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Application of pulse charging techniques to submarine lead-acid batteries

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Abstract

The development of pulse charging equipment for the unique application to submarine lead-acid batteries is described. A prototype pulse charger has been developed and applied to individual twin-cell submarine batteries, plus a 20 twin-cell pulse charger has been commissioned at the battery manufacturing facility. The paper provides a description of the pulse charging equipment and preliminary test results and analyses using the prototype twin-cell pulse charger, based on application of a range of positive and negative pulse parameters. The tests so far indicate potential benefits may arise from this form of charging, including enhancement of battery charge levels, reduced gas charging (Stage 3) times and reduced gas evolution rates.

Keywords: Submarine; Lead-acid batteries; Pulse charging

1. Introduction

The main storage battery (MSB) on the Collins Class submarine consists of flooded lead-acid battery cells. The submarine has a large number of cells connected in series and is divided into four battery sections each rated at a nominal 440 VDC. Charging routines for the Collins Class submarine batteries are based on a PEI regime (constant power, constant voltage, constant current/gas charging). The submarine is designed to use only the first two stages at sea with Stage 3, constant current/gas charging used prior and post deployment. At sea cycles of constant power charging (10–12) followed by a Stage 2 constant voltage maintains a high SOC and high charging efficiency. Stage 3 constant current/gas charging only returns about 3% of the battery capacity and has very low charging efficiency (15%).

Inherent small variations in cell impedance result in cells having slight differences in capacity and self-discharge rates. These variances can lead to imbalances in cell SOC, which will become accentuated over extended deployments. Periodic Stage 3 gas charging is necessary to equalise the cells, and to remove sulphate build up to restore cell capacity and performance. During extended deployments it may become necessary to conduct remedial charging at sea to restore cells impacted by the imbalance.

Investigative testing on end of life cells has shown, as would be expected, that positive plate corrosion was advanced, possibly the result of overcharging at high voltage (gas charging) and high operating temperatures. To address this issue the RAN initiated the development of pulse charging techniques for submarine batteries due to the potential to reduce the gas charging time to reach full SOC.

2. Review of pulse charging literature

Lam et al. [1] offered the following explanation of their findings. During normal charging using constant current, crystals will form at active sites because they require less deposition energy. As the current continues, the crystal will become progressively larger. The larger crystals formed during constant current charging lead to a lower surface area of the active mass. Yamashita and Matsumara [2] have demonstrated that the reactivity of the active mass is decreased when

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such crystals are formed. Both of these factors work to lower the capacity of the battery.

Yamashita and Matsumara [2] also refer to Pavlov's gel zone theory. Pavlov [3] proposed that the active material consists of PbO_2 crystals connected by $PbO(OH)_2$ gel zones. These gel zones form a current carrying bridge between agglomerates. As the active mass becomes increasingly crystalline the conductivity decreases.

With high pulsed current charging, average voltage is similar, but instantaneous voltage is much higher. This increased driving force allows crystals to form more randomly and rapidly. During current off-time, the crystal growth will cease. Upon current being applied again, new crystals will form as opposed to existing ones continuing to grow. Therefore, crystals are prevented from becoming large and capacity is maintained.

Briggs [4] claims that most forms of reduction of capacity and charging efficiency are brought about by ionic unbalance in lead-acid batteries. This is caused by the disproportionate loss of hydrogen and oxygen gas molecules, which leads to crystallisation of the active material and other negative effects. The use of pulsed charging helps to offset this ionic unbalance and leads to improved cell performance.

Podrazhansky and Popp [5] claim that multiple discharge pulses should be used "... so that natural chemical and electrical gradients within the battery will serve to disperse the ions more evenly throughout the electrolyte". They also claim that short duration charging pulses create small size crystals (therefore greater surface area) with no sharp edges. Discharge pulses tend to remove sharp edges on a crystal so it is possible to obtain the smaller size crystals with rounded edges using longer duration charging pulses and short, high magnitude discharge pulses.

Preliminary tests on the Collins Class submarine batteries have indicated that only frequencies in the range 0.1–100 Hz would be beneficial. It also needs to be noted that we have found no record of pulsed charging of large lead-acid batteries of a size comparable with submarine batteries. This does not necessarily show that such tests have not been performed. Some research organizations may have tried pulsed charging of submarine batteries but for a variety of reasons, not published their results.

3. Experimental

A project was initiated to investigate pulsed charging for use on submarine cells [6]. A pulsed charger capable of pulse charging a Collins class twin-cell was developed by Boeing Aerospace Support for the ADF. Note that a twin-cell is two single 2 V cells connected in series and housed in a common container. Initially a prototype pulsed charger was developed, which employed metal oxide semiconductor field effect transistors (MOSFETs) and could produce both positive and negative pulses of amplitude 40 A. This unit was tested using one of the cells of a 6 V car battery, and operated satisfactorily.

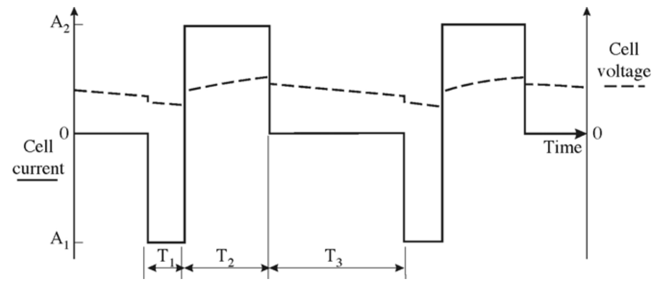

Fig. 1. Ideal pulsed charging waveforms of twin-cell charger.

3.1. Twin-cell pulse charger development

Using the knowledge gained from the prototype unit, a twin-cell pulsed charger was developed based on MOSFET technology. It is capable of applying positive and negative pulses of adjustable amplitudes and durations. The ideal waveform is shown in Fig. 1, where T1 is adjustable from 0 to 200 ms, T2 is adjustable from 0 to 1 s, and T3 is adjustable from 1 to 9999 ms, A1 is adjustable from 0 to −800 A, and A2 is adjustable from 0 to 800 A. The timed-average output charge current is limited to 500 A.

The unit has been satisfactorily demonstrated on twin-cells for the Collins class submarine. A typical charging current waveform with a submarine twin-cell is shown in Fig. 2. Initial tests show a significant reduction in the time taken for Stage 3 charging.

The twin-cell pulsed charger is being used to investigate the effect of pulsed charging, with the following priorities:

(a) Testing similar cells to the same cycle regime, one with pulsed charging and one with conventional charging.
(b) Use of pulsed charging to accurately and quickly determine cell state-of-charge.
(c) Variation of pulsed parameters with variation in state-of-charge of battery.
(d) Study effect of negative pulses.
(e) Optimise pulsed parameters to reduce gassing.

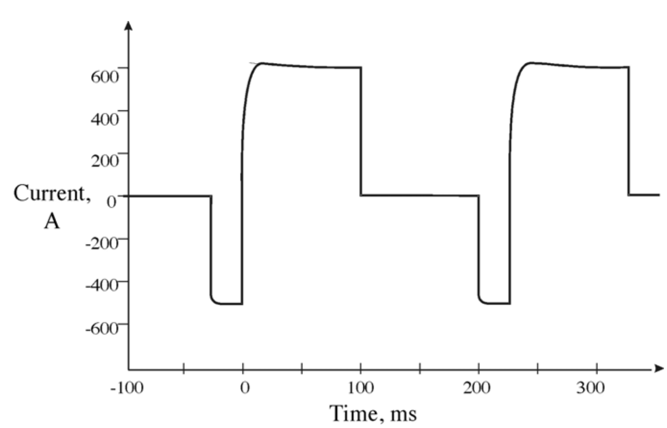

Fig. 2. Typical test current waveform of twin-cell charger.