Sensors and Actuators A 212 (2014) 123–126

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

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

Transferring electrical energy between two dielectric elastomer actuators

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ARTICLE INFO

Article history:
Received 5 August 2013
Received in revised form 10 March 2014
Accepted 14 March 2014
Available online 24 March 2014

Keywords:
Dielectric elastomer
Electronics
Efficiency
Electrode resistance

ABSTRACT

Soft dielectric elastomer (DE) devices used for actuation and power generation are typically operated at kilovolt potential. Effective recovery of the electrical energy inherently stored during operation will greatly improve the efficiency of a DE device. One method of energy recovery involves the use of DC–DC step-down circuits to convert the high voltage energy into a low voltage form. The energy would then go to a storage component and eventually be reconverted back to high voltage for recharging the DE. However, the voltage conversion process incurs significant energy loss. Simply transferring the energy to a capacitor or another DE without large changes in the voltage can achieve better efficiencies. In our experiments, we achieved 51% energy transfer from one DE to another DE of similar size. Improved energy transfer is expected with lower electrode resistance.

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1. Introduction

Dielectric elastomer (DE) transducers can be used for actuation, electricity generation, strain sensing, and switching [1,2]. They are stretchable capacitors which typically operate at a few kilovolts. Special electronics are required to power these devices [3–5]. This involves electrically charging and discharging the DE at the correct time [6,7]. To achieve good efficiency, discharge of the DE must involve recovery of the stored electrical energy.

Step-down circuits can be used to perform the energy extraction and convert the energy into a low voltage form for storage and use [3,4]. However, repeatedly converting electrical energy between low voltage and high voltage forms is not always the best solution due to significant energy loss and the need for complex electronics. It would be more efficient to simply transfer the energy elsewhere while retaining its high voltage form [8]. The energy could be transferred to a capacitor for temporary storage or to another DE for actuation or power generation.

One method has been used for DE generators (DEGs) which pumps charge from a low voltage reservoir to a high voltage reservoir [9]. When the voltage across the DEG increases to that of the high voltage reservoir, a connection is made between them. Charge is subsequently pumped into this reservoir as the DEG decreases in capacitance. However, the connection must be made when their voltages are equal. Failing to do so will cause a large peak current and significant losses through the small resistance of the connecting path, equal to I^2R, where I is the current and R is the resistance of the path which the current flows through.

The inclusion of an inductor to the circuit reduces the peak current without adding significant losses, where the current I is related to the inductance L and the integral of the voltage V across it, $I=(1/L)\int V\,dt$. The circuit shown in Fig. 1a would allow efficient transfer of electrical energy from a capacitor at a high voltage to a capacitor at a lower voltage. Furthermore, it is possible for a small capacitor receiving the charge to attain a higher voltage than the larger capacitor being discharged [8].

In this paper, we will briefly assess the practical performance of this circuit when used with DE actuators (DEAs). This will reveal the impact of high series resistance of DEs on the performance of power electronics.

2. Experiment

Energy is to be transferred from one charged DE actuator, DEA1, to another uncharged DE actuator of similar size, DEA2. A large inductor of 1 H was used to overcome the detrimental effect of the large electrode resistance [10]. The inductor had the dimensions of 25 mm × 25 mm × 20 mm, had a mass of 24 g, and constitutes approximately 50% of the total circuit mass. Miniature and entirely soft DE systems would enable extremely portable and unobtrusive

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http://dx.doi.org/10.1016/j.sna.2014.03.020
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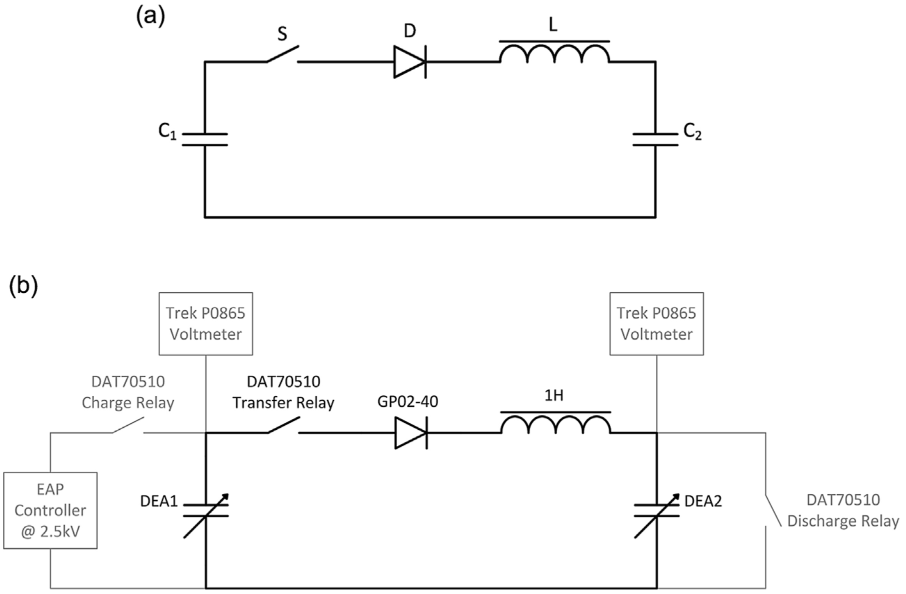

Fig. 1. (a) Circuit used to transfer electrical energy from one charged capacitor C1 to another uncharged capacitor C2 [8]. (b) Circuit diagram of the experimental setup. Initially, DEA1 was charged to approximately 2.5 kV and DEA2 was discharged to 0 kV. The 'Transfer Relay' was turned on to transfer electrical energy from DEA1 to DEA2. The Trek P0865 voltmeter measured the voltages of DEA1 and DEA2 which were recorded using a LabVIEW program.

devices. Many types of electronic components can be made very small, flexible, or soft [11,12]. However, producing physically small or soft inductors with large inductances is a major challenge.

A schematic of the experimental setup is shown in Fig. 1b. The electrical efficiency of this process was measured. Equipment and components with low leakage currents were used to minimize energy loss and improve measurement accuracy. Two DAT70510 reed relays were used to establish the initial voltage across DEA1 and DEA2. Another 'Transfer Relay' was used in the main circuit to begin the energy transfer.

2.1. *DE capacitances*

DEA1 and DEA2 were similar dot actuators of 30 mm diameter, fabricated using 3 M VHB 4905 with 3-by-3 equi-biaxial pre-stretch and Nyogel 756G carbon grease electrode. The capacitances of the charged DEA1 and the uncharged DEA2 were determined to be approximately 0.96 nF and 0.73 nF respectively. These capacitance values were assumed to have remained unchanged when the voltages were measured immediately after the energy transfer. This assumption can be made because the mechanical time constant of the DEA was several orders of magnitude greater than the electrical time constant of the circuit. The time to transfer the electrical energy is governed by the damped natural frequency of the series RCL system as shown in Eq. (1). Given that the series resistance R was measured to be approximately 25 kΩ, C_1 and C_2 were 0.97 nF and 0.73 nF, and L was 1 H, the electrical energy would be transferred within 74 μs. The much slower mechanical response time of VHB is in the order of 1 s [13]:

$$t = \frac{\pi}{\sqrt{(((C_1 + C_2)/(LC_1C_2)) - (R/L)^2)}} \qquad (1)$$

2.2. *Electrical connections*

Two different methods of establishing an electrical connection to the DEAs were used to investigate how the length of the carbon grease connection affects the performance of the circuit. A shorter electrode path would have lower series resistance. Fig. 2 illustrates the two configurations. The measured equivalent series resistance were approximately 25 kΩ for the configuration in Fig. 2a and 5 kΩ for the configuration in Fig. 2b.

2.3. *Method*

Using relays, DEA1 was charged to approximately 2.5 kV using a Biomimetics Laboratory EAP Controller while DEA2 was fully discharged to ensure it holds no energy initially. The relays were then turned off, disconnecting both the voltage source from DEA1 and the discharge path from DEA2 so no more energy would enter the system. The energy transfer would then occur by switching on the

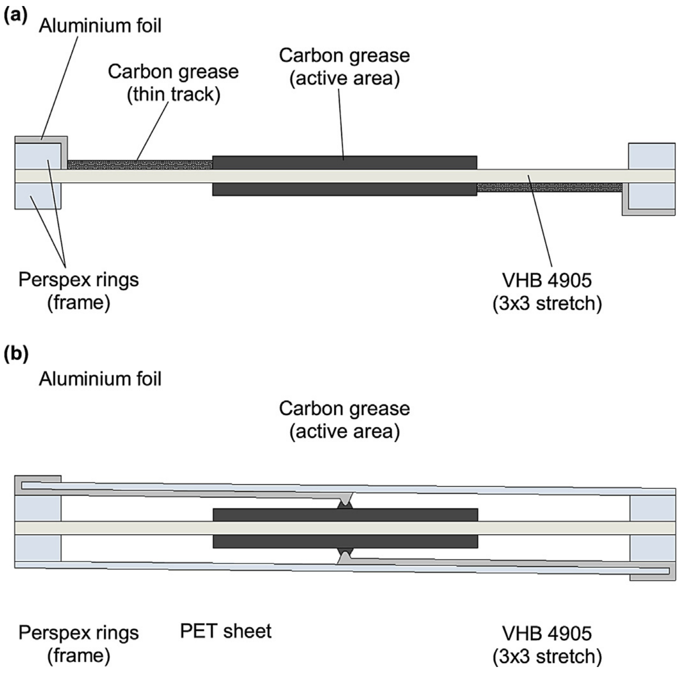

Fig. 2. Cross-sectional diagrams of the DEA configurations used in the experiment. (a) High resistance: a thin carbon grease track establishes an electrical connection to the DEA's active area. (b) Low resistance: an aluminium foil track establishes an electrical connection to the centre of the DEA's active area.

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