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International Lead Zinc Research Organization-sponsored field-data collection and analysis to determine relationships between service conditions and reliability of valve-regulated lead–acid batteries in stationary applications

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Abstract

The International Lead Zinc Research Organization (ILZRO), in cooperation with Sandia National Laboratories, has initiated a multi-phase project with the following aims: to characterize relationships between valve-regulated lead–acid (VRLA) batteries, service conditions, and failure modes; to establish the degree of correlation between specific operating procedures and PCL; to identify operating procedures that mitigate PCL; to identify best-fits between the operating requirements of specific applications and the capabilities of specific VRLA technologies; to recommend combinations of battery design, manufacturing processes, and operating conditions that enhance VRLA performance and reliability. In the first phase of this project, ILZRO has contracted with Energetics to identify and survey manufacturers and users of VRLA batteries for stationary applications (including electric utilities, telecommunications companies, and government facilities). The confidential survey is collecting the service conditions of specific applications and performance records for specific VRLA technologies. From the data collected, Energetics is constructing a database of the service histories and analyzing the data to determine trends in performance for particular technologies in specific service conditions. ILZRO plans to make the final report of the analysis and a version of the database (that contains no proprietary information) available to ILZRO members, participants in the survey, and participants in a follow-on workshop for stakeholders in VRLA reliability. This paper presents the surveys distributed to manufacturers and end-users, discusses the analytic approach, presents an overview of the responses to the surveys and trends that have emerged in the early analysis of the data, and previews the functionality of the database being constructed.

Keywords: Charging; Lead–acid battery; Premature capacity loss; Reliability; Service life; Stationary; Valve-regulated

1. Background

Although valve-regulated lead–acid (VRLA) batteries have served in stationary applications for more than a decade, proprietary concerns of battery manufacturers and users and varying approaches to record-keeping have made the data available on performance and life relatively sparse and inconsistent. Such incomplete data are particularly detrimental to understanding the cause or causes of premature capacity loss (PCL) reported in VRLA batteries after as little as two years of service [1,2]. The International Lead Zinc Research Organization (ILZRO), in cooperation with Sandia National Laboratories, has initiated a multi-phase project with the following aims: to characterize relationships between VRLA batteries, service conditions, and failure modes; to establish the degree of correlation between specific operating procedures and PCL; to identify operating procedures that mitigate PCL; to identify best-fits between the operating requirements of specific applications and the capabilities of specific VRLA technologies; to recommend combinations of battery design, manufacturing processes, and operating conditions that enhance VRLA performance and reliability.

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PRODUCTS AND MANUFACTURING SITES

How many VRLA cell types do you manufacture?

Which cell do you address in this survey (name or #)?

Where do you manufacture this product?

❑ North America ❑ South America ❑ Asia

❑ West Europe ❑ East Europe ❑ Africa

PHYSICAL CHARACTERISTICS OF CELLS

What are the cell's exterior dimensions (cm)?

Length Width Height

In what medium is the electrolyte suspended?

❑ Absorbed glass mat ❑ Thixotropic gel ❑ Other

Are that any characteristics unique to this electrolyte?

What is the separator material and thickness (mm)?

❑ Polyvinylchloride ❑ Polyethelyne ❑ Other

❑ Porous rubber ❑ Glass cloth

What is the separator saturation (%)?

How much electrolyte is in each cell (ml)?

How much variation from nominal electrolyte volume is allowed (%)?

What is the specific gravity of the electrolyte in a fully charged new cell?

What is the cell case material and thickness (mm)?

❑Polyvinylchloride ❑ Polypropylene ❑ Poly carbonate

❑ ABS ❑ Polystyrene ❑ Other

What process is used to seal the cover to the case?

❑ Ultrasonic weld ❑ Asphalt ❑ Hot plate

❑ Bead mash heat ❑ Epoxy ❑ Other

What are the vent-valve opening/reseal points (psi)?

Open:

Seal:

PHYSICAL CHARACTERISTICS (CONT.)

How is the post/cover seal made?

❑ Welded ❑ Epoxied ❑ Other

In what orientation are the cells designed to operate?

❑ Plates horizontal ❑ Plates vertical ❑ Either/both

Please circle the maximum & minimum recommended operating temperatures for this cell (°C).

-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 40 50 60 70 80

Does this cell use/require thermal management?

❑ No ❑ Yes, method

How much space is between cells in a module (cm)?

Vertical space Horizontal space

How much space is between modules in a string (cm)?

Vertical space Horizontal space

PHYSICAL CHARACTERISTICS (CONT.)

What is the allowable valve opening/reseal variation (%)?

Open: _____ Seal:

What is the Ah of the plates? Positive _____Negative

What is the plate geometry?

Geometry	*Positive plate*	*Negative plate*
Flat	❑	❑
Tubular	❑	❑
Other	❑	❑

What is the nominal stack compression (psi)?

What is the allowable variation in compression (%)?

What elements do the paste alloys contain (wt%)?

Element	*Positive paste*	*Negative paste*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

What elements do the grids contain (wt%)?

Element	*Positive grids*	*Negative grids*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

What elements do the post/busbars alloys contain (wt%)?

Element	*Positive*	*Negative*
Lead	❑	❑
Copper	❑	❑
Cadmium	❑	❑
Antimony	❑	❑
Silver	❑	❑
Other	❑	❑

PERFORMANCE & LIFE CHARACTERISTICS

For what application(s) is this cell designed?

❑ Float ❑ Deep Cycle ❑ Shallow Cycle

Sketch the cell's cycle life vs. depth-of-discharge in ideal temperature, discharge & charge conditions.

2. Approach

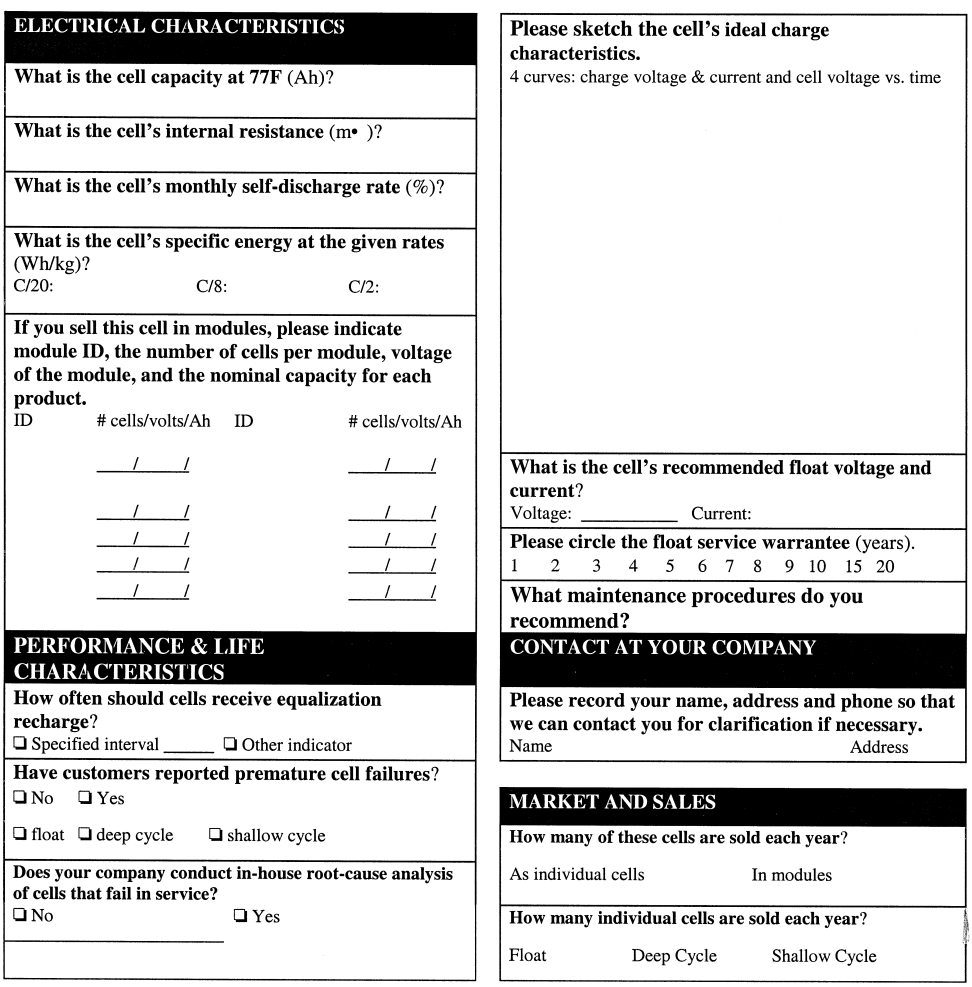
With input from Sandia and ILZRO, Energetics developed survey instruments for VRLA manufacturers and end-users. The surveys are designed to collect the following information pertinent to VRLA cells in stationary applications:

- manufacturing processes
- intended use (as designed)
- expected performance and life
- actual service conditions
- actual performance and life.

Existing relationships, Internet and library literature searches, and supplemental information from battery experts at Rutgers University (working with ILZRO on a separate component of the VRLA reliability effort) provided information to compile an international list of more than 25 VRLA battery manufacturers who received surveys. Analysts contacted a representative at each manufacturing company before mailing the survey to confirm the company's willingness to participate in the study and willingness to complete a survey. The largest group of surveys were mailed late in June, 1998. Two smaller mailings were issued in July. Manufacturers were asked to respond within a month of receiving the survey with information about three VRLA products: (i) highest sales volume VRLA product; (ii) best-performing product in the field; (iii) most problematic product in the field.

As shown in Fig. 1, the survey was in a check-box format to reduce the amount of time needed to respond, and solicited information about the physical and electrical characteristics of the products, expected service and life performance of the product, research and development conducted on the product, and market information regarding the product. The last page of the survey, not shown in this paper, asked manufacturers to write additional comments.

To ensure that data collected from end-users would include feed-back from those with a wide range of experience with VRLA cells in stationary applications, the distribution list for the end-users' survey was compiled from a number of sources: pre-existing relationships and Internet and library searches, customers who manufacturers identified on page 3 of the manufacturers' survey, and a small



ELECTRICAL CHARACTERISTICS

What is the cell capacity at 77F (Ah)?

What is the cell's internal resistance (m•)?

What is the cell's monthly self-discharge rate (%)?

What is the cell's specific energy at the given rates (Wh/kg)?
C/20: C/8: C/2:

If you sell this cell in modules, please indicate module ID, the number of cells per module, voltage of the module, and the nominal capacity for each product.

ID	# cells/volts/Ah	ID	# cells/volts/Ah
	___/___/		___/___/
	___/___/		___/___/
	___/___/		___/___/
	___/___/		___/___/
	___/___/		___/___/

PERFORMANCE & LIFE CHARACTERISTICS

How often should cells receive equalization recharge?
❑ Specified interval _____ ❑ Other indicator

Have customers reported premature cell failures?
❑ No ❑ Yes
❑ float ❑ deep cycle ❑ shallow cycle

Does your company conduct in-house root-cause analysis of cells that fail in service?
❑ No ❑ Yes

Please sketch the cell's ideal charge characteristics.
4 curves: charge voltage & current and cell voltage vs. time

What is the cell's recommended float voltage and current?
Voltage: _____ Current:

Please circle the float service warrantee (years).
1 2 3 4 5 6 7 8 9 10 15 20

What maintenance procedures do you recommend?

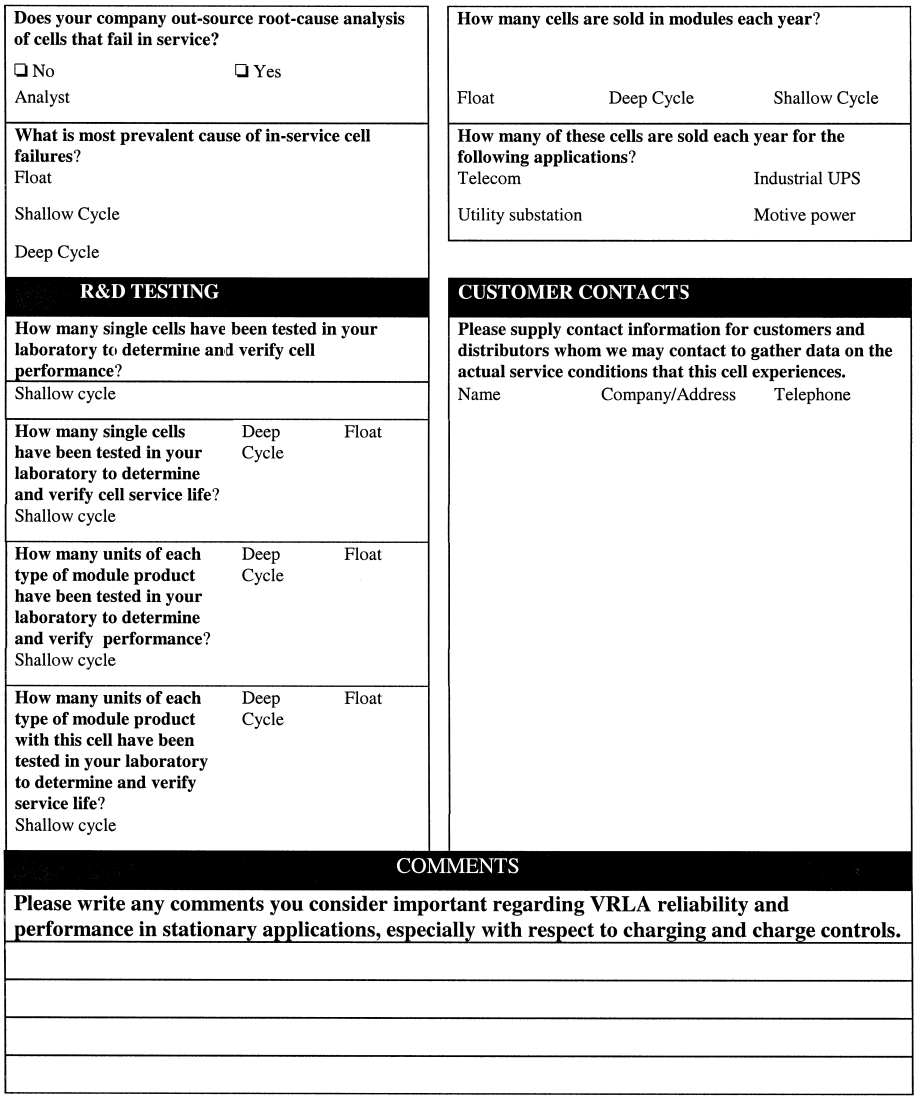
CONTACT AT YOUR COMPANY

Please record your name, address and phone so that we can contact you for clarification if necessary.
Name Address

MARKET AND SALES

How many of these cells are sold each year?
As individual cells In modules

How many individual cells are sold each year?
Float Deep Cycle Shallow Cycle



Does your company out-source root-cause analysis of cells that fail in service?

❑ No ❑ Yes

Analyst

What is most prevalent cause of in-service cell failures?

Float

Shallow Cycle

Deep Cycle

R&D TESTING

How many single cells have been tested in your laboratory to determine and verify cell performance?

Shallow cycle

	Deep Cycle	Float
How many single cells have been tested in your laboratory to determine and verify cell service life? Shallow cycle		
How many units of each type of module product have been tested in your laboratory to determine and verify performance? Shallow cycle		
How many units of each type of module product with this cell have been tested in your laboratory to determine and verify service life? Shallow cycle		

How many cells are sold in modules each year?

Float Deep Cycle Shallow Cycle

How many of these cells are sold each year for the following applications?

Telecom Industrial UPS

Utility substation Motive power

CUSTOMER CONTACTS

Please supply contact information for customers and distributors whom we may contact to gather data on the actual service conditions that this cell experiences.

Name Company/Address Telephone

COMMENTS

Please write any comments you consider important regarding VRLA reliability and performance in stationary applications, especially with respect to charging and charge controls.

Fig. 1. ILZRO Valve-regulated lead–acid battery survey.

number who responded to a solicitation posted on an Internet web-page [3] which was registered with major search engines under the keyword, 'VRLA'. The site, intended to attract responses from end-users and manufacturers who had not been uncovered by other methods, attracted fewer than 50 visitors, and prompted only one e-mail enquiry.

As shown in Fig. 2, the end-users' survey requested information about the source of the VRLA product, the operating conditions in which the product served, the monitoring conducted during the service life of the product, and about the performance and service life for batteries with the best and worst performance in the end-user's experience. As in the approach with manufacturers, the strategy in soliciting participation from end-users included contact previous to mailing to verify their willingness to participate. The initial end-user distribution list included electric utilities, telecommunications companies, and government facilities. The final list will also include others identified in manufacturers' survey responses.

Because information about manufacturing and operation of VRLA cells is often business sensitive, Energetics offered to establish formal non-disclosure agreements with each participant. This action assured participants that the survey responses would be confidential and the data reported in the final results would be an anonymous aggregation of information that protects the proprietary interests of all of its constituents.

From the responses to the survey, analysts are constructing a database of cell characteristics, required and actual service conditions, and service histories. The approach is based on queries to the database that organize the data to identify performance and service life trends for particular technologies in specific service conditions. The database (that protects all proprietary information) will be available to ILZRO members, participants in the survey,

and participants in a follow-on workshop for stakeholders in VRLA reliability. The database constructed for analysis will contain detailed product- and installation-specific information about manufacturing and installation and operating history of the cells in service at sites of interest in this study. This detailed information will be accessible only to the analysts conducting the study. The database to be distributed to the public, however, will be a comprehensive and searchable log which contains the following information:

- contact information for manufacturers and end-users
- published specifications for VRLA products
- characteristics of installations for families of applications
  - –telecommunications substations and relays
  - –electric utility substations
  - –military security installations
  - –building energy efficiency associations
  - –public school back-up power, and performance histories for families of VRLA technologies in categories separated by manufacturing characteristics:
  - –absorptive glass mat (AGM) vs. gel
  - –vertical vs. horizontal plate orientation
  - –type of plate alloy
  - –type of case and post seals, and other features.

The contact information is assembled through a commercially available, dBase-compatible, contact management software package, ACT! The remainder of the data is contained in a database constructed with dBase-compatible Microsoft Access. This software permits construction of a relational database which permits construction of an analytic tool and a public version which protects proprietary information. The analytic database has capabilities to assist in identification of similarities and disparities between discrete reports of field monitoring data, and to facilitate trending of performance and life of specific VRLA technologies in specific applications.

3. Project Status

The willingness of VRLA battery manufacturers was a key concern at the outset of this project. The preliminary response from the industry suggested that manufacturer participation will be more than adequate. At the Battery

BATTERY IDENTIFICATION

Please provide the manufacturer's name and model number for the valve regulated lead acid (VRLA) product that you will describe below.

Manufacturer _____ Model

What application does the battery serve?

How many volts/amps does the application require?

From whom did you purchase the batteries?
❑ Battery manufacturer
❑ Original equipment manufacturer
❑ Battery vendor/distributor
❑ Other

How many have you purchased?

BATTERY OPERATION

Did the manufacturer/vendor provide operating specifications? ❑ Yes ❑ No

FLOAT	**What float voltage do you maintain** (volts/cell)? **What current do you apply during float** (amps)?
CYCLE	**How many cycles/year does the battery experience**?

BATTERY MONITORING

Which parameters do you monitor, how often?

	Cell	Module	String
°C/°F	❑ _____	❑ _____	❑
Volts	❑ _____	❑ _____	❑
Amps	❑ _____	❑ _____	❑
Other	❑ _____	❑ _____	❑

If you log readings, what format is used?
❑ Print ❑ Electronic

What are the maximum, average, and minimum ambient temperatures in the battery room (°C)?

Max. Temp ____ Avg Temp ____ Min Temp

What % of a year is the temperature at or near the maximum?

Do you use thermal management for this battery? If yes, please specify method

Please sketch the recharge regime (for charge voltage and current and expected cell voltage) or provide details as an attachment.

Were there any issues of concern related to the operation or performance of this battery?

	Do cycles occur at regular intervals? If yes, what is the interval length? If no, is cycling ❑ Random ❑ Clustered		**What is the warranted service life** (years)? **What percentage of the batteries at your facility achieved the following service lives**? 1/4 warranted life ____ 3/4 warranted life 1/2 warranted life ____ Warranted life
	What are the maximum, average and minimum depth of discharge that cycles demand (%)? Max. DOD ____ Avg DOD ____ Min DOD **What percentage of the cycles are at a maximum, average and minimum depth of discharge**? Max _____ Avg _____ Min **At what rate does the battery discharge** (A)?		**Have you ever had a failure analysis performed and, if so, by whom**? **Yes** **No** ❑ Vendor ❑ Manufacturer ❑ In-house ❑ Consultant **What were the root causes (in order of frequency)**?

Please provide the following information for the battery in service for the longest amount of time.	
Vendor	**Date of purchase**
Date of installation	**Date of removal from service**
Reason for removal from service **Please attach copies of operating and monitoring logs**	

Please provide the following information for the battery that failed previous to it's warranted service life (if applicable):	
Vendor	**Date of purchase**
Date of installation	**Date of removal from service**
Reason for removal from service **Please attach copies of operating and monitoring logs**	

ADDITIONAL COMMENTS
Please feel free to add any additional data or comments.

Fig. 2. Battery end-users survey.

Council International conference in April 1998 in Washington DC, the chairs of two sessions (both who were battery manufacturing company representatives) announced the ILZRO study, and encouraged their colleagues to participate. During preliminary phone calls, more than 25 manufacturers were contacted in the United States, Europe, and Asia. All of those contacted agreed to receive the survey; at least a quarter of that population expressed enthusiasm for the project and made a commitment to complete the survey. The actual response has been less enthusiastic. Negotiation of the details of non-disclosure agreements and heavy competition for the manufacturers' time and attention contributed to slow responses from the manufacturers. The database will, however, have responses from sufficient manufacturers to represent more than 50% of the VRLA market share.

End-user response was also expected to be adequate. Before incorporating customers identified by manufacturers, analysts constructed a list of 20 organizations which use VRLA cells in a wide variety of stationary applications. If each VRLA manufacturer identifies one customer, the list will include more than 45 end-users. End-user participants were not recruited from the Internet web page. From this population, analysts expect to have representation of end-users with favourable and unfavourable experience with VRLA products. This cross-section will increase the likelihood of identifying impacts on performance and life for specific combinations of cell design and operating regimes. Trends in this data can be compared with other data compiled for telecommunications applications only [4].

ILZRO plans to make the final report of the analysis and a version of the database (which will contain no proprietary information) available to ILZRO members, participants in the survey, and participants in a follow-on workshop for stakeholders in VRLA reliability. The database, still under construction as a result of the delayed responses, will allow users to perform queries which show data trends, but will not provide any site- or product-specific information. The workshop will be held when the outstanding responses arrive; at present, the analysts are hopeful of scheduling the event to coincide with the 1999

Battery Council International Convention to be held in Nashville, TN, in May 1999.

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