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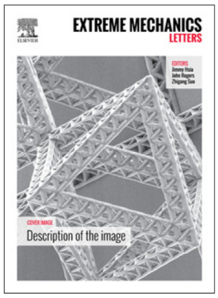

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A Novel Dielectric Elastomer Membrane Actuator Concept for High-Force Applications

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Abstract:

Dielectric elastomer actuators (DEAs) are known to be lightweight, energy efficient, and scalable in performance. Two well-studied DEA concepts are represented by stacked and membrane DEAs, respectively. The first configuration is known for providing high forces, while the second one results in high strokes. This work proposes a novel design solution, which combines the advantages of both concepts, i.e., high force and stroke, based on a stack of high stroke (3 mm) membrane DEAs. While a single silicone-based DE membrane provides an actuation force on the order of hundreds of mN only, the proposed stacking results into a parallel mechanical connection, which increases the overall force to the double-digit newton range. The biasing mechanism, which is necessary to operate the dielectric elastomer membrane as an actuator, is placed within the passive frame of the DEAs, leading to an overall compact design. To demonstrate the potential of the concept, two prototypes capable of generating record high forces are assembled and tested. The first one allows to lift a weight of 10 Kg up to 3 mm, while the second one allows to generate a compression force of 87 N, while working compressing a linear spring with a stiffness of 30.7 N mm^{-1} up to 2.8mm. These prototypes allow to establish a boosting factor of about 200 for the force output of membrane DEAs.

Keywords: Dielectric Electroactive Polymer; DEAP; Dielectric Elastomer; DE; Actuator; High Force Actuator; Manufacturing; Membrane Actuator; Performance Scaling

1. Introduction

A dielectric elastomer transducer (DET) consist of a thin elastomer layer sandwiched in-between two compliant electrodes. The resulting structure, shown in Fig. 1, resembles a compliant capacitor. On the one hand, a DET reacts to an applied mechanical pressure with a change in capacitance. This feature allows to use DETs as sensors [1] and energy harvesters [2]. On the other hand, the application of a voltage results into electrostatic forces, which deform the DET and, consequently, generate a motion. When a high voltage is applied, the capacitor is electrically charged. The resulting charges on the two electrodes attract each other, resulting in an electrostatic force called Maxwell pressure σ_{Max}. Such a compressive stress acts onto the surfaces of the elastomer layer, and is proportional to void permittivity ε_0, relative permittivity ε_r, and the square of the electric field E, as follows

$$\sigma_{Max} = \varepsilon_0 \varepsilon_r E^2. \qquad (1)$$

Due to the incompressible nature of the elastomer [3], the Maxwell pressure causes a decreases in thickness and an expansion in area (see Fig. 1, right).

This paper focuses on DET actuator applications. Several different types of dielectric elastomer actuator (DEA) configurations have been proposed in the literature, based on different designs, geometries, and materials. All these factors highly affect the performance of the devices. For example, equation (1) already shows the importance of the material's relative permittivity. Materials commonly used as dielectrics are silicone, acrylic (VHB4910), or polyurethane, having relative permittivities of 2.8 [4], 4.7 [5], and 7 [4], respectively. However, polyurethane and acrylic are suffering from their strong viscoelasticity, which is resulting in very low driving frequencies (<5 Hz), while silicones can be actuated in the kHz-range [6]. The reader should keep these aspects in mind, when comparing the performance of the different actuators.

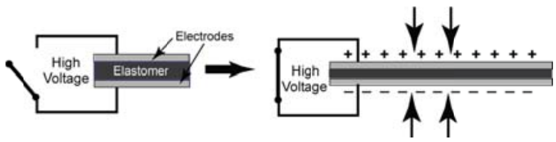

Fig. 1: DEA in its initial state (left) and after high voltage application (right). The Maxwell pressure causes the elastomer layer to decrease in thickness and to expand in area.

One of the most popular DEA configuration is represented by stacked actuators. They consist of a stack of alternating layers of elastomer and electrode material. An applied voltage causes a contraction of the whole stack, which can be used for actuation, as shown in [4,7,8]. In [4], Maas *et al.* presented on manufacturing of silicone- and polyurethane-based stacked DEAs, capable of generating forces up to 4 N and 10 N, respectively, with a stroke of 350 µm (3.5% of original length). The 2.5 times higher force of the polyurethane actuator is directly related to the