2011 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY (P&M) MINI-SYMPOSIUM
AUGUST 9-11 DEARBORN, MICHIGAN

LITHIUM ION VEHICLE START BATTERIES – POWER FOR THE FUTURE

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ABSTRACT

Vehicles on today's battlefield need batteries for more than just starting, lighting and ignition (SLI) loads. Power requirements and the need to provide this power during silent watch scenarios have been steadily increasing as modern vehicles use increasingly more sophisticated communications and other vetronics systems. Along with this need for more power is a need to communicate to the warfighter the state of their vehicle batteries. Battery management that provides the warfighter with accurate information about the current state of charge and health of their vehicle batteries will allow them to use the energy in their batteries without fear of not being able to start their vehicle after a silent watch. Lithium Ion batteries, particularly Nanophosphate, show great potential for providing long life, high capacity, lightweight, safe solutions to these issues, enhancing the warfighter's capabilities in the field.

INTRODUCTION

As electronics become increasingly important on the battlefield, vehicle batteries that were designed for engine start and providing minimal lighting during engine off are now being used to provide increasing loads when the vehicle engine and generator are off. Communications, jammers, sensors and other critical components all need to be kept running throughout a mission. In many cases this includes the need to power these loads for extended periods of engine off for silent watch scenarios.

The increased demand on batteries requires high capacity even when the battery load is demanded at a higher rate. Lead acid batteries are typically rated for a capacity at a C/20 rate and the capacity decreases as the rate the energy is used increases (a result of Peukert's law). So the more load on the battery, the less capacity the battery can provide. Lithium Nanophosphate is significantly less impacted by this effect and can continue to provide closer to rated capacity even at higher C rates.

As batteries are cycled for silent watch they are discharged to lower states of charge. This results in a reduced battery voltage (and less battery power) when the engine is cranked at the end of silent watch. Lithium Nanophosphate has a flatter voltage curve and provides more consistent voltage and power throughout a deep depth of discharge use.

Lithium Nanophosphate also provides a life cycle advantage as it utilizes an integrated battery management system to provide state of charge and state of health information. This information allows the warfighter to confidently use the battery for its useful life and know when to change the battery, so good batteries do not need to be discarded due to uncertainty of their state of health. Lithium Nanophosphate also exhibits longer life than lead acid batteries, reducing the frequency of battery replacement.

CURRENT CHALLENGES FOR BATTERIES ON THE BATTLEFIELD

In addition to the increasing power and capacity requirements for batteries on today's battlefield, providing a robust battery design requires consideration of several other factors.

Batteries on the battlefield are used in a wide variety of duty cycles. A battery is required to have long storage life, whether sitting in storage as a spare part or sitting in a vehicle motor pool that is not currently in high use. On the other extreme, the same battery may be required for repeated high depth of discharge silent watch scenarios where the battery is drained to a low state of charge and then required to start the vehicle engine. The battery may not be returned to a full charge before the next silent watch, so accurate state of charge information needs to be available to the warfighter.

The environmental requirements for a military battery also require use at extreme hot and cold temperatures, exposure to dust, wind, snow and high levels of shock and vibration both in use and during transportation. For 12 Volt or 28 Volt starter batteries these environmental conditions are especially challenging as the batteries are not typically in conditioned compartments or provided with any heating or cooling. A successful replacement battery of any chemistry needs to take these requirements into consideration.

COMPARING LITHIUM NANOPHOSPHATE AND LEAD ACID

Lead acid batteries offer a robust design that has been proven in use on the battlefield. In order to replace these batteries with a different chemistry, qualification testing must show that the new chemistry can also withstand the abuse it will take in the field as well as advantages that make the transition worthwhile.

Lithium Nanophosphate offers several advantages over lead acid and other chemistries that make it a leading candidate for the next generation of military starter batteries.

Voltage Throughout SOC Swing

Starter batteries are typically evaluated in terms of their current delivering capability, as they have a set nominal voltage. As you vary the chemistry it is important to note that voltage is not actually constant as a battery is discharged.

Lead acid (and lithium oxide) chemistries exhibit a reduction in voltage as their state of charge decreases. This results in less power being available as the battery state of charge (and voltage) is decreased. Lithium Nanophosphate ($LiFePO_4$) exhibits this to a much lesser extent. As shown in figure 1, the voltage v. SOC curve for $LiFePO_4$ is nearly flat throughout most of its state of charge.[1] This results in more consistent power availability throughout the batteries use.

This is especially critical when the battery is used for silent watch. The battery is drained to a low state of charge, but then needs to have the power available to start the vehicle engine from this low state of charge. Maintaining a higher voltage results in more power being available at lower states of charge.

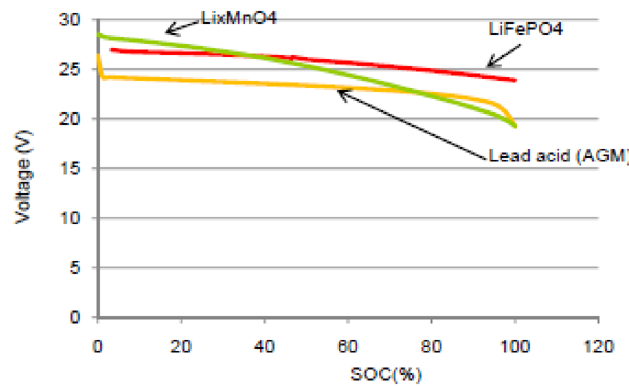

Figure 1: Voltage v. SOC for various chemistries

Peukert Effect

Lead acid battery capacity is typically rated at a C/20 rate, or a current load that would take 20 hours to deplete the battery charge. For a battery that has very low loads on it when not starting a vehicle this approximates real world use. As silent watch demands increase, actual battery loads are higher.

As charge is removed from a battery at a faster rate, the battery capacity provided is reduced, so a battery rated for 120 Ah actually provides a lower capacity when drained at a higher rate.

Lithium Nanophosphate batteries exhibit this effect to a much lesser extent than lead acid chemistries. As a vehicle power load draws power from the batteries at a higher rate, Lithium Nanophosphate batteries begin to exhibit higher capacities than lead acid batteries they were equivalent to at a C/20 rate.

For a battery with a rated capacity of 120Ah at a C/20 rate (a typical rate for testing lead acid battery capacity), using a Peukert coefficient of 1.1 (a typical value for AGM batteries, which exhibit this effect less than other lead acid batteries) the battery capacity if discharged at 120A will only be between 80 and 90 Ah (about 75% of the C/20 rated capacity).[2] A Lithium Nanophosphate battery rated at 120Ah, will provide 114Ah when discharged at a 120A rate, or 95% of the rated capacity.

Battery	C/20 Capacity (Nameplate)	1C Capacity
Typical AGM	120 Ah	88Ah
A123 Nanophosphate	120 Ah	114 Ah

As silent watch loads increase, the useable energy of the battery at the rate it will be used becomes very important and the Peukert effect needs to be taken into account. Different battery chemistries with the same stated capacities will not necessarily provide the same performance.

Battery Management

Existing battery management systems for lead acid batteries have been items that are added to the battery (and often developed by someone other than the battery producer). This makes their integration and use cumbersome on vehicles.

Lithium ion batteries require more active battery management. While this adds to their complexity, it means the electronics for battery management are already available as part of the battery system. As long as the battery supplier packages these within the 6T space claim, battery information can be made available to the vehicle CAN network without additional hardware.

Battery management is important for providing the warfighter with accurate information about how long they can sustain a silent watch scenario and still be confident in the ability to start their vehicle at the end of the watch.

Typical information that can be provided to a vehicle through a battery management system includes:

- Battery state of charge
- Battery health (current capacity)
- Maximum discharge current the battery can provide
- Maximum charge current the battery can take
- Battery voltage
- Battery temperature

This information and how it is formatted is customizable and can be delivered to the vehicle as needed.

The information made available by a battery management system also allows for better use and charging of the battery. On currently used AGM batteries, approximately 80% of incorrect voltage failures were serviceable and improved charging techniques could result in doubling the battery life. [1] Unfortunately, without a battery management system it is much more difficult for the soldier to understand what their batteries require for proper charging.

Logistics (Storage, Weight and Life)

A successful military starter battery has to have long life, both in use and in storage. By designing electronics with a shelf mode to minimize parasitic draw, the shelf life of Lithium batteries can be as good as lead acid. Additionally, Lithium Nanophosphate batteries have more power available at low states of charge, so they are more likely to be capable of starting an engine after a prolonged storage period.

As batteries are transported to the battlefield, the weight of the battery presents a transportation burden. Once on the vehicle this battery weight drives up the weight of battery brackets and displaces cargo capacity that could have been used for ammunition, food, fuel or other supplies. A Lithium Nanophosphate battery weighs about half of the corresponding lead acid battery, greatly reducing these burdens.

A 6T form factor Hawker battery weighs 88 lbs (40 kg). This requires a two man lift for movement of each battery. A comparable Lithium Nanophosphate solution can be constructed at a weight of 20 kg, making the battery well below the one man lift weight limits. This greatly reduces logistic burdens of using the battery for maintenance, transportation and carrying the battery on the vehicle.

USE OF LITHIUM NANOPHOSPHATE

Starter batteries on today's military vehicles are usually built to the NATO 6T form factor and provide 12V power. Vehicles typically use a 28V bus, so they employ 2 of these 12V batteries in series and then repeat series groups as needed to increase capacity. MIL-PRF-32143 has requirements for design of these batteries. For a Lithium Nanophosphate (or any other chemistry) to be a viable alternative for the battlefield it would need to address the requirements in MIL-PRF-32143 and be capable of being used in series and parallel configurations.

Vehicles with an emphasis on silent watch capability, like scout and reconnaissance vehicles, would have the most to gain from batteries with greater silent watch capability. In addition to silent watch, a Lithium starter battery could also provide the warfighter with better information on the current charge available from their batteries and the current health of their batteries.

If a new starter battery is designed it would also be possible to design the battery so that a single battery could support a 28V power architecture. This would allow the use of a single battery on vehicles with lower auxiliary loads, or use of any number of batteries (not just use in pairs) so that the battery capability can be better matched to the vehicle need.

CONCLUSION

Lithium Nanophosphate is a chemistry that is used widely in commercial applications and is ready for use on the battlefield. A starter battery designed to the required military performance and environmental requirements would offer several advantages in weight, increased battery life, better silent watch capability and enhanced state of charge, diagnostic and prognostic information made available to the warfighter.

REFERENCES

[1] Skalny, David, "Technical Challenges for Vehicle 14V/28V Lithium Ion Battery Replacement", Joint Services Power Presentation, May 4, 2011.

[2] http://www.bdbatteries.com/peukert.php, as accessed on 30 June, 2011.