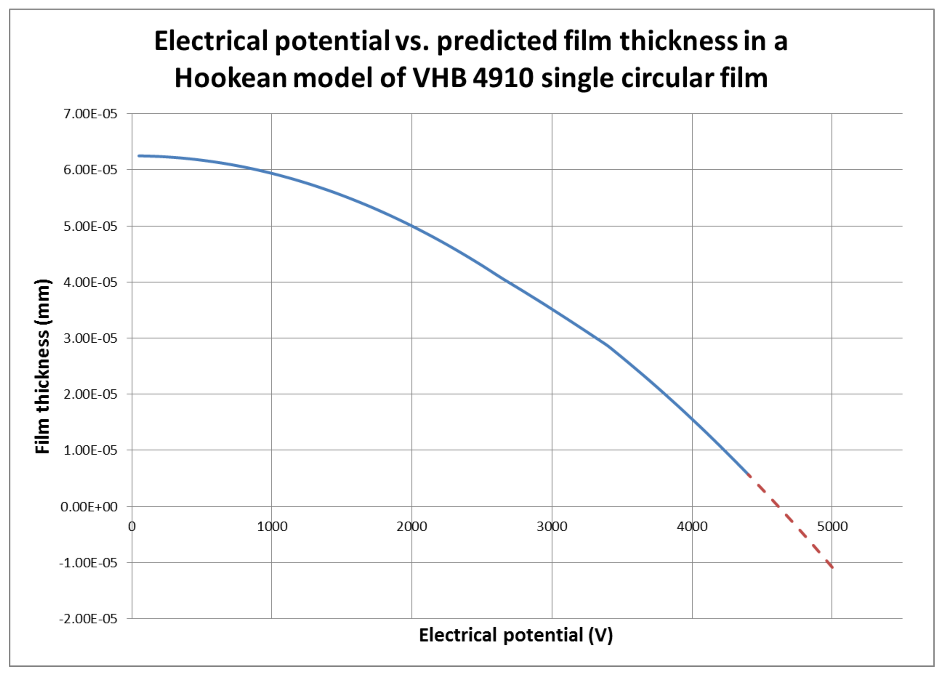


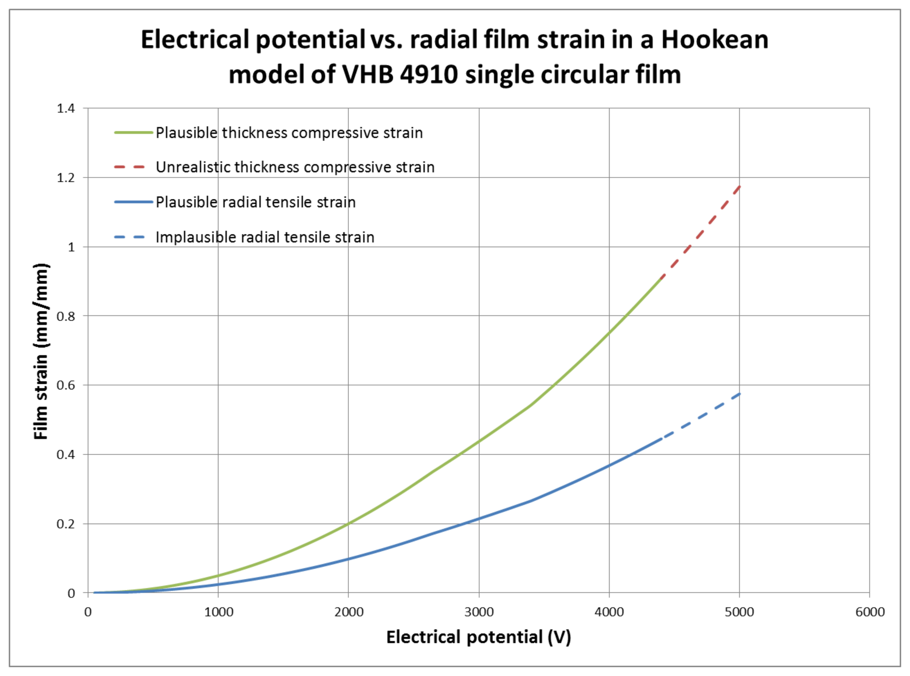
EAP deformation measurement apparatus.

Results

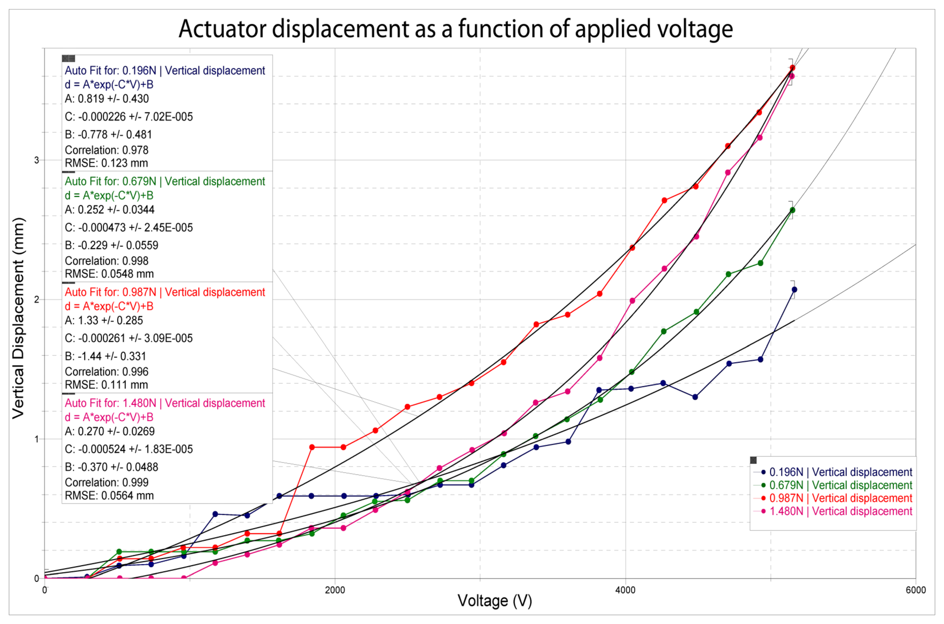
EAP modeling using Hooke's elastic equations:

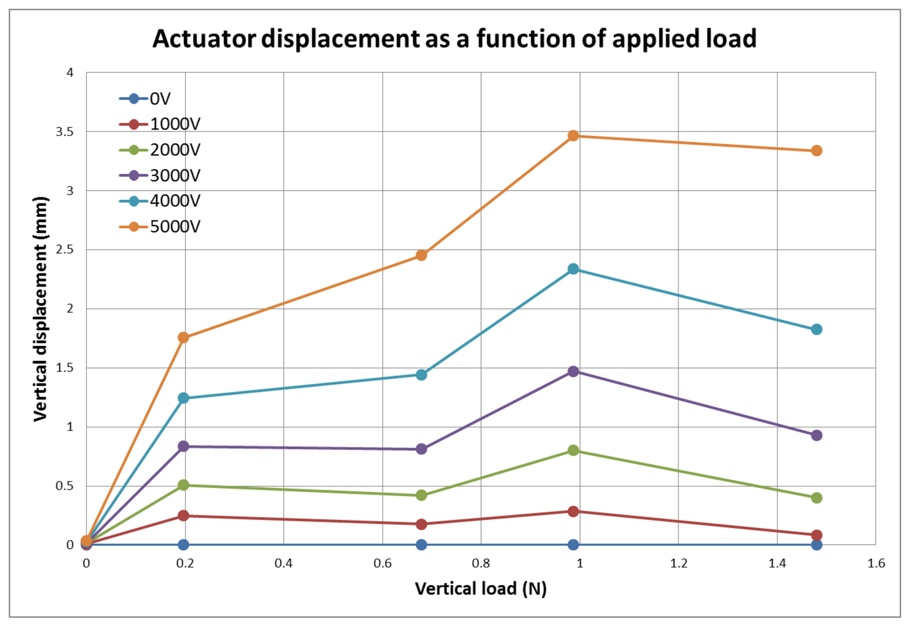
- Model limited to strain below 0.44.
- Not suitable for pre-strained films where strains are typically over 1.





Experimental modeling of EAP film displacement:





Results

- Pre-strained EAP film displacement fits exponential model d = A*e$^{(CV)}$ – B, where A, B and C are experimentally determined.
- Model-data correlation is 0.978, suggesting a good fit.
- EAP deformation was fully elastic, even with 400% pre-strain. Films returned to original vertical position when voltage turned off.
- A 0.987N load produced greatest displacement, while higher or lower loads produced smaller displacements.

Conclusions and recommendations

- EAP modeling using Hooke's linear elastic equations is limited, good exponential model fit supports this conclusion.
- Oghden or Mooney-Rivlin differential models with finite element analysis are recommended for EAP modeling.
- An optimal EAP stress level exists, which produces greatest film strain, and therefore greatest displacement of load.
- No viscoelastic deformation was observed even with 400% biaxial EAP pre-strain. May be promising for long-term reliability.
- Recommend testing many EAP samples using biaxial straining apparatus in a universal testing machine.
- The current design employing 10 EAP films could potentially move a 1kg weight by ~4mm. Adding extra films would increase the weight allowance, but not load displacement.
- The presently low displacement of applied loads limits the potential of this actuator design in biomedical applications.

Acknowledgements

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