DEVELOPMENT AND TESTING OF AN ULTRA BATTERY EQUIPPED HONDA CIVIC

Donald Karner, Tyler Gray, Russell Newnham

Electric Transportation Applications, 430 South 2nd Ave, Phoenix, Arizona

1. INTRODUCTION

A license for this technology, termed the 'Ultra Battery', has been purchased by East Penn Manufacturing Co., Inc. (East Penn), and they are currently adapting the technology for production at their facility in Pennsylvania. As the final step in demonstrating this technology as suitable for use in HEVs, the US Department of Energy, the ALABC and East Penn are working with Electric Transportation Applications (ETA) to retro-fit a Honda Civic HEV with an Ultra Battery from East Penn (EPUB). After completing the conversion, ETA will then test the novel HEV in accordance with, and in cooperation with, the Advanced Vehicle Testing Activity of the US Department of Energy FreedomCAR and Vehicle Technologies Program. This approach will allow direct performance comparisons with the current battery technologies used in modern HEVs. A profile, termed the 'Simulated Honda Civic HEV Profile' has been developed in order to provide reproducible laboratory evaluations of different battery types under 'real time' HEV conditions. An Ultra Battery from Furakawa has just commenced operation under this profile. The performance of Ultra Batteries from Furakawa (FUB) and standard lead-acid batteries (included for baseline data) has been evaluated under both standard cycling conditions and a simple HEV screening test. The Ultra Battery operated for over 32 000 HEV cycles with minimal loss in performance, whereas the standard lead-acid unit experienced significant degradation after only 6273 cycles.

2. EXPERIMENTAL DETAILS AND DISCUSSION

Development of the Simulated Honda Civic HEV Profile. ETA has performed extensive studies on a fleet of standard Honda Civic HEVs. This has included 160000 mile road tests and operation on a dynamometer (dyno) under UDDS and HWFET schedules to determine fuel economy. All relevant battery parameters have been monitored during this testing and, as a result ETA, has obtained an excellent understanding of how the batteries operate in such vehicles. Data obtained during dyno studies and field operation of Honda Civic HEVs have been used as a basis to formulate a profile (termed the 'Simulated Honda Civic HEV Profile') that simulates the power requirements of the batteries in these vehicle. The profile is based on data derived from five independent passes through the UDDS and the HWFET schedules, as well as information from the field regarding the affect of air-conditioning, hill climbing, etc., on battery state-of-charge. One pass through the Honda Civic profile takes 2140 s and provides 17.7 miles of operation at an average speed of 28.9 mph - 3 months of duty under the profile provide > 64 000 miles of simulated driving. Also, one pass through the schedule requires the battery to deliver and accept 2.89 Ah. Hence, over the design life of the vehicle (160 000 miles), the battery would need to deliver 26 124 Ah, or the equivalent of almost 4000, 100% SOC cycles.

Capacity and resistance of Furakawa Ultra Batteries. Each of ten FUB modules was subjected to cycling to determine an initial capacity, as well as assess variations in performance from module to module. The 1C performance of the modules was found to vary from 7.1 and 7.5 Ah. Capacities at different rates were also determined and these were found to be in good agreement with those obtained by CSIRO (from 20 to 40 mohm between 100 and 0% SOC).

.

Benchmarking of Furakawa Ultra Battery and Genesis battery HEV screening test. The performance of a FUB and a Genesis battery (10 Ah at 1C rate, nominal) have been evaluated under the following HEV screening test;

(i) discharge at 1C for 30 min (~ 50% SOC); (ii) rest for 10 s.; (iii) charge at 2C for 60 s; terminate test if voltage hits 17.5 V; (iv) rest for 10s; (v) discharge at 2C for 60 s. If battery temperature exceeds 50 ^{o}C, cycling is suspended until the temperature drops to 49.5 ^{o}C; (vi) repeat (ii) through (v) until the voltage during (v) drops to 11.5 V (~40% SOC), then go to (vii); (vii)rest for 10s; (viii) charge at 2C with a TOCV of 15 V until the equivalent of 2C for 60 s has been returned; (ix) rest for 10s; (x) discharge at 2C for 59.1 s; If battery temperature exceeds 50 ^{o}C, cycling is suspended until the temperature drops to 49.5 ^{o}C; (xi) repeat (vii) through (x) 100 times (note, changing the discharge time from 60 s to 59.1 s results in the SOC of the cell increasing by 5% over the 100 repeats) then go back to step (ii).

The results are shown in Figs. 1 and 2. The blue, bottom line represents the battery voltage taken at the end of the 1 min discharge periods, i.e., at the end of step (v) or step (x), above, (termed end-of-discharge voltage, or EODV). The red, middle line is simply the temperature of the battery, as measured via a thermocouple attached to the side of the battery (and covered with a small piece of insulating foam). The green line located at the top of the graph, which represents the battery voltage taken at the end of the 1 min charge periods, i.e., the end of step (iii) or step (viii), above (termed top-of-charge voltage, or TOCV).

The EODV (blue, bottom line) started at 12 V and slowly decreased during 2700 cycles until it had reached 11.5 V (~40% SOC). At this point, step (x) was activated which resulted in a gradual increase in SOC of 5% over the following 100 cycles (note, for the sake of clarity, the data during these 100 steps is not shown). When the profile restarted at step (ii), the EODV has risen by ~ 200 mV and the gradual decrease in EODV recommences, although the time taken to reach 11.5 V is now less as the SOC started at ~ 45%, rather than the 50% at the commencement of cycling. This process continued for 11 of these SOC corrections, at which stage the TOCV reached 17.5 V (not shown on graph) and cycling was terminated (6273 HEV cycles). In effect, the number of SOC corrections in relation to the total number of cycles performed (573 cycles/correction) can be used as a simple measure of the charging efficiency of the battery under these cycling conditions.

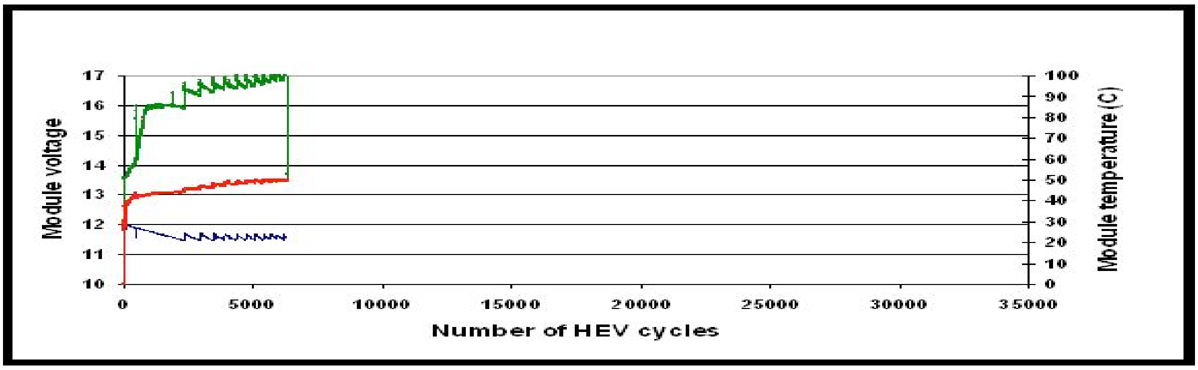

Fig. 1, Performance of Genesis module under the HEV screening test.

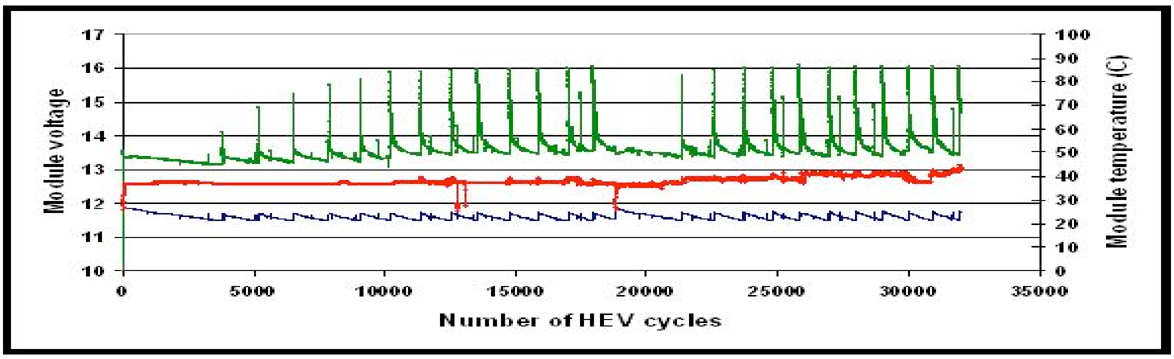

Fig. 2. Performance of FUB module under the HEV screening test.

The TOCV (green top line) started at ~ 13.5 V, and then increased to 16 V within the next 1000 cycles. It then remained at ~16 V until the completion of 2700 cycles, at which point the EODV had dropped to 11.5 V (~ 40% SOC) and an SOC adjustment was activated (see step (x)). When normal cycling restarted, the TOCV jumped immediately to 16.8 V, and then decreased to 16.5 V over the next 50 cycles. During the 11 SOC corrections experienced by the battery, the TOCV continued this upward zigzag behavior until the 17.5 V cutoff was activated after 6273 cycles. The initial capacity of the battery was 9 Ah, but this had dropped to just 5.6 Ah at the completion of cycling.

The voltage behavior of the FUB module followed the same general trends as the Genesis battery, except that there were the following notable differences;

(i) the FUB performed many more cycles than the Genesis, and was still in good condition at the end of testing.

FUB - 32 000 cycles, initial capacity = 7.3 Ah; capacity after 19 000 cycles = 7.2 Ah; final capacity = 6.0 Ah.

Genesis - 6273 cycles; initial capacity = 9.0 Ah, final capacity = 5.6 Ah.

(ii) the FUB performed more cycles between SOC corrections.

FUB - 24 corrections over 32 000 cycles (1333 cycles per correction).

Genesis - 11 corrections over 6273 cycles (570 cycles per correction).

(iii) the TOCV immediately after an SOC correction, and the overall average TOCV were much lower for the FUB.

FUB - average TOCV < 14 V; maximum TOCV = 16 V

Genesis - average TOCV > 16 ; maximum TOCV = 17.5 V

3. SUMMARY

- A Simulated Honda Civic HEV Profile has been developed which mimics operation in the field.
- The Ultra Battery has been characterized (capacity and resistance) and tested under a HEV screening test. It was found to be very resistant to polarization during charging.