3 April 2020

Summary of the Battery Expansion Sensor Testing

This summary consists of 3 sections. The 1st Section is the test set up. 2nd Section is be the data from the April 1 to April 3 and the 3rd section is the controlled humidity and compensation conclusion.

1) **Test Set up.**

The variables to be monitored or controlled are as follows.

- Track the expansion of the battery during normal charge and discharge cycles
    - Using a Heidenhain height gauge
- Monitor the battery's state of charge
- Track the Bend Sensor® as it is attached to the battery shell
- Use a second Bend Sensor® in a fixed position to track humidity changes
- Charge the battery then connect it to a load and discharge the battery

To track the expansion of the battery we are using a Heidenhain unit with an output of 10^{-6} inches. The battery is mounted to the .50" thick aluminum base plate. The Heidenhain is mounted to a post on the plate and the gauge is zeroed on the plate. The battery is then adhered to the plate using a pressure sensitive adhesive and placed under the probe near the sensor. The output represents the overall height and the changes to the overall height of the battery. The battery used in the testing is a 1200mAh 3.7V with PCM from PKCELL p/n 503562.

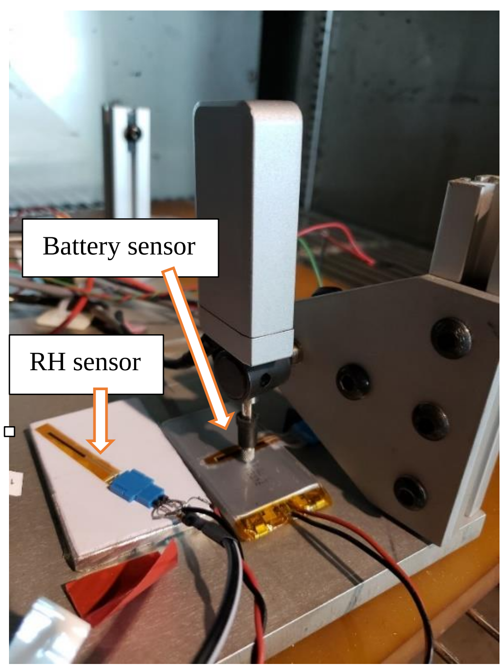
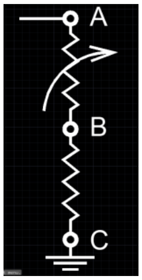


Figure 1 Heidenhain head in contact with the battery

To monitor the battery status, the positive and negative leads are connected directly to the data acquisition unit.

To track the Bend Sensor® it is attached to the battery using a cyanoacrylate adhesive. The sensor is a custom sensor 6.5mm x 48mm with an active area 26mm x 1.2mm printed on HN 200 Kapton film. The substrate thickness is 0.002” [0.05mm]. The base resistance of the sensor is about 16.5K ohms and it is paired with a 10K ohm fixed resistor in a voltage divider. The voltage is measured a crossed the Bend Sensor®. The power supplied to the circuit is 5 VDC. The data acquisition leads are connected at points “B” and “C”.



Tracking the humidity is also accomplished by a Bend Sensor®. This sensor is adhered to an aluminum plate using a cyanoacrylate. This sensor is fixed in position and not allowed to move. All changes in resistance are due to environmental conditions and not movement. In a fixed position, resistance in the sensor changes in response to changes in humidity. The base resistance is 10K ohms and it is in a similar voltage divider as the battery sensor with a 10K fixed resistor. The data acquisition leads are connected in a similar fashion at points “B” and “C”.

The charging of the battery is controlled by a mechanical timer set for a 4-hour charge at 4.2 VDC and 0.24 amps as recommended by the manufacturer. The timer controls a relay that will switch between the charge circuit and the discharge circuit. A load is connected to the battery that will discharge the battery in approximately 4 hours. This cycle repeats itself.

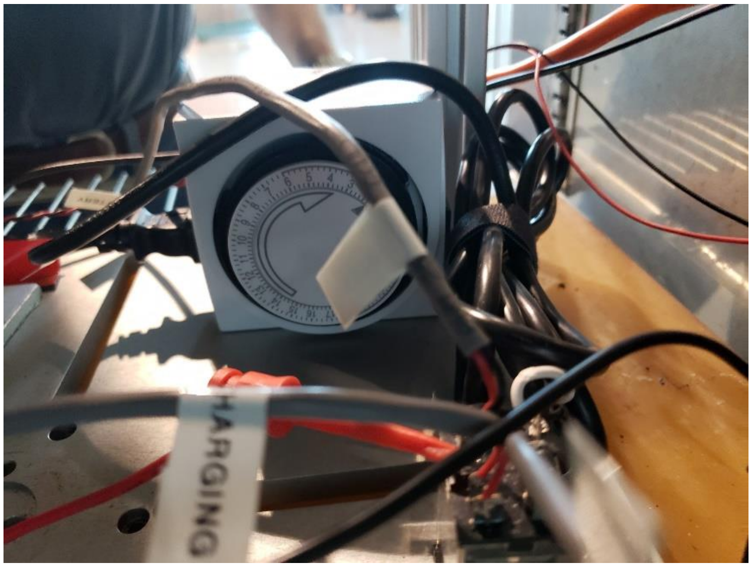


Figure 2 Mechanical timer and relay in the foreground

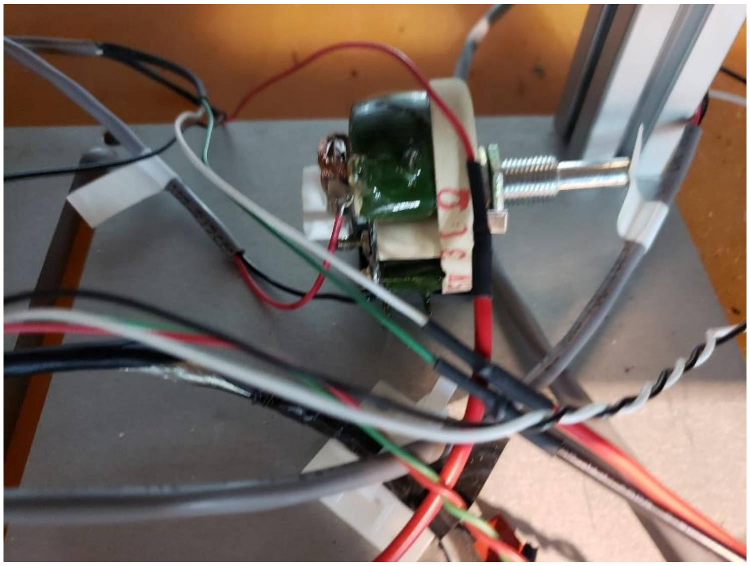


Figure 3 Load resistor

Results after approximately 40 hours. The humidity has varied between 25% RH to 75% RH.
The shaded box represents a disconnect in the data acquisition device and subsequent restart

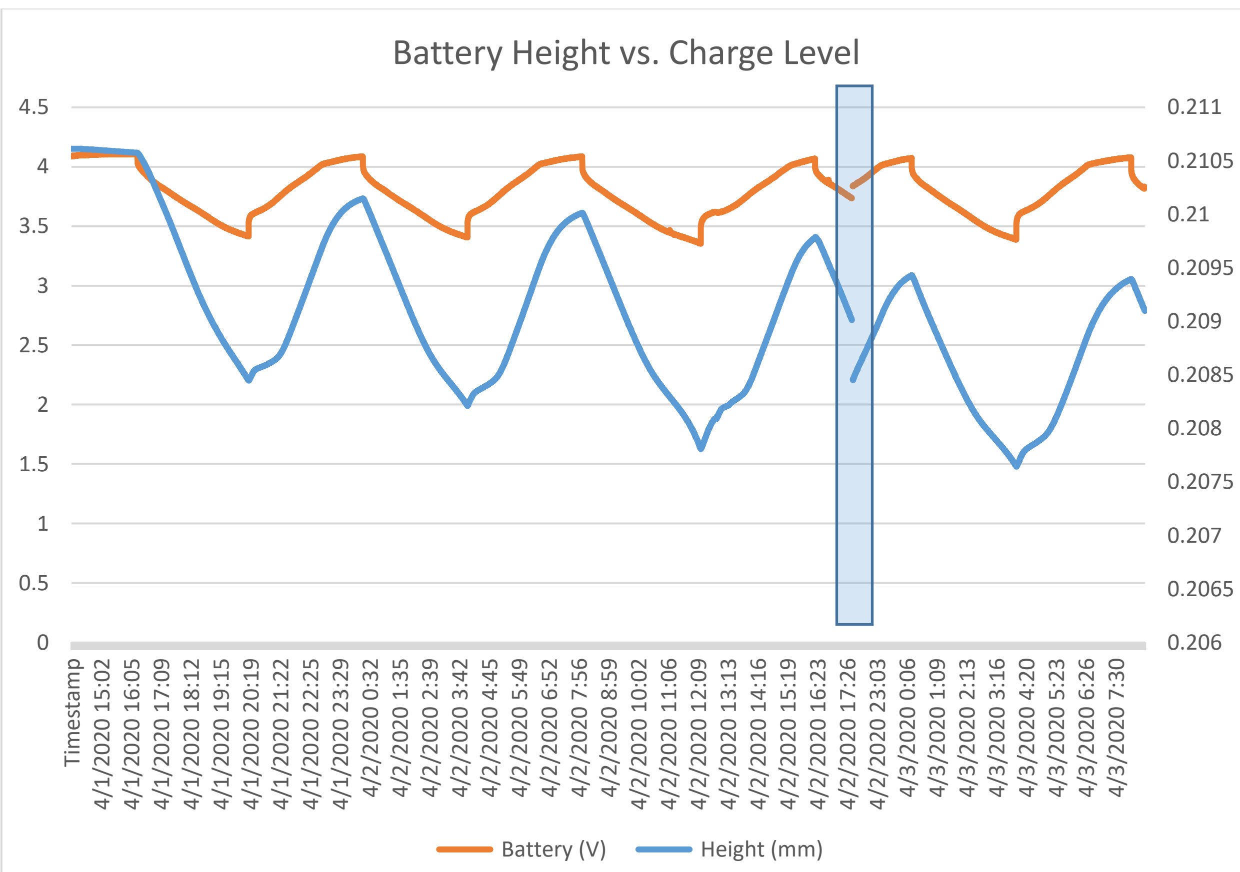


Figure 4

Flexible Sensor Systems

The graph of Fig. 4 represents the relationship between the charging cycles and the height (thickness) of the battery. As shown the battery swells as it charges and shrinks with discharge.

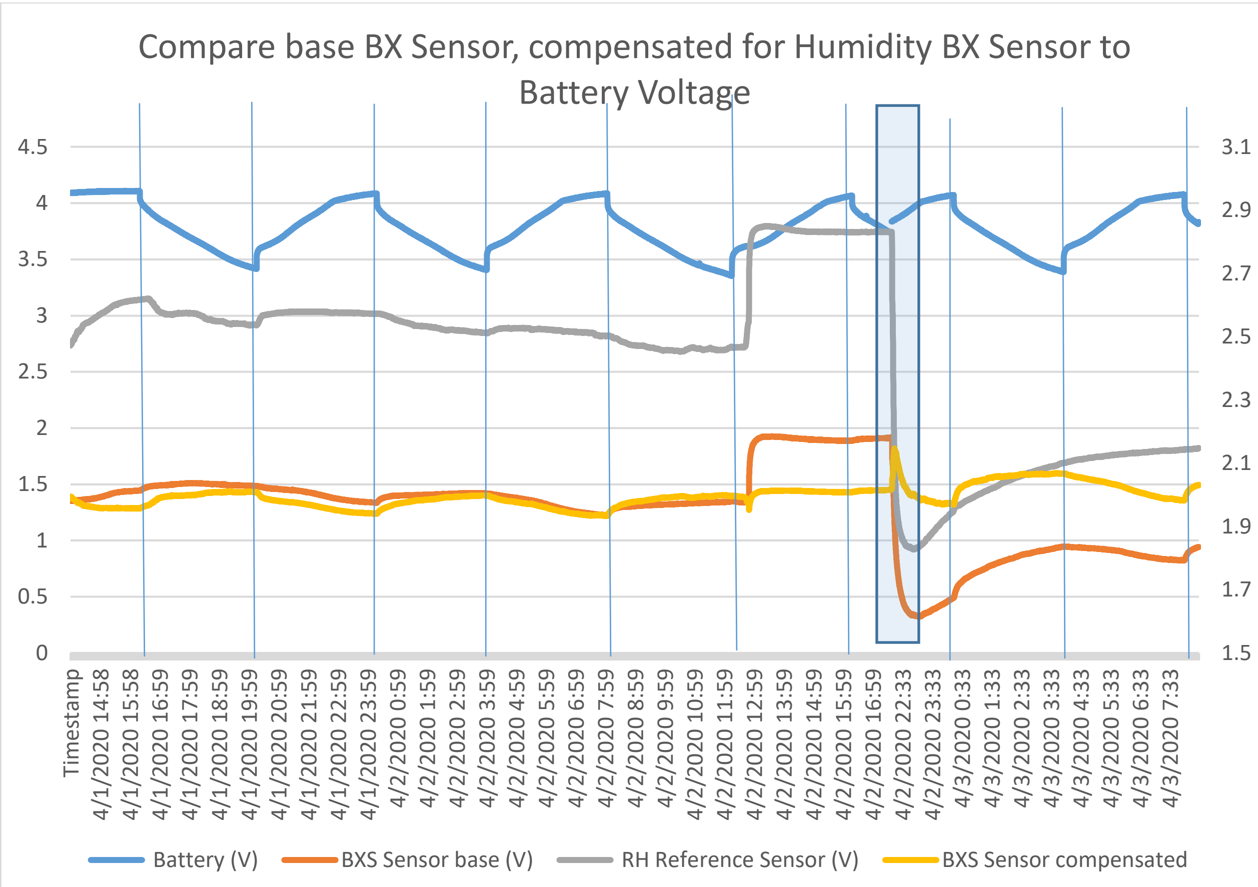


Figure 5

In Fig.5 this graph illustrates the relationship of the base sensor to the changes in humidity. Random changes were allowed in the initial part of the test. Then the humidity was forced to 75% RH. As noted in the legend, the gray line is the humidity reference Bend Sensor®. It is, as mentioned, fixed to the aluminum base plate. Its changes are based solely on the environment and not the movement of the sensor. The orange line gives the raw readings of the combination of the battery movement and the effects of the humidity. The yellow line is the compensated values for the battery expansion.

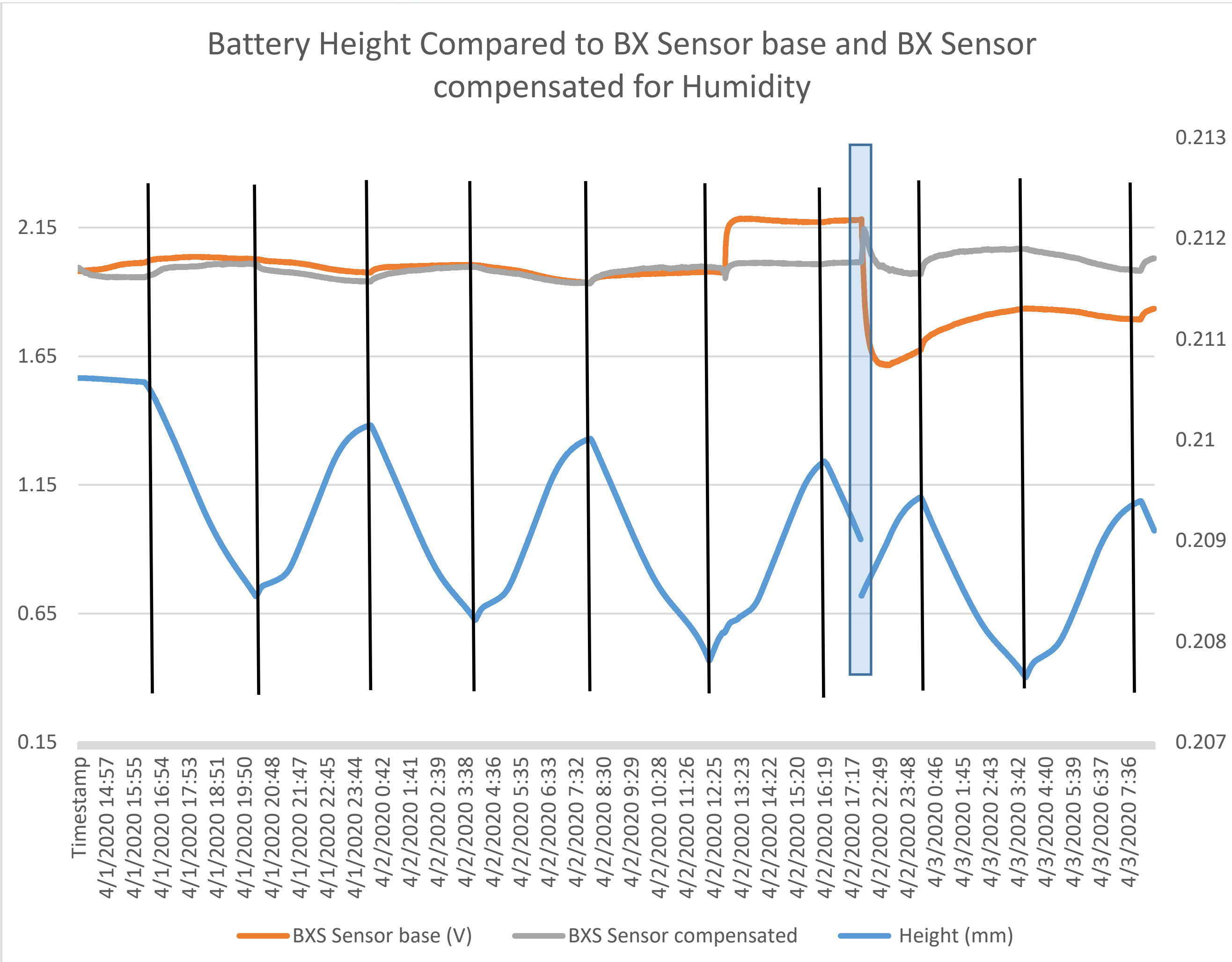


Figure 6

The final graph, Fig 6 shows the correlation between the Bend Sensor® and the height of the battery cell. Figure 4 has already shown the relationship of the height with charge state of the battery. The relationship shown here confirms the sensor tracking the height or expansion changes of the battery.

Conclusion and summary. In the process of collecting this data several iterations of sensor construction and mounting methods were used. Here are our conclusions from the results:

- Sensors printed on several thicknesses of material. Kapton (polyimide film) of .005” [.127mm] thickness with a 0.001” [.025mm] polyester overlaminate were used. These yielded little or no change to the resistance. The strength of the material did not allow the sensor to deform sufficiently to show a change in resistance. Thickness of material is critical to success. This does bracket the stress in the system. Less expensive materials like polyester could be used.
- A pressure sensitive adhesive was used on one test set up. It slips too much to get good data on the small movements of the battery. Additional tests will utilize clear polyesters and UV curable adhesives for production ease.
- The initial humidity compensation equation is very close in this application. We are looking more closely at the data in the rapid transition zones to fine tune the compensation algorithm.

The tests confirm that the Bend Sensor® can easily and consistently monitor the changes in the battery due to the expansion of the envelope. There is compensation for the changes in the sensor, due to other factors, primarily humidity.