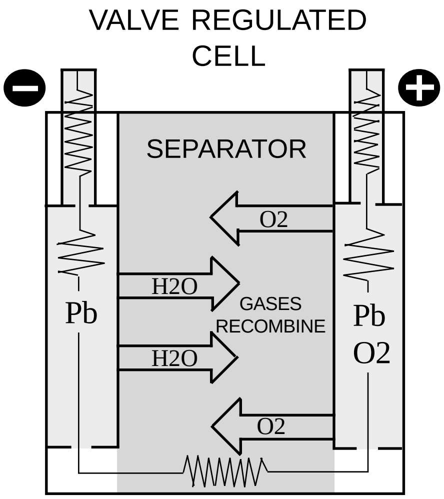
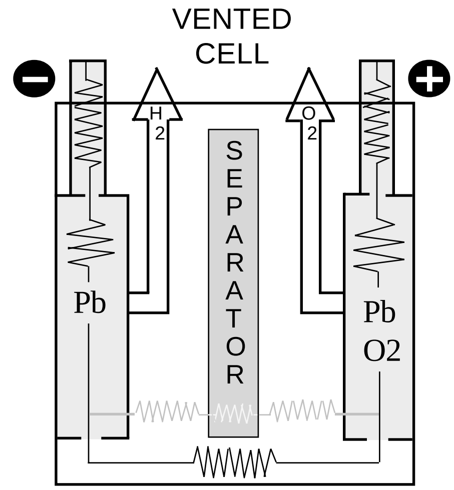


Electrolyte absorbed in separator

INTERNAL RESISTANCE and the CELLCORDER



Liquid electrolyte

INTRODUCTION

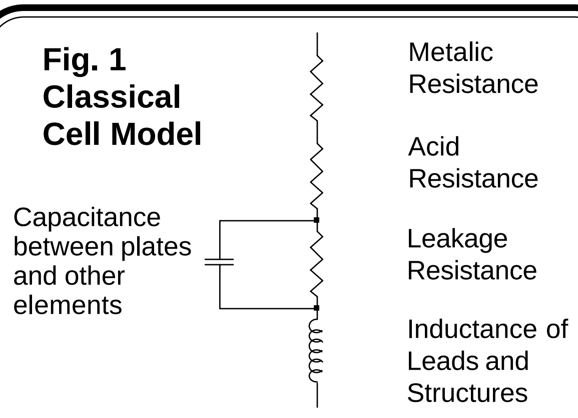
With the changeover from “vented” cells to “sealed,” VRLA cells, and the proliferation of UPS systems, an even greater impetus has been placed in finding economical and reliable ways to establish the state of a battery’s capacity and its conduction path. In this Application Note, the primary focus will be on a new, relatively low cost aid in determining a battery’s health by virtue of its cells’ internal resistances together with float voltages and intercell connection resistances. All three of these variables are rapidly measured and conveniently recorded by the Albercorp Cellcorder, the storage battery multimeter.

THE SEARCH

The search for new approach to capacity and conduction path testing has been ongoing. Traditionally, a battery’s capacity to store energy has been specified by its manufacturers as its ability to supply a *constant* amount of current, or power, to the load for a defined time period to a final voltage. The real test of the battery’s *actual* capacity as opposed to its rated capacity frequently involves hours of manpower and load and data acquisition equipment.

Unfortunately, a new approach has yet to gain industry-wide acceptance. The consensus of battery experts is still that load testing under controlled conditions is the *only method with certainty* of establishing a battery’s actual capacity. This is reflected in several national standards; the latest of which was issued in 1995.[1,2]

Fig. 1 Classical Cell Model



However, after many years of experience, studies and experiments, a wealth of information about battery behavior and measurements has been produced and some light has been shed on new tools that will help assess a battery’s condition. As early as 1959, the equivalent circuits of cells and typical circuit values were published.[3] (See Figure 1 at center.) These circuit models of a battery’s cell, are critical to understanding how its condition relates to cell internal parameters, conduction paths and capacity.

THE BASICS: RESISTANCE, INDUCTANCE AND CAPACITANCE

The models’ circuit elements are resistance, capacitance and inductance. Researchers have investigated battery parameters from DC through several thousand hertz and have made measurements in all units. They tried to relate those to cell capacity, often with mixed or conflicting results.

In almost all typical battery applications, the inductance has no practical impact on battery performance because of its small magnitude (from 0.05 to 0.2 *micro*henries.) On the other hand, the actual capacitance of cells is surprisingly large, as much as 1.7 Farads per 100 Amp-Hours. This cell characteristic is put to good use by charger manufacturers. They depend on it to filter their charger output.[3]

However, little evidence has evolved that ties capacitance with the actual capacity of a cell. It’s worth noting that one researcher felt capacitive reactance “obscures” the predominant indicator of cell capacity, electrochemical resistance. More so, as the test frequency is increased. Impedance and admittance measurements include both capacitance and inductance in their readings.

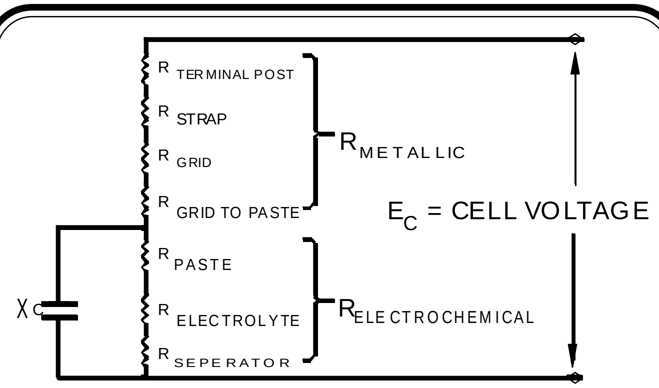


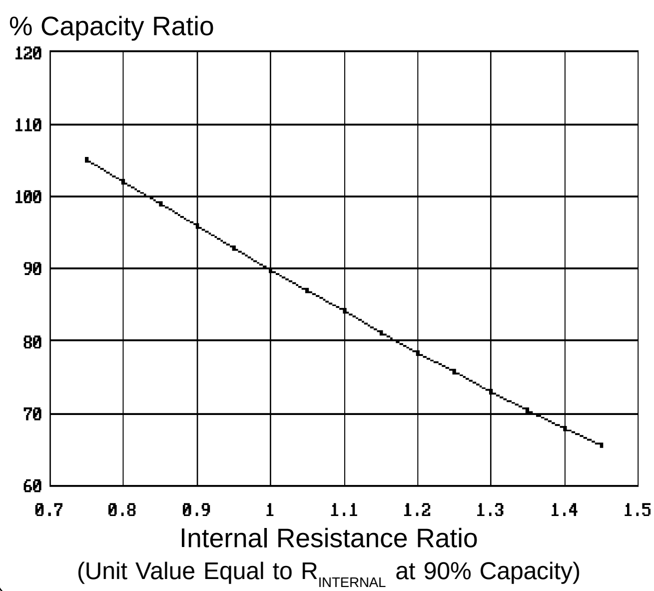
Fig. 2 - Internal Resistance Model

THE NATURE OF INTERNAL RESISTANCE

At Albercorp, we have centered our efforts on cell internal resistance. A refined cell model has been developed which subdivides the internal resistances of a cell, as shown in Figure 2, into its metallic and electrochemical components. These resistances do not change with test frequency. Indeed, researchers have concluded that a zero frequency, DC, or extremely low frequencies, yield the best results when studying capacity relationships.[4,5]

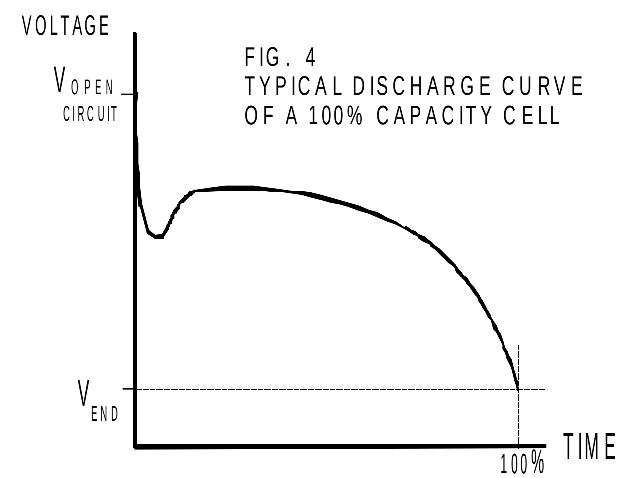
Another group focusing on internal resistance is prestigious Nippon Telephone and Telegraph. Their research and field personnel have shown that a major result of the lead acid battery deterioration mechanism is an increased internal resistance. A 500 microsecond duration pulse technique is used to measure cell internal resistance. Test results lead them to conclude that battery deterioration (capacity) can be estimated within +/-10% by internal resistance measure.

Fig. 3 - CAPACITY & INTERNAL RESISTANCE ESTIMATED FROM PULSE DISCHARGES



Note that Capacity vs. Normalized $R_{INTERNAL}$ curve, shown in Figure 3, is *somewhat curved.* Some feel the relationship between most cell internal parameters and capacity is not a simple straight line as has been described in recent times but rather a more complex *curvi*-linear function.[6]

Part of this belief that a straight line cannot describe a capacity relationship is rooted in the differences exhibited during battery discharges from cells with metallic vs. electrochemical resistance problems. The typical discharge curve of a cell at 100% capacity is shown in Figure 4.



A battery's capacity is adversely effected by *an increased* internal resistance. Obviously, the power is dissipated internally, $I^2 \times R_{INTERNAL}$, and is not available where it is really needed... at the load. Thus, *actual* capacity is diminished. However, during *discharge* this reduction in capacity appears differently depending upon whether the resistance change is primarily metallic or electrochemical in nature.

METALLIC RESISTANCE

This portion of the internal conduction path troubles most battery test experts. It is here that deterioration of a cell can occur most rapidly and then will often go undetected between the yearly integrity tests or, even less frequently, the capacity tests.

The tear down of failed batteries with abnormal internal resistances has proven that the terminal posts and the internal straps and grids are most often the victims of corrosion, poor welds or “burns”.[7] Where found, contact surfaces of a copper insert can corrode or loosen from its surrounding lead post. The Cellcorder easily detects these types of problems.

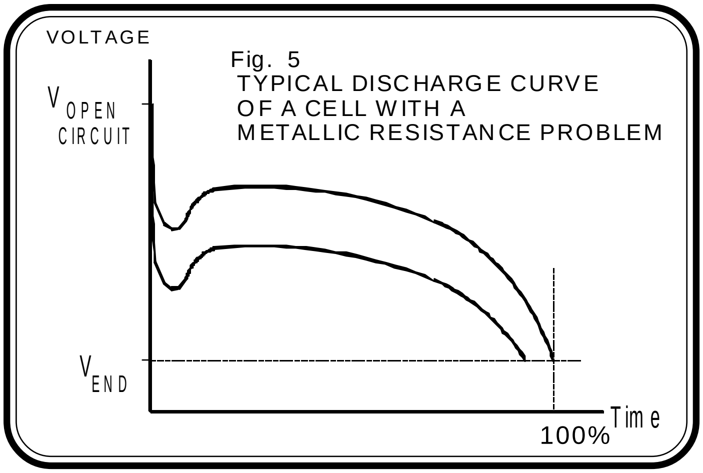


Fig. 5
TYPICAL DISCHARGE CURVE
OF A CELL WITH A
METALLIC RESISTANCE PROBLEM

Fig. 5 clearly shows the loss of capacity due to a high internal *metallic* resistance. The available voltage at the battery's terminals is reduced from the start of the discharge and continues to the end.

ELECTROCHEMICAL RESISTANCE

Cell paste, electrolyte and separators form the electrochemical part of cell internal resistance. Long-term increases in $R_{ELECTROCHEMICAL}$ can be caused by loss of active material or paste due to aging. Short-term changes also occur naturally during parts of the charge or discharge processes when the specific gravity is altered; or when the contents of the separators varies and/or the chemical composition of the surfaces change.

Separator compression, clogging or shorts, and conditions like sulfation are frequently causes of abnormal, increased electrochemical resistance; however, ***accelerated electrolyte dryout appears to be public enemy #1*** when it comes to VRLA failures.

Figure 6 reveals how a battery with an *electrochemical* resistance problem behaves. Its reduced capacity does not become apparent until much further into the discharge, like "running out of fuel." On the other hand, the metallic resistance problem can be viewed as pinching the fuel line! In either case, the worse the resistance, the greater the shortfall between the cell's *rated* and *actual* capacity.

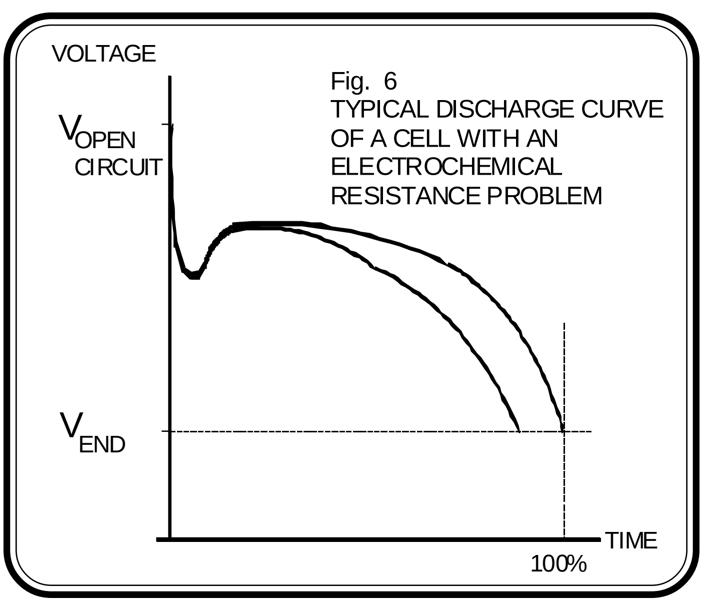


Fig. 6
TYPICAL DISCHARGE CURVE
OF A CELL WITH AN
ELECTROCHEMICAL
RESISTANCE PROBLEM

BATTERY AGING AND INTERNAL RESISTANCE

Internal resistance provides a clue to aging. The aging process of a battery's cells is based upon the rates at which their materials and construction deteriorate under design conditions. For example, the life of nearly all stationary cells is specified at 77°F, under particular float charge conditions and discharges of stipulated depth and frequency.

Very slow corrosion of conduction paths, the loosening of active materials from plates, grid deformation and, in the case of VRLA cells, dry out of electrolyte are all *natural* processes that push a cell to its end life. This aging process is marked by increasing cell internal resistance and decreasing capacity. It is generally agreed that below 80% actual capacity, the cell's deterioration will accelerate rapidly and replacement is recommended.

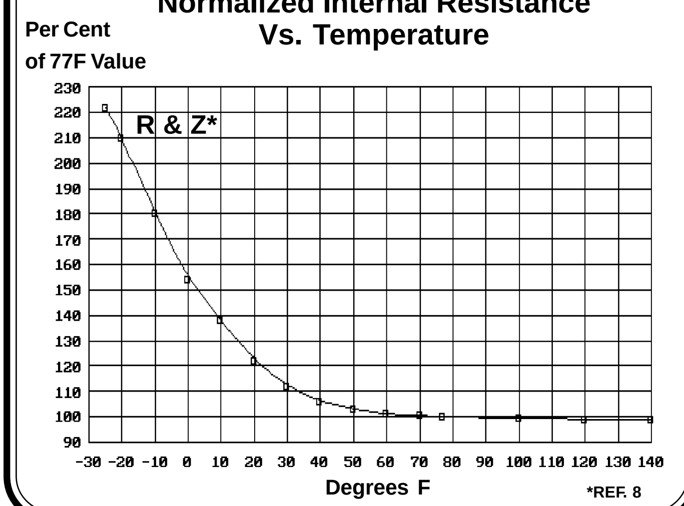
The internal resistance increases slowly but, toward the end of a cell's life, it accelerates greatly. Its end-life value is normally about 25% or so above its initial value, but can be as high as 50%.

TEMPERATURE AND INTERNAL RESISTANCE

Being aware of the effect of temperature on internal resistance is important. Figure 7, for a typical AGM VRLA cell, clearly shows rapid internal resistance and impedance increases below temperatures of about 45°F.[8]

In temperate climates, VRLA cells in *unconditioned* temperature environments may show considerable internal resistance variation between quarterly measurements. Recording of the ambient temperatures at the time of

Fig. 7
Normalized Internal Resistance
Vs. Temperature



measurement will might save you further testing and false alarms. Similarly, cells chilled by air conditioning exhibit higher readings than their sheltered neighbors. If possible, try to re-direct the air flow.

THE CELLCORDER

The Cellcorder is invaluable in determining what a battery or cell's internal resistance is and in helping to identify abnormal conditions and normal aging. *While a battery or cell is on-line,* it accurately and repetitively measures the internal resistance using DC techniques. The AC filtering currents, stray 60 hertz fields, noise and normal float currents have virtually no effect on its readings.

The authors can't help but wonder what earlier researchers could have accomplished if they had access to microprocessor and solid state technology. The microprocessor of the Cellcorder permits it to not only control measurements, but to also precisely time the readings and performs calculations. To boot, it can tell whether a reading is valid and then records the results.

THE MOMENTARY TEST DISCHARGE

This is a feature worth your time to understand. It is, in part, what distinguishes the Cellcorder from most instruments presently on the market and will help provide readings in which you can be confident.

For rated cell capacities of less than 1000 amp-hours, the discharge is short, only three to four seconds, in the order of 20 to 75 amps. For larger capacities, the duration is close to 10 seconds.

To prove a point about safety and the effects of *short-term* high currents, we performed the following experiment. We imagined an internal conductor corroded down to the size of this white dot 3.

We found that passing the Cellcorder's test current through a skinny wire (27 inches of #20 gauge wire) caused no damage nor barely heated it. Try it! The reason is that very little energy is involved. It amounts to only a maximum of 5 watts per *1000 micro*hms and *lasts only seconds*.

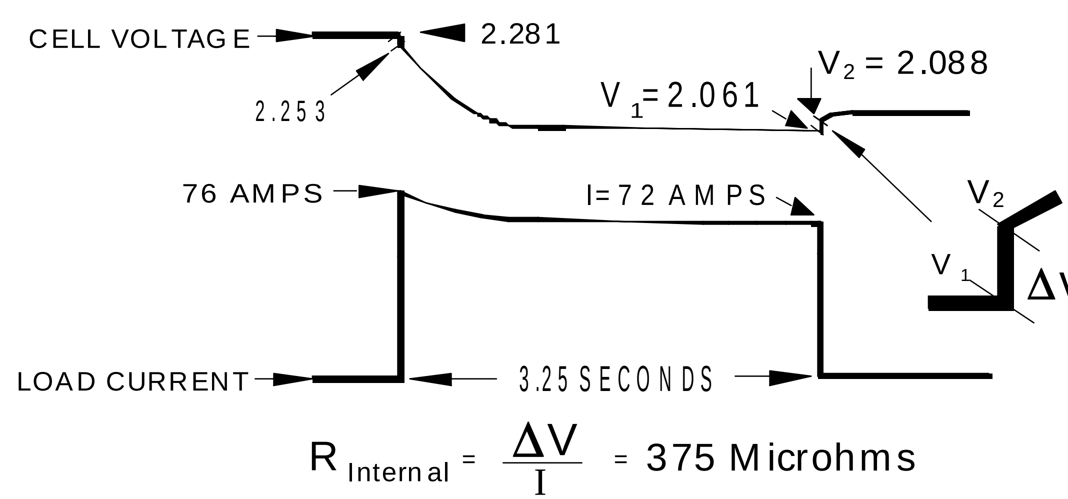


Fig. 8 - Measuring Internal Resistance

The battery manufacturers have customarily determined the internal resistance of cells using simple Ohms Law. They usually measure the voltage differences and current during a battery discharge.

The Cellcorder does the same thing... but <u>very quickly and accurately</u>. Figure 8 above reveals what happens when a battery is subjected to a load. The instantaneous voltage drop when the load is applied, or the instantaneous voltage recovery when the load is removed, is due to the internal resistance. The Cellcorder reads the current and the cell voltage just prior to removal of the load and then measures the recovered cell's voltage. The resultant resistance is simply $R_{INTERNAL}=\Delta V/I$. [9]

In an actual test, within milliseconds of starting, the Cellcorder senses the current level. If there is a very high internal resistance, the current will be low and the discharge will be instantaneously terminated. Thus, a cell with an exceptionally corroded internal conductor will not be further damaged.

After tens of thousands of cell tests, there have been no reports indicating that the Cellcorder's test discharge has caused a cell to open circuit. Interestingly, many battery specialists feel disappointed that their most severely corroded cells have <u>not</u> opened. They would rather have them open during a supervised test than during an actual emergency when no one is around!

ALBERCORP RESEARCH

Carefully conducted Albercorp experiments have revealed other important properties of cell internal resistance. One is the relationship between metallic resistance and electrochemical resistance.

Many would expect that as the energy stored in a fully charged cell diminishes, the internal resistance of the cell would increase both *proportionately and significantly.* This belief is widely held because of how the lead acid cell electrochemistry is envisioned.

Measured amounts of energy were methodically removed and each time the internal resistance was read. It was found that the internal resistance rose no more than 3% after removal of 32% of the cell's energy. Upon continued discharge, the internal resistance increased rapidly in a non-linear fashion.

Since it is extremely unlikely that the cells' metallic resistance could have changed while the cells were discharged, it can be concluded that:

1) the changes noted in total internal resistance were due exclusively to electrochemical resistance change;
2) the electrochemical resistance change is a small part of total internal resistance as the stored energy drops from 100% to substantially lower levels of charge.[9]

In the real testing world, this is good news. It means that a battery can be reliably tested by the Cellcorder at float, open circuit voltage and even partially discharged.

THE "BASELINE" AND WHEN BEST TO GET IT

The fantasy of a "battery literate" person is that *complete* capacity and internal resistance test data, from *day zero,* is available for analysis. <u>He seeks to determine the typical internal resistance of cells at 100% and 80% as well as the trend from 100% through 80% capacity</u>.

The fantasy begins with the battery's installation. An acceptance capacity test is conducted and the cells' internal resistances measured. The results should be fairly uniform and he would safeguard this data. He knows it serves as the ideal baseline, or "reference" per IEEE/ANSI P-1188, for future internal resistance tests. He will then be able to make *cut and dry* decisions about maintenance or cell replacement.

Unfortunately, it's a fantasy in most environments because, in the rush and tumult of getting a facility on-line, establishing a baseline usually has low priority. As a result, we are then left to getting data in the best ways possible.

The second best time to obtain a set of data is shortly after capacities have been determined on *the same model cells of the same age*. Lastly, try obtaining data on *the same model cells* of any age. Over time, data to the end-life or 80% capacity level will be accumulated.

-CAUTION-

Internal resistance data taken *without* the benefit of correlated known capacities is often referred to as "as-found comparative values." This as-found data could be used to set a baseline, but be *very cautious*. It is not unusual to find an entire string of cells of uniform internal resistances, and normal appearance on float, but with *failing capacities*. In this situation, we highly recommend <u>at least</u> a crude service/load test be performed to lend some credence to the internal resistance measurements.

THE COURSE OF ACTION

If you do not have end-life or 80% baselines developed from significant samples of the same cells, age, etc., you should use the following rough rules-of-thumb based upon Cellcorder user reports and in-house experience.

If the internal resistance is:
20%-50% above the 100% baseline, then the cell be load tested... the sooner the better if it's towards the high end; at 50% or above the baseline, the cell be replaced.

Surprisingly, the IEEE/ANSI VRLA P-1188 proposed standard is more liberal in this matter. It recommends that from 25% to about 43%, the cell's manufacturer be contacted. Above 43%, a load test be done ASAP. Actually, the standard is expressed in the reciprocal of internal resistance, conductance (*mhos.*)

DATA ANOMALIES

Another part of the battery literates' fantasy is also likely to be shattered: that *all* the data gathered for the baseline, or test readings taken afterward, would fall reasonably close to any trendline. That is, higher capacity cells will have uniformly lower internal resistances and lower capacity cells will have proportionately higher internal resistances. Even cells fresh off of a tightly controlled production line fail to completely conform with this expected behavior.[5]

In the course of your own testing, you will find *tested,* <u>high</u> capacity cells with an unusually *high* internal resistance. Similarly, there will be cells with the *low* internal resistance characteristic of a good cell that would fail a capacity test. Unfortunately, the current state of the art does not permit impedance, conductance, admittance or resistance testing to definitively identify the cells with anomalies... without the assistance of a load test.

If you are fortunate to have large amounts of both capacity and corresponding internal resistance data, developing a baseline should be no problem. When a program is just starting, or there are few cells of a particular model, some educated "guess-timating" helps in sorting out data. If you need baseline data try calling us or the cell's manufacturer.

INTERNAL RESISTANCE TEST FREQUENCY

The whole purpose of the internal resistance check is to determine whether a cell has deteriorated and if so, how much and how fast. Logically, checks are done periodically.

At least quarterly, check cells that have exhibited signs of abnormality either from inspection or an earlier capacity, integrity or internal resistance test.

Since neither specific gravity nor visual checks can be done on sealed cells, you would want to do much more frequent testing than on vented cells. For that reason, it's no surprise the P-1188 VRLA proposed Standard recommends internal measurements be taken <u>quarterly</u>.

On the other hand, the standard for vented batteries, 450[1], doesn't specify this type of check. However, it does call for annual connection resistance readings and you would want to take the internal resistances at the same time.

That's the nicest part of the Cellcorder... its "multimeter" functions measure and record both the internal and connection resistances at the same time! It saves you time and you don't even move the test leads for single post cells. For detailed information, request Cellcorder Application Note CC002, *Intercell Resistance Measurement Procedures* which covers single and multiple-post cells measurements.

MANAGING THE CELLCORDER'S DATA FILES

As a testing program progresses, the number of computer data files will increase rapidly... as many as four yearly per battery string if the P-1188 guidelines are followed.

To quickly identify these type files and manage them with minimum errors through DOS or through Windows File Manager, a file naming system can be important. Try to include in the filenames' eight characters as many descriptors as possible to reflect the data's date, location and battery. Thus, filename ***941WPB1A.DAT*** would describe the first test data, in 1994, for location WPB's battery 1, string A.

Whether you use numbers or characters, the important thing is to make the filename as recognizable as possible while avoiding duplicate filenames. This helps immensely in finding files and to avoid overwriting, deleting or copying wrong files, especially when using operating systems before version MSDOS 6.

SAFEGUARDING THE CELLCORDER

By far, the most common cause of damage to the Cellcorder is from *grossly* excessive input voltages, particularly when taking UPS cell readings.

AWARENESS is the most important factor in avoiding these kind of problems. Before any testing begins, take five minutes to survey the battery bank to make sure that:

- cells are <u>not</u> misnumbered;
- the intertier cable routing is unmistakable;
- the main battery terminals and other spanable high voltage points are identified and temporarily covered.

Also, before making a measurement that includes a cable routed through a tray to another tier, use a voltmeter to identify the other end. Make sure no potentially damaging voltage is present.

POWER-UP the Cellcorder <u>*before*</u> connecting it to a battery. This activates additional protective circuitry.

CLEAN-UP is also important especially in preserving the jaws and clips of the test leads. Wipe off all grease and then apply an acid neutralizing solution.

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(9) G. Alber, "*Are Internal Cell Parameter Measurements a Substitute or Supplement to Capacity Testing?*",

For further information on the Cellcorder or other Battery Test and Monitoring Systems, contact your local representative or

Albércorp.

Phone (561) 997-2299 Fax (561) 997-5588
990 S. Rogers Circle, Suite 11
Boca Raton, FL 33487

Represented By:

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