**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. 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 describe the parameters such as the tip displacement or the blocking force.

One possible approach to model the behaviour of an EAP is through the curvature and bending moments.

Anton *et al* added an elongation to an IPMC actuator and constructed a mechanical model. One important conclusion of their experiment was that the distribution of an EIBM (Electrically Induced Bending Moment) is not constant along the length of the actuator i.e. the deflection of the actuator is larger near contacts and decreasing by moving away from contacts.

Punning et al introduced the correspondence between IPMC actuators 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.

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 charge along the actuator. 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. EIBM and therefore curvature along the actuator have been minimise the variation of EIBM is by reducing the surface resistance of the electrodesThis approach is especially useful for actuators with large electrode resistance and large capacitance such as carbon polymer composites.

**Back-relaxation.**

It is a widely reported fact that IPMC exhibits back-relaxation i.e. a slow large relaxation towards cathode after quick bending towards anode.

The major difference in actuation due to the size of the cations has been also denoted by Bar Cohen. (Two time constants.)

This paper is concerned with description of bending behaviour of ionic EAPs by means of electrically induced bending moment as a function of time and coordinate along the actuator.







**Model description**

The key component of the model is time and coordinate dependent voltage U(s,t). This voltage is creating moments along the actuator which are the cause of bending motion. The model consists of two parts: an electrically induced quick bending that produces electrically induced bending moment (EIBM) followed by slow relaxation in 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:

where is the coefficient relating charge and moment.

The relaxation of the actuator can be also expressed in terms of time and coordinate dependent charge with an additional exponential term. This equation is very similar to the Kelvin-Voigt model which is often used to model creep of polymers. The difference lies on the parameter of the exponent which is replaced by an integral of charge. Notice that from the time the charge has reached its maximum value i.e. the charge is constant in time, the presented integral term is simply growing linearly in time as in Kelvin-Voigt model. In figure X.Y it is shown that in case t>600 the charge is nearly constant and relaxation component can be fitted with an exponent in the meaning of high accuracy.

We have stated the relations between input voltage and corresponding bending moments. A famous Euler-Bernoulli beam theory is applied to describe the linkage from moment to curvature:

where is the bending stiffness, is the effective young modulus and is the second moment of area. In our case the cross-section of the beam is a rectangle, thus is represented as:

and are width and height of the cross-section of the beam respectively.

Substituting the Euler-Bernoulli theory into Z results the equation for curvature:

where is the initial curvature of the actuator.

After a few simplifications, the final solution for curvature is obtained.

The following equation holds to transform the curvature into Cartesian coordinates:

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 3.75 frames per second. Grabbed video was filtered after which the vector representation of the actuator was obtained. 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 scripts for numerical model evaluations. The four input parameters of the model were determined using the differential evolution optimisation algorithm minimising the differences between the measured and the modelled voltage. The optimised parameters are depicted in the table 1.

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| --- | --- |
| Parameter | Value |
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Table 1. Measured parameters for CPC actuator.

The value of k/EI was set by assuming back-relaxation component to be zero near the beginning of the actuation. The a/EI was obtained by dividing the back-relaxation component by U(s,t) and fitting to exponential function.

**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.

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Load function by gravity:

Shear force:

Moment:

Euler-Bernoulli’s law:

where is the bending stiffness, is the effective young modulus and is the second moment of area. If the cross-section of the beam is a rectangle, is represented as:

and are width and height of the cross-section of the beam respectively.

Angle-curvature relationship:

Relationship between the angles along the actuator and the corresponding point in (x,y) plane: