Extreme Mechanics Letters 2 (2015) 72–77

Contents lists available at ScienceDirect

Extreme Mechanics Letters

journal homepage: www.elsevier.com/locate/eml

Tunable force/displacement of a vibration shaker driven by a dielectric elastomer actuator

Ujjaval Gupta, Hareesh Godaba, Zijie Zhao, Chee Kong Chui, Jian Zhu *

Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 2 February 2015
Accepted 12 February 2015
Available online 14 February 2015

Keywords:
Tunable force
Tunable displacement
Dielectric elastomers

ABSTRACT

Recently dielectric elastomer actuators have been explored for applications to haptic feedback. The force/displacement of the vibration shaker driven by the dielectric elastomer actuator will determine the user's tactile sensation. In this paper, we investigate how to tune the output force/displacement induced by a dielectric elastomer actuator. The dielectric elastomer made of natural rubber – Oppo band, Singapore – is employed in the experiments and can exhibit large amplitude of oscillation. The effect of damping is taken into account in modelling the system, which may lead to disappearance of the superharmonic and subharmonic response. The media, which connect the vibration shaker and the user, are found to play an important role in influencing the output force/displacement. Both theory and experiments show that as the stiffness of the media increases, the output force of the vibration shaker increases, while the output displacement decreases. We hope that the current analyses can improve the understanding of dynamic behaviour of dielectric elastomers and enhance their applications to haptic feedback.

© 2015 Elsevier Ltd. All rights reserved.

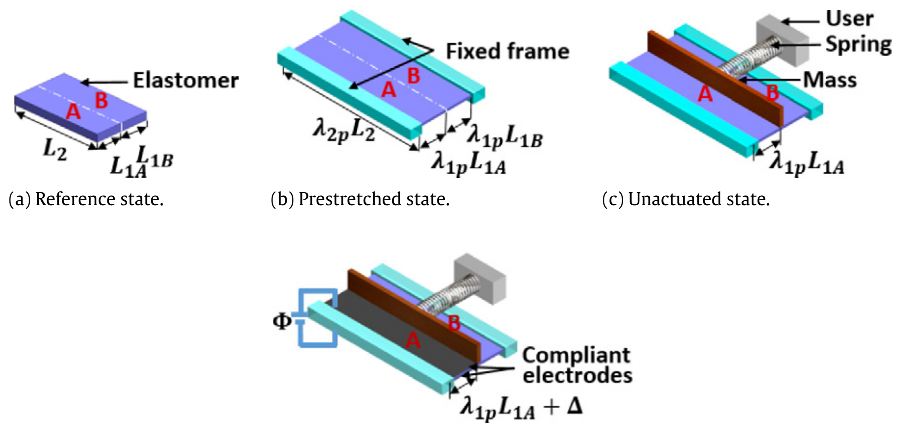
A dielectric elastomer actuator, consisting of a thin layer of elastomer sandwiched between two compliant electrodes, can deform in response to voltage [1–3]. Subject to DC voltage, the dielectric elastomer actuator can exhibit large voltage-induced deformation with an areal strain greater than 1000% [4–6]. Subject to AC voltage, the actuator can oscillate. Its oscillation is strongly nonlinear due to large deformation and nonlinear electromechanical coupling [7–9].

The output force and the output displacement are fundamental and vital factors to evaluate and determine applications of actuators. A piezoelectric actuator can achieve a large output force (with a pressure ∼ 1 GPa), but a small output displacement (with a strain ∼ 1%). A dielectric elastomer actuator can achieve a not-large output force (with a pressure ∼ 1 MPa), but a large output displacement (with a strain ∼ 100%). These attributes make dielectric elastomer actuators resemble natural muscles in the aspects of large deformation and high energy density [1–3]. Applications of dielectric elastomers include stretchable ionic conductors [10], artificial muscles for facial expressions [11], etc. In particular, the first mass-produced application of dielectric elastomer technology, a vibrating haptic-feedback device for a gaming headset (developed by Vivitouch), is driven by dielectric elastomer actuators [12]. The force/displacement induced by the oscillation of dielectric elastomer actuators plays a significant role in determining the user's tactile sensation. Most of the existing dynamic analyses of dielectric elastomer actuators focused on the output displacement – the amplitude of oscillation [7–9,13–15]. Less attention was paid to the output force – the interaction between the vibration shaker and the subject requiring haptic feedback (say, the user).

In this paper, we investigate how to tune the output force/displacement of a vibration shaker driven by a dielectric elastomer actuator. Both theory and experiments show that the media, which connect the vibration shaker and the user, play a significant role in influencing the output force/displacement. As the stiffness of the media increases,

* Corresponding author.
E-mail address: mpezhuj@nus.edu.sg (J. Zhu).

http://dx.doi.org/10.1016/j.eml.2015.02.004
2352-4316/© 2015 Elsevier Ltd. All rights reserved.



(a) Reference state.

(b) Prestretched state.

(c) Unactuated state.

(d) Actuated state.

Fig. 1. A schematic of a vibration shaker of a dielectric elastomer. (a) In the reference state, the elastomer consists of two parts. Part *A* is of the dimensions $L_{1A} \times L_2 \times H$, and Part *B* is of the dimensions $L_{1B} \times L_2 \times H$. (b) The elastomer is subject to bi-axial prestretches, and is then fixed by two clamps. Parts *A* and *B* have the same length $\lambda_{2p}L_2$, but widths $\lambda_{1p}L_{1A}$ and $\lambda_{1p}L_{1B}$, respectively. (c) A mass *m* is attached in the middle of the membrane to separate Parts *A* and *B*. The mass is connected to the user (which is fixed) through a spring of spring constant *K*. (d) Part *A* is smeared with carbon grease as the electrodes, and is then subject to voltage. The mass moves by Δ, and Parts *A* and *B* have the same length $\lambda_{2p}L_2$, but widths $\lambda_{1A}L_{1A} + \Delta$ and $\lambda_{1B}L_{1B} - \Delta$, respectively.

the output force increases, while the output displacement decreases. The effect of damping is taken into account in the theoretical analyses. It is interesting to find that a large damping can lead to disappearance of superharmonic and subharmonic resonance, which explains why these nonlinear phenomena, such as superharmonics, subharmonics, etc., have not been observed in the experiments. The theoretical calculations are qualitatively consistent with the experimental results.

Fig. 1 illustrates a vibration shaker driven by a membrane of a dielectric elastomer. At the reference state, the membrane of a dielectric elastomer is of the dimensions $L_1 \times L_2 \times H$ (Fig. 1(a)), subject to no mechanical and electrical loads. The membrane is prestretched in the in-plane directions, and the two boundaries along the length are fixed by two clamps (Fig. 1(b)). A mass, which functions as a vibration shaker, is attached in the middle of the membrane to separate it into Parts *A* and *B*, and a spring is employed to connect the mass to the subject requiring haptic feedback, say, the user. At the initial moment, the spring is at rest (Fig. 1(c)). At the reference state, Parts *A* and *B* have the same length L_2, but widths L_{1A} and L_{1B}, respectively (Fig. 1(a)). In the prestretched and unactuated states (Fig. 1(b) and (c)), Parts *A* and *B* have the same length $\lambda_{2p}L_2$ (=100 mm), and widths $\lambda_{1p}L_{1A}$ and $\lambda_{1p}L_{1B}$, respectively. The separation between the two clamps is fixed as $d = \lambda_{1p}(L_{1A} + L_{1B}) = 40$ mm. In a current actuated state (Fig. 1(d)), Part *A* is smeared with carbon grease as the electrodes and is then connected to a voltage source, while voltage is absent in Part *B*. There are different methods for the vibration shaker to output force/displacement to the user [12]. In this paper, we consider a simple scenario: the mass is connected to the user through a spring of spring constant *K*, as illustrated in Fig. 1(c) and (d). In the absence of voltage, the spring is undeformed. When subject to voltage, Part *A* deforms and causes the mass to move by Δ, thus outputting force/displacement. In the current state, Parts *A* and *B* have the same length $\lambda_{2p}L_2$, but widths $\lambda_{1p}L_{1A} + \Delta$ and $\lambda_{1p}L_{1B} - \Delta$, respectively.

We conduct experiments to measure the output displacement and the output force. Natural rubber, Oppo Band, Singapore with a thickness $H(=0.482$ mm) is employed as the dielectric elastomer, since it exhibits low viscoelasticity, large reverse deformation, excellent durability against cyclic operation, and high fracture toughness [16]. Unless otherwise stated, the prestretches of the membrane are fixed at $\lambda_{1p} = 2$ and $\lambda_{2p} = 2$, and the widths of Parts *A* and *B* at the reference state are the same, $L_{1A} = L_{1B}$. The mass of the elastomer is 0.375 g. The vibration shaker, an acrylic plate, has a mass of 6.4 g. It has dimensions of 91 mm × 4 mm × 21 mm, and is attached to the membrane through adhesive tape. Voltage is programmed through Labview (BNC-2120, NI), and is then amplified by a high voltage amplifier (10/40 A, Trek). When subject to AC voltage $\Phi = V_{ac}\sin(\omega t)$, where V_{ac} and ω are the amplitude and the frequency of sinusoidal AC voltage, respectively, Part *A* oscillates, and the vibration shaker can transmit force to the user through the spring. The output displacement and the output force are measured by a laser sensor (ILD1700, MicroEpsilon) and a force/torque sensor (ATI Gamma series), respectively (see the insets of Fig. 2(a) and (b)).

Fig. 2(a) plots the experimentally recorded amplitude of the output displacement as a function of the frequency of AC voltage, when no spring is connected between the vibration shaker and the user (with $K = 0$). In the current analyses, we define the amplitude of the displacement/force as the difference between the maximum and minimum values of the displacement/force, respectively. The experimental setup to measure the output displacement is shown in the inset of Fig. 2(a). When $V_{ac} = 7$ kV, the amplitude of oscillation reaches peak (about 2000 μm) at the harmonic resonance, which is much larger than that (abut 200 μm) reported in Ref. [12], where the actuator of similar dimensions was made of silicone rubber. The dielectric elastomer made of Oppo band, Singapore seems excellent in both actuation and energy harvesting due to its low viscoelasticity [16].

Download English Version:

https://daneshyari.com/en/article/778506

Download Persian Version:

https://daneshyari.com/article/778506

Daneshyari.com