Lithium-Ion Batteries for Autonomous Underwater Vehicles

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Abstract

Lithium-Ion batteries provide significant advantages over lead-acid, nickel cadmium and silver zinc chemistries for Unmanned Underwater Vehicles. Lithium-Ion batteries with excellent energy densities provide significant benefits in weight, volume and extended mission. Other advantages of the lithium-ion technology include excellent cycle and calendar life with an exceptionally low self-discharge. Hermetically sealed cell assembly combined with protection electronics provides a maintenance free system, improved reliability, no out gassing, excellent performance and safety. This paper will highlight Saft lithium-ion advantages over mature chemistries for Unmanned Underwater applications.

Introduction

Over the past decade, lithium ion chemistry has emerged from the laboratory to become today's fastest growing battery technology. It is becoming the premier power source for a wide range of rechargeable battery applications, from laptop computers and cell phones, to electric vehicles and satellites. In the marketplace, lithium ion is challenging mature battery technologies such as lead-acid, nickel-cadmium, silver-zinc, and nickel-hydrogen. Lithium ion is also competing with another new rechargeable technology: nickel-metal hydride.

Lithium ion technology is beginning to be considered for a wide range of unmanned vehicle (UV) applications. The need for UV power includes propulsion, electronics, load leveling, switching, and emergency power. Today, lead-acid, nickel-cadmium, or silver-zinc batteries power virtually all unmanned vehicles utilizing rechargeable batteries. Lithium ion batteries offer distinct performance advantages over these older systems as outlined below:

- Higher Cell Voltage – One lithium-ion equivalent to three Ni/Cd or NMH
- Excellent Energy Density – (a) Extended service hours (b) Lower in weight (c) smaller in size
  - Volumetric, Wh/liter: 300, Two times higher than Ni/Cd
  - Gravimetric, Wh/Kg: 145, Three times higher than Ni/Cd
- Excellent Power Capability
  - 1350 W/Kg
  - 2900 W/liter
- Low Self Discharge or Superior Charge Retention
  - Li-Ion: <5%/year
  - NMH & Ni/Cd: 20-25%/Month
- No Memory Effect
  - Li-Ion can be shallow discharge any depth without any degradation
  - Shallow cycling improves the cycle life up to 1000,000 cycles

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- Fast Charge Capability
  - 80% of full charge in one hour
  - 97% of full charge in Two hours

- Cycle Life & Calendar life
  - >3000 cycles at 100% depth of discharge (95% cap. Remaining)
  - 15 years as calendar life

- Broad Operating Temperature Range: –20C to +60C

- Hermetically sealed and no out gassing

- Maintenance free

At SAFT, lithium ion batteries have been developed for UV's. This paper describes two of these batteries and their advantages over older battery technology.

Cell Electrochemistry and Construction

Saft's lithium ion electrochemistry consists of a mixed metal oxide positive material reverse roll coated onto aluminum foil substrate and a negative material admixture of two graphites coated onto copper foil substrate. The electrolyte consists of lithium salt dissolved in a mixture of carbonate solvents. The positive, negative, and separator are spiral wound onto a mandrel rod to make the wind assembly. This is assembled into a cylindrical or prismatic metal can and tabs from the electrodes are welded to the cell terminals of the cover. The cover is welded to make the hermetic dry cell. This is then filled with electrolyte through an orifice and sealed off. Because the cell is assembled in the discharged state, it must be charged. During this process called formation, a solid electrode interface (SEI) layer is formed on the negative. This layer gives Li ion cells superior charge retention and excellent cyclic efficiency compared to other rechargeable battery systems.

During charge, lithium ions are intercalated into the graphitic structure at the negative. During discharge, they are reinserted into the metal oxide structure at the positive. The intercalation and extraction of lithium occurs with very little volume change of the electrodes. This contributes to an extended cycle life.

REMUS / SHARV AUV

The Oceanographic Systems Laboratory of the Woods Hole Oceanographic Institution has developed REMUS (Remote Environmental Monitoring UnitS). REMUS is a low cost AUV designed for coastal monitoring and multiple vehicle survey operations. Over 10 vehicles are in the field making a variety of scientific measurements. Unmodified, the REMUS vehicle is 54 inches long with a body diameter of 7.5 inches; however, the vehicle's length may be increased to support any payload within reason. The current design weighs 64 pounds in air, and may be trimmed for operations in fresh or salt water. The REMUS vehicle is shown in Figure 1.

Objectives of the current REMUS program include: (1) development of adaptive sampling strategies; (2) performing coastal hydrographic surveys; and (3) supporting the requirements of Navy Special Warfare teams. This last objective is fulfilled by the SAHRV (Semi-Autonomous Hydrographic Reconnaissance Vehicle), a modified version of the REMUS used by the US Navy SEALS for shallow-water reconnaissance. To meet mission requirements, the SHARV requires greater energy then is provided by the original lead acid battery.

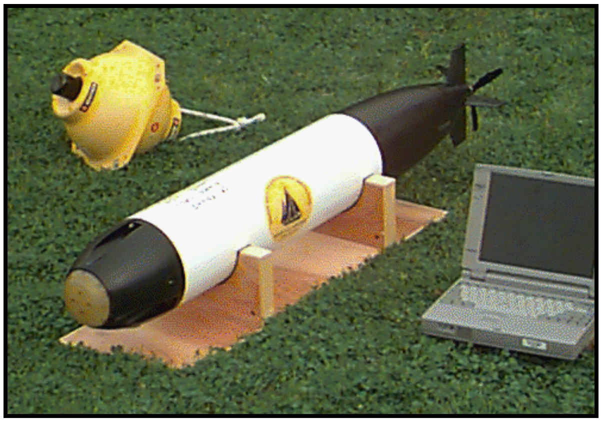

Figure 1: REMUS Vehicle shown with Acoustic Transponder and Laptop

SAFT was initially contacted by Woods Hole Oceanographic Institution (WHOI) in 1999 to evaluate the possibility and advantages of using an advanced battery technology in this application. A two-phase program started shortly thereafter:

- Prototype battery delivery for demonstration.
- Development effort with safety evaluation.

For the first phase, SAFT built a battery made of three soft-packs. Each pack contained 14 cells, type MP176065. The battery total energy (three packs) is approximately 750Wh with a nominal voltage of 26.6V and a demonstrated vehicle run time of 6.3 hours. Although a prototype, this battery was built with full electronic circuit protection to prevent overcharge, over-discharge, over-temperature and over-current.

During the second phase of the program, which began in 2000, the battery was designed and developed to fit maximum energy into the vehicle. By reconfiguring the cells and optimizing the packaging, four 250 Wh packs now fit the available space. Furthermore, in addition to full protection electronics, each pack now contains an integral DC/DC converter charger, a smart gas gauge board and a power connector. The Phase 2 battery soft-pack is shown in Figure 2. The finished brick is enclosed in an aluminum case as shown in Figure 3. The battery system provides about 1kWh at a specific energy of 99 Wh/kg. Saft completed development of the battery in 2000 and is now in low rate production.

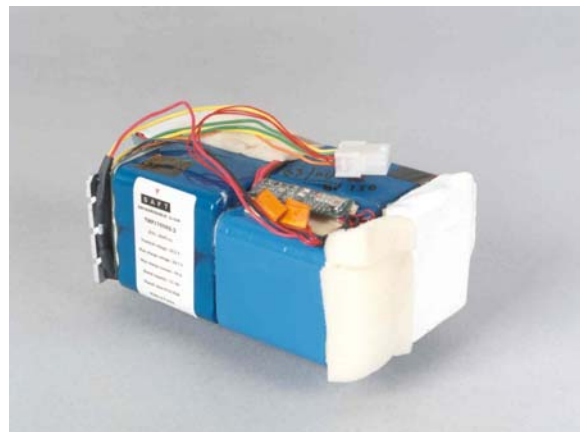

Figure 2: Phase 2 lithium ion battery pack with 14 cells type MP-176065

Figure 3: REMUS/SAHRV lithium ion battery brick

Contents

The advantages of Saft's lithium ion battery compared to the lead acid battery are shown in Table 2.

Table 2: Lithium Ion Versus Lead Acid for REMUS/SAHRV

	Lead/Acid	Li-Ion
Gas generation	Yes	None. Hermetically sealed cells. No need to open and close the pressure seal
Charging battery in the vehicle	No	Yes
Total energy	380Wh or about 3.2 hours of mission at 5 knots	1000Wh or 8.3 hours (2.6 times)
Cycle life	100's	400-1000 cycles

SAMS

The SAMS (Semi-Autonomous Mapping System) is a full 6 km depth rated vehicle for ocean floor mapping under development by WHOI for the Naval Oceanographic Office. SAMS is a reconfigured REMUS for deep operations with the advantage of increasing the effective deep sonar-mapping rate by four times. Operation is two systems with 12 hours mission duration each: one is recovered and the second unit begins sortie during processing of the first sortie data set.

SAFT completed development of the lithium ion battery in June 2001. The battery system comprises eight one kWh modules connected in parallel. Each 28 volt module consists of seven high-energy HE44 cells complete with balancing and protection electronics as shown in Figure 4. The cells are held in place by two end constraints with electronics mounted to an aluminum heat-sink end piece. The module is 6.9 inches diameter by 10.64 inches length for a volume of 6.520 liters and weighs approximately 8.87 kg

The eight kWh battery system is designed to be charged to 28 volts and discharged to 18 volts. When discharged at 608 watts necessary for a vehicle speed of 4 knots, the battery system will provide over 13 hours of run time. It delivers over 320 Ah at a nominal 25.2 VDC. A 76 W (608 W / 8 modules) discharge profile of a typical module is shown in Figure 5. The module as shown has a specific energy of 117 Wh/kg and an energy density of 159 Wh/L.

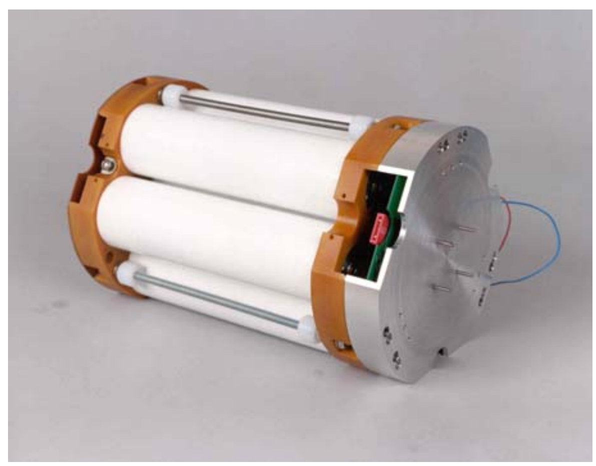

Figure 4: SAMS 1 kWh lithium ion module with protection electronics

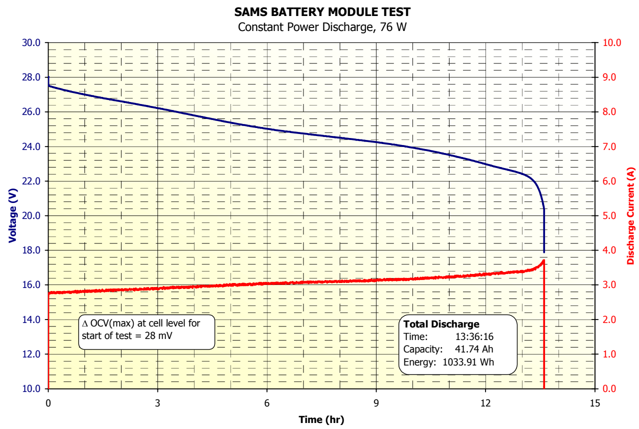

Figure 5: Typical 76 W discharge profile of a SAMS lithium ion battery module

Conclusion

Today, lithium ion technology is a one that can be widely used for UV applications. It offers the following advantages:

- High energy resulting in increased mission time.
- High power, which can meet torpedo applications.
- No gas generation enabling simple sealed housings.
- No maintenance.
- Plug-in charging reducing handling and possible incidents.
- Battery management system with state of charge display making the battery easy to use.
- High reliability.
- Long calendar life.
- Long cycle life.
- Lower life cycle cost

To summarize, lithium ion provides better performance, longer life, and improved reliability than other rechargeable battery technologies.