A New Procedure for the Optimization of a Dielectric Elastomer Actuator

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Abstract  A novel mathematical procedure is proposed, which makes it possible to optimize lozenge-shaped dielectric-elastomer-based linear actuators for known materials and desired force/stroke requirements. Simulation results are provided which both demonstrate the efficacy of the novel procedure with respect to traditional design approaches and show that simpler, cheaper, lighter and better-behaved lozenge-shaped actuators can be conceived which do not require any integration of compliant frame elements.

1. Introduction

Dielectric Elastomers (DE) are deformable dielectrics which can experience isochoric finite deformations in response to applied large electric fields [1]. Thanks to the strong electro-mechanical coupling, DE intrinsically offer great potentialities for conceiving novel solid-state mechatronic devices, such as sensors and actuators, which are more integrated, lightweight, economic, silent, resilient and disposable than equivalent systems based on traditional technologies [2].

For actuation usage, DE are usually shaped in thin films coated with compliant electrodes on both sides and piled one on the other to form an Electro-Active Film (EAF) [1-4]. Activation of the EAF via the placement of differential electric potentials (hereafter also called voltages) between the electrodes can induce film
area expansions and, thus, point’s displacements which can be used to produce useful mechanical work (whenever forces are applied to such points).

Usually, DE-based actuators are obtained by first uniformly pre-stretching the EAF (which is necessary since the film has negligible flexural rigidity) and then by coupling some segment of its boundary to some portion of a flexible supporting frame [3-5]. The major roles of the flexible frame are: 1) to coerce the EAF expansion in preferred directions; 2) to maintain the EAF in a tensioned state so as to prevent buckling effects; and 3) to provide a desired actuator stiffness characteristic (typically a nearly naught stiffness through the whole actuator stroke). Practical examples of DE-based linear actuators are depicted in Figs. 1.a and 1.b. The actuators are based on a lozenge-shaped pre-stretched EAF coupled to elastic frames made by a four-bar mechanism with equal links and either two identical non-linear tension springs (Fig. 1.a, [3]) or a compliant symmetric double slider-crank mechanism with elastic joints on the slider pivots (Fig. 1.b, [5]). As depicted in Fig. 2, in such actuators, activation of the EAF makes it possible to control the relative distance \( x \) (hereafter also called “EAF length” or “actuator length”) of the centers \( O \) and \( P \) of two opposing revolute pairs of the four-bar mechanism, which are the points of application of the external forces \( F \).

The actual procedure for designing DE-based actuators consists in first selecting the appropriate EAF topology; second, empirically determining EAF pre-stretches and dimensions; and, finally, mathematically or experimentally designing a flexible polymeric frame which complies with points 1-3 described above. Although valid, this procedure is not rigorous, neither provides optimal actuators.

In this paper a novel procedure is proposed for the optimal design of lozenge-shaped DE-based linear actuators like the one depicted in Fig. 2. The procedure is efficient, based on a mathematical model and makes it possible to improve the

**Fig. 1** Lozenge-shaped DE-based linear actuators

**Fig. 2** Inactive (**off**) and active (**on**) lozenge-shaped DE-based linear actuator