A REVIEW ON DIELECTRIC ELASTOMER AND ITS APPLICATION

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ABSTRACT

Dielectric elastomer is one of the important electroactive polymer used as actuator in adaptive structures due to its outstanding ability to generate very large deformations under the influence of an external electric field. The positive feedback may cause the elastomer to thin down drastically and enhances the effective electric field which causes a dielectric breakdown. Dielectric elastomers have been the topic of much interest over the past decade due to its wide range of applications in industries and research. In earlier years, much of the focus was on the configurations of actuators. In more recent years the focus has shifted to the properties of the investigating material for enhancing actuator's performance. This paper reviews and highlights some of its advantages over existing actuator technologies. Further it identifies some of the challenges associated with its development, and examines the main focus of research with key parameters affecting the performance in some of the potential applications.

Keywords: *Electrostriction, Dielectric Elastomer, Actuators*

1. INTRODUCTION

An actuator is an electro-mechanical device for controlling the mechanism of a system used in wide range of industrial applications. Traditional actuators include pneumatic actuators, electronic actuators, motors, and hydraulic cylinders. The weight, limited size, complex transmission, and restrictive shape of such actuators have led researchers to investigate alternative technologies for various applications. A comparison of the properties of Electroactive Polymers (EAP) and widely used transducer actuators have been outlined in table 1 [1-3].

Electroactive polymers (EAPs) are being intensely studied in recent years. Examples include dielectric elastomers, shape-memory polymers, and stimuli-responsive gels. Once a voltage is applied to a layer of VHB (Very High Bondage) acrylic elastomer, a kind of dielectric elastomers, a strain of 200% or more is easily achieved [1]. This is two orders of magnitude larger than the maximum strain of piezoelectric ceramics [4] indicating a significant enhancement in mechanical properties of VHB acrylic elastomer over piezoelectric ceramics.
The aim of this review is to familiarize to researchers with recent developments in the area of dielectric elastomer actuators technology which way encourage further research in this area to overcome some of its challenges and also to inspire new and creative applications.

2. DIELECTRIC ELASTOMERS

Dielectric elastomers are a subset of the electronic electroactive polymers that have been shown to have a great potential for use as artificial muscles and other linear actuators. These materials, which include silicons and acrylic, are incompressible and have a high dielectric constant, and typically have good elastic properties. Characteristics of these materials include the large strain, high energy densities, fast response times, high efficiency, and lightweight [5-6].

Table 1: Comparative study between Electroactive polymers (EAP) and widely used transducer actuators

Property	Electroactive Polymers (EAP)	Shape Memory Alloys (SMA)	Electroactive Ceramics (EAC)
Actuation Displacement	>300%	<8% (short fatigue life)	0.1 - 0.3 %
Pressure (MPa)	0.1 - 3	About 700	30-40
Reaction Speed	ms to S	second to minute	ms to S
Density	1- 2.5 g/ml	5 - 6 g/ml	6-8 g/ml
Drive Voltage	4 - 7 V	NA	50 - 800 V
Power Consumption	mW	W	W
Fracture toughness	Resilient, elastic	Elastic	Fragile

These materials develop actuation using the principle of Maxwell stresses. A thin planar film of the elastomeric material is coated on opposite ends with a compliant electrode material. When a high voltage is applied to the electrodes, an electric field is developed, and the electrostatic forces developed by the opposite charges on the two electrodes cause a compression of the material in the direction of the electric field. Since the film is an incompressible material, this compression results in an expansion of the material in the orthogonal directions [6]. This is the fundamental mechanism of actuation by the dielectric elastomer. However the compression

Table 2: Classification of electroactive polymers (EAP)

Electronic EAP	Ionic EAP
Dielectric EAP Electrostrictive Graft Elastomers Electrostrictive Paper Electro-Viscoelastic Elastomers Ferroelectric Polymers Liquid Crystal Elastomers (LCE)	Carbon Nanotubes (CNT) Conductive Polymers Electro Rheological Fluids (ERF) Ionic Polymer Gels (IPG) Ionic Polymer Metallic Composite (IPMC)

along the field direction enhances the effective electric field which sometimes causes dielectric breakdown.

3. ELECTROMECHANICAL ACTUATION MECHANISMS

An electromechanical actuation mechanism is a physical process whereby a mechanical system is activated by electricity. Two mechanisms, electrostriction and Maxwell's stress effect are considered prime contributors to the large electric-field-induced strain exhibited by electronic EAPs.

The resulting stresses and strains relating to both mechanisms exhibit a quadratic dependence on an applied electric field. The strain response of an elastomer can be contributed either by one of them as in the case of dielectric elastomers or by both of them as in polyurethane and graft elastomers [7].

3.1 Electrostriction Phenomenon

Electrostriction arises due to the change in dielectric properties of the material with strain i.e. there is a direct coupling between electric polarization and mechanical strain response [8] and is given as

$$S_p = - A g_0^{\text{ɜ}} (e_r - 1)^2 E^2 \qquad (1)$$

where S_p denotes induced strain, E is the electric field strength, is the relative dielectric constant and A is the pure electrostrictive coefficient. The dielectric constant, ε, is given by the product of the permittivity of free space and the relative permittivity. For electrostriction to be present, the material must have some crystalline characteristics in its structure. The likelihood of an electrostrictive effect being present is indicated by an increase in the dielectric constant of the material when pre-strained. The dielectric constant of a material may be measured using a dielectric analyser. An electromechanical response is the physical response (stress or strain for example) of a mechanical system to electrical stimulation. Electrostriction contributes largely to the electromechanical response of polyurethane and to a lesser degree in graft elastomers.

3.2 Maxwell Stress Effect

The Maxwell Stress Effect is a consequence of a change in electric field distribution inside the dielectric with strain [9]. For the electrostrictive actuator, the effective stress is twice that of a conventional parallel-plate electrostatic actuator, and can be expressed as

$$S_m = g_r g_0 E^{\text{ɜ}} \qquad (2)$$

where is the free-space permittivity , is the relative dielectric constant, and E is the electric field. Thus, the strain in the thickness direction is given by

$$s_z = g_r g_0 E^{\text{ɜ}} / Y \qquad (3)$$

where Y is the Young's modulus of elastomer materials.

From equations (2) and (3), it is observed that electrostrictive elastomer should have high breakdown voltage, large dielectric constant, and small Young's modulus in order to obtain large deformation. A study carried out by Pelrine et al. [1], suggests that the field-induced strain in acrylic elastomers is primarily due to the Maxwell stress effect, since experimental data closely fits the transverse strain response predicted by above equations. In almost all cases, the slight discrepancy is observed in the strain response and it is attributed to imperfection in experimental setup geometry.

3.3 Principle of Operation

The basic structure of DEs, shown in Fig. 1, is quite simple. A polymer film, typically but not necessarily an elastomer, is sandwiched between two electrodes. As noted above, DEs transduce mechanical energy, and in order to accomplish the changes, the electrodes must typically stretch and contract accordingly with the polymer. Thus, the electrodes in a DE transducer are compliant, with the extent of compliance determined by the magnitude of strain of DE transducer for sustained tolerance [9-12]. However there is also a strong possibility of extension of material along the direction of applied field due to increase in separation between opposite charge centres.

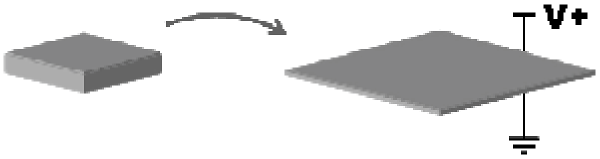

Figure.1: Schematic diagram indicating expansion of lateral dimension and compression along the applied field

4. APPLICATION OF DIELECTRIC ELASTOMER ACTUATORS

In a move to illustrate the potential of dielectric elastomer actuators, we take a look at some applications. Pelrine et al. [9] at SRI (Stanford Research Institute) reported high-speed, giant-strain, electrically actuated elastomers with unprecedented electromechanical transduction performance. These materials were demonstrated for so-called dielectric elastomer actuators, deformable capacitors made of a film of a soft insulator (such as acrylic, polyurethane, or silicone elastomer), with compliant electrodes. When subjected to an external electrical field, purely electrostatic forces cause the elastomer film to undergo substantial thickness compression and surface expansion [14]. The exceptional performance of these dielectric elastomer actuators gives rise to a scientific and technological revolution in the field of artificial muscles and touch screen mobiles (figure 2 & figure 3). The main benefit of dielectric elastomer is to show how a muscle like actuators can operate without the rigid support of a skeleton, just like worms do in nature.

Figure 2: Dielectric elastomers could be used for human prostheses and make the six million dollar man a reality [12]

Figure 3: In touch screen dielectric elastomer actuators could produce effects that enhance the user's experience with such devices [13].

5. CHALLENGES

5.1 Selection of Appropriate Materials

The important elastic dielectric materials are VHB-4910, TC-5005 (B1B Enterprises) and CF19-2186 (Nu Sil Technology) used in various applications. The material VHB-4910 exhibits high viscoelastic behaviour with low modulus of elasticity (i.e. higher strain & flexibility) and low dielectric breakdown strength [15].

The following parameters have to be considered for the selection of an appropriate material for specific requirement in the applications:

(a) Since the electrically induced strain is inversely related to the material's modulus of elasticity, so the material with smaller modulus of elasticity should be preferred for greater movement and flexibility.

(b) The electrically induced strain is linearly dependent on the material's relative dielectric constant. A material with large dielectric constant will result in greater movement.

(c) A material with a high dielectric strength should be preferred to prevent disruptive electrical discharge.

Moreover one has to make a choice between the electrical and mechanical properties of the material as per requirement in the specific application.

5.2. Role of Compliant Electrodes

In order to sustain very large surface strains of dielectric EAPs, the electrodes with the same amount of strain are required to prevent damages. This is more challenging, because the conductive materials are generally not compliant and compliant materials are generally not conductive [9]. The electromechanical performance of dielectric elastomer is mainly dependent on the material of electrode.

The most recent development in design of compliant electrode is carbon nano tube (CNT) [16]. This electrode exhibit self-clearing (i.e. self-healing by vaporization of the electrode material) behaviour in case of a dielectric breakdown through the elastomer and this prevents the destruction of device. This is a very interesting property for the reliability and lifetime of DEAs, but impact of the nanotubes on the mechanical properties of the elastomer must also be quantified to further assess the applicability of this method for artificial muscles.

6. CONCLUSION

The field of dielectric elastomer transducers is rapidly maturing and broadening, and the limits of their applications surely will be stretched. The question is whether future applications will be enabled by the two key factors that have thus far prompted their vast and diverse impacts: a simple and reliable physical principle, and the possibility of effective implementation with inexpensive and off-the-shelf materials.

While much research and development still remains to be done, EAP technology is already emerging from the laboratories. A number of companies e.g. TRS Technologies (USA), Akzo Nobel (Denmark), Wacker (Sweden), are offering commercial products based on EAP.

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