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The Temperature Effect on the Characteristics of the Dielectric Elastomer Actuator

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***Abstract*— In this paper, the material constant of the dielectric elastomer (DE) has been observed under three parameters; the electrical frequency, the prestretch ratio, and the environmental temperature. While the dielectric elastomer actuator (DEA) can be used under different environmental conditions, the temperature factor is considered in this paper at the prestretch condition and various frequencies. Which shows a significant effect on the constant of the DEA.**

Keywords*— Dielectric Elastomer (DE), Soft Actuators, Temperature, Material Constant, Prestretch Ratio.

I. INTRODUCTION

The high demands of using robots in medical applications such as rehabilitation and surgery increase the requirement to invent more friendly types of robot systems. In comparison with traditional rigid robots, the soft robots which are made from soft and flexible materials provide numerous advantages such as small weight to force ratio, compliance, environment friendly, safe to human-robot cooperative, low cost, and flexibility to deform and manufacturing [1-3]. Several types of actuators which are made from smart materials such as shape memory alloy (SMA) which offer actuate by changing its temperature [4], and the pneumatic muscle actuator (PMA). The PMA has numerous shapes and actuation behaviours including liner contraction and expansion [5] [6], bending, and circular pneumatic muscle actuator (CPMA) [7]. One of the major types of soft actuators that attract the researchers during the last decade is the dielectric elastomer actuator (DEA) [8] [9]. Utilizing the dielectric elastomer (DE) has been increasing dramatically to design soft actuators for use in robotic design due to its ability to deform and actuate under several factors such as the applied voltage and material dimensions [1] [10].

The DEA has been developed and its model is discussed by many researchers. The twisting DEA has been proposed by [11]. Rolled actuators are developed by [12] and [13]. The hemispherical shape has been presented in [14].

Modelling of the DEA is presented by [15] [16] and [17]. The effect of the frequency on the DE material constant has been observed by [8] under various prestretch ratios.

Because of the wide use of the DEA and to test how the environment may affect the material characteristics, this paper presents the effect of the environment temperature on the DE constant at various frequencies.

The definition of the DE and the actuation principle are given in section two. Section three presents the experiment and its results. And the paper outcomes are concluded in section four.

II. DIELECTRIC ELASTOMER

The dielectric elastomer actuator is usually made from soft elastomeric membranes as a sandwich with two electrodes. The electrodes need to be compliant due to the softness and the flexibility of the DEA. Carbon black, thin copper tab and numerous carbon-based materials are commonly used for electrodes.

The DEA one of the soft electroactive materials affected by the electrical voltages. The applied voltage deforms the shape of the DE and provides actuation. Fig.1 shows the construction of the DEA.

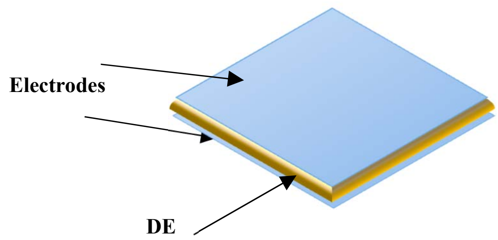


Fig. 1. The construction of the dielectric elastomer actuator

The actuation behaviour of the DEA depends on its dimensions and, the position and shape of electrodes. The main aim of this paper is to study the effect of the environment temperature on the characteristics of the DEA.

III. EXPERIMENTS AND RESULTS

The principle operation of the DE can be expressed by (1) as follows:

$$P = \varepsilon_0 \varepsilon_r E^2 \qquad (1)$$

P represents the electrostatic pressure, ε_0 and ε_r are the vacuum permittivity (8.854 X 10^{-12} F/m) and the dielectric material constant respectively. E is the electric field.

In this experiment, VHB-4910 made by 3M is used at the shape and dimensions as given in Fig.2. Thin squares of copper have been used for electrodes.

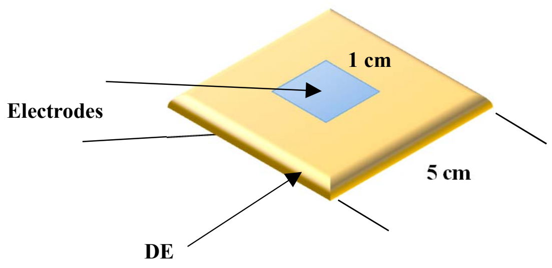


Fig. 2. Dimension, structure, and shape of DEA under test

The DE is cut as a square of 2.5 cm in each side and then stretched by a prestretch ratio λ=1, where:

$$\lambda = [(L - L_0)/L_0] \quad (2)$$

Or:

$$L = L_0(1 + \lambda)$$

L_0 is the initial length and L is the length after stretching. Therefore, L equal to 5 cm. The electrodes have been attached after that and DE has been fixed by using a plastic frame (see Fig.3).

Fig. 3. The DE and the electrodes fixed on the frame at a 100% prestretch ratio.

Fig.3 shows the DE as a capacitor and the capacitance C can be given as in (3).

$$C = \varepsilon_0 \varepsilon_r A/d \quad (3)$$

In (3), A is the area of capacitor cross-section and d is the thickness of the DE. The amount of prestretch affects both A and d.

A high voltage pulse transformer is used in this experiment, and the full electrical diagram is shown in Fig.4.

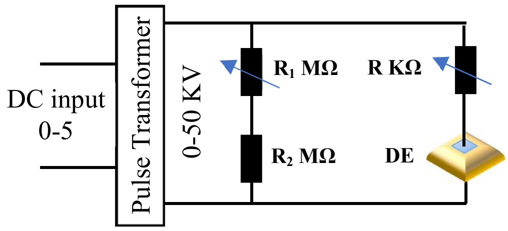


Fig. 4. The electrical circuit for testing the DEA

The DEA has been tested in a closed high-temperature resistance glass box. And the inner environment temperature is adjusted by a heating system. Seven steps of temperature T have been adjusted by the heating system between 20°- 80° Celsius. At each temperature, the value of R is adjusted to change the discharging time/ frequency and record the effective capacitor voltage V_c and the applied voltage V.

While:

$$Xc = RV_C/(V^2 - V_C^2)^{0.5} \quad (4)$$

From (3) and (4), the dielectric material constant is:

$$\varepsilon_r = a(V^2 - V_C^2)^{0.5}/(\lambda^2 f V_C) \quad (5)$$

The coefficient is constant and can be calculated by (6) as follows:

$$a = d_0/2\pi\varepsilon_0 R \quad (6)$$

The frequency varies from 100 Hz to 20 kHz and ε_r has found by (5). Fig.5 illustrates the variation of the dielectric constant at three different temperatures.

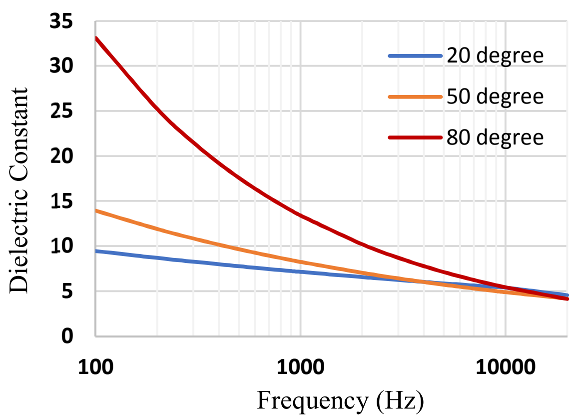


Fig. 5. The dielectric constant of the DE versus frequency at three different environment temperatures.

Fig.5 shows that the environment temperature has a high impact on the dielectric constant at frequencies less than 10 kHz. Thus, in order to reduce the effect of temperature, the operations need to be at high frequency. On the other hand, from (5), the increase of operating frequency leads to a decrease in the DE constant and the verse versa. Fig.6 gives the dielectric constant as a function of temperature at three different frequencies.

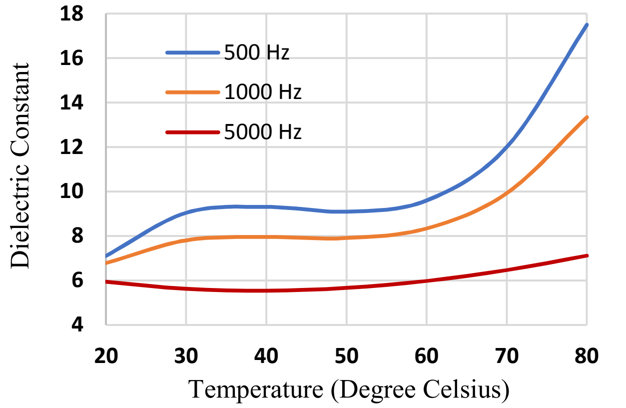


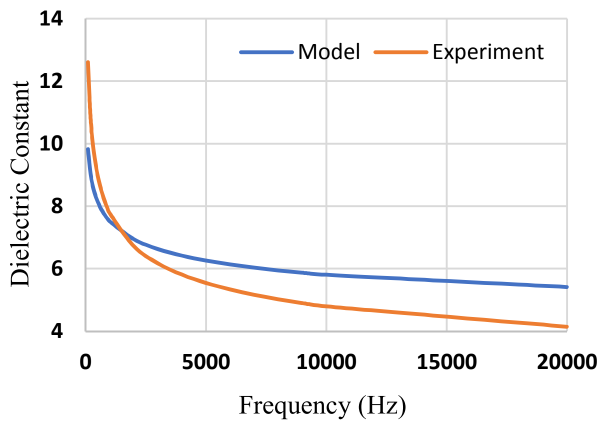
Fig. 6. The dielectric constant versus temperature at various operating frequencies.

Fig. 6 illustrates the variation of the dielectric constant of the DE at three different operating frequencies. This figure shows that the material constant increase with the environmental temperature. Furthermore, the increment of temperature has a high effect on the material constant at 500 Hz and 1kHz, while it less on the 5 kHz. This again with the results of Fig. 5, shows that the operation at high frequencies has less temperature impact.

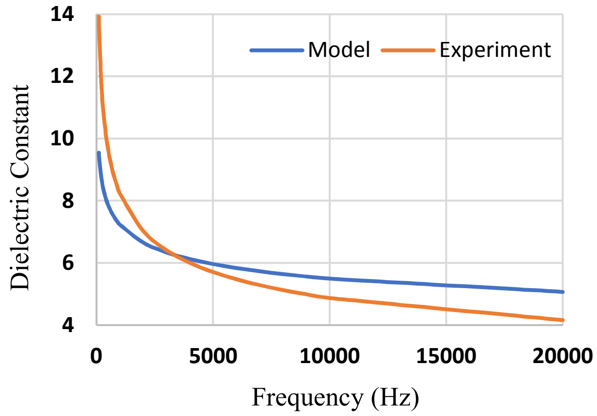
By the analysis of the recorded data and from (5), the material constant can be found as:

$$\varepsilon_r = [a(V^2 - V_C^2)^{0.5}/(\lambda^2 f V_C)] + [(T/100)e^{-0.01f}] \quad (7)$$

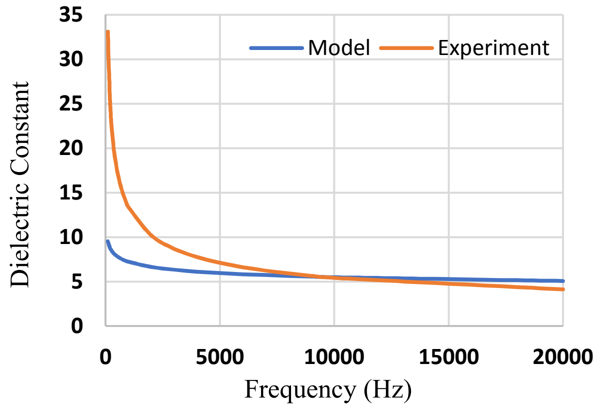
Fig. 7a-c show the experimental and the model data (7) for the dielectric constant as a function of operating frequency.



(a)



(b)



(c)

Fig. 7. The model and the experiment results for the material constant at three temperatures. (a) at 40°, (b) at 50°, and (c) at 80°.

These figures illustrate that the model behaves as the experimental data with a little variance. And it can be utilised for pre-evaluation.

IV. Conclusion

The dielectric elastomer (DE) is one of the wide uses of soft materials due to its high deformation. The characteristics and behaviours of the DE are changing under several factors such as applied voltage, dimensions, size and shape of electrodes, and the prestretch ratio.

The DE has been used recently to design a soft actuator for use in indoor and outdoor applications. Numerous dielectric elastomer actuators (DEA) are used in soft robotics design.

In this paper, the effect of the environment temperature is studied on the DE of VHB-4910 made by 3M. This DE pre-stretched by 100% in cross-section dimensions. The temperature is adjusted at different values from 20° to 80°. The experiments show that the effect of the temperature can be ignored at frequencies more than 10 kHz and it has a significant impact at low frequencies.

From the experiment results, this paper proposed a model to calculate ε_r as a function of operating frequency and take an account of the environment temperature.

As future work, the presented model can be used to select the operation points for the actuators.

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