Automotive Grade Nanophosphate Cells, Modules and Pack Evaluation

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Abstract: *A123 has developed automotive grade Nanophosphate™ cells in both cylindrical and prismatic formats. US Army TARDEC has been testing and providing support for cell improvements and characterization. In addition A123Sytems has been building module and packs for US Army evaluation and commercial applications. The purpose of the work in this report has been to evaluate the cells, modules and packs for military applications. The work was to take a critical look at commercial grade cell module and pack designs and evaluate them against military criteria. The results would help the US Army TARDEC determine if Commercial off the shelf products from A123 could meet performance specifications without significant design changes. Data presented will include charge discharge cycling, module and pack configuration, DOT qualification testing.*

Introduction

The success of lithium ion chemistry in the consumer electronics industry has helped to generate interest in the chemistry for larger commercial and military applications, including batteries for satellites, aircraft, and ground vehicles where volume is often at a premium and reduced weight allows for extended usage or more payload capability.

Lithium ion batteries have begun to receive attention in these arenas as the technology has matured to a point that it is able to demonstrate enhanced life and high reliability. Using small mass produced cells such as the A123Systems 26650 cell provides a means of creating light weight, highly reliable packs that are easily customizable to a variety of applications and volumes. Further, the safety characteristics of the iron-based phosphate chemistry, coupled with a robust, battery management system offers an additional layer of protection of the battery system.

Cell Description

A123 Systems has developed a prismatic cell that has been designed specifically for EV and PHEV applications. The cell has been optimized for volumetric packaging efficiency and the pouch construction minimizes the weight contribution in module and pack configurations. Figure 1 shows the cell configuration, and
Table 1 provides details of the cell.

Figure 1 20 Ah Prismatic Cell

Table 1: Cell Data

Features		Size (mm)	7.2 x 161 x 227
		Weight (kg)	0.500
		Volume (L)	0.263
Electrical Specifications	Cell Level	Capacity (Ah)	20
		Energy (Wh)	66
		Max Discharge Pulse(A)	300
		Max Charge Pulse (A)	300
		Nom. Voltage	3.3
		Max Charge Voltage	3.6
		Min Voltage	2.0
		Self Discharge	<2%/month
Thermal		Operating Temperature	-30°C to 55°C
		Storage Temperature	-40°C to 60°C

Cells have been tested in abusive conditions for nail penetration, overcharge, overdischarge, thermal stability, external short circuit and crush. The pass/fail criteria used is from the European Council on Automotive R&D (EUCAR), the results are shown in Table 2 Additionally, tests have been performed to evaluate the performance of this cell design. Testing included, pulse discharge capability at various temperatures, rate capability of the cell, and cycle life. The following plots provide results of that testing

Table 2: EUCAR Abuse Test Results

Test Item	Pass Criteria	Test Result
Nail Penetration	≤EUCAR level 4	Pass – EUCAR 3
Overcharge	≤EUCAR level 4	Pass – EUCAR 3
Over Discharge	≤EUCAR level 4	Pass – EUCAR 3
Thermal Stability	≤EUCAR level 5	Pass – EUCAR 4
External Short	≤EUCAR level 4	Pass – EUCAR 3
Crush	≤EUCAR level 4	Pass – EUCAR 3

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C Rate	Average Capacity (Ah)	Max Capacity (Ah)	Min Capacity (Ah)
1	19.87	19.94	19.77
2.5	19.86	19.94	19.77
5	19.82	19.91	19.70
7.5	19.76	19.87	19.59
10	19.67	19.82	19.48

Module Design

The pouch prismatic format of the cell provides a large amount of flexibility in the design of modules, and by extension, packs. Cells can be connected in a variety of formats to optimize packaging space, while meeting specific performance requirements.

Modules ranging from 66 Vdc and 1320 Wh of energy storage to 66 Vdc and 5280 Wh are possible affording a high degree of design flexibility. Integrated within the module design is a Measurement and Balance Board (MBB), that provides balancing and monitoring function to the module. The board is designed to monitor individual cell voltages, provide cell balancing and monitor the module for any over voltage conditions. Additionally, the board includes temperature sensors to monitor the temperature of the module at various locations.

Table 3: Module Options

Voltage Options	Cells	80	70	60	50	40	30	20	10
	Whrs	**5280**	**4620**	**3960**	**3300**	**2640**	**1980**	**1320**	**660**
	1P							66	33
	2P				83	66	50	33	17
	3P			66			33		
	4P	66		50		33		17	
	5P	53	46	40	33	26	20	13	7
	6P			33			17		
	7P		33						
	8P	33							
	10P	26	23	20	17				

Pack Design

This approach to module design allows packs to be created quickly that meet specific volume requirements, while maintaining a high degree of design commonality. Figure 2 shows 2 packs with very different volume constraints, the packs are very similar in performance and voltage, only the layout of the modules is different. This allows A123Systems to rapidly produce units from common building blocks to meet a wide variety of applications.

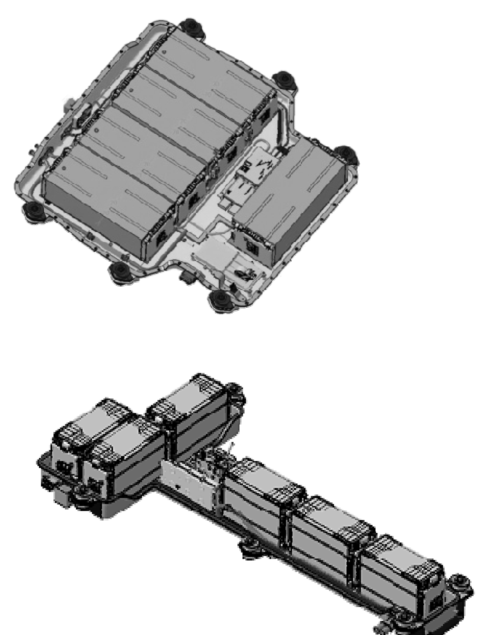

Figure 2: Pack Configurations

6T Development Efforts

A123Systems is developing lithium ion starter batteries as a light weight high performance alternative to traditional lead acid starter batteries. Weight and volume densities are improved using a lithium-ion battery. Figure 3 below shows a 12V unit in a 4s10p configuration. This approach is easily adapted for military vehicle applications

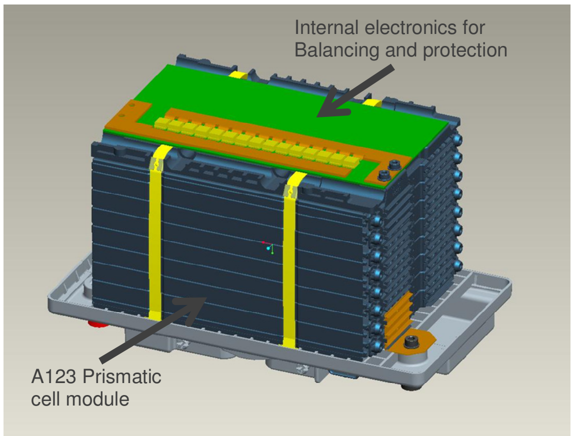

Figure 3: Lead Acid Replacement Battery

Figure 4 shows the an A123 Systems module in a 6T package, this provides a direct drop-in replacement for current lead acid type batteries.

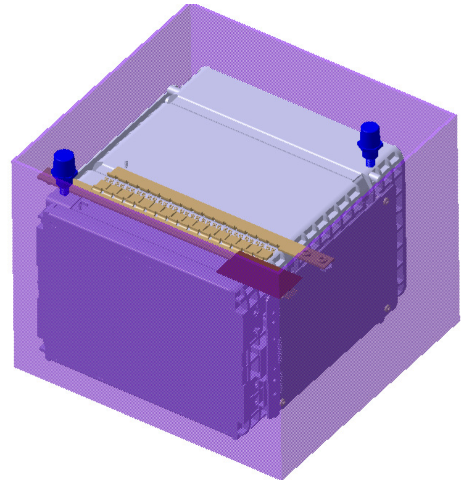

Figure 4: Lithium-Ion Battery in a 6T volume space

The following table provides a comparison between a standard lead acid 6T battery, and a battery of equivalent volume using A123 Systems, Inc. Nanophosphate^{tm} chemistry. There is a 40% improvement in capacity, and a 28% weight reduction.

	A123 Li-Ion	Pb Acid 6T
Capacity	200 Ah	120 Ah
Weight	63 lbs	88 lbs
Volume	850 in^3	850 in^3

The A123 Systems, Nanophosphate^{tm} chemistry offers excellent power capabilities even at low temperature. Figure 5 below shows the cold cranking capability at -28°C

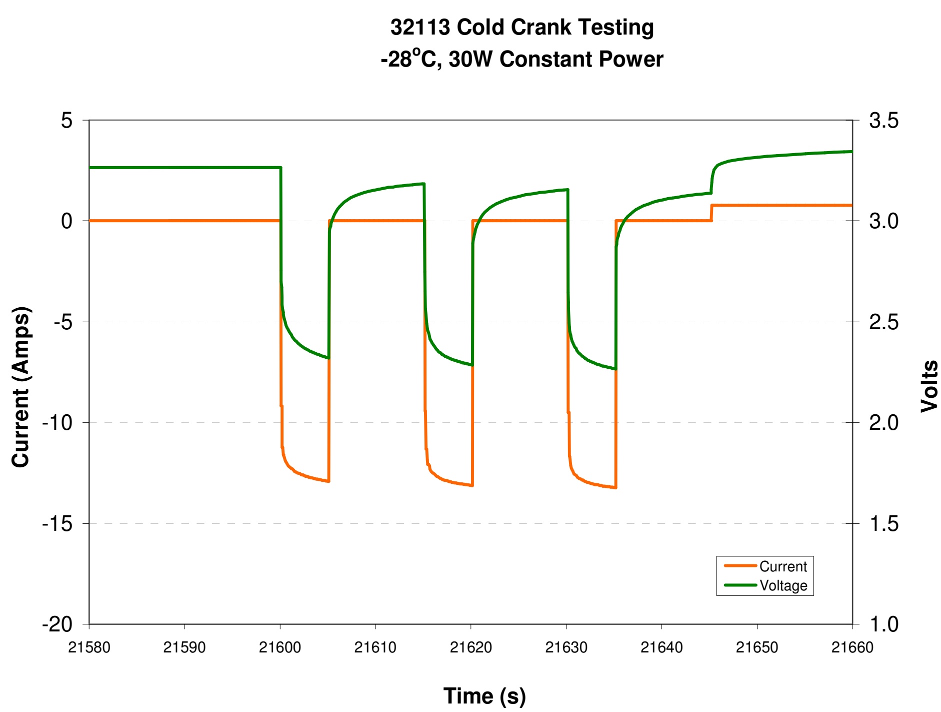

Figure 5: Cold Cranking Capability of Nanophsphate Cells

Challenges

A123 Systems, Inc. is currently developing lithium-ion batteries to serve as lead acid replacements in both automotive and stationary back-up power arenas. Challenges arise when transitioning this technology from commercial to military applications. These include, designing for the more demanding environmental conditions that are anticipated in a military vehicle application, information provided from the battery to provide the user with real-time SOC and SOH updates. These issues can be overcome by applying good design principles in the planning and design portion of the development program. The cell has already been tested in many abuse conditions. Internal short circuit via nail penetration has been performed on the cell design, along with over-charge and over-discharge. Because the method of assembling cells into modules provides some additional structural support to the cell, The goal then becomes designing the module and pack to meet the rigorous environments imposed by the military. Any program to develop a lead acid replacement for military vehicles would include baseline testing of the “as- designed” pack to determine what if any are the weaknesses in the design. This provides a foundation for additional design efforts to ruggedize the pack for military purposes.