A TEST AND DATA REDUCTION ALGORITHM FOR THE EVALUATION OF LEAD–ACID BATTERY PACKS

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Experience from the DOE Electric Vehicle Demonstration Project indicated severe battery problems associated with driving electric cars in temperature extremes. The vehicle batteries suffered from a high module failure rate, reduced capacity, and low efficiency. To assess the nature and the extent of the battery problems encountered at various operating temperatures, a test program was established at the University of Alabama in Huntsville (UAH). A test facility (seen in Fig. 1) was built that is based on Propel cycling equipment, the Hewlett Packard 3497A Data Acquisition System, and the HP85F and HP87 computers. The objective was to establish a cost effective facility that could generate the engineering data base needed for the development of thermal management systems, destratification systems, central watering systems and proper charge algorithms. It was hoped that the development and implementation of these systems by EV manufacturers and fleet operators of EVs would eliminate the most pressing problems that occurred in the DOE EV Demonstration Project.

Fig. 1. Battery test laboratory at the University of Alabama in Huntsville.

Fig. 2. 96 V test battery in the environmental chamber.

Since information about battery systems rather than single modules was needed, UAH tested various 96 V lead–acid batteries, such as seen in Fig. 2, in environmental chambers at temperatures ranging between −20 °C and 60 °C (mainly using a discharge current of 120 A). Recently, discharge currents between 25 A and 400 A have been used. These tests were designed to obtain data about heat development rate, heat storage in the battery, cooling properties of tray ventilation, electrolyte stratification, charge energy acceptance, discharge efficiency, and the influence of temperature on the energy storage properties of battery packs, which includes the effect of battery module matching. A total of 68 sensors were installed in each battery, measuring the following parameters:

all module voltages;
all cell temperatures;
ventilation intake and exhaust temperatures;
current;
gas rate of a selected number of battery cells.

Recently:

oxygen content in the gas and the
cell and electrode potentials of selected cells have been measured.

Several thousand data points are collected in each test. This much information can only be analyzed by using an efficient data reduction algorithm. Such an algorithm has been developed and transformed into a computer code at UAH. The code makes it possible to produce report-ready information in the form of graphs and tables of all important parameters of a multimodule battery system within several hours after each test. The information obtained for each test run is listed in Table 1. The list contains over 30 important battery parameters, which can be presented as functions of charge/discharge time. A specially developed user-interactive analysis

TABLE 1

Listing of time functions generated by the computer code used in the test data reduction

Column	DIM	On charge	On discharge
(1)	V	Total voltage	Total voltage
(2)	V	Module voltage	Module voltage
(3)	A	Charge current	Discharge current
(4)	C	Average cell temperature	Average cell temperature
(5)	ml/min	Gassing rate	–
(6)	A	Current consumed by electrolysis	–
(7)	A	Current available for charging	Discharge current
(8)	A h	A h stored	A h discharged
(9)	A h	A h lost to gassing	
(10)	V	Equilibrium voltage	Equilibrium voltage
(11)	mmHg	Vapor pressure in the battery	Vapor pressure in the battery
(12)	–	Average specific gravity of electrolyte in the battery	Average specific gravity of electrolyte in the battery
(13)	kW	Power needed to store energy on the plates	Power generated during the energy removal from plate
(14)	kW h	Chemically stored energy	Energy removed from plate
(15)	kW	d.c. power generated by the charger	d.c. power generated on the load
(16)	kW h	d.c. energy into the battery	d.c. energy out of the battery
(17)	–	Charge energy acceptance	Discharge efficiency
(18)	kW	Rate at which energy is converted into heat	Rate at which energy is converted into heat
(19)	kW h	Energy converted into heat	Energy converted into heat
(20)	kcal	Heat generated	Heat generated
(21)	–	Instantaneous energy acceptance	Instantaneous discharge efficiency
(22)	ml	Water loss due to evaporation	Water loss due to evaporation
(23)	ml	Water loss due to electrolysis	–
(24)	A h	d.c. charge into the battery	A h discharged
(25)	–	Charge acceptance	–
(26)	l	Total gas volume developed	–
(27)	kcal	Heat stored in the battery	Heat stored in the battery
(28)	kcal	Heat removed from the battery	Heat removed from the battery
(29)	ohm	Internal resistance due to electrolysis alone	–

(continued)

TABLE 1 *(continued)*

(30)	ohm	Internal resistance due to the charging process	Internal resistance due to the discharging process
(31)	ohm	Total internal resistance	Internal resistance
(32)	ml/min	Production rate of oxygen	–
(33)	V^2	Parameter for battery overheating	–

program correlates parameters, subjects them to mathematical procedures, cleans out "noise", presents data in various fashions, etc. This permits a much more thorough and faster analysis of battery test data with conventional spreadsheet programming methods.

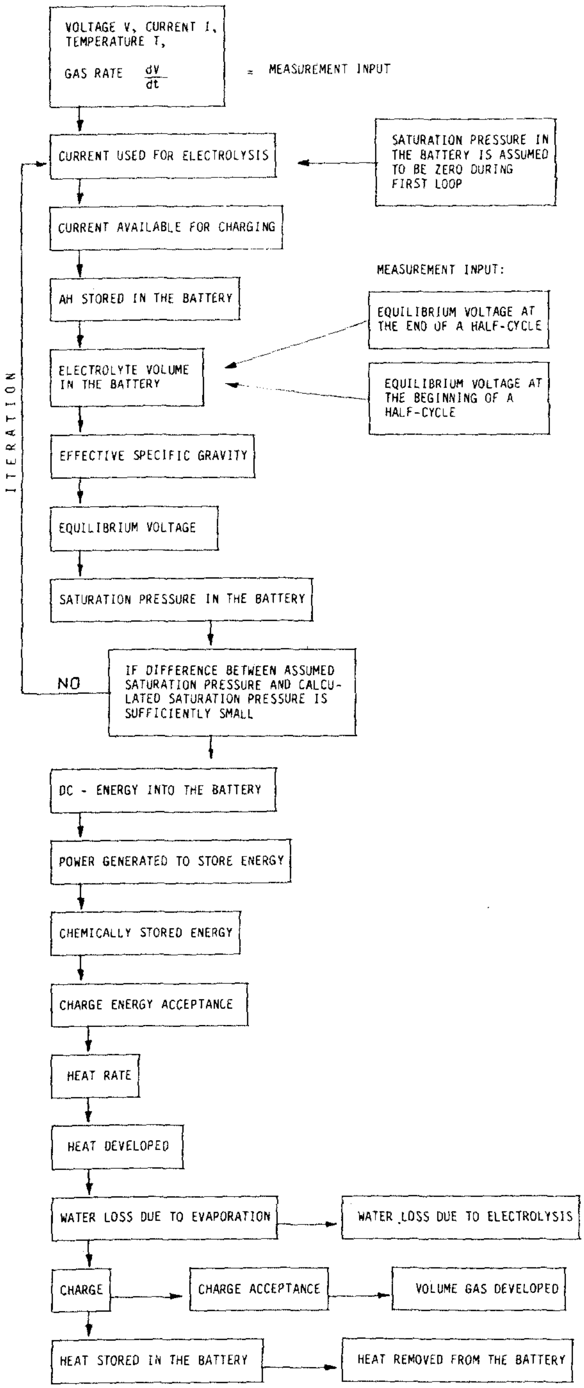
The algorithm is designed to make maximum use of the data collected and eliminates unnecessary information early in the data acquisition process. The corresponding software is divided into four parts. The first part facilitates the data collection and test control during the test. This program permits conducting any battery test schedule that is compatible with the battery and the electrical power constraints of the equipment. During data collection, the data are screened, and only essential data are stored in memory. This reduces the number of data that must be analyzed. To allow economical storage, the data which are collected as time related parameter values are coded and stored on disk as one 13 digit number per value pair. The matrix of 13 digit numbers is the end product of the data acquisition process.

The second part of the algorithm is the beginning of the data analysis. It facilitates the decoding and arrangement of the parameter/time values as matrices, where the time consistently increases and has the correct channel value associated with it. As 68 parameters are measured, 68 parameter/time matrices are obtained. They are reduced in the third part of the computer code.

The third part generates the parameter/time matrices of the parameters listed in the Table for each module, as well as for the 96 V battery. A flow chart indicates the process. An additional input to the data obtained from the data acquisition system, equilibrium voltage at the beginning and the end of cell half-cycles, must be supplied. Also, the specific heat coefficient of the battery modules must be entered.

The fourth part of the code is a user-interactive analysis program. Several hundred data sets can be stored in the computer simultaneously. The number of data sets that can be stored depends only on the number of value points in the set. The code allows correlation of data sets, data enhancement by adding digitized data from strip charts taken during the same tests, elimination of "noise", and presentation as multi-axis graphs. The code can also subject the data to complex mathematical procedures, thus generating additional parameter matrices.

The result is an exhaustive picture of the behavior of each battery pack that was tested. This information can readily be composed into a test report.



Battery data reduction algorithm.