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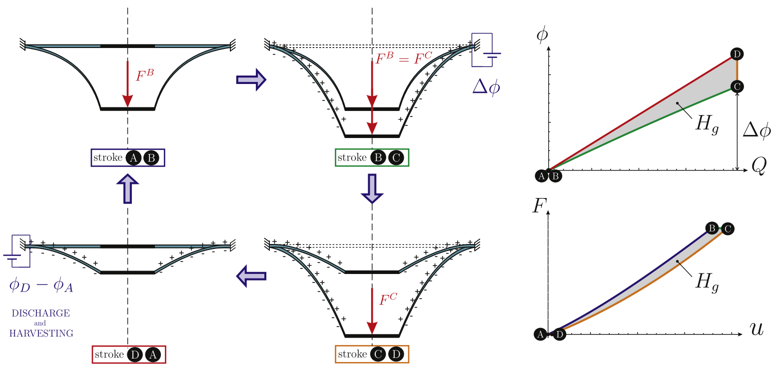
Harvesting energy with load-driven dielectric elastomer annular membranes deforming out-of-plane

Eliana Bortot [a], Massimiliano Gei [b,*]

[a] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, I-38123 Trento, Italy

[b] School of Engineering, Cardiff University, The Parade, Cardiff CF24 3AA, Wales, UK

GRAPHICAL ABSTRACT



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ABSTRACT

The capabilities of a dielectric elastomer generator formed by a hyper-electro-elastic annular membrane deforming non-homogeneously out-of-plane are investigated. The mechanical-to-electric energy conversion is determined for a four-stroke cycle, driven by an external oscillating force, that may extend within an admissible state region delimited by the typical four failure modes of dielectric elastomers: electric breakdown, electromechanical instability, maximum stretch limit, and loss of the tensile state. Performance in terms of harvested energy per unit mass and efficiency of the generator is determined in relation to: (i) initial prestretch of the membrane, (ii) external to internal radius ratio, and (iii) intensity of maximum external load. The analysis concludes with a comparison between the behaviours of two different soft materials (i.e. an acrylic elastomer and a type of natural rubber), and an estimation of the most effective generator geometry among those analysed by the authors here and in past studies.

1. Introduction

Renewable energy conversion is a key theme in the current political agenda and science and technology are

* Corresponding author.
E-mail address: geim@cardiff.ac.uk (M. Gei).

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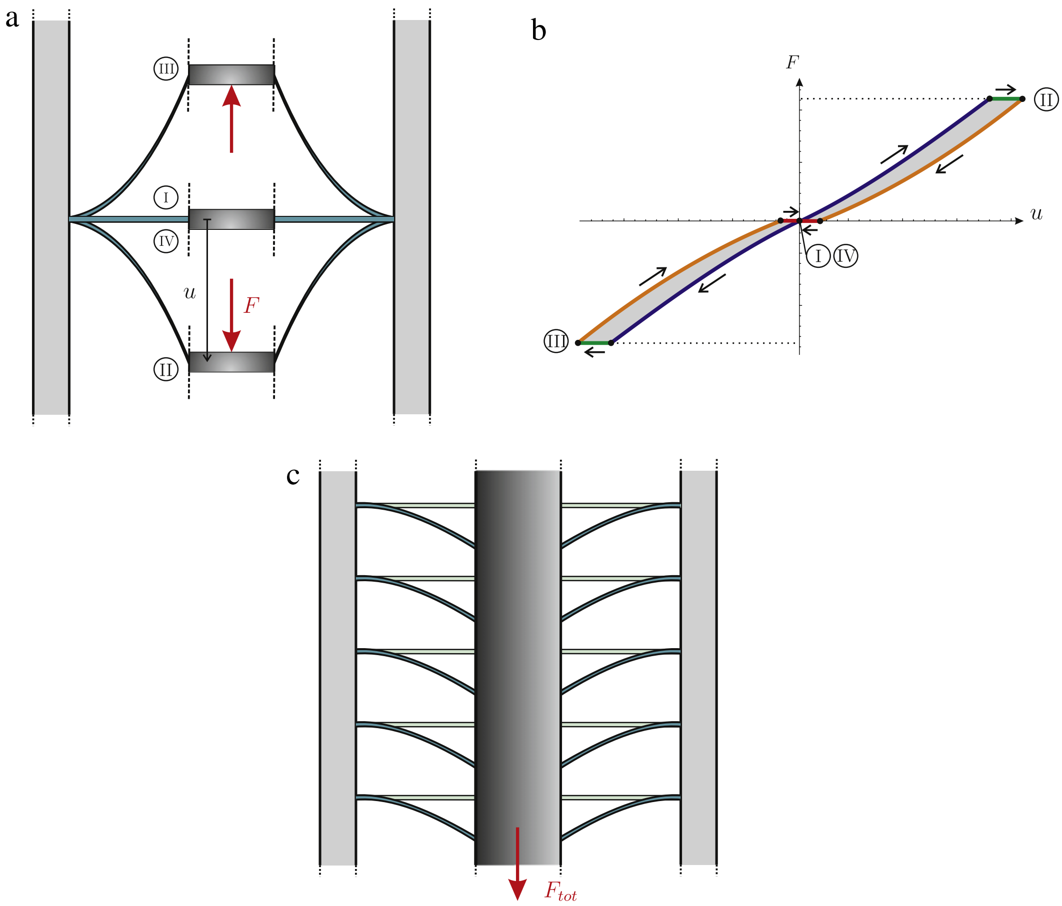

Fig. 1. Sketch of the layout of the investigated electroactive membrane generator and of the periodic four-phase cycle (phases IV and I coincide): (a) membrane configurations; (b) mechanical force (F)-out-of-plane displacement (u) plane; (c) multi-membrane device subjected to the total force F_{tot}.

facing fascinating challenges to provide convincing responses to the issue. Harvesting energy from natural resources by means of dielectric elastomer generators could be one of the solutions, once all fundamental aspects of this method will be thoroughly analysed and the shortcomings overcome. A *Dielectric Elastomer Generator* (DEG) is a soft device based on a deformable parallel-plate capacitor made up of an elastomeric film coated with two compliant electrodes on its opposite faces able to produce electrical energy converting the mechanical work done by an external oscillating load [1–12]. In particular, the energy transformation is promoted by the significant capacitance change of the elastomeric capacitor occurring when the film is highly deformed.

In a real harvesting field, we can think that the mechanical action be outlined as an oscillating force, or pressure, that stretches and releases periodically the soft capacitor at a frequency on the order of the Hz. Therefore, electrical energy can be collected after a four-step cycle where (i) an initial, relatively slow, stretching of the material induced by the growing force is followed by (ii) a fast charging phase; then, (iii) the slow decrease of the force will relax the capacitor at constant charge and, finally, (iv) the charge is harvested at high electric potential at low force. A similar cycle has been already considered to determine optimal working ranges of homogeneous hyperelastic planar generators deforming in uniaxial plane strain [13] and biaxially [14].

In this work we assume that the external source deforms non-homogeneously out-of-plane an annular DE membrane, a layout preliminary investigated in [15,16] as an actuator and in [17] as a generator (Fig. 1(a), (b)). Regarding the latter, however, it is important to point out that the developed analysis was incomplete, as many of the fundamental features necessary to evaluate the effectiveness of this configuration (prestretch influence, failure modes, maximum load, etc.) as a DEG were not considered. Our article aims at filling the gap and provides a complete analysis of this harvester layout along the lines traced in [13,14]. The adoption of the same methodology will also enable us to compare the different configurations on a common ground, offering the possibility to reflect on the best coupling between geometry and material for a particular energy harvesting application. Interestingly, the comparison of different DEG layouts demonstrates that the annular DEG can compete with the equibiaxial planar generator, in terms not only of efficiency, but also of harvested energy.