**Electro-mechanical model of something**

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**INTRODUCTION**

Electro-active polymers or EAPs are materials that change their shape and size when electrically stimulated. As both actuators and sensors they are considered attractive for various applications in e.g. biomedicine and robotics. Roughly EAPs can be divided into dielectric and ionic actuators. In this work the focus is on ionic EAPs. The state of art of EAP devices is reached the level of the first commercial outputs of EAP actuators, e.g. the ViviTouch tactile feedback system taking the gaming experience of mobile devices to the next level and Optotune’s electrically tuneable lens.

Although there are some commercial products of the EAPs, there is still much research to carry out. Whereas the bending motion of described actuators is easily attainable, it is rather complicated to estimate that bending motion and control the system precisely. Already some decent models have been developed to describe the tip displacement{{1085 Bhat,N.D. 2004}} or the blocking force for instance. In the models currently available, several assumptions are made which are more or less limiting the usability of the models.

One possible approach to model the behaviour of an EAP is using curvature and bending moments along an actuator. Anton *et al* added an elongation to an IPMC actuator and constructed a mechanical model. One important conclusion of their work was that the distribution of an EIBM (Electrically Induced Bending Moment) is not constant along the actuator i.e. the deflection of the actuator is growing faster near contacts and slower by moving away from contacts. The reason of this effect is the combination of high electrode resistance and high capacitance of the composite.

 Similar behaviour is occurring in carbon polymer composites (CPC) – a composite material made of polymer membrane, carbon electrodes and ionic liquid. Although the electrode conductance have been improved by laminating an extra layer of highly conductive metal (e.g. gold), several issues arise. First of all, it is complicated to obtain a highly durable bond between metal layer and carbon electrode. Secondly, the composite becomes unusable in applications where avoidance of metals is compulsory. Therefore, it is not possible to consider the radius of curvature as a constant and distributed model of curvature is essential for accurate estimations.

Punning et al introduced the correspondence between IPMC (ionic polymer metal composites) and a RC transmission lines. It appears that the voltage distribution along the IPMC actuator can be expressed similarly as RC lines. Although there was noticeable linear correlation between the charge and the curvature, it was validated in a short time frame, thus neglected the back-relaxation phenomena – first the actuator exhibits quick motion after which it slowly restores its initial state. Therefore it is important to consider back-relaxation for accurate modelling in a long time perspective.

In previous work the relaxation has been expressed by fitting tip displacement to multiple exponential decay terms{{1085 Bhat,N.D. 2004}}, modelling creep.

The objective of the work is to obtain the time-dependent correspondence between the transient input voltage and the shape of the actuator. Similarly to the model of Punning, we consider EIBM to be a linear function of distributed charge. Additionally, the back-relaxation phenomenon is modelled completing the model for long time actuations. Compared to most of the models developed so far, the distributed curvature analysis adds the possibility to estimate the shape of the actuator much more precisely.

**Model description**

The key component of the model is time dependent and coordinate dependent charge. This charge initiates internal stresses and results bending motion of the material. The model consists of two parts: an electrically induced quick bending that produces electrically induced bending moment (EIBM) followed by slow relaxation component in the opposite direction. The relaxation is described through back-relaxation bending moment (BRBM) – a bending moment opposite to EIBM that is increasing in time. For the sake of simplicity let us assume that the charge is producing EIBM linearly:

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where is the coefficient relating charge and moment.

The relaxation of the actuator can be also expressed in terms of charge with an additional exponential term (eq. 2). This equation is very similar to the Kelvin-Voigt model which has been used to model creep of polymers. The difference lies on the argument of exponent where linear time component is replaced by an integral of charge over time. Notice that from the time charge has reached its maximum value i.e. charge is constant in time, the presented integral is simply growing linearly in time as the argument of exponent in Kelvin-Voigt model. Similarly to Kelvin-Voigt model we have accommodated the parameter that denotes the rate of relaxation and is expressed by, where and are the modulus of elasticity and viscosity of the material correspondingly.

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Combining eq. 1 and 2, the total bending moment is given by:

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We have stated the relations between the charge and corresponding bending moments. Next, a well-known Euler-Bernoulli beam theory is applied to obtain curvature from bending moments.

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where is the bending stiffness, is the effective modulus of elasticity and is the second moment of area. In our case the cross-section of the beam is a rectangle, thus can be found from, where and are width and height of the cross-section of the beam respectively.

Denoting and substituting eq. 3 into eq. 4 we can now write the equation for curvature:

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where is the initial curvature of the actuator.

The curvature can be also presented in Cartesian coordinates as:

where and are the initial position of the curve and

where is initial angle at s=0.

**Experimental setup**

The actuation process of a carbon polymer composite (CPC) material was observed visually. The shape of the actuator was recorded by CCD camera (Pointgray) at 10 frames per second. Grabbed video was filtered after which the vector representation of the actuator was obtained. The length of each vector was 2.6 mm. All tasks from controlling the voltage between the electrodes up to the post processing of the curvature changes were carried out with NI LabView software with Matlab engine for numerical model evaluations. The four input parameters of the distributed RC model were determined using the differential evolution (DE) optimisation algorithm minimising the differences between the measured and the modelled voltage between electrodes along the actuator. DE algorithm is genetic type algorithm that combines and rearranges parameter vectors. The algorithm is converging fast and is effective for solving problems with multiple local minimums as this particular task is. The value of was determined from eq. 1 by assuming the back-relaxation component to be zero near the beginning of the actuation. The second parameter can derived from eq. 5:

It is obvious that at the beginning of actuation the relative error of is large thus has a major impact to Therefore was determined by averaging the values in between The parameters for distributed voltage optimised parameters for charge calculation along with the determined parameters and are depicted in the table 1.

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| --- | --- |
| Parameter | Value |
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|  |  |
|  |  |
| a | 2.0 |
|  | 1/0.3 |

Table 1. Measured parameters for CPC actuator.

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**Results**

The simulated points are clearly following the actual shape of the actuator. The shape of the actuator

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| Fig. 1 Measured and modelled shapes of the actuator at 2.5V. | Fig. 2. Measured and modelled shapes of the actuator at 2.5V |

**Conclusion and discussion**

**Acknowledgments**

References

[1] Chenying Yang, Wei Wang and Zhihong Li, "Optimization of corona-triggered PDMS-PDMS bonding method," in *Nano/Micro Engineered and Molecular Systems, 2009. NEMS 2009. 4th IEEE International Conference on,* 2009, pp. 319-322.