IONIC POLYMER-METAL COMPOSITES USED AS A FORCE SENSOR

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Abstract. *It is well known that Electroactive Polymers present attractive characteristics that make it a potential material to be used for product-integrated actuators and sensors. In general Ionic Polymer-Metal Composites can be described as a polymer membrane (electrolyte) with electrodes on both sides. When a potential difference is applied between the electrodes there is a redistribution of the cations and water inside the IPMC. This movement generates different gradients of pressure inside the IPMC, hence the volume of the clusters within the cathode and anode boundary layers changes and stimulates a bending movement to the IPMC. Using the inverse concept, the shape changes can generate a difference of voltage between the electrodes in an IPMC. Based on this principle it is possible to use the IPMC as force and position sensor. This paper presents tests and the results of the use of an IPMC as a punctual force sensor as a one-dimensional.*

1.INTRODUCTION

IPMC are a class of intelligent materials, that present an electrical performance similar to the muscle (Bar-Cohen et al., 1998; Bar-Cohen, 2004). According to Bar-Cohen, (2004) IPMC present many advantages in comparison with other alternative actuators such as EAC and SMA (Bar-Cohen et al., 1997) as can be seen in table 1.

Table1 – Comparison of the properties of EAP, SMA and EAC (Bar-Cohen et al., 1997)

Property	**Electroactive polymers (EAP)**	**Electroactive Ceramics (EAC)**	**Shape memory alloys (SMA)**
Actuation strain	>10%	0.1 - 0.3 %	<8%*
Force (MPa)	0.1 - 3	30-40	about 700
Reaction speed	msec to sec	msec to sec	sec to min
Density	1- 2.5 g/cc	6-8 g/cc	5 - 6 g/cc
Drive voltage	1 - 7V / 10-100V/μm	50 - 800 V	NA
Consumed Power	m-watts	watts	Watts
Fracture toughness	resilient, elastic	fragile	Elastic

Generally, the IPMC can be described as a perfluorinated íon exchange membrane, NAFION® (DuPont), FLEMION® (ACG – Asahi Glass) or ACIPLEX® (Asahi Chemical Industry), with a metal electrodes. With an electrical tension applied to these electrodes the IPMC bends. When a voltage is applied between its electrodes it instigates the cations and water to move to one side. This makes one side to swell and the other shrink generating the movement.

Besides the eletro-mechanical characteristics, the IPMC are malleable, biocompatible and can be fabricated in different sizes and shapes. These characteristics instigate researches to continue investigating the IPMC' use as biomimetic sensors (Kim and Shahinpoor, 2002).

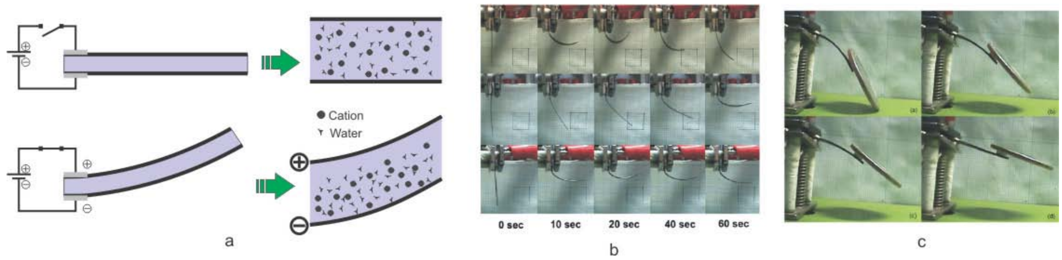

Figure 1- (a) The mechanisms of IPMC as a actuator (Shen and Dai, 2007). (b)-The IPMC as an actuator (Nguyen et al., 2007). (c) – The IPMC as an actuator loading a coin(Nguyen and Yoo, 2007)

According to David J. Griffiths (2008) from 1992 to 1997 almost 400 papers about IPMC were published, but only 31 were related with sensors. The use of IPMC as a sensor was more significant after 1999 (Ferrara et al., 1999; David J.Griffiths, 2008; Keshavarzi et al., 1999; Paola et al., 2008). The studies about the IPMC as biomimetic sensors are growing, but there are many gaps that need to be filled. This paper presents some results with IPMC as pressure sensors to clarify its behaviour and a comparison between these results and other in literature.

2.METHODOLOGY

IPMC are composed by perfluorinated íon exchange membrane, on which a platinum metal is deposited (Bar-Cohen, 2004). The IPMC used in this work were made from the NAFION-117 (DuPont) membrane, with one layer of platinum. The method used to aggregate metal to the membrane surface was the metal reduction method, and it is described in Pack et al (Pak et al., 2001) and in Kim and Shahinpoor (Paquette et al., 2003). 5 IPMC with 36 mm x 5 mm x 0.7 mm were produced. The IPMC were placed in a solution of 1,5N of NaCl for ion exchange. It is well know that the IPMC' properties change with the water losses, (Bar-Cohen, 2004). To avoid these changes a coating was developed for the IPMC, this coat must keep its moistness.

A transparent adhesive tape was used to seal the IPMC. In the base of the adhesive tape a small cut was made to insert an aluminium electrode. This electrode was used to capture the IPMC response to the applied forces as can be seen in Figure 1.

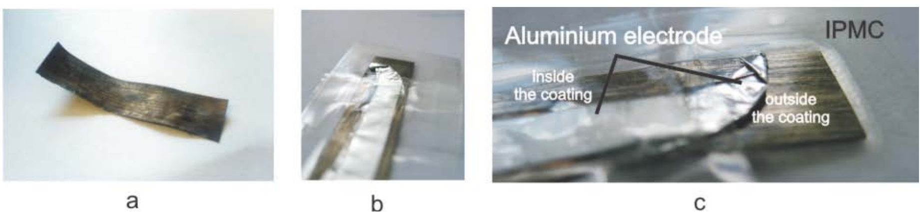

Figure 2 – (a) – IPMC without coating. (b) – IPMC with coating. (c) – IPMC, the aluminium electrode.

In the most part of the tests, the aluminium electrodes were in contact with the platinum electrodes, covering all the IPMC, to maximize the measured signal. This is necessary because the platinum electrode presents a high electrical resistance, and according to many models of sensors and actuators this resistance affects the IPMC behaviour.

To test its properties to a punctual force, a small workbench was developed (Figure 2). This workbench presents a motor and a cam to generate an oscillatory movement. This movement is transmitted to spring system with a tip of 13,30 mm^2 with which the IPMC is compressed over a Load Cell.

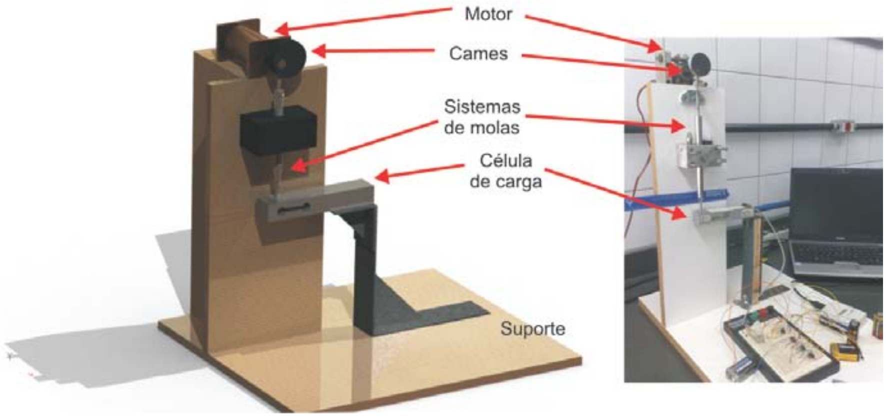

Figure 3 – Workbench for the IPMC force tests.

The IPMC and Load Cell responses were captured using USB-6008 from National Instruments. An electrical circuit was built to filter and to amplify the signal as can be seen in Figure 4.

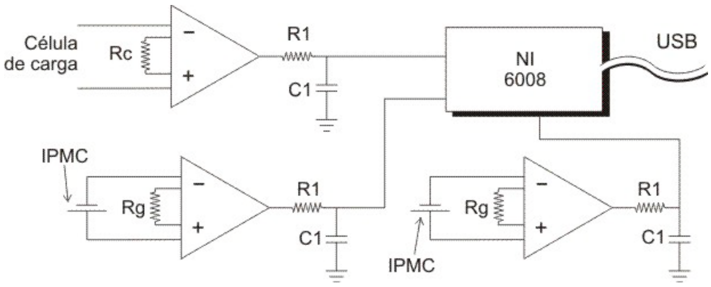

Figure 4 – Electrical circuit to capture the IPMC and Load cell values.

The main curves of Force x IPMC tension for different configurations were plotted and analysed.

3.RESULTS

The first test was developed with the IPMC without coating or an aluminium electrode, to evaluate its response to water losses. Figure 4 presents the tension measured on the IPMC during a cyclical bending movement. It is possible to see that there are changes in the amplitude of the signal and in the mean value of the signal. This proves that it is necessary to cover the IPMC for a better use as a sensor. Keeping the moistness of the IPMC.

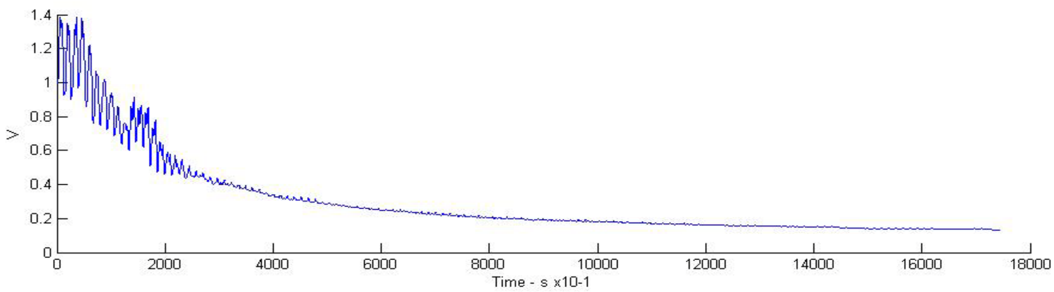

Figure 5 – Decay of an IPMC used without a coating layer.

The adhesive tape was used to seal the IPMC, as described, and its behaviour during a cyclical force was measured (Figure 5).

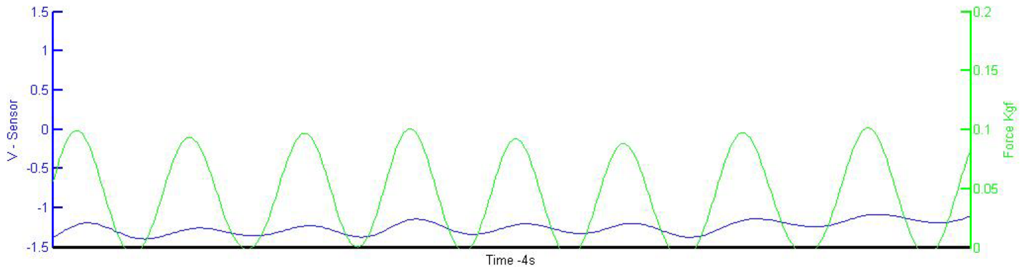

Figure 6 – First test as a force sensor. No aluminium electrode.

It is possible to notice that the IPMC' signal response to the force applied to it apparently follows a linear relation, but it responds with a small amplitude. To solve this problem the IPMC was tested with an aluminium electrode over its entire platinum electrode. Figure 7 presents the response of this IPMC to a cyclical force.

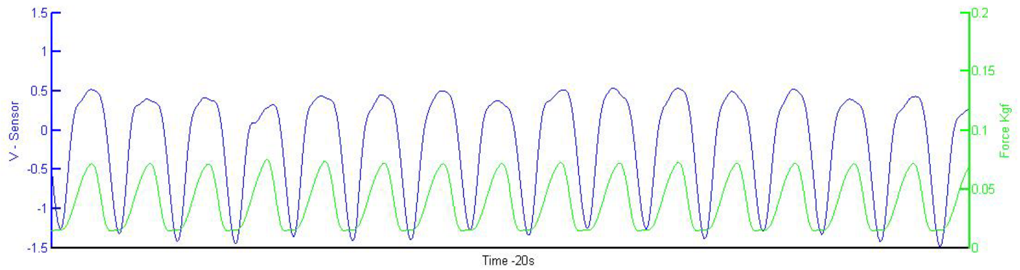

Figure 7 – IPMC voltage with an aluminium electrode.

It is possible to see that the signal measured in this IPMC is over 3 times the signal measured in the IPMC without the aluminium electrode, and the force to generate this signal is about half the force applied in the first test as a force sensor.

It is possible to see that the electrode resistance affects directly the IPMC response, this means that it is necessary a better metal adhesion on the NAFION core for the development of more precise sensors.

Using Figure 6 and 7 it is possible to notice that the IPMC presents a linear relation with the applied force at the frequency less than 1 Hz. This is also noticed by Keshavarzi et al (1999), which measured the maximal force applied to IPMC simulating a blood pressure as a rhythm force applied to the IPMC, with a maximal force of a 50g. But to confirm that the IPMC presents linearity with the force is necessary to perform more tests at different frequencies once the conductivity of the IPMC is based on ion diffusion.

Figure 8 shows the IPMC response to a force applied with a higher frequency higher than 1 Hz. It is possible to notice that the IPMC signal does not present a linear relation with the force. There appears to be a delay between the IPMC signal and the force applied to it. This behaviour is a characteristic of dynamic systems and cannot be modelled with a linear relation as presented by Keshavarzi et al (1999). It was noticed that the linear relation (Keshavarzi et al., 1999) can only be observed on very specific cases, low forces and small frequencies. Figure 9 presents the IPMC response for another force curve applied.

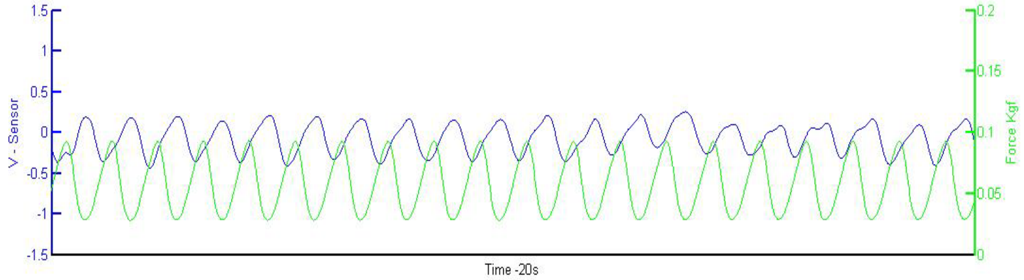

Figure 8 – IPMC voltage with a force applied with a higher frequency.

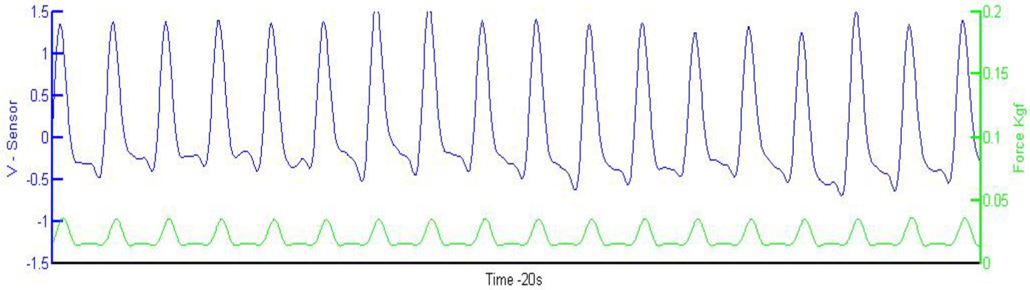

Figure 9 – IPMC voltage with a force applied as a pulse.

With the analysis of the Figure 9 it is possible to notice that the IPMC presents behaviour similar to a second order system with an overshoot, but if analyzed under a square wave force curve the behaviour is very unusual (Figure 8). This behaviour means that it is not possible to create a simple model of the IPMC as a force sensor. Its model must consider the non-linear relation present in Figure 8 to 10.

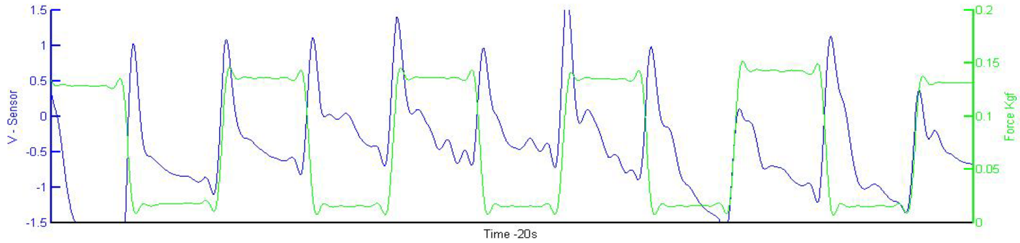

Figure 10 – IPMC voltage for a force as square wave curve.

Figures 8, 9 and 10 prove that the IPMC presents a nonlinear relation with the force applied to it and the overshoot in IPMC is a function of the variation of the force, and not directly from the force itself.

4. CONCLUSION

The properties of an IPMC as an actuator are well known, but its behaviour as a sensor is still something new. In this work an IPMC as a force sensor was presented. It was possible to notice that the IPMC behaviour can be easily confused with linear systems and in this article it was proved that its behaviour is non linear and the modelling of its properties as a sensor present a great challenge. Figure 10 presents a very unusual behaviour for a sensor and its analysis can be the key to understand and to create a model to allow the IPMC be used as a force sensor.

5.ACKNOWLEDGEMENTS

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6.REFERENCES

Bar-Cohen, Y., (2004). “Electroactive polymer (EAP) actuators as artificial muscles: reality, potential, and challenges”. SPIE- The international society for optical engineering.

Bar-Cohen, Y., Xue, T., Joffe, B., Lih, S. S., Willis, P., Shahinpoor, M., Simpson, J., Smith, J., (1997). “Electroactive polymers(EAP) low mass muscle actuators”. Smart structures and materials 1997- Smart structures and integrated systems 697-701.

Bar-Cohen, Y., Xue, T., Shahinpoor, M., Simpson, J. O., Smith, J., (1998). “Low-mass muscle actuators using electroactive polymers” (EAP).

David J.Griffiths, (2008). “Development of Ionic Polymer Metallic Composites as Sensors.” Master of Science .

Ferrara, L., Shahinpoor, M., Kim, K. J., Schreyer, H. B., Keshavarzi, A., Benzel, E., Lantz, J. W., (1999). "Use of ionic polymer-metal composites (IPMCs) as a pressure transducer in the human spine".

Keshavarzi, A., Shahinpoor, M., Kim, K. J., Lantz, J. W., (1999). "Blood pressure, pulse rate, and rhythm measurement using ionic polymer-metal composite sensors."

Kim, K. J., Shahinpoor, M., (2002). "A novel method of manufacturing three-dimensional ionic polymer-metal composites (IPMCs) biomimetic sensors, actuators and artificial muscles". Polymer 43**,** 797-802.

Nguyen, V. K., Lee, J. W., Yoo, Y., (2007). "Characteristics and performance of ionic polymer-metal composite actuators based on Nafion/layered silicate and Nafion/silica nanocomposites." Sensors and Actuators B-Chemical 120**,** 529-537.

Nguyen, V. K., Yoo, Y. T., (2007). "A novel design and fabrication of multilayered ionic polymer-metal composite actuators based on Nafion/layered silicate and Nafion/silica nanocomposites." Sensors and Actuators B-Chemical 123**,** 183-190.

Pak, J. J., Cha, S. E., Ahn, H. J., Lee, S. K., (2001). "Fabrication of ionic polymer metal composites by electroless plating of Pt."

Paola, B., Fortuna, L., Giannone, P., Graziani, S., Strazzeri, S., (2008). "IPMCs as Vibration Sensors."

Paquette, J. W., Kim, K. J., Nam, J. D., Tak, Y. S., (2003). "An equivalent circuit model for ionic polymer-metal composites and their performance improvement by a clay-based polymer nano-composite technique." Journal of Intelligent Material Systems and Structures 14**,** 633-642.

Shen, M. Y. H., Dai, Z. D., (2007). "Manufacture and Performance of Ionic Polymer-Metal Composites." Journal of Bionic Engineering 4**,** 143-149.