Reliability measurements of Ionic EAP Materials

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***Abstract*—The research is focused on lifetime and electromechanical conversion of IEAP in different hazardous environments like gamma, X-ray and UV radiation, temperature cycling, and just aging issues. Large scale effort was taken to test different materials developed in several labs. The overview of the methodic and equipment is given.**

1. Introduction

A major goal in soft polymeric electromechanical actuator research is to develop a device of low energy consumption that operates rapidly with high displacement or high force at low voltage applied. The current technologies based on electromechanical and pneumatic actuators make application product often too noisy, heavy and too complicated. For that reason a notable demand exists for soft, simple and miniature actuation devices in many technological solutions. The ionic electroactive polymer (iEAP) actuators are good candidates for this purpose. Nevertheless, the reliability (or perceived lack thereof) of the iEAP devices, rather than the actual performance, is limiting their acceptance in critical applications, e.g. medicine or space crafts.

2. Survival Test

The mission of this project was testing reliability of the iEAP actuators subjected to different harsh environments: X-ray, UV and Gamma radiations, as well as low atmospheric pressure and very low temperatures. The survival tests were carried out with 7 different types of iEAP including the aqueous IPMC [1], conductive polymer actuators [2,3], bucky gel [4] as well as carbon-polymer composite (CPC) actuators [5]. The total number of samples was 50-70 pieces of each. The samples were divided into separate portions for the different environmental afflictions, 7-10 pieces of each. The measurements of reliability included the following steps:

1. Testing the initial performance of each particular sample;
2. In 60 days the performance of each particular sample was tested again. This step allows determining the rate of the spontaneous self-degradation of the materials.
3. All separate sets of samples were subjected to their pre-assigned hazardous environments;
4. In 60 days from the Step 2 the lifetime of the samples under continuous loading was determined.

The lifetime measurements were carried out using identical methodology upon the different iEAP types. Here arises the second goal of the project - comparing the different iEAP materials with similar methodic – similar dimensions, driving voltage signals, timing, ambient environment, etc..

3. Lifetime Test

The long-lasting experiments demonstrated that, in general, the performance of the iEAP actuators decreases. The decrease rate depends on a variety of processes, some of them are probably unknown yet. A few examples are spontaneous self-degradation, number of performed working cycles, applied load, just the time passed, etc. Testing the lifetime of IEAP actuators was carried out by measuring their electrical and electromechanical impedances under continuous load, until their performance decreased under a defined level. As the initial performances of different materials, and even of the separate samples, differed up to several times, we used the relative "end-of-life" criterion – a fraction (e.g. 10%) of the initial performance of each particular sample. As the lifetime of the actuators is reported being up to 10^5 ... 10^7 bending periods, the lifetime test may take very long – up to several months. Nevertheless, it is unnecessary to measure just each cycle. It is enough to test each sample after a while of working. Therefore between performance tests, the samples passed the training cycles – exciting separately to perform a defined number (e.g. 100...1000) actuations.

4. Large Scale Test Equipment

Today, most of the iEAP materials are prepared manually. Even when the manufacturing process is developed until being perfect, the parameters of the samples manufactured manually, are divergent. In order to obtain trustworthy results, the number of samples involved in the tests of reliability should be as large as possible. This requirement, in turn, increases the total number of the tested samples drastically.

Performing the testing procedure manually is a tough and precise work for the operator. Therefore we designed an authentic equipment to perform this process upon many actuators automatically. This setup excludes the human errors and guarantees that all samples are tested in exactly similar conditions.

4.1 Prerequisites

The large scale test equipment was designed according the following requirements:

1. The equipment should enable tediously protracted testing of many actuators.
2. The equipment should enable effortless switching between testing cycles and training cycles.
3. The samples are measured in cantilever mode – fixed end attached to contacts. In order to minimize the bending moment produced by the own weight of the actuators, the samples under testing are positioned horizontally and edgewise. However, in order to minimize the creep of the actuators, caused by their own weight, the samples under training, are hanging vertically.
4. The equipment should enable testing the “wet” type of actuators by soaking them in their appropriate solvent from time to time. The samples are taken out from the solvent only for testing, while the continuous load is carried out in a wet environment.
5. The round of testing should not exceed a few minutes, covering all required frequencies. This requirement is grounded to avoiding drying of the “wet” iEAP materials.

4.2. Mechanical Design

The testbench is presented in Fig. 1. It is a circular conveyor standing of 4 floors. Each floor can hold up to 60 actuators of similar type, so the whole bench can hold up to 240 samples of up to four different types. Actually, the “similar type” stands for similar driving voltages and measured currents only. Concurrently, two samples of one floor are under testing, - one of them is in the cameras field of view; the other, located at the opposite side of the circular floor, acts upon the force sensor. The remaining 58 samples are under training.

The mechanics of the conveyor is explained in Figure 2. It consists of 4 circular platforms sharing the same axis, one motorized linear actuator and one motorized rotational stage.

The Thorlabs TravelMax Stage LNR50VK1/M and Thorlabs CR1/M-Z7E were used respectively. These two motorized control devices can lift the circular turntable up and down within 5 cm, as well as rotate infinitely around the vertical axis. The iEAP samples are attached to the convertible clamps, hanging around the turntable.

As all 4 floors act synchronously. Concurrently 4 samples are measured by the cameras (one for each floor); and 4 samples are measured with the force sensors (one for each floor). After performing the measurement cycle, the circular conveyor turns 6 degrees, sets the 8 just tested samples for training, and positions the new 8 samples for testing.

Only the samples under testing are positioned horizontally while all remaining samples under training are hanging vertically. The process of turning the samples between the two positions is explained in Fig. 3. Initially the sample is hanging vertically, possibly in a container of solvent, while the turntable squeezes the electrical terminals of the clamp against the properly positioned electric contacts (Fig. 3-A). In order to align the sample horizontally, the turntable with all clamps lifts up and turns, positioning the particular clamp over a tubular support, named “lower support”. The lowering turntable forces turns the clamp up (Fig. 3-B), until the electrical terminals are squeezed against the appropriate spring contacts (Fig. 3-C). After that, the sample is ready for testing - in the cameras field of view or pushed against a force sensor. The state of the remaining 58 samples is as in Fig. 3-A. Aligning the sample back vertically is performed by lifting the turntable up, and pushing the clamp against the upper tubular support. Next, the turntable is rotated by 6 degrees, while lifting it down arranges the just measured sample in the alignment depicted in Fig. 3-A, and sets the next one under measurement (Fig. 3-C). This mechanism allows switching between two alignments synchronously 8 samples – two on each of the four floors. This way, rotation of the turntable enables measurement of all samples, one after another.

4.3. Acquired Data

The response of iEAP’s might be highly nonlinear, therefore the wide spectrum signals, e.g. sweep, white noise, chirp, etc. are strongly unobjectionable. Instead, a gradual sweep was used as the exciting signal is. It consists of series sequence of sine signals of different frequencies. Each frequency lasts

3 half periods. The delay between the sequences is at least 0.5 half periods of the previous frequency while the initial phases are opposite. The 9 frequencies were: 10, 5, 2.5, 1.25, 0.64, 0.32, 0.16, 0.08 and 0.04 Hz. In this order the amplitude of bending grows and the influence of the residual shape is minimal. As the goal of this project was testing the endurance of the samples to harsh environments, rather than trying to demonstrate their ability to perform millions of working cycles, the amplitude of the applied voltage was chosen close to the uppermost allowed for each particular type.

The recorded electrical signals involved the input voltage and the input electric current, measured as a voltage drop over a shunt resistor of a properly chosen value.

The recorded mechanical outputs were the output of the force gauge and the information of bending. However, measurement of force with a force gauge is a complicated operation even by manual positioning, especially in the case of actuators suffering from creep. Therefore the most reliable parameter describing performance of iEAP actuators is the visual information of bending. Therefore the behavior of the actuators was recorded by a camera, particularly the monochrome USB camera DMK 22BUC03 equipped with a lens of long focal length. The 640x480 pixel images were converted to vector interpretation using the National Instruments LabView image processing package.

The vector interpretation of the shape of the actuator expresses its bending with respect to the distance from the input contacts along the sample [6]. The curved line representing the shape of the actuator is divided into vectors of equal lengths as depicted in Fig. 4-A, assuming that within every vector the curvature is constant. The shape of the actuator is characterized by a number of angles *a1*, *a2*, ... *aN*. Each next angle along the length of the actuator is relative to the previous one, while the angle of the first column may be arbitrary. Since the segments are independent, it is possible to interpolate the resulting array of data along the coordinate to recover the continuous curve of the actuator.

A convenient quantitative parameter to evaluate the performance of an actuator is the angle between the tpi tangents in the case of maximal bending displacements to the opposite directions. It describes pretty nice the behavior of an actuator of given length. As depicted in Fig. 4-B, the parameter β will not fail even in the case of considerable creep of the sample.

4.4. Reducing the Amount of Data.

An experiment, set up like described hereinabove, generates a huge amount of data, when acquiring data with the sampling rate, appropriate for the highest frequency. The required disk space, especially for saving the video information, can easily grow to terabytes. In order to reduce the amount of data and to fit to the bandwidth of an ordinary PC, especially by means of USB cameras, a specialized hardware signal generators were exploited. The schematics of the measurements is depicted in Fig. 5.

The specialized generator, realized using an Atmel microprocessor, generates the AC signal for driving the actuators, and the synchronizing signals for the hardware triggered camera and for the DAQ device. This setup allows measurements synchronized with the input signal with the minimal sampling rate for each particular frequency. This way the number of frames taken by the camera and the number of DAQ samples in two minutes of measurement were reduced to 170 and 700 respectively.

Nevertheless the file size of the video was approximately 50 MB. For further reducing the amount of saved data, the videos were converted to the vector representation "on the fly", while saving the video itself was obsolete. Like that, the amount of data describing a single measurement was reduced to a few tens of kilobytes only.

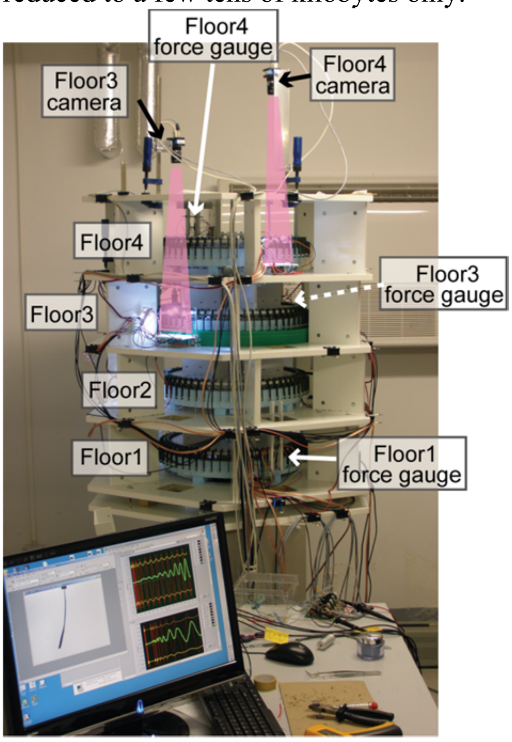

Fig. 1. The large scale testbench.

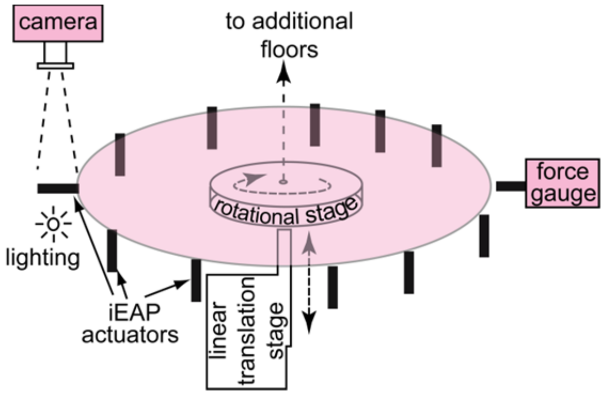

Fig. 2. Mechanics of the conveyor. For clarity only one floor with only a few iEAP samples are depicted.

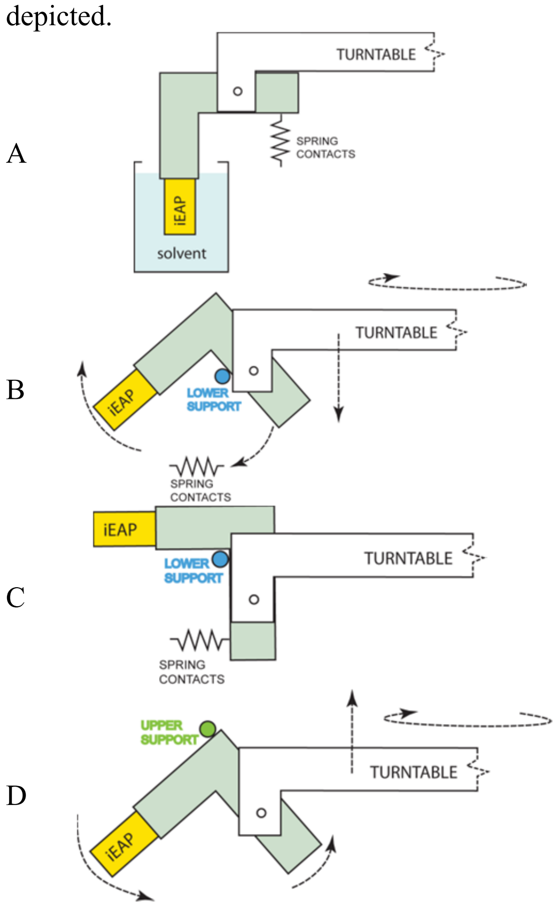

Fig. 3. Repositioning the samples between vertical and horizontal alignments.

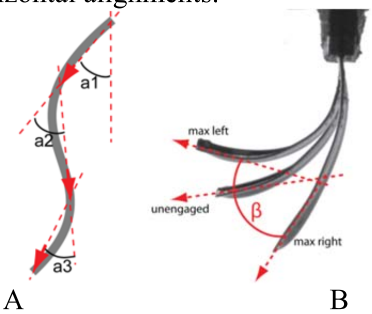

Fig. 4. A - Vector representation of an actuator;
B – Performance of an actuator.

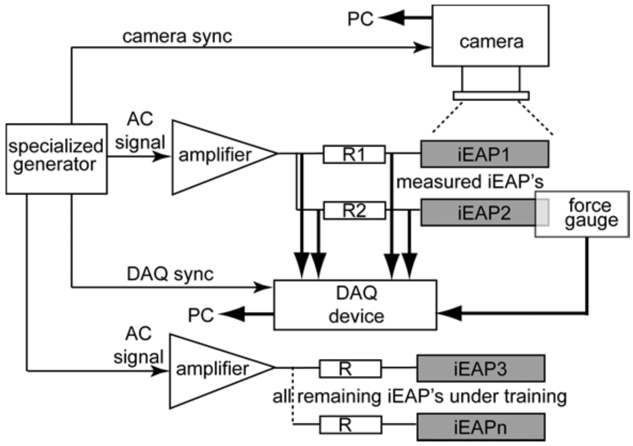

Fig. 5. Schematics of measurements of a single floor.

Acknowledgments

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