THEORETICAL DESCRIPTION AND FABRICATION OF A NEW DIELECTRIC ELASTOMER ACTUATOR SHOWING LINEAR CONTRACTIONS

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Abstract:
Dielectric elastomers represent today excellent materials for the realisation of electric field driven polymer actuators capable of high performances. A new kind of actuator made of dielectric elastomers, able to show in principle electrically activated linear contractions, is here theoretically described. The device consists of an elastomeric hollow cylinder, having two helical electrodes integrated within its wall. Principle of operation, design features and fabrication skills concerning the realisation of the new device are presented, as well as very preliminary data on active contraction strains measured from the first rough prototypes.

Keywords: dielectric elastomer, linear actuator, polymer actuator, contractile actuator.

Introduction

Since their launch at the end of the 1990’s, dielectric elastomers as actuators have gained, thanks to the work held by the SRI group, the status of one of the most performing means of transduction of electrical energy into mechanical energy operated by polymer materials [1-6].

When a thin film of such materials is sandwiched between two compliant electrodes and a voltage difference is applied between them, the polymer undergoes an electric field-sustained deformation, mainly due to the electrostatic forces exerted by free charges on the electrodes. The resulting stress and strain are proportional to the square of the applied electric field [1].

So far, several configurations for dielectric elastomer actuators have been proposed, demonstrated and studied, including planar, tube, roll, extender, diaphragm, bender [1-10]. Owing to their linear (along a line) actuation capabilities, tube and, mainly, roll actuators (see Fig. 1) are potential candidates for the realisation of “*artificial muscles*”. However, they present a mechanism of actuation opposite to that of natural muscles: under electrical stimulation they elongate, instead of contract. In order to overcome this limitation, actuators able to undergo electrically-activated contractions are demanded.

Well-known devices showing such a property are actuators having a stack configuration (frequently implemented with ceramics), consisting of the mechanical series of planar actuating elements connected in electrical parallel. By exploiting the thickness contraction of each active element in response to an imposed electric field, the stack generates useful axial contractions. However, the discontinuity presented by the two series of electrodes of this configuration and the consequent need of electrical shorting among the electrodes of each series make the fabrication of devices particularly onerous, especially if polymer materials are used. Furthermore, each electrical contact for electrode shorting can be source of charge accumulation and local field increasing, which can lead to premature electrical breakdown of the dielectric. Finally, volume encumbrance and/or deformation hindrance, potentially deriving from the connections established (e.g. by wiring) among the electrode contacts, have to be opportunely prevented.

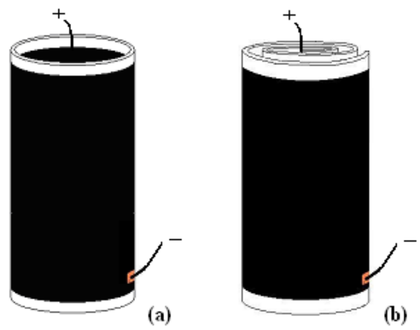

Fig. 1: Tube (a) and roll (b) actuators made of dielectric elastomers

Therefore, in order to obtain a dielectric elastomer actuator showing the attracting active axial contractions of stack devices but enabled by a structure capable to overcome the disadvantages deriving from their fabrication and use, we have conceived a new actuating configuration, described in the next Section.

A novel actuating configuration

The new configuration is based on a structure designed more generally for EAP devices and recently patented [11]. It consists of an hollow cylinder of dielectric elastomer, having two helical compliant electrodes integrated within its wall, so that to result continuously alternated to the dielectric material (see Fig. 2).

By applying a voltage difference between the electrodes, the interactions among their free charges cause axial contractions of the actuator, as well as related radial expansions. Therefore, devices based on this actuation scheme may be regarded as electrically activated polymer springs.

In comparison with a typical stack-like linear actuator, this new configuration offers the advantage of the continuity of the electrodes. This makes easier the fabrication and avoids typical disadvantages potentially deriving from the need of shorting of two series of discontinuous electrodes.

The applied electric field will tend to be directed along the contraction axis of the device, as much as the angle α (>π/4) of inclination of each electrode with respect to the axis results closer to π/2 (see Fig. 3). Therefore, it is likely that a maximisation of α corresponds to a maximisation of the output mechanical energy.

By assuming that the elastomer is a linearly elastic body and that the applied electric field E is approximately uniformly distributed inside it, it can be demonstrated that the axial and radial strains generated in this configuration are described by Eqs (1) and (2).

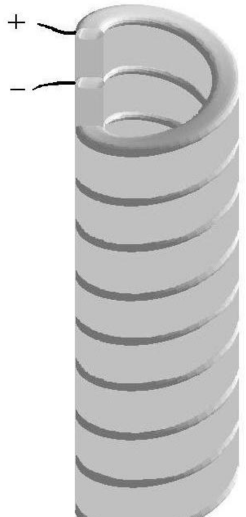

Fig. 2: *Novel actuating configuration*

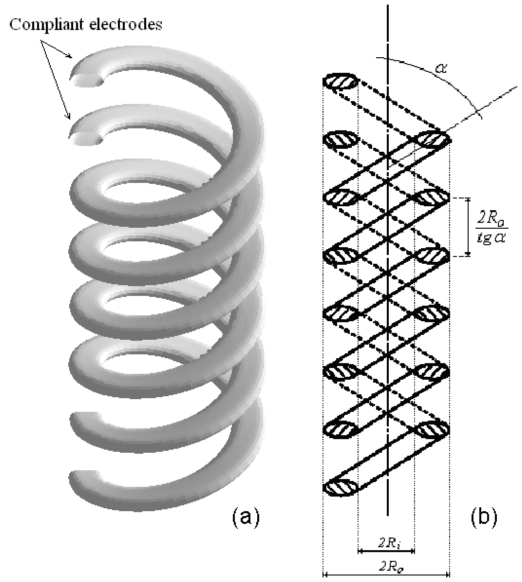

Fig. 3: *Drawing of the structure of the electrodes (a) and of their transverse section (b). Each electrode is tilted of an angle α with respect to the main axis of the device. R_i and R_o are respectively the inner and outer radii of the actuator*

$$Axial\ \ Strain = \frac{\varepsilon_0 \varepsilon_r E^2}{Y}(\cos\alpha - sen\alpha) \qquad (1)$$

$$Radial\ \ Strain = \frac{\varepsilon_0 \varepsilon_r E^2}{2Y}(sen\alpha - \cos\alpha) \qquad (2)$$

where ε_0 is the dielectric permittivity of vacuum, ε_r is the relative dielectric constant of the material and Y is its elastic modulus. According to this equations, higher values of α are responsible of higher strains (and stresses), as expected owing to the improved alignment of the applied electric field along the working direction. This makes the actuating configuration potentially able not only to show contractions, but also to generate strains and stresses higher than those permitted by several existing (non-stack) linear actuators. In fact, available devices exploit strains and stresses typically occurring in a transverse direction respect to the electric field, and thus resulting lower (of a factor ½ for a linearly elastic body with Poisson ratio ½) than those in the field direction. In the borderline case (physically senseless) of α=π/2, Eqs. (1) and (2) indicate an axial and radial strain of $-\varepsilon_0\varepsilon_r E^2/Y$ and $\varepsilon_0\varepsilon_r E^2/(2Y)$, respectively, which correspond to the expressions theoretically expected from a stack-like actuator.

Materials and method of fabrication

Currently, we are developing silicone-made prototype devices based on the proposed configuration, as described below.

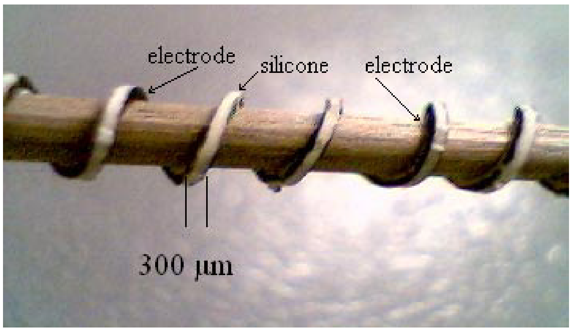

***Fig.** 4: Dielectric elastomer helix (on a wooden support) with two compliant electrodes fabricated on its opposite surfaces*

Firstly, a three component silicone (BJB Enterprises Inc., U.S.A., TC-5005 A/B-C) is processed in the form of tubes, realised by mould casting. Secondly, helical pieces are cut from the tubes by a blade, whose motion is automatically made helicoidal by an ad-hoc developed machine able to compose a motion of rotation with one of translation. Thirdly, two compliant electrodes (made of carbon loaded silicone or graphite spray) are fabricated on each silicone helix opportunely masked (see Fig. 4). Finally, one actuator can be completed by alternating one dielectric helix to one electroded helix and sealing the two parts with further silicone.

The resulting final assembly of a early prototype device is reported in Fig. 5.

Preliminary data on contraction performances

Owing to the very recent fabrication and testing of successfully working devices (the first functioning prototype was obtained a few days before the writing of this paper), only very preliminary and poor data on the actuation performances of the first rough prototypes can be here presented.

Fig. 6 reports the first data on the contraction (axial strain) of a prototype actuator along its main axis, in response to the application of very "low" electric fields.

Future efforts will be mainly devoted to the final set up of the overall fabrication procedure, in order to obtain an expected drastic improvement of the actuating performance of the realised devices.

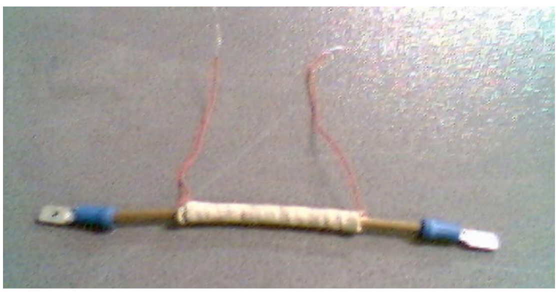

***Fig. 5:** Actuator final assembly*

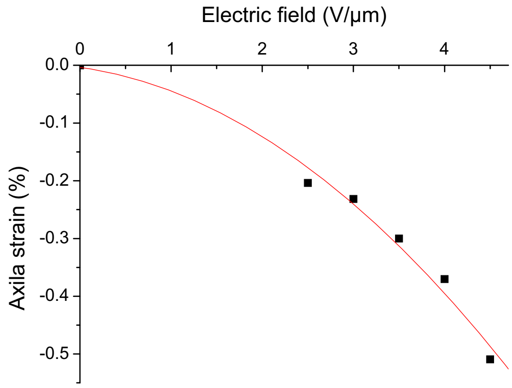

***Fig. 6:** Preliminary data on axial contraction strain versus applied electric field*

Conclusions

This paper has presented the conception, the principle of operation, the fabrication skills and very preliminary data on actuation capabilities of a new configuration proposed for dielectric elastomer actuators with electrically activated linear contractions. The new architecture may consent to achieve the advantageous active contractions shown by stack-like devices, with a conceptually simpler structure, enabling an easier fabrication and avoiding some disadvantages presented by the stack configuration. Silicone-made prototype device based on this configuration are currently under development.

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