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Cycle life measurement of a sealed lead/acid battery

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Abstract

The cycle life of a 'D' type, sealed, recombinant lead/acid battery, rated by the manufacturer at 2.5 A h at the 10 h rate, was determined experimentally. The criterion used for cycle life was the number of continuous cycles at 50 °C during which the battery was capable of delivering 1 A h of capacity at a minimum of 1.9 V. Statistical analysis of the results of these tests on 12 sample batteries indicated a cycle life of 93 with a standard deviation of between 8 and 9 cycles.

Introduction

A battery must have a dependably long life to gain acceptance for use as backup in uninterruptable power supplies. The small, sealed, recombinant lead/acid battery is sufficiently new for confidence, based on years of performance, not to be justified yet, particularly in applications where battery life is a critical parameter. The purpose of this study is to add to the knowledge of the life capability of a particular single-cell, recombinant lead/acid battery.

Testing was performed on one type of 'D' size battery with a capacity rating of 2.5 A h. The batteries were manufactured by the Gates Battery Company. The test was designed to determine, in a short period of time, the capability of this battery to meet a particular cycling regime. The results are intended to help the determination of the life cycle capabilities of these batteries in particular, and of small, recombinant lead/acid batteries in general, as potential replacements for nickel–cadmium batteries in uninterruptable power supplies for electronic equipment.

Experimental

The objective of the test program was to determine a characteristic cycle life of the battery type in a short period of time. Specifically, the test consisted of subjecting a group of batteries to a continuous series of charge/discharge

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cycles at elevated temperature while controlling and/or measuring the voltages and currents at regular and frequent intervals Cycling was performed at elevated temperature in order to accelerate the normal cycle-to-cycle degradation in capacity

The testing was carried out using 12 batteries The batteries were arrayed electrically in 3 strings of 4 batteries each The three strings were wired in parallel and were supplied with current during the charge mode from a single, adjustable, constant-voltage power supply Some voltage variation during charge occurred because the current was supplied through a solid-state switch which had sufficient resistance for the voltage to the batteries to be reduced slightly during the initial high current phase of charging The power supply was adjusted to provide a charge voltage exceeding 2 32 V per battery during the low-current, end-of-charge condition The end-of-charge voltage was checked on subsequent cycles and corrected as needed Charging was for a fixed period of time

After the charge phase, the batteries were placed on open circuit for a short period of time and were then switched to the discharge phase Each string was discharged through a separate adjustable resistor The resistance was set to provide the desired nominal discharge current, taking into account the decrease in current induced by battery voltage drop during discharge through a fixed resistance Battery voltage was measured frequently during the discharge phase The discharge phase was terminated after a fixed time (1 h) or when the voltage across any battery in the string dropped to a predetermined value (1 9 V) After a battery reaches 1 9 V for several cycles during discharge, it is removed from the circuit The batteries were switched to open circuit after the discharge phase and left on open circuit for a short period of time before the cycle was repeated

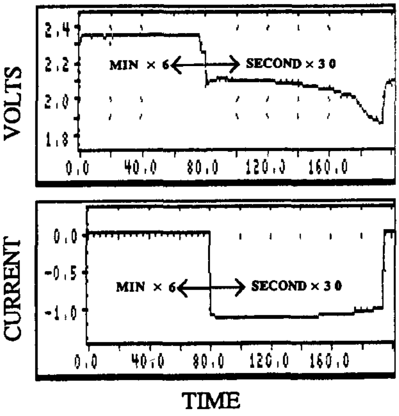
The cycling was computer controlled, as was the data collection Data collected at each interval consisted of the voltage across each battery (12 channels), the current in each battery string (3 channels), and the temperature in the battery enclosure (1 channel) All tests were run with the batteries in an insulated, electrically-heated enclosure in which the temperature was computer controlled at a nominal 50 °C Cells were charged for 8 h and discharged for 1 h (or less), with a short period at open circuit between each condition Data were collected at 6 min intervals during charge and at 30 s intervals during discharge for a total of 200 data intervals for each cycle The data were digitized and stored on diskettes

Data analysis

The voltage and current for any battery for any cycle could be readily displayed in graphical form, for example, in Fig. 1. The number of cycles required for the voltage of a battery to drop to 1 9 V under an arbitrarily fixed load and time duration was a predetermined critical parameter The discharge current was adjusted so that the battery delivered 1 08 A h during the 1 h discharge period. This is 60% of the manufacturer's nominal rating of 1.8 A h capacity at the 1 h discharge rate [1], but the end of discharge voltage used is a more stringent requirement than the manufacturer's rating of 'the knee of the discharge curve' The cells were not discharged to the lower voltage so that results could be obtained more quickly and so that the cells would be relatively unharmed for subsequent tests

Figure 1 shows the voltage of the example battery dropping to 1.9 V at the end of discharge cycle 70 Observation of the voltage at the end of discharge in previous cycles revealed that at 1 9 V the end of discharge was imminent To insure that the reduction in battery capacity was not the result of insufficient charging, the battery was subjected to an extra 8 h charge prior to the 70th cycle The low current at the indicated charge voltage is consistent with a fully charged battery Figure 2 shows the voltage of this battery dropping to 1 9 V at about 50 min, indicating the continued deterioration of this battery at cycle 80

The charge/discharge cycling was continued until 11 of the 12 test batteries met the failure criterion of 1 9 V at 1 A h of discharge in 1 h Each failure was converted into percent failed, and the cumulative failure is shown in Fig 3 plotted against the number of cycles until that failure The scales used in plotting Fig 3 allow Weibull statistical analysis of the experimental results to be obtained directly from the graph [2] In this case, a straight line was drawn which passes closely through the first 9 failure points This line intersects the 63 2% failed line at 93 cycles, indicating a Weibull characteristic, or most probable life, of 93 cycles On Weibull coordinates, the slope of this line is known as the shape factor In this case, the slope, measured directly from the graph, is found to be 5. The close fit of the first 9 data points to a straight line indicates that these failures followed



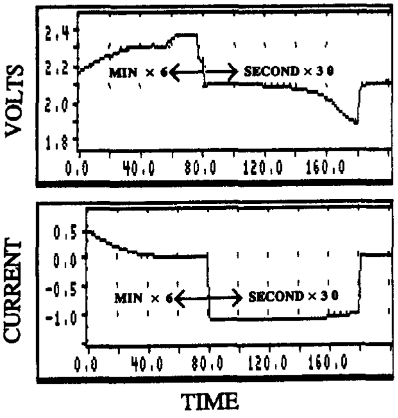


Fig 1 Voltage and current during cycle when the discharge voltage initially drops below 1 9 V (cycle 70)

Fig 2 Voltage during later cycle showing reduced capacity at discharge voltage above 1 9 V (cycle 80)

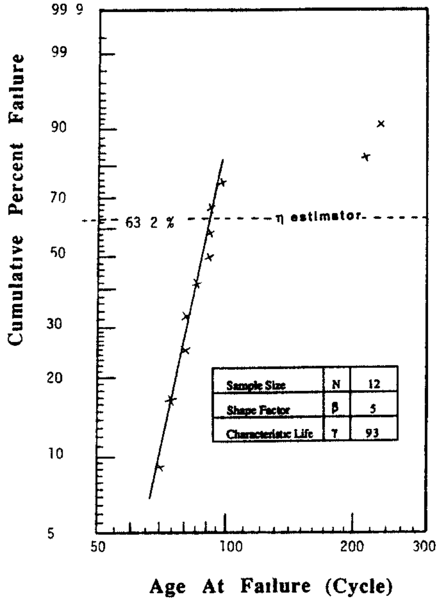


Fig 3 Weibull plot of failures

a Weibull distribution and the steepness of the slope indicates a small standard deviation The standard deviation was calculated to be between 8 and 9 cycles.

The batteries were cycled on a relatively short time interval and were maintained at an elevated temperature to accelerate the testing An empirical formula [3] for relating the temperature to acceleration effect is

$$\ln F = A(T - 25\ ^\circ\mathrm{C})$$

where F is the acceleration factor relating the cycles at temperature T to the number of cycles at 25 °C producing the same deterioration, and A is an empirical constant The value of A has been reported as 0 039 [3] and later as 0 030 [4] This results in the prediction of an acceleration factor, F, for these tests of 2 6 and 2 1, respectively

Results

Cycle life is defined as the number of continuous cycles for which the battery is capable of delivering 1 A h of energy in 1 h while maintaining a minimum of 1.9 V A characteristic, or most probable, cycle life of 93 cycles with a standard deviation of 8–9 was found, based on statistical analysis of experimentation at 50 °C and of only the first 9 failures Cycle life at 25 °C is estimated to be between 195 and 242 cycles based on acceleration factors of 2 1 and 2 6, respectively

Figure 3 shows that 3 of the batteries continued to operate for well over 200 cycles, suggesting the existence of an additional failure mode. Also, four, randomly selected, failed batteries were later restored to acceptable capacity by extensive charging. A scanning electron microscope was used to examine the electrode surfaces of both the early- and later failing batteries. No significant differences were detected.

References

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