# Dynamic Electroactive Polymer Actuators Fabrication Analysis

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***Abstract****- This paper presents an overview of the widely used conventional linear actuator technologies. It also provides the conceptual, control and driver design considerations for a new dielectric electro-active polymer (DEAP) based incremental actuator. The DEAP incremental actuator consists of three independent DEAP actuators with a unique cylindrical design that potentially simplifies mass production and scalability compared to existing DEAP actuators. To accomplish the incremental motion, a high voltage (HV) bidirectional DC-DC converter, independently charges and discharges each capacitive DEAP actuator. Artificial muscle has the potential to fundamentally shift the way many types of industrial, medical, consumer, automotive, and aerospace products are powered and operated. It offers significant advantages over typical electromagnetic-based technologies because it is much lighter, smaller, quieter and cheaper. It also offers more controllable and flexible configurations. Artificial muscle enables a wide variety of applications, including haptic displays to improve human computer interaction, adaptive optics, flat conformal loudspeakers, and, potentially, implantable active medical prosthetics. The technology has also demonstrated promise for a variety of actuator and electric power generation applications.*

***Keywords***- linear actuators, dielectric electro-active polymer (DEAP), scalability, DC-DC power converters

## I. INTRODUCTION

The various types of natural muscle are incredible material systems that enable the production of large deformations by repetitive molecular motions. Polymer artificial muscle technologies are being developed that produce similar strains and higher stresses using electrostatic forces, electrostriction, ion insertion, and molecular conformational changes. Materials used include elastomers, conducting polymers, ionically conducting polymers, and carbon nanotubes. The mechanisms, performance, and remaining challenges associated with these technologies are described. Initial applications are being developed, but further work by the materials community should help make these technologies applicable in a wide range of devices where muscle-like motion is desirable. The performance of the emerging polymer actuators exceeds that of natural muscle in many respects, making them particularly attractive for use anywhere where a muscle-like response is desirable, including in medical devices, prostheses, robotics, toys, biomimetic devices, and micro/nanoelectromechanical systems, Commercial application of these materials is at an early stage. Challenges remain with many of the technologies, most of which can be overcome via improvements in material properties. Here we seek to relate material properties to performance in the hopes of galvanizing the materials community into improving existing materials and inventing new ones. In this review, polymer artificial muscles have been divided into two major groups. In the first group, dimensional change (actuation) is in response to an electric field. These are commonly known as electronic or electric electroactive polymers (EAPs). Some of the technologies that fall under this category are dielectric elastomer actuators (DEAs), relaxor ferroelectric polymers, and liquid crystal elastomers. The second group of polymer artificial muscles is a class of materials in which the presence and movement of ions is necessary to make actuation possible. This group is referred to as ionic EAPs. For the ions to be able to move, an electrolyte phase is necessary, which is often liquid; so these actuators are also known as wet EAPs. Actuators described in this review employ conducting polymers, ionic polymer metal composites (IPMC), and carbon nanotubes (CNTs) as active materials. Gel actuators also fit into this category but are not covered here. A number of other artificial muscle technologies exist that respond to heat, which have also been omitted. We also give a brief description of some exciting directions in actuation in which molecular design is used to create actuation that is either voltage or light driven.

A pneumatic linear actuator [1] operates with an external source of compressed air. It generates precise motion, but relatively complex to control via pressure valves and compressor manipulation. A hydraulic linear actuator [2] requires an external source for fluid pressurization. Hydraulic actuators not only allow the generation of large forces but also capable of closed-loop velocity controlling or highly precise positioning of heavy loads. Its control is complex, involving compressor and hydraulic valves. A piezo actuator [3] converts electrical energy directly into mechanical energy and vice versa.

Besides a higher resolution, the piezo actuators have other advantages such as small size, light weight, operation under magnetic fields, low energy consumption, and low wear and tear. The disadvantages are high cost, low shock robustness, and requirement of high driving voltage. The DEAP incremental actuator technology can be used in various challenging industries such as, automotive, space and medical. It provides a comparison of DEAP technology with piezo and pneumatic actuator technologies, and electromechanical motors.

To summarize, the DEAP incremental actuator technology has lower force density but has the potential for higher strain, better energy efficiency, and higher structural flexibility and robustness compared to other technologies. The composition, mechanisms, properties, and materials challenges are described for each technology. The key properties of interest are elastic modulus, strain, stress, work density, power density, and electromechanical coupling. Work density is the amount of mechanical work per unit volume in one actuator stroke. The convention in work density used in the piezoelectric and dielectric elastomer literature is to report the work done in elastically deforming the actuator material itself in one dimension, $u = \frac{1}{2}E\varepsilon2$, where $E$ is the elastic modulus and $\varepsilon$ is the strain. In acting on a matched elastic load, only half of this work can be extracted, so in fact the work out is $\frac{1}{2}u$ to provide an upper bound on the external work done under such loading conditions. This challenge is being addressed by reducing film dimensions and increasing the dielectric constant. These materials feature good electromagnetic coupling coefficients and high work densities (a hundred times that of muscle).

## II. DIELECTRIC ELASTOMER ACTUATORS

### *A. Design Of An Axial Deap Actuator*

The dielectric elastomer (DE) film consists of two DE sheets laminated together. Core DE technology comprises an electrical insulating layer of elastomer sandwiched between two deformable layers of electrically conductive material (electrodes). As shown in Fig.1, only one of the DE sheets of a DE laminate is metallized at either lateral end to the left and to the right. This is to realize a safe electrical connection in the actuator by avoiding short circuiting. Some of the design parameters are assumed before the design and the remaining parameters are calculated using the known parameters.

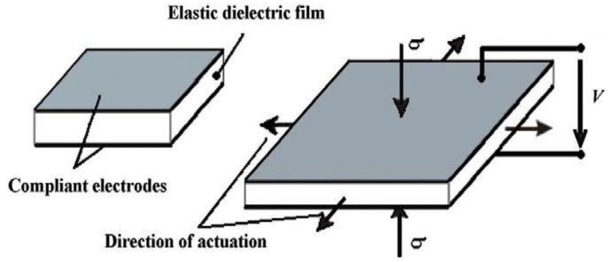


Fig. 1 The mechanism of actuation in DEAs.

The application of the voltage V between the two electrodes results in the generation of a Maxwell stress of σ, compressing the dielectric and resulting in its lateral expansion.

The operating region of an axial DEAP actuator can be represented by the relationship between its force, stroke and applied voltage (or electric field strength). Rolled dielectric elastomer actuators (DEAs) are subjected to necking and non-uniform deformation upon pre-stress relaxation. Though rolled up from flat DEAs, they performed much poorer than the flat ones. the oil encapsulation and large pre-stretch help realize fuller actuation potential of tubular dielectric elastomer, which is subjected to initially non-uniform deformation. This study shows that oil encapsulation, together with large hoop pre-stretch, helps single-wound rolled DEAs, which are also known as tubular DEAs, suppress premature breakdown.

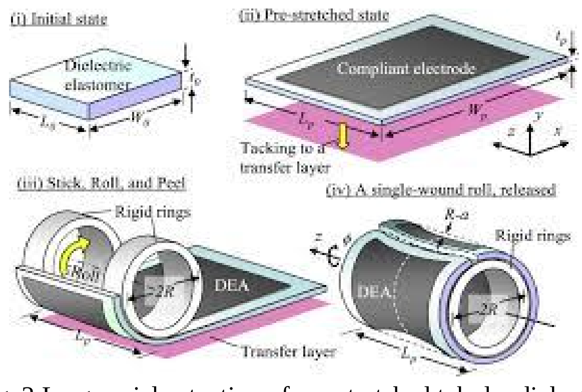


Fig. 2 Large axial actuation of pre-stretched tubular dielectric elastomer

Their electrically induced axial strains were previously reported as not more than 37.3%, while the flat ones produced greater than 100% strain. Often, the rolled DEAs succumb to premature breakdown before they can realize the full actuation potential like the flat ones do. Consequently, the oil-encapsulated tubular DEAs can sustain higher electric fields, and thus produce larger isotonic strain and higher isometric stress change. Under isotonic testing, they sustained very high electric fields of up to 712.7 MV $m^{-1}$, which is approximately 50% higher than those of the dry tubular DEAs. They produced up to 55.4% axial isotonic strain despite axially stiffening by the passive oil capsules. In addition, due to the use of large hoop pre-stretch, even the dry tubular DEAs without oil encapsulation achieved a very large axial strain of up to 84.2% compared to previous works.

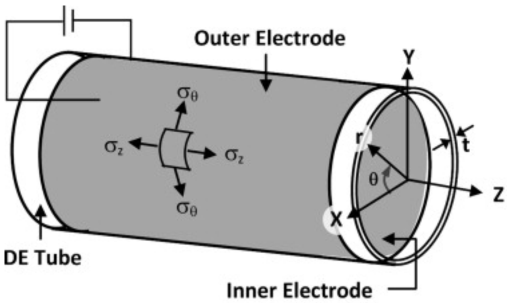


Fig. 3 dielectric elastomer tubular actuator for refreshable Braille displays

Electroactive polymer actuators stimulated by appropriate levels of electric field are particularly attractive for human-assist devices such as Braille. The development of a full page refreshable Braille display is very important for the integration of the visually impaired into the new era of communication. The test results demonstrate the potential of the compact, lightweight, and low cost dielectric elastomer as actuators for a refreshable full page Braille display.

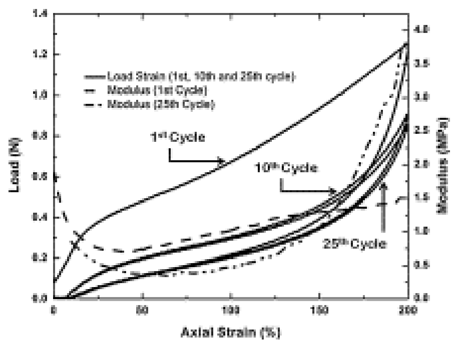


Fig. 4 Actuator stroke and strain as a function of applied voltage for the scaled design

### III. INCREMENTAL MOTOR

The extender expands axially along the guiding bar. During the operation, one gripper holds the guiding bar while the other gripper is in a released position. The extender either pushes or pulls the released gripper. The drive frequency for all scaled designs is not the same, since the scaled DEAP actuators' capacitances are different.

Most DEAs are composed of a thin dielectric elastomer layer sandwiched between two compliant electrodes. DEAs vary in their design to provide bending, torsional, and stretch/contraction motions under the application of high external voltages. Most compliant electrodes are made of carbon powders or thin metallic films. In situations involving large deformations or improper fabrication, the electrodes are susceptible to breakage and increased resistivity. The worst cases result in a loss of conductivity and functional failure. In this study, we developed a method by which to exploit stretchable metallic springs as compliant electrodes for cylindrical DEAs. This design was inspired by the extensibility of mechanical springs. The main advantage of this approach is the fact that the metallic spring-like compliant electrodes remain conductive and do not increase the stiffness as the tube-like DEAs elongate in the axial direction. This can be attributed to a reduction in thickness in the radial direction. The proposed cylindrical structure is composed of highly-stretchable VHB 4905 film folded within a hollow tube and then sandwiched between copper springs (inside and outside) to allow for stretching and contraction in the axial direction under the application of high DC voltages. To achieve an actuator with high strain and high stress coupled with low density, used a silicone rubber matrix with ethanol distributed throughout in micro-bubbles. The solution combined the elastic properties and extreme volume change attributes of other material systems while also being easy to fabricate, low cost, and made of environmentally safe materials.

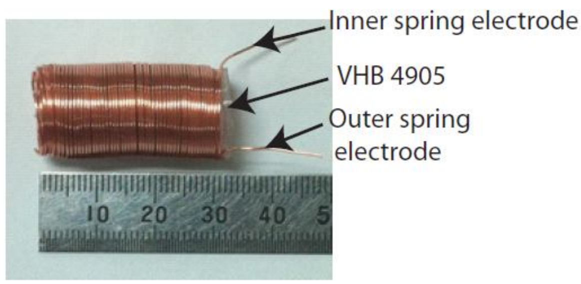


Fig. 5. Photograph of fabricated spring-based-electrode cylindrical DEA.

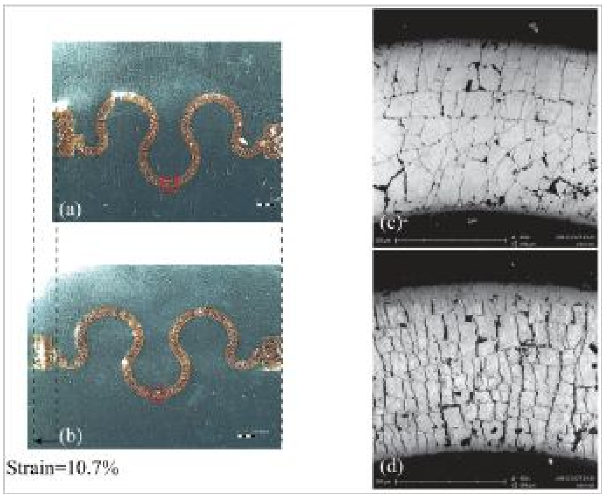


Fig. 6 (a) without stretching and (b) with stretching (c),(d) scanning-electron-microscope (SEM) images of meandered parts at 410 magnification

The individual copper spring presented a linear stress-strain relation with little overall impact on the actuator. In other words, the non-linear behavior of the proposed DEA was due mostly to the nonlinear properties of VHB film. The Young's modulus of the proposed metallic springs was lower than that of the electrodes coated with a metallic film, falling within the GPa range suitable for actuation applications.

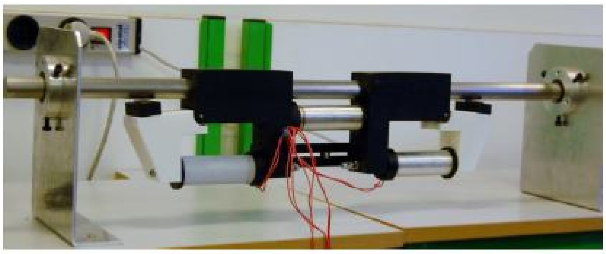

Fig. 7. Setup of the DEAP incremental actuator driven by three HV drivers.

Inspired by living organisms, soft material robotics hold great promise for areas where robots need to contact and interact with humans, such as manufacturing and healthcare. Unlike rigid robots, soft robots can replicate natural motion grasping and manipulation to provide medical and other types of assistance, perform delicate tasks, or pick up soft objects.

After being 3D-printed into the desired shape, the artificial muscle was electrically actuated using a thin resistive wire and low-power (8V). It was tested in a variety of robotic applications where it showed significant expansion-contraction ability, being capable of expansion up to 900% when electrically heated to 80°C. Via computer controls, the autonomous unit is capable of performing motion tasks in almost any design.

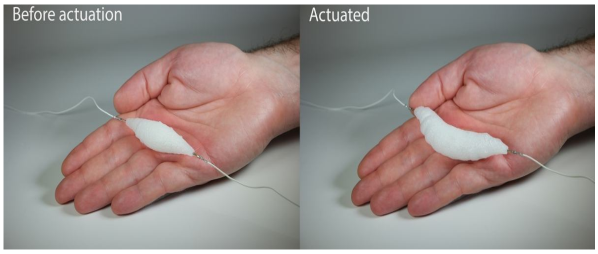


Fig. 8 (L) The electrically actuated muscle with thin resistive wire in a rest position; (R) The muscle is expanded using low power characteristics (8V).

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