LOSS OF COMPRESSION OF THE ABSORBENT GLASS MAT IN VRLA BATTERIES

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ABSTRACT

Valve regulated lead acid (VRLA) batteries have become a regular choice for stand-by battery systems over the past several years. One of the primary reasons for their rapid acceptance is that the applications which these batteries support have migrated away from maintained, centrally located, environmentally controlled sites to remotely located sites with limited environmental controls and limited personnel available to inspect and maintain the batteries. They have also been the subject of considerable discussion as some users have experienced operational lifetimes that are less than expected. In some cases this was due to the harsh operating environment in which the batteries have been placed and in other cases this was due to manufacturing defects. Recently, GNB Technologies discovered a phenomenon regarding the loss of compression of the absorbent glass mat (AGM) separator that is widely used in the manufacture of VRLA batteries. This paper discusses the discovery and verification of this new phenomenon and the steps taken to recover the reduced capacity of field installed batteries that had been affected by this phenomenon.

INTRODUCTION

In 1994, GNB began to receive reports that some of the Absolyte® II batteries installed in the field were suffering from an unexplained premature capacity loss. Up to that point, all battery failures reported to GNB were found to be attributable to known causes, either related to operational abuse or manufacturing defects. At the same time, industry forums were starting to report wide spread capacity loss problems with all manufacturers of VRLA batteries. At Intelec '95, Dr. David O. Feder reported a 64.4% failure rate of VRLA batteries from a database representing nine manufacturers and over 24,000 cells (see Table 1). Clearly, all manufacturers were suffering from premature capacity loss in VRLA products at that time with very few answers as to why the batteries were failing. GNB Technologies embarked on a comprehensive research program to determine the root cause of this premature capacity loss and to verify that all of the critical design parameters that were part of the Absolyte® technology were aging and performing as designed. Once the new phenomenon was understood, GNB proactively and aggressively communicated the new findings to Absolyte® users and instituted a field adjustment procedure that quickly and safely would restore the lost capacity, thereby extending the useful life of the installed base of batteries.

Table 1 - Capacity Test Results Cells 3-7 Years Old
David O. Feder, "Performance Measurement and Reliability of VRLA Batteries"

Manufacturer	# Tested	# Failed	% Failed < 80%
Mfr. A	15627	10747	69%
Mfr. B	4791	2568	54%
Mfr. C	712	338	47%
Mfr. D	288	171	75%
Mfr. E	1509	1298	86%
Mfr. F	1265	519	41%
Mfr. G	472	293	62%
Mfr. H	66	18	27%
Mfr. I	192	102	53%
Total	24922	16054	64.4%

RESEARCH & PROBLEM SOLVING

Having established that a general phenomenon was occurring which was in fact causing VRLA batteries to exhibit premature capacity loss, GNB began an aggressive research program into root causes. This program involved the detailed examination of hundreds of Absolyte® cells and exhaustive compilation of data on product five to ten years old. The intent was to examine all aspects of cell design and evaluate them as possible causes for the failures.

The first step was to screen out of the study, product which failed due to known causes. These failures, although no less serious, were understood with well defined corrective actions. What GNB wished to focus on was the question of why cells, with no known manufacturing defects and properly operated, were failing capacity tests.

Having isolated this group of low capacity cells, GNB invested many man-hours evaluating cell performance, tearing down cells and analyzing battery components. Specifically the following parameters were studied:

- Cell capacity performance
- Internal resistance and conductance
- Float characteristics

- Paste weights, composition, surface area and porosity
- Grid corrosion measurements; rates and mass of products formed
- Water consumption and transmission rates
- Electrolyte specific gravity and separator saturation
- Separator thickness, cell stack-up heights
- Vent valve performance and integrity

This thorough inquiry lead to a significant database of findings. Factors which generally correlated included low capacities (on the order of 0% to 60% of rated) with high internal cell resistance (two to four times that of a new cell). Negative plate sulfation and low electrolyte specific gravities were observed. This made sense since higher sulfate content on the negative active material necessarily meant that it was not in solution in the electrolyte, thus the electrolyte would have a lower specific gravity. One finding which was difficult to explain was the high float currents observed on high resistance cells.

It is significant that positive grids and active material were in excellent condition. Grid corrosion rates were found to be below the necessary design corrosion rate for twenty year life and correlated well with accelerated life testing data. Paste adhesion and cohesion properties were excellent. Porosimitry data on active material appeared normal while X-ray diffraction testing indicated slightly elevated sulfate content on the positives, similar to the negatives. In short, the plates appeared to be from healthy, if slightly discharged Absolyte® cells.

In response to the theory that water loss was a major contributor to the capacity loss, GNB conducted a number of tests to determine if this was the case.

Water can be consumed or lost from a cell in three ways:

- Through positive grid corrosion according to the relationship:

$$Pb + 2H_2O \leftrightarrow PbO_2 + 2H_2$$

- By being exhausted out of the cell through the pressure relief vent.
- As vapor diffusing through the jar or cover material.

As noted, the teardown of hundreds of cells resulted in satisfactory corrosion rates. Amounts of corrosion products were measured and used to determine the moles of water consumed by grid corrosion. This coupled with the amounts of H_2O lost through the jar and vents were combined to provide a H_20 consumption rate for these cells which were exhibiting premature capacity loss. This consumption rate was then proportioned to 20 years to estimate end of life system saturation levels. (Cell saturation is defined as the volume of electrolyte proportioned to the total cell void volume.) These projected saturations were found to be within design criteria.

Another way of determining the total quantity of water lost from the system was to examine the separator saturation of the five to ten year old cells. This was determined using separator density and measured specific gravities. This data confirmed the water loss calculation described above.

A subsequent test was then conducted to determine the importance of water loss alone on cell performance. In this experiment, cells with identical electrolyte saturation levels in separator were overcharged to drive off water over a 12 month period. As the saturation values decreased, cell performance and impedance values were monitored. The test showed that while saturation values were reduced to what was previously believed to be end of life values, the capacities remained over 100% despite rising internal resistance (see Figure 1). Teardowns of some of these cells showed good correlation between the calculated water-loss and measured saturation levels.

An examination of separators removed from failed cells demonstrated that the thickness of the aged separator material had decreased from the dry specification value by 20% to 40%. Elements of some cells were loose in the jar at teardown; their elements easily slid out. These facts lent credence to our hypothesis of loss of compression. To validate this theory, tests were conducted where cells that were exhibiting premature capacity loss were externally compressed. Lab results showed typical capacity recoveries from 40 to 60% to greater than 90% (see Table 2).

To summarize, cells examined which did not suffer from other manufacturing or application related problems were found to have predicted grid corrosion and acceptable water consumption rates. Saturation values for five to ten year old Absolyte® cells were found to be in the desired operating range. Indeed a test which drove saturation values to levels previously thought to represent end of life, showed capacities unaffected. Finally, the separator thickness of naturally aged product was found to have decreased significantly from its original value and capacities were readily restored via external cell compression. All of these facts point unequivocally to the conclusion that the cause of the premature capacity loss suffered by Absolyte® cells, and absorbent glass mat VRLA technology in general, has its roots in compression loss and not dry-out.

FIELD ADJUSTMENT PROCESS

As the root cause analysis of the premature capacity loss phenomenon neared completion, GNB faced a difficult dilemma. A significant amount of product was already out in the field that potentially could exhibit this capacity loss due to loss of compression. A great deal was at stake for our customers whose systems were in jeopardy of not providing the needed support power. At the time of the discovery of the capacity loss phenomena, GNB Technologies determined that a proactive approach was mandatory in order to protect its customers.

The first step was to determine what options were available for a field solution. A possible solution was to increase compression by external force. This solution was not optimum, however, since the only way to restore the design compression (the 20 to 40% lost as separator material becomes saturated) is to overcompress the containers, potentially increasing stress on jar to cover seals.

A second solution approached the problem from another perspective. A large amount of the compression loss occurs as the separator becomes saturated with the addition of acid, due to glass fiber slippage. However the capacity loss does not show up until some time later as the separator gradually loses contact with the plates. To remedy the problem, it is necessary to reestablish ionic contact between the separator and plates. Experiments showed that the addition of water caused the separator material to reexpand.

The next step was to obtain data on the effectiveness of water addition in regaining and maintaining contact between the plates and separator. Through experimentation, an optimal amount of water addition was found which would restore capacities to acceptable levels without causing a significant change in the electrochemical properties of the cell or overfilling. Therefore, a simple field solution could be implemented with minimal disruption to the users. Water addition showed an immediate improvement in the capacity of cells (see Table 2).

Table 2 - Average Cell Capacities Before and After Lab Experiments

	External Compression	Water Addition
Before	42.1%	43.5%
After - Cycle 1	87.2%	90.1%
After - Cycle 2	92.6%	91.1%

Now the time came to develop and initiate a program. Labeled the FAR (Field Adjustment Repair) program, GNB launched an initiative in March 1995 to add a specified amount of water to all cells in service that were manufactured prior to 1991. GNB entered into this field adjustment procedure with full disclosure to customers and field representatives. It was imperative that battery users, installers and maintainers understand the difference between a battery that had a compression loss problem, a battery that had been subjected to harsh operating environments and a battery with manufacturing defects. It was important to recognize that the water addition corrects only the problem it is designed to correct - loss of compression of the absorbent glass mat separator.

Since the program was launched, GNB has been monitoring cells that have gone through the program both in the laboratory and in the field. The repair procedure has been successful in maintaining the rated capacities (see Figure 2). As expected, the repair procedure had not been successful in compensating for damage to cells from harsh environment, improper care or manufacturing defects. Field data points will continue to be gathered as part of the research.

CONCLUSION

Through this process of extensive research and development and the continued commitment to the advance of VRLA technology, GNB Technologies has identified several key factors regarding VRLA AGM design batteries.

- Absorbent Glass Mat VRLA batteries can suffer from a loss of compression leading to a loss of capacity.
- All other design characteristics of Absolyte® technology are performing and aging within design expectations when installed and operated in accordance with GNB instructions.
- Absolyte® II batteries manufactured before 1991 which are exhibiting premature capacity loss can be recovered through the addition of a prescribed amount of water to extend the useful service life.
- The field adjustment does not correct other problems - such as manufacturing defects or application related issues.

The proliferation of VRLA batteries is expected to continue. This is because the nature of the applications these batteries serve continues to evolve away from central locations and the ability to inspect and maintain batteries on a routine basis continues to decline. VRLA batteries have only been in existence for a relatively short period of time and have, as with any new technology, been exposed to the learning curve. We continue to learn about flooded batteries, even though they have existed for over 100 years. Not all VRLA batteries are created the same and it is important that the user engage in technical discussions with the manufacturers to determine the best solution for a given application. When this occurs, VRLA batteries can provide a highly reliable and economical solution.

REFERENCES

1. Feder, D. O., "Performance Measurement and Reliability of VRLA Batteries," Proceedings of the Seventeenth INTELEC Conference, The Hague, The Netherlands, October 1995.

Figure 1 - Cell Saturation and Impedance vs. Capacity

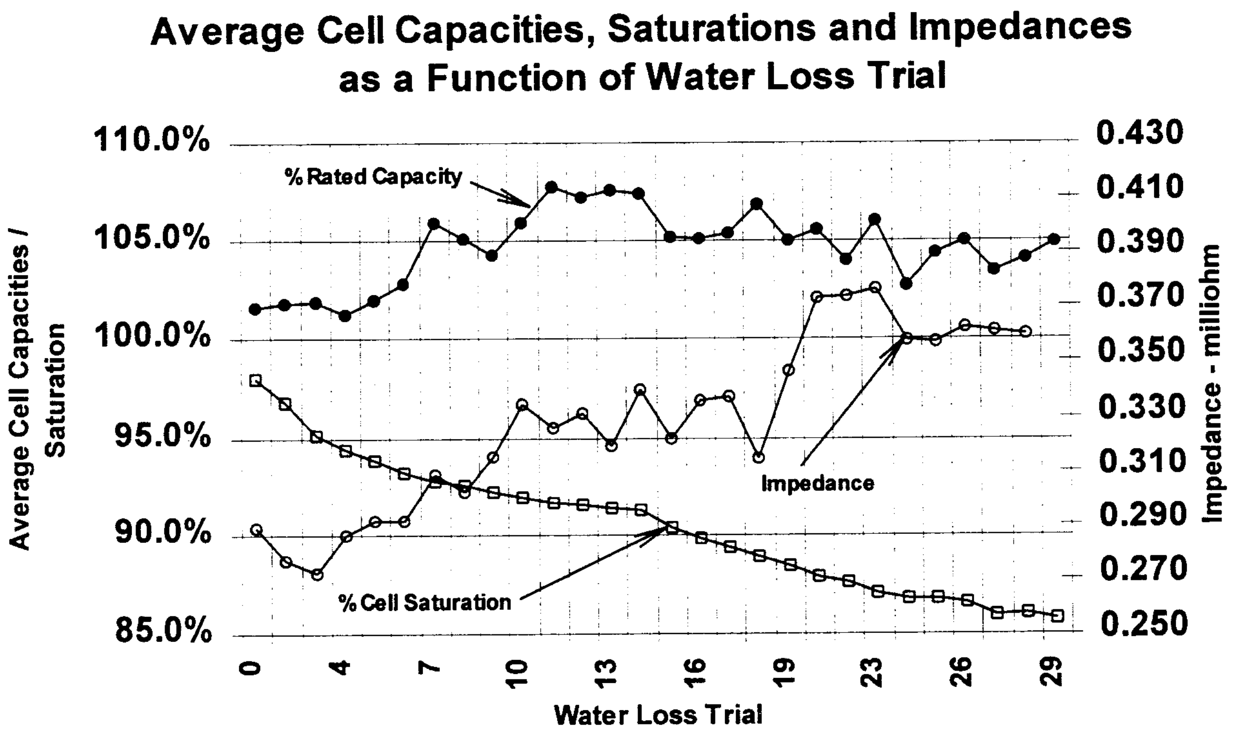

Figure 2 - Trend of Average Cell Capacities Before and After Water Addition