YES...INTERNAL CELL RESISTANCE MEASUREMENTS ARE VALID

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ABSTRACT

Many presentations have been made over the last five years dealing with the correlation between a capacity of a Lead Acid Cell and its internal resistance. Until now these technical papers have been presented either from a battery manufacturers or from a battery service company's view. This presentation will illustrate internal resistance readings and trends from raw data obtained in the field to substantiate the effectiveness of AirTouch Cellular's maintenance program as used by its service technicians.

The AirTouch preventative maintenance program has proven 100% effective in the early detection of internal cell problems and has provided the company with a 100% up time at all locations. Quarterly, semi-annual, and annual internal resistance measurements and follow-up on capacity load testing is performed to detect cell resistance, which indicates potential problems with each installed battery cell. The test data gathered during this program has been used to settle warranty issues with some of the major battery manufacturers.

INTRODUCTION

The goal is to make the investment both monetarily and procedurally to do the "right thing right". This will save your company long-term dollars. With the proper maintenance, specifically, resistance readings and acceptance testing you will develop and trend your readings throughout the life cycle of the batteries. This program that I have refined is based on the manufacturer's installation and operating instructions and is also compliant with current IEEE recommended practices and standards. These standards aide in insuring long life of the batteries that I have maintained throughout my career at AirTouch Cellular. This program is now the recommended practice for AirTouch Cellular battery maintenance.

Planning is one of the most important parts for our system network. Sizing, maintenance, and testing procedures can be used to optimize the life and performance of valve-regulated lead-acid (VRLA) batteries. Testing also provides guidance to determine when batteries should be replaced. I have developed the cradle to grave program, which consists of the following four main categories for documentation:

- Annual Site Planning and Battery Sizing
- Battery Installation Preferably by the Manufacturer
- Battery Maintenance
- Disposal of Spent Batteries

THE PROGRAM

The first step is planning for the batteries that each site will require for the load that the site will carry. First in this process is sizing the right battery for the runtime that you anticipate the site will need; meaning anticipated down time per any one given incident, which could require anywhere from two to eight hours of battery capacity. After you have determined which battery to specify for the installation, you need to select the manufacturer that will deliver the highest quality product and back the product with a warranty program. The product should then be delivered to the local manufacturer's representative for warranty documentation. The batteries should have consecutive serial numbers for ease of documentation and to further insure consistency of the product. Parallel battery strings should be used in all sites for maintenance and testing practices.

The second step is receiving and installing the batteries at the site they were specified for. A receiving inspection should be done at the time of actual unloading. Each package should be visually inspected for apparent damage and electrolyte leakage. Storage should be indoors in a clean, level, dry, and cool location. Batteries should not be stored without applying a charge to the battery for more than the time recommended by the manufacturer.

The initial charge to the battery needs to be completed before the acceptance test at the specified site. Internal ohmic measurements are used to check connection resistance between the cells and the ionic conductivity of the electrolyte and the activity of the electrochemical processes occurring at the plate surfaces. Three techniques are used in the industry, resistance measurements, impedance measurements and conductance measurements. In my experience, I have used all three techniques and have found resistance measurements to be the most accurate.

Recharging of the battery after the acceptance test is required. The batteries are then delivered and installed by the battery manufacturer's representative. The installation report is then completed, including work order, internal ohmic measurement, and the acceptance testing for each string of batteries that are installed. The initial readings will then be the benchmarking baseline for the installed battery system. When the report is delivered to AirTouch, we add the information to our master site spreadsheet.

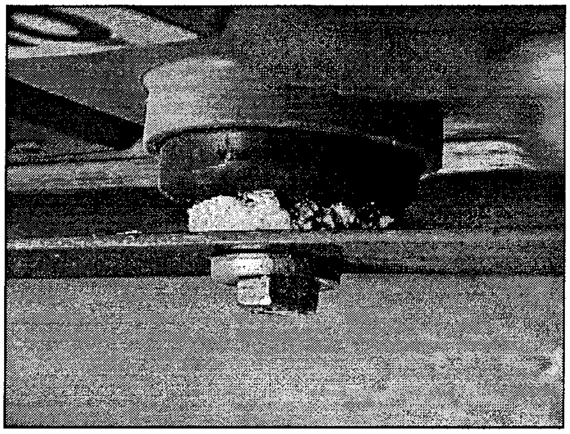
	BATTERY TYPE			BATTERY			
SITE NAME	DIGITAL Y/N	MAKE	MODEL	CODE DATE	INSTALL DATE	NO. OF STRINGS	COND OF BATT.
A	N	GNB	90A-17	JAN-96	06-Mar-96	2 (H)	G
B	Y	GNB	90A-17	JAN-96	08-MAR-98	2 (H)	G
C	Y	GNB	90A-17	JAN-96	13-Mar-96	2 (H)	G
D	Y	GNB	90A-17	JAN-96	21-Feb-96	2 (H)	G

MAINTENANCE				FLOAT CHARGE		
CELL CORDER TEST	AVERAGE INTERNAL RESISTANCE (MICRO OHMS)	PILOT CELL NO. STRING A	B	BATT CAPACITY TEST	AMBIENT ROOM TEMP	FLOAT VOLT
15-Jan-00	295/304	7	10	28-Feb-99	67	27.00
31-Jan-00	310/313	8	8	28-Feb-99	80	27.00
01-Feb-00	282/284	4	7	27-Feb-99	82	27.00
10-Mar-00	300/290	3	1	19-Feb-99	70	27.00

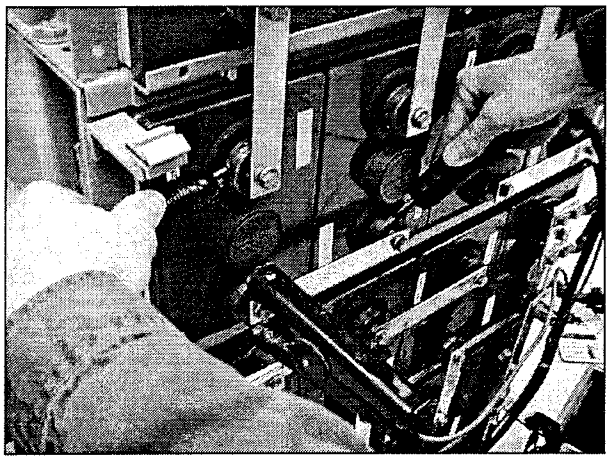
CHARGE	POWER EQUIPMENT			
OR INITIAL EQUALIZATION	GENERATOR Plug Y/N	Plug Y/N	MAKE	NO. OF RCTFR
29-Feb-96	Y	N	LORAIN	4
29-Feb-96	Y	N	LORAIN	4
28-Feb-96	Y	N	LORAIN	5
20-Feb-96	Y	N	ERICSSON	5

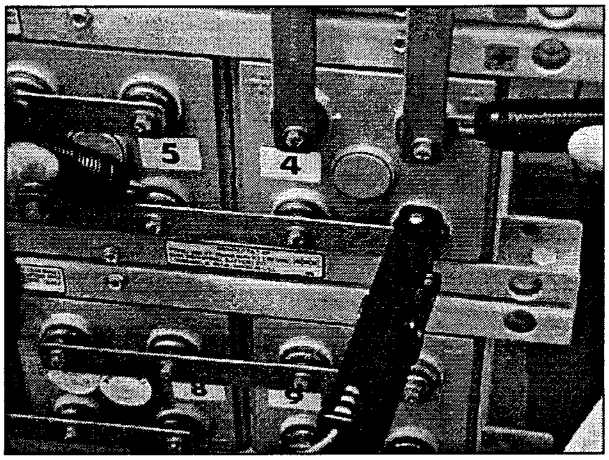
The third step in the program is maintaining, testing, and replacing the battery systems. Battery maintenance should be performed by personnel who are trained and experienced in battery systems and the safety precautions involved. Inspections should be made under normal float conditions if possible, i.e. 2.25 volts per cell. Readings should be taken in accordance with the manufacturer's instructions. This information needs to be verified for accuracy and compared to previous readings ***on site***. Any inconsistencies detected should be rechecked and values should be downloaded at that time. All measurements and observations should be recorded ***on site*** for future comparisons. It is imperative to capture data at the site. These readings cannot be reverified or changed off site by other team members because there is virtually no access to specific data captured during that specific time in the battery's life cycle. At AirTouch Cellular, we also maintain a written journal of events that alert any team member as to the history of any power outages, maintenance performed, and equipment replacements and upgrades that have occurred at each site.

The sites that are more crucial to your company's operation should have monitoring equipment that can conduct these quarterly, semi-annual, and even annual readings automatically. This data should be sent to a remote monitoring center to insure timeliness in addressing any potential problems. This is also where your alarm parameters come into play. They need to be defined in such a way that your team members have an opportunity to address potential failures before they jeopardize your system's network. This, by no means, takes place of routine visual inspections. This illustration below was not detected by any data readings or alarms:



Resistance readings should be taken from battery's posts and not from the battery's inter-cell connectors. Researching the frequency of maintenance on each battery system is important due to the applications they will be utilized for; some being more critical than others are.





The following readings are imperative to the benchmarking of each battery system:

- Overall float voltage measured at the battery terminals
- Charger output current and voltage
- Ambient temperature and the condition of ventilation and monitoring equipment
- Visual individual cell/unit condition check to include:
    - Cell/unit integrity for evidence of corrosion at terminals, connections, rack, or cabinet.
    - General appearance and cleanliness of the battery, the battery rack or cabinet and battery area including accessibility.
    - Cover integrity and check for cracks in cell/unit or leakage of electrolyte.
    - Excessive jar/cover distortion.
    - Cell/unit internal ohmic measurements.
    - Temperature of the negative terminal of each cell/unit of battery.
    - Retorque the battery hardware to manufacturer's ratings.

The relationship between capacity and internal resistance values is inversely proportional; as the capacity of the battery diminishes the values of the internal resistance measurements start to increase. According to IEEE, ideally, "A performance test of the battery capacity should be performed at one-year intervals until it shows signs of degradation, at which time semiannual performance tests should be given." (Ref. 1). However, it isn't practical when you are managing hundreds of strings of batteries. From my experience at AirTouch Cellular, an increase in internal resistance measurements is an indication that the battery's capacity is degrading and should be tested. With limited resources in both time and labor, AirTouch Cellular has made a conscious decision to utilize internal resistance measurements as the prime indicator for scheduling a performance test on any given battery system. For example, an increase in internal resistance measurements at our site #582 was approximately 30% from the baseline readings prior to the acceptance test. This string was targeted for a performance test because the readings went from 263 to 374 as regular maintenance was being performed. As illustrated in the reports at the end of this document, the string failed its performance test.

The fourth and final step in this program is to dispose of the batteries at the end of their useful life cycle. When a lead-acid battery is spent, it shall be disposed of in a proper fashion. In most cases, you can return these batteries to your local manufacturer. The manufacturer will then issue a Certificate of Proper Recycling of Spent Batteries, which gives your company a paper trail as to what application the laded batteries came from and that they were disposed of in accordance with EPA guidelines. Documentation is necessary and is able to prove to environmental officials where your spent lead-acid batteries were recycled. If you don't know where your spent lead-acid batteries end up you could be exposing yourself and your company to environmental liability, which could result in legal complications, large fines and even criminal prosecution.

CONCLUSION

A comprehensive, conscientious maintenance program can prevent battery failures. Accuracy in data collection will lead to preventative measures in a non-critical environment instead of reactive measures in a critical one when your company needs alternative power the most. Acting on your findings and working with the distributors and manufacturers will yield high performance in the area of alternative power for your company. Time is money and when one of your sites goes to battery power you need to be ready. You don't want to be caught holding an empty hand. As with anything, preventative maintenance is the key to preserving your company's capital investment. The best way to ensure proper maintenance is to develop a program of consistent data collection and comparison to base line benchmarking. Keep your company and the manufacturers apprised of your findings. This will, in turn, provide a continuous flow of information yielded by actual data for all to learn from and improve. It is worth the investment.

04:42:41************** BCT-2000 LOAD TEST REPORT**************04/17/96

REPORT BASED ON 10:00 TIME INERVAL

GERNERAL TEST DATA:

TEST LOCATION	CELLONE INHOUSE
TEST DATE	04/16/96
TEST START TIME	21:59:21
TEST END TIME	00:59:21
BATTERY ID	190869 3G-3H
BATTER MFG & MODEL	C&D HD-700
INSTALLATION DATE	06/27/96

=TEST PARAMETERS:

PROGRAMMED LOAD	0202 AMPS
PROGRAMMED TEST TIME	03:00:00
TEST MODE	MULTIPLE STRING
NUMBER OF CELLS	026
OVERALL VOLTAGE ALARM	43.20
OVERALL VOLTAGE SHUTDOWN	42.00
CELL VOLTAGE ALARM	1.75
TEMPERATURE	071 f Degrees- IEEE
RATED BATTERY DISCHARGE TIME	03:00:00

********** TEST RESULTS *************

ACTUAL DISCHARGE TIME	=	03:00:00
RATED DISCHARGE TIME	=	03:00:00
OVERALL STRING % CAPACITY	=	100.0

THE FOLLOWING CELLS DROPPED BELOW THE ALARM LEVEL:

CELL #	TEST TIME	% CAPACITY

IF THE PROGRAMMED ALARM LEVEL REPRESENTS THE TRUE END VOLTAGES FOR THIS TEST THEN - THE FOLLOWING CELLS FAILED THE CAPACITY TEST (BELOW 80%), AND SHOULD BE INVESTIGATED FOR POSSIBLE REPLACEMENT:

END VOLTAGES FOR BATTERY STRINGS AT THE END OF THE TEST:

Print 0020 Test Time = 03:00:00 Battery Volts = +44.7 Amps = 202

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-----------------------------------------------------------------------
---------------------------BATTERY STRING A--------------------------
001= +1.83  002= +1.84  003= +1.82  004= +1.84  005= +1.87  006= +1.84
007= +1.84  008= +1.88  009= +1.81  010= +1.86  011= +1.83  012= +1.85
---------------------------BATTERY STRING B--------------------------
001= +1.87  002= +1.87  003= +1.85  004= +1.83  005= +1.87  006= +1.84
007= +1.85  008= +1.86  009= +1.84  010= +1.84  011= +1.86  012= +1.85
```

STRING A # 582

Battery Cell Averages Trend Report

String A # 582 **C&D HD-700**

Cell Parameter Average Values

Date	Voltage	Internal Res.	Intercell R1	Temp. (F)
09/06/1996	2.152	263.417	25.667	80.100
10/30/1997	2.250	267.833	33.417	72.108
10/14/1998	2.248	288.167	34.583	79.825
09/14/1999	2.251	364.083	36.917	74.267
09/22/1999	2.251	374.750	34.417	71.933

End of STRING A # 582 Report

STRING B # 582

Battery Cell Averages Trend Report

String B # 582 **C&D HD-700**

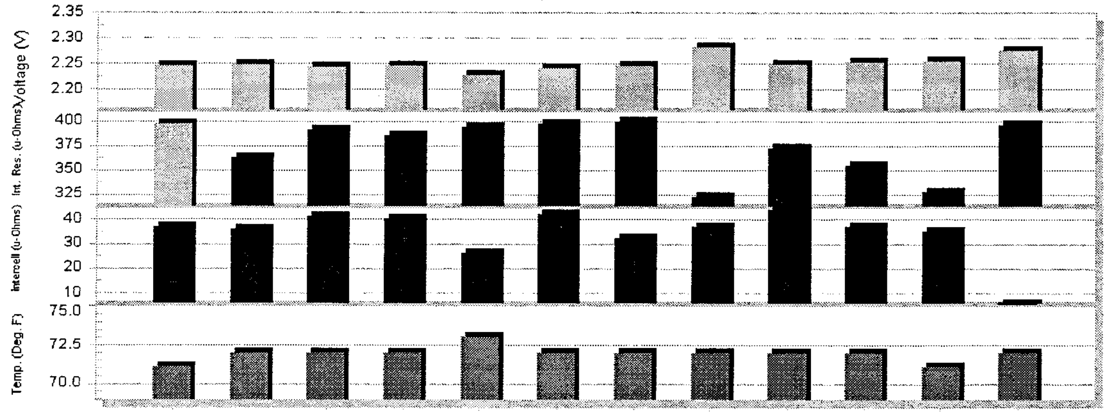
Cell Parameter Average Values

Date	Voltage	Internal Res.	Intercell R1	Temp. (F)
09/06/1996	2.152	263.417	25.667	80.100
10/30/1997	2.250	268.417	34.500	72.833
10/14/1998	2.248	281.083	38.083	78.925
09/14/1999	2.251	322.500	35.583	74.083
09/22/1999	2.251	334.083	34.250	71.775

End of STRING B # 582 Report

STRING A # 582

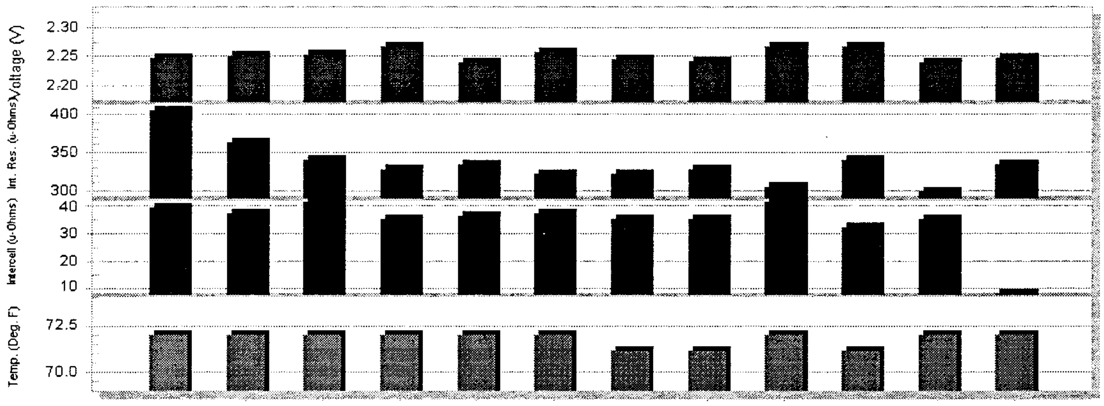
Data Set Detail Graph for 09/22/1999



Cell Number	1	2	3	4	5	6	7	8	9	10	11	12
Voltage	2.246	2.249	2.243	2.246	2.227	2.242	2.246	2.283	2.248	2.252	2.254	2.276
Internal Res	397.000	362.000	391.000	385.000	394.000	397.000	400.000	322.000	372.000	354.000	327.000	396.000
Intercell R1	37.000	36.000	41.000	40.000	26.000	42.000	32.000	37.000	44.000	37.000	35.000	6.000
Temperature	71.100	72.000	72.000	72.000	73.000	72.000	72.000	72.000	72.000	72.000	71.100	72.000

STRING B # 582

Data Set Detail Graph for 09/22/1999



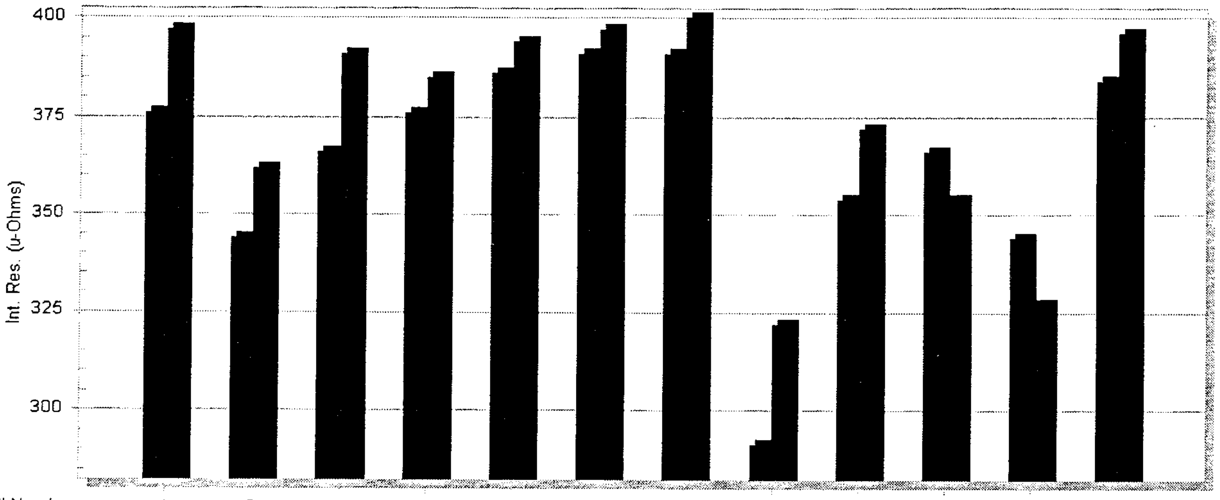
Cell Number	1	2	3	4	5	6	7	8	9	10	11	12
Voltage	2.246	2.251	2.252	2.267	2.240	2.257	2.245	2.241	2.267	2.266	2.239	2.246
Internal Res	404.000	363.000	339.000	327.000	333.000	321.000	321.000	327.000	304.000	339.000	298.000	333.000
Intercell R1	39.000	37.000	41.000	35.000	36.000	37.000	35.000	35.000	41.000	32.000	35.000	8.000
Temperature	72.000	72.000	72.000	72.000	72.000	72.000	71.100	71.100	72.000	71.100	72.000	72.000

STRING A # 582

Dataset Comparison Graph

Reference Dataset: 09/14/1999

Comparison dataset: 09/22/1999



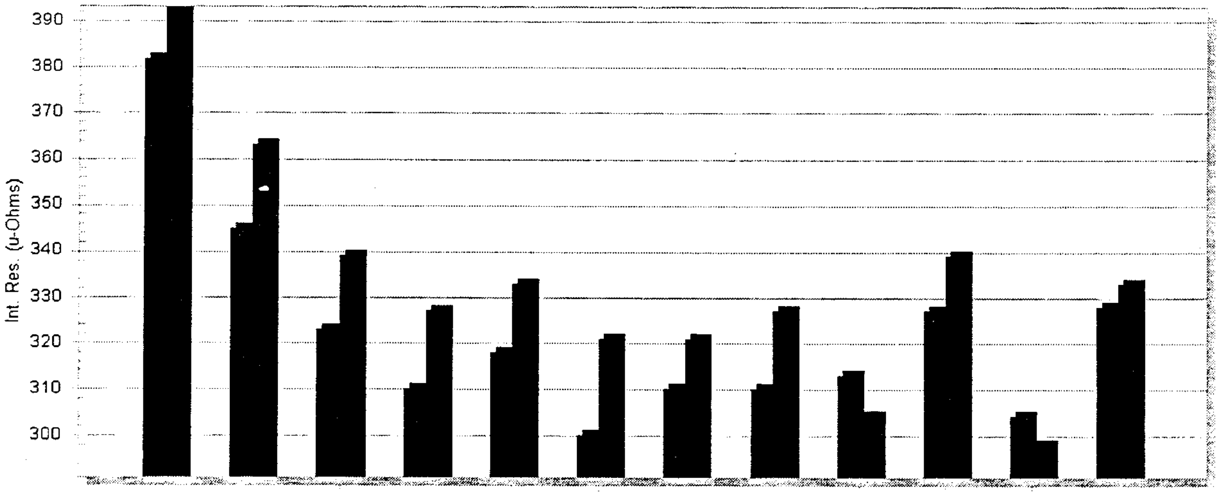
Cell Number	1	2	3	4	5	6	7	8	9	10	11	12
Internal Res(Ref)	376.000	344.000	366.000	376.000	386.000	391.000	391.000	291.000	354.000	366.000	344.000	384.000
Internal Res	397.000	362.000	391.000	385.000	394.000	397.000	400.000	322.000	372.000	354.000	327.000	396.000

STRING B # 582

Dataset Comparison Graph

Reference Dataset: 09/14/1999

Comparison dataset: 09/22/1999



Cell Number	1	2	3	4	5	6	7	8	9	10	11	12
Internal Res(Ref)	382.000	345.000	323.000	310.000	318.000	300.000	310.000	310.000	313.000	327.000	304.000	328.000
Internal Res	404.000	363.000	339.000	327.000	333.000	321.000	321.000	327.000	304.000	339.000	298.000	333.000

BCT-2000 Battery Load Test Report

Test Results

The Following cells dropped below the low threshold level of 1.750 Vs

String	Cell	Step	Step Time	Test Time	Capacity (%)
1	4	1	2:11:07	2:11:07	72.8
1	5	1	1:42:27	1:42:27	56.9
1	7	1	2:18:54	2:18:54	77.2
1	9	1	2:03:04	2:03:04	68.4
2	1	1	2:06:45	2:06:45	70.4

The Following cells Failed the CAPACITY TEST (BELOW 80%):

String	Cell	Capacity (%)
1	4	72.8
1	5	56.9
1	7	77.2
1	9	68.4
2	1	70.4

Battery string results:

Battery Capacity = 78.6%

Cell Summary

String	Cell	Float V	Start V	V @ 30 Sec	End V
1	1	2.202	2.047	1.937	1.759
1	2	2.198	2.053	1.943	1.801
1	3	2.197	2.037	1.934	1.755
1	4	2.200	2.044	1.936	1.690
1	5	2.181	2.021	1.907	0.911
1	6	2.198	1.973	1.937	1.749
1	7	2.199	2.103	1.937	1.738
1	8	2.218	2.143	1.985	1.898
1	9	2.200	2.104	1.952	1.540
1	10	2.205	2.112	1.950	1.804
1	11	2.202	2.112	1.952	1.823
1	12	2.208	2.106	1.960	1.772
2	1	2.197	2.080	1.940	1.657
2	2	2.204	2.100	1.961	1.785
2	3	2.205	2.106	1.963	1.844
2	4	2.200	2.051	1.969	1.831
2	5	2.197	2.019	1.955	1.821
2	6	2.197	2.015	1.958	1.847
2	7	2.196	2.012	1.959	1.858
2	8	2.196	2.001	1.953	1.809
2	9	2.204	2.125	1.960	1.855
2	10	2.204	2.126	1.960	1.831
2	11	2.197	2.128	1.960	1.811
2	12	2.199	2.047	1.969	1.827

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   Valve-regulated (Sealed), Lead Acid Batteries Installation and Operating Instructions

3. **GNB Technologies; February 1997**
   GNB Basic Operating and Maintenance Instructions for GNB Absolyte Batteries

4. **IEEE Standard 1188-1996**
   IEEE Recommended Practice for Maintenance, Testing, and Replacement of
   Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
   August 20, 1996 by IEEE Standards Coordinating Committee 29
   Specific Page Reference 6; Item 6.3