Short Communication

Energy Harvesting System Based on Ionic Polymer-Metal Composites – Identification of Electrical Parameters

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Received: 20 June 2013
Accepted: 24 October 2014

Abstract

This paper presents the results of preliminary studies concerning the creation of a precise mathematical description of the ionic polymer-metal composite (IPMC) element that works in an electrical circuit. Such a model could simplify the design and accelerate the prototyping of a new generation of actuators, sensors, and energy harvesters. Energy harvested by the IPMC can be used to power everyday use electronic devices. Energy harvesting utilizing smart materials can be a breakthrough in energy-savings, thus it can provide some additional environmental protection. Series and parallel connections of two IPMC samples are researched in order to check the influence the samples have on each other.

Keywords: ionic polymer-metal composites, energy harvesting, smart materials

Introduction

The ionic polymer-metal composites (IPMC) are a promising class of ionic electroactive polymers. They can be utilized as sensors, actuators, or energy harvesters. They consist of two metal electrodes and an ion-conducting polymer between them. Low actuation voltages (max. 5V) cause the material (formed as a cantilever beam) to bend with large strains [1] – the tip displacement often equals the length of the sample. The presence of a polar solvent (e.g. water) is necessary for the work of the IPMC. The molecules create ionic clusters with cations that can change their position inside the membrane. This causes a local increase of density, and bends the sample toward the negative electrode. The presence of the solvent makes it possible for the material to operate (with some considerations) underwater [2]. Using different solvents changes the behavior of the material substantially [3]. Applications range from entertainment to military and aerospace industries [4]. The IPMC are also promising in the field of sensing and energy harvesting [5, 6]. Energy harvesting utilizing smart materials can be a breakthrough in energy-savings, thus it can provide some additional environmental protection. Such materials enable the creation of portable systems that can scavenge energy from the environment, e.g. from human movement. In the case of the IPMC, the values of generated power are low, but a network of interconnected microgenerators would be capable of powering an electronic device. Calculations say, that 7W of power can be generated from human walking. This energy is normally wasted on deformation of clothing and soles of the shoes. On the other hand, an everyday use electronic device such as mobile phone or mp3 player uses approx. 1W of power [7, 8]. An effective use of even a few percent of this energy would render stationary battery chargers useless. Using the devices would become much more comfortable and the load on the power grid would decrease. The creation of a distributed network of power generators would allow

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resigning from some parts of outdated power plants. Energy produced by the IPMC is clean and renewable. It also promotes a healthy lifestyle in the same time. The materials are lightweight and elastic, making them ideal to implement in clothing or shoes.

The aim of this preliminary research is to test the electrical properties of the IPMC. Every element that works in an electrical system should be accurately modelled and described to prevent any unexpected problems during the work. The researched smart materials are particularly problematic in modelling due to being non-linear and non-stationary.

Electrical Model of the IPMC

An equivalent circuit of the IPMC is a commonly-acceptable model of these materials. Its simplest form is presented in Fig. 1a.

According to the model presented by Farinholt [9], the capacitance of the IPMC is given by the equation:

$$C = \kappa_e WL/2h \tag{1}$$

...where: W, L, h – dimensions of the sample (width, length, thickness), κ_e – dielectric permittivity [F/m]. Equation (1) is consistent with parallel-plate model of a capacitor. Resistor R1 is responsible for the current that flows through the element in a steady (fully charged) state. The R2 resistor lowers the maximum value of current during charging of the C1 capacitor.

Experimental Results

The IPMC samples were tested using signal generation and data acquisition based on a PC with LabView software. A current generated by analog output card (NI9263) was

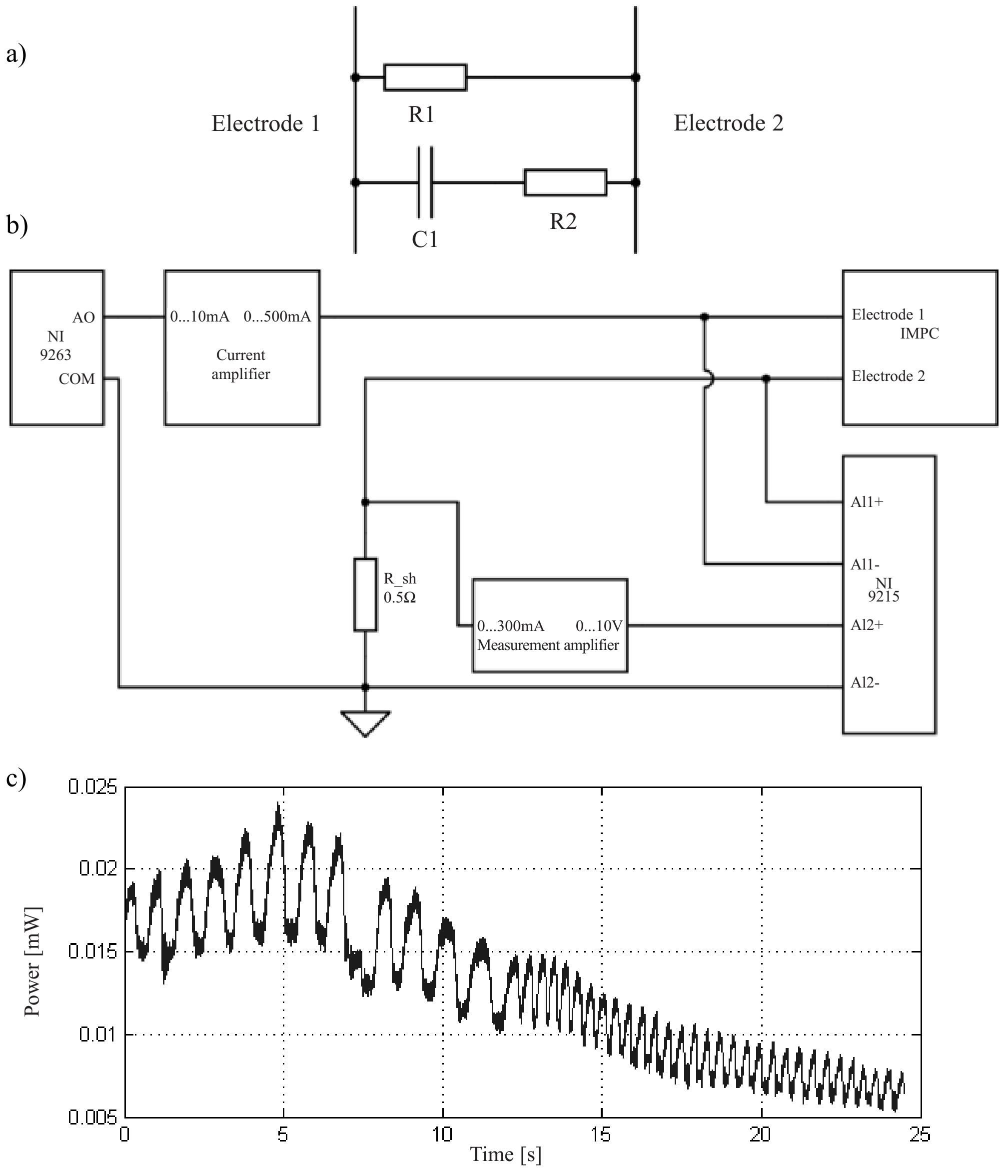

Fig. 1. IPMC modelling: a) equivalent electrical circuit of the IPMC, b) signal generation and data acquisition circuitry, c) time-domain signal from data acquisition card (IPMC power generation capabilities).

amplified by an op-amp regulated push-pull amplifier and supplied to the actuator. A voltage drop across the IPMC was measured. Simultaneous measurement was taken of the current flowing through the IPMC. A non-inverting operational amplifier was used to measure the voltage drop across a 0.5Ω shunt resistor. The measurements were acquired with NI9215 analog input card. Based on this value, the current was calculated online in LabView software. Block diagram of the testing station is shown in Fig. 1b.

Two samples of Flemion™-based IPMC samples were researched. The samples were cut in the shape of a rectangular beam: sample A: 18×10×0.2 mm, sample B: 50×10×0.2 mm. The researched samples were obtained from Environmental Robots Inc. [10] The provided samples were manufactured separately, thus their properties may differ.

The experimental results were based on the analysis of time responses of the current and voltage drop across the IPMC.

Internal Resistance of the IPMC

According to an equivalent electrical circuit model [11], the IPMC element consists of equivalent capacitance C and two equivalent resistances. While charging, the initial current of the capacitor relies only on the values of its internal resistance. The initial current vs. voltage plot for the IPMC samples is presented in Fig. 2. Samples were tested separately and with a series or parallel connection.

The relations were fitted with linear function. The slope of the fitted lines gives the conductances of the samples; based on this, the resistance values are calculated. This value corresponds to the series resistor R1 from the IPMC equivalent circuit. Numerical values of the resistances are, for sample A: 44.5Ω, B: 21.02Ω; both samples in series: 119.46Ω; both samples in parallel: 16.09Ω.

Internal Resistance of the IPMC in a Steady State

According to the electrical circuit model of the IPMC, the existence of parallel resistance causes current to flow through the element when the capacitor is fully charged. This proved to be true through the experiments – the values of steady state current and calculated resistance are presented in Fig. 2.

The calculated resistances for cooperating samples are not consistent with the laws of calculating equivalent resistances in parallel and series connections of resistors. Based on the numerical values, the relative error for parallel connection is 11.3% and for series 45%. This shows that some unknown phenomena may occur during simultaneous work

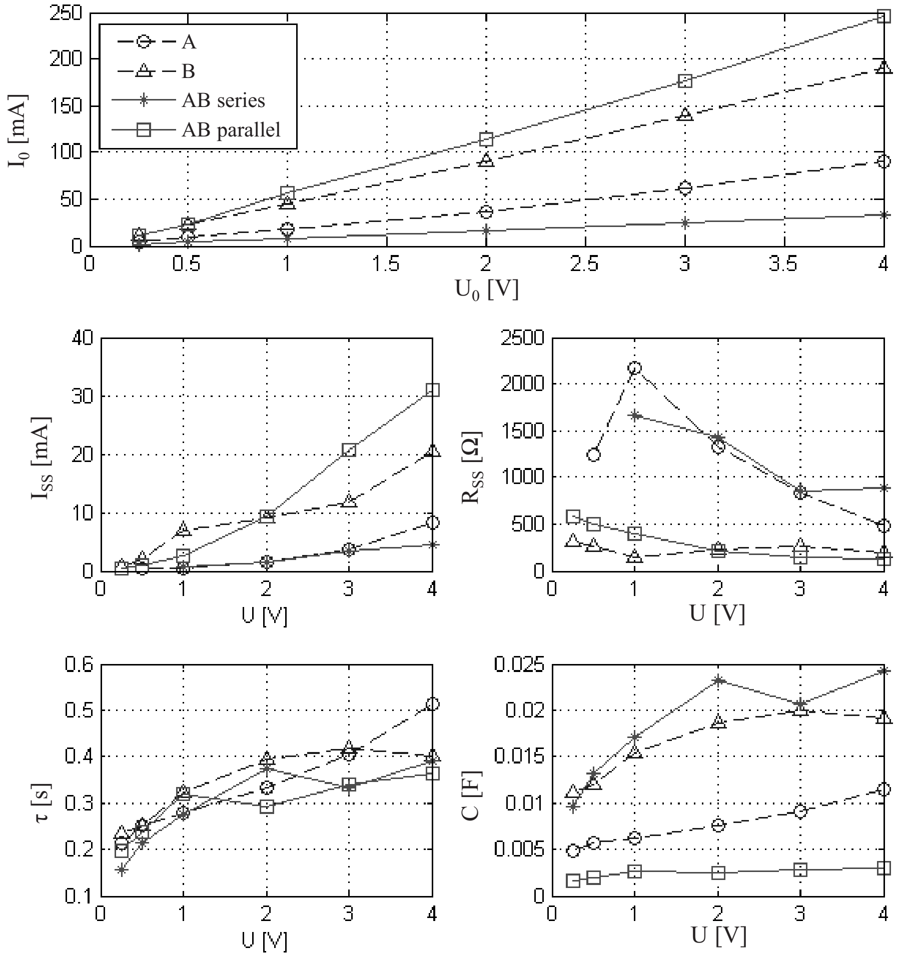

Fig. 2. Relationships between actuation voltage U and: I_0 – maximum charging current, I_{SS} – steady state current, R_{SS} – steady state resistance, τ_S – time constant, C – capacity.

of more than one IPMC sample. For the steady-state situation, these relationships are even more distorted.

The Time Constant of Charging the IPMC

The time constant of an *RC* circuit is a time that describes the rate of charging and discharging a capacitor. The charging current is governed by an ordinary differential equation:

$$RC\frac{\mathrm{d}I(t)}{\mathrm{d}t} + I(t) = 0 \tag{2}$$

After integration:

$$\ln\frac{I(t)}{I} = -\frac{1}{RC}t \tag{3}$$

Finally, the time constant $\tau=RC$ is calculated by equation (4):

$$\tau = -\frac{\Delta t}{\ln\frac{I(t_0)}{I(t_0+\Delta t)}} \tag{4}$$

...where t_0 – starting time of charging, Δt – time difference between consecutive measurements. In an ideal capacitor, τ is independent of any parameters. In the case of the IPMC samples, the time constant depends on voltage and time. Fig. 2 shows the relationship between actuation voltage and time constant of the sample.

Capacitance of the Samples

Capacitance of the samples is calculated from the time constant and internal resistance for the dynamic work. Values calculated with parallel-plate model of the capacitance are much smaller (in the order of μF), but the values calculated from experimental values are consistent with the behaviour of the sample.

Energy Harvesting Capabilities

During the research considering the electrical model of the IPMC, energy harvesting capabilities also were tested. (Fig. 1c) shows the amount of power generated by the IPMC (sample B) in response to 30 mm tip displacement. The first part of the plot shows external oscillatory deformation and the second is a resonant oscillation of the beam itself. Peak power value was 0.024 mW. During the 25 s time of the test, 0.31 mJ of energy was generated.

Conclusions

This paper presents the results of preliminary studies concerning the creation of a precise mathematical description of the Ionic Polymer-Metal Composite element. Such a model could simplify the design and prototyping of new generation of actuators, sensors, and energy harvesters. Experimental results have proven, that most parameters of the IPMC are non-linear and change during actuation. The elements of the equivalent circuit can be identified, but not for every situation. The most interesting phenomena occurs when two samples of the IPMC interact – a simplified electrical model of the element is insufficient, because the calculated capacitances and resistance do not follow the laws of calculating their equivalent values for parallel and serial connections. Research concerning the energy harvesting possibilities is connected with the Self-Excited Acoustical System. The operation of this measurement system is based on generating vibrations. The energy of these vibrations is normally lost, but thanks to the IPMC energy harvesters, some of it could be reclaimed and used to power the electronic systems controlling the measurement.

Further research will focus on investigating the relationship between the electrical parameters and time, creating a mechanoelectrical model, and studying the simultaneous work of multiple IPMC samples.

The energy harvesting capabilities of the single sample were tested. Successful further research would enable the production of commercially available energy harvesters based on the simultaneous work of multiple IPMC elements. The availability of such devices could render the stationary battery chargers useless and decrease the power demand from the electrical grid. The energy provided by the IPMC-based chargers is clean and renewable because it is harvested directly from human movement.

Acknowledgements

Our research was supported by the Polish government as part of research program No. N N501 208140 conducted in 2011-14.

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