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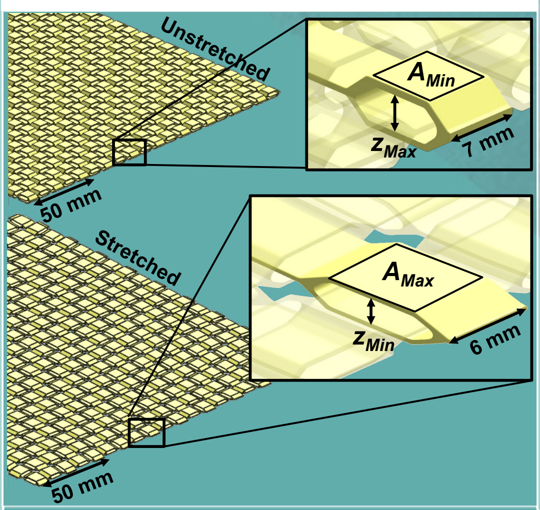
Hexagonal Distributed Embedded Energy Converters (HexDEECs)

J. NIFFENEGGER[1], B. BOREN[1], N. MENDOZA[2], P. MURDY[3], and J. WEBER[1]
1 Water Power R&D, National Renewable Energy Laboratory (NREL), Golden, CO, United States
2 Wind Energy Systems, NREL, Arvada, CO, United States
3 Hydropower and Water Systems Deployment, NREL, Golden, CO, United States

INTRODUCTION

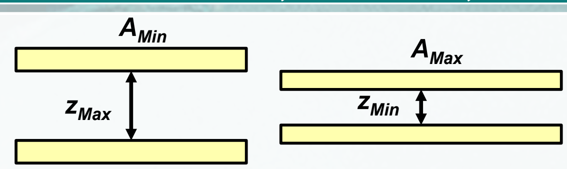
The HexDEEC is a small, ~1 cm, energy transducer that converts tensile inputs into electricity via variable capacitance. It is part of a new domain for marine energy research, Distributed Embedded Energy Converter Technologies (DEEC-Tec), that combines a multitude of small energy harvesters or DEECs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

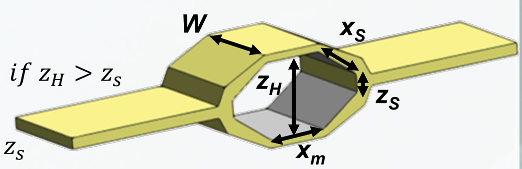
ANALYTICAL, NUMERICAL, & MANUFACTURING METHODS



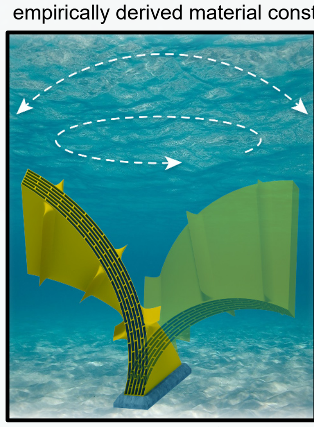
$$C = \frac{\varepsilon A}{z} \qquad C_{initial} < C_{stretch}$$

$$U = \frac{1}{2}CV^2 \qquad \Delta U = U_{stretch} - U_{initial}$$

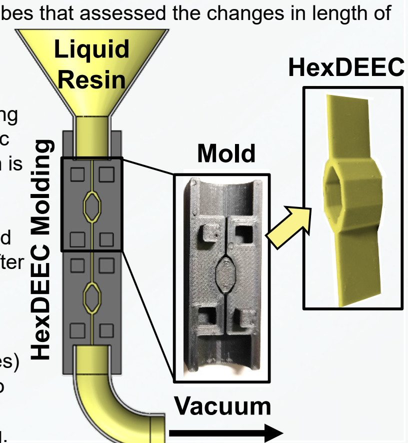
$$C_{Hex} = \begin{cases} \varepsilon W\left(\frac{x_m}{z_H} + \frac{2\sqrt{x_s^2 - \left(\frac{z_H - z_s}{2}\right)^2}}{z_H - z_s}\ln\frac{z_H}{z_s}\right) & if\ z_H > z_s \\ \varepsilon W\left(\frac{x_m}{z_H} + \frac{2x_s}{z_s}\right) & if\ z_H = z_s \end{cases}$$



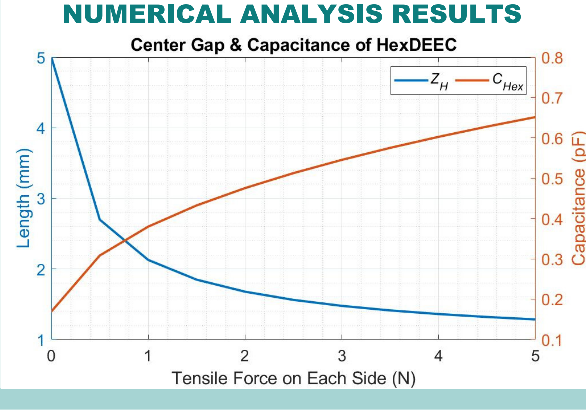
As with any variable capacitor with a constant voltage cycle, the energy produced by the HexDEEC is dependent on its change in capacitance [1]. The capacitance (C) of a parallel plate capacitor is determined by the permittivity of the dielectric (ε), area of the plates (A), & distance between them (z). The potential energy (U) depends on C & the applied voltage (V). The HexDEEC's capacitance (C_{Hex}) was derived by approximating the slanted plates as many thin parallel plate capacitors. The mechanics of the HexDEEC's hyperelastic housing & its capacitance under tensile loading were assessed via STAR-CCM+. The nonlinear material properties of the silicone housing were modeled using a 3-parameter Mooney-Rivlin model with empirically derived material constants from literature [2]. Point probes that assessed the changes in length of 5 variables (W, x_m, x_s, z_H, z_s) were used to determine the overall capacitance. The HexDEECs are made by pouring liquid resin for their hyperelastic housings into molds, a vacuum is used to ensure proper filling. While two molds are shown in this example, more can be used to create a HexDEEC array. After the resin dries, the arrays are removed & can then be woven into a metamaterial. Electrical components (wires & electrodes) can be placed into the molds to embed them into the housing material to ease manufacturing.



Example FlexWEC



NUMERICAL ANALYSIS RESULTS



DISCUSSION

The results from STAR-CCM+ show that the distance between the central plates (z_H) decreases significantly at low tensile forces then plateaus, unlike the other lengths that change linearly. Similarly, the rate of increase in C_{Hex} is highest at low forces then plateaus. Therefore, z_H could contribute the most to the change in capacitance. However, this must be validated with an optimization study & future experimental work. Afterwards we will create & assess the 2D HexDEEC metamaterials, which will be used to demonstrate how to create flexWECs.

REFERENCES

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CONTACT INFORMATION

Corresponding author email:
james.niffenegger@nrel.gov