Effect of Charging on Life of Float-Operated Lead Acid Batteries

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ABSTRACT

Stationary lead-acid batteries continue to be used in a myriad of applications for telecommunications, switchgear power, UPS, load leveling and even remote area power systems. While the chemistry of lead-acid has changed only modestly over the past 140 years (Starved vs. flooded electrolytes, Pb/PbCa/PbCaSn instead of PbSb grids), the methods for charging and state-of-charge monitoring of these have changed drastically, especially in the past decade. This paper discusses the various ways that lead-acid batteries can be charged and monitored in order to achieve better life and reliability.

Bode (Ref. 1) differentiates the causes of battery failure to parameters under the battery manufacturers control ("inner parameters") and those under the battery users control ("outer parameters"). Sometimes the battery manufacturer can change the "inner parameters" (materials, designs, processing) to optimize the battery product for the expected application, or "outer parameters." The latter includes temperature, depth of discharge, rate of discharge, type of charge or recharge, etc.

Traditionally, stationary lead-acid cells have been "floated" or overcharged slightly, to compensate for the natural, spontaneous self-discharge of the cells. Most modern floating lead-acid cells are made from high-purity materials, or at least not made with materials that affect float voltage, such as Sb, As and most of the transition metal elements. Float voltage is proportional to electrolyte specific gravity and temperature (Refs. 2, 3). Alternative to float include: (1) discontinuous charging of the entire battery string, (2) discontinuous charging of individual cells, and (3) charging by pulses.

These categories are different from float, "hysteresis charging" and individual cell equalization which have been discussed in previous conferences (BATTCON, NEPC, INTELEC, etc).

We will discuss these alternatives to float in light of our past BTC field and lab experience with floated cells (both flooded and starved), and our observations in an ongoing accelerated life test of some starved electrolyte (AGM) batteries. In summary, our testing has shown longer life for individually charged cells than for floated cells.

EXPERIMENTAL

In order to test two complete strings (48V each string) of AGM/VRLA batteries, we built an oven from cement board and steel 2x4 studs. The front of the oven was enclosed by two hinged doors. The doors were gasketed to minimize heat loss. The oven was heated with 6 each 120 volt 1kw bar heaters connected in a series loop. One phase of 240v 3Ø AC power was hooked to every other heater. The heater was controlled with an RTD temperature sensor and a 1/4 DIN temperature controller. The output of the temperature controller operated the input of 3 solid state relays in series between the line and the heaters. An auxiliary heater of 3 x 2Kw heaters also in a triangular loop could be operated from the temperature controller or a simple line switch. This set of heaters could be used to help bring up the temperature more quickly.

Float charge and recharge after each test discharge was done with two lab power supplies, one for each battery string. Discharge at the C rate (1hr) was done with a Powermate LL-300B solid–state load bank in series with large, high voltage fixed resistors which kept the load dissipated by the LL300B to less than 1Kw. The load was connected to either battery string via a heavy-duty high voltage DC contactor. A 100A 100mv shunt was connected in series with each string to monitor the string current on charge and on discharge.

The voltage of each cell, the string current and temperatures at several locations in each string were recorded by a Fluke 2240 data-logger which had an RS-232 output. This output was connected to a 486 computer system for archival storage. The data was later handled "off-line" by other computers to generate charge profiles and discharge profiles.

Prior to the test, we measured and recorded open-circuit cell voltages, impedance and cell weight. Impedance measurement was done at 1 KHz using a HP 4328 A milliohmmeter. Weight was measured to the nearest tenth-gram using an Ohaus 119D triple-beam balance. The voltage, impedance and weights were then re-measured periodically, at least at the point where the cell was being disassembled.

As cells were removed from each string, we found that we had to shim out the physical gaps where a cell had been, in order to keep the cells packed and the plates from going out of contact with the AGM.

The major experimental variable was the float charge method. One string was floated at the battery manufacturers recommended voltage of 2.27 VPC. The other string was charged using the charging portion of a battery management system. In the discussion below, the two strings are called merely "control" or "BMS."

The life test was accelerated by using a temperature of 160°F (60°), which is at the maximum recommended by the battery manufacturer. Batteries were new production units of a particular brand, which we will call Brand XX.

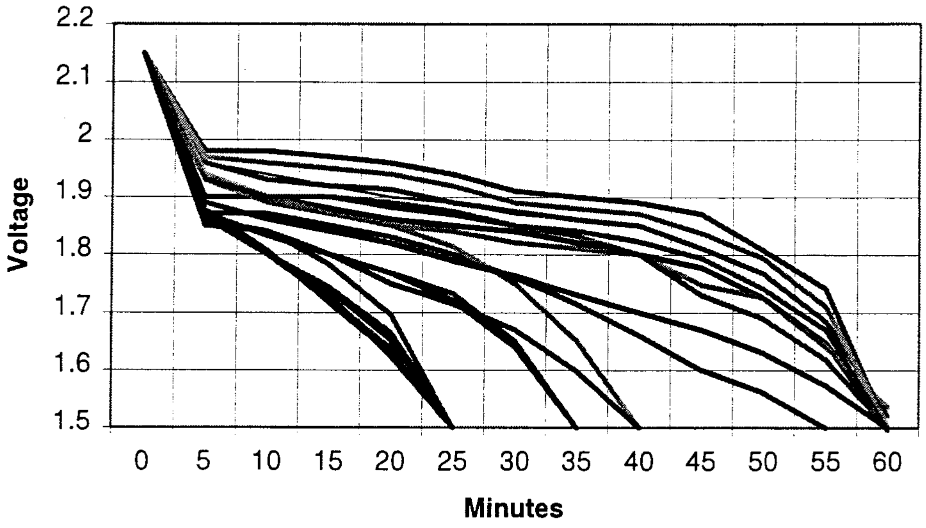
Cells were removed from each string when their capacity had declined more than 10% below the string average. Each cell was marked profusely, photographed and torn down. Teardown consisted of sawing the case-cover junction and sliding the cell out of the case. As cells corroded (positive grid growth) it became necessary to cut down the sides of the case to allow the bulged positive plates to be removed. One outside negative and the adjacent positive were saved from their respective group straps, washed, dried and inspected. Sections of positive grid were cut out, potted and cross-sectioned to evaluate the depth of corrosion.

RESULTS AND OBSERVATIONS

In general, the control cells had much shorter life, much more grid corrosion, a greater variation in float voltage, and a higher through-put of charge ampere hours. The control cells had a higher capacity, but this was due to an undercharge of the BMS cells: without complete recharge the capacity would normally be expected to decline. The undercharge was due to the tremendous amount of self-discharge of the negatives at 160°F. In the field, BMS charging is adequate to overcome the relatively low self-discharge at battery operating temperatures at or below 100°F. (Typically at or below 80°F)

Typical discharge curves, for the 14^{th} test discharge are shown in Figures 1 and 2. The BMS curves show only cell 13 is significantly below the average. The control cell curves show only cells 6(30), 7(31), 11(35), 18(42), 19(43), 20(45), 23(47) and 24(48) still had reasonable capacity. All these "good" cells had a kink in their discharge voltage, due to the loss of current control as the rest of the cells plunged to very low voltage. At the end of the 14^{th} discharge of the control cells, the discharge current had fallen from approximately 69 amperes to less than 55 amperes.

Float Charged - 14th Discharge



Automated Single Cell Charged - 14th Discharge

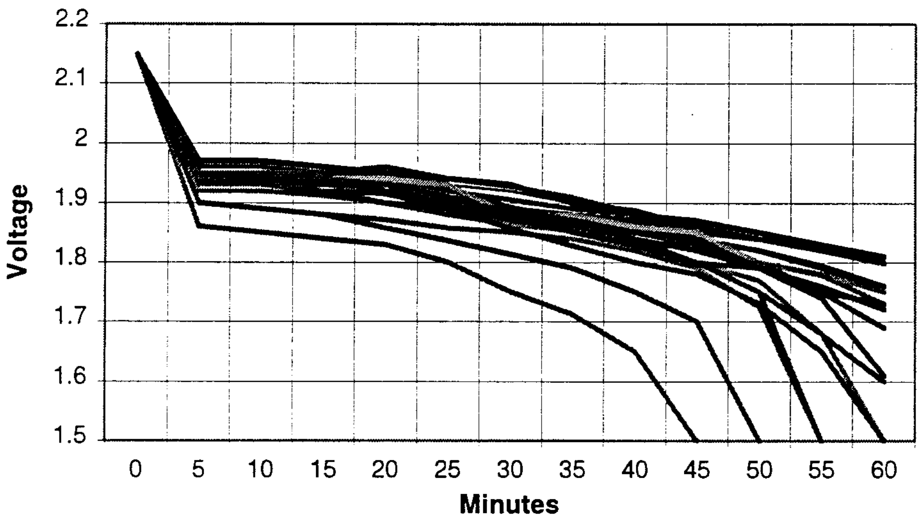


Figure 1 and 2

When we tore the batteries down, we observed significant positive grid growth, buckling, loss of positive active material and positive grid corrosion in the control cells after the 14[th] discharge. Many of the control cells were grown so much that the cells were nearly impossible to remove from the battery rack. Some cells from the field that we also examined had plugged vent caps: these bulged in both the long axis and short axis direction of the cell cross-section, and this bulge was relieved when the vent cap was removed or the cell punctured. The controlled cells were truly grid-grown and gassing bulge was minimal if not non-existent. A typical cell long-axis bulge is shown in Figure 3, while there was no short-axis bulge as is shown in Figure 4 for the same cell.

Figure 3

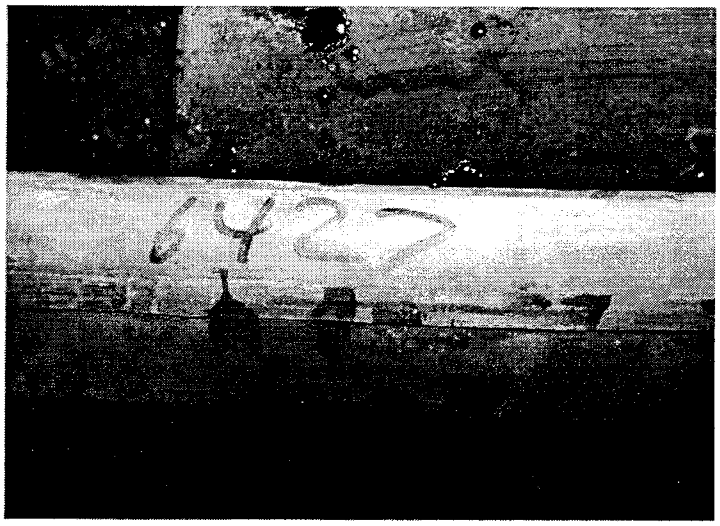


Figure 4

The control cells removed from test after the 8th discharge showed some positive grid growth and buckling. These were even more pronounced after the 14th discharge. The positive plates had grown out beyond the separators and negative plates (Figure 5), and the top of the positive grid frame was even bulged out against the negative group strap, as is shown in Figure 6. A typical corroded, buckled positive plate is shown in Figure 7. The missing positive pellets were adhering to the AGM separator in large chunks, as shown in Figure 8.

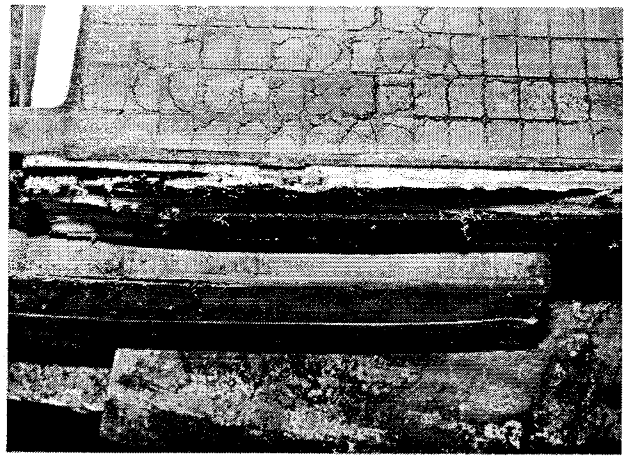


Figure 5

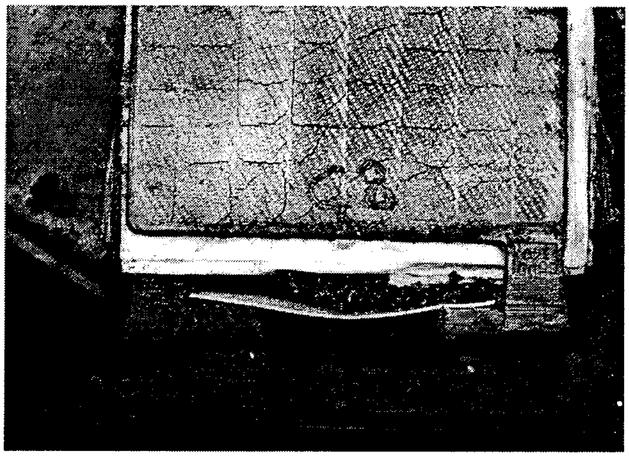


Figure 6

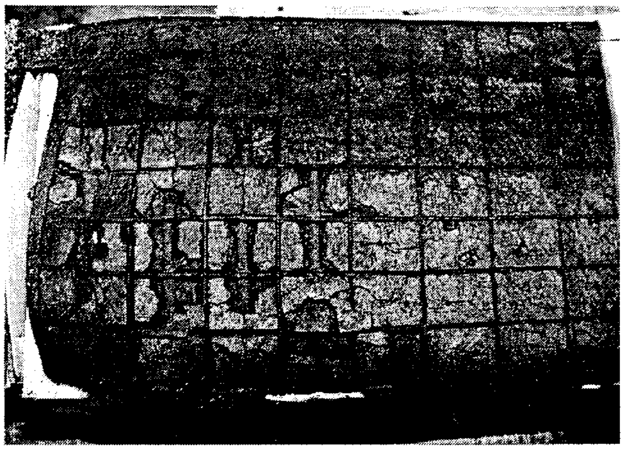


Figure 7

Figure 8

Portions of positive grids from control and BMS cells were removed from the respective plates, potted in "Quick Mount" resin and cross sectioned. Table 1 shows the amount of grid corrosion in terms of the grid thickness.

Table 1 – Corrosion Depths

Sample	Life Units	Depth of Corrosions (% of half-thickness)
BMS	3	< 10%
BMS #13	8	< 15%
Control	3	31%
Control # 21	8	76%
Control # 22	8	87%
Control # 8	8	93%

Clearly, the control cells are much more corroded than the BMS cells.

Weight loss was highly variable from cell to cell in both of the strings, although as expected there was a lower average weight loss from the BMS cells.

Resistance (impedance) increased slightly in the BMS cells and significantly (by a factor of 2x to 10x) in the failed control cells. OCV's were reasonable for all cells, showing that there were no shorted cells. Slightly low OCV's on some BMS cells reflects the residual sulfation in the plates caused by the accelerated life test conditions.

Since the test is ongoing past the "write date" of this paper, we will present the latest data available during our presentation.

DISCUSSION

Traditionally, floating batteries have indeed been floated. Different lead-acid designs have different equilibrium full-charge voltage, with this voltage for any cell being proportional to specific gravity of the cell's electrolyte. Various floating battery systems have occasionally been charged by other means. The charging is an "external parameters" as discussed in the abstract above, and affects battery capacity, performance, life and reliability.

When a few cells in a string have been found to be undercharged, the SCE "single cell equalizing" has been done. The usual cause of a few low cells in a string had been soft shorts (moss or dendrites) in these cells. A better cure than SCE is to add a BTC proprietary material, DPA, to the cells or to specify DPA as an ingredient in new cells. Floating batteries are normally kept at 100% SOC. Some applications with a lot of cycling (RAPS, load leveling, etc.) have batteries operated at less than full charge, for example, from 30 - 40% SOC to 70 - 80% SOC. Although lower average SOC would be expected to lead to greater positive grid corrosion, this apparently doesn't happen, or we would have seen more corrosions of the BMS cells positive grids.

The BMS battery string in the present test was also run at less than 100% SOC. This was due to the very high self-discharge of batteries at 160°F, which took more current than we expected at the beginning of the test.

The control batteries had a much higher through-put of AH, and this appears to be the cause of the higher amount of grid corrosion and grid growth. We are sorting through a lot of data (over 1 gigabyte) and will report the AH through each string in our oral presentation.

There has been some criticism of using higher temperatures for an accelerated float life test (Ref. 4). Most of the controversy relates to the correlations of "accelerated life" with room temperature life. We have not tried to develop an exact acceleration factor for Brand XX batteries. Both strings had the same temperature-time exposure.

References:

(1) H. Bode, "Lead-Acid Batteries," Wiley, N.Y., 1977.

(2) G.E. Mayer, Chapter 14 Lead Acid Batteries in D. Linden "Handbook of Batteries and Fuel Cells," McGraw Hill, N.Y., 1984

(3) G.W. Vinal, "Storage Batteries," Wiley, N.Y., 1955

(4) J. Rhoades, presentation at 15th Annual Battery Conference, CSULB, January 2000.