Hexagonal Distributed Embedded Energy Converters (HexDEECs)

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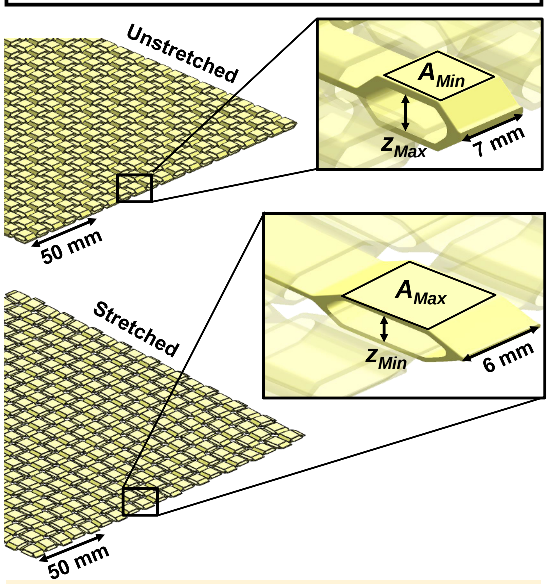
Introduction

The HexDEEC is a small, ~1 cm, energy transducer that converts tensile inputs into electricity via variable capacitance. It is part of a new domain for marine energy research, Distributed Embedded Energy Converter Technologies (DEEC-Tec), that combines a multitude of small energy harvesters or DEECs into larger metamaterials, which can then be used to build flexible ocean wave energy converters (flexWECs). FlexWECs can use a broad band of ocean wave frequencies, lack highly loaded rigid bodies, and can actively change their shape and stiffness in real time to optimize energy harvesting. The HexDEEC was designed to aid the adoption of and further develop the DEEC-Tec domain. This poster presents the promise of the HexDEEC and current work on analyzing its performance.

The HexDEEC



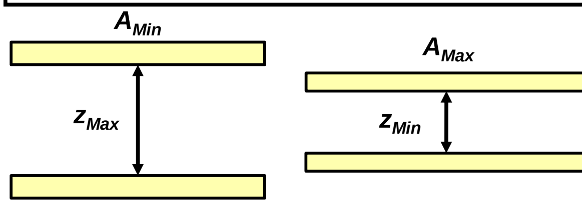
The HexDEEC uses variable capacitance to generate electricity from the dynamic deformation of its hyperelastic housing. The capacitance of the electrode plates in the internal hexagonal space change as the housing stretches and alters the gap between the plates (z) and their area (A). This change in capacitance causes a change in electrical potential energy, which is then harvested by the device. When the load is removed the shape and material properties of the housing enable it to spring back to its original configuration. A metamaterial can be constructed of interwoven linearly repeating arrays of HexDEECs to enable energy harvesting in two dimensions. This metamaterial can then be used to construct flexWECs.

References

1. F. Invernizzi, et al., Energy harvesting from human motion: materials and techniques, The Royal Society of Chemistry 45 (2016) 5455-5473. doi:10.1039/c5cs00812c.

2. D. Viljoen, Characterising material models for silicone-rubber using an inverse finite element model updating method, Stellenbosch University (2018).

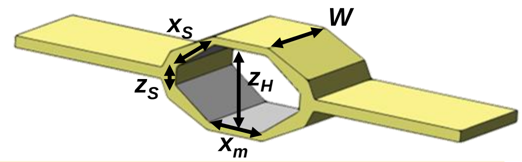
Analytical, Numerical, and Manufacturing Methods



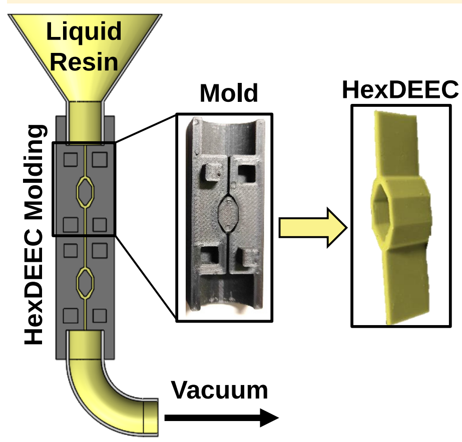
$$C = \frac{\varepsilon A}{z} \qquad C_{initial} < C_{final}$$

$$U = \frac{1}{2} C V^2 \qquad \Delta U = U_{final} - U_{initial}$$

$$C_{Hex} = \varepsilon W \left(\frac{x_m}{z_H} + \frac{2\sqrt{x_s^2 - \left(\frac{z_H - z_s}{2}\right)^2}}{z_H - z_s} \ln \frac{z_H}{z_s} \right)$$

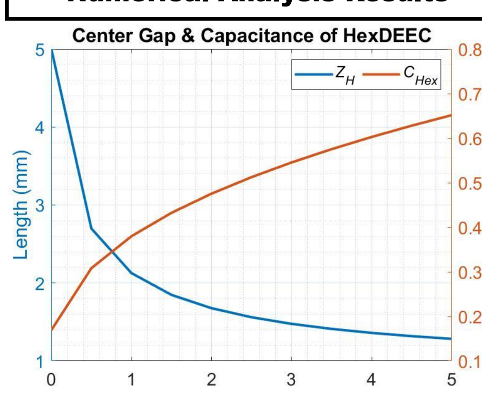


The electric energy produced by the HexDEEC can be determined by approximating it as a multitude of simple parallel plate capacitors, such as the pair shown above on the left. The capacitance (C) of a typical variable capacitor is determined by the permittivity of the dielectric (ε), area of the plates (A), and distance between the plates (z). The potential energy of such a system (U) can be described using the capacitance and the applied voltage (V). To account for the angled plates in the hexagonal capacitor, a new capacitance equation (C_{Hex}) was derived by approximating the slanted plates as many thin parallel plate capacitors connected in parallel, so their capacitances sum together. The energy produced by a variable capacitor can vary depending on whether voltage, charge, or electric field strength are kept constant [1]. In this case we plan to use a constant voltage due to its more simplified control requirements [1]. The mechanics of the HexDEEC's hyperelastic housing and its subsequent capacitance under differing levels of tensile loading were assessed using STAR-CCM+. The nonlinear material properties of the hyperelastic silicone housing with a shore hardness of 50A were modeled using the 3-parameter Mooney-Rivlin model with empirically derived material constants from literature [2]. Point probes that assessed the changes in length of the 5 variables (W, x_m, x_s, z_H, z_s) were included in the simulation and used to determine the overall capacitance.



The HexDEECs are constructed by pouring liquid resin for their hyperelastic housings into molds. A vacuum is used at the bottom of this molding system to create a negative pressure gradient and ensure that they are filled properly. While two molds are shown in this example, many more can be stacked on top of each other to create a HexDEEC array. After the resin dries the HexDEECs are removed from the molds and can then be woven into the metamaterial. The electrical components such as the electrodes and wires can be placed into the molds so that they are embedded into the hyperelastic housing material to ease manufacturing.

Numerical Analysis Results



Discussion

The results of the numerical analysis in STAR-CCM+ show that the distance between the central plates (z_H) decreases significantly with a minimal amount of tensile force, then plateaus to 1.4 mm, unlike the other lengths that linearly decrease or increase due to stretching. Similarly, the rate of increase in C_{Hex} is highest at the lower tensile forces and then becomes consistent as the forces increase. This indicates that the dramatic change in the center gap contributes the most to the change in capacitance. However, this still must be validated with an optimization study and future experimental work that would use the manufacturing process described above. After analysis of individual HexDEECs is complete, we will create and assess the 2D HexDEEC metamaterials, which could be used to create novel flexWECs.

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