HASEL and HALVE actuators for artificial limbs and physical therapy aids

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Introduction

In recent years, dielectric elastomers have been seeing massive breakthroughs with systems such as hydraulically amplified self-healing elastomers (HASEL) and hydraulically amplified low-voltage elastomers (HALVE).

HASEL and HALVE actuators are dielectric elastomers that have a liquid dielectric encased in two polymer shells, with electrodes on both sides of the shells. As the electrodes become larger, the actuation strain increases, but a lower force is exerted. [1][4]

HALVE actuators utilize a high-permittivity dielectric in order to reduce their voltage, and more specifically, multilayered sheets of polyvinylidene fluoride-co-hexafluoropropylene (PVDF-HFP), and polyvinylidene fluoride-trifluoroethylene-chlorotrifluoroethylene (PVDF-TrFE-CTFE) [1]

HASEL and HALVE actuators require high voltages for actuation, approximately 6-10 kV for HASEL actuators, and 600V – 3 kV for HALVE actuators, which justifies the need for a specialty power supply. [1][3][4]

Because of their self-sensing, self-healing nature, as they are soft-body capacitors, our group believes that they can be utilized as haptic aids and could be further utilized for artificial limbs, once problems such as their high-voltage actuations are addressed. [4]

Portable High Voltage Power Supply

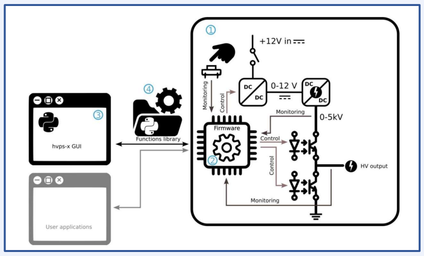

Figure 1: Peta-Pico-Voltron HVPS diagram [5]

Our team is utilizing the high-voltage power supply (HVPS) from the open-source peta-pico-Voltron project, which is a board that takes a lower input voltage (~5V) and steps up the voltage to approximately 5kV. It does this by using a DC-DC converter, which is an oscillator that converts a DC input into an AC source, which is then fed into a transformer to step up the voltage, but reduce the current, and then fed back into a rectifier. Note that due to the high output voltages, FETs and similar transistors are not a feasible option, so instead, optocouplers are used for switching. [5]

Control Systems

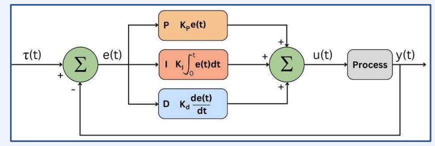

Figure 2: PID Controller state diagram [6]

As dielectric elastomers function as soft-body, free-form capacitors, their state of deformation can be measured using the charge held between the two actuators. This means that using a proportional, integral, and derivate controller, we can set a target state, and feed the current capacitance value back into the system to approach the target goal.

Due to the variation in the output from the high voltage power supply, oscillations may occur in the actuator, which may be able to be reduced down by having a finely tuned PID controller.

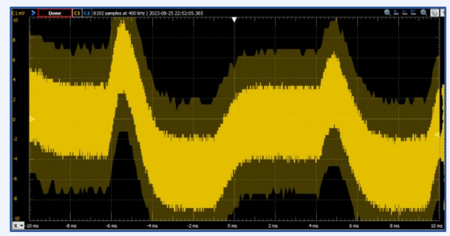

Figure 3: Output noise generated by the HVPS in regulated voltage mode, at 2ms/div [5]

HASEL and HALVE actuators

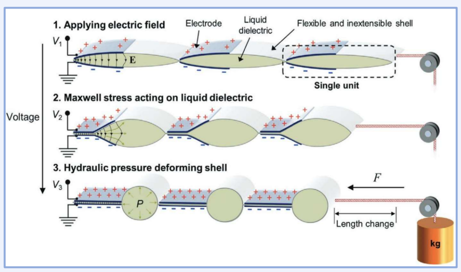

Figure 4: HASEL actuator force demonstration when voltage is applied [4]

HASEL and HALVE actuators work based on the same properties, where when a voltage is applied across two electrodes through a dielectric, deformation occurs, where the force F is calculated based on the following equation [1]

$$F = wt\frac{cos(\alpha)}{1 - cos(\alpha)}\varepsilon_o\varepsilon_{app(E)}E^2$$

Where w is the width of the actuator, t is the thickness, α is the angle of the actuator, ε_o is the vacuum permittivity, ε_{app}(E) is the experimentally determined permittivity, and E is the amplitude of the electric field of the actuator.

Additionally, with a force model defined (and verified)[1], and the total electrical energy defined in U_e, the full equation for the free energy, U_t of the system is defined as follows, where X is the total distance moved by the actuator:[1]

$$U_t = Fx - Ue$$

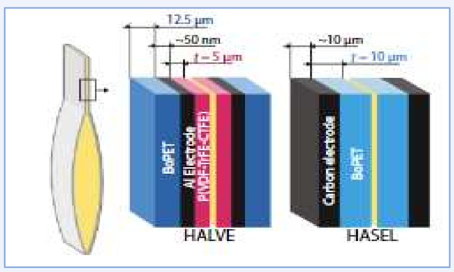

Figure 5: Comparisons between HALVE and HASEL actuators [1]

HALVE actuators have a more complex construction, with 3 outer-shell layers compared to a single-layered shell with exposed electrodes. Based on the equations provided by Stephan et. Al. it is found that the thinner the actuator layers become, the lower the actuation voltage. This can be described in several equations [1][2][4] :

$$P_{eq} = \varepsilon_0\varepsilon_r\frac{U}{z^2} \qquad U_e = \frac{1}{2}\frac{wl\epsilon_0\epsilon_r}{t}V^2$$

Where ε_o is the vacuum permittivity, ε_r is the dielectric constant of the material, W is the width of the capacitor (actuator material, for example, BoPET or PVDF-TrFE-CTFE), l is the length of the capacitor, and V is the voltage applied across the capacitor, and z is the current thickness of the capacitor. [1]

It can be observed that the total electrical energy (U_e) can be increased by decreasing the thickness (t), both in the model presented for electromechanical pressure, and for the Kellaris et. al. based model from Stephan et. al.

Proposed Application

By creating reservoir pockets of the liquid dielectric, it is possible to create "bending" motions, demonstrated by Keplinger et. al By using this property, and the self-feedback mechanism with the PID controllers, our group believes that it is possible to create a glove to be placed on a human hand to prevent tremors that may occur from medical issues, and to assist the user In grasping objects by providing additional strength to each finger.

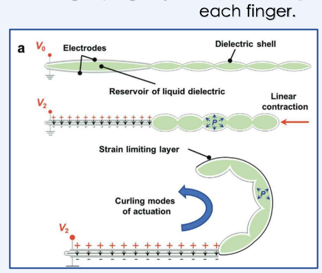

Figure 6: Curling HASEL demonstration [4]

Based off of the findings of Stefan et. al, it was demonstrated that with a 1 x 1 cm actuator, a strain rate of approximately 7% was calculated when 800 V was applied to lift a 20g weight. The peak specific power of HALVE actuators was able to reach 132.7 W/kg, and reached a maximal strain rate of 971% [4]

As human muscles have a strain rate of 500%, this means that the actuators can exert almost double the force of human muscles.

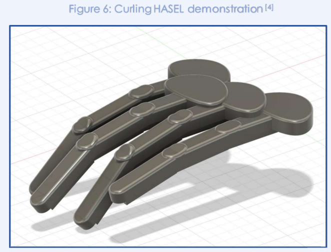

Figure 7: Demonstration of several curling HASELs together [4]

It is theorized that by having multiple independent, self-sensing reservoirs, utilizing a combination of HALVE and HASEL actuators, the clasping motion of a human hand can be recreated, using the hand as the frame itself. Once it is determined that a sufficient force is applied, the frame can then be replaced with an artificially constructed frame, where the actuators can be constructed antagonistically.

References

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