PERFORMANCE EVALUATION OF LEAD ACID BATTERIES FOR USE WITH SOLAR PANELS

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ABSTRACT

This paper discusses the preliminary results of a long term evaluation of the charging of sealed lead acid batteries with unregulated solar panels. The U.S. Coast Guard (USCG) uses unregulated solar panels to recharge batteries that power night navigational aides. The USCG is examining the benefit of replacing the current maintenance free lead acid batteries with sealed batteries. The test will determine the useful life and failure mode of batteries exposed to unprotected outdoor environments. Preliminary results of the test found that the batteries were being exposed to charge voltages of between 12.5 and 16.0 volts, which are well outside the designed charging voltages for sealed lead acid batteries of 13.5 to 14.2 volts. Charging at these voltages (both overcharging and undercharging) accelerates the decay of sealed lead acid battery positive plates and greatly reduces the expected service life. Preliminary results of fielded batteries found that the maintenance free batteries lasted approximately 60% longer than sealed lead acid batteries.

PURPOSE

This paper will examine the effects of charging batteries in an uncontrolled environment using solar panels. The paper will examine the type of charge provided by the solar panels, the effects of seasonal variation on the charge, and the effect of the charge on the battery. The results of the dissections of actual fielded batteries that failed will also be discussed.

BACKGROUND

The U.S. Coast Guard (USCG) has approximately 14,000 navigational buoys and aides throughout this country. These aids use various types of flashing lights during the night which are powered by batteries. In the past these aids used large non-rechargeable batteries that had to be replaced every one to three years. In the 1970's and 1980's, the USCG began to phase in solar powered rechargeable batteries. Initially the batteries required maintenance, such as the addition of water, but these batteries were replaced with the new maintenance free and sealed lead acid types.

In 1990 the USCG requested Crane Division, Naval Surface Warfare Center to perform a long term evaluation test of Solar Panel Powered Navigational Aide batteries. The test will examine the performance of the sealed lead acid batteries and compare it to the maintenance free batteries presently in use. The batteries will be tested for up to six years or until they fail and then they will be examined to determine likely failure mechanisms. The test data will also provide the USCG with information to the relative operating life of these batteries.

Actual fielded maintenance free and sealed lead acid batteries will be dissected and evaluated to determine failure modes. These batteries were deployed in buoys for up to 6 years constantly being cycled by solar panels and nightly lamp discharge. The batteries were deployed throughout the coastal waters of the Atlantic, Pacific, and the Gulf of Mexico in buoys that had no temperature control.

Today's new sealed lead acid batteries are designed to provide optimum performance within narrow operating parameters. In the past, batteries were designed to allow the addition of water to replace what was lost due to hydrolysis during overcharging, which permitted a wide range in charging voltages as is shown in Table 1. Charging in excess of the voltages provided in Table 2 causes hydrolysis, which is the breakdown of H_2O into H_2 and O_2 gas. Limited overcharging results in increased periodic maintenance such as the addition of water and cleaning of the battery. These maintenance batteries have been replaced in the last 30 years with "maintenance free" batteries designed for low capacity applications and automobile engine starting. This battery is designed with improved grids that contain either calcium or very low levels of antimony and a large surplus of electrolyte which lowers the gassing rate and permits the battery to operate without any watering. The newest improvement in lead acid batteries is the "sealed lead acid battery." These batteries are manufactured with minimal quantities of electrolyte which is either held in a gel or absorbed in the separator. The plates in most sealed lead acid batteries use non antimonial grid additives such as calcium which reduces the amount of gassing. The sealed lead acid batteries are also designed to vent at higher internal pressures than either the flooded or maintenance free designs. This which retains the gases produced during minor overcharge for reuse.

Undercharging or overcharging of lead acid batteries adversely affects the positive plates. Extended periods of undercharging (below 13.5 volts) can cause grid corrosion, sulfation, and plate buckling. Sulfation, the formation of excess

amounts of lead sulfate on the positive plate that is not reduced during charging, reduces both the capacity and current carrying capabilities of the battery and can eventually cause cell shorting. Extended overcharging at voltages above those provided in Tables 1 and 2 causes loss of water in the electrolyte, increases the internal heat, and accelerates the corrosion rate of positive plate grid. Grid corrosion increases the volume of the positive plate, forcing the plate to expand and resulting in positive plate growth or buckling. Corrosion also causes higher internal resistance and eventual failure of the grid to carry electrical current. Both the loss of electrolyte and grid corrosion significantly reduce the life of the battery. Batteries such as sealed lead acid with very minimal electrolyte volumes are much more susceptible to accelerated grid corrosion due to charge abuse. Under severe overcharging, gassing increases until internal pressures exceed the designed venting pressure resulting in permanent loss of water, and internal heating occurs. Both conditions accelerate positive grid corrosion.

TEST METHOD

The USCG provided NAVSURFWARCENDIV Crane with two identical batteries from each of six suppliers (five sealed and one maintenance free) to be tested using actual navigational aides. Each navigational aide consists of a MAR-10 10 watt solar panel, a 0.77 ampere lamp, one of two types of flashers that control the lamp rhythm, and a daylight control. The solar panels recharge the batteries that were partially discharged the previous night by the light. Each supplier's batteries were placed on both a FL2(5) and a FL4(.4) flasher.

The solar panels and batteries were assembled using actual USCG equipment and procedures. The panels were

mounted facing due south and at an angle of 60° from the horizontal. The batteries and navigational aides were placed near the solar panels in boxes. These navigational aides were monitored using a Hewlett-Packard (HP) HP 3852A Data Acquisition Unit and a micro computer. The following were measured every 1/2 hour: solar panel currents, battery currents, voltages, reference cell solar irradiance, panel temperature, battery box temperature, and air temperature.

All the batteries were tested to determine the initial capacity before attachment to the navigational aides. This capacity test will be repeated yearly in order to determine the effect of charging in an exposed environment.

Batteries that fail either on test or in the field will be dissected and the results discussed.

PRELIMINARY RESULTS

The solar panels were found to be charging the batteries to voltages outside the designed range of 13.5 to 14.2 volts for sealed lead acid batteries. Histograms of the maximum charge voltage for both flashers (see Fig. 1) showed that the batteries were charged outside the recommended voltage on approximately 82% and 73% of the days respectively and that the voltage ranged from 12.5 to 16.0 volts. Batteries attached to both flashers were constantly undercharged during the winter periods and overcharged during the summer months as shown by the variance of the maximum charge voltage outside the ideal charging range of 13.5 to 14.2 volts (see Figs. 1 to 3). The panels also rarely approached the designed output of 10 watts (see Fig. 4). All these figures show the range of charging conditions provided by these unregulated solar panels.

TYPE	FLOAT VOLTAGE		CHARGE VOLTAGE	
	CELL	BATTERY	CELL	BATTERY
FLOODED	2.17-2.34	13.0-14.0	2.33-2.70	14.0-16.2
MAINTENANCE FREE	2.25	13.5	2.6	15.5
SEALED	2.20-2.30	13.2-13.8	2.25-2.37	13.5-14.2*

* Some manufacturers have recommended 14.4-14.6 V for cyclical applications.

Table 1. Comparison of charge voltages for various lead acid batteries with calcium

TEMPERATURE (°C)	CELL VOLTAGE	DIFFERENCE FROM 25°C	BATTERY VOLTAGE
50	2.30	-0.09	13.80
40	2.33	-0.06	13.98
30	2.365	-0.025	14.19
25	2.39	0	14.34
20	2.415	0.025	14.49
10	2.47	0.08	14.82
0	2.54	0.15	15.24
-10	2.65	0.26	15.90
-20	2.97	0.508	17.92

Table 2. The Effects of Temperature on Gassing Voltages¹

Fig. 1 Gaussian Distribution of Maximum Voltages (7/1/92 - 12/31/92)

Batteries attached to both flashers were overcharged during the summer with the batteries attached to the FL4(.4) flashers experiencing the most severe overcharging. On average the batteries were charged to over 200% of the previous nights discharge. The daily maximum charge currents rarely exceeded 0.6 amperes for a battery rated between 80 to 100 ampere hours. The effects of this overcharge will be determined by dissection upon completion of test.

During the period from November to April batteries attached to the heavier load (flasher FL2(5)) were constantly charged to below the minimal recommended float charge voltage of 13.5 V. During December to March the battery charge voltage often did not exceed the open circuit voltage of 12.75 V. The lighter load FL4(.4) flasher batteries during this same period were being undercharged to a lesser degree and for shorter periods (see Fig. 2).

Early capacity testing results show that batteries attached to FL2(5) flashers had capacity levels consistently lower than comparable batteries attached to a FL4(.4) flasher. One of the batteries attached to the FL2(5) flasher failed a load test and was dissected. The battery was found to have been severely sulfated and the positive plate grids were almost totally corroded.

The examination of fielded batteries found that maintenance free batteries lasted approximately 6 years and sealed lead acid batteries lasted approximately 3 years. The maintenance free batteries that were removed from service were between 5.5 and 7.0 years old. Three of eight samples still had between 60% and 83% of the original capacity. The major mode of degradation of all the maintenance free batteries was decay of the positive plate and grid and in some cases severe loss of electrolyte. During dissection most of the positive plates

crumbled in hand and little metallic lead was seen in the grids. All the sealed absorbed electrolyte lead acid batteries dissected had failed after they reached an age of between 2.0 and 3.5 years. Only one of five batteries had any capacity remaining (57% of original capacity). Three of five batteries dissected had positive plates that were in a worse state of decay than the much older maintenance free batteries. The batteries examined showed severe positive plate grid corrosion, positive plate growth, and loss of electrolyte.

Undercharging appeared to severely affect the capacity and physical condition of a battery that was attached to a FL2(5) flasher. Test data showed that the sample was consistently under charged. Excessive undercharging eventually lead to sulfation, as evidenced by white crystals and a brownish color on the positive plates found during the dissection. Extended periods in a low charge state also caused grid corrosion, which reduced the battery capacity. Overcharging of the second similar battery attached to a FL4(.4) flasher, did not appear to have a noticeable effect on the condition or capacity of the battery during this time period.

PRELIMINARY CONCLUSIONS

The unregulated solar panels consistently undercharged the batteries during the months of November to April and overcharged during the months of May to October. The batteries attached to the heavy load FL2(5) flasher were exposed to longer periods of undercharging. Both these types of abuse can damage the battery.

Extended undercharging of the batteries can cause sulfation and grid corrosion which will shorten battery service

Fig. 2 Maximum daily charge voltages

Fig. 3 Seasonal effects on FL2(5) flasher voltage and current during charge.

life. The overcharging of batteries can cause loss of electrolyte and grid corrosion, both of which will shorten battery service life.

The batteries attached to the FL2(5) flasher were more noticeably affected by the periods of excessive undercharging than similar batteries attached to the lighter duty cycle FL4(.4) flasher, as was evidenced by the differences in capacity after nearly 1.5 years of testing. This loss in capacity appears to be caused by both sulfation and grid corrosion, two products of prolonged undercharging, as found during the dissection of a test sample. Sulfation not only passivates the positive plate surface it also increases the rate of grid corrosion, which eventually decreases the battery capacity.

The charging of sealed lead acid batteries by solar panels should not exceed the designed operating range. Charging sealed lead acid batteries outside this range can cause

accelerated decay of the positive plates resulting in extremely short service lives. Preliminary results of dissections of batteries returned from the field show that maintenance free batteries lasted approximately 60% longer than comparably sized sealed free lead acid batteries.

The maintenance free lead acid batteries that have been examined have an estimated service life of 6 years in this application. These batteries also have a cost advantage over the much more complex sealed lead acid technology.

REFERENCES

- [1] D. Linden (ed), "Handbook of Batteries and Fuel Cells", McGraw-Hill, New York, 1984, pp. 14-89.

FIG. 4 RELATIONSHIP OF VOLTAGE AND CURRENT (FL2(5))