ON THE USE OF A NOVEL ALL-SOLID-STATE BATTERY AS A COMPOSITE STRUCTURE DAMAGE SENSOR

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1. INTRODUCTION

In the last decades, the use of battery technologies, especially lithium-ion (Li-ion), has been a very important trend for numerous electrical applications. The combination of high energy and power density makes it a substantial solution in applications such as portable electronic devices and vehicles. This type of battery has, however, a couple of limitations, such as slow charging, and a flammable electrolyte [1].

Aiming at greener energy storage, and more efficient and safer types of batteries, companies and governments have invested great amounts of money in developing newer technologies for energy storage [2]. Thus, the development, production, and use of environmentally friendly batteries are the key to achieving a sustainable, and climate-neutral technology [3].

An alternative to the well-established Li-ion battery is the use of solid-state electrolytes, which have been attracting significant attention due to their advantages, such as non-flammability, higher thermal stability, no leakage risk, and non-volatile materials. In addition, this alternative also demonstrates better mechanical properties and a higher electromechanical window of stabilities in comparison to the Li-ion counterpart, making it an interesting alternative in energy technology [4].

Considering the aforementioned aspects, the present study considers a novel all-solid-state battery to investigate the possibility of using it as a piezoelectric sensor. Figure 1(a) shows a depiction of the battery used, in which the electrodes are made of Zinc and Copper, and the electrolyte is formed by a Sodium solution. The battery is coated with a polymeric protective film, as shown in Figure 1(b).

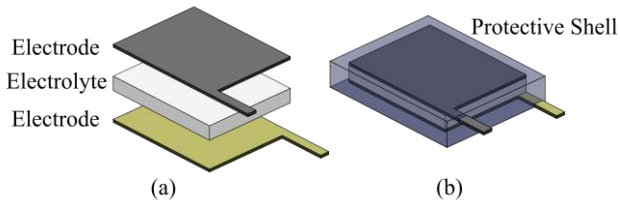

Figure 1 – Schematics of the all-solid-state battery: (a) electrodes and electrolyte; (b) battery assemble and protective polymeric shell.

In this work, the objective is to use an all-solid-state battery as a piezoelectric sensor and to discuss the potentialities and limitations of this type of battery for such applications. Thus, vibrational tests are performed using this battery coupled to a composite beam and a shaker. The battery signal variation is obtained when the battery is subjected to constant vibration. This type of test seeks to understand the potential of applying this type of battery as a sensor, which can be very promising in several engineering applications.

2. EXPERIMENTAL SETUP

To evaluate the piezoelectric response of the battery, a case study is examined using a composite carbon fiber beam. The geometry is that of a cantilever beam with 2.2 mm thickness, 30 mm width, and 150 mm long. The battery is attached to the beam and it is positioned close to the clamp device, as schematically shown in Figure 2.

The beam is clamped to a rigid grip, which is then mounted on an electrodynamic shaker, subjecting the specimen to a base excitation condition. The shaker is set to produce a constant frequency sine wave signal, and the response of the battery at different excitation frequencies is examined. It should be noted that the first bending mode of the beam is located at around 90 Hz, while the second bending mode is found only at 350 Hz. The base-acceleration load is applied in the z-direction (as shown in Figure 2), and in some tests, an added mass is glued to the free tip of the beam, thus increasing its vibration amplitude.

The battery is connected to a circuity mounted directly into a breadboard, which is designed to remove its DC output voltage but allowing the passage of the voltage oscillations expected to happen during the vibration tests. The signal is then sent to a Kistler LabAmp 5167A data acquisition system.

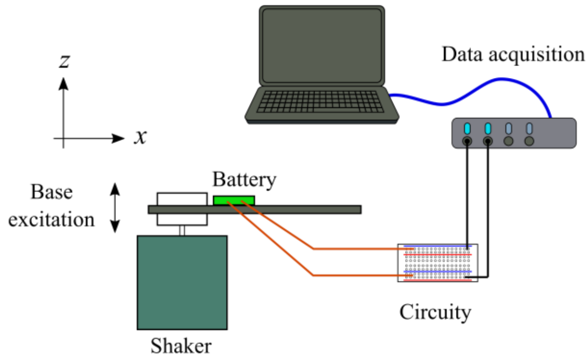

Figure 2 – Setup of the vibration test.

The battery is attached to the beam using a rapid curing, single component adhesive, and it is positioned close to the clamp device, as schematically shown in Figure 3. In addition, two accelerometers are used for comparison measures. The first accelerometer is attached to the rigid grip to measure the base acceleration. The second accelerometer is attached to the tip of the beam, and its signal is compared to the battery signal.

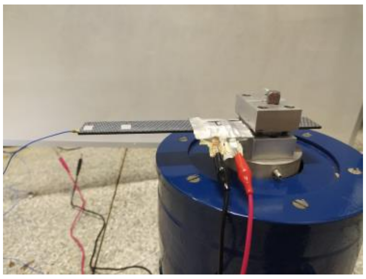

Figure 3 – Depiction of the battery attached to the composite beam mounted to the shaker.

3. RESULTS AND DISCUSSION

In a preliminary study, the battery behavior under a constant base excitation of the system is investigated. An excitation frequency of 25.0Hz is chosen for the vibrational tests since this frequency is sufficiently distant from the natural frequencies of the system. The vibrational test is initiated with the shaker off, and then it is suddenly turned on, and after a few seconds, it is turned off again. The time signal of the battery and the highlights of the regions in which the shaker is off and on are shown in Figure 4.

In the region where the shaker is turned on, it is noticed that the battery is capable of generating a variation in the electrical potential difference at the same excitation frequency as the system, that is, 25.0Hz. Another characteristic noted in the test is that in regions where the shaker is turned off, the battery signal oscillates at a frequency of 60.0Hz, due to electromagnetic interference from the electrical network.

It is important to note that the amplitude of the battery signal when the shaker is on is about 10 times greater than the amplitude of the signal when the shaker is off. In this way, the battery can generate a representative electrical signal for the analyzed case, even with the noise coming from the electrical network.

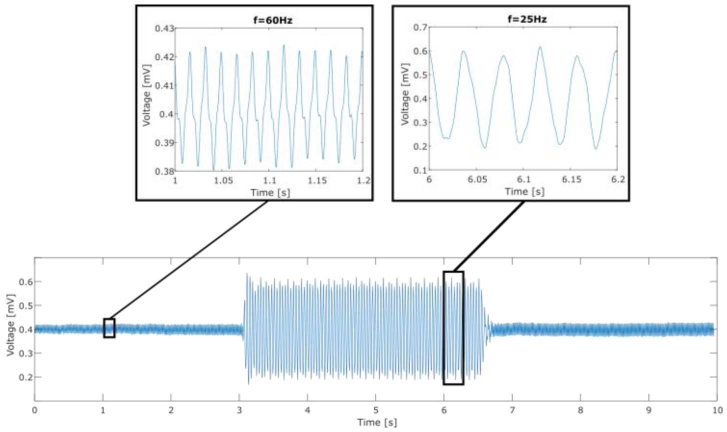

Figure 4 – Battery signal in the time domain under a constant base excitation of 25.0Hz - shaker is suddenly turned on and then turned off after a few seconds, and highlights of the regions where the shaker is off and on.

In a following analysis, the battery signal in the frequency domain is investigated. Thus, the Fast Fourier Transform (FFT) is used to convert the signal in the time domain to the frequency domain. Figure 5 shows the battery signal in the frequency domain, as well as the signal of the accelerometer on the tip of the beam. It can be seen that both the battery and the accelerometer can detect signal peaks at the working frequency of the system (25.0Hz), as well as its harmonics (multiples of 25.0Hz). In addition, it can be seen that the battery presents signal peaks in frequencies multiple of 60.0Hz, due to electromagnetic interference due to the electrical network.

As initial conclusions, it can be said that there are possibilities of using the battery as a piezoelectric sensor since it generates a potential difference when excited at a constant frequency. Also, the amplitude of the signal generated by the battery when excited is much higher than the amplitude of the signal due to electromagnetic noise.

For future work, the battery will be excited at different frequencies to investigate the limit of battery usage. The higher the excitation frequency of the system, the smaller the signal amplitude generated by the battery. Thus, we have to investigate at what working frequency level the signal amplitude generated by the battery is equal to or less than the electrical network noise, which implies the impossibility of using the battery at these frequencies.

Hereafter, we will use a sweep-type excitation signal, to find the natural frequencies of the system through the signal generated by the battery. Finally, aiming at applications in Structural Health Monitoring (SHM), the battery will be used to compare systems using an intact beam and a damaged beam. With this investigation, it will be possible to determine if the signal generated by the battery is capable of detecting variations in the natural frequencies of the system, due to damage to the composite beam.

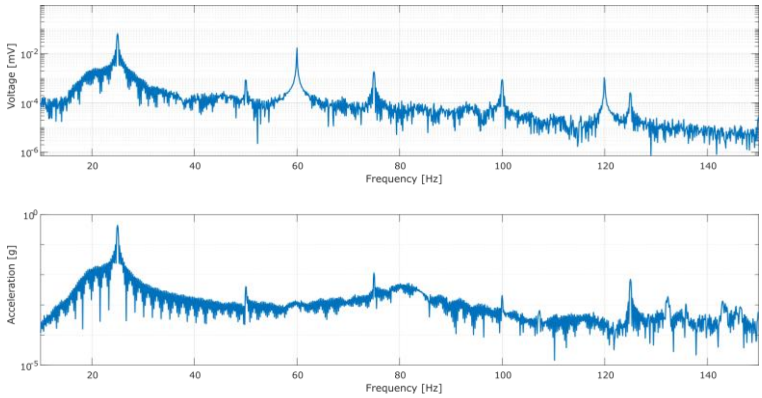

Figure 5 – Battery and accelerometer signals in the frequency domain.

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