High-Performance Battery Engineering for Undersea Applications

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Increasing demands are being placed on battery power for undersea applications such as vehicle propulsion, operating portable equipment such as cameras or measurement devices, and operating installed equipment such as telecom infrastructure. Factors such as longer missions and higher peak-energy demands from more sophisticated and intelligent systems call for greater energy density, improved reliability, greater safety and high resilience to the elevated pressures experienced in undersea environments.

Overall, the design of the battery system must ensure high levels of reliability and safety, so as to minimise danger to personnel as well as disadvantages such as property loss, down time, mission failure, and high maintenance costs resulting from battery failures in the field.

Lithium battery technology has several advantages over other types, particularly its higher energy density. However, creating a lithium-based battery system capable of delivering the optimum performance and meeting reliability and safety-acceptance criteria, at the right price, demands careful attention to aspects such as cell technology, cell balancing, charge control and production quality.

This white paper describes these issues and discusses potential solutions that can be built into a lithium battery pack for undersea applications.

Preferred Battery Chemistry

Modern undersea missions require battery chemistry offering significantly higher energy density than existing chemistries such as Lead-Acid, Alkaline, Ni-Mh, or Ni-Cd. This is necessary to supply all the energy requirements of modern equipment, and to support longer manned or unmanned missions.

More modern lithium-metal and lithium-ion (Li-ion) battery technologies have matured and now offer up to four times greater energy density than the older technologies. They also overcome many of the associated limitations, particularly those related to operating or charging the battery in sealed conditions during use.

Applications and Environment

Because water has its densest phase a few degrees above freezing, temperatures near the sea bed are generally in the region of 4-5°C. This is comfortably within the usual operating range of a lithium battery.

The pressure experienced by the battery pack can be very much greater than normal atmospheric pressure, depending on the depth at which the equipment is required to operate. The pressure exerted on equipment operated near or on the sea bed can be as high as 10,000 psi.

High outside pressures are capable of deforming the battery casing and bursting seals, leading to effects such as contamination of the electrolyte and failure of the battery. To combat this, the battery pack and other subsystems may be mounted in a pressurised container, depending on the application, to minimise the pressure exerted on the battery module including any internal control circuitry. Lithium batteries are known for their suitability for use under high pressures in oil-filled or potted enclosures. For example, within other critical markets such as the down-hole oil and gas industry, lithium packs are operating in harsh applications where extreme pressure, high shock and vibration are commonplace during drilling and measurement operations.

A suitable battery system for sub-sea applications must be able to operate below the surface in a sealed environment. Lithium-metal, Li-ion and Li- polymer batteries provide an ideal solution as they can be recharged with no need for venting, since (unlike lead-acid or Ni-Cd batteries) the battery generates no gases during recharging. Since there is no need to disturb the sealing mechanism, the risk of early seal failure is greatly reduced and batteries can be recharged more easily on the surface or in situ, if required.

As with all cell chemistries, lithium-type batteries are not immune to failures in the field. There is a risk of fire or explosion if lithium batteries are overcharged or allowed to overheat. Some high-profile failures have been seen in the computer industry, which have resulted in the recall of large numbers of notebook PCs. The main causes of lithium battery failures are overheating, overcharging, and imbalances between cells. Proper control of charging, including temperature monitoring, is therefore essential to ensure robust and reliable performance in mission-critical applications.

The rate of charging, for lithium battery technologies, is relatively inflexible, and is typically around 1C or less. The battery is initially charged at maximum charge current until the rated voltage is reached. The current then falls as the maximum voltage is reached, and charging terminates when the current falls to below 3% of the rated value. The maximum voltage for a lithium battery is typically around 4.1V-4.3V per cell. Overcharging to a higher voltage can cause instability, gassing and temperature increase giving rise to risk of fire. For this reason, protection circuits are implemented to prevent excessive charge voltage from being applied and to halt charging if the temperature increases to critical levels.

It is also important to provide circuitry that will protect the battery against becoming over discharged, by shutting down the system when the battery voltage reaches a minimum level. This is typically in the region of 2.7V-3.0V per cell (in the design phase, it should be considered that, although the charged voltage is a nominal 4.2V, the typical on-load voltage may be reduced to 3.2V to 3.3V).

Circuitry to control charging and prevent over discharge can be implemented externally, in a battery-specific charger, or internally within the battery itself. Either approach may have advantages: external charge control may permit smaller, lower-cost batteries; on the other hand, integrating the circuitry allows a variety of energy sources such as a DC power supply or a fuel cell (or a combination of sources) to be used more easily.

Cell Balancing

As far as cell balancing is concerned, today's Lithium battery chemistries display relatively low imbalances. However, imbalance remains a common cause of failures among complex systems containing large numbers of cells connected in series. Imbalances typically occur due to uneven discharging, differential external leakage currents, localised temperature variations, manufacturing or age-related differences, or loss of battery electrolyte. Replacing a single module within a large battery subsystem may also give rise to a cell imbalance with the potential to cause early failure. To prevent such failures from occurring, cell balancing circuitry may be necessary.

Two commonly used balancing techniques include discharge balancing and charge-transfer balancing. In discharge balancing, any cells detected as having higher capacity are discharged until they have equal capacity to those having the lowest capacity. Charge-transfer balancing describes a process of transferring charge from higher capacity cells into those of lower capacity so as to equalise the capacities throughout the batteries. The usable capacity of the battery pack remains the same in either method.

Engineering Batteries for Undersea Use

Battery specialists serving the undersea application space, such as Steatite, configure lithium battery packs to deliver an optimal combination of energy storage, size, weight and cost for specific applications. Charge control circuitry is designed into the battery pack or dedicated charger as required. High-quality manufacturing techniques ensure a high degree of uniformity between individual cells over time and temperature. In addition, suitable cell balancing circuitry is engineered into the solution as required.

Safety Standards

Lithium batteries are subject to a large number of safety criteria, relating not only to safety when in use but also when being transported. Since lithium cells and batteries are considered to be hazardous materials according to bodies such as the Department of Transportation (DOT), nearly all lithium batteries must pass section 38.3 of the United Nations "UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria". The document defines eight tests, which are designated T.1 through T.8 and are often referred to as the UN "T" tests. The tests are applicable to batteries only; other documents such as the Class 9 Hazardous Materials Regulations define specifications for aspects such as packaging, marking, labelling, and the supporting documentation required for shipping.

UN standards 3480, 3481, 3090 and 3091 have been published, specifying shipping restrictions and applicable testing and labelling requirements for lithium-metal and lithium-ion batteries when transported in their own right, or contained in equipment, or packed with equipment. Almost all types of lithium-based cells or batteries must pass these tests to be acceptable for shipping, either by mailing, by road or rail freight, or in passenger or cargo aircraft. Some exemptions may apply to small batteries, such as lithium primary cells containing less than 1 gram of lithium metal.

The eight T tests describe criteria for altitude simulation, thermal shock, vibration, mechanical shock, external short circuits, impact and overcharging Tests T1 To T5 are applicable to all cells and batteries. T6 and T8 apply to all cells, while T7 applies to rechargeable batteries only. Passing the T tests will involve testing a number of units, which can add significantly to development costs; particularly when small production volumes are planned.

When testing a battery assembly in which the aggregate lithium content of all anodes, when fully charged, is not more than 500 grams, or in the case of a Li-ion battery, with a Watt-hour rating of not more than 6200 Watt-hours, that is assembled from cells or batteries that have passed all applicable tests, one battery assembly in a fully charged state shall be tested under Tests 3, 4, and 5, and, in addition, Test 7 in the case of a rechargeable battery assembly. For a rechargeable battery assembly, the assembly shall have been cycled at least 25 cycles.

When batteries that have passed all applicable tests are electrically connected to form a battery assembly of a size comparable to a large battery, or in the case of a Li-ion battery, with a Watt-hour rating of more than 6200 Watt-hours, that battery assembly does not need to be tested if it is equipped with a system capable of monitoring the battery assembly and preventing short circuits, or over discharge between the batteries in the assembly and any overheat or overcharge of the battery assembly.

Conclusion

Lithium battery technology is the most suitable for applications such as undersea equipment, as it has high energy density and can be recharged more easily within the operating environment than alternative battery technologies. Proper attention, however, must be paid to aspects such as charge control and cell balancing, to ensure reliability and safe recharging meeting standards such as the UN standards.

Configuring a solution that will satisfy all these requirements and deliver long-lasting trouble-free operation is a task best performed by specialists with a full understanding of the demands of the environment and the particular needs of lithium battery chemistries.