Abstract: Principles and mechanism of energy transduction of dielectric polymer materials are well known from the various smart material related publications. However their introduction to industrial actuator applications is limited mainly due to difficulties to guarantee controllability and reliability. Most of the previous publications have elaborates energy transduction physics of chunk of polymer while development of construction methods for feasible actuators made of the material is rarely proposed. In the present article, a conceptual design of multi-DOF linear polymer actuator construction that is to be controllable with moderate level of control work os introduced. In addition, numerical models that are developed with a unified energy based approach are presented not only for basic working mechanism analysis of the polymeric soft actuator but for providing analytical foundation to expend the concept toward design of multi-DOF actuator controls.

Key words: Electroactive Polymer, Dielectric elastomer, Linear actuator

1. Introduction

For many years, electroactive polymer (EAP) has tempted serious attention of many researchers as new types of energy transducers. Dielectric elastomer is one of the particular sorts of EAP have been demonstrated to be able to generate larger strains than other types of EAP. It also accommodates considerable amount of stresses even in high frequency operation. They are to be considered for the best alternative material to replace electromagnetic transducers in high performance device design.

The basic operation of the material as an actuator is simply that the polymer intrinsically deforms either in expanding or in contracting when electrical voltage is applied at its surfaces. Their basic types of deformation are expansion(active) contraction(passive) which can be used in various ways of actuation and have been used experimentally to the present. But they showed only single-DOF actuation of elastomer qualitatively but quantitatively. So that, we need to construct the model which has multi-DOF controllability of its compliance. In this paper basic concept of the proposed actuator are addressed. numerical model is also formulated and simulation results are shown for the verification of the proposed concept.

2. Multi-DOF Actuator Design

2.1. Design Actuator

Its generic assembly concept is illustrated in Fig. 1. The actuator is consist of eight dielectric elastomer sections, four sections on each side. Each film is mounted on a circular frame that works as a ground electrode. The eight mounted films are prestrained by sandwiching a pretensioning rod. It could be manufactured by simply partitioning the elastomer surface and applying the carbon coating process. Since each polymer section is to be packaged separately, each quadrant must be controlled independently. proper combination of individual motions of each section might provide continuous multi-DOF actuation.

Once the assembly is done, the rod positioned and remain at the strain force equilibrium of the eight pretensioned elastomer units unless electrical input applied. If the elastic force equilibrium is broken by any reasons, the rod will move either up & downward or rotation and stops at a new equilibrium position. For example, when sections d and h are actuated, the output terminal moves to positive direction. Fig. 2 shows a generic idea for creating translational motions. If sections c and f are turned on in nonsymmetric input pattern, the output terminal will be tilt with respect to positive axis. Then if the control action succeeds to provide electrical input to sections d and e, the terminal will rotate about positive y axis. The further continuous control action with proper adjustment of input voltage during the transition of the rotation axis enables to keep the terminal in smooth ro-
2. System and TATE EQUATIONS

All required constitutive relations are derived in the previous section, a system level model is constructed and a set of state equations of the system followed by example simulations is to be presented in this section. The proposed actuator is firstly modeled in a lumped manner as shown in Fig. 2. Design Concept of a Multi-DOF Polymer actuator.

In this figure the polymer block (pretensioner) move vertically and rotate about the axis which penetrate this paper. That is, the proposed actuator has planar motion with multi-DOF. But we can easily extended for a spatial motion actuator as assemble the proposed model into a orthogonal actuator.

Since no actual volume change of the elastomer is assumed, all required constitutive relations are derived in the previous section, a system level model is constructed and a set of state equations of the system followed by example simulations is to be presented in this section. The proposed actuator is firstly modeled in a lumped manner as shown in Fig. 2. Design Concept of a Multi-DOF Polymer actuator.

In the model $K_n$ represent mechanical stiffness or inverse of compliances, and $B_n$ are energy dissipation elements. Mass of the pretensioner which delivers transduced force of the actuator is represented by $m$. Identifying state variables of the system as is momentum of the mass, $x_n$ are displacement of the mechanical compliances, $q_n$ are electrical charges stored in each dielectric elastomer, and $z_n$ are thickness of the elastomer respectively, a set of nonlinear state equations can be derived as

$$\dot{x}_1 = S_f A, \quad \dot{x}_2 = S_f + A$$
$$\dot{x} = (S_f A), \quad \dot{x} = (S_f + A)$$
$$\dot{z}_1 = \alpha_1 (S_f A), \quad \dot{z}_2 = \alpha_2 (S_f + A)$$
$$\dot{q}_1 = \frac{1}{R_1} V \frac{z_1^2}{\varepsilon_o \varepsilon_r V_1} q_1, \quad \dot{q}_2 = \frac{1}{R_2} V \frac{z_2^2}{\varepsilon_o \varepsilon_r V_2} q_2$$
$$\dot{q} = \frac{1}{R} V \frac{z^2}{\varepsilon_o \varepsilon_r V} q, \quad \dot{q} = \frac{1}{R} V \frac{z^2}{\varepsilon_o \varepsilon_r V} q$$

where $A = \frac{\alpha_1}{2 \alpha_f + \frac{m}{2}}, \quad B = \frac{\alpha_1}{\varepsilon_o \varepsilon_r} z_1 + \frac{\alpha_2}{\varepsilon_o \varepsilon_r} z_2$, respectively. $V_o(t)$ are the electrical voltage inputs on each electrode of dielectric elastomers and $S_f$ represents velocity of the system boundary. The non-dimensional transformation moduli $\alpha_n$ are determined by

$$\alpha = \frac{1}{\nu} \sqrt{\frac{z}{V_o}}$$

Since no actual volume change of the elastomer is assumed, and Poisson’s ratio $\nu$ is 0.5. They are of course function of
the state variables. Electrical resistance of the elastomers is modeled as lumped serially connected resistances $R_n$. The derived state equations show that momentum of the mass $m$ can be completely controlled by the electrical input $V_n(t)$. Therefore so could the exerting thrust force by the actuator be.

![Fig. 4. Displacement for Half Square voltage Input](image)

![Fig. 5. Rotation for Half Square voltage Input](image)

### 2. Experiments

The proposed dielectric elastomer was based on M HB4 05 thickness of 500µm, volume of 150mm³. This material is coated with carbon powder for the electrodes. Numerical calculations that are performed using state equation SET and result are shown in Figs. 4 - 7. HB is driven by $V_1(t) = KV$ square and sign wave.

### Conclusion

A new soft actuator based on dielectric elastomer was proposed. The concept developed in the presented paper extends a basic operation of dielectric elastomer introduced in previous publications that remain merely at a level of simple material movement, and shows a controllable thrust force generation. It has a lot of advantages over the existing actuator, such as light in weight, simple, cost-effective, easy of manufacturing and expandable to multi-DOF actuation concept that few existing literatures addressed.

### References
