

Validation of IP²C devices as touch sensors.

Lia Cavallini and Paolo Di Giamberardino

Abstract—In the paper Ionic polymer-polymer composite (IP²C) membranes are considered. They are usually addressed and studied as sensors or actuators making use of the relationship between voltage and deflection that they exhibit. Here a different use as sensor is proposed, studying some of the effects that a mechanical pressure produces on the output voltage once a constant or a alternate power supply is applied. The most relevant results obtained performing some tests, making use of an ad-hoc experimental set up developed for this purpose, are presented and discussed, putting in evidence the feasibility and the effectiveness of the proposed usage.

I. INTRODUCTION

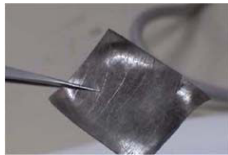


Fig. 1. Membrane

The development of smart materials has always been an interesting challenge for giving impulses to new technological applications. Among these, in the last years a wide interest has been devoted to the so called Ionic polymer-metal composite (IPMC) membranes (Fig. 1). They are usually constituted by a membrane of Nafion covered, on both sides, by a metal layer (usually Platinum). The Nafion membrane works like a sponge soaked by a ionic solution while the metal layers are used as conductive surface electrodes. Detailed description of the structure of IPMCs as well as the physical background and their working principles can be found in several works in literature. Among them, some relevant aspects are addressed in [1], [2], [3], [4], [5], [6], [7], [8], [9], [10].

The interest for such new devices and the need to investigate on their possible use has produced a great effort for the development of models able to capture aspects of IPMC behavior. Some interesting results in this direction can be found in [11], [12], [13], [14], [15], [16], [17], [18], [19], [20].

The diffusion and the importance of IPMC is proved also by the presence of such materials and their behavior among the contents of advanced academic courses ([21]).

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Applications where IPMCs play a fundamental role have been proposed and, in some cases, experimentally or numerically validated ([22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33]).

More recently, an improvement in the structure of such smart materials has been proposed; the metallic electrode surfaces has been replaced by a polymeric material, PEDOT:PSS is the most used, so leading to all-organic materials with the same operative characteristics as the IPMC: the IP²C (Ionic polymer-polymer composite).

Despite the qualitative characteristics are the same, some differences between IPMC and IP²C are present, both when used as sensor and as actuator; then the results known for the IPMC must to be reformulated for the new organic material ([34], [35], [36]).

In this paper the qualitative analysis of the use of an IP²C element as a touch sensor is addressed. In this starting phase, the qualitative instead of quantitative results are motivated by the fact that, being a new and different way to use such devices, the first question that had to be answered was whether or not they can be successfully adopted.

Then, after that in Section II the description of the experimental set up is given, in Section III the experiments for such analysis are described. In Section IV the measurement results are presented and discussed. Some concluding comments end the paper.

II. THE EXPERIMENTAL SETUP



Fig. 2. Experimental setup

With reference to Fig. 2, the experimental setup is composed by four main devices.

First of all, a rigid board where the testing membrane can be blocked so that it cannot deflect once an input voltage is provided. Electrical connections at both the extremities

TABLE I
OSCILLOSCOPE CHARACTERISTICS

| | |
|---------------------|--------------------|
| Max sampling rate | 2x240Msample/s |
| Bandwidth | 300MHz |
| Input impedance | 1M Ω /20pF |
| Vertical resolution | 8 bits \pm 1 bit |
| Input sensibility | 1 mV |

allow to feed the device at one side and to acquire the output signal both from the same side and from the other one. The rigidity of the board assures that when a pressure is applied to the membrane, the main mechanical effect is a compression of the membrane itself, without any sensible deflection. Depending on the particular experiment, as presented and discussed in next Section, the input voltage has been generated by a 5 V stabilized power supply for the constant voltage case, and by a signal generator by Tektronix, whose output has been amplified, by a low noise amplifier.

The electrical measurements have been performed using a part of the electronic board consisting of an electronic low noise amplifier, whose output is read by an oscilloscope APS230 by Velleman that can be connected, by a serial link, to a computer to store the acquired waveforms. Some of the characteristics of the oscilloscope are reported in Table I.

Last component of the experimental setup, the most important for the kind of tests performed, is a dynamometer. In view of more accurate experiments for the identification of a mathematical model of the analyzed behavior, the FH5 dynamometer by Sauter has been chosen. It has a resolution of 10^{-3} N and an input range of 0-5 N. Moreover, to store the force it is applying and to allow numerical analysis, the dynamometer is provided by a RS232 serial port which allows to transfer data, making use of a dedicated interface software called "AFH Fast", at a maximum rate of 10 sample/s.

The whole system allows to acquire, on a PC, the force (pressure) applied and the output consequent voltage with a maximum frequency, due to the dynamometer bandwidth, of 10 Hz.

III. THE EXPERIMENTS

As discussed in the Introduction, a different behavior of IP²C (or IPMC) membranes has been addressed, trying to put in evidence the existence of a relationship between deformations produced by compressions and output voltage and current variations.

The fact that the realization procedures does not guarantee quantitative repeatability of the performances between different membranes together with the high dependency of the

electrical characteristics from both humidity and temperature ([9]), in this first analysis a ON/OFF behavior has been addressed in the sense that the attention has been devoted to demonstrate that it is possible to detect a variation of surface mechanical pressure both when it is pushed and when it is released.

The IP²C membrane used for the measurements here reported is constituted by a 50 mm x 5 mm Nafion layer covered on both sides by an organic conductor: the PE-DOT/PSS ([35], [34], [36]). It has been produced in the Labs of the Dipartimento di Metodologie Fisiche e Chimiche per l'Ingegneria of the University of Catania, Italy. A deep chemical and physical description of such a membrane can be found in [35], [34] while the realization procedure is described, for example, in [36].

Several different experiments have been carried out. Among them, in this paper two different cases have been chosen for presentation: in the first one the IP²C membrane is fed at one end by a 5V constant voltage while in the second one a sinusoidal voltage input, 6V pp, at the frequency of 1 Hz, has been used.

Although change of behavior according to the position of the pressure applied has been investigated, such an effect is not here discussed and the data here reported are all referred to the application of the force about at 1/3 of the length near the input voltage side.

In Section IV the acquired data for each experiment are reported and some analysis are performed to put in evidence the proposed behavior.

IV. MEASUREMENTS ANALYSIS

In what follows, the two cases of DC and AC power supply are reported and analyzed. In the first case a 3V and 5 V voltage has been applied at one end and the resulting voltage at the other end of the membrane has been acquired while the pressure was applied. In the second one the input voltage has been changed into a sinusoidal voltage, with amplitude 3 V (6V pp), and frequency 1Hz. The choice of presenting the results for this frequency is mainly due to the pretty slow electro-mechanical dynamics of the IP²C and because of the bandwidth (10 Hz) of the whole measurement system that implies a 5Hz maximum bandwidth for the signals analyzed.

A. DC power supply

For the DC supply case, the effect of a pressure on the membrane is firstly studied by means of a direct visualization and analysis of the output voltage.

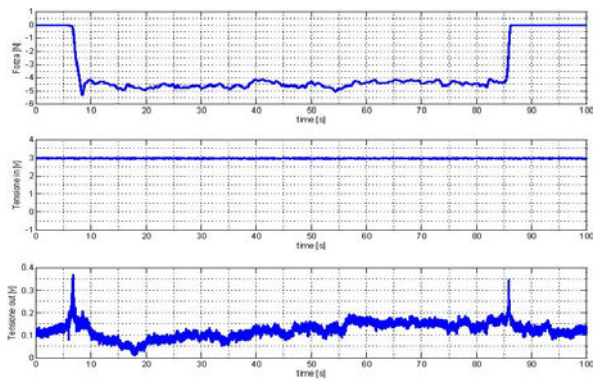


Fig. 3. Pressure close to the feeding extremity

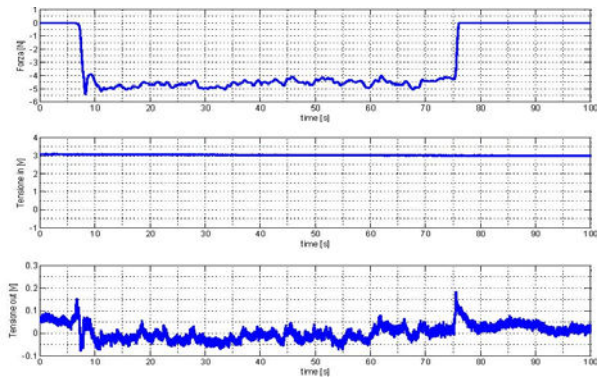


Fig. 4. Pressure close to the measurement extremity

1) *Direct instantaneous effects:* For this experiment, a pressure of 5 N has been applied; such a pressure has been kept for more than 80 s, in order to reach a steady state condition, and then the pressure has been released. The time history of the so applied input is depicted in the upper picture of Fig. 3. The middle picture represents the 3V voltage supply while the bottom graph depicts the output voltage measured during the experiment.

It is evident that, correspondingly to the pressure variation, a very clear local change in the output voltage happens, resulting to be easily detectable. This change is produced both during the compression and the release phases, but the two cases are not distinguishable by means of this qualitative approach.

If the position of pressure point is changed, the corresponding output behavior presents some changes but within the same general characteristics. This fact is evidenced by the result of a different test here presented just for comparison reasons. In fact, from Fig. 4 organized as the previous one, the effects when the force is applied closer to the

measurement side are reported. The fast higher amplitude oscillations in correspondence of the pressure variation are again well evident, but both the amplitude itself and the local behavior, in particular for the transient phases just after the change of pressure, seem different.

Then, these preliminary results show that it seems possible to detect a change of pressure over a IP²C membrane and some differences have been observed changing the point in which the pressure acts.

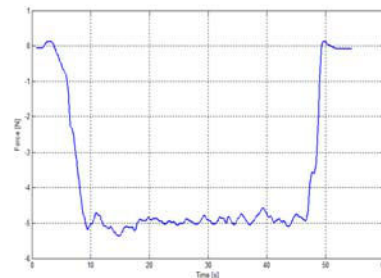


Fig. 5. Force behavior during the second DC voltage experiment

2) *Frequency effects:* In this case, again under a constant input voltage supply, with the amplitude raised to 5V to improve the signal/noise ratio, the output voltage has been analyzed performing Digital Fourier Transform (DFT) over 5s time length intervals shifting from [4, 9]s to [14, 19]s in order to consider the variations around the pressure action during the compression phase. Being the time interval length $T = 5s$ and having the data used for the Fourier analysis a sampling time $T_s = 0.1s$, each DFT has been computed starting from 50 samples and the discrete samples in the frequency domain correspond to values of frequency $f_i = i * 0.2Hz$, $i = 0, \dots, 49$. Then, the three module values depicted in Fig. 7 and Fig. 8 are referred to $f_0 = 0$, $f_1 = 0.2Hz$ and $f_2 = 0.4Hz$.

The whole time history of the force applied during the test is depicted in Fig. 5.

In Fig. 7 the module of the Fourier transform over the 6 shifting time intervals containing the compression phase are reported.

In the frequency domain, the change of the voltage output consequent to a pressure on the membrane can be detected observing that the continuous component decreases (second and third graphs) in correspondence of the input force variation. At the same time, first (and second) frequency component has a small increment.

This facts correspond to the fast variation of output voltage described in Subsection IV-A.1.

In the same way, Fig. 8 reports the module of the Fourier transform over the 6 shifting time intervals containing the release phase.

Also in this case, a reduction of the continuous components (forth and fifth graphs) follows the change of applied force with a small raise at the higher frequencies.

The meaning of this behavior follows the same reasoning as the compression phase. The difference with respect to that is in a sort of delay with respect to the input variation. This could be justified by the fact that in the compression phase the mechanical, and the consequent electrical ionic behavior, is directly driven by the velocity of the dynamometer action while in the release phase the mechanical changes follow the elastic structural characteristics of the materials: the membrane is not *pulled* but *released*.

However, the result is the same as in Subsection IV-A.1: changes of pressure directly influence the output voltage and the consequent variations can be easily detected. Is a little bit harder to distinguish between compression and release actions.

This observations will be very useful in the mathematical model design, which is one of the next steps that will be performed.

B. AC (sinusoidal) power supply

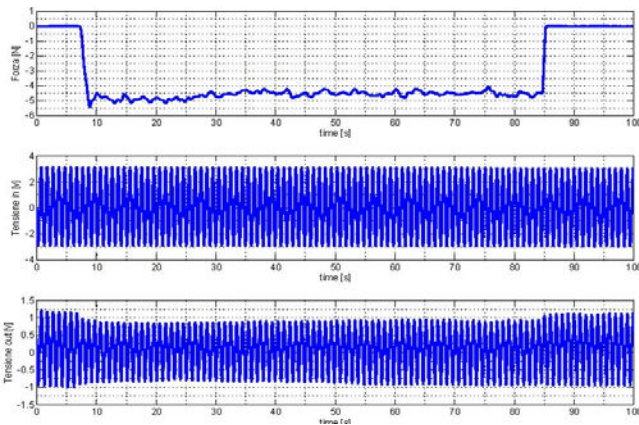


Fig. 6. Output voltage for 1Hz input

Fig. 6 reports the result of one experiment performed feeding the membrane with a sinusoidal voltage as previously described. The upper graph depicts the input force, the middle graph shows the input sinusoidal voltage at 1 Hz frequency and 3V amplitude while the lower picture reports the output voltage measurement.

In this case the result is more interesting than the constant voltage supply. In fact both the compression and release

phases are detectable, as in the previous case, but in addition it is possible to distinguish between the two: a reduction of the amplitude follows the compression while the release produces a raise in the amplitude.

The frequency analysis is not reported, for sake of space, but the result comes obviously from the observation of the time history: the amplitude at 1Hz changes during the pressure variations according to Fig. 6-3.

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

In this paper IP²C membranes have been considered as sensor devices in the new configuration of pressure (tactile) sensor units.

Some preliminary results coming from some testing experiments have been reported and briefly commented to show the feasibility of the use of such devices in this configuration.

The behavior under constant and sinusoidal voltage inputs has been considered, showing that in both cases a variation of pressure can be detected and, when alternate power supply is used, positive and negative variations can be easily distinguished.

The way to present here these results is mainly in the direction of showing the detectability of the presence or the absence of a pressure on a membrane. This fact has strongly simplified the analysis because qualitative aspects have been faced rather than more precise and quantitative description, for which both the physical model, for the chemical, electric and mechanical parts, and the identification of a mathematical model would be required.

Clearly, such a quantitative approach represents one of the necessary developments, at present under study, before an actual use of such sensing configuration for these devices can be proposed.

B. Future Works

The main directions of the future works are two. The first one is mainly devoted to further experiments with different membrane shapes and interconnections, towards the validation of the feasibility of a all-organic sensor able to detect a mechanical pressure and the coordinates (point) where the pressure acts, so getting organic tactile sensors. The second one addresses the problem of computing a mathematical model able to describe the behavior of IP²C membranes in the configuration here considered. All the models developed up to now, both as sensor and as actuator, refers to membrane deflection. Starting from these results, a different model has to be computed, so letting it possible to predict and to give a correct interpretation to this kind of behavior.

Some of this work is already under investigation, showing positive forthcoming results.

VI. ACKNOWLEDGMENTS

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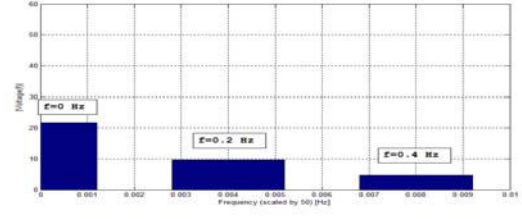
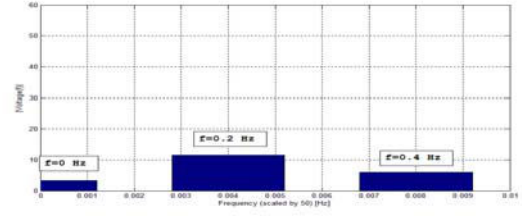
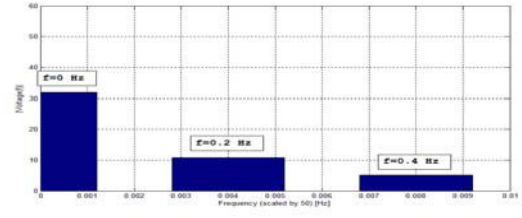
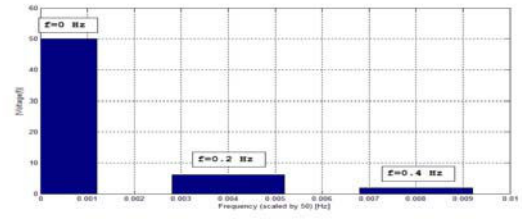
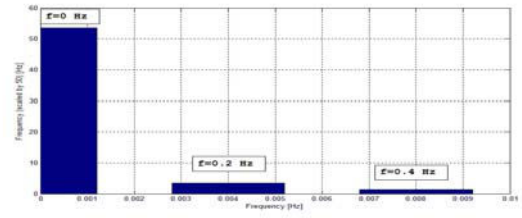
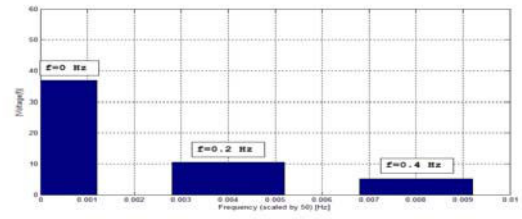
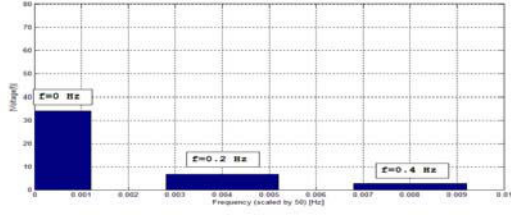
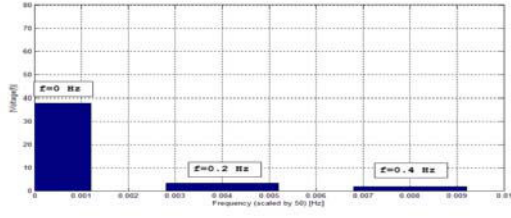
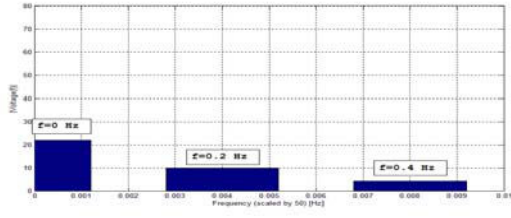
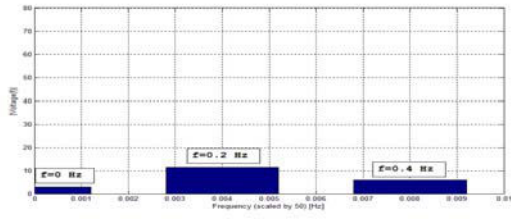
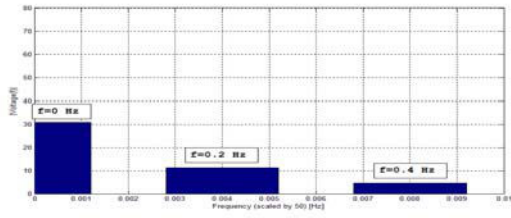
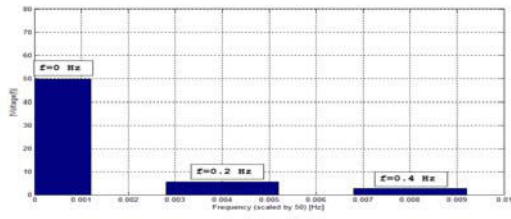


Fig. 7. Fourier analysis for the first three components for shifting time intervals during the compression phase. The time intervals are 4s–9s, 6s–11s, 8s–13s, 10s–15s, 12s–17s and 14s–19s respectively from top figure to bottom one.

Fig. 8. Fourier analysis for the first three components for shifting time intervals during the release phase. The time intervals are 40s–45s, 42s–47s, 44s–49s, 46s–51s, 48s–53s and 50s–55s respectively from top figure to bottom one.