Experimental characterization of dielectric elastomer actuator

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Abstract. As a next generation soft actuation technology, dielectric elastomer actuator (DEA) is of particular interest because of its similar capability to human muscle. The dielectric elastomer (DE) gives DEA the compliant structure, however, it also limits performance due to the nature of viscoelasticity. For the accurate modelling and control of the actuation, a good understanding of its behaviour is required. This work characterizes the planar DEA in the isometric loading condition over the bandwidth up to 100 Hz. The most commonly used DEs, silicone and polyacrylate, are tested and compared. The experimental results show distinctive viscoelastic characteristics. The frequency responses were simulated by treating as a conventional spring-damper system. The simulation results reveal the nonlinear behaviour of the polyacrylate.

Introduction

Dielectric Elastomers (DEs) form a specific class of Electro-Active Polymers (EAPs), which have significant potential in the next generation of soft actuated systems. Their electro-mechanical properties allow conversion of energy between electrical and mechanical forms. DE-based actuators produce mechanical deformation in response to an applied voltage. The actuation features low cost, high energy density, noise-free operation and does not require a rigid mechanical structure. Applications have been explored in robotics and muscle-like actuation, as well as in pumps [1], valves [2], loudspeakers [3] and optical position systems [4].

The actual deformation and dynamic force output of a DEA depends on the viscoelastic properties of the elastomer, which are often based on spring-damper rheological models. While most DEA models have been developed to describe the nonlinear viscoelastic behaviour of the elastomer, typically based on first order parameterisation that contains one spring and one spring-damper, few accurately simulate the DEA actuation. Physically, the elastomer contains numerous molecular segments oriented in different directions, which have dissipation properties. The relaxation of each segment may not occur simultaneously, hence the first order material model is an obvious approximation. The viscoelasticity of a DE has a significant influence on the performance of actuators, sensors and energy harvesters, however, the actual dynamics of these DEAs have received only limited attention in the open literature. This work experimentally characterizes the response of DEAs over a bandwidth up to 100 Hz compared to predictions from the conventional material model.

Theory

The conventional DEA model contains one spring and single spring-damper as shown in Fig. 1b. The relationship between the displacement and the force is derived in the state space form as

$$\begin{cases} \dot{\boldsymbol{q}} = \boldsymbol{A}\boldsymbol{q} + \boldsymbol{B}F \\ y = \boldsymbol{C}\boldsymbol{q} + DF \end{cases} \quad \boldsymbol{q} = [x_0 \quad \dot{x}_0 \quad x_1]^T \tag{1}$$

$$\boldsymbol{A} = \left[0 \quad 1 \quad 0\,; -\frac{k_1+k_0}{M} \quad 0 \quad \frac{k_1}{M}; \frac{k_1}{c_1} \quad 0 \quad -\frac{k_1}{c_1}\right] \; \boldsymbol{B} = [0 \quad \frac{1}{M} \quad 0]^T \; \boldsymbol{C} = [1 \quad 0 \quad 0] \; D = 0$$

where M is the mass, k_0 and k_1 are the spring constants and c_1 is the damping coefficient. It is assumed that the dynamics of a DEA are affected only by the mechanical property of the DE. The model was used to simulate the dynamics of a DEA. The parameter identification was done iteratively by comparing with experimental frequency responses. It is focused specifically on minimizing the offsets and errors in fitting with the actual natural frequency and the change of phase around the resonance.

Experimental Setup

For the DEA fabrication, in order to demonstrate the validity of the model, two types of dielectric elastomer with distinct viscoelastic properties were selected to be subjected to force measurements. One relatively elastic candidate elastomer was PlatSil 7315, a clear Room Temperature Vulcanization (RTV) silicone rubber, the other was polyacrylate. Both elastomers were cut into the same planar configuration, despite of their different thicknesses, then the same electro-active regions (ARs) were applied. The electrode material used in this work was graphite powder. The powder-type electrode material was chosen for ease of the electrode deposition using the screen printing technique. For the experiment, the DEA samples were clamped to the test rig as in Fig. 1a. A load cell connected to the sample for taking force measurements. A high voltage (HV) generator was used to amplify the input voltage (0-10 V). The frequency responses of the DEA were measured for both elastomers. The frequency responses of the samples were identified using a Schroeder Phased Harmonic Sequence (SPHS) input signal that covered a bandwidth from 0.1 Hz to 100 Hz.

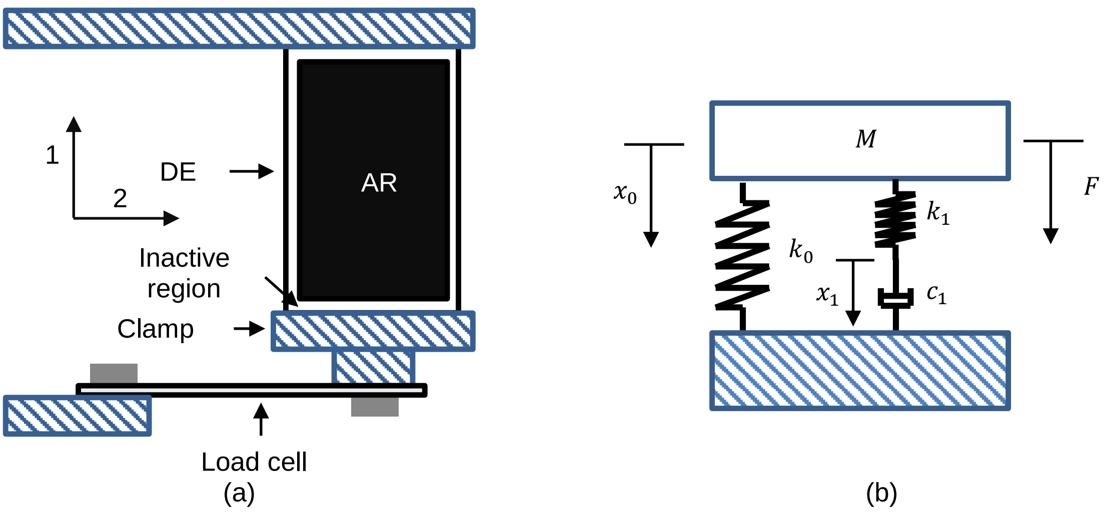

Fig. 1: Schematic diagram for (a) experimental setup and (b) conventional DE model

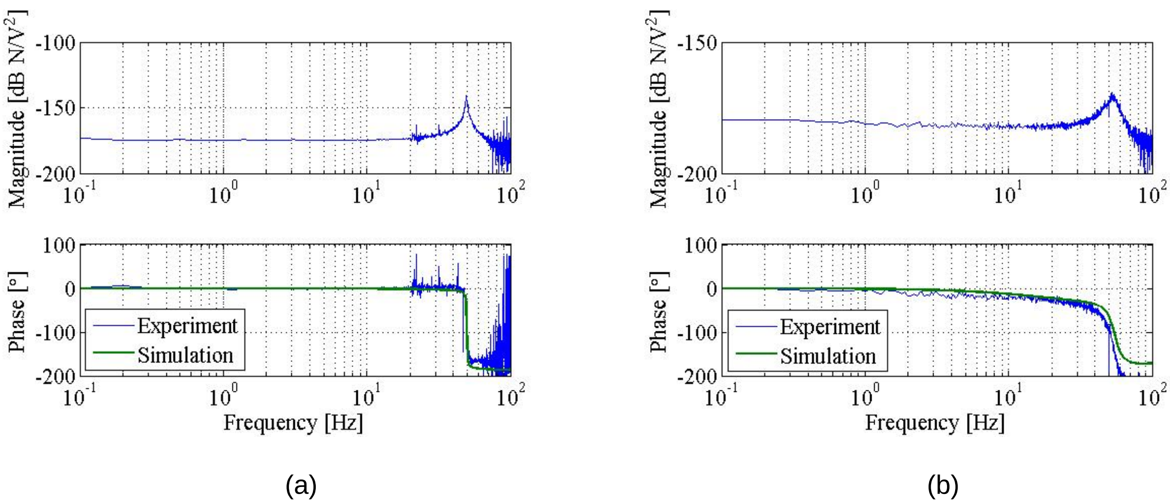

Fig. 2. Bode plot of experimental results in force/voltage2 over 0.1 Hz to 100 Hz for (a) the silicone-based DEA and (b) the polyacylate DEA. They are compared with simulation results in phase plot.

Results

Figure 2 shows the frequency responses of the DEAs. For both DEAs, the magnitude peaks and the phase plots indicate that the systems are underdamped. The silicone is evidently less viscous than polyacrylate through a high rate of change of phase around resonance. The simulation results in the phase plots show a better match with the silicone-based DEA compared with the polyacrylate-based DEA.

Conclusions

It is concluded that the conventional DEA model is sufficient in describing the dynamics for silicone-based DEA. However, its accuracy drops significantly in simulating the polyacrylate-based DEA that behaves more viscously in comparison due to the nature of nonlinear viscoelasticity. Advanced DEA modelling is therefore required for better presentation of the dynamics.

References

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