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Electromechanical Characteristics of Core Free Folded Dielectric Electro-active Polymer Soft Actuator

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ABSTRACT

This paper investigates the active dynamic and electromechanical characteristics of a new thin folded dielectric electro-active polymer actuator developed by Danfoss PolyPower. The high voltage is supplied to the actuator during dynamic testing to identified the effect of the electrical field on dynamic characteristics. The electromechanical characteristics are investigated by varying the amplitude and frequency of the voltage supplied. The experimental results, such as natural frequency, amplitude response, and loss factor are presented to show the influence of such an electrical field on the characteristic of the actuator. There is a reduction of resonance frequency from 14 Hz to 12 Hz as voltage supply up to 2000 V. The actuating response of the actuator was subjected more to frequency rather than the amplitude of the voltage supplied. Hence, the results may guide the exploration of a new folded thin actuator as an active vibration controller.

Keywords: Active dynamic, core free, dielectric electro-active polymer, electromechanical, thin actuator

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INTRODUCTION

A material that has human muscle characteristics potentially could provide an effective alternative to conventional actuator technology. Energy density, strain, actuation pressure, response time and efficiency are the important elements of an actuator material that need to be considered. In addition, the environmental tolerance,

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fabrication complexity, and reliability also need to be considered for good actuator designs (Pelrine et al., 2000). Thus, rapid developments and research of the so-called artificial muscle led to the design of dielectric electro-active polymers (DEAP). These materials can undergo large deformation, respond quickly and have high energy density hence they were also called artificial muscles (Berardi et al., 2010). Other attributes of dielectric elastomer include fast response, no noise, lightweight and low cost (Suo, 2010).

The ability of DEAP to deform by applying voltage is like the deformation shown by any dielectric material subjected to electric field. However, the corresponding deformation was markedly enhanced by the softness of the polymer itself, as well as compliance of the electrodes. These two key-features distinguish actuating devices made of dielectric elastomer from those based on different electric-field-driven electrics, such as piezoelectric and electro strictive materials (Carpi et al., 2008). Kornbluh et al. (1999) suggested that, the dielectric elastomer showed the promising potential for being used not only as actuator but as well as sensor and generator, or it may be used to replace existing impractical technologies.

Besides that, one of the unique properties of DEAP is that it can be formed in any complex shapes and still provide actuation. Li et al. (2018) fabricated stacked dielectric elastomer actuator to enhance the homogenous and reproducible properties of the actuator. Hau et al. (2016) described how to establish DEAP membrane actuators to become high force actuator that can be pushed to the high double-digit Newton range and beyond. One of the most popular shape of DEAP actuator was tubular or cylindrical shape (Berardi et al., 2010; carpi, et al., 2003; Carpi & de Rossi, 2004; Sarban, et al., 2011; Tryson et al., 2010; Wissler et al., 2007). For these shapes of DEAP actuator, the principal work was 'push actuator'. To date, very few studies have explored on the DEAP actuator working as 'pull actuator'(Wahab et al., 2020).

Thus, the purpose of the present study is to investigate the new core free folded thin DEAP actuator established by PolyPower®. In this paper, the experimental works are conducted to identify the electromechanical characteristics of the actuator as static and harmonic voltage was supplied.

MATERIAL AND METHOD

Folded Thin DEAP Actuator

The actuator was made-up from sheets of dielectric elastomer that was developed by Danfoss PolyPower A/S (Benslimane et al., 2002; Berardi, 2013; Sarban et al., 2011). The actuator was fabricated by rolling multilayers of PolyPower DEAP sheet which were then pressed to form a flat and thin structure as shown in Figure 1. It was fully made-up from DEAP sheet without any supporting material or core inside the flat rolling structure that resulting soft and flexible actuator. For voltage supply, flexible wires and conductive tape were attached at whichever side of electrodes. At each end of the actuator, hard plastic clipper was put to ensure the actuator always in the flat structure shape. Table 1 shows the geometry of the flat structure actuator used in this study.

a.

b.

Figure 1. (a) A rolled multilayer DEAP composite pressed to form a flat structure. (b) A photograph of the final assembly of Poly Power flat DEAP actuator (Rahimullah Sarban, 2011)

The new actuating formation described in this work provide a simple means to obtain an electrically contractile thin, soft, flexible (human muscle looks alike) and uniform actuator. For this thin actuator, the corrugated surface is the basic actuating force. This condition ensures the elongation of the actuator is in axial direction and in maximum condition (Berardi, 2013; Sarban et al., 2011). It is also avoiding the complexity of fabrication of any shape actuator either in tubular or flat thin condition.

Table 1
Actuator specifications and properties

Geometry	Value	Material constant	Value
Actuator's length (m), L	0.28	ε(F/m)	8.854e^{-12}
Actuator's width (m), w	0.07	ε_0(diamensionless)	3.1
Weight (kg), M	0.0645	Elastic Modulus (MPa), *Y*	1.1
Clipper's weight (kg), Mc	0.105	Laminate's thickness (μm), *h*	70
		Young's Modulus (MPa), *E*	1.1
		Density (kg/m^3), ρ	1100

**Source:* (Berardi, 2013)

Active Dynamic Testing

The purpose of this experiment was to identify the effect of electrical field towards the dynamic response of the new actuator. Figure 2 shows the diagram and the setting of equipment for the experiment. One end of flat DEAP pull actuator was clamped at static iron beam and another end was hung freely. This condition is in single degree of freedom (SDOF). The pre-stretch condition of flat DEAP pull actuator due to the mass of caliper (Mc) was assumed as equilibrium condition. Electro-magnetic shaker was used to excite the actuator in only one direction, so that the modal response in just that direction can be obtained. The signal used to drive the shaker in the tests was set as pseudo random. The transfer function of acceleration per unit force (accelerance) has been acquired by spectrum analyser for 30 s, rectangular windows and over an average of 75 times. The tests were conducted by supplying a voltage from 0 to 2 kV, in steps of 500 V.

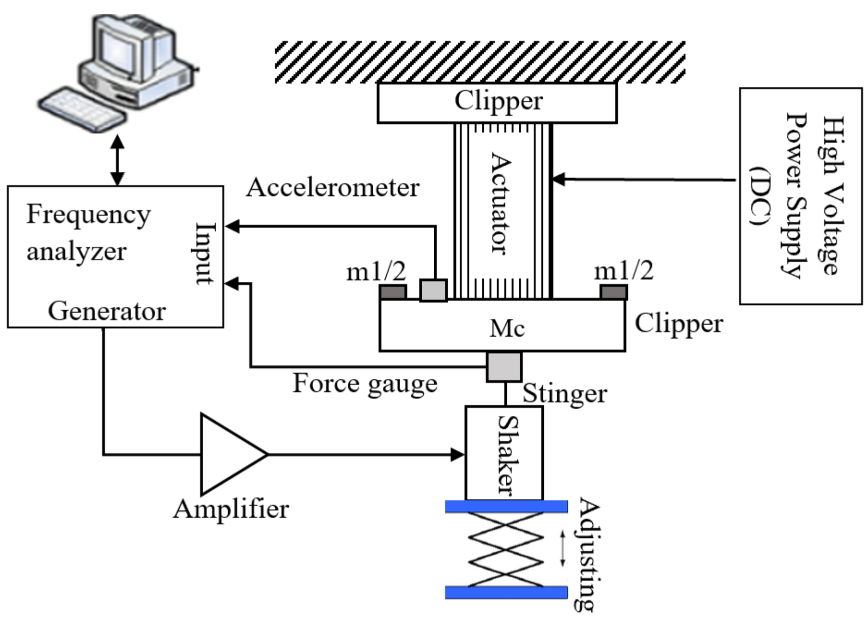

Figure 2. Active dynamic testing

Electromechanical Testing

In order to identify the electromechanical response, harmonic electrical inputs were stimulated with the actuator. Figure 3 shows the experiment set up.

In this experiment the voltage inputs were peak to peak value for 500V, 1000V, 1500V and 2000V. Frequency for each value of voltage has been changing in step of 3Hz up to 21Hz. The Fourier coefficient for each data has been determined by FFT calculation and graph amplitude-frequency for each voltage has been plotted.

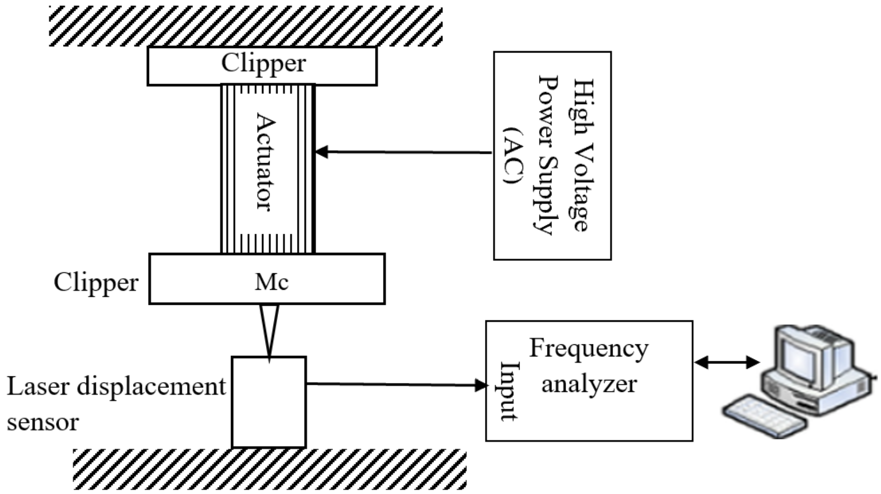

Figure 3. Harmonic electrical input testing

RESULTS AND DISCUSSION

Active Dynamic Characteristic

The finding suggests that, the natural respond of the actuator in this work is at low frequency range. The first order mode of resonance is around 14 Hz at zero voltage supplied. Figure 4 shows that the voltage applied at 500 V, 1000 V and 1500 V do not affect the natural frequency of the actuators. Only at 2000 V, the effect of high voltage can be observed with reduction of natural frequency into 12 Hz.

The loss factor of the actuator was calculated using 3dB method. Referring to Table 2, the voltage supplied does affect the loss factor of the actuator as the highest lost factor of 0.7917 occurs at 2000 V. As voltage was supplied towards dielectric elastomer, the electric field was created due to existence of charges. The electric field established electrostatic pressure which is created pressure on the elastic sheet of DEAP that caused a compression of the elastomer sheet (Pelrine et al., 1998). The electric field dictate the electrostatic pressure (Onyenucheya et al., 2019). Thus, as voltage increased which mean electric field strength increases, the more stretches and reduces of the thickness of the elastomer sheet. As a result, the stiffness of the actuator decreases. Hence, resulting in the decreasing of the natural frequency of the actuator. This condition is in line with Berardi (2013).

Electromechanical Characteristics

Figure 5 shows the first Fourier coefficient of flat DEAP pull actuator for voltage at 500V, 1000V, 1500V and 2000V at varying frequencies 0Hz – 21Hz. It can be seen at zero frequency input, the higher voltage produced higher stroke or actuating response. As

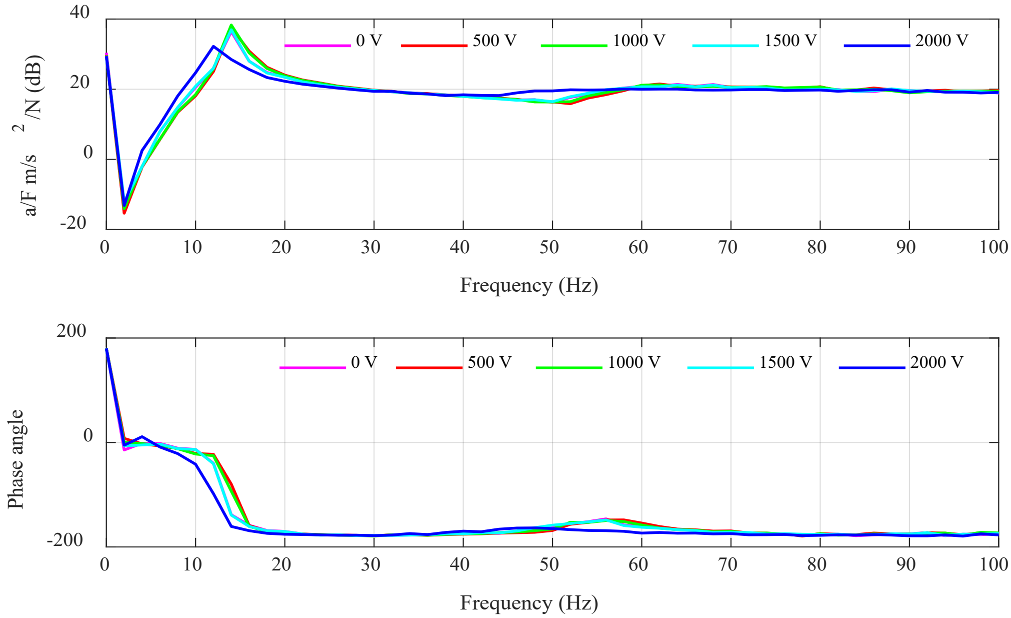

Figure 4. Acceleration per unit force for different DC voltage supply at mass = 0 (pre-stretch due to clipper mass of 105 g)

Table 2
The effect of voltage on loss factor of prototype actuators

Voltage (V)	Loss Factor
0	0.3929
500	0.4107
1000	0.3393
1500	0.3929
2000	0.7917

crosses the frequency range, the highest stroke for each voltage occurs at around 12 Hz. This was the range of natural frequency for the actuator which has been determine during dynamic testing. Beyond the resonance frequency, the amplitudes were decreased to zero for each of different voltage.

In theory, the resonance frequency of an actuator is dependent on its stiffness and mass while the peak values at resonances are dependent on the materials damping coefficients. Results indicate that damping of this actuator growths as voltage increases. The elastomeric material is highly deforming as high voltage is applied. This deformation causes the internal friction to rise and as a result the occurrence of energy loss is increased.

Actively actuator is the main part of active vibration control technology. The actively actuators reduce the unwanted vibrations in structure by exciting the vibrating structures with harmonic motion resulting in an overall vibration reduction. At the initial of the frequency range, the high voltage of harmonic electrical inputs produce high stroke is due to inhomogeneity of the actuator (Bertoldi & Gei, 2011). As high voltage applied, the thickness of the actuator starts to varies due to deformation occurs at the actuator (Suo, 2010) . This condition contributes to increasing the elongation of the actuator.

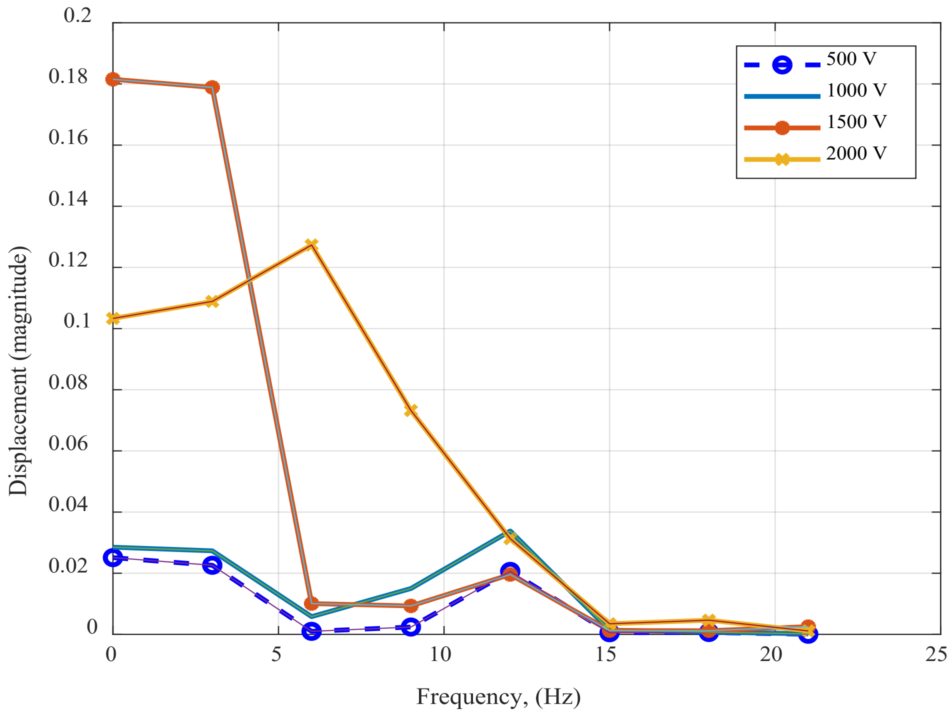

Figure 5. Fourier coefficient versus Frequency for a harmonic response of the actuator

Across the frequency range, the actuating response of the actuator was subjected more on frequency rather than the amplitude of the voltage supplied. This was consistent with Molberg et al. (2009), who suggested that the performance of elastomer actuator was dominated by the frequency dependence of the elastic response and was less influenced by dielectric properties. In fact, over the frequency range the amplitude of the actuator is constant as dielectric remaining roughly constant although different voltage supplied.

The results also show that the actuator has the potential to provide harmonic motion with moderate operating speed.

CONCLUSION

In this work, the effect of electric field toward dynamic and electromechanical characteristic of the new core free folded thin DEAP actuator were investigated. It was found that the natural frequency of the actuator reduces from 14 Hz into 12 Hz as voltage supplied up to 2000 V. For the harmonic electrical stimulation, near to zero frequency, the high actuating response for high voltage input is due to inhomogeneity of the actuator. Across the frequency of harmonic electrical input, the actuating response of the actuator depending more on frequency rather than amplitude. The performance of this actuator for active vibration control is necessary in the future study.

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