Proceedings of SPIE's 6th Annual International Symposium on Smart Structures and Materials, 1-5 March, 1999, Newport Beach, CA. Paper No. 3669-41

Electro-statically stricted polymers (ESSP)

C. Liu[a], Y. Bar-Cohen[b], and S. Leary[b]

[a] University of Illinois at Urbana-Champaign (UIUC) 61801, changliu@uiuc.edu
[b] Jet Propulsion Laboratory (JPL), Caltech., Pasadena, CA, *yosi@jpl.nasa.gov*

ABSTRACT

Miniature, lightweight, miser actuators that operate similar to biological muscles can be used to develop robotic devices with unmatched capabilities and impact many technology areas. Electroactive polymers (EAP) offer the potential to producing such actuators and their main attractive feature is their ability to induce relatively large bending or longitudinal strain. Generally, these materials produce a relatively low force and the applications that can be considered at the current state of the art are relatively limited. While improved material are being developed there is a need for methods to develop longitudinal actuators that can contract similar to muscles. In addition, it is desirable to have these actuators in a fiber form that can be bundled to provide the necessary characteristics of stiffness, fracture toughness, resilience and large force actuation. To address this need efforts were made to develop both the material basis as well as the electromechnical modeling of the actuator.

Keywords: Miniature Robotics, Electroactive Polymers, EAP Actuators

1. INTRODUCTION

Efficient miniature actuators that are light, compact and driven by low power are needed to drive telerobotic devices and space mechanisms in future NASA missions. Actuators that are driven by transduction phenomena, where electrical, thermal or magnetic signals are converted into an displacement or strain have already, are increasingly finding applications in planetary mechanisms. Electroceramics (EAC) offer effective, compact, actuation materials and they are incorporated into such mechanisms as ultrasonic motors, inchworms, translators and manipulators. Also, Shape Memory Alloys (SMA) are finding applications where low speed, large force actuation at <4% strain actuation is needed. In contrast to EAC and SMA, electroactive polymers (EAP) are emerging as new actuation materials [Furukawa and Wen, 1984] with displacement capabilities that cannot be matched by the striction-limited and rigid ceramics. EAPs are lighter and their striction capability can be as high as two orders of magnitude more than EACs [Bar-Cohen, et al, 1998]. Further, their response speed is significantly higher than Shape Memory Alloys (SMAs). Polymers actuators offer unique capabilities that are the result of their resilience, fracture toughness, large actuation strain constant, inherent vibration damping and tailorable properties [Bar-Cohen, et al, 1997, Hunter and Lafontaine, 1992; and Kornblush, et al, 1995]. Generally, once their ability to induce large force is sufficiently enhanced they can be designed to emulate the operation of biological muscles.

The development of actuators that emulate muscle is involved with interdisciplinary efforts using expertise in materials science, chemistry, electronics, and robotics. The infrastructure of this field is still lack key technologies and capabilities that need sufficient progress before such actuators can be used for such applications as augmenting handicap mobility. EAP materials can be categorized in mostly two groups including (a) bending actuators and (b) longitudinal actuators. The emphasis of this manuscript is on the longitudinal EAP actuators with emphasis on electrostatically activated EAPs. In parallel to the authors research effort to develop efficient materials, they are seeking to identify robotic and planetary applications in NASA future missions to transfer the technology. Beside the design of mechanisms where the EAP actuators can employed while accounting for their deficiencies, a study is underway to develop computer control capability for remote operate. An important issue that needs adequate attention is the current lack of effective sensors that are flexible and lightweight to provide feedback data for robotic tasks actuated by EAP materials.

2. LONGITUDINAL ELECTROSTATIC POLYMER ACTUATORS

Polymers with low elastic stiffness and high dielectric constant can be used to induce large actuation strain by subjecting the material to an electrostatic field. These characteristics of polymers allow producing longitudinal actuators that operate similar to biological muscles using Coulomb forces between electrodes to squeeze or stretch the material. Traditional electrostatic actuators are fabricated as a capacitor with parallel electrodes with a thin air gap between them. One of the major disadvantages of this type of actuators is their relatively low breakdown voltage and they are producing longitudinal extension rather than contraction. The authors adopted the approach that was reported by Kornslush, et al, 1998, where a longitudinal electrostatic actuator is made of dielectric elastomer film coated with carbon electrodes. The force (stress) that is exerted normally on such a film with compliant electrodes is as follows:

$$P = \tfrac{1}{2}\, ee_0 E^2 = \tfrac{1}{2} ee_0 (V/t)^2 \qquad (1)$$

Where: *P* is the normal stress, $,_0$ is the permittivity of vacuum and , is the relative permittivity (dielectric constant) of the material, *E* is the electric field across the thickness of the film, *V* is the voltage applied across the film and *t* is the thickness of the film.

Examining the equation above, it is easy to notice that the force magnitude is twice as large as that for the case of rigid parallel electrodes. To obtain the thickness strain the force needs to be divided by the elastic modulus of the film. Use of polymers with high dielectric constants and application of high electric fields induces large forces and strains. To obtain the required electric field levels one needs to either use high voltage and/or employ thin films. For elastomers with low elastic modulus, it is reasonable to assume a Poisson's ratio of 0.5. This means that the volume of the polymer is kept constant while the film is deformed under the applied field. As a result, the film is squeezed in the thickness direction causing expansion in the transverse plane. For a pair of electrodes with circular shape, the diameter and thickness changes can be determined using the following relation, where the second order components are neglected.

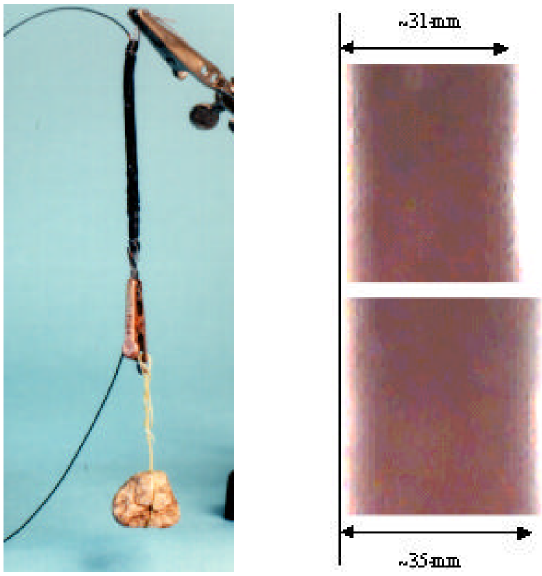
$$\Delta D / D_0 = -(1/2)\Delta t / t_0 \qquad (2)$$

Where: D_0 is the original diameter of the electrodes and ΔD is the resultant diameter change, t_0 is the original thickness and Δt is its change under electric activation.

To produce a longitudinal actuator with large actuation force, a stack of two silicone layers (Dow Corning Sylgard 186) was used with carbon electrodes on both sides of one of the layers. The displacement in the rope cross section is a rotational one around the rope axis and it is constrained by interlaminar stresses. Therefore, the total actuation extension of the rope is proportional to its length and the resultant actuation force is proportional to the cross-section area normal to the axis. To develop an EAP muscle using such a rope, the length and diameter are used as design parameters, enabling the adaptation of the rope actuator to specific applications. In Figure 1, a silicone film is shown to produce about 12% extension at 2500-V and in a rope form it is used to drop and lift a 10-g rock with displacement of about 6%.

3. DESIGN AND MODELING OF MUSCLE ACTUATORS

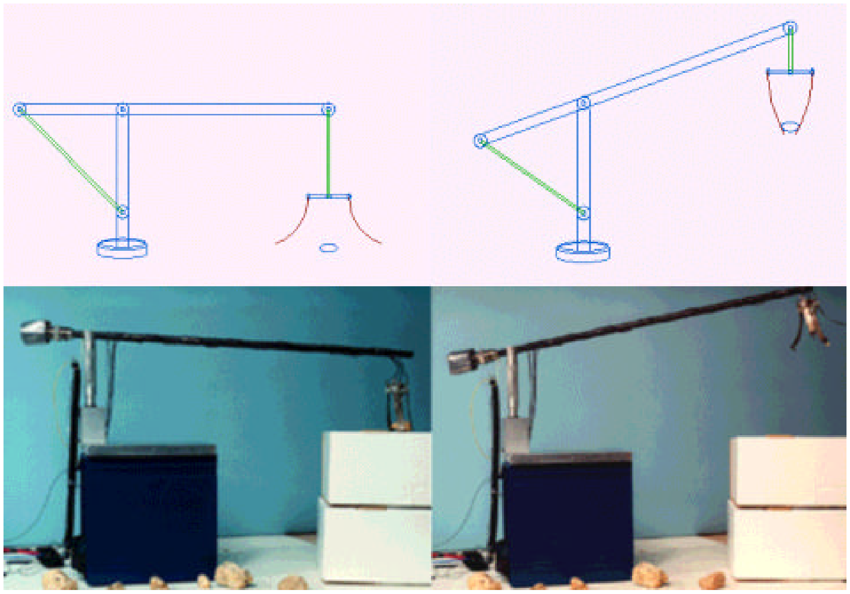
Figure 1: Using an electroded silicone film a 12% extension was obtained by electro-activation (right) and in a rope shape the actuator is shown lifting 10.3-g rock (left)



4. ROBOTIC APPLICATIONS USING EAP ACTUATOR

The availability of EAP actuators that can bend or extend/contract allows producing unique robotic devices that emulate human hands. The JPL authors investigated several potential applications for the ESSP type EAP and a robotic arm was developed with a gripper end effector. A computer program was developed using MATLAB computer code that allowed controlling the lifting and dropping of the arm as well as the operation of the end effector as shown in Figure 2.

Figure 2: A simulated view (top) and a constructed robotic arm, which takes advantage of the capability of longitudinal and bending EAP actuators.



To form this miniature lightweight robotic arm a 5-mm diameter graphite/epoxy rod was used and an ESSP rope was connected on the short end of this balanced rod and was used to lower and raise the arm as shown in Figure 2. On the right of the rod a gripper was mounted as an end effector using bending EAP fingers and miniature hooks to secure the gripped objects. The rope was consisted of a silicone film and it required voltage levels of 30-70 V/μm, which reached between 1000 and 2500-Volts to produce the levels of several percents actuation strain (shown in Figure 1). Since the film is squeezed as a result of the activation, it becomes longer under the electro activation making the rope longer. This longitudinal EAP rope actuated the arm by tilting its balance and the lifting displacement is determined by the ratio between its connection distance from the pivot point compared to the gripper distance. The longitudinal EAP was used here as the equivalent of human muscle with the exception that it becomes longer under activation. The gripper having fingers to grab and hold objects formed the equivalent to human hand. The inability of the bending EAP to lift any significant mass was taken into account in this application by avoiding this necessity. The fingers, which have remarkable opening capability, were used to "hug" the samples and grab on them by hooks that attached at the finger bottom. The fingers move back and forth opening and closing the gripper similar to human hand, embracing the desired object and gripping on it. The hooks at the end of the fingers are functioning similar to fingernails to hold the object securely. The gripper was driven by 2 to 5-V square wave signal at a frequency of 0.1-Hz to allow sufficient time to perform a demonstration of the gripper capability. The robotic arm was programmed such that it is lowered near the object to be collected, the gripper fingers are opened as the arm comes down and allowed to close on the object and holding it with aid of the hooks. At this point the fingers are closed and the object is lifted. The demonstration of this robotic arm and gripper capability to lift a rock was intended to pave the way for a future application to planetary sample collection tasks providing miniature ultra-dexterous and versatile tool.

5. CONCLUSION

Longitudinal EAP actuators are important family of materials that has the most potential to emulate biological muscles. Key elements of making such materials as the actuators of choice in the future is the development of material with enhanced force actuation, method of making them in a fiber form and the ability to theoretical model complex configurations. The ability of such material to support miniature robotics was demonstrated by the JPL authors who developed a robotic arm and controlled its performance via computer. Two types of electroactive polymer actuators were used to construct the arm and a gripper end effector. The longitudinal displacement actuation was obtained by electrostatically activated films that were rolled to form ropes and served as the equivalence of biological muscles. These electroactive polymers are showing a superior actuation displacement, mass, cost, power consumption and fatigue characteristics over conventional electromagnetic, EAC and SMA actuators. While the force actuation capability of EAPs is limited, their actuation displacement levels are unmatched. A miniature robotic arm was constructed similar to human hand using a composite rod and a scrolled rope electrostatic actuator for the lifting mechanism and a 4-finger gripper as an end-effector.

6. ACKNOWLEDGEMENT

The research at Jet Propulsion Laboratory (JPL), California Institute of Technology, was carried out under a contract with National Aeronautics Space Agency (NASA) as part of the telerobotic program, funded by Code S. and Dr. Chuck Weisbin is the Program Manager at JPL.

7. REFERENCES

Bar-Cohen Y., T. Xue, M. Shahinpoor, J. O. Simpson, and J. Smith, "Flexible, low-mass robotic arm actuated by electroactive polymers (EAP)," *Proceedings of the SPIE International Smart Materials and Structures Conference*," SPIE Paper No. 3329-07, San Diego, CA, 1-6 (March 1998).

Furukawa and J. X. Wen, "Electrostriction and Piezoelectricity in Ferroelectric Polymers," Japanese Journal of Applied Physics, Vol. 23, No. 9, pp. 677-679, 1984.

Hunter I. W. and Lafontaine, S. "A comparison of muscle with artificial actuators," *IEEE Solid-State Sensor and Actuator Workshop*, pp. 178-165, 1992.

Kornbluh R., R Pelrine., J. Joseph. Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation," *Sens. Actuat.*, vol. A64 pp. 77-85 (1998).

Yoshiko, A., A, Mochizuki, T. Kawashima, S. Tamashita, K. Asaka and K. Oguro, "Effect on Bending Behavior of Counter Cation Species in Perfluorinated Sulfonate Memberance-Platinum Composite," *Polymers for Advanced Technologies*, Vol. 9. (1998) pp. 520-526.