Adv. J. Sci. Eng.

Advanced Journal of Science and Engineering

https://adv-j-sci-eng.com
eISSN: 2717-0705

Original Research

FEM Analysis and Designing a Dynamic Sensor Made of Ionic-Polymer-Metal Composites

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Advanced Journal of Science and Engineering. 2022;3(1):49-54. https://doi.org/10.22034/advjse22031049

Received: 17 January 2022 / ***Revised***: 09 February 2022 / ***Accepted***: 13 February 2022 / ***Published***: 15 February 2022

Abstract: With science and technology fast developing, demand for smart materials has been on the rise, raising expectations for the better performance of such materials Ionic polymer metal composite (IPMC) as a new smart material with low voltage and large deformation has gained increasing attention, nowadays, thanks to its properties. This study analyzes the performance of IPMC as a sensor in two dimensional mode using finite element method for one and two Hz frequencies. The present work focuses on polymer composites in which an electroactive layer coated with platinum on two sides and studies their electromechanical and piezoelectric effects. It also examines the effects of alternating current on the number of signals received from Ionic membrane. The outcomes demonstrate that vibrations of 1.5 & 2 Hz frequency produce respectively voltages of 2.4 & 2.5 millivolts.

Keywords: Polymer composite; Ionic metal; Electromechanical; Finite element; Sensor.

Introduction

These days, producing energy by renewable energy and the reduction of environmental pollution are gaining important attention in both developed and under-developing countries. The sterling engine is one of the ways to produce energy without using fossil fuels [1]. Superconductors and electroactive polymers are widely used nowadays. High energy demand and emerging trends in automation have helped develop smart materials [2]. Smart material converters have presented new solutions for sensing and actuation and enabled the implementation of works beyond the capabilities of conventional converters. For instance, electrical and piezoelectric converters are now used for high-speed, high-precision geographical positioning and different alloys are used in structures temperature control [3]. During the past two decades ionic-polymer-metal composites, composed of a thin ion exchange membrane coated with a noble metal on two sides, has received increasing attention from researchers for two applications, namely, sensing and actuation. This shows, in fact, they are capable of converting electrical energy into mechanical energy. The advantages of polymer composites include, inter alia, mechanical flexibility, low weight, easy process ability, and causing large deformation when subjected to a low voltage. Besides, sensors made of such materials are more sensitive than conventional piezoelectric sensors in charge sensing mode. They are used for such applications as artificial muscles, sophisticated aqueous bionic robots and aerospace equipment. Also, because of their high flexibility, they can help future generations of robots better interact with their environment [4-6]. Such (IPMC) sensors are usually made of an electro-active polymer layer (mostly Nafion™ or Flemion™) coated with two metal electrodes on two sides. Inside polymers, anions, which are connected to polymer chains in the form of covalent bonds are made and balanced by moving cations of nano channels.

IPMC sensors can drastically bend through electrical conductivity for possessing, as mentioned earlier, properties such as high bendability and sensitivity. Ionic polymer composites essentially possess sensing properties. When subjected to a force and deformation, an Ionic polymer composite layer produces a measurable electric signal [7-10]. One can sense the amount of mechanical force and membrane deformation and vice versa by measuring the inductive voltage on the electrodes [11]. While IPMC has been widely studied for actuation it has not been studied as much for sensing [12]. A thicker model of IPMC in simulation proved to act better as sensor. However, a longer model (of IPMC) produced low voltage when subjected to an equal bending force. Change of width (of IPMC model) showed little effect on the voltage produced. To produce higher voltage one can proportionately increase the thickness of the ionic membrane or reduce the length of it [13]. The properties of electrode play the crucial role in displacement of IPMC and the produced voltage. For instance, among gold, copper, titanium, and aluminum, gold is the best metal to use as electrode in an actuator because its acceptable displacement [14]. Humidity and temperature can affect the structure of IPMC and change the Young's Modulus [15]. In this study, an Ionic polymer metal composite is consisted of an electroactive layer coated with platinum on two sides, like the one shown in Figure 1, was subjected first to a frequency of 1.5 Hz and then to a frequency of 2 Hz to study it as a sensor. In the used model for simulation, each layer was 70 micrometer in thickness, 55 millimeter in length and 5 millimeter in depth.

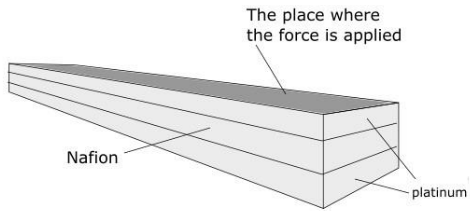

Figure1: Three-dimensional view of polymer-metal ion composite simulation.

Materials and Methods

Simulation of IPMC for Sensor

Finite element method is usually used for solving equations arising in engineering and mathematical modeling problems. This method turns a problem into a system of algebraic equations and gains the approximate amounts of the unknown functions for a number of points in the numerical domain for solution. To solve a problem, finite element method subdivides a large system into smaller, simpler parts called finite elements. Then, the simpler equations representing the finite elements are placed in a larger system of equations constituting the general form of the equation. Using this method to study or analyze a phenomenon is called finite element analysis. In similar essay, it was done. The IPMC was investigated as an actuator under a certain voltage and implement this method to explain the function of micro pump and its IPMC [16]. IPMC was examined on the FEM Model in an environment with atmospheric pressure and temperature of 25 centigrade. The properties of the materials used in the simulation are reflected in Table 1.

Table 1: Properties of the used materials in simulation.

Platinum	Electroactive Polymer	Property
21450	3105	Density ($\frac{kg}{m^3}$)
0.38	0.49	Poisson's Ratio
1.68×10^{11}	4.1×10^{7}	Young's Modulus (Pa)
1	4.1×10^{-10}	Relative Permittivity

Then, the composites are subdivided into 19107 parts with a quality of 0/8 through meshing. The composites, which are supported on the one side in the form of cantilever beam, can measure the amount of electricity produced when subjected to forces of 1.5 and 2 Hz.

The deformed gradient which includes deformed derivatives of the main coordinates is expressed through eq. (1).

$$F=I+\nabla \qquad (1)$$

In eq. (2), F_v represents the force per unit volume, I represents the first surface moment, S represents the surface area and T represents the fixed time.

$$\nabla*(FS)^T+F_V=0 \qquad (2)$$

In eq. (3), C represents the tensor of the final deformation of Couchy-Green and it is a function of the Green-Lagrange strain tensor. The first symbol in eq. (3) namely Sad is derived from eq. (4).

$$S=S_{ad}+\int_i F_{in\,el}^{-1}(C)\,F_{in\,el}^{-T} \qquad (3)$$

$$S_{ad}=S_0+S_{ext}+S_q \qquad (4)$$

The elastic Green-Lagrange strain tensor is derived from the elastic deformation gradient tensor according to eq. (5). When we get the non-elastic deformation gradient, the elastic deformation gradient tensor is derived from eq. (6).

$$\in_{el}=\frac{1}{2}(F_{el}^T F_{el}-I) \qquad (5)$$

$$F_{el}=FF_{inel}^{-1} \qquad (6)$$

In no-linear geometry, strains are calculated on the basis of the Green-Lagrange strain tensor according to eq. (7) in which U represents displacement vector [17].

$$\in=\frac{1}{2}[(\nabla u)^T+\nabla u+(\nabla u)^T\,\nabla u] \qquad (7)$$

Under static conditions, electric potential is calculated by eq. (8); the density (charge density) in space is calculated by eq. (9); D represents electric Flux and it is derived from eq. (10).

$$E=-\nabla V \quad (8)$$

$$\nabla . D= \rho_v \quad (9)$$

$$D=\epsilon_0 \epsilon_r E \quad (10)$$

For finite deformations, electromechanical stress and polarity of materials can be derived from eq. (11) using thermodynamic potential named electric enthalpy in which the mechanical energy function $W_s(c)$ depends on the simulated solid model. The Couchy-Green final deformation tensor is derived from eq. (12). This is a definite symmetric tensor equation which calculates the stress but not the rotation. In eq. (13), J represents the elastic volume ratio. Eq. (14) calculates the second Piola-Kirchhoff stress and eq. (15) calculates the electric displacement [18].

$$H_{eme} = W_s(C) - \frac{1}{2} \epsilon_0 \epsilon_r JC^{-1} \quad (11)$$

$$C=F^T F \quad (12)$$

$$J=\det(F) \quad (13)$$

$$S=\frac{2\partial H_{eme}}{\partial C} \quad (14)$$

$$D=\frac{\partial H_{eme}}{\partial E} \quad (15)$$

Results and Discussion

In this study, using COMSOL Multiphysics® simulation, a cantilever beam was subjected to forces of 1 and 2 Hz and triangle meshes were built in the software [17, 18]. Figure 2 shows the voltage in the vibration frequency of 1Hz. The voltage resulting from the vibration equals 2.34 millivolts.

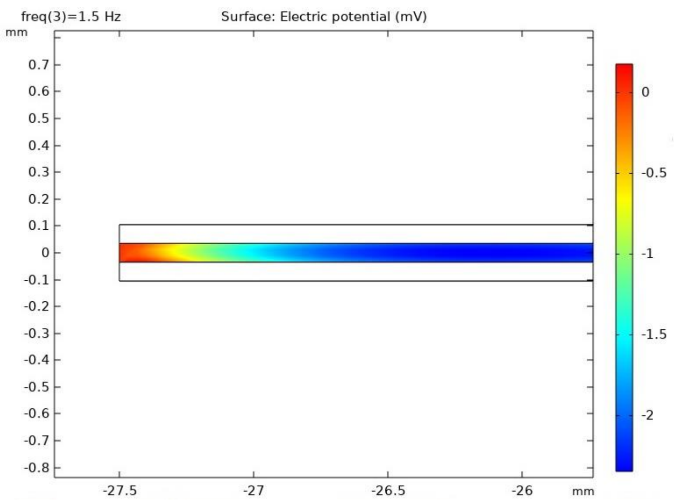

Figure 2: The outcome voltage of 1.5 Hz.

From this study we conclude that the further we proceed from the supported end to the free end of cantilever beam the higher would be the voltage. The experimental outcomes proved to be very close to the outcomes derived from the FEM simulation model with the difference being less than 10 percent. The maximum amount of voltage in the frequency fluctuation of 2 Hz is 2.5 millivolts as we see in Figure 3.

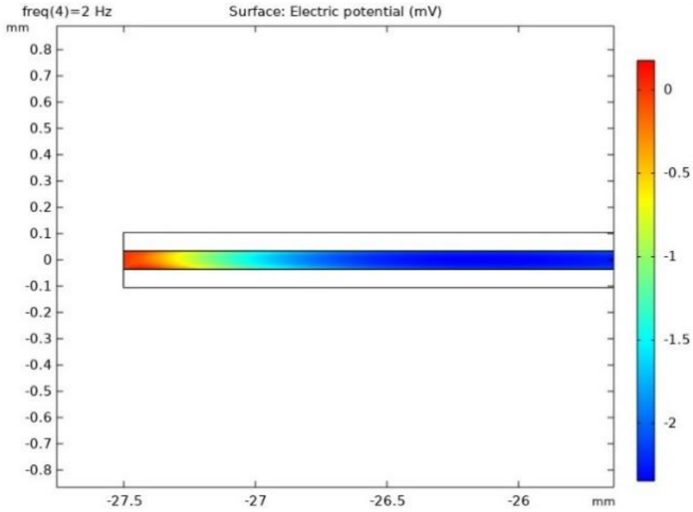

Figure 3: The outcome voltage of 2 Hz.

Conclusion

In IPMC is capable of producing electricity in a vibration environment, which can be used for different applications. To analyze IPMC, this material is subjected to forces of 1and 2 Hz with an electroactive layer coated with platinum on two sides. The produced voltage can be measured using the equations governing electromechanical materials. The produced voltage is proportional to the mechanical vibration frequency of the ionic membrane. The maximum voltages from vibrations of 1 and 2 Hz are respectively 2.4 and 2.5 millivolts.

Disclosure Statement

The author(s) did not report any potential conflict of interest.

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- **How to cite this article:** Nasrollah A, Nikkhou MH, Soleimanimehr H. FEM analysis and designing a dynamic sensor made of ionic-polymer-metal composites. Advanced Journal of Science and Engineering. 2022;3(1):49-54.
- https://doi.org/10.22034/advjse22031049