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RSX-11M AND A CAMAC SERIAL HIGHWAY

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DISCLAIMER

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ABSTRACT

This paper describes the computer system used to test batteries in the National Battery Testing Laboratory located at Argonne National Laboratory. The computer system is designed around a PDP-11/45 running the RSX-11M V3.1 operating system. A CAMAC serial highway connects the computer to the crates that contain the data acquisition and cycler control modules in the laboratory. An interactive color CRT provides the means for operator control of the system. An LSI-11 microcomputer is used as a satellite processor to provide fast response for specialized tests that simulate the load placed on a battery by an electric vehicle.

INTRODUCTION

The National Battery Testing Laboratory (NBTL) is located in the Chemical Engineering Division of Argonne National Laboratory. The NBTL was established to test batteries, modules, and cells for battery development programs sponsored by the Department of Energy and others. Battery testing, evaluation, and analysis are important components of these programs. The number of tests and measurements to be performed simultaneously creates a data-acquisition and control requirement that dictates the use of a computer. The computer system has three main functions: 1) provide automatic control of the tests; 2) acquire and log data; and 3) provide computational facilities for the analysis and display of the data. This paper describes that computer system.

BATTERY TESTING

The term "battery" is used generally in this paper to also include modules and cells as the NBTL computer system treats the testing of batteries, modules, and individual cells in a similar manner. Only the size of a charger and load bank at a test station depends on whether a battery, module, or cell is being tested.

To test a battery with the aid of a computer, the operator must first describe the type of test to be run. For example, a test might consist of a constant voltage-current limited charge (the power supply maintains a constant current until a certain voltage is reached after which the power supply maintains a constant voltage) followed by a discharge at constant current or constant power until the battery's voltage drops to a prescribed level. This cycle of charging and discharging may be repeated many times, and would constitute one type of test. During the test the computer monitors the battery parameters (temperature, voltage, and current). From these parameters the computer calculates the amp-hour and watt-hour capacities of the battery along with the amp-hour and watt-hour efficiencies (the ratio of discharge amp hours to charge amp hours and the ratio of discharge watt-hours to charge watt-hours respectively). After conducting many tests one can determine the capacity of a battery for various charging and discharging currents. The battery's performance over a given temperature range can be determined as well as the battery's cycle life (the number of charge/discharge cycles it can to through before its capacity declines to a specified level). The computer also monitors certain parameter to which the operator may enter operational limits. Reaching these preset limits (*e.g.* temperature, current, or cell voltage) will automatically cause the test to be suspended.

Another type of test monitors the performance of a battery when it is used to power an electric vehicle. One way to accomplish this type of test would be to build an electric vehicle, install a battery, and then drive the vehicle until the battery was discharged. There are several major disadvantages to this approach: 1) the high cost of building an electric vehicle; 2) the ability to test only one battery at a time; 3) the requirement of a full scale battery (since testing of modules or cells on a scaled down power level is not convenient); and 4) the non-reproducibility of results caused by the battery's performance being a function of the wind, the terrain over which the test is conducted, and the manner of operation of the vehicle.

Another way to accomplish this test is to simulate the load the electric vehicle places on the battery by the use of a computer and a programmable power supply. The data necessary to perform the simulation can come from actual measurements made in an electric vehicle, or from computer modeling programs. In

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either case the computer is fed a driving profile (power vs time) that represents the load the electric vehicle places on a battery. The computer can then impose this profile on several batteries at once, and/or scale it down to apply it to a single cell. The computer must measure the battery's parameters and update the profile at a high sampling rate (greater than once per second) to adequately simulate the electric vehicle load.

SYSTEM DESIGN

The NBTL system was designed (1) to test between 50 and 100 modules/cells as well as 12 to 15 batteries with capacities greater than 20 kW-hr. Tests are performed on many different types of electrochemical systems (lead-acid, nickel/zinc, nickel/iron, etc.). Each test station in the system may be running a different test or they may be in a different phase of the same test. The system is flexible enough to accomodate new types of batteries or new kinds of test without interrupting the current tests. At first the system measured voltages, current, and temperatures; however in later stages requirements to measure safety related parameters such as gas pressure, hydrogen and chlorine concentrations, etc. were added. Thus the software design had to include provisions to accept new types of sensors.

The software system and the test equipment were to have several layers of protection so that under no circumstances would the failure of any single component (computer, power supply, etc.) result in damage to the battery under test.

The computer not only logs data, but also monitors the data logged and reports any deviation from a preset window. These requirements stemmed from a need to insure high data integrity without requiring a large staff.

SYSTEM HARDWARE

The main computer system (Fig. 1) is based on a PDP-11/45 processor with 124k words of memory, a floating point unit, and three-hundred megabyte disk drive. A magnetic tape transport archives data from battery testing. The Tektronix 4014 and Versatec electrostatic printer/plotter generate graphical displays. The DEC writer serves as the system console and error message logger for the data acquisition system. The interactive control console (color CRT, keyboard, trackball, and interrupt button) are interfaced to the computer through the CAMAC (2) crate in the control room. This crate also interfaces the CAMAC serial highway driver to the computer.

The CAMAC serial highway in the NBTL is a shielded twisted pair running at 2.5 megahertz in bit serial mode. It is transformer coupled to provide a high degree of isolation and fiber-optic cables are available to increase the isolation. The serial highway can also be run in byte serial mode to gain speed. It can be easily lengthened so that additional testing can be done in other buildings if necessary. The crates on the serial highway in the laboratory contain digital-to-analog converters (D/A's) to control the battery cyclers, and analog-to-digital converters (A/D's) to measure the battery voltage, battery current, cell voltages, and cell temperatures. The analog-to-digital converters employed are the self scanning type. They allow the computer to read a data channel from a register rather than wait for the A/D to convert each channel as the computer reads it. The A/Ds and D/As are close to the battery being tested. This results in the local digitization of the analog signals and eliminates a mass of analog signals coming into the computer room.

A microprocessor based CAMAC module collects temperature data. The microprocessor samples thermocouples, converts millivolt readings to degrees centigrade, and stores the result in its memory. When the main computer wants a temperature reading it gets it from the microprocessor's memory.

The cell and battery test stations (cyclers) can normally provide charge and discharge currents of 0 to 500 amperes. The cell/module test stations operate at voltages of 0 to 8.5 volts, and the battery test stations operate up to 225 volts. Test stations can also be connected in parallel and/or series to increase the current and/or voltage. In order to ensure the operation of a cell or battery within safe limits, each test station has hardware-adjustable maximum/minimum limits for current and voltage.

The LSI-11 satellite processor (Fig. 2) resides in the laboratory near one of the crates on the serial highway. Programs for the LSI-11 are down-line loaded over the serial highway to memory in the CAMAC crate, which is shared by the LSI-11. This shared memory eliminates the need to have proms in the LSI-11. The memory can be addressed by the 11/45 via CAMAC commands and it also appears as a 4k bank in the LSI-11 address space. The LSI-11 uses an auxiliary crate controller to access the D/A for the battery cycler and the A/Ds that measure the battery parameters. The 11/45 can also access these same A/Ds and D/As via the serial highway. The L2 crate controller arbitrates whether the LSI-11 or the 11/45 has control of the CAMAC dataway (the bus in the CAMAC crate). A CAMAC communications interface module is connected to a DLV11 on the LSI-11 to permit the 11/45 to function as the LSI-11's console. This allows the PDP-11/45 to gain absolute control over the LSI-11 and eliminates the need to run a separate RS232 line from the 11/45 to the LSI-11.

SOFTWARE

Overview

To provide the required flexibility the system is completely table driven. Tables for each test station are stored on the disk. The tables contain the following items: 1) control currents and voltages for the cycler, 2) the CAMAC crate and module number of the cycler controller D/A and the A/Ds used to measure parameters, 3) the limit conditions that control the termination of the charge and discharge cycles. The programming is done mostly in FORTRAN IV, except for a few routines in MACRO that interface to the tables and to the file system.

The system software is organized into three main task groups (Fig. 3): 1) data acquisition and control; 2) interactive color CRT console; and 3) graphics. These three task groups communicate with a "resource allocator" task to get the tables from the disk necessary to run a particular battery test. Communication with the "resource allocator" task is via the RSX-11M SEND/RECEIVE data directives and global resident common blocks. The operator of a test interfaces with the computer through the interactive CRT console.

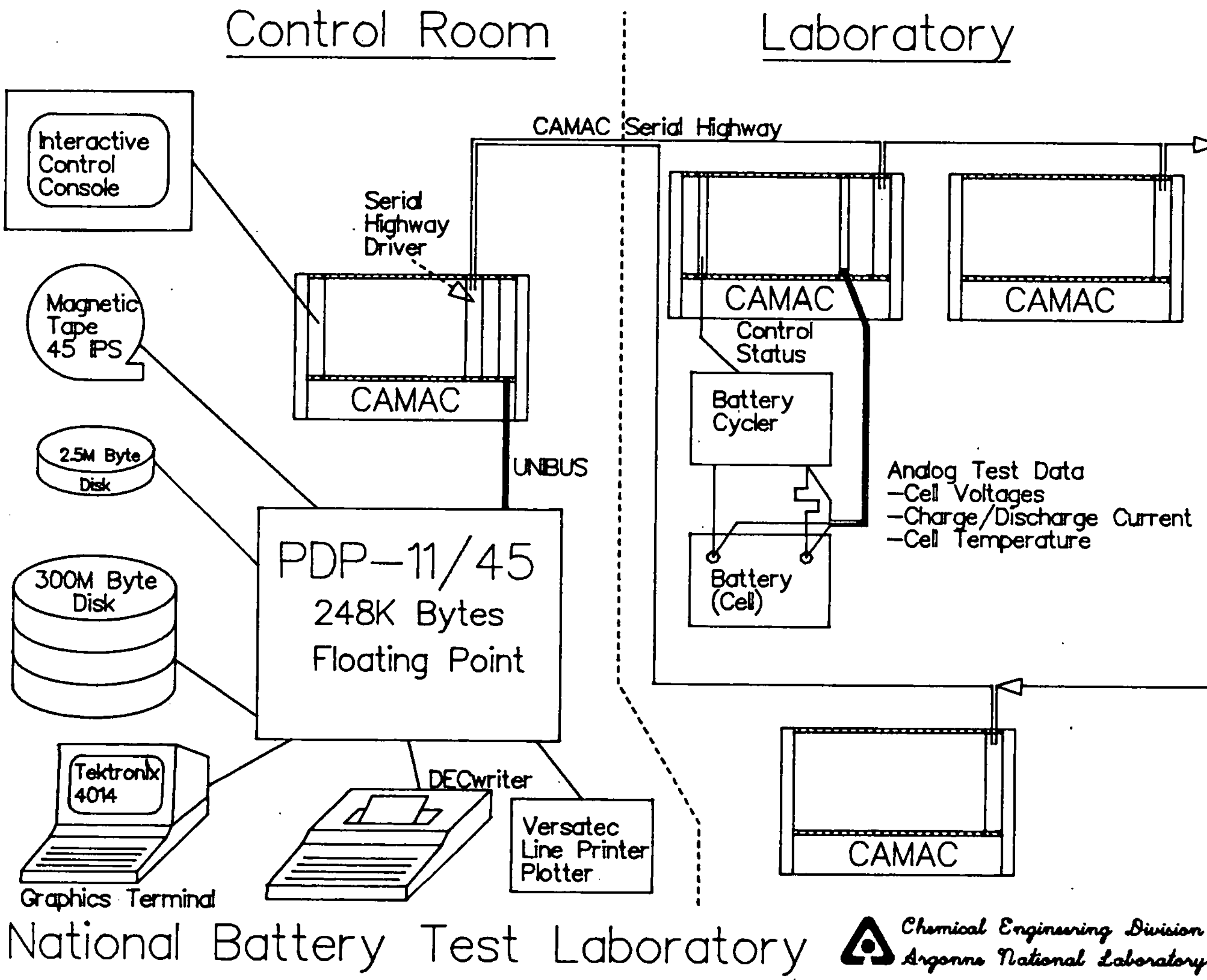

Fig. 1. Block diagram of the National Battery Testing Laboratory computer system and representative test station.

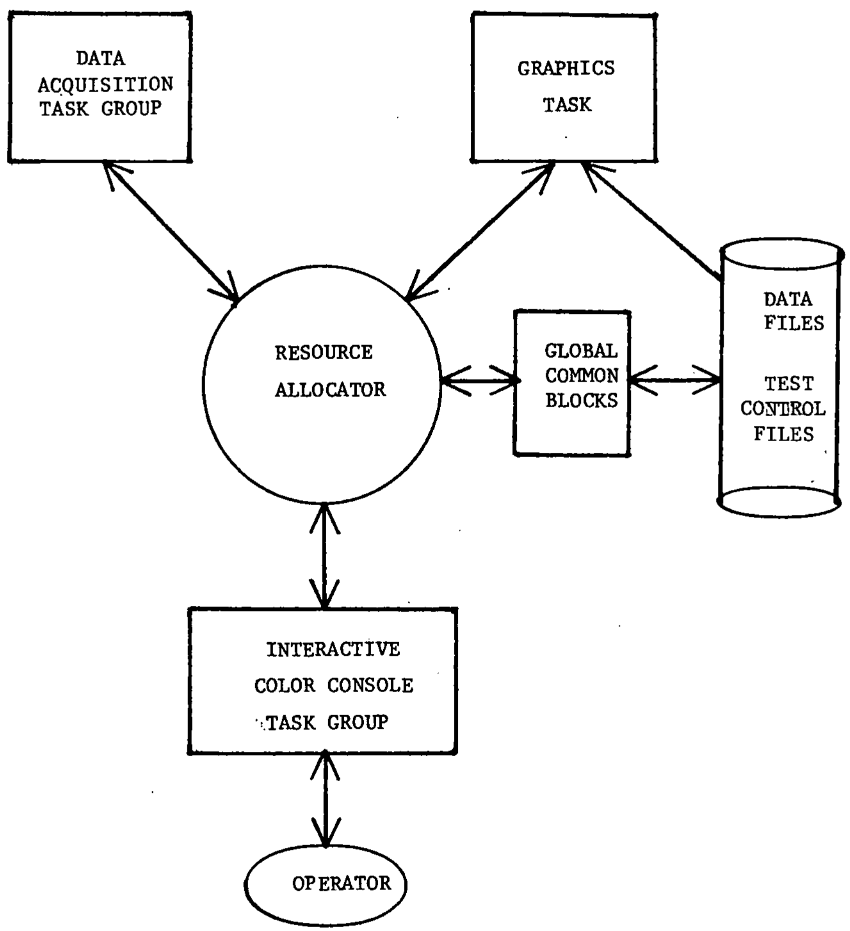

Fig. 3. Block diagram showing the relationship between major software components and data structures.

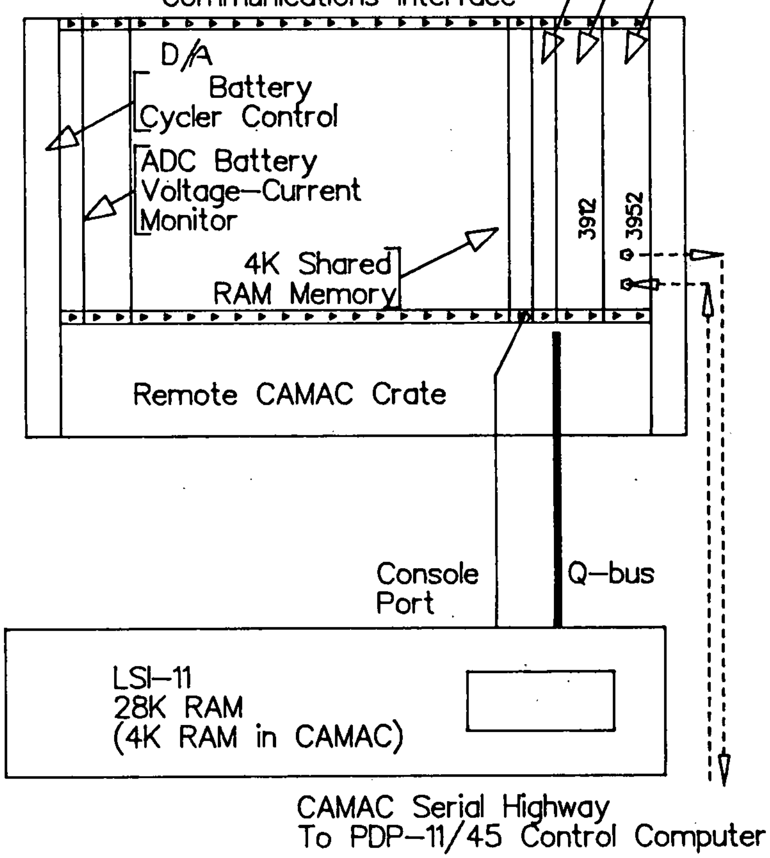

Fig. 2. LSI-11 satellite processor connected to a remote crate on the CAMAC serial highway.

CAMAC I/O

The system uses a CAMAC driver (3) written for RSX-11M to do all of its I/O through the CAMAC serial highway. There are six subroutines in the system that actually issue requests to the driver. The rest of the system calls these routines with a request for a generic parameter, such as battery voltage, cell voltage, or cell temperature. These six routines use the generic parameter and scan the tables to find the CAMAC location of the sensor and the scaling factors to convert the A/D reading to engineering units. Thus the majority of the system software has no idea what type of sensor measures a particular parameter. Therefore, adding a new sensor to the system requires very few changes to the system software. Likewise, the control software uses generic commands like STOP, START, and POWER ON/OFF to control a cycler. About eight subroutines interpret these generic commands and map them to actual CAMAC hardware, using the tables to turn on a particular cycler. Thus, one can change the type of cycler with only minor changes to the system software.

Graphics

The Tektronix 4014 is used for interactive graphics and the graphics programs use the Tektronix PLOT-10 subroutine library. Hard copy of plots can be generated on the Versatec printer/plotter with an optional piece of hardware from Versatec. The graphics allow one to plot a test in progress or one that has been saved in an off-line data set on the disk. To plot a test that has been archived to magnetic tape, one must first read the tape into an off-line dataset on the disk.

Data plots are initiated via the interactive CRT console. Each test station (battery) has axis and labeling information stored in a table on the disk. The plots (Fig. 4) show battery voltage, battery current, cell voltages, and cell temperatures as a function of time. The plots also integrate amp hours and watt hours and print them at the top of the plot. Two additional pages are appended to the plots, listing the start time of each state (charge, discharge, etc.), the times the test was suspended or resumed, and the amp hours, watt hours, amp hour efficiency, and watt hour efficiency for each charge/discharge cycle of the test.

Interactive Console

The console consists of a color CRT, keyboard, interrupt button, and trackball (which controls cursor positioning). A menu is presented on the color screen and the operator may select any function by moving the cursor over the function name and depressing the interrupt button. Each function presents a new display on the CRT. The operator moves the cursor to a field where input (e.g. battery current) is desired. He then enters the numeric value of the current on the keyboard. When all inputs are filled in satisfactorily the operator moves the cursor to the RECORD field and depresses the interrupt button. The system then validates the parameters and stores them on the disk. The menu approach differs significantly from serial prompting in that all questions are presented simultaneously and can be answered in a "random access" manner. Previous responses can be restored so that infrequently changed parameters need not be re-entered continuously.

Color offers an added dimension to human interaction with the computer. The interactive console uses dark blue to display parameters that the user can look at, but not alter. Magenta fields can be altered by the operator. Default values are white and input from the keyboard is in yellow. Green displays status parameters that are in a normal condition, and parameters that are out of range flash red.

The interactive console has menu of eight pages: 1) LOGIN, 2) DEFINE CAMAC, 3) TEST SETUP, 4) CYCLER CONTROL, 5) CYCLER STATUS, 6) BATTERY STATUS, 7) TERMINATION CONDITIONS, and 8) GRAPHICS CONTROL. The best way to describe these pages is to illustrate their use in setting up a battery test.

The LOGIN page is selected to assign the battery an identification number and to record descriptive data, such as dimensions, weight, specific gravity, etc. The battery is physically moved to a test station (cycler) and wired to a power supply. The DEFINE CAMAC page is used to enter the crate and module numbers of the D/A selected to control the power supply and the A/D channels chosen to measure the voltages, currents, and temperatures. The TEST SETUP page is used to enter the test type (driving profile, constant power, constant current, etc.) and the names of the two tasks that will be used to switch states and log data. A battery test consists of four states: 1) charge; 2) open circuit after charge; 3) discharge, and 4) open circuit after discharge. During a test the battery passes through the four states, and when it gets to open circuit after discharge, it goes back to charge. One pass through this loop is called a cycle, and the operator can specify how many cycles there are in a test. One can also specify the start and stop states of the test. The operator also defines how frequently the system should sample the battery's data for each of the four states. The TERMINATION CONDITIONS page is used to define the conditions under which one state will terminate and proceed to the next state. The charge state may be terminated by time, accumulated amp hours, a low current (current limited/constant voltage), or by a dynamic calculation such as restoration of 110% of the amp hours removed on the previous discharge. The open circuit after charge is a rest period for the battery. It can be terminated by time or temperature. The discharge is typically terminated when the battery voltage or the voltage on any cell gets too low. It may also be terminated when a certain number of amp hours have been removed, or if the temperature of the battery gets too high. Open circuit after discharge is another rest period for the battery. It is terminated by time or by waiting until the battery cools down to a certain temperature. The discharge state can be a complex ordered pair of power vs time values that describe an electric vehicle's driving profile. The operator can impose a window of "normal" values for any of the test parameters. If the value of a parameter moves outside of this window during a test the computer will suspend the test and notify the operator.

After the test is set up, one proceeds to the CYCLER CONTROL page to turn on the cycler. The test starts logging data and sends it to the "resource allocator" for storage on the disk. From the CYCLER CONTROL page the operator may suspend, resume, or stop a test. The operator may monitor the progress of a test by using the BATTERY STATUS page to show the battery current, battery voltage, cell voltages, and cell temperatures. During the course of a test the

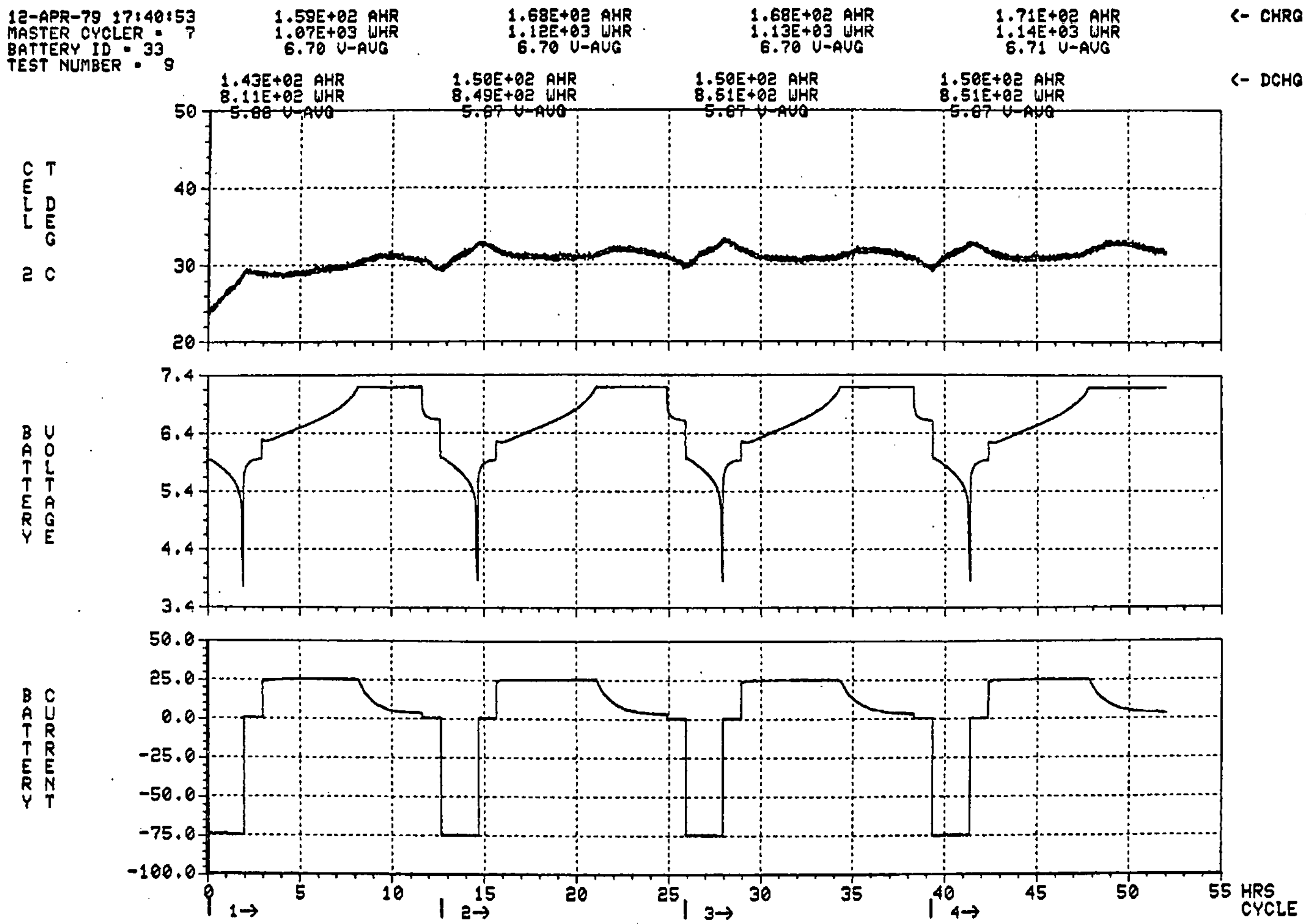

Fig. 4. A plot of battery current, battery voltage, and cell temperature for a three cell lead acid battery. Amp-hours, watt hours, and average voltage for each charge/discharge sub-cycle are shown at the top of the graph.

operator may use the GRAPHICS CONTROL Page to plot the measured parameters as a function of time. When a test ends the "collect" Program is invoked to copy the data from the on-line dataset to an off-line dataset. Later the off-line dataset may be archived to magnetic tape.

Data Acquisition and Control

The tasks in this group control the cyclers and collect data from the battery under test. The table for a test station (test control table) contains the names of two tasks. One task handles the special functions that are not needed very often (changing from one state to the next, etc.). This special task may be large, since it does not permanently occupy memory. The data logging task is smaller and is responsible for logging the data from the battery under test and passing data to the "resource allocator" for disk storage. The data logging tasks to the system without affecting ongoing tests.

Resource Allocator

This program allocates resources to the system. It is the only program that has disk files open. A task in the system will request a service from the "resource allocator" with the SEND/RECEIVE data directive in the RSX-11M executive. Global common blocks pass information back and forth between tasks and the "resource allocator". When a task wants something from the "resource allocator" it sends a data packet to the allocator task and suspends itself. The allocator receives the packet and checks to see if the resource is free. If it is not free, the allocator queues the request. If the resource is free, the allocator marks it busy and processes the sending task is resumed. The sending task must end with a request to the allocator to free the resource. The "resource allocator" was created mainly to provide resource locking and to keep the number of open files on the system small. To increase speed the common blocks are handled like a write through cache. If the block from a file is already in the common block the allocator does not read it again. When a block is written to the common block it is always written to the disk. To speed up the allocator a set of FORTRAN callable subroutines were written to access the FCS macros, READ$ and WRITE$, so that the allocator can do direct disk block I/O.

LSI-11 Satellite Processor

To provide an adequate simulation of an Electric Vehicle power profile the 11/45 computer must monitor the voltage and current at an increased rate. It was felt that maintaining a high sampling rate (greater than once per second) on more than two batteries would compromise the time given to other tests running on the main computer. The decision was consequently made to use a satellite processor that could provide the high speed control without interfering with the tests running on the 11/45. The LSI-11 would be connected on the CAMAC serial highway (2). The PDP-11/45 will charge the battery and then send the LSI-11 a driving profile for the discharge cycle. The LSI-11 will run the discharge and perform the following four functions: 1) compare the actual battery voltage and current with the desired power, and update the current to force the desired power; 2) log all data parameters being measured in the LSI-11's local memory; 3) integrate the amp hours and watt hours; and 4) monitor all parameters to make sure they are within specified limits. At the end of each profile, the PDP-11/45 will ask for the amp hours and watt hours consumed during the profile. Occasionally the PDP-11/45 will ask for all of the data points taken during the profile. Occasionally the PDP-11/45 will ask for all of the data points taken during the profile so that the operator can graph the profile to ensure that the test is proceeding properly. All of the data received from the LSI-11 will be stored on the disk drive of the PDP-11/45 computer for analysis by its data base management system and its graphical software.

One LSI-11 should be able to handle several batteries. If the need arises to support additional batteries, multiple LSI-11's can be accomodated with negligible impact on the loading of the 11/45.

SUMMARY

1) The use of table driven software provides the means to expand the system with very little change to the software. The accomodation of new cyclers or new sensors requires very few changes to the system.
2) Allowing each test station to have its own special task and data logging task has allowed new types of test programs to be added to the system without disturbing the ongoing tests.
3) The use of scanning A/Ds and temperature modules with microprocessors has allowed an increase in data acquisition speed. Since these modules appear to the computer as always ready, the CPU does not waste time waiting for a multiplexor or an A/D to finish a conversion.
4) In addition to logging the data, the system is continually checking the values of parameters to see that they are within "normal" limits.
5) The use of a satellite processor has resulted in very accurate Electric Vehicle profiles without overloading the main computer system. This distributed processing has been a major factor in letting us expand the facility without incuring very large costs.
6) The use of a menu approach, along with the color CRT, has added greatly to the ease of operation of the system. The menu alleviates the need for the operator to learn a lot of special commands; the machine prompts him for everything. The use of color has been especially helpful in making equipment that is malfunctioning "stand out" when status is reviewed.
7) Separating the three major functions of the system resulted in a modular design that allows modifications to take place on the graphics or interactive console without forcing an interruption in the data acquisition system.
8) The CAMAC serial highway has brought us many advantages:

A. Speed - 2.5 megahertz bit serial and if need be it can go up to 5.0 megahertz byte serial.
B. There is no mass of analog signals coming into the back of the main computer. Signals are digitized locally to reduce the noise on the analog lines.
C. Expansion - If another building is needed for more testing space, only serial wire has to be extended.

FUTURE ENHANCEMENTS

1) The four states we now have (charge, open cir-

cuit after charge, discharge, and open circuit after discharge) will be expanded to "N" states. This will allow easier implementation of charge cycler with multiple current steps and equalization cycles.

2) The data logging task should adjust the data sample interval based on the slope of the battery voltage. This would allow a high sample rate as the battery gets near the end of its discharge, yet not waste a lot of disk space when the battery voltage is not changing very must in the middle of the discharge.

3) The use of FORTRAN IV resulted in a somewhat slow graphics, so FORTRAN IV PLUS was purchased to speed this up.

4) The data acquisition system will be modified to post a summary record at the end of each charge/discharge cycle into a RMS-11 file. The summary record will contain amp hours, watt hours, efficiencies, cycle number, etc. This data will be available for access by DATATRIEVE so that comparisions on different batteries can be made more easily.

ACKNOWLEDGMENTS

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   1) Modular Instrumentation and Digital Interface System (CAMAC), IEEE std. 583-1975.
   2) Serial Highway Interface System (CAMAC), IEEE std. 595-1976.
   3) Parallel Highway Interface System (CAMAC), IEEE std. 596-1976.
   4) Block Transfers in CAMAC Systems, IEEE std. 683-1976.
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