Electroactive polymer artificial muscle. Experiments

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Abstract: The present study investigates actuator properties of ElectroActive Polymers - EAP – like artificial muscle. After presenting a brief introduction on the structure and experimental applications of the artificial muscle, the paper aims at highlighting the experimental results on the response of Ionomeric Polymer-Metal Composite (IPMC) EAP to the application of a bipolar and rectangular signal type. In order to develop a realistic solution for bionic structure, the experiments are oriented to finger like structure. The present paper explore the dynamic model of two link finger structure as tendon type actuation. The results offer a strong background for future research in the use of EAP IPMC in robotics and mechatronics.

Keywords: Robotics, mechatronics, electroactive polymer (EAP), ionomeric polymer-metal composite (IPMC).

1. INTRODUCTION

Actuators are the key element in building an efficient technological solution. In terms of the energy source, the conventional solutions are based on electricity, pneumatic or hydraulic power. No doubt that unconventional element are emerging solutions, bringing to the forefront of technological development researchers and actuating systems based on chemical energy, thermal energy and photonics.

In the category of unconventional solutions there are also the artificial muscles. The performance of an artificial muscle is the dimension changes in case of applying energizing stimulus. Dimensional changes are important, the lowest level of changes, expressed in percentage is 8%. In terms of energy type activation, artificial muscles are classified into four main categories: thermally active polymers, optically active polymers, magnetically active polymers and electrically active polymers (Wallace, 2005).

Thermally active polymers are in the form of deformable gels at different temperatures depending on how constructive they are. Active polimer with form of gels is used in the construction of thermal valves. Activation temperatures are usually around ambient temperature (36°C - 38°C).

Optically active polymers are also found in the form of polymer gels that, when they are active, they are born osmotic pressure. These osmotic pressures are deformed gels. Usually, they are energized by an infrared light source, sometimes using (in some applications and special structures) lasers. The applicability of their aim is to achieve efficient detection devices and actuators.

Magnetically active polymers are structures containing magnetized particles inside which large adhesion forces arise when subjected to the influence of a magnetic field. Such polymers are often used in the automotive industry.

Electrically active polymers can be subdivided in two categories: electroactive polymers and ionic electroactive polymers. In the first category, there are found elestomers and ferroelectric polymers and in the second group, polymer gels and ionomeric polymer-metal composite. These types of polymer (electroactive polymer) are most widespread, being the ideal material in many mechatronics applications and beyond (Yoseph, 2000).

EAP is an important category of artificial muscles. They are excellent for robotic applications. Most reasons for preference relates to energy consumption (up to 10 V), fast response (less than 10 Hz in an aquatic environment), durability and mechanical stability (Bîzdoacă, 2009).

2. ELCTRICAL MODEL

An electrical model for a section of IPMC band, can be approximate (in electrical terms) with a RC circuit Fig. 1 (Xiaoqi Bao and all, 2002).

Under step voltage *V*, the response of input current is derived as:

$$I(t) = \frac{V}{r_0 + r_2}\left[1 + \left(\frac{r_1 + r_2}{R} - 1\right)e^{-\alpha t}\right] \qquad (1)$$

where:

$$R = r_1 + \frac{r_0 \cdot r_2}{r_0 + r_2}, \qquad (2)$$

and:

$$\alpha = \frac{1}{R \cdot C}. \tag{3}$$

This model has three adjustable parameters: r_1, r_2 and R. These parameters can be calculated or experimental obtained and offers theoretically results approximately identically with experimental result.

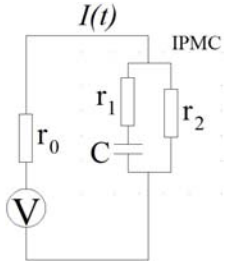

Fig. 1. RC model for a section of IPMC band

where: r_0 is the internal resistance of voltage source and r_1, r_2 and C is the electrical model of IPMC.

3. EXPERIMENTAL RESULTS

For conducting experiments there have been used a series of equipment and materials research previously purchased by the contract PNCDI 2 - code 289/2009 - REVERSE ENGINEERING IN COGNITIVE MODELING AND CONTROL OF BIOMIMETICS STRUCTURES - project director Professor. Nicu Bîzdoacă. The electroactive polymer artificial muscles used in this study form a IPMC strip with a thickness: 200 µm, width: 10.9 mm and length: 42 mm.

To excite them there was used a square wave generator with adjustable frequency and voltage. The generator is based on the integrated circuits (I.C.) LM555CM, SN74HC04N, LM2491T and SN754410NE.This are integrated circuits that are part of the oscillator circuit, training bipolar signal, half-bridge and the last its adjustment between defined limits. OUTPUT VOLTAGE is a potentiometer that lets you adjust the voltage amplitude applied to the polymer strip, while the potentiometer PULSE offers the possibility of adjusting the frequency (Data sheet for I.C. LM2941), (Data sheet for I.C. SN74HC04), (Data sheet for I.C. SN754410NE).

To determine the frequency and amplitude of energizing polymer tension was a digital multimeter AMPROBE 38XR-A and the intensity of electric current that runs through the polymer with DT-5807 type amp meter.

To determine the behaviour of electroactive polymers there have been carried out a series of experiments consisted of a maintained constant of some parameters and varying another parameter to determine the behavioural properties of artificial muscle actuators.

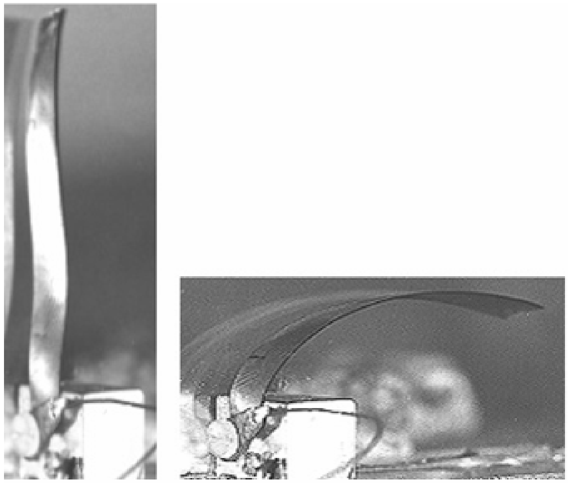

Fig. 2. IPMC in relaxed state (left) and activated state (right) (Yoseph, 2004)

The connection diagram of the experiment is shown in Figure 3.

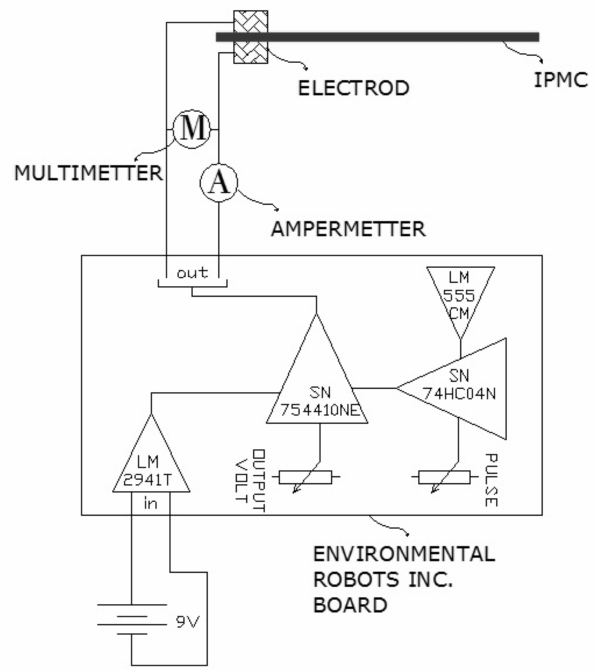

Fig. 3. Schematic representation of an experimental work stand

Next, the experimental results will be described as a consequence of this methodology.

3.1 Current depending on the applied voltage

At this stage, there was followed the evolution of the current absorbed by the EAP IPCM varying voltage across it. Between voltages limits were set to 1.5 V... 6V. The voltage of 6V was chosen as the upper limit as most are used biomimethic EAP IPMC actuators have a maximum voltage of 6V. Another reason to choose this threshold is that at higher voltages the polymer deteriorates (electrodes breaks) and dehydration is violent, which affects the accuracy of a negative feature. Following the results of the experiment results in Fig. 4:

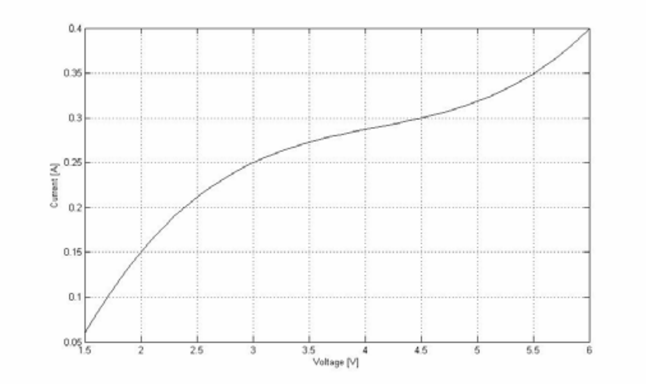

Fig. 4. Current dependency of voltage at constant frequency f = 1Hz

3.2 Current depending on the applied frequency

At this stage the voltage was kept constant, monitoring the current variation in frequency change. This was determined before through experiment the maximum for frequency for which the polymer is still visible movement achieved an electrical stimulus under the influence. The resulting frequency value was 19Hz. The minimum threshold was chosen 3Hz. Graph result is showed in Fig.5.

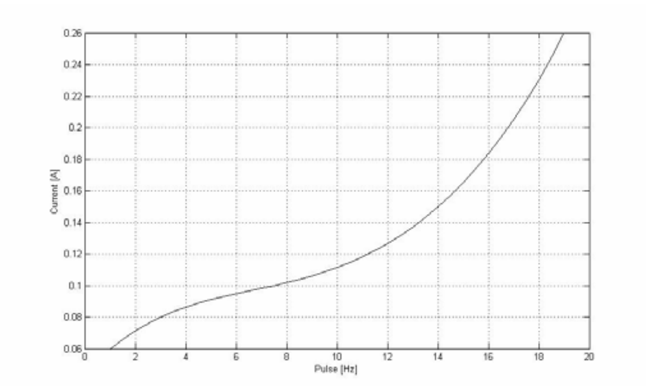

Fig. 5. Current dependency on the applied frequency, a constant voltage U = 1.5V.

It was observed that with increasing work frequency, the current absorbed by the polymer increases significantly when you change the polarity. If the frequency is sufficiently large that the polymer cannot achieve until a movement of 0° - 90° (the equivalent of arousal - rebound), the recovery phase current polarity changes correspondingly, increases of 1.5 times more.

3.3 Frequency depending on the applied voltage

At this stage we wanted to determine the maximum frequency response that was visible to the application of electric stimulus. The response obtained has the form:

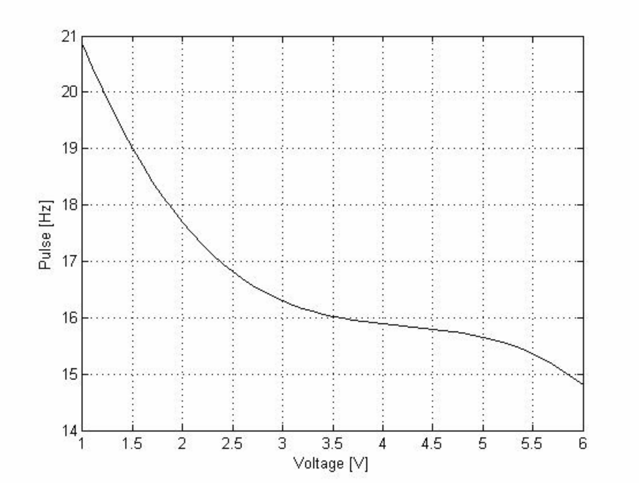

Fig. 6. Frequency variation according to voltage applied to the terminal.

After the experiment there was observed that the maximum frequency can be obtained from a different response depending on the length of the strip of polymer. Thus, for the same polymer tape, if the stimulus is applied at half, its frequency may be increased to a value of 35Hz, since then there cannot be seen any response.

4. DYNAMICS OF TWO-LINK TENDON-DRIVEN FINGER

In order to develop a realistic solution for bionic structure, the experiments are oriented to finger like structure actuations and control. For efficient control a simple mathematical model of two rotational link robotic architecture have to be used. There are many methods for generating the dynamic equations of mechanical system. All methods generate equivalent sets of equations, but different forms of the equations may be better suited for computation different forms of the equations may be better suited for computation or analysis. The Lagrange analysis will be used for the present analysis, a method which relies on the energy proprieties of mechanical system to compute the equations of motion. We consider that each link is a homogeneous rectangular bar with mass mi and moment of inertia tensor

$$I_i = \begin{bmatrix} I_{xi} & 0 & 0 \\ 0 & I_{yi} & 0 \\ 0 & 0 & I_{zi} \end{bmatrix} \quad (4)$$

Letting $v_i \in R^3$ be the translational velocity of the centre of mass for the i[th] link and $\omega_i \in R^3$ be angular velocity, the kinetic energy of the manipulator is:

$$T(\theta, \dot{\theta}) = \frac{1}{2} m_1 \|v_1\|^2 + \frac{1}{2} m_1 \omega_1^T I_1 \omega_1 + \\ + \frac{1}{2} m_1 \|v_2\|^2 + \frac{1}{2} m_1 \omega_2^T I_2 \omega_2 \quad (5)$$

Since the motion of the manipulator is restricted to xy plane, $\|v_i\|$ is the magnitude of xy velocity of the centre of mass and ω_i is a vector in the direction of the y axis, with

$\|\omega_2\| = \dot{\theta}_1$ and $\|\omega_2\| = \dot{\theta}_1 + \dot{\theta}_2$. We solve for kinetic energy in terms of the generalized coordinates by using the kinematics of the mechanism. Let $p_i = (x_i, y_i, 0)$ denote the position of the i^{th} centre of mass.

Letting r_1 and r_2 be the distance from the joints to the centre of mass for each link, results

$$x_1 = r_1 \cdot \cos(\theta_1) \tag{6}$$

$$\dot{x}_1 = -r_1 \cdot \theta_1 \cdot \sin(\theta_1) \tag{7}$$

$$y_1 = r_1 \cdot \sin(\theta_1) \tag{8}$$

$$\dot{y}_1 = r_1 \cdot \theta_1 \cdot \cos(\theta_1) \tag{9}$$

$$x_2 = l_1 \cdot \cos(\theta_1) + r_2 \cdot \cos(\theta_1 + \theta_2) \tag{10}$$

$$\begin{aligned} \dot{x}_2 = &-(l_1 \cdot \sin(\theta_1) + r_2 \cdot \sin(\theta_1 + \theta_2)) \cdot \theta_1 - \\ &- r_2\theta_2 \cdot \sin(\theta_1 + \theta_2) \end{aligned} \tag{11}$$

$$y_2 = l_1 \cdot \sin(\theta_1) + r_2 \cdot \sin(\theta_1 + \theta_2) \tag{12}$$

$$\begin{aligned} \dot{y}_2 = &-(l_1 \cdot \cos(\theta_1) + r_2 \cdot \cos(\theta_1 + \theta_2)) \cdot \theta_1 - \\ &- r_2\theta_2 \cdot \cos(\theta_1 + \theta_2) \end{aligned} \tag{13}$$

Using the kinetic energy and Lagranage methods results:

$$\begin{aligned} &\begin{bmatrix} \alpha + \beta c_2 & \delta + \frac{1}{2}\beta c_2 \\ \delta + \frac{1}{2}\beta c_2 & \delta \end{bmatrix} \cdot \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \\ &+ \begin{bmatrix} -\frac{1}{2}\beta s_2 \dot{\theta}_2 & -\frac{1}{2}\beta s_2 (\dot{\theta}_2 + \dot{\theta}_1) \\ \frac{1}{2}\beta s_2 \dot{\theta}_1 & 0 \end{bmatrix} \cdot \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} \end{aligned} \tag{14}$$

where

$$\begin{aligned} \alpha = &\frac{m_1}{12}(l_1^2 + w_1^2) + \frac{m_2}{12}(l_2^2 + w_2^2) + \\ &+ m_1 r_1^2 + m_2 (l_1^2 + r_2^2) \end{aligned} \tag{15}$$

$$\beta = m_1 l_1 l_2 \tag{16}$$

$$\delta = \frac{m_2}{12}(l_2^2 + w_2^2) + m_2 r_2^2 \tag{17}$$

with w_1, w_2, l_1,l_2 the width and respectively the length of link 1 and link 2.

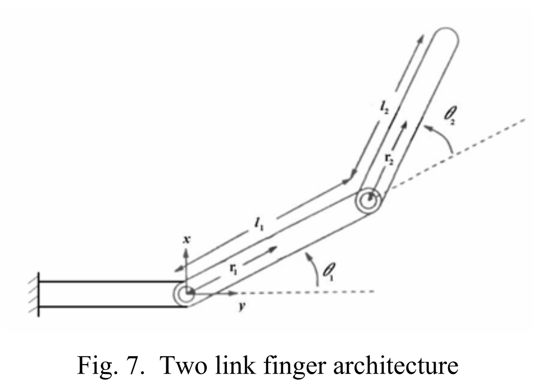

Fig. 7. Two link finger architecture

These results confirm the hypothesis regarding the efficiency of the artificial IPC EAP muscle to actuate and control bionic structure.

The τ_1 and τ_2 can be easy implemented by the torque offer by the energized EAP muscle.

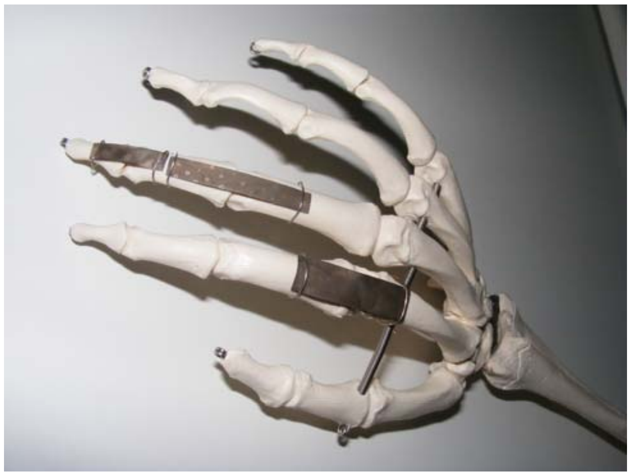

Fig. 8 . Experimental structure for two link finger architecture

5. CONCLUSIONS

Once the temperature starts to grow, the polymer absorbs a great amount of current. For example, at a current supply with the properties u=6V and f=2 Hz, the current absorbed by the polymer at the temperature of 30ºC is approximately 0.4 A. If the temperature rises to 70ºC, the absorbed current reaches the value of 0.8 A.

At low frequencies and high voltages, (e.g. U=6V and f=0.2Hz), the polymer tends to deteriorate; in some cases we can even have its own electrodes getting cracks. To avoid this, it is best that the polymer should work in an environment which assures its necessary cooling and hydration.

Another advantage of using such an environment is the decrease of the absorbed current (of course assuming there are no forces opposing the deformation direction of the polymer, like friction forces). This is brought into focus by the fact that, if we apply forces to the polymer not to let it deform, in a dry environment it absorbs a current which is an order of measure greater than it would absorb in damp environment subjected to the same forces.

A great influence on the response given by the polymer has the hydration grade; at repeated manipulations in a dry environment, the polymer dehydrates and the answer becomes weaker and weaker. The absorbed current in this case decreases. Is recommend when we work in a dry environment and the polymer is not hydrated, to exciting it for a short interval and introducing as many breaks in its usage.

A great advantage observed is that of regeneration, similar to the exoscheletic muscular structure. After the complete exhaust of the polymer (the moment in which this is not capable of giving any response to an electric stimulus), it recovers its structure in a certain amount of time. This time of recovery decreases to a few minutes (in the case of the experiment approximately 10 minutes), if it is introduced in water.

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REFERENCES

Bao, X.., Bar-Cohen, Y., Lih, S. S. (2002): Measurements and Macro Models of Ionomeric Polymer-Metal Composites (IPMC), San Diego.

Bîzdoacă, N.G., Ivănescu, M. (2009): *Controlul si integrarea tehnologică a materialelor si structurilor inteligente*, vol. IV, Craiova.

Data sheet for I.C. LM2941: http://www.national.com/ds/LM/LM2941.pdf

Data sheet for I.C. SN74HC04: http://focus.ti.com/lit/ds/symlink/sn74hc04.pdf

Data sheet for I.C. SN754410NE: http://www.datasheetcatalog.org/datasheet2/c/0hljt0cjelaj2s2rl3lqrquk9wcy.pdf

Wallace, G.G., Spinks, G.M., Kane-Maguire, L.A.P., Teasdale, P.R. (2005) – *Conductive Electroactive Polymers*, Dublin.

Bar-Cohen, Y. (2000) – *Electroactive Polymer (EAP) As Artificial Muscles*, Passadena.

Bar-Cohen, Y. (2004): *Bionic Humans Using EAP as Artificial Muscles Reality and Challenges*, Pasadena.