Detailed Test Results

True Balancing – Gen 3 – Phase 2

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Overview of this Report

This report presents complete results of each test we have performed in Phase 2 of the True Balancing Gen 3 system.

We are conducting the tests in three phases:

Phase 1: One 12-cell module with 2.4Ah NMC cells

Phase 2: Two 12-cell modules connected in series, also with 2.4Ah NMC cells

Phase 3: One 12-cell module with LFP cells to verify True Balancing performance with an alternate battery chemistry

All test results in this report are from Phase 2.

Overview of Phase 2 Testing

The goal of phase 2 tests is to quantify the performance of True Balancing with two 12-cell modules connected in series.

Pack 1 and pack 2 (from Phase 1) were connected in series with no changes in the individual cells in each of the packs.

Pack 1 comprised the lower 12 cells; pack 2 comprised the upper 12 cells.

In Phase 2, the number of wire turns on the current transformer was increased from 10 to 30 to achieve higher resolution in coulomb counting.

All tests were performed at ambient room temperature.

Comment on the cells in this set-up

We used the same cells as in Phase 1 – cells that we have been using (and in some cases abusing) for the past 4 years of testing the performance of True Balancing.

This creates test conditions that represent real-world situations in which a battery has been used for an extended period of time in an uncontrolled environment. We are not using "ideal cells" and "ideal conditions" in our tests. We are making the test conditions as close to real world as possible and as tough as possible.

Tests Performed to Date

As of Aug 26, the following tests have been completed:

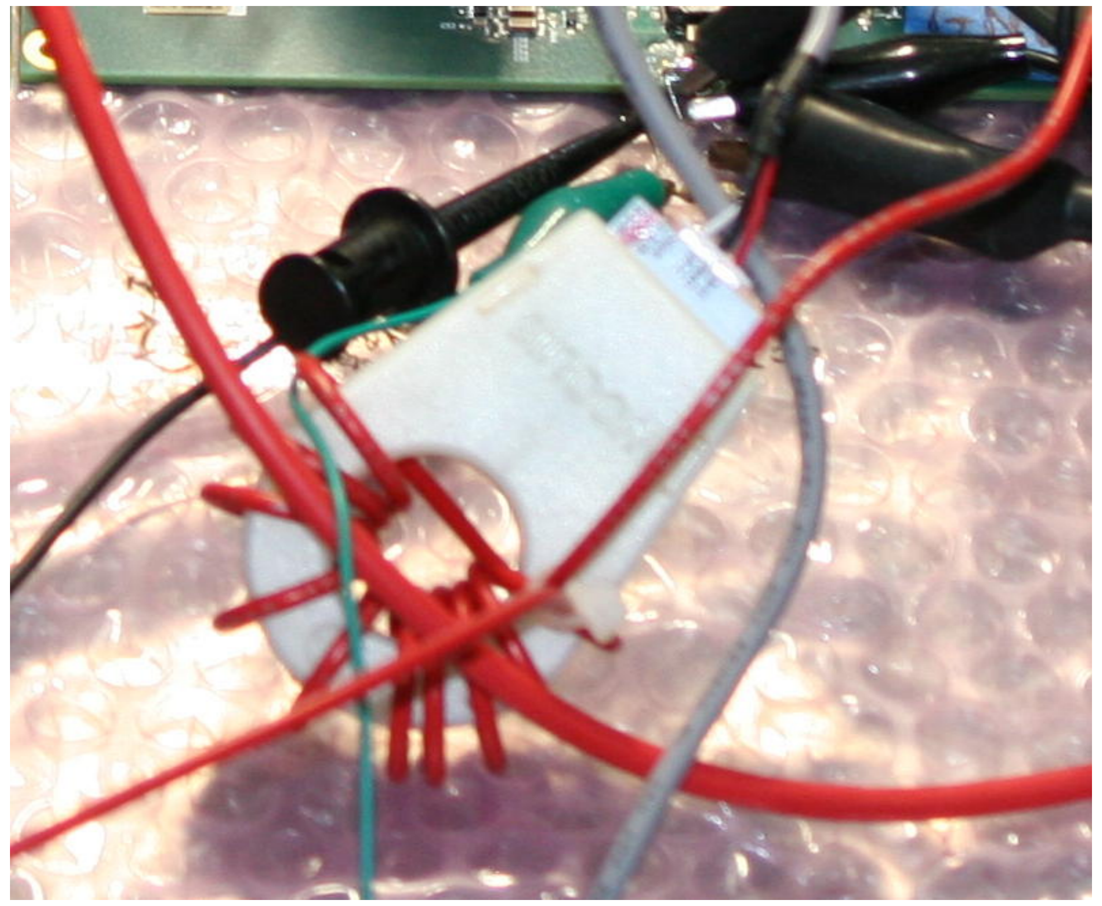
Test 1: Coulomb counter accuracy test

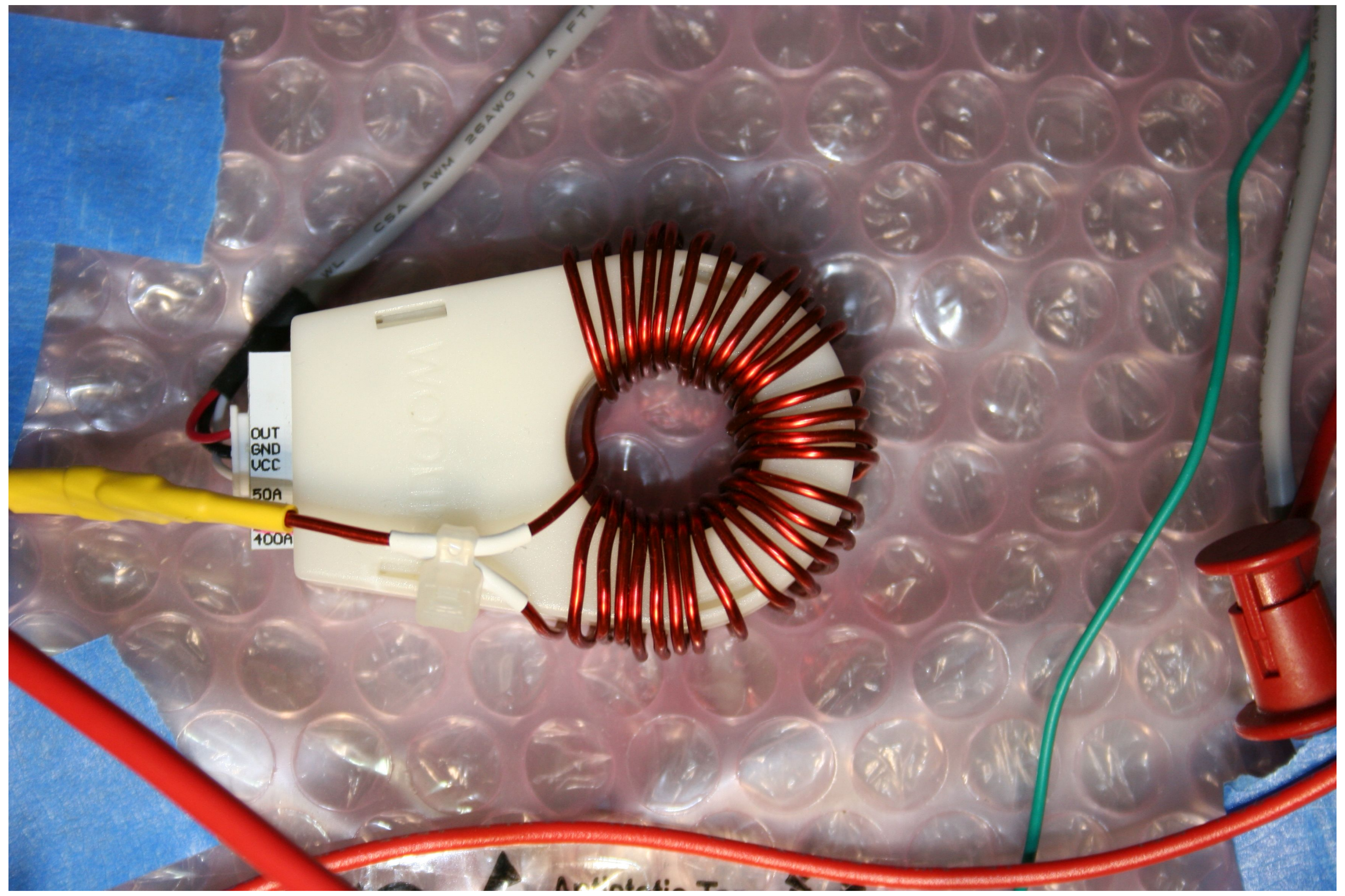
Test 2: Measure capacity gain in 24-cell pack over several cycles of charge and discharge

Test 1: Coulomb Counter Accuracy Test

Test Set-up

- Compare readings from the coulomb counter to readings from a lab instrument with 0.1% accuracy (a Wavetek 85XT)
- In Phase 2, the number of wire turns was increased from 10 to 30 to improve the resolution of the coulomb counter.





Test 1: Coulomb Counter Accuracy Test

Test Procedure and Results (part 1)

- Recalibrated the coulomb counter at the start of the test
- Placed a load of 38Ω @ 1.26A across the 24-cell series
- The lab instrument showed a constant current of 1.503 amps
- The coulomb counter showed a constant current of 1.483 amps
- The coulomb counter reads current (A) 1.33% lower than the lab instrument, and it reads coulombs (Ah) 1.0% lower. There appears to be a compensating integration error term in coulomb measurement.

Test 1: Coulomb Counter Accuracy Test

Test Procedure and Results (part 2)

- Continued to run the current for 130.5 minutes
- This is a total of 3.27Ah per the lab instrument
- The coulomb counter measured 3.237Ah
- This is 1.00% lower than the value from the lab instrument

Comment: The difference of about 1% between the lab instrument and the coulomb counter (which we use during the tests) is typical for the grade of coulomb counter that we are using.

Test 2: Measure Capacity Gain During Charge and Discharge

Step 1: First charge cycle

- Discharge all 24 cells to 0% SOC (using True Balancing to balance during discharge) to start the test with a completely discharged battery pack.
- Start charging at 1.50A with True Balancing off, until first cell reaches 100% SOC
  - Counted 195Ah
  - COC = 407mA
- Turned on True Balancing with zero charge current for 38 minutes
- At 38 minutes, resumed charging until all cells were at 100% SOC
  - Counted 238Ah total capacity in the pack
  - COC = 290mA

Result: Gain in capacity of 22.1%

Test 2: Measure Capacity Gain During Charge and Discharge

Step 2: First discharge cycle

- Start with the pack at the end of step 1: All cells at 100% SOC.
- Start discharging through 38Ω @1.26A with True Balancing off, until first cell reaches 0% SOC
  - Counted 183Ah
  - COC = 283mA
- Turned on True Balancing with zero charge current for 23 minutes
- At 23 minutes, resumed discharging until all cells were at 0% SOC
  - Counted 223Ah total capacity in the pack
  - COC = 270mA

Result: Gain in capacity of 21.9%

Test 2: Measure Capacity Gain During Charge and Discharge

Step 3: Second charge cycle

- Start with all cells at 0% SOC from end of step 2
- Start charging at 1.50A with True Balancing off, until first cell reaches 100% SOC
    - Counted 198Ah
    - COC = 213mA
- Turned on True Balancing with zero charge current for 38 minutes
- At 38 minutes, resumed charging until all cells were at 100% SOC
    - Counted 248Ah total capacity in the pack
    - COC = 60mA

Result: Gain in capacity of 25.3%

Test 2: Measure Capacity Gain During Charge and Discharge

Step 4: Second discharge cycle

- Start with the pack at the end of step 3: All cells at 100% SOC.
- Start discharging with True Balancing off, until first cell reaches 0% SOC
    - Counted 192Ah
    - COC = 277mA
- Turned on True Balancing with zero charge current for 44 minutes
- At 44 minutes, resumed discharging until all cells were at 0% SOC
    - Counted 231Ah total capacity in the pack
    - COC = 230mA

Result: Gain in capacity of 20.3%

Test 2: Measure Capacity Gain During Charge and Discharge

Step 5: Third charge cycle

- Start with all cells at 0% SOC from end of step 4
- Start charging with True Balancing off, until first cell reaches 100% SOC
  - Counted 196Ah
  - COC = 220mA
- Turned on True Balancing with zero charge current for 38 minutes
- At 38 minutes, resumed charging until all cells were at 100% SOC
  - Counted 248Ah total capacity in the pack
  - COC = 60mA

Result: Gain in capacity of 20.9%

Test 2: Measure Capacity Gain During Charge and Discharge

Comments

- Measured gain in capacity with the 24-cell pack is about 20%
- This is approximately double the capacity gain we measured with the 12-cell packs
- We need to perform further analysis to understand why gain in capacity with the 24-cell pack is so much greater than with the 12-cell pack