**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 which takes 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. Therefore, different models have been developed to 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 moment of force. The objective of the work is to obtain the time-dependent correspondence between the transient input voltage and the shape of the device. 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.

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. The

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 confirmed in a short time frame, thus neglected the back-relaxation phenomena.

Similarly to the … we consider EIBM to be a linear function of voltage between the electrodes.

**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 voltage between electrodes is producing EIBM linearly:

where is the coefficient relating voltage and moment.

The relaxation of the actuator can be also expressed in terms of time and coordinate dependent voltage with an extra exponential term which is often used to model creep of materials and is known as Kelvin-Voigt model.

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

Applying the Euler-Bernoulli theory into the model 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 x-y plane:

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 steps from controlling the voltage between the electrodes up to post processing of the curvature changes were carried out with NI LabView software. The four input parameters of the model were measured using the technique that is described by Punning *et al* {{1082 Punning,A. 2008}}. The 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: