Effects of mechanical stress on electrical parameters and noise of supercapacitors

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***Abstract* — Results of noise and electrical parameters measurements of prototype electrochemical double layer capacitors (EDLC) are reported at the presence of selected mechanical stress. This issue is of great importance due to future applications in wearable technology. The measurement results are compared, and we may conclude than flicker noise is more sensitive to any stress than other considered electrical parameters.**

Keywords— EDLC, supercapacitor, noise, mechanical stress

I. INTRODUCTION

Electrochemical double layer capacitor (EDLC) is a device that is capable of storing a relatively high amount of electrical energy in comparison to its mass. Additionally, it may work effectively for a long time. The charge is stored in a double electrical layer, formed between the porous electrode and the electrolyte solution interface. The interface is very fragile to any changes in the EDLCs due to the low size of pores, even below 1 nm, where the ions preserve electrical charge.

The device may be applied as an energy supplier in wearable electronic systems of low power consumption. It means that it should be cheap and resistive to mechanical stress during exploitation. We present measurement results of selected electrical parameters of exemplary EDLCs when mechanically bent. These parameters were compared with low frequency noise measurements (in flicker noise and white noise regions).

II. SAMPLES

In our experimental studies, the prototype EDLC cells were used. The cell comprises of two electrodes with a porous carbon layer with ion permeable separator between them that is typical for such elements. The internal structure of the EDLC is shown in Fig. 1.

The electrolyte solution fulfills the space between electrodes. The structure is enclosed in a hermetically welded pouch cell. Electrodes are led out on both sides of the pouch to assure electrical contacts. The pouch cell is flat and flexible and may be attached to cloths. Its size is approximately about 8 cm x 9 cm. The applied electrolyte is organic and the nominal voltage is 2.7 V. The cell capacitance C ~ 7 F, which is sufficient to supply energy for tiny electronic systems. As the single EDLC cell is relatively thin (approx. 0.5 mm), cells could be stacked to reach a higher value of capacitance.

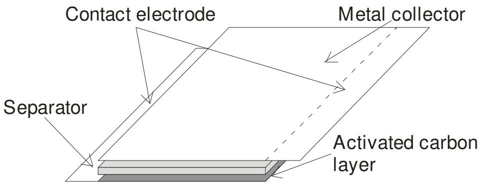

Fig. 1. EDLC internal structure

Mechanical stress applied to the cell, especially bending, could cause shifting of inner layers of the EDLC structure (electrodes and separator) and possible changes in distance between them. The movements of inner layers shouldn't cause a change in capacitance, as it results from electrode-electrolyte interface, unless the space between electrodes remain fulfilled by the electrolyte. The bending of the cell could result in cracks in the active carbon layer and possible electrical short-circuits between positive, and negative electrodes. Those failures should be visible in changes of capacitance and equivalent series resistance values, as well as in low-frequency noise level observed during element operation.

III. EXPERIMENT

The measurement set-up comprises of programmable potentiostat and galvanostat to assure the charging-discharging process of the tested EDLC, and noise measurement channel utilizing low-noise amplifier and 24-bit analog-to-digital converter [1, 2]. The block diagram of the measurement set-up is shown in Fig. 2.

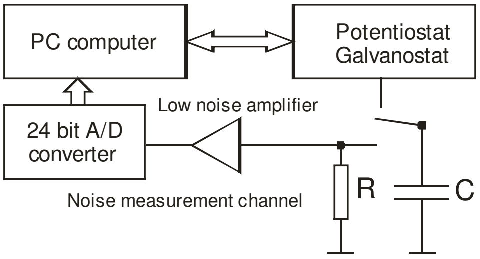

Fig. 2. Measurement set-up block diagram

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The specimen was charged to different voltages from 0.5 V to 2.5 V and back. At each voltage, the specimen was kept for 2 hours (this stage is called floating). Next, the specimen was discharged through the loading resistance 100 Ω, and the noise was recorded. During noise recording, the sample was disconnected from the charging-discharging circuit to avoid interferences. After discharge, the specimen was five-time charged and discharged and capacitance C, and ESR were estimated from the current and voltage of the fifth discharge by the method described in [3]. The time waveform of voltage over EDLC contacts is shown in Fig. 3.

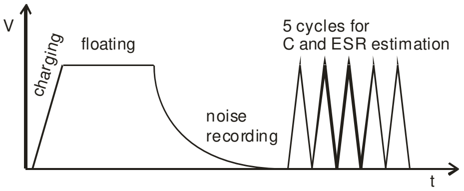

Fig. 3. The time waveform of EDLC voltage during the experiment

Recorded discharge signals with DC and noise component were subjected to a procedure of DC component removal [4], and the power spectral density of the noise component was estimated.

During the measurement, the tested EDLC was placed on a flat surface and pressed by 1 kg mass to stabilize its geometry. The same experiment was repeated by bending the samples using the selected rigid forms (Fig. 4), fabricated by 3D printing technology. Two forms were used: first with a radius equal 55,2 mm which corresponds to 20 mm of bending, and second with a radius equal 117.8 mm which corresponds to 10 mm of bending. Each form consists of two parts what allows to place EDLC pouch cell between them and press to force uniform bending. Contact electrodes protrude out of form to allow contact to measurement set-up. The form with EDLC inside was pressed by 1 kg mass to stabilize bending. Each sample was tested in two deformations. Specimen denoted JP5.4 was first bent by 20 mm, then by 10 mm, whereas the one denoted JP5.5 was first bent by 20 mm, then by 10 mm. Forms with specimens mounted inside are shown in Fig. 5.

Fig. 4. The forms used for bending the investigated EDLC specimens

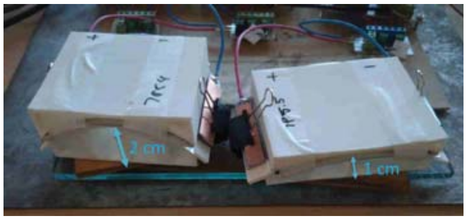

Fig. 5. The forms used for bending the investigated EDLC specimens

IV. RESULTS

Tested specimens were first measured when flat and loaded by 1 kg mass. The specimens capacitance and ESR estimated during measurement are shown in Fig. 6 and Fig. 7 respectively (arrows show the direction of changes).

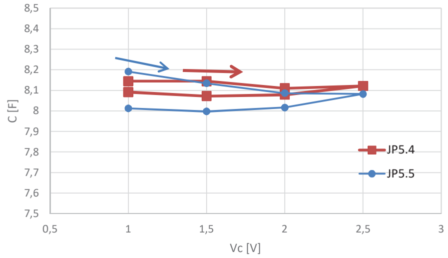

Fig. 6. Evolution of capacitance of specimens when flat

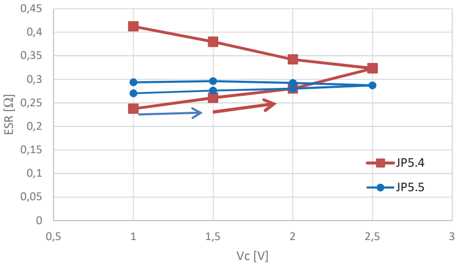

Fig. 7. Evolution of capacitance of specimens when flat

We observe some changes of C and ESR values at different polarizing voltages. The changes are not significant, except the ESR values of specimen JP5.4, which increased much more than for specimen JP5.4.

For each floating voltage the power spectral density of the discharge voltage were estimated. Typical curve of power spectral density of discharge voltage fluctuations is shown in Fig. 8.

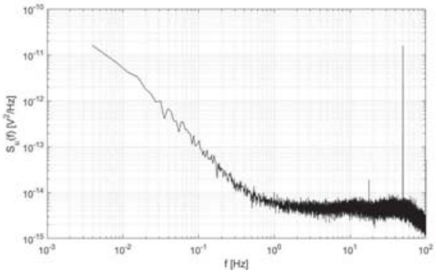

Fig. 8. Power spectral density of EDLC specimen discharge voltage

To compare the noise intensity at various experiment voltages the mean of power spectral density multiplied by frequency square, f^2, for 1/f region (0.02÷0.1 Hz) and mean value of power spectral density for white noise region (3÷10 Hz) were calculated. Results are shown in Fig. 9 and Fig. 10 for specimens JP5.4 and JP5.5 respectively.

The noise level increases slightly with voltage for 1/f region. Better reproducibility is observed for specimen JP5.5, however, the dispersion of mean values is within half of the decade.

The same procedure was repeated for bent specimens. As we mentioned before, each sample was tested while bent with both forms (10 mm and 20 mm). Results of capacitance and ESR estimation of specimens JP5.4 and JP5.5 are shown in Fig. 11 and Fig. 12 respectively.

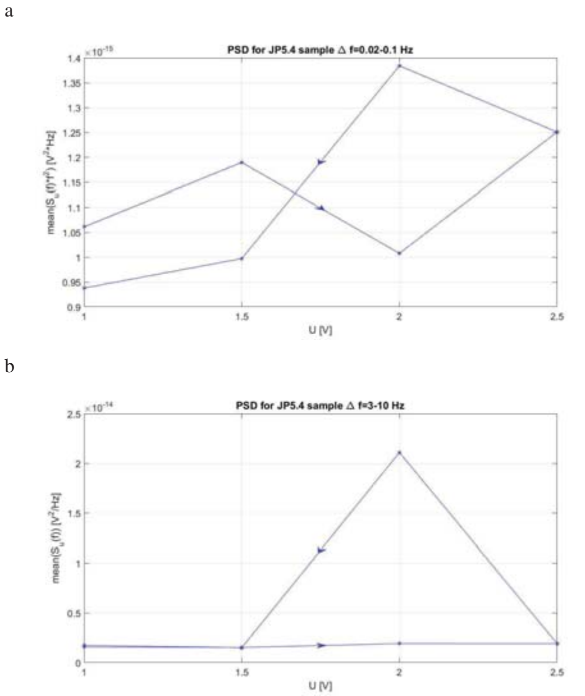

Fig. 9. Mean value of power spectral density of JP5.4: a – 1/f noise region, b – white noise region

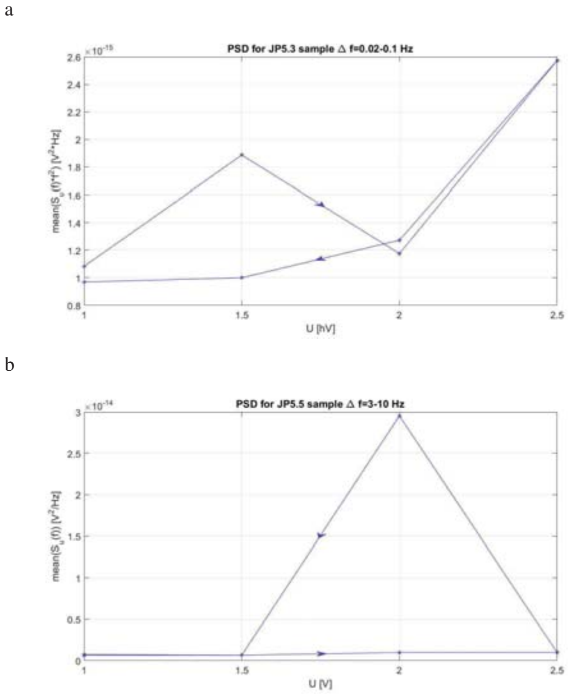

Fig. 10. Mean value of power spectral density of JP5.5: a – 1/f noise region, b – white noise region

We observe good reproducibility of C and ESR values for various voltage values. When the specimen is more bent, it shows lower capacitance. Resistance ESR seems not to depend on bending. The noise results are presented in Fig. 13 and Fig. 14 for the specimens JP5.4 and JP5.5 respectively.

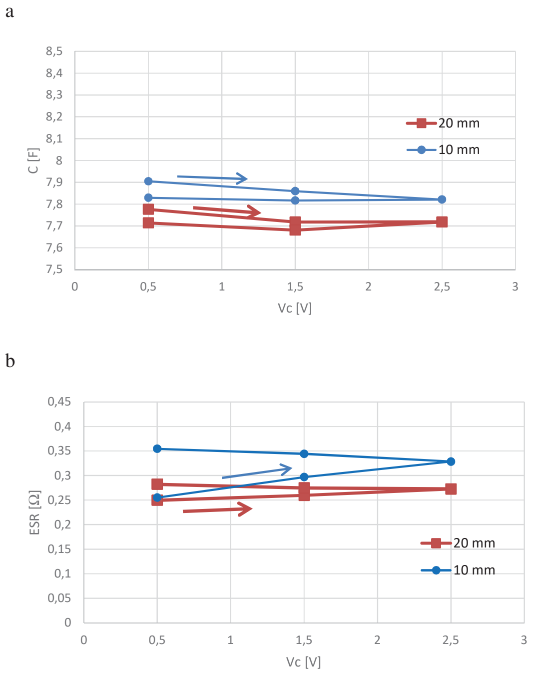

Fig. 11. Capacitance and ESR of JP5.4 when bent: a – capacitance, b – ESR

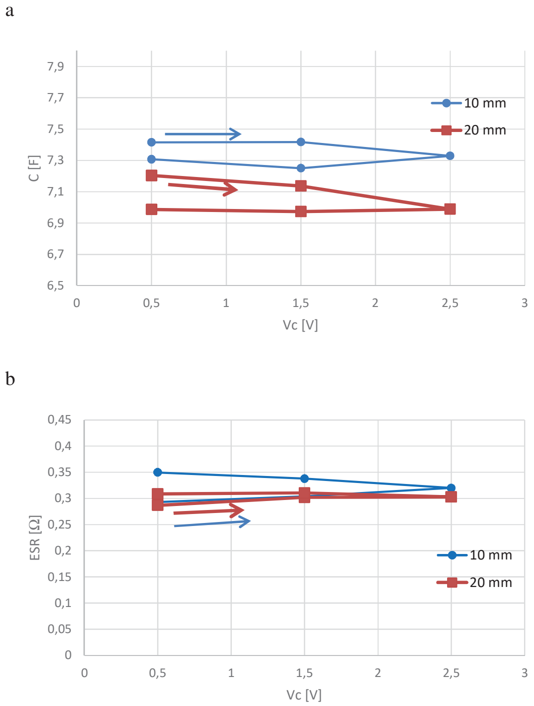

Fig. 12. Capacitance and ESR of JP5.4 when bent: a – capacitance, b – ESR

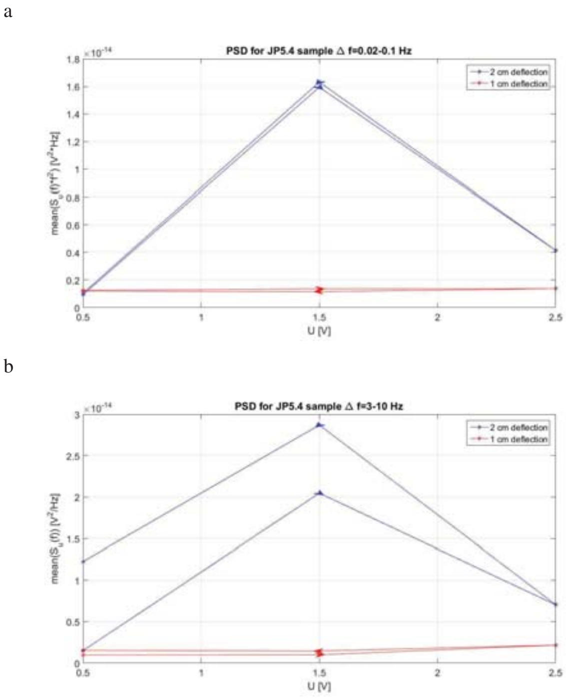

Fig. 13. Mean value of power spectral density of bent specimen JP5.4: a – 1/f noise region, b – white noise region

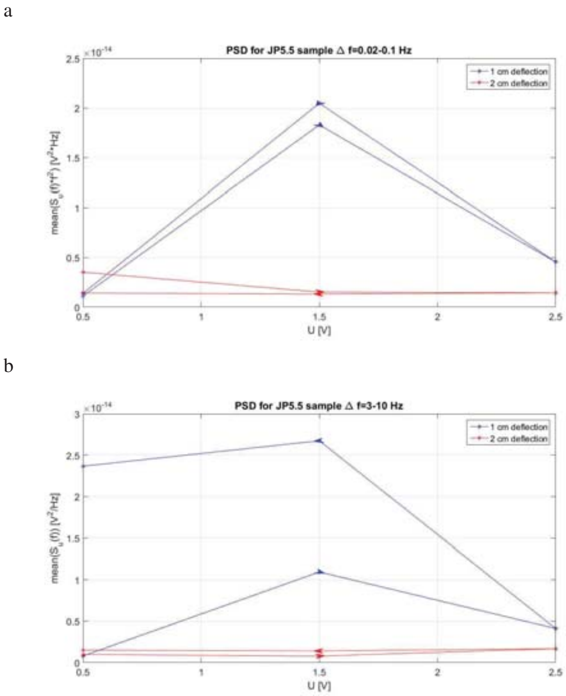

Fig. 14. Mean value of power spectral density of bent specimen JP5.5: a – 1/f noise region, b – white noise region

Noise results of the bent specimens show better reproducibility then for flat sample measurements (Fig. 9, Fig. 10). We observe some increase of noise intensity at 1.5 V when the sample is bent for the first time (JP5.4: 2 cm, JP5.5: 1 cm). The change in the bending curve seems not to influence the noise of specimens.

V. CONCLUSIONS

We have observed some changes of C and ESR values at different polarizing voltages and bending. Noise intensity depended on polarizing voltage as well and changed when bent or when we repeated the experiment. The mechanical pressure and bend stabilize the noise and electrical parameters of EDLC.

We may conclude that noise seems to be more sensible than electrical parameters to any mechanical stress. Mean value of the product of power spectral density of voltage fluctuations and frequency square at low-frequency range is one order higher for bent specimen than for the flat one, while the capacitance dropped 5% and 9% only after the first bend.

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