A PRIMER ON NODULAR CORROSION IN STATIONARY LEAD-ACID BATTERIES

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WHY DID I WRITE THIS WHITE PAPER

This paper is written for end users as an introduction to the little known about issue of nodular corrosion which occurs in vented/flooded lead-acid stationary batteries. This is not written for those that want scientific reasons as to what causes this condition, or for the battery manufacturers, as all of the manufacturers are fully aware of this issue. However, most users are not aware of nodular corrosion and the risks it can impose, and my objective is to introduce you users to this infrequently occurring but very real and potentially very dangerous condition.

Nodular corrosion when it has had time to advance enough (years), depending upon the cell technology and post seal design, will cause the internal resistance of the positive post to increase, or will actually eat away at the positive post within the post seal well. In both cases the resistance of the current carrying path of the post increases. This condition is particularly important with batteries that have a high inrush load as compared to their rated amp-hour, such as power plants, substations, and UPS systems. With lower rated loads it can cause a reduction in the runtime under load (capacity).

These changes to the positive post(s) have caused battery posts to melt apart when the site load was applied. This melting apart of the positive post(s) has occurred in batteries that were on-line with the resulting damage to the generator being supported, as well as when the battery was off-line and undergoing a service test that mimicked the site loads. Those users that experienced the failure of their posts when their batteries were off-line obviously dodged a bullet as if their batteries had been online protecting their equipment when their posts melted apart their stories would have had a much sadder ending.

WHY AM I WRITING THIS NOW

Nodular corrosion in vented lead-acid batteries has been around for longer than most of us have been alive. The first paper that we are aware of, that explained its causes was presented at Intelec 1988 [1]. Every battery manufacturer, and numerous nuclear plants are aware of this so it should be easy for anyone to understand that nodular corrosion is not a fringe “the sky is falling” type issue.

Over the years at various power plants, we have performed two of the three known procedures that have been utilized in attempting to address it. The process utilized depends upon the specific battery design and condition. We also pioneered inserting a borescope into the headspace of the cell in order to be able to inspect parts of the post seal wells that are not visible from outside the cell.

For decades now we have been aware of how to identify the condition visually after it has had many years to attack the positive post. We accepted that looking for the cracks in the post seal well walls, or the compression seal nuts, or the covers was the only way to identify it. We also realized that there was no way to identify the development of the condition until it had advanced to the point where the damage to the post was severe enough that it was causing the plastics to crack.

It was not until 2024 that we decided that there needed to be a way to detect the problem earlier on in its development. We also realized that the inspection process needed to be able to be done by anyone that knows how to safely work on these battery systems, and that it be performed with the type of equipment that those technicians are familiar with. With those two objectives as our guide, we ended up developing two different inspection processes that will detect increases in resistance within the positive post. One process requires the battery to be out of service with all hardware removed and the other process can be performed with the battery fully assembled and either in service or out of service.

This previously generally unknown issue is now more widely understood, and important enough that the NRC is now aware of and addressing it, and one manufacturer has recently rewritten their I&O manual and included a section entirely devoted to how to visually inspect for it. At this moment in time (2026) the existing IEEE 450 document does not include any reference to nodular corrosion. When the IEEE 450 was last reviewed this issue was not known about or understood by the reviewers of the document. That document is presently under review. I anticipate that now that the issue has been exposed, that when that document has completed its review process, there will be nodular corrosion detection explanations included.

Again: This paper is not intended to be a scientific paper which explains what the exact causes are, but rather an explanation from a user's experiences with this issue through the years and explains what any user can do to determine if this is present in any of their cells, or to prove if it is not there.

GENERAL STATEMENTS

Anyone that has been involved long enough in the maintenance and/or discharge testing of vented lead acid stationary batteries is aware that sometimes batteries when aged will fail the discharge test if the test is run at a shorter duration high rate discharge, such as the one hour rate but will easily pass the test if it is run at a longer duration lower rate, such as the three or five hour or longer rates.

Or they have seen cracking in the covers, or in the positive post seal nuts, or the positive post seal well area. And some even will have seen a positive post melt apart within the cover during a discharge test or event but the cell did not explode because the gas mixture was not right for combustion, or have witnessed a cell exploding during a discharge test because a positive post opened inside the cell and the gas mixture was right for combustion.

These issues can all be attributed to nodular corrosion occurring within the positive post or positive post seal well area. Nodular corrosion only occurs on the positive post; it does not occur on the negative post.

We are going to explain what causes nodular corrosion, how to visually identify it, and then how to electronically measure and quantify the extent of the damage it has caused to the resistance within the positive post. Even though this issue has been around for decades I would guess that less than 0.01% of us in this industry understand or have even thought about nodular corrosion, or the risk it imposes. Most users are unaware that when substantially advanced, it can and has caused posts to melt apart when the site's load was applied, with the resultant damage to the equipment it was supporting.

By the time you finish reading this, I believe that you will agree that nodular corrosion is very possibly the most dangerous condition that you could have in your vented lead-acid stationary battery if you are not aware of how to detect it early on in its advancement. However, if you do perform electronic inspections of the posts periodically you will never be able to have a surprise post failure caused by nodular corrosion unless you neglect to act on the information obtained through the inspections.

INTRODUCTON

The cause of all nodular corrosion begins with a failure of the inner post seal within the positive post seal well. This seal is designed to control electrolyte from migrating up the positive post and into the post seal well, and/or continuing up the post and through the cover to where it can be observed as creep corrosion.

Nodules, bumps, or pits grow on the surface or within the post within the post seal well, which as it expands causes stress to the plastic material and cracking is observed in the cover, post seal compression nuts when utilized, or sides of the post seal well. It can change the cross-sectional area of the post to lead sulfate, and/or create microcracks in the post (s), either of which changes the post from being a low resistance current carrying path to a higher resistance current carrying path [1] [3].

With some post designs the post material physically is eaten away as is shown in figures 11, and 21, and with some designs the corrosion can occur in the lead insert of the post seal and not within the post itself Figures 33 - 36.

The amount of damage to the post(s) is dependent upon a variety of different issues, such as, but not limited to, the ambient temperature, electrolyte level, rate of decay, post design, and the duration that the post(s) have been under attack. With all cells, once the nodular corrosion has had adequate time, usually years, to advance, there will be an expansion or growth (nodules) of or on the post and can include microcracks forming within the post. Over time it can cause the post or the post seal well wall to increase in size to the point where it will cause cracking of the plastic parts such as the post seal well wall, post seal compression nut, or the cover. These are all visual proof of its presence.

All battery manufacturers are aware of this condition. The causes and reactions that occur with nodular corrosion were first written about that I am aware of, at Intelec 1988 [1] and then again at Intelec 2001 [4] and both provide scientific explanations as to what causes nodular corrosion and the differing results. Both of those papers were explanations regarding the development and progress of C&D's new (at that time) vulcanized rubber post seal. They explained that nodular corrosion has been around since covers were first put on cells, and that all manufacturers are aware of the issue, have most likely experienced it. Both papers emphasized the need to prevent or control electrolyte migration from within the cell up the positive post and into the post seal well area.

They also explained that there are three basic post seal designs which are Epoxy (Figure 1), Compression (Figure 2), and Vulcanized rubber (Figure 3), and that once nodular corrosion begins attacking the positive post that there is no stopping it. It will continue to attack the positive post(s) or the post seal lead bushing, until it completely changes the structure and current carrying capability of the post(s). Or if it is attacking the lead bushing in a vulcanized rubber post seal, and not the post itself, will still cause extensive cover cracks but will not impact the current carrying ability of the post(s). Only by measuring the resistance of the posts themselves can one determine if there is a risk to the cell's ability to function as expected, or if there is not.

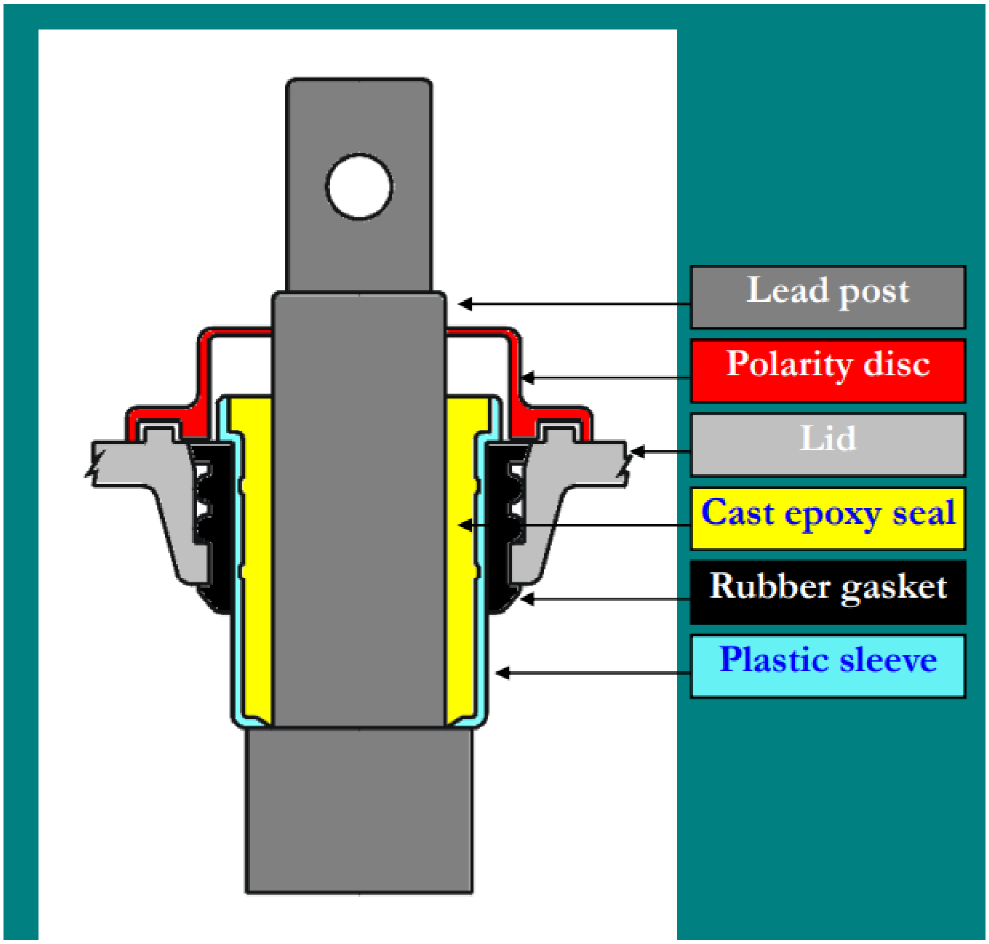


Figure 1: a typical epoxy type post seal design

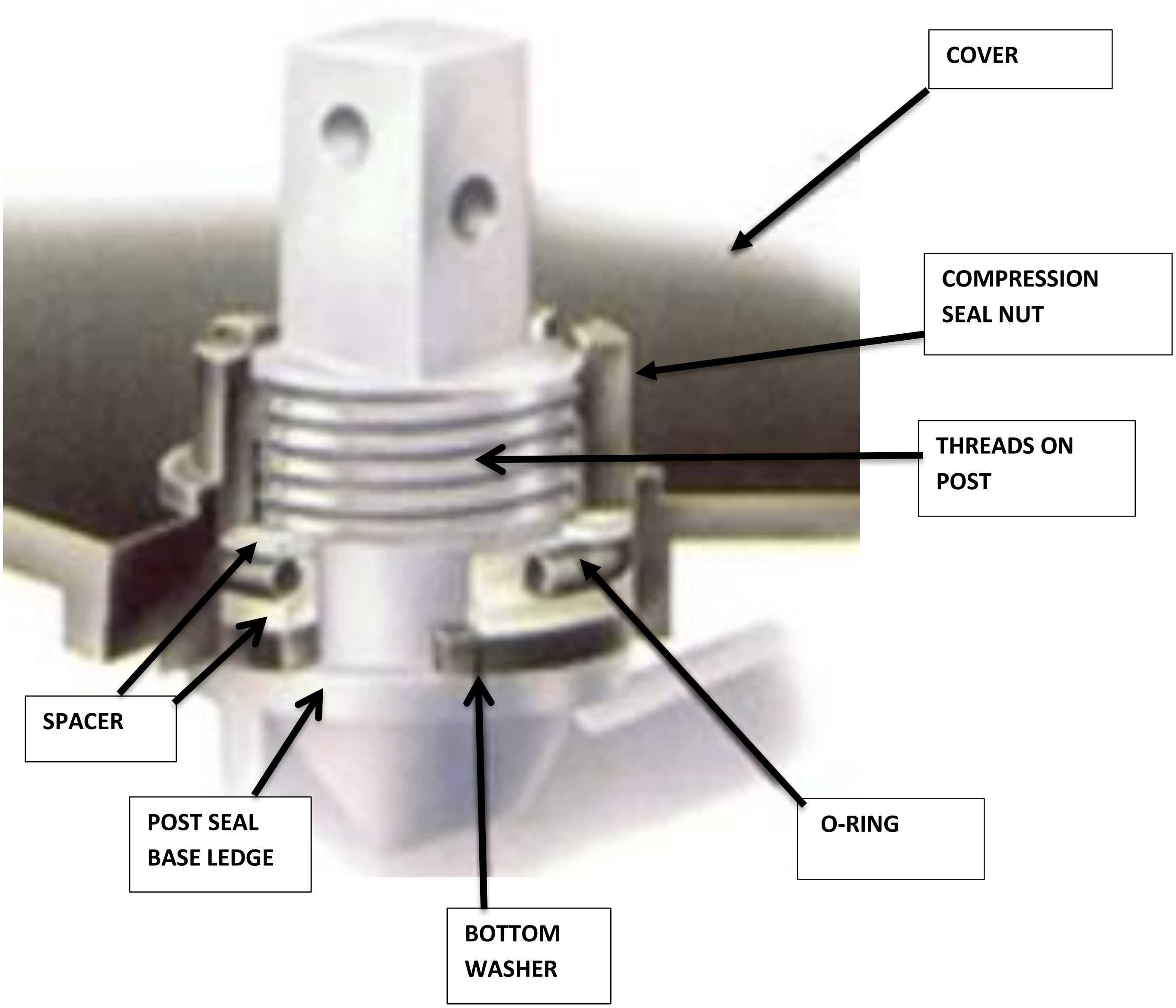


Figure 2: a typical compression type post seal design

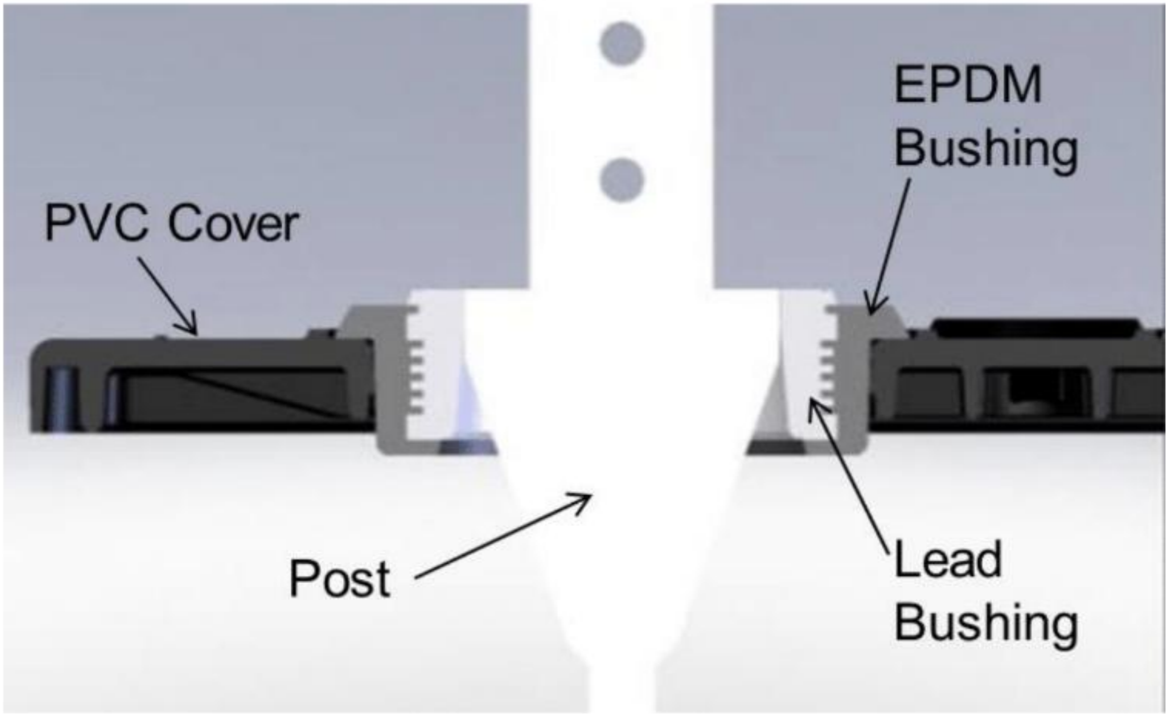


Figure 3: a typical vulcanized rubber post seal design

As a user, I really do not care what the scientific cause of nodular corrosion is as there is nothing that I can do about that. But I do care about knowing as soon as possible about its presence and how much of a negative impact it has had on my battery system. The goal of this paper is first to inform you of how to determine if your cells have it. Then secondly if they do have it, how to determine what the amount of increase in the resistance within the post(s) is at that moment in time. This information will allow you to understand the amount of risk that it is placing on your battery system, and which provides time to take actions as necessary.

The only battery manufacturer that I am aware of, that initially took into consideration their users being able to easily inspect for nodular corrosion was the Bell Round cell. The BELL SYSTEM PRACTICE KS-20472 BELLCELL* BATTERY VISUAL INSPECTION PROCEDURE SECTION 157-269-702 issue 1, December 1981 clearly describes (with drawings) the procedure for inspection for nodular corrosion. That procedure was commonly called the "hook and look". There was a PVC tool (boot lifting hook) which you inserted through the vent opening, then hooked the edge of the rubber boot, lifted it, and then looked at the positive post for nodular corrosion.

Until very recently that Bell procedure was the only one that we are aware of that instructed individuals in how to visually inspect for nodular corrosion. Recently (02/26) Stryten Energy took the lead regarding informing their users of the nodular corrosion issue and published an updated Installation and Operating Instructions for Nuclear Flooded Batteries document in which there is a new section, Section 20 (Troubleshooting) which is entirely devoted to how to visually inspect for Nodular Corrosion.[10] While their instructions are directed toward their batteries used in the Nuclear industry, the exact same procedures can apply to all vented lead-acid cells, as there is very little, or no difference, in the construction of their other models. These same visual inspection procedures can be utilized with any manufacturer's vented lead acid cells.

It must be understood that this is a rare but reoccurring condition that when present, can place the battery system and equipment at great risk. Prior to the development of the means to measure the internal resistance of the post(s), it was unable to be detected until the damage to the current carrying path of the positive post(s) had substantially advanced and visible evidence of its presence was noticed. By the time visual observation can be made the nodular corrosion will have been attacking the positive post(s) current carrying path for many years.

WHAT NODULAR CORROSION IS NOT

It is not the colorful corrosion that is observed on the positive posts where they contact the connection hardware, nor is it the black discoloration that you can see “creeping” up the positive post where it exits the cover. That is commonly called creep corrosion. Figure 4 shows a post with both creep corrosion indicators. When these are observed there is a high likelihood that nodular corrosion is also occurring because both are caused by uncontrolled electrolyte migration past the post seals.

Figure 4 creep corrosion

PREVIOUS ATTEMPTS AT STOPPING OR SLOWING DOWN NODULAR CORROSION

There have been only three actions that we are familiar with that were attempts to stop or slow down nodular corrosion, and in hindsight none of them stopped the progression of the corrosion. They did hide it sort of.

The most extensive action which was performed on cells that utilized the compression seal nuts, we last performed over 20 years ago. First you removed all hardware, then the post seal nuts, then we would core drill the corrosion off of the post threads and post(s) down to the base, then clean the threads (tap them), clean the post seal, coat the post with no-co, then install new inserts and gaskets and post seal nuts. With some we would insert a rubber gland in place of the original gaskets and spaces. This did not stop the post from continuing being attacked internally, as it only relieved the pressure that the nodular corrosion was placing on the plastics.

There also were some limited attempts where a dike was created around the edge of the cover and some type of fluid was poured into that area, which eventually hardened and became a new cover. Our company has never performed that process, but we have witnessed batteries where this was done. This also did not stop the corrosion but also hid its progression for some period of time.

The most recent attempt at a process to address the issue when it is causing the covers to crack is the process of gluing (plastic welding) the cracks, or gluing new sectional covers on top of the existing covers. This also does not do anything to address the nodular corrosion, as it only seals or covers the cracks. Eventually as the nodular corrosion continues, the cracks will continue to grow beyond the glued portions.

HOW TO VISUALLY DETERMINE IF YOU HAVE NODULAR CORROSION

Anyone can easily detect nodular corrosion visually when it is in an advanced stage, if they just actually look for it. Since the area where it occurs is in the post seal well, which is the area from beneath the cover to the lowest portion of the post seal well, the sides of the positive post seal well are where it is typically first observed. It begins with minute cracks in the plastic there, which can be seen from the front of the cell with a flashlight. This allows inspection of the front half of the positive post that is closest to the aisle. To inspect the rear half of that front positive post, plus the front half of the positive posts that are on the rear side of the row, a borescope is inserted into the headspace [2].

In the Batteries & Energy Storage (bestmag) N0. 69 Summer 2020 issue, nodular corrosion was explained and information provided on how to visually detect the condition once it had time to advance. That article explained how to use a flashlight and a borescope to perform a thorough inspection for this condition. The name of that article was “Avoid catastrophic failure events – Detecting internal post-seal failures due to nodular corrosion in VLA cells” [5]. Back in 2020 we had not yet figured out how to detect it earlier on in its development before it had time to impact the resistance of the positive post and we, just like everyone else, had to wait for it to degrade the post to the extent that we could visually observe its results.

One visual indicator that nodular corrosion might be present is observing a creeping black or dark color working its way up the side of the positive post(s). This DOES NOT PROVE that nodular corrosion is present, but it does prove that there has been a failure with the post seals. Creep corrosion often is observed with posts that do have nodular corrosion, but it does not have to be present for nodular corrosion to be occurring.

With cells that utilize compression seal nuts, verification of suspected nodular corrosion can be done by removing the compression seal nut and inspecting the threaded area of the post. If the threads are not smooth in nature and instead show corrosion, then nodular corrosion is occurring and the resistance of the post itself will have increased. It must be understood that external observations will tell you that the issue is present, but it will tell you nothing about the changes that have already occurred to the internal resistance of the post. To understand the degree of degradation to the post, the resistance of the post must be measured, which until recently there was no way to do that.

With posts that do not utilize removable compression seal nuts, a change of the color (darkening) of the post seal or post, or a deformation of the post seal can also be indicators of nodular corrosion but does not always mean it is there, or that the nodular corrosion is attacking the positive post or if it is attacking the post seal bushing. If a turned upward edge to the lead bushing is observed this also is an indicator of nodular corrosion.

Almost all cover cracks that radiate away from a positive post are caused by nodular corrosion [2] [6] [7]. Figures 5 to 18 are all visual observations made either by just looking at the cover area, or through the side of the jar with a flashlight, or by use of a borescope inserted into the headspace of the cell which is one of the recommendations from Stryten Energy utilized to detect the problem.

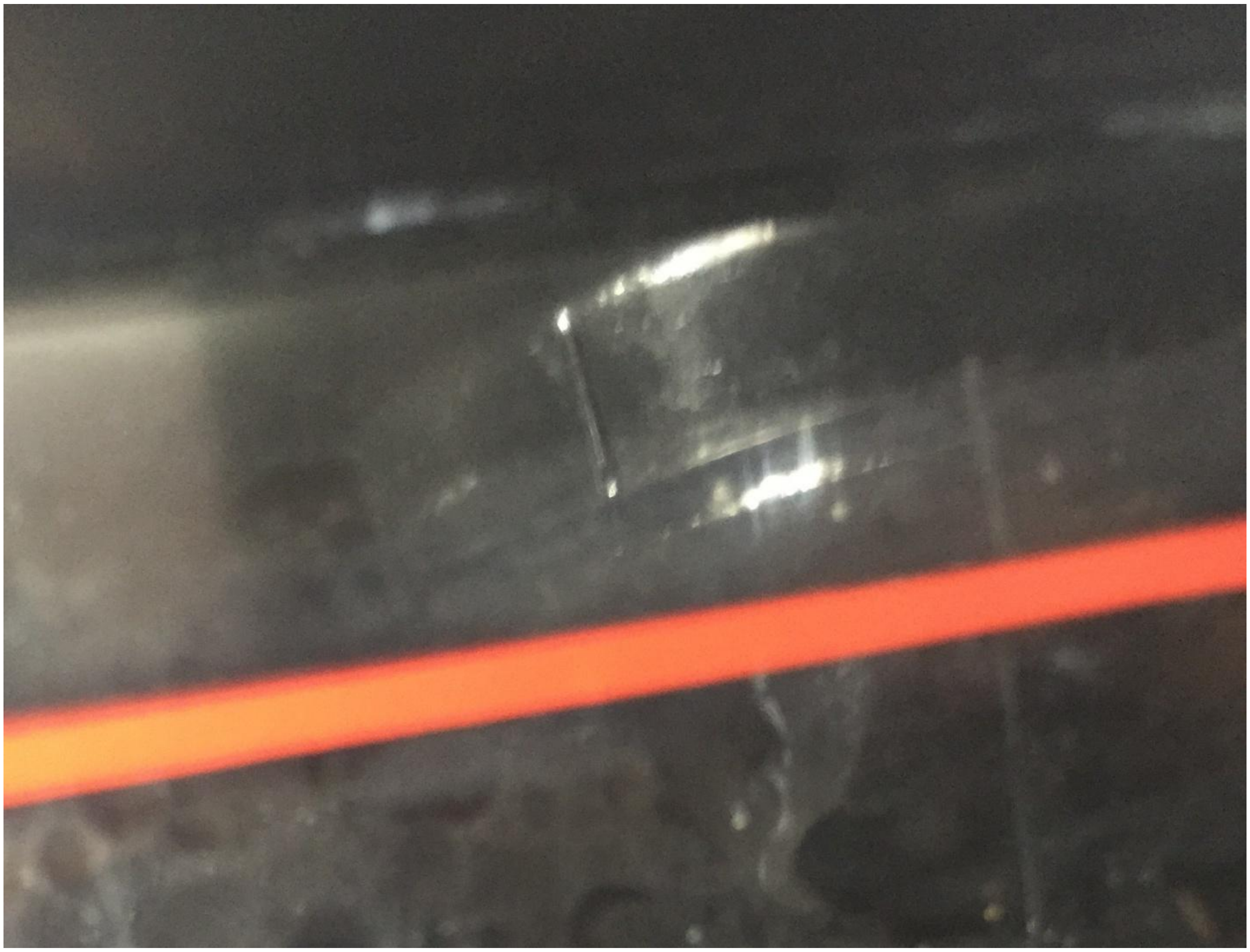


Figure 5 early detection of a crack in the post seal well wall through jar wall capture

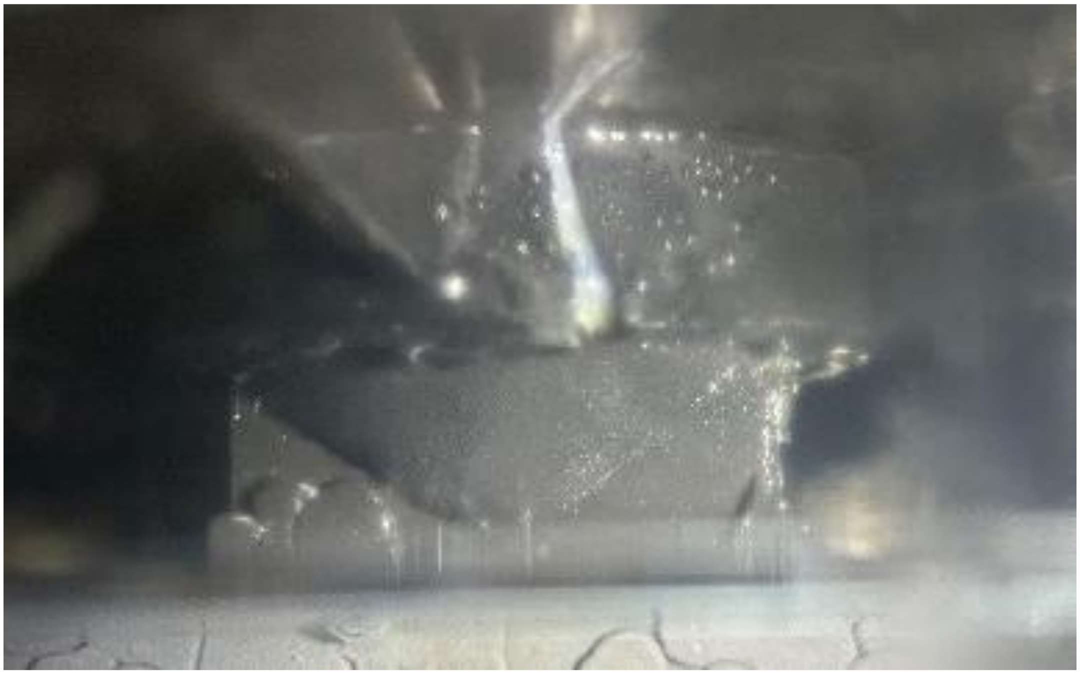


Figure 6 crack in the side of positive post seal well wall

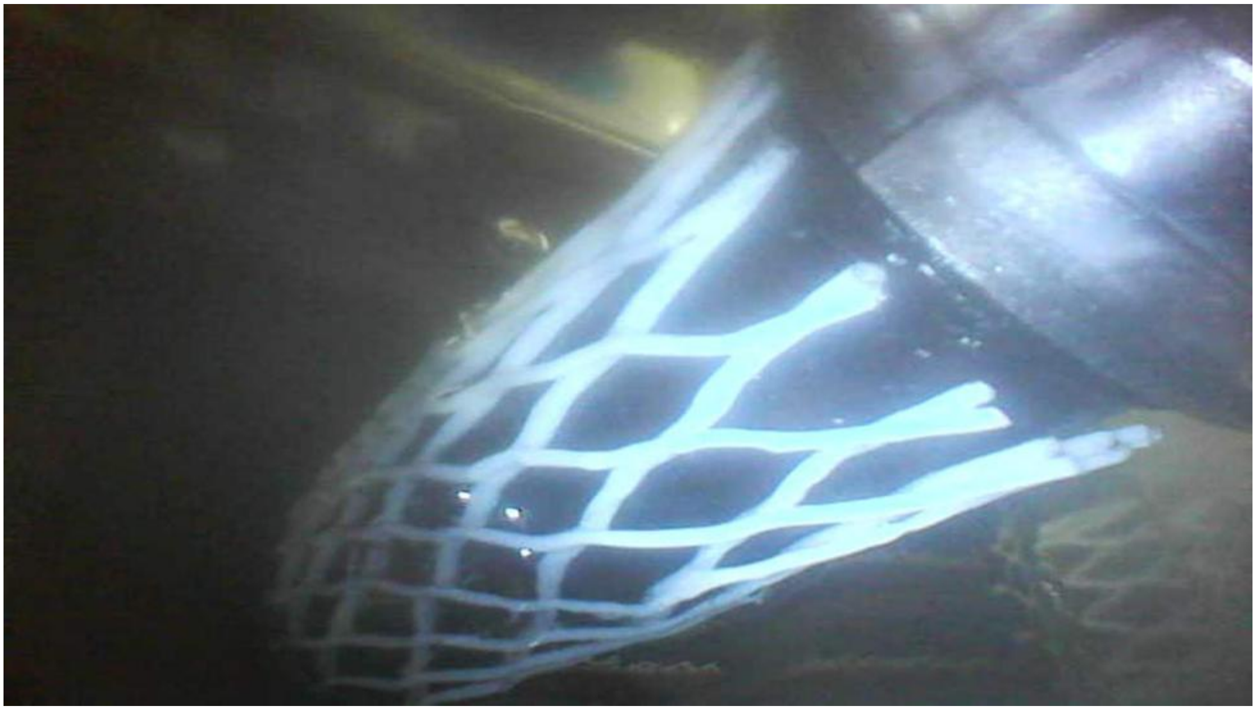


Figure 7 beginning of a crack in the side of positive post seal well wall

Figure 8 advanced expansion under plastic and post degradation viewed through jar wall

Figure 9 early stages of plastic rupturing due to post expansion borescope capture

Figure 10 medium advanced expansion borescope capture

Figure 11 medium stage of nodular corrosion decay on rear side of post viewed with borescope. The plastic material that had been broken off was observed in the electrolyte.

Figure 12 advanced stage of expansion through jar wall capture

Figure 13 very advanced stage of degradation through jar wall capture – broken off plastic material was in electrolyte.

Figure 14 both creep corrosion and cover cracking due to nodular corrosion

Figure 15 cover cracking proof of nodular corrosion presence

Figure 16 cover cracking radiating away from positive post indicates nodular corrosion presence

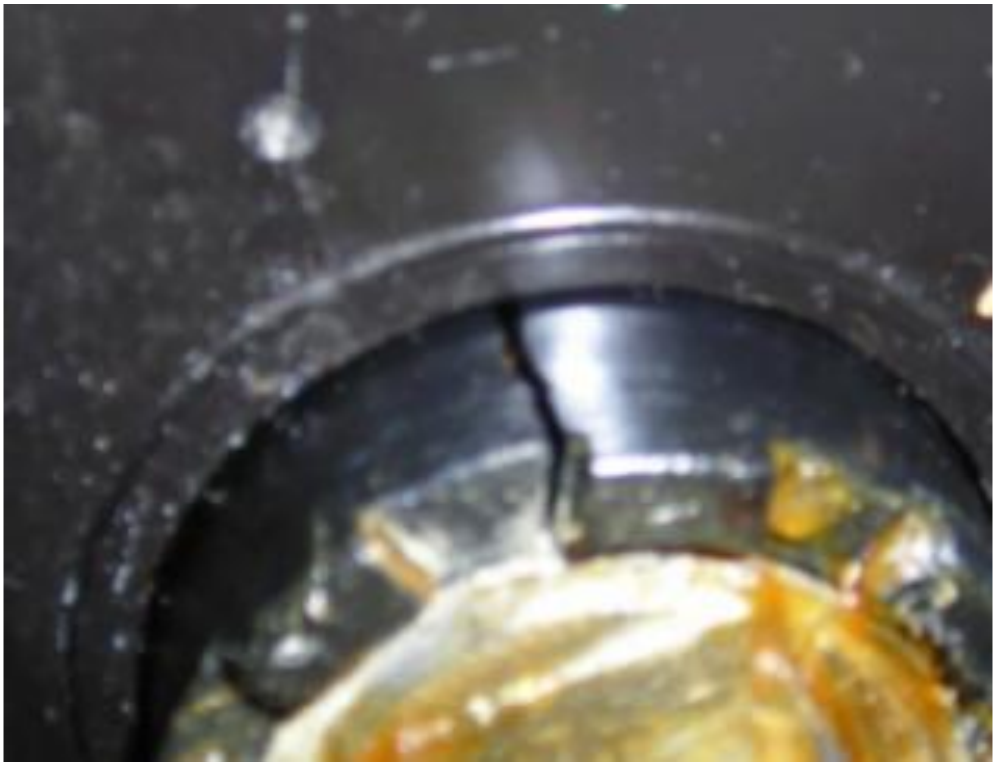


Figure 17 a positive post compression seal nut cracking proof of nodular corrosion presence

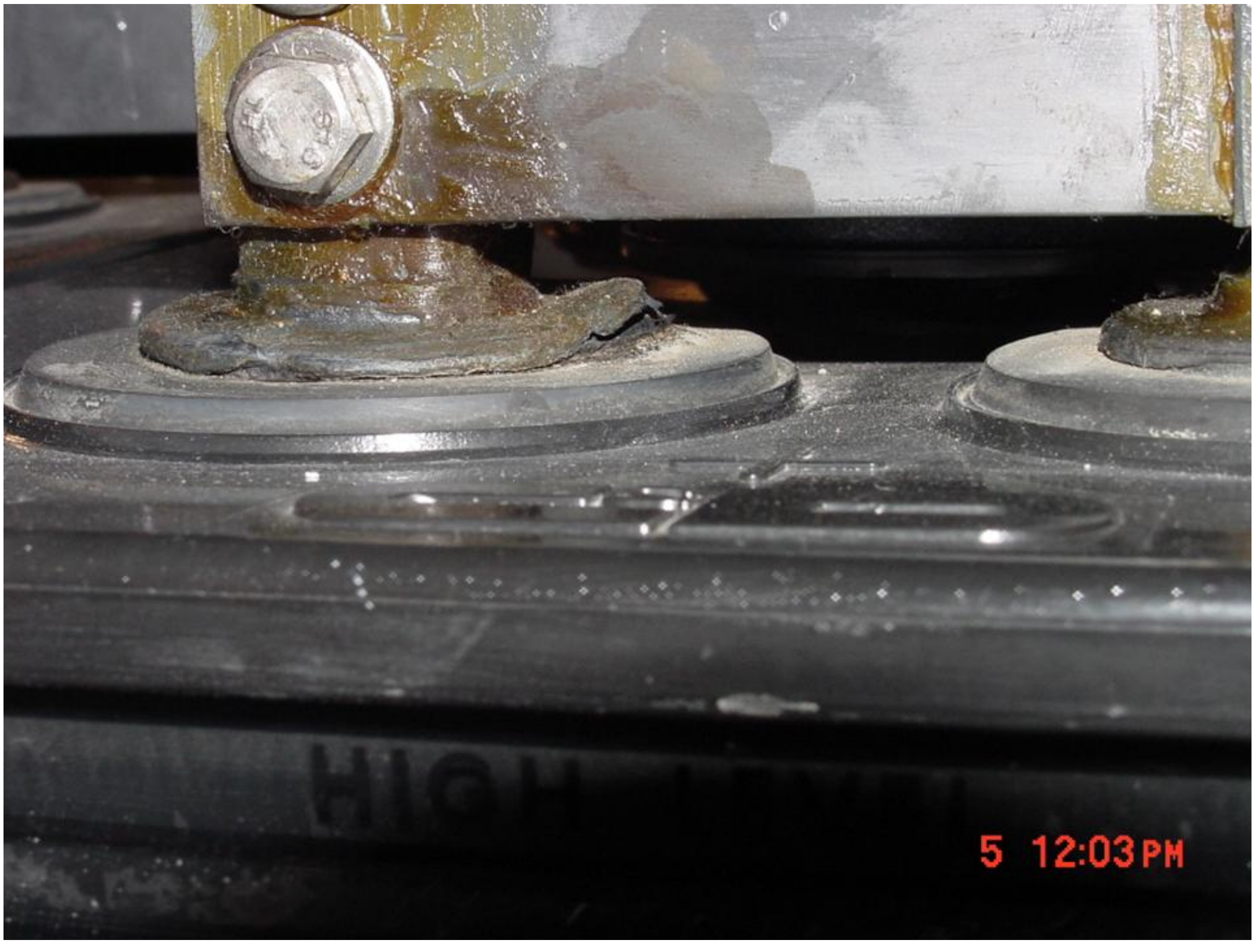
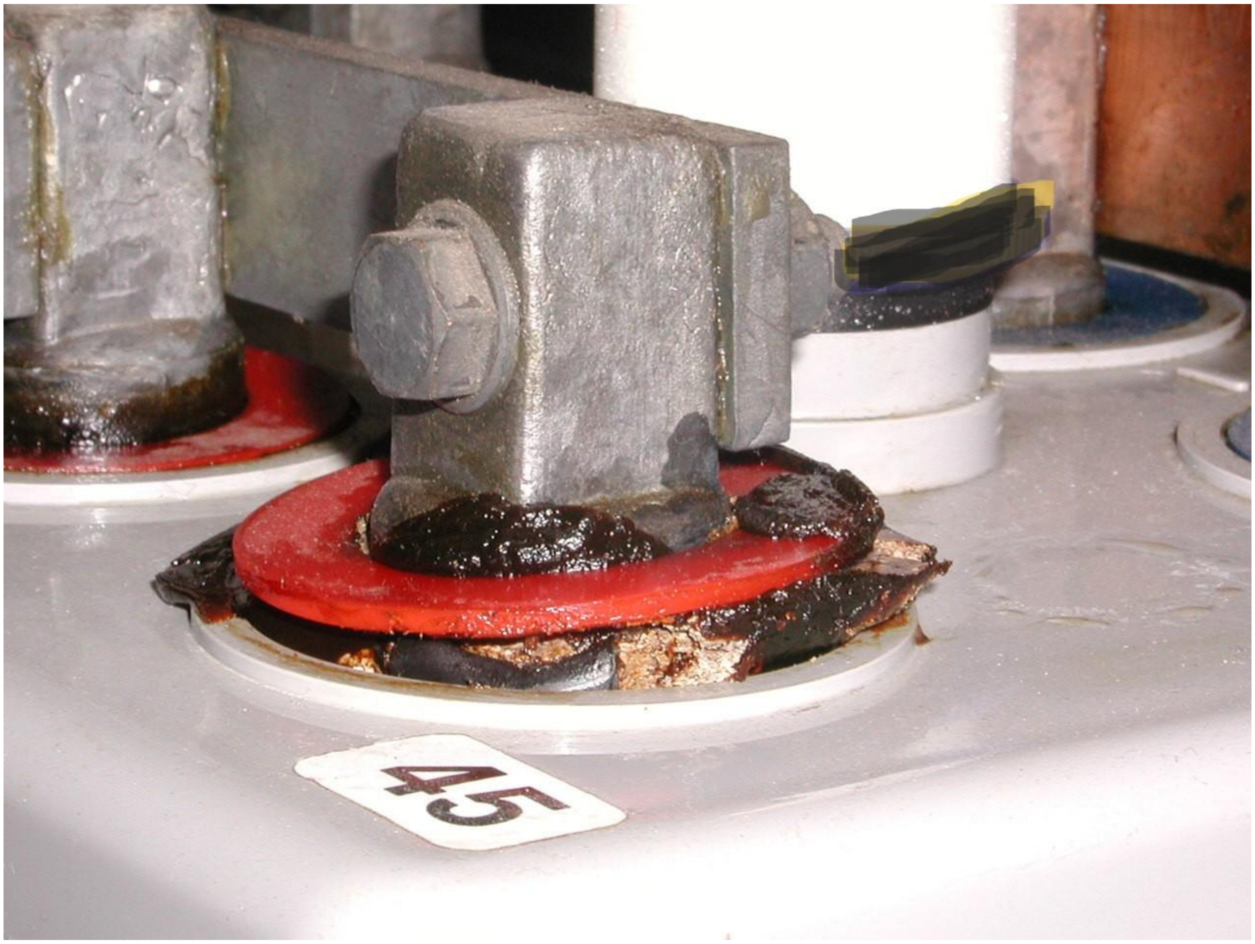


Figure 18 Blackening of positive post, creep corrosion, and edge of the post seal bushing being turned upward are all indicators that nodular corrosion is present.



[redacted]

Figure 19 slight creep corrosion on both posts and advanced nodular corrosion in one

All these visual observations are proof that nodular corrosion had been attacking the positive post(s) or the post seal bushing for some extended period. None of them, no matter how severe the damage appears, can inform us of the changes that have already occurred to the resistance within the post(s). That change to the resistance within the post(s) is the most important piece of information you need to know to be able to determine if your battery and the equipment being supported is at risk, and if so, the level of that risk.

It is important to think about the resistance within the post the same as you do about connection resistances between the cells, with the exception being that the resistance within a post can increase substantially before it becomes a threat to the post(s) integrity. IEEE 484-2019 [8] states in section 6.2.2 item l) that when measuring the connection resistances that any like type connection resistance that is either 1.1 times the average or 5 microohms greater than the average, that the connection needs to be remade. This is required so that the connection provides the minimum amount of resistance to the passage of current. For example, if the average resistance of a particular post to post connection is 100 microohms, then 1.1 = 110 microohms, or using the average + 5 microohms then the answer is 105 microohms. If the connection resistance measured is greater than these values, then based upon IEEE 484-2019 [8] the connection is unacceptable and needs to be addressed.

I believe that no matter how bad a cell post looks, whether it be from creep corrosion, cracked seal wells, covers, etc., the only meaningful and most important item is the resistance of the post(s) themselves. If they can pass current without an unacceptable voltage drop, or from creating a temperature rise that threatens the post(s), then it is acceptable for the specific load(s). Yes, you may still want to replace it, but at least you can be assured that it will not have a negative impact due to post failure or the battery's capability to protect your equipment until you do.

The discovery of the means that anyone can utilize to measure the resistance of the post(s) is new, so there is no history to fall back on. However, since we can now measure those values, it makes sense that if the values of both polarities are approximately the same or the positive post value does not increase by more than three or four hundred percent, there should be little or no risk of damage to the system. We do believe though that if the positive post(s) resistance exceeds an established baseline or the value of the negative post value by over 100 percent, that the manufacturer should be contacted in order make them aware that you are aware of the issue and ask them for advice.

The above value of three to four hundred percent IS NOT to insinuate that this amount of increase will create a failure of the post. Depending upon the load that the post(s) must carry, the resistance could increase by many thousands of percent and still serve its function. Ohm's law can be utilized to determine the voltage drop as well as the heat generated within the post during the current flow.

The objective of the measurement of the connector resistances upon installation as well as the requirement for annual connection resistance measurements per IEEE 450-2020 [9] is to verify that the resistance is adequate and/or has not changed over time and allows for a 20% change from initial readings or the baseline provided by the manufacturer. This is done to prove that the voltage drop through the connections is within the acceptable range as required by the manufacturer for the respective load and will not cause excessive heating or damage to the post during a discharge.

Since we all understand why it is important to ensure that our connection resistances do not degrade, then it should not be very difficult to accept that the same concept applies to the resistance within the post(s). The post(s) are designed by every manufacturer so that they are capable of the passage of a certain amount of current while maintaining a certain amount of voltage drop at whatever current rate that they publish.

When nodular corrosion is present in the positive post the resistance in the post(s) will exceed the negative post(s) by some value. When their resistance increases, they cannot pass the same amount of current without a decay in their capability. Ohm's law applies equally.

We need to think about the post(s) like a fuse. When it no longer can pass the current through itself, it melts, which is exactly what has occurred when the resistance within the positive post(s) has exceeded their current carrying capability and a load was applied.

One easily performed check for this condition is that when a discharge test is being performed to infrared scan the area where the posts go through the cover. If the positive scans are higher than the negative ones, this is proof that there is greater resistance within that post.

BASELINE RESISTANCE VALUES

To know what is acceptable and what is not acceptable, or that shows a change has occurred, requires a baseline value to reference to. When a battery is new the resistance of the positive post(s) and the negative post(s) are the same or very close to each other. When nodular corrosion is attacking the positive post(s) its resistance increases depending upon the extent of the changes that have occurred within the post(s). The negative post(s) does not change. There are three ways to determine what the baseline value should be for the cell being measured and our suggested order of priority.

1. Obtain the value from the manufacturer.
2. Create a baseline value when the battery is being installed.
3. Use the average negative post value for the battery and reference the positive post value for each individual cell to that negative post average.

MEASURING THE RESISTANCE WITHIN THE POSTS

There are presently only two known processes that we are aware of that are capable of measuring resistance within the post(s) and there are different requirements for each. Both processes are called a NCDI℠ (Nodular Corrosion Detection Inspection). The first method requires the battery to be offline with all hardware removed from the cells and is primarily utilized with cells that have multiple posts per polarity. The second method allows for measurement of cells that are in a fully assembled battery that is either online or offline.

When the positive post readings exceed the baseline value for that model cell a determination is then made as to the impact that increase in resistance will have on the cell's capacity or capability.

The following graph figure 20 shows the resistance readings of the current carrying paths for a sixteen-year-old 60 cell Enersys 2GC-17 string using method 1 [8]. Each cell has two posts per polarity. The readings were taken first with all the connecting hardware on the cells, and the second set with all hardware removed.

As can be seen with this method, measuring the resistance between the two posts when the connectors are installed provides results which provide no relationship to the resistance in the current carrying portion of the posts. This misleading information (for our needs) is due to the multiple current paths and materials being measured.

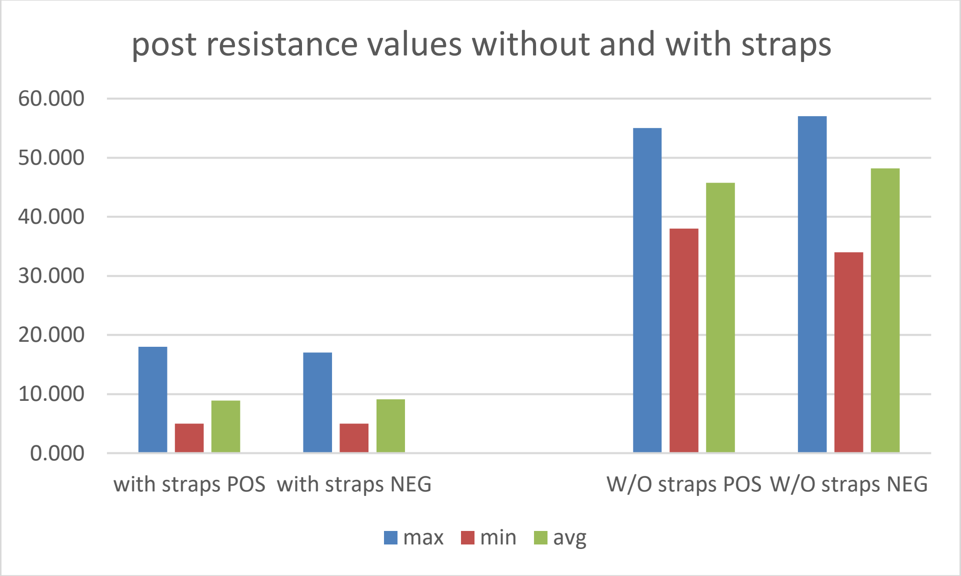


Figure 20 different post(s) microohm resistance results from performing a Nodular Corrosion Detection inspection incorrectly and performing it correctly (clue with straps is incorrect).

If we use the recommendation from the IEEE 484-2019 [8] IEEE Recommended Practice for Installation Design and Installation of vented Lead-Acid Batteries for Stationary Applications, section 6.3.2 Cell Mounting and connections item l) which explains an acceptable or not acceptable connection, it is noted that an acceptable connection is either within 1.1 of the average or 5 microohms above the average. Based upon that recommendation, if we transfer the same type of thought process to the resistance of the post(s) then with the above chart showing an average of 46 and 49 for the separate polarities and we take a conservative average and we will round those numbers up to 50 microohms, and then add 20% not 10% we end up with an estimated baseline value of 60 microohms for this model cell. We also can assume that the resistance through each single post will be approximately 27 microohms.

What using this logic means is that when the positive post path exceeds the baseline number by some percent, then nodular corrosion is present. If a reading's previously recorded value was 60 and it is now 90, then you will know that nodular corrosion is present. Each resistance excursion needs to be individually analyzed to determine how it impacts the battery system and your attached equipment.

Figure 21 shows a post that we cut off which as can be seen, was substantially degraded but which had not yet failed. Figures 22 through 27 show posts that failed open when the battery was online, the unit tripped and the post could not support the load, or the battery was offline and undergoing a service test that duplicated the loads that the battery would be required to support if called upon, or that broke apart due to hand pressure being applied to the post. Figure 28 shows a cell with the cover removed, which shows the difference between the positive and the negative posts in a cell that has nodular corrosion attacking the positive posts. Figure 29 shows a post that had melted apart internally but was still in service. Since there were two posts per polarity the cell remained charged. Figures 30, 31 & 32 show posts that have advanced positive post decay. Figure 33 shows a very advanced cover crack. Figure 34 shows a side view of a positive post seal bushing. Figure 35 shows a view of the nodular corrosion attacking the post seal bushing. Figure 36 shows a horizontal cut through the post in figure 34. Figure 37 shows a vertical cut through the post in figure 35. As can be seen, in this instance, the positive posts current carrying capability were not being impacted by the nodular corrosion. Figure 38 shows the impact that a 404% increase in resistance in the positive post at differing discharge rates will have on the voltage of the cell. Obviously not all the cells will develop this condition, but this graph does show the impact on the overall voltage if every cell had this same amount of increase.

Figure 21 shows the type and degree of degradation that had occurred in this post at the time of dissection. We cut this post off from the plates so that we could more closely examine how the post was being degraded.

Figure 22 shows the positive post that melted apart when the power plant that it was supporting tripped offline. The battery failed open as soon as the inrush loads were applied. This battery had PASSED a capacity test at its published three-hour rate just 14 months prior to this event, and this cell was not the weakest cell in the battery string. It passed the test with over 100% capacity. The cell did not explode. This failure caused damage to the generator which took months to rebuild, and cost millions in repair costs and lost revenue.

Figure 23 is a closeup of the upper portion of the post from the previous picture. This is within the post seal well. As can be seen the metallic structure has undergone severe change. This post melted open but the cell did not explode.

Figure 24 shows a cell that exploded during an offline discharge test due to nodular corrosion in the right rear positive post causing that post to open. Lucky for this user this occurred when it was offline as if it had been online with the generator running, the generator would have been damaged with the resulting costs and lost revenue.

Figure 25 is the positive post in a very small cell that melted apart under its load. I previously identified this as a fragility issue and the result of "torque' checking of the connection, but upon further study realized that it was a separation under load.

Figure 26 shows the lower portion area of this post that melted apart when the load was applied. This occurred when the string was out of service and was undergoing a service test. As can be seen, this separation is within the post seal well. The upper portion of the post was still connected to the connection hardware. The cell did not explode. This plant also dodged the bullet because if it had been online and it caused damage to the generator the losses again would have been substantial.

Figure 27 shows one of the positive posts in a two-post per polarity cell that was broken apart by simple hand applied pressure which demonstrates the fragility that can be caused by nodular corrosion. As can be seen there is some slight creep corrosion on the post.

Figure 28 shows the difference between the posts in a cell that has nodular corrosion. The posts on the right are the negative posts. Nodular corrosion does not impact the negative posts. Notice how smooth the bottom area is of those posts and how sharp the threads are. The posts on the left are positive posts and have advanced nodular corrosion. The lower portion of the posts are deformed, as nodular corrosion is present in those areas. As can be seen the threaded area of these posts are degraded with advanced nodular corrosion. The post on the lower left is further advanced than the post on the upper left. The top threads on the post on the upper right still show some sharpness to some of its thread edges. This demonstrates that both posts in a cell with multiple posts per polarity do not have to be attacked equally.

Figure 29 shows a post that was discovered during an online inspection of a battery whose cells had 2 posts per polarity. It was discovered during a normal online inspection and initially identified as “suspect” because the voltage was measured at above 3 volts, which flagged it for attention. The site repeated the measurements and observed that the voltage gradually decreasing until it eventually returned to within the average ICV range for the cells in the string. The cell was then removed from service for analysis, and this was discovered.

Figure 30 post attack that is not observable visually, but which can be measured electronically.

Figure 31 post attack that is not visually detectable, but which can be detected electronically. Notice how much of the current carrying path of the post has been impacted.

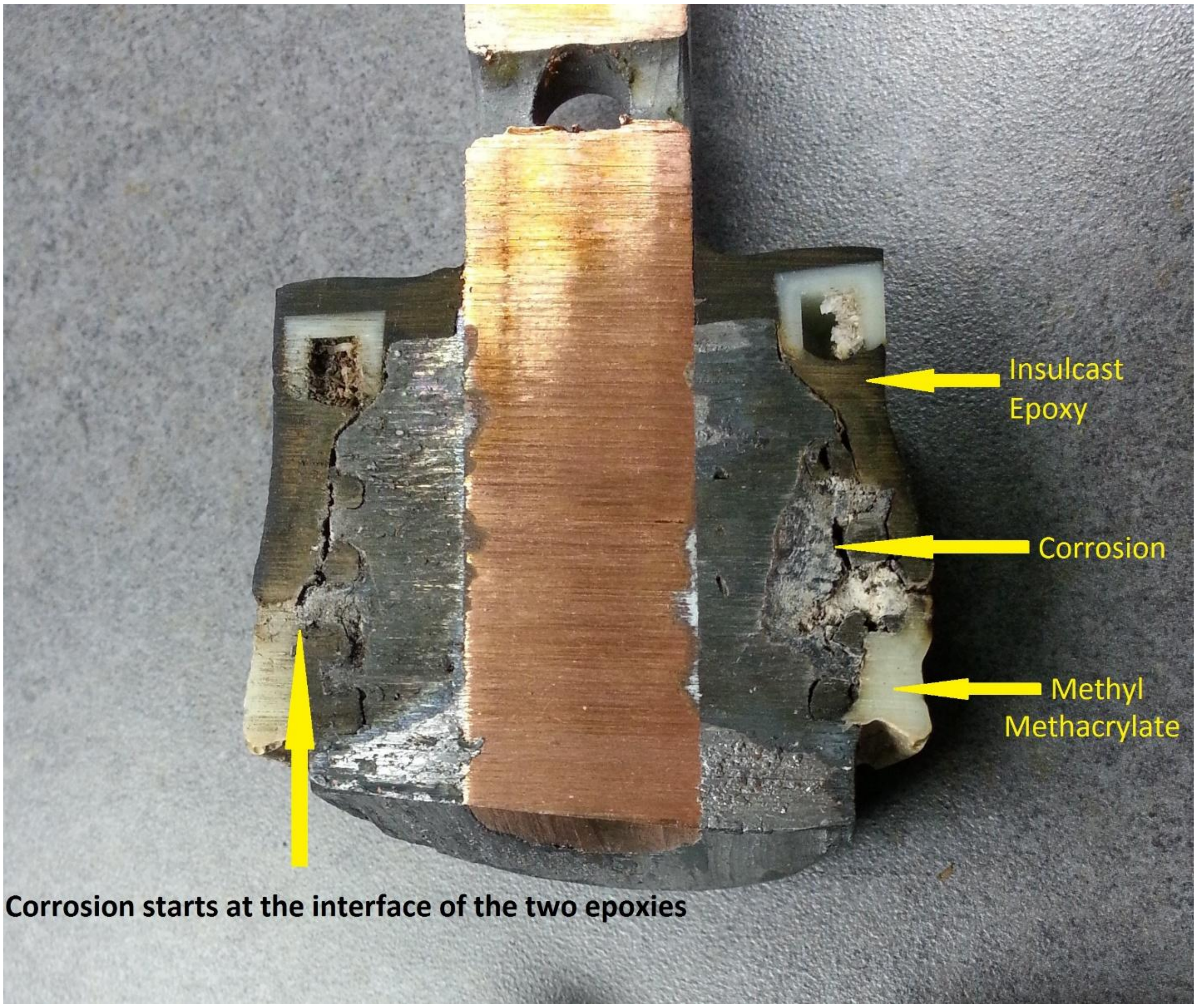
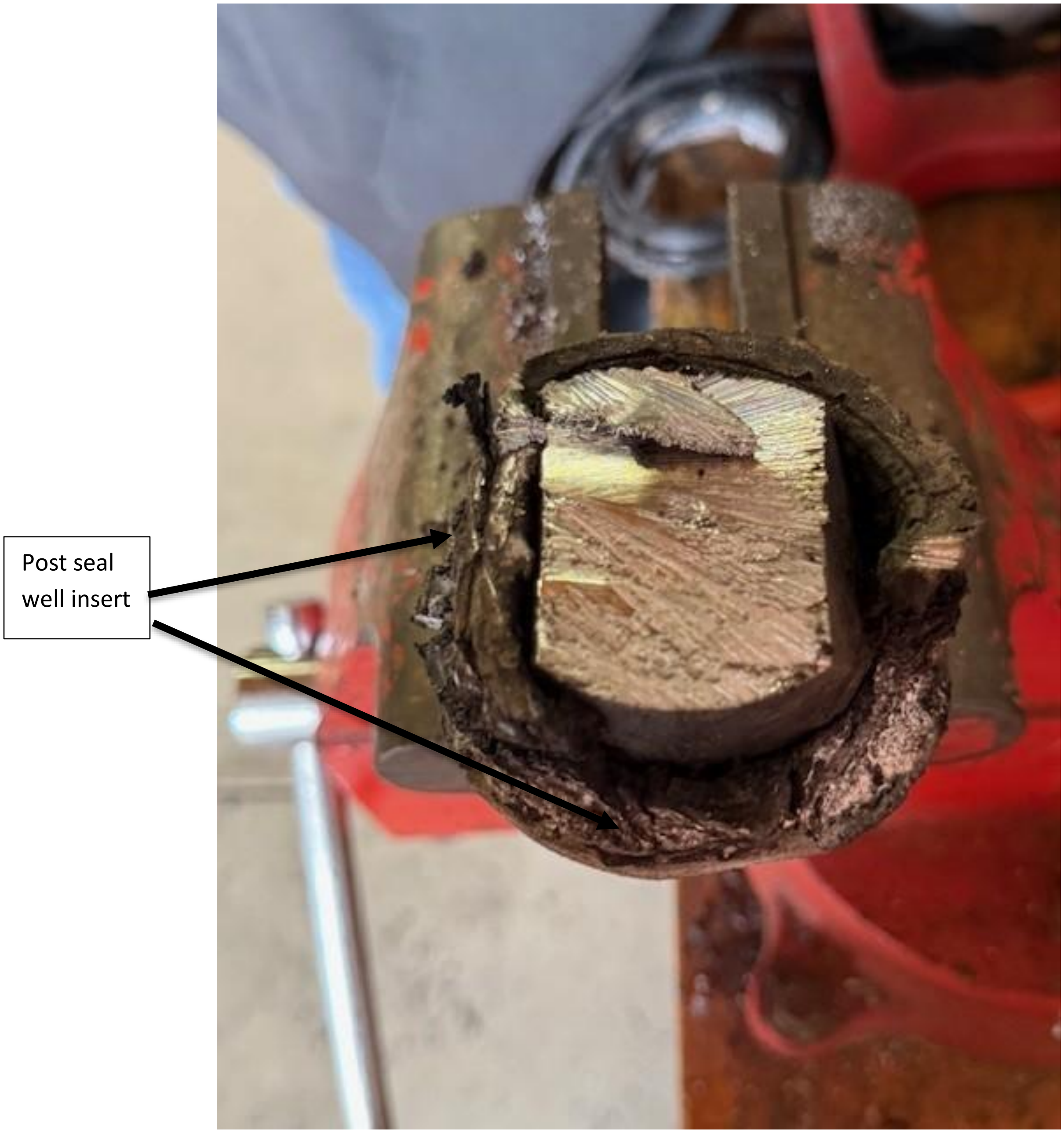


Figure 32 shows a vertically cut post that shows where the corrosion started in this post.

Figure 33 shows a cover with an extremely well-advanced crack that has turned at the edge of the cover and started down the side of the jar. This cell is over 19 years old.

Figure 34 shows the side of the post seal for one of the positive posts in the cell in figure 33. In order to remove this post from the cell, the cover was cut away from the posts, and it took excessive pressure back and forth to break the post and the collector buss apart from the plates. The strength (fragility) of the post was not impacted by the corrosion because that was attacking the lead bushing in the cover and not the post. The resistance of this post was 49 microohms which demonstrated that there was no change from the baseline resistance range for this post.

Figure 35 shows the other positive post of the cell in figure 33. The nodular corrosion was attacking the lead bushing in the cover, not attacking the post itself. The resistance of this post was 51 microohms, which again demonstrated no change from the baseline resistance range for this post.



Post seal well insert

Figure 36 shows the horizontal cut through the post shown in figure 34. The resistance of this post was 49 microohms. As can be seen, in this case the nodular corrosion was attacking the post seal well insert, not the post.

Figure 37 shows the vertical cut through this post. The resistance of this post was 51 microohms

What is important to take away from these pictures is that observance of cover cracks alone will not inform you of how much damage has already occurred to the positive posts. Only electronic measurements of the resistance of the post will inform you of the condition of the posts.

HOW NODULAR CORROSION IN THE POSITIVE POSTS CAN IMPACT DISCHARGE TEST RESULTS

Now that you are aware of nodular corrosion, and how it can create substantial increases to the resistance in the positive posts when it is present, it should also be easy to understand why the exact same aged battery will deliver substantially different capacity results when tested at different rates.

For as long as I can remember it has been commonly accepted that older batteries often would deliver different capacity test results when tested at either a longer duration, lower rate, or a shorter duration higher rate, and that the reason for this difference was the age of the cells. I do not believe that the difference has as much to do with the age of the cells as it does with there being an increase in the internal conduction path resistance of the positive post(s).

Yes, normal increases in resistance in all the internal conduction paths will create some minor impact in the aged cells performance at different rates, but when there are substantial differences in the results, I believe that it is primarily the result of the increased resistance caused by nodular corrosion.

It also should be understood that the engineers that design the cells are fully aware of the normal changes that occur to the resistance within the cells and allow for those known increases over the life of a battery. Nodular corrosion overrides the known increases in the internal resistances and is not a typical planned for resistance change.

The following Figure 38 is an example of the differences in the voltage drops for the same 60-cell string if the average internal post resistance increases by about 400%. An increase of 400% most likely will not be visually observable. Not every cell in a string will necessarily be attacked, or attacked to the same extent, nor do both positive posts in cells that have multiple posts of the same polarity in the cell have to degrade equally, or there may be no degradation to one of the posts. The cells in this following example are for a 930AH model. The numbers are rounded.

Time	discharge rate amps	individual cell voltage drop	OA string voltage drop	watts generated at post
8 H	116	0.017	1.022	2
5 H	158	0.0232	1.392	4
3 H	213	0.0312	1.876	8
2 H	279	0.0409	2.458	14
1 H	413	0.0606	3.638	30
15 M	649	0.0953	5.718	75
1 M	752	0.1104	6.624	100

Figure 38 shows how an increase in resistance of 404% over the baseline value will have on the results of a discharge test when run at the different published discharge rates.

Nodular corrosion is a very slow-moving condition, and because of the precision of the resistance measurements obtainable with an electronic nodular corrosion detection inspection, the degree of degradation can be determined. This provides the user with warning of changes to the resistance within the post(s), which provides them with time to prepare for whatever proactive actions are required to protect their site. Because this is slow moving, once the initial inspection is performed, if no resistance changes are discovered we recommend performing the inspections on five-year intervals. If an increased resistance is discovered, and it is not yet at a point where actions need to be taken soon, then we suggest two-year intervals. There presently is no information on this subject in the IEEE 450 document so the interval between inspections needs to be made by the battery owner.

IS NODULAR CORROSION POTENTIALLY THE MOST DANGEROUS CONDITION THERE IS RIGHT NOW FOR VENTED LEAD-ACID BATTERIES

Now that you are aware of this generally unknown condition you must now realize that by the time you notice cracks in the sides of the seal well, cover, or post seal nuts or area, that nodular corrosion will have been attacking the positive post(s) or post seal insert for many years and that substantial increases in the resistance of the current carrying path(s) may already have occurred.

Stryten Energy has taken the lead in alerting users in how to visually detect nodular corrosion through the rewriting of their I&O manual to include a new Section 20 (Troubleshooting) which is specifically dedicated to nodular corrosion. This explains how to inspect for and identify this condition [10], and they also issued a 10CFR notification [2]. The NRC has issued Integrated Inspection Reports [6] [7] and others, regarding nodular corrosion and cover cracking. All these actions clearly provide proof of the existence of the problem, and the importance of all battery users, not just the users at nuclear plants needing to be informed of this previously generally misunderstood or unknown about condition. The only real difference between a cell made for a nuclear plant from other cells of the same design is the documentation and paperwork required.

Also to demonstrate that there is more awareness of the issue in some circles than most users realize, on 1/9/26 it was presented to the nuclear battery working group of the ESSB committee [11], and BESTMAG published an article on the issue in the BESTMAG Spring 2026 Issue # 92 [12].

Until recently, there was no way to identify which positive post(s) were being negatively impacted by this issue and which were not. Even after we could see the covers and seals cracking and realized that nodular corrosion was occurring, we still did not know how to measure the resistances of the posts nor were we able to determine the damage that had already been done. Because this out-of-sight and out-of-mind condition can cause a complete failure of the battery system when it is needed the most, would you not consider this to be the most dangerous issue there is for our vented lead-acid stationary batteries? If you do not know it is there, how can you do anything about it? As Dr. David Feder once said to me when I asked him why Bell Labs had not figured out a specific issue related to PCL in VRLA batteries, before others did, he responded that "you do not know what you do not know". So simple and yet so true and it also applies to how little most users know about nodular corrosion. Hopefully this paper has allowed you to learn a little bit about an issue that you previously did not know about so you now know what you did not know.

SUMMARY

Every stationary vented lead-acid cell can be attacked by nodular corrosion, most are not, but those that are being attacked can pose a substantial risk to the system. Visual detection of the issue by observing the darkening of the positive post(s) or cracks or deformation in or of the various parts, is doable by anyone, however, by the time there are visual observations, the positive post(s) in most cases will have been under attack for numerous years and can already be severely degraded. A visual observation will not inform you of the resistance within the positive post(s) and knowing those resistance values is critical to understanding the condition of your battery. It is also important to understand that not all covers that are cracking due to nodular corrosion are because of a positive post attack, it could be occurring on the post seal insert and that may not pose as much of a risk to your system.

The plates in aged cells can be perfectly capable of supplying current at any of their designed rates, but due to increased resistance within the positive post(s) current carrying path, the battery capability or capacity will be reduced at the higher rates of discharge than at longer duration lower rates. Because of this potential issue we recommend that any battery that has inrush loads that are substantially greater than the normal loads, should be discharge tested using the modified performance test procedure.

Electronic measurement of resistance in the post(s) is the only presently known means of providing the earliest possible detection and most accurate understanding of the problem. These measurements allow for accurate quantification of the degree of degradation at that point in time, if there is actual post degradation occurring. The two NCDI℠ Nodular Corrosion Detection Inspection processes [13] [14] are presently the only means of performing these electronic inspections. Trying to determine the resistance of a post without electronically measuring it is no different than trying to determine a cell voltage without using a voltmeter.

Anyone that can perform stationary battery in-service inspections can perform a NCDI℠ Nodular Corrosion Detection Inspection, so there is no acceptable excuse for not performing this inspection which will provide you information that is not able to be obtained by any other means.

I also want to reach out to anyone that has had an unusual experience either with a battery exploding unexpectedly, or with a positive post, where it failed open or broke apart, or anything unusual happened. Allen Byrne and I both have long agreed that only with all of us individuals that work in this industry sharing our respective experiences can all of us users benefit, which is why Battcon was originally created. Please contact me with any questions of info on unusual experiences at info@batteryresearch.com.

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[14] A METHOD FOR PERFORMING A NODULAR CORROSION DETECTION INSPECTION ON STATIONARY BATTERY LEAD-ACID CELLS WITHIN A FULLY ASSEMBLED BATTERY STRING WITH THE BATTERY STRING BEING EITHER IN SERVICE AND ON CHARGE OR OUT OF SERVICE AND OFF CHARGE, BY MEASURING THE CURRENT FLOWING THROUGH THE POST, MEASURING THE VOLTAGE DROP THROUGH THE POST, AND USING OHM'S LAW CALCULATIONS TO DETERMINE THE RESISTANCE THROUGH THE POST, AND USING THAT MEASURED VALUE TO IDENTIFY AND QUANTIFY DEGRADATION OF THE POST – patent pending – application number 63/988/898