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Energy harvesting from a backpack with an auxetic dielectric elastomer generator

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Abstract

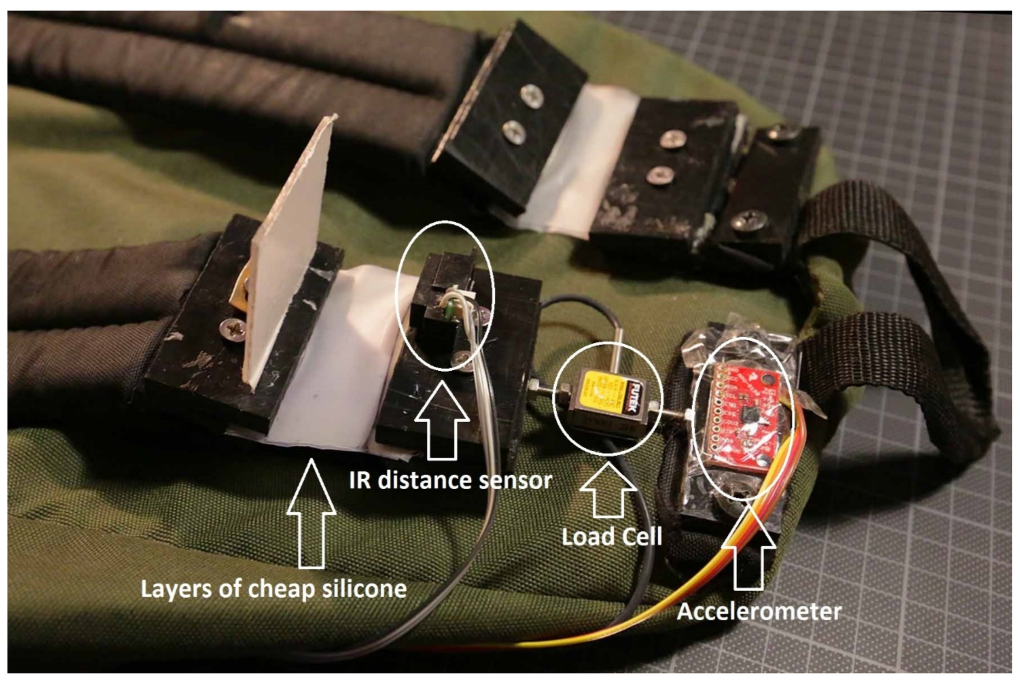
The focus of this research is to develop a Dielectric Elastomer Generator (DEG) able to harvest energy from the stretch of the backpack straps without providing additional load as the present energy harvesting systems mostly do [1]. After having proved that the mechanical energy available in the backpack straps is high enough to scavenge significant power (stretch 45% for 11Kg), different mechanical DEG configurations have been compared in term of energy output in order to evaluate which one allows to optimally exploit the stretch of the backpack straps during walking. Auxetic frames, converting the uniaxial stretch in a biaxial deformation of the DEG, have been proved to significantly increase the DEG performance (26.8uW at 1kV). A silicon based DEG with compliant electrodes has been fabricated and characterized. The use of the same matrix for all the DEG layers and rubber electrodes enables a great structural stability that allows the integration of such generators into real systems [2]. The mechanical behaviour has been determined with stress-strain measurements performed on a uniaxial testing machine aided by a video extensometer inferring a maximal deformation of 73% and low viscous losses. The electrical behaviour has been evaluated performing dielectric spectroscopy over a frequency range of 10^{-1} to 10^{5} Hz at 23°C. In the range typical of human motions (1-2Hz), the dielectric permittivity is slightly decreased and the loss tangent is halved comparing to the reference values.

Backpack Characterization

Test on an **instrumented backpack** to prove that the mechanical energy available in the backpack straps is high enough to scavenge significant power.

Experimental Setup

The dynamic parameters have been evaluated performing 5 walks for 7 different weights placed in the backpack: 2.4 - 10.9 Kg.



Backpack test results

The mechanical energy available in the backpack straps is high enough to scavenge some significant power (**stretch 45% for 11Kg**).

Backpack load (Kg)	Parameters			
	% W_{mean}	% W_{std}	% d_{mean}	% d_{std}
2.4	24.7	1.6	14.3	0.33
3.4	21.9	1.4	17.8	0.53
5.1	23.9	2.4	23.8	1.4
5.8	23.8	1.17	27.3	1.6
7.5	21.3	0.67	33.3	1.1
8.5	21.7	1.4	37.9	2
10.9	21.5	1.1	44.9	1.5

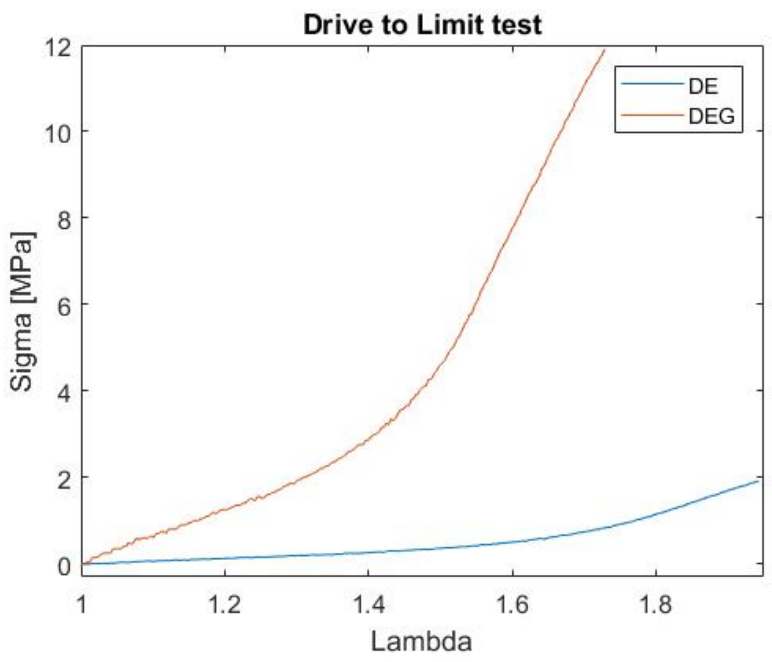
DEG Mechanical Characterization

Uniaxial Tests + Video Extensometer

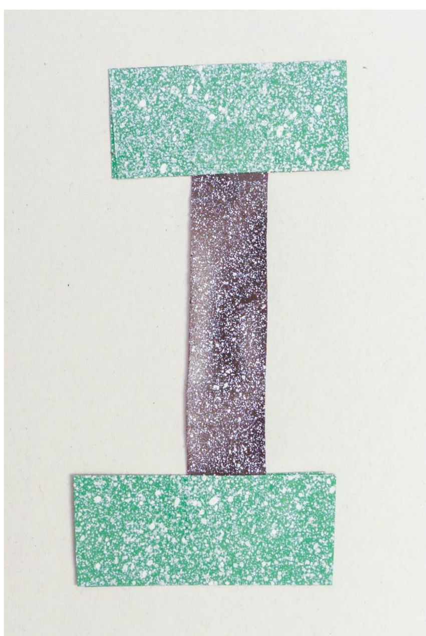
- Test sample dimensions: Size standard ISO 527-2
- Dielectric material: PDMS Sylgard 184 (+ Graphene NanoPlatelets (GNP) for the electrodes)

λ_{max} = 1.73; **ε_{max} = 73%;** → **ε_{max} > 45%**

σ_{max} = 11.9 MPa; Y = 6 MPa

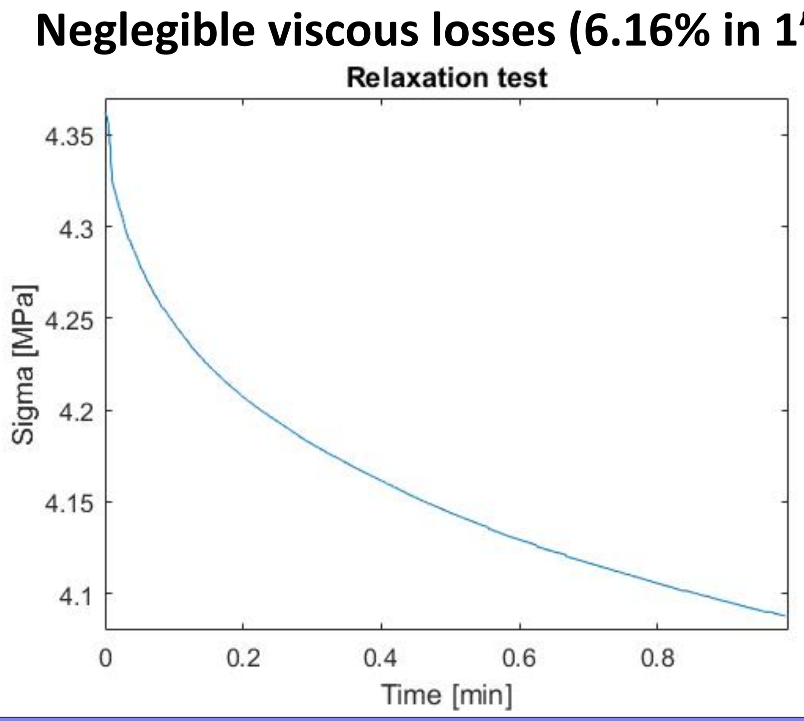


DEG sample



Deformation up to λ = 1.5

Neglegible viscous losses (6.16% in 1')



DEG configuration comparison

- Stretch on the vertical direction fixed (λ_y = 1.15)
- Maximum device size fixed (2x6 cm)
- The **contraction ratio** [3]

$$\alpha = \frac{A_{min}}{A_{max}} = \frac{z_{max}}{z_{min}} = \sqrt{\frac{C_{min}}{C_{max}}}$$

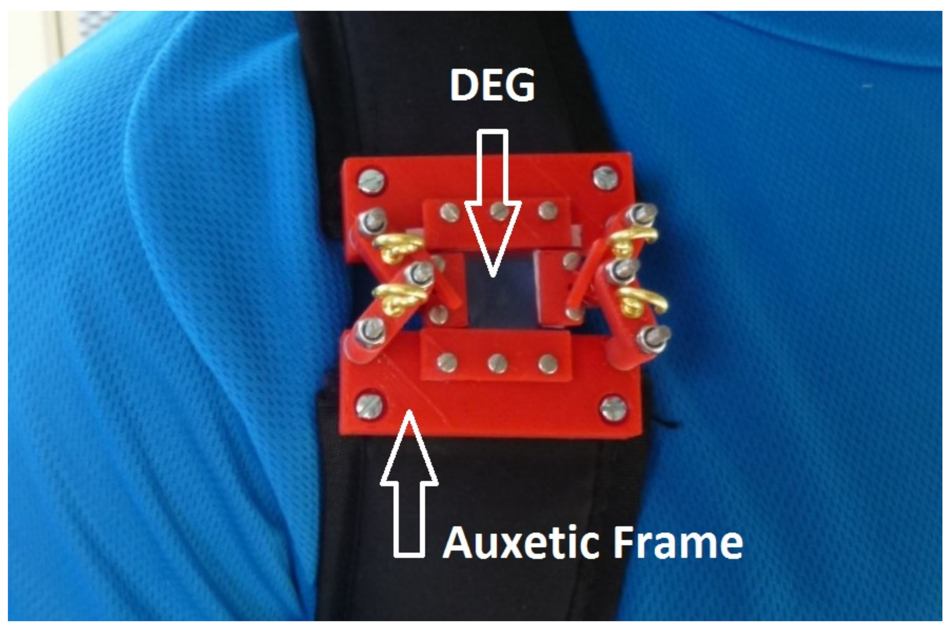
Stretch mode [3]	Configuration	α	$U_{rel,Q}$	λ_x	λ_z
Biaxial stretch $\Delta C \propto \lambda^4$ $\lambda_x > 0$	Rect_in_Bowtie	0.8085	0.5298	1.0755	0.8085
	Bowtie_Full	0.8292	0.4543	1.0755	0.8085
Pure-shear stretch $\Delta C \propto \lambda^2$	Rectangle	0.8696	0.3225	1	0.8696
Biaxial stretch $\Delta C \propto \lambda^4$ $\lambda_x < 0$	Hexagon_Full	0.8895	0.2639	0.9739	0.8929
	Rect_in_Hexagon	0.8929	0.2543	0.9739	0.8929
Uniaxial stretch $\Delta C \propto \lambda$	Cylinder	0.9325	0.15	0.9325	0.9325
	Roll	0.9325	0.15	0.9325	0.9325

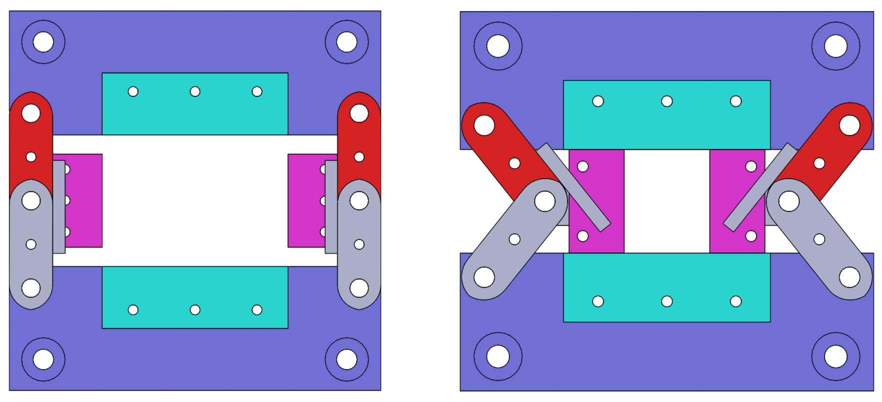
The rectangular shape in the bowtie frame gives the lowest alfa and therefore the higher energy gain ratio ($U_{rel,Q}(\alpha)$)

Why? The bowtie is an **auxetic frame**.

Bowtie auxetic frame

Theoretical evaluation: 26.8µW at 1kV





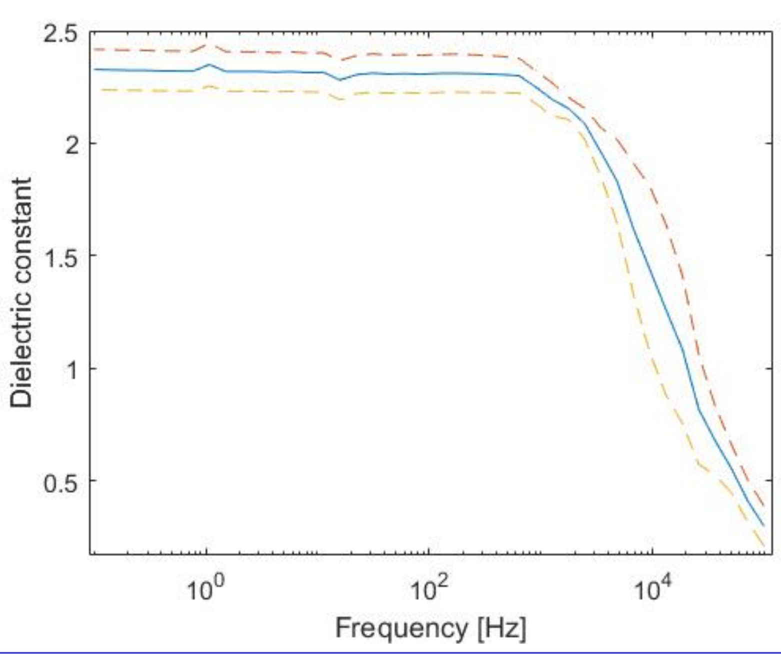
DEG Electrical Characterization

Dielectric spectroscopy

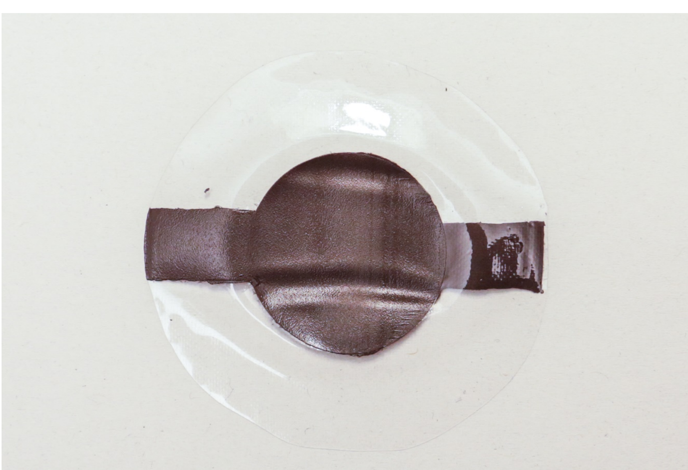
- Test sample dimension: Øelectrodes 28mm; Ødielectric 55mm
- Frequency range: 10^{-1} to 10^{5} Hz at 23°C
- Reference: dielectric elastomer samples with gold electrodes
- Maximum error: about 5%

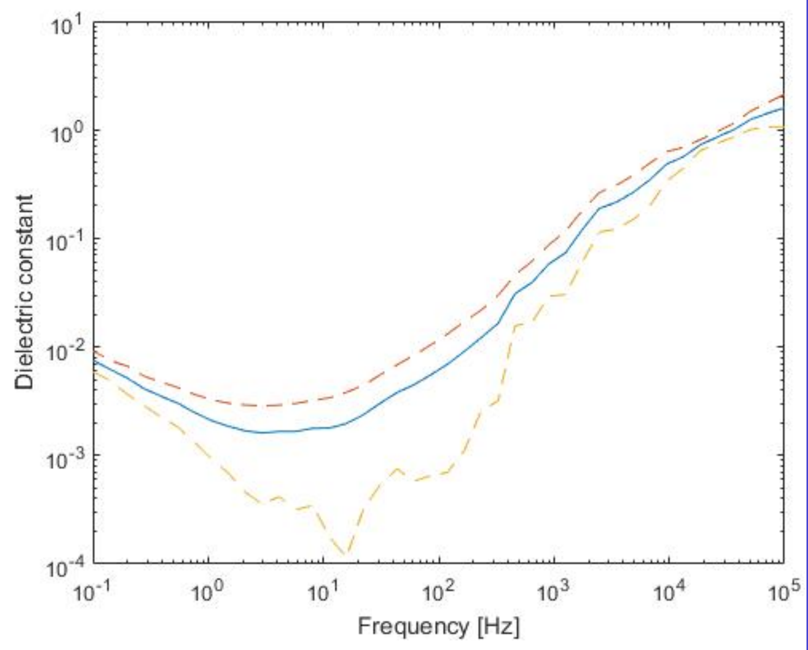
$$\epsilon_r^*(\omega) = \epsilon_r'(\omega) - j\epsilon_r''(\omega) \qquad tan\delta = \frac{\epsilon_r''(\omega)}{\epsilon_r'(\omega)}$$

Parameter	Ref	DEG
ε'_r @ 0.1Hz	2.68	2.3
ε'_r @ 10^5Hz	2.61	0.3
ε'_r @ 1-2Hz	2.66	2.29
tan δ@ 0.1Hz	$324 \cdot 10^{-4}$	$75 \cdot 10^{-4}$
tan δ@ 10^5Hz	$93 \cdot 10^{-4}$	$179 \cdot 10^{-2}$
tan δ@ 1-2Hz	$41 \cdot 10^{-4}$	$27 \cdot 10^{-4}$



DEG sample





Conclusion and future developments

- The available mechanical energy in the backpack straps during walking is high enough to be scavenged by a DEG.
- The bowtie auxetic frame is the DEG configuration that optimally scavenges the backpack strap stretches.
- The compliant electrodes have a acceptable stiffening impact for the considered application.
- In the human body motion frequency range (1-2Hz) the viscous losses is still negligible.
- The interface between the electrodes and the dielectric elastomer is at the origin of the changes in the dielectric properties.

- Deeply integrated auxetic structures, with high potentials for the assimilation of DEGs into textile, could be developed.
- Characterization of the auxetic frame to determine the net scavenged energy are under development.
- Actions should be taken to reduce the stiffening and viscous effect of the electrodes

References

[1] L. C. Rome, L. Flynn, E. M. Goldman, and T. D. Yoo, "*Generating electricity while walking with loads*", Science, vol. 309, pp. 1725-1728, 2005

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[3] C. Graf, J. Maas, and D. Schapeler, "*Energy harvesting cycles based on electro active polymers*", Proc. SPIE, vol.7642, pp. 7642-12, 2010