LARGE FORMAT LITHIUM ION BATTERY MANUFACTURING

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Abstract

Saft America, inc. Space and Defense Division (SDD), located in Cockeysville, Maryland, is the world leader in providing state of the art lithium ion systems for the demanding defense and space markets. Saft has been manufacturing batteries at its facility in Cockeysville for over 26 years. The major focus of the facility today is large format high power lithium ion cells and battery systems for defense applications.

Saft SDD has been developing lithium ion cells and batteries since 1993. Recent efforts have focused on the industrialization of the technology for use in military hybrid vehicles. Since 2004 Saft SDD has been developing US based manufacturing capability of the entire cell and battery manufacturing processes. This effort is focused under the ManTech program with TARDEC. Overall goals of the program are aimed at improving the technology readiness to support the production of military hybrid vehicles, with areas of focus on improved performance, reliability, manufacturability, and overall cost.

Efforts to date have yielded improvements in performance, reliability, and cost. Advances have been realized for improving the power and cold temperature performance of the high power cells. Power in excess of 20kW/kg has been realized. The improved power performance from the cells improves their use in hybrid vehicles by improving the overall energy efficiency of energy storage. Power efficiencies in excess of 95% have been demonstrated for typical hybrid vehicle duty cycles. Operation at temperature less than -40°C has also been tested. Operational improvements and design activities, with an emphasis on manufacturability, have led to a lean production operation for the electrode, cell, and battery manufacturing activities. These efforts have led to a dramatic reduction in cell cost since 2004. These products are offered as complete battery systems, fully design and manufactured and Saft SDD.

1.0 Introduction

Saft SDD is a fully integrated facility complete with research, development and manufacturing capabilities. Saft SDD produces complete energy storage systems, including electrode manufacturing and locally made hardware to assemble the cells, modules, and system. Saft SDD also performs all of the electrical tests for both the cells and the batteries in house.

One major focus of the facility is large format high power Lithium Ion cells and battery systems for defense applications. Recent effort has focused on the industrialization of the technology for use in military hybrid vehicles, under the scope of a ManTech program with TARDEC. Overall goals are aimed at improving the technology readiness to support the production of military hybrid vehicles, with areas of focus on improved performance, reliability, manufacturability, and overall cost. All of the improvement efforts utilize design for manufacturing techniques and results are carried across the entire product range at Saft SDD to develop a standard product line.

The Saft SDD HEMV standard series of batteries is designed specifically for use in military hybrid vehicles. The HEMV scalable design can be configured with 4 to 8 standard modules, for a nominal system voltage range from 175V to 350V. The HEMV pack design is based around the VL34P cell design, a cell within Saft SDD's P Series (High power) cell line.

2.0 High Power Cell Technology

Saft has been developing high power battery systems for military and automotive applications for the past 12 years. This high power battery technology has been steadily improving as advances in electrochemistry are proven and implemented. The VL34P cell was developed to provide the ideal dual performance of power and energy suited for military vehicle applications. This cell has been used in series hybrid applications to support battery only operation, silent watch and drive assist. The performance characteristics of the cell make it an ideal candidate for integration into battery systems for hybrid electric drive vehicles.

The cell incorporates improvements in many aspects of the cell design. The electrochemical design has been updated to improve the performance of the cell for high rates and low temperatures. It has been repackaged to improve the volumetric and gravimetric power and energy densities, while moving to lower cost components and processes. Improved packaging and assembly methods have also allowed for a significant reduction in the internal resistance of the cell, resulting in increased power, improved energy, and lower heat generation. This allows for a uniform temperature distribution within the cell and a means of effectively removing heat from the cell to improve cell life. The following table is a summary of the performance characteristics of the VL34P Li-Ion cell.

Table I – VL34P Performance Characteristics

	Units	Value
Mass	kg	0.94
Volume	L	0.41
Charge Voltage	V	4.1
Nominal Capacity	Ah	33
Specific Energy	Wh/kg	120
Energy Density	Wh/dm3	280
Terminal-to-Terminal Length	mm	184
Max Discharge Current @ 25°C - Continuous	A	500

Max Discharge Current @ 25°C – 2 sec pulse	A	1900
1kHz AC Impedance	mΩ	0.4

The VL34P cell exhibits a uniform low resistance over the SOC range is ideal for hybrid vehicle type applications that operate in the 30-70% SOC range.

2.1 VL34P Rate Performance

The VL34P cell was discharged at various rates while at 25°C and -30°C in order to characterize its performance. The results confirm the excellent rate capability of the cell. The cell can support a 510A (15C rate) constant current discharge and still deliver its full capacity. Figure 1 shows the results of the testing.

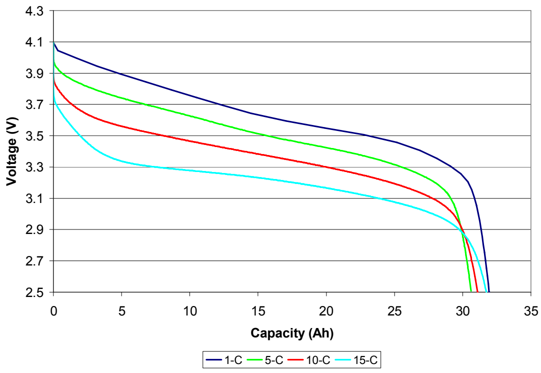

Figure 1 – VL34P Constant Current Rate Capability @ Room Temperature

Figure 2 shows a similar series of constant current discharge tests at -30°C. The excellent cold temperature performance of the cell is shown with 85% of the cell capacity delivered at C rate discharges at -30°C.

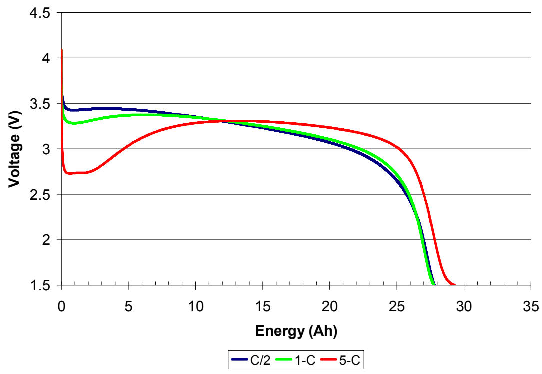

Figure 2 – VL34P Rate Capability @ -30°C

Because of the low internal resistance, the cell is able to handle large continuous currents and still maintain an internal temperature that is acceptable. A continuous constant power discharge at 15C shows that the cell can sustain a draw of 1.6 kW for over 3.5 minutes before reaching end of discharge voltage, while delivering 29.7 Ah capacity.

2.2 Cold Temperature Performance

Even at cold temperature, over 80% of the capacity can be removed from the cells, at current up to 10C (340A). The effect of the self heating of the cells at cold temperature is seen for the higher current draws at 5C and 10C (170A to 340A). Observe the dip in voltage in the discharge curves and subsequent rise, especially pronounced at higher rates. This self heating is due to higher internal resistance at cold temperature which allows the cell to self heat, which in turn reduces internal resistance allowing for more power and energy usage. The cell has also been shown to deliver current at C/10 and C/3 rates at temperatures as low as -60°C.

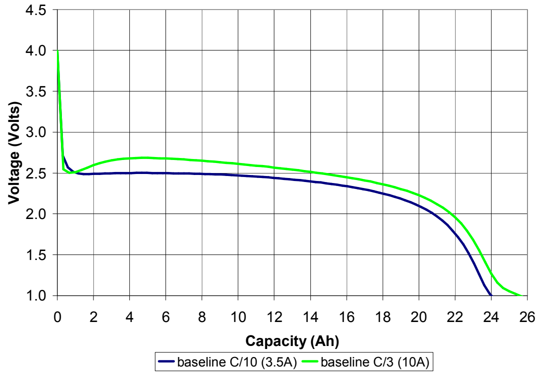

Figure 3 – VL34P Rate Capability @ -60°C

It is shown that the design of the cell allows for removal of over 70% of the capacity of the cell at extreme cold conditions of -60°C.

2.3 VL34P Pulse Discharge Power

Pulse testing was performed on the VL34P. 4.7 kW constant power pulses were applied to the cell for 2 seconds, followed by 30 second rests. Twenty six (26) pulses were completed, with the twenty seventh pulse lasted 1.8 seconds before hitting the lower voltage limit. The average discharge current during the pulse chain was 1,350 A, with the minimum current 1,150 A, and a peak current of 1,850 A. Over 23 Ah of energy was discharged from the cell during the pulse series, again confirming the high rate capability of this cell. The results are shown in Figure 4 below.

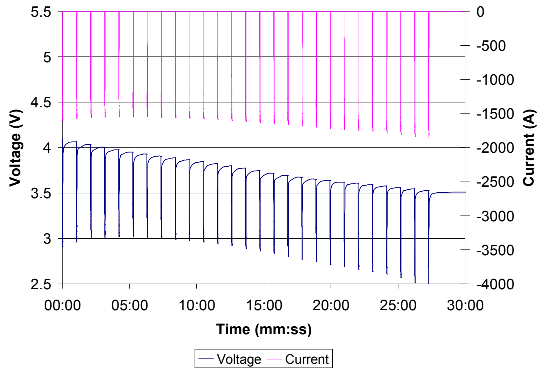

Figure 4 - VL34P 4.7kW 2 sec Pulse Discharge Power

3.0 VL34P Module Performance

In order to fully evaluate the VL34P cell, testing was done at the module level to quantify the heat generation during cycling. Testing was done in ambient air at 28°C with no forced air cooling, only natural convection. Various tests were run on the VL34P modules. Thermocouples were attached to the cells in the modules to fully evaluate the cell temperatures at various locations. Figure 5 shows results from cycling the VL34P module. The initial testing was run at a constant current cycle of 50A for 3 hours. The cycling was performed around 50% SOC with a 30sec charge and 30 sec discharge. The temperature for the cycling at 50A stabilized at 37°C. This testing was immediately followed by cycling at 100A for three hours under the same conditions. The temperature for the cycling at 100A stabilized at 45°C.

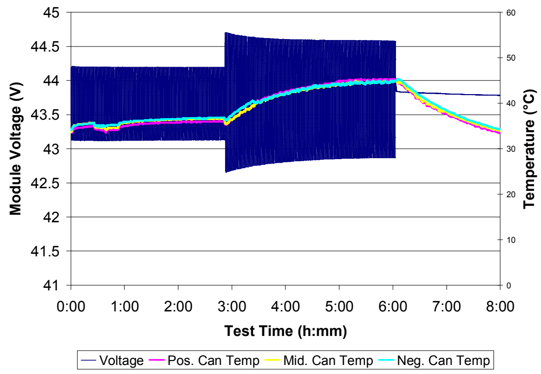

Figure 5 - VL34P Module Cycling: 50A Cycling followed by 100A Cycling

The cycling performance shows that the lower cell internal resistance results in less heat generation rates that can be easily managed with simple cooling methods.

4.0 Heat Generation and Thermal Management

A distinct advantage with the cells developed by Saft SDD is the low internal resistance and resulting low heat generation. In a HEMV-7 system with a typical duty cycle that results in a 150A RMS average current in and out of the battery pack, the resulting steady state heat generation is <10W per cell, or 0.8kW of heat at the pack level. At this current the charge power is 46.6kW and the discharge power is 45.0kW, for a power efficiency of 96.5%. For a typical duty cycle that results in a 200A RMS average current in and out of the battery pack, the resulting heat generation is <18W per cell, or 1.5kW of heat at the pack level. At this current the charge power is 62.9kW and the discharge power is 60.0kW, for a power efficiency of 95.3%. This shows a very efficient design with minimal losses due to electrochemical inefficiencies internal resistance in the system.

The 0.8kW of heat generated with 45kW cycling of the pack requires the same heat rejection rate as a crew compartment occupied by 8 idle people. The cell and module within the pack are specially designed to allow for easy heat rejection from the components that generate the heat. The battery pack design is flexible and can be equipped with liquid cooling or air cooling, while still maintaining the sealed box design. Saft

5.0 Ultra High Power Technology

In addition to the industrialization of the high power lithium ion cells, Saft has also developed a series of cells with ultra high power cells capable of continuous discharge power of over 10kW/kg and pulse power of over 30kw/kg, in a 5Ah cell format called the VL5U. SAFT focused its development efforts in two main areas. These are improving the mechanical bussing of Li-ion cell and further optimization of the electrochemistry. Providing such increases in power required multi-science approach where mechanical and electrical engineering interfaced with materials science and electrochemistry. In addition, the development effort is also built around standards which have been industrialized to allow for a high level of technology that can be manufactured.

Increasing the power capability of the electrochemistry has been a lengthy process. It involved a number of iterations with studies of both active and inert materials, variations in electrode morphology, exploration of novel manufacturing processes, etc.. In late 2007 SAFT put all acquired knowledge to use and produced the first pilot run of a prototype Ultra High Power cell. Table II shows the progression of SAFT's Li-ion technology over the years expressed in terms of capacity and impedance evolution. The 2006 variation of the technology only employs the improved mechanical design of the cell, without any additional advances in electrochemistry.

Table II – Power Evolution of Lithium Ion Cells

	Capacity, Ah	**Impedance, mΩ**		**Weight,** grams
		AC (1000Hz)	2 sec	
2002	**6.2**	**0.85**	**1.6**	**320**
2006	**6.2**	**0.5**	**1.25**	**335**
2008	**5.0**	**0.3**	**0.8**	**350**

The latest VL5U cell uses a novel approach to cell interconnection and major improvements to the electrochemistry. These cells are demonstrated to have exceptional rate capability with continuous discharge power exceeding 10kW/kg.

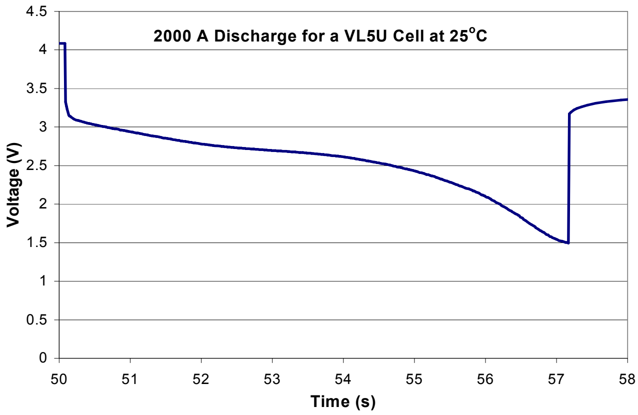

Figure 6: Continuous discharge of VL5U cell

Figure 6 shows complete discharge of VL5U cell over 7 seconds time period. In this test the cell delivered 4Ah from its rated 5Ah capacity. This represent 80% capacity delivered at 400C current rate. All this comes with very little heat generation. Temperature did not exceed 50°C measured on the cell skin and on the terminals. The actual average power delivered during this test is 5200W or over 14kW/kg of specific power.

For determining pulse power, the cell was subjected to pulses with varying duration, typically 2 seconds for long pulses and few hundred milliseconds for short pulses. Figure 7 shows a 2 seconds constant 3000A pulse test and a Figure 8 shows constant 4000A pulse test lasting 200 msec. From these tests the specific pulse power of these cells is measured at 20kW/kg for 2 seconds pulse power and close to 30kW/kg of milliseconds long pulse.

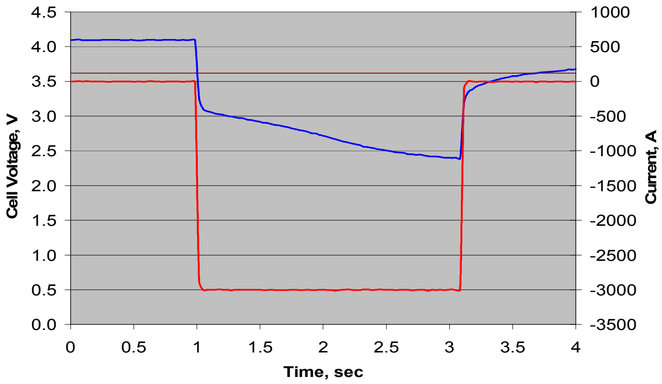

Figure 7: Two seconds 3000A pulse on VL5U cell

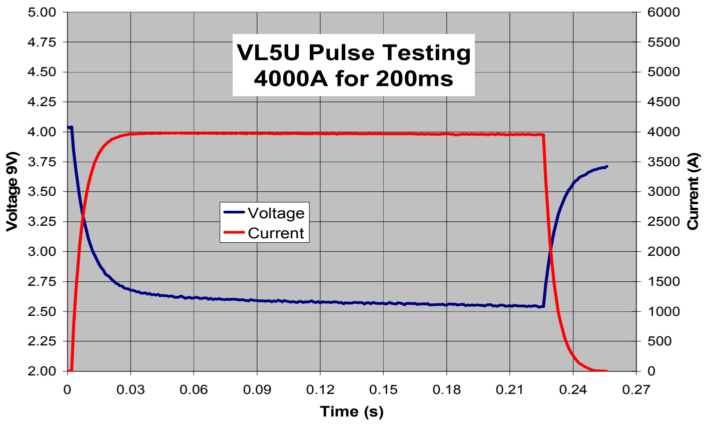

Figure 8: 200msec 4000A pulse on VL5U cell

The behavior of the UHP technology resembles the behavior of Ultra Capacitors. In addition to double layer capacitance, Ultra Capacitors employ phenomenon called pseudo capacitance, where only surface layers of the active material undergo Faradaic reactions. These reactions are very fast because they do not involve transport in the active material or in the electrolyte. Effectively Ultra Capacitors deliver more energy than can be stored only in the double layer. Saft UHP technology behaves similarly under pulse testing allowing discharge to be performed at much higher power levels. Between the pulses the battery recharges its double layer as well as the surface layers of the active material. This allows for several repeated short duration pulses prior to applying an external charge.

6 Conclusions

Saft's effort in industrializing the lithium ion manufacturing process has yielded a technology that is well suited for use in military vehicle applications. The high power of the cell is able to support the charge and discharge power profiles of hybrid vehicles. The low cell resistance allows for simple cooling methodologies for the modules and batteries and Saft's implementation of controls in the battery systems for vehicles provide an excellent means of effectively monitoring and integrating the battery within the vehicle controller. The ultra high power technology provides unsurpassed pulse power in excess of 20kW'kg. This technology has been proven as a solution in not only a hybrid vehicle application, but other load leveling applications for power systems.

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