Fundamental Study of Continuous Contraction Assessment of HASEL Actuator based on High-Voltage Dielectric Spectrometer

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Introduction

The HASEL actuator, which achieves softer motion compared to conventional actuators, operates based on Maxwell stress induced by high electric fields. Therefore, understanding its dielectric properties is essential. Required characteristics include a high breakdown voltage and suppression of dielectric loss during operation [1]. However, conventional dielectric measurement methods struggle to evaluate characteristics under high voltage, and this challenge is even greater for objects that undergo structural changes.

In this study, the dielectric spectrum was acquired by applying appropriate signal processing to the current response using the fabricated high-voltage dielectric spectrometer. The contraction behavior of the HASEL actuator was evaluated based on the time-series characteristics of the impedance trajectory and Maxwell stress.

Experimental Procedures

A dielectric shell was formed by vacuum heat sealing 6 mL of either vegetable oil (FR3, 34 mm²/s, relative permittivity 3.2, Cargill) or silicone oil (Si-Oil, KF96, 30 mm²/s) into a 22 µm thick OPP film bag. Conductive paint was applied to the outer surface of the shell as electrodes, creating two pairs of parallel-plate electrodes. An integrator filter composed of capacitor C_d (97 nF) and leakage resistor R_d (1 MΩ) was connected to the sample for detection.

A step voltage $v_i(t)$ of 1 kV, 3 kV, or 6 kV (Rising 80 ms, Falling 520 ms, Frequency 0.033 Hz, Duty ratio 3%) was applied 60 times, and the voltage $v_o(t)$ across the filter terminals were recorded. Signal processing was applied to these measurements to obtain the impedance trajectory (Fig. 1) and the cumulative Maxwell stress (Fig. 2).

Results and Discussion

As a result, contraction does not occur at 1 kV and 3kV for either FR3 or Si-Oil. Since the polarization and depolarization processes of the impedance trajectory are approximately equal, this implies a result without contraction. On the other hand, although significant contraction was observed at 6 kV, it was halted after 30 applications of voltage for FR3 and 3 applications of voltage for Si-Oil. In this condition, the impedance trajectory of the polarization and depolarization processes is also different. In other words, these results suggest that the condition of the actuator changes during these processes.

As the number of voltage applications increases, the impedance trajectory on the real and imaginary axes shifts to low resistance and high capacitance with each repeated contraction, respectively.

On the other hand, the value of the Maxwell stress increased, even though no contraction was observed. The apparent shortening of the distance between the electrodes, caused by the charging up resulting from continuous high-voltage application, could explain the decrease in the resistive component and the increase in the capacitive component of the actuator. Additionally, the time dependence of Maxwell stress is reasonable when we consider that the charging phenomena relaxes the electric field.

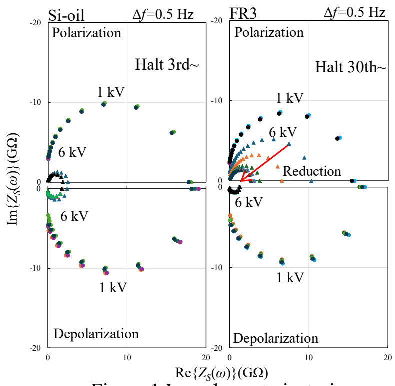

Figure 1 Impedance trajectories

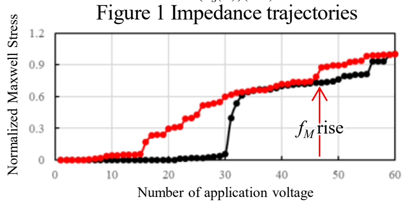

Figure 2 Cumulative Maxwell stress

Conclusion

The time-dependent changes in impedance trajectories and Maxwell stresses suggest that electrostatic charging may cause contraction failure in the HASEL actuator.

References

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