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Pulse Power Nickel Metal Hydride Battery

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ABSTRACT

EEI bipolar nickel metal hydride batteries and cells were tested under various conditions relevant to consumer and aerospace pulse power applications, with differing power and discharge pulse time requirements. A generic hybrid vehicle specification required that a full scale battery obtain 300,000 life cycles, while being able to deliver 25 kW discharge power after 18 seconds and 30 kW recharge power after 2 seconds. This corresponds to 15 years of normal use. Using this testing procedure, over 300,000 life cycles were obtained (using 25 Wh energy swings, scaled) on single full-capacity cells, with less than 10-15% pulse power capability loss measured. The projected full-sized battery mass was 40 kg and volume was 20 L. Testing of selected cells is continuing. Another test related to an automotive application demonstrated that a 6 Ah cell starting at 50% SOC was capable of being discharged at 200 A for 10 seconds (33C), with an end voltage of 0.945 V. An application involving the use of 1 second discharge pulses demonstrated power densities of about 3 kW / kg and 8.6 kW / L at the single cell and small battery (6 V) levels. About 120,000 cycles were obtained under these conditions. These test cells used thinner electrodes than those related to automotive applications. Based on these data, several alternative pulse power designs are presented.

INTRODUCTION

As a departure from classic cylindrical or prismatic battery packaging approaches, EEI is developing a flat, wafer, bipolar design for the nickel-metal hydride chemistry. Figure 1 shows a sketch of the design concept. Individual flat wafer cells are constructed with outer contact faces with one positive electrode, a separator and one negative electrode. The contact faces serve to contain the cell and make electrical contact to the positive and negative electrodes. The contact faces are sealed around the perimeter to contain the potassium hydroxide electrolyte. To fabricate a multi-cell battery, identical cells are stacked one on top of each other such that the positive face of one cell contacts the negative face of the adjacent cell making a series connected battery. The current is collected at the ends of the cell stack. Structural integrity for the cell stack is obtained by housing the stack in an outer container, which holds the cells in compression.

This battery design has several advantages. The need for conventional terminals, tabs, current collectors, and cell containers is eliminated. Use of available space is maximized, with the headspace for tabs and terminals required in conventional cells eliminated. The path that current has to move in the electrodes and from cell to cell is minimized, since the current flows normal to the plane of the electrodes. Battery impedance is reduced, making this design particularly effective for high rate, power applications. The wafer stack design has excellent thermal conductivity in the planar direction due to the metal foils in the wafer cell that aid thermal management. Compared to conventional cylindrical and prismatic packaging designs, the use of plastic bonded electrodes offers considerable reduction potential in cost and volume.

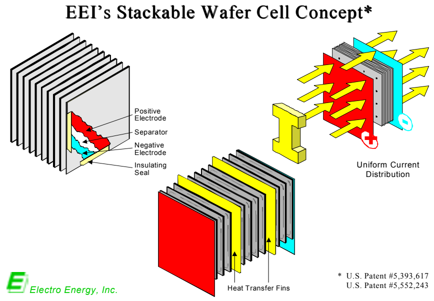

Figure 1. Schematic depiction of the wafer bipolar battery design

HYBRID VEHICLE APPLICATIONS

EEI has performed development of hybrid vehicle batteries under the sponsorship of the Dept. of Energy. Under the test conditions provided, the battery must be able to provide 25 kW of discharge power (after 10 seconds), and 30 kW of recharge power (after 2 seconds) after undergoing 300,000 25 Wh life cycles. To evaluate the power capability of the cell, a test known as the “High Pulse Power Capability” test (or HPPC) was developed. The HPPC test is run every 30,000 life cycles, and is done at 10% SOC increments. In this way, the power capability of a cell or pack as a function of state of charge is determined. Figures 2 and 3 are a reproduction of these test profiles from the PNGV Test Manual (Rev. 3).

Cells using electrodes of nominal 6 Ah capacity and of 6” x 12” area were constructed and tested under this project. Table 1 displays the power performance of a representative series of cells after 300,000 cycles of operation. Note that the data presented is scaled by a “Battery Scale Factor” (BSF), chosen such that the end-of-life requirements of 25 kW discharge power, 30 kW recharge power, and an available energy (Ea) of 0.300 kWh are all simultaneously met at the end-of-life number of cycles. The voltage window on a single cell basis was 1.520 V maximum, and 0.950 V minimum.

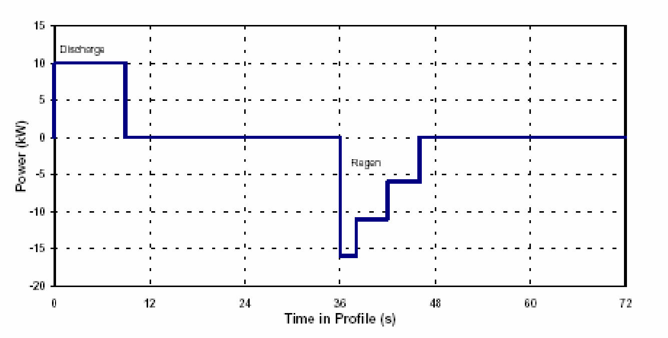

Figure 2. Power assist hybrid vehicle life cycle

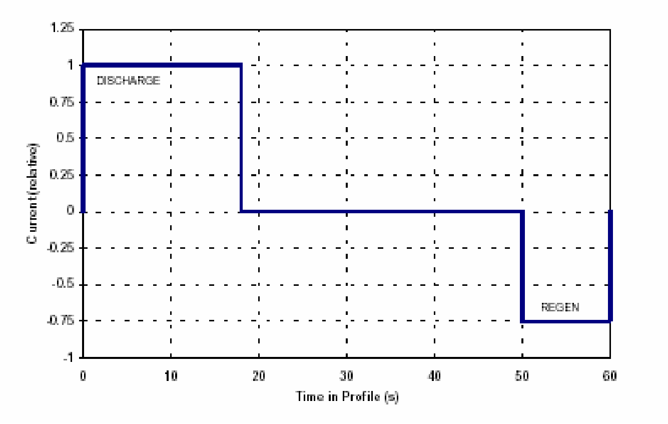

Figure 3. High pulse power characterization profile

The discharge and recharge power characteristics for a cell (scaled by the BSF) are given in Figure 4. One can note that the power and energy requirements are met at end-of-life.

The power and energy fade rate is also of interest. Figure 5 displays the power fade rate for this series of cells while Figure 6 displays the fade in available energy.

The baseline battery design of BSF=289 predicts a weight of 40 kg and volume of 20 L, corresponding to power densities of 0.63 kW / kg and 1.25 kW / L on a 25 kW discharge power basis.

Table 1. Power performance of HV223 cell series

Cell ID	# cycles	BSF	Ea (kWh)	P-dis (kW)
HV223-01	300341	328.5	0.300	25.00
HV223-02	300217	347.0	0.300	25.00
HV223-03	300791	313.5	0.300	25.00
HV223-04	300791	362.3	0.301	25.00
HV223-05	300844	313.8	0.300	25.00
HV223-06	300748	284.5	0.300	25.00
Targets	300000	-	0.300	25.00

SHORT PULSES WITHOUT RECHARGE

There exists various applications where pulse power is needed, but an “on-line” recharge capability is not readily available. A brief analysis of this case follows.

The voltages of a 6 Ah cell of similar design to the HV223 series at the end of 10 second discharge and recharge pulses were examined. The entire set of data is given below as Figure 7. Starting at 50% SOC, the cell is discharged and recharged for 10 seconds at progressively higher currents, ranging from 40 A to 200 A (6 to 30+C rates).

The end-of-charge and end-of-discharge data is given below as Figure 8. This set of data shows that one may expect a current of 240 A will yield an end-of-discharge voltage of 0.9V. These parameters represent a cell which would be competitive in the hybrid vehicle marketplace. To project performance of batteries of higher power than the 25 kW hybrid requirement, the 200 A data may be more relevant than the results of the HPPC testing, since the HPPC specification requires testing at much lower current levels: resistances are calculated from pulse data in the 20-30 A range.

A simple paper design for a battery capable of delivering a series of 180 kW 1 second pulses was done. The relevant measurements and calculations are given as Table 2. Note that the calculated weight was based on a proportional scale-up of a hybrid vehicle design which found that a battery with a scale factor of 289 would weigh 40 kg and occupy 20 L. The calculated discharge power was based on an assumed minimum of 0.95 V.

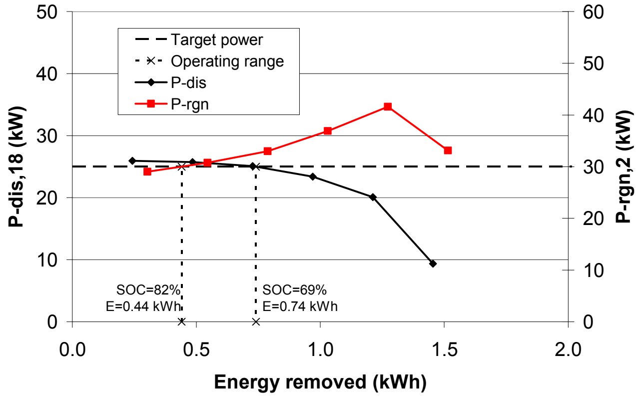

Figure 4. HPPC results for cell HV223-01 after 300,000 cycles

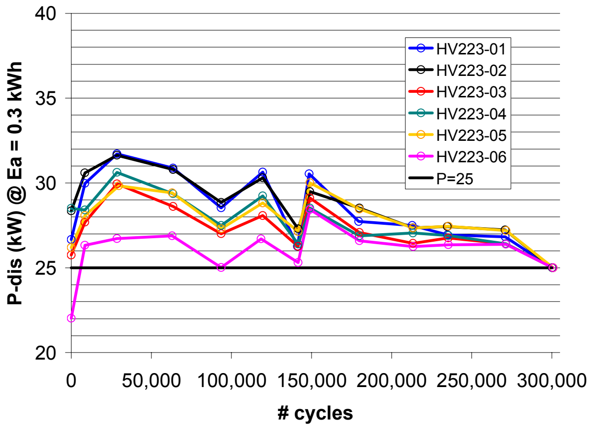

Figure 5. Power fade rate for the HV223 cell series.

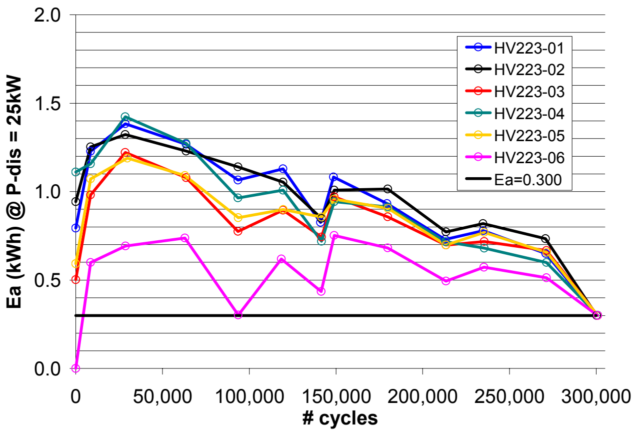

Figure 6. Energy fade rate for the HV223 cell series.

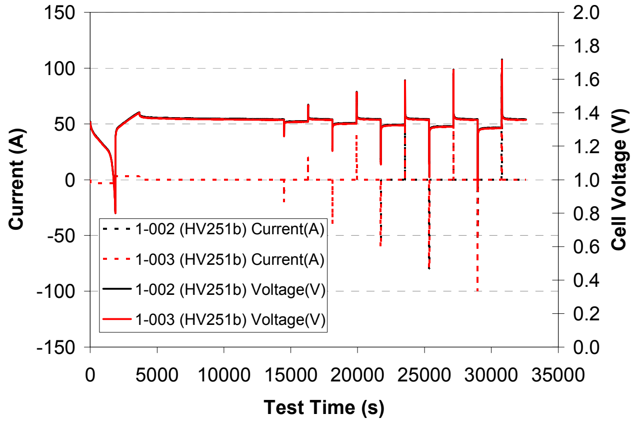

Figure 7. 10 second charge and discharge power test. Note that the graph displays the output of 2 paralleled testing channels.

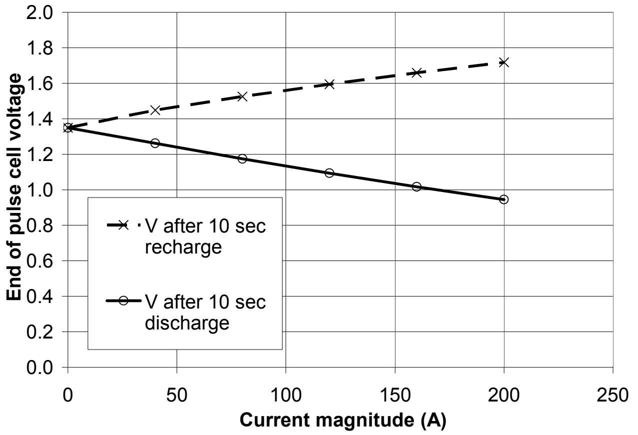

Figure 8. Power performance measurements using high current levels. Data from cell HV251B at 50% SOC.

Also recall that the resistance data was acquired at 50% SOC, and it is assumed that all of the battery energy to 50% is available to be delivered in the pulses. Over 50 pulses would be expected to be delivered, with power densities of 1.76 kW / kg and 3.53 kW / L. Another somewhat better method of estimating the power capability is to include the OCV vs SOC data in the calculation, and to assume that the discharge resistance is constant. This includes the effect of OCV variations, and is somewhat conservative, since the discharge resistance should be lower at SOC levels higher than 50%. The result of this analysis is given as Figure 9. The relationship between battery weight and number of available pulses is given as Figure 10, and it shows that above a minimum threshold size, relatively large incremental gains in number of pulses can be obtained. This method predicts a mass of about 110 kg for a battery capable of delivering 50 pulses.

SHORT PULSES WITH RECHARGE

Other applications may include situations where high pulse power discharge is required and recharge power is available. This scenario was tested as part of peaking battery work sponsored by the U.S. Ballistic Missile Defense Organization under a Phase I SBIR.

To obtain higher power densities with the EEI bipolar technology, one strategy is to reduce the electrode thickness. A cell pack was constructed, and used electrodes which were of 6” x 6” area, but only 1.0 Ah in nominal capacity. These electrodes were about 1/3rd the thickness of those of the hybrid vehicle battery cells previously shown, and were in the 0.002-0.005” range. A trace of a 35C constant current discharge of a 5-cell, 6 V pack is given in Figure 11, and shows that about 2/3 of the 1-hour capacity is obtained, with reasonable pack voltage. Figure 12 shows the performance of the pack on a life cycle consisting of a 18.6 A – 4 second charge, and a 74.4 A – 1 second discharge. At these rates, the discharge power density is nearly 3 kW / kg and 8.7 kW / L volumetrically. These figures include the cell weight and volume only, and do not include the external fixturing required. Such corrections would become less significant as the pack voltage increases, however. The pack was operated under these conditions for approximately 1 week (120,000 cycles). A summary of the performance characteristics is given as Table 3.

CONCLUSION

Data related to high pulse power applications of Electro Energy’s bipolar nickel metal hydride technology were presented. It appears that the technology is capable of both accepting and supplying very high power density pulses, which could be used in a variety of applications.

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Table 2. Design of a battery which delivers 180 kW, 1 second pulses.

Targets	
P discharge (W)	180000
V minimum on discharge	500
I discharge (A)	360
Measured Values	
OCV (V)	1.357
V-1sec (V)	1.04
R-dis, 1 sec at I-dis=200 A (ohm)	0.001585
Calculated Values	
Assumed per-cell Vmin	0.95
I-pred, single cell unscaled (A)	256.78
P-pred, single cell unscaled (W)	243.94
Scaled Values	
Battery scale factor	737.87
Area scale factor	1.402
Electrode area (in^2)	100.9
# cells	526.3

Battery mass (kg)	102.1
Battery volume (L)	51.06
Power density (kW / kg)	1.76
Power density (kW / L)	3.53
Battery capacity @ C-rate (Ah)	8.40
Battery V @ C-rate, 1.25 V per cell	658
Battery Energy (kWh)	5.53
50% E (kWh)	2.77
# pulses to 50%	55

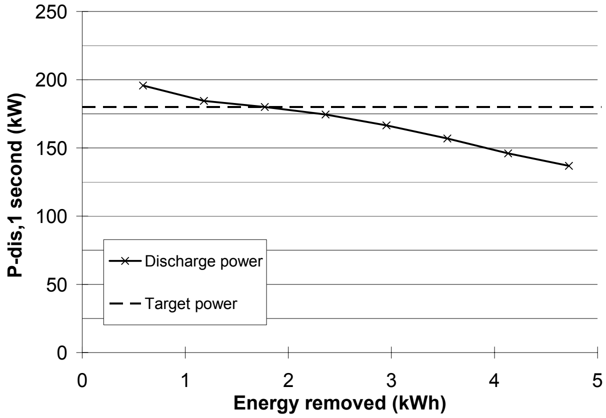

Figure 9. Power vs SOC relationship. Scale factor used is 800.

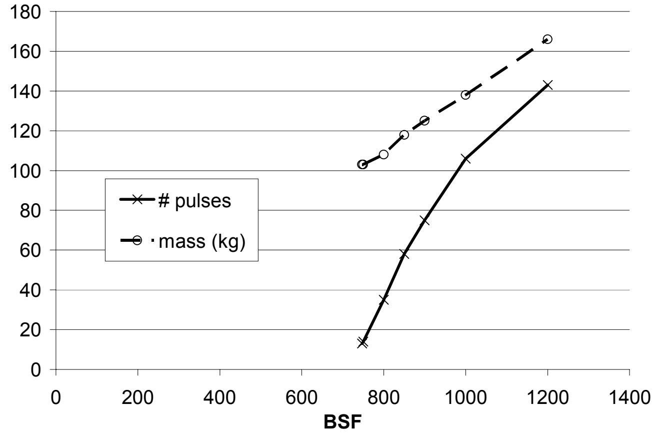

Figure 10. Relationship between battery size and number of available pulses.

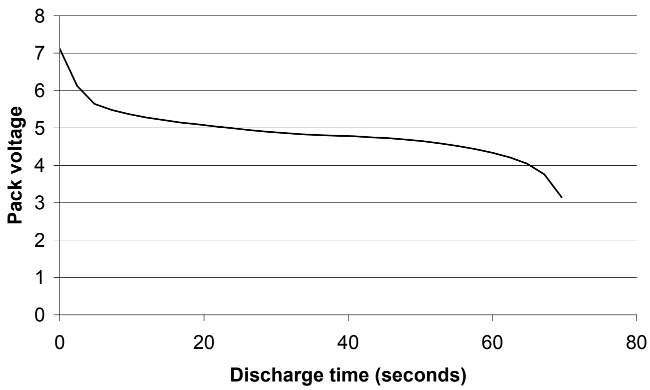

Figure 11. Discharge trace of 5 cell pack PK119 at 35 A (35 C rate).

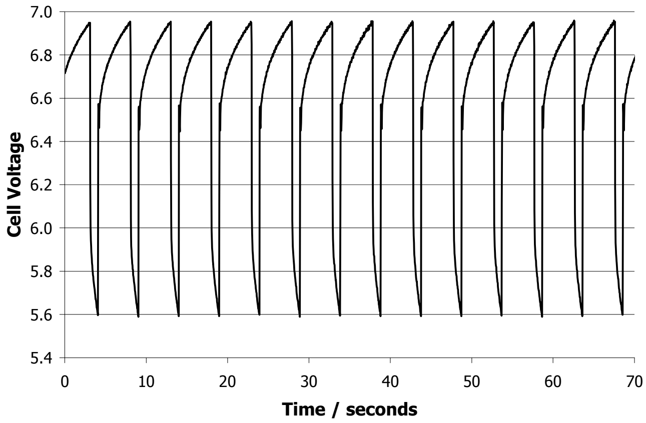

Figure 12. Life cycling performance of cell pack PK119

Table 3. Performance characteristics of cell pack PK119

Discharge current (A)	74.4
End-of-discharge voltage	5.6
Discharge power (W)	416.6
Discharge CD (mA / cm^2)	320
Discharge capacity (Ah)	0.02
DOD (%)	2.0
Stack dimensions	7” x 7” x 0.060”
Stack volume (cc)	48
Stack weight (g)	140
Power density (kW / kg)	2.98
Power density (kW / L)	8.68