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Advances in Pressure Compensated Lead-Acid Batteries

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Pressure compensated lead-acid storage batteries eliminate the need for heavy, bulky, expensive pressure housings for many underwater applications. They are field repairable, and may be transported by air cargo aircraft. Without a pressure protective housing, power can be delivered within smaller weight and space constraints, with arguable improvements in system safety. The greater weight of lead-acids over other pressure compensated chemistries is often used to counter-ballast the positive displacement of air-filled chambers. Power storage at a remote site allows trickle charging through smaller gage wires when intermittent high current demands are satisfactory.

Pressure compensation means pressure in all interior voids is equal to the ambient external pressure. This is achieved by filling the interior air space of a battery above the plates and electrolyte with an inert fluid, often white mineral oil, with enough excess volume to compensate for effects of temperature contraction and pressure compression.

This paper is focused on advancements in the venerable lead-acid battery. The use of other chemistries such as Silver-Zinc and Lithium-Ion, are covered by other authors in great detail in other papers.

In 2010, ABS Type Approval will be necessary for systems utilizing pressure compensated batteries conforming to ABS Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities.

Technical Overview

Batteries generate electrical power by making use of electro-potential differences of dissimilar materials brought together in an ion-rich media called an *electrolyte*, and connected by a separate electrical path, called a *circuit*. Batteries are divided into two main groups: non-rechargeable or primary batteries, and rechargeable or secondary batteries.

First available in 1859, lead-acids were once available only as “wet-cells.” Battery acid electrolyte would spill if the battery was tipped over. They required routine maintenance to replace the water lost by every cell through evaporation or electrolysis. In close confines with limited air circulation, a combustible hydrogen-oxygen mixture could accumulate.

Lead-acids got progressively better over the next 90 years, as the problems were identified and solved.

An improvement in safety and handling came with the introduction of “gel cells.” Electrolyte is mixed with a very fine silicon dioxide powder to create a gel-like paste which won’t spill in any orientation. Gel cells are leak proof, and produce minimal off-gassing.

Today’s lead-acid batteries

Incremental improvements continued to be found and now the Absorbant Glass Mat (AGM) lead-acid is the most advanced sealed lead-acid battery available. The AGM battery has all the advantages and more of gel cells, with none of the downsides. AGMs use electrolyte saturated absorbent boron silicate glass mats between the plates. The plates and glass mats are sandwiched tightly together within a rigid frame. As a result, they are very shock and vibration resistant, and can be operated even if inverted. AGMs are more readily available, less costly and more easily shipped than lithium based cells. Some AGM batteries are designated as “high rate discharge”, and can deliver short bursts of higher current due to denser electrolyte concentration, wider and taller plates, and increased plate surface area.

These additional features make today’s AGM lead-acid batteries still the best choice for many applications. While lower temperatures in the deep sea lowers the capacity of all batteries, the associated higher pressure increases the capacity in lead-acid batteries, tending to balance the two effects. Lower temperatures also increase the charge retention ability of lead-acids, an important feature for long term deployments.

Absorbent Glass Mat (AGM) batteries inherently produce very minimal gas in normal operation, allowing them to be designated “maintenance free.” AGM batteries are "recombinant”, meaning the oxygen and hydrogen created while charging recombine back into water inside the battery. This is due in part to the use of low or zero antimony lead alloy grid. The recombinant affect is typically better than 99% efficient, so almost no water is lost, and almost no gas is generated during normal use. This has been confirmed in testing at DeepSea Power & Light. Gas generation is possible, however, with battery overcharging and deep discharge.

Any gas volume that may be generated can be captured by a flexible diaphragm, and vented manually or by use of a pop-off valve. For added safety, DSPL recommends recharging an AGM SeaBattery™ on deck, where a technician can oversee the process, and vent any gas that may be generated.

<u>Pressure Compensated Battery Components</u>

Pressure compensated batteries often have the following components or features:

A. The specially modified AGM lead-acid batteries and wiring, which passes through to the outside world through a feedthru, located in DSPL's SeaBattery in the top diaphragm.

B. The lower housing, usually a molded single piece of impact resistant plastic, a mating lid, and a seal. DSPL housings are heavy wall, rotationally molded, Linear Low Density Polyethylene (LLDPE), that survive a lot of physical abuse.

C. The pressure compensating device that produces a slightly positive pressure over external ambient pressure. Positive internal pressure allows for inspection for leaks prior to deployment. The fluid compression and thermal expansion characteristics are both calculated and measured to ensure there is sufficient volume used. A compensator may be a flexible diaphragm, a piston, or a bellows.

D. The compensating fluid must be inert to the electrolyte and battery chemistries, possess low vapor pressure at room temperature, and have a density less than the battery electrolyte. The fluid should also be non-conductive, have low flammability, be non-hazardous to humans on contact and to the environment if spilled, and be safe for aircraft transportation. Clear mineral oil, such as Drakeol 35, is often chosen.

E. The fill port is sealed by a cap seal, and is alternately used to vent excess gas. Provision could be made for automatic venting of excess gas, like a pop-off valve, but this has to be done with some forethought to avoid subtle but significant problems such as water leakage at the cracking or sealing pressure of the pop-off.

F. A set of handles will make lifting easier for the deck crew.

G. Battery charging should be possible with the battery installed in the underwater system as long as the operator is able to inspect for outgassing and open the vent if needed. The charger must be designed to limit charge rate and total charge to minimize gas generation.

H. Shipment: Ground transportation is the generally preferred method of shipment as it is the cheapest way to move the weight of the battery, though it does take longer. Pressure compensated AGM lead-acid batteries have the advantage of using components that in aggregate may be labeled non-hazardous for cargo-only air shipment, if there is an urgent need for delivery. The shipping box must conform to all applicable DOT/IATA construction requirements, using appropriate labeling, padding, and packing tape.

In addition to a type approved battery, ABS system requirements include the use of overload and short circuit protection, per section 11.13, breakers or external fuses, per section 15.5, switch and proper wire size and construction.

In qualifying the battery type and manufacturer, DSPL found AGM batteries are run through rigorous manufacturer’s performance tests, including: Medium and High Load Capacity Tests, Cycle Life, Overcharge, Short Circuit, Drop and Vibration, Shelf Life, and Accelerated Float Life, all useful characteristics in the offshore field.

ABS Type Approval

ABS Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities (2002), defines general PBOF battery specifications in section 11.7: Pressure Compensation.

The procedure for a product becoming ABS Type Approved involves 3 steps.

1. An Engineer's evaluation of a design to determine conformance with specifications. The manufacturer submits sufficient information to allow ABS to determine if the product meets specification. This results in a Product Design Assessment Certificate (PDA).
2. An ABS Surveyor witnesses the manufacture and testing of a sample of the product to determine compliance with the specification
3. An ABS Surveyor's evaluation of the manufacturing arrangements to confirm that the product can be consistently produced in accordance with the specification. This results in the issue of a Manufacturing Assessment Certificate (MAC).

An Annual Plant Survey is required for maintenance of ABS Type Approval.

The SeaBattery from DeepSea Power & Light is now Type Approved by the ABS for use at sea on projects requiring ABS certification.

Conclusion

Pressure compensated underwater batteries produce electrical energy for divers, vehicles, and instruments. Low temperature, high pressure, long duration deep sea deployments, and ABS certification can be accommodated.

The goal of producing a cost-effective, rugged, easy to use undersea battery capable of producing high currents on demand, without the added cost and weight of a bulky pressure case has been achieved.