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Journal of Power Sources 52 (1994) 251–260

JOURNAL OF POWER SOURCES

The development of a high-power automatic battery test facility

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Received 27 May 1994; accepted 22 August 1994

Abstract

The design, development and operation of a microcomputer-controlled, 16-bit, 0.5 MW battery test facility is described. Discharge/charge profiles of up to 45 steps of constant power, current and resistance on discharge, and constant current or voltage on charge, can be programmed in any combination. The discharge uses a resistive load, allowing a maximum current of 16 000 A to be resolved to about 250 mA. However, control precision is limited by the current measuring shunts to better than $\pm 0.2\%$ of reading. Charging is carried out using a thyristor-controlled analogue supply to provide up to 3000 A at 50 V; the charger can be operated under local or remote control. Both charging and discharging can be carried out automatically, under computer control, or under manual supervision using a manual control console. Typical performance testing of submarine traction cells is reported, as is the load simulation testing of a helicopter engine starter transformer-rectifier unit.

Keywords: Batteries; Test facility

1. Introduction

The Battery Section at the Defence Research Agency, West Drayton has undertaken research, development and testing of electrochemical power sources, on behalf of the Royal Navy, for more than 70 years. The capacity of the cells and batteries investigated has ranged from button cells of a few mAh to lead/acid traction cells of approximately 10 000 Ah. This report concentrates on high capacity/power systems.

It is of great tactical importance that the submarine commander knows the capability of the submarine propulsion battery under any operating regime; providing the required data has been the task of this establishment.

A thyristor-controlled, analogue submarine battery test facility was developed at West Drayton in the late 1970s [1]. The facility allowed simple discharge testing of submarine propulsion cells. However, the sequential stepping control mode was slow to react to changes, and the effective current resolution was approximately 50 A.

The rapid advances in digital technology has made it possible for the development of a new, high-performance facility, which is capable of high precision evaluation of realistic, operational profiles.

This report describes the new, high-power battery test facility, which has been made flexible enough to undertake precision testing of other electrochemical power sources of lower current capability (including fuel cells), and of non-electrochemical d.c. power sources.

2. Facility description

2.1. Hardware overview

An overview of the battery test facility is shown in Fig. 1, and the hardware is schematically shown in Fig. 2. The facility consists of two major submodules: a charging unit and a discharging unit. Both of these units are under the direct control of the manual control console (MCC). The MCC determines whether testing is performed completely automatically, using the system control computer (486 DX 66 MHz), or under operator supervision. Under automatic control, d.c. power sources can be subjected to complex profiles of up to 45 stages of any combination of charge and discharge. The MCC, discharge and charge units are described below.

2.1.1. The manual control console

The MCC has two main functions:

(i) it acts as the buffer between the primary interface, within the system control computer (SCC), and the system hardware, allowing automatic control of the test facility by the SCC, and

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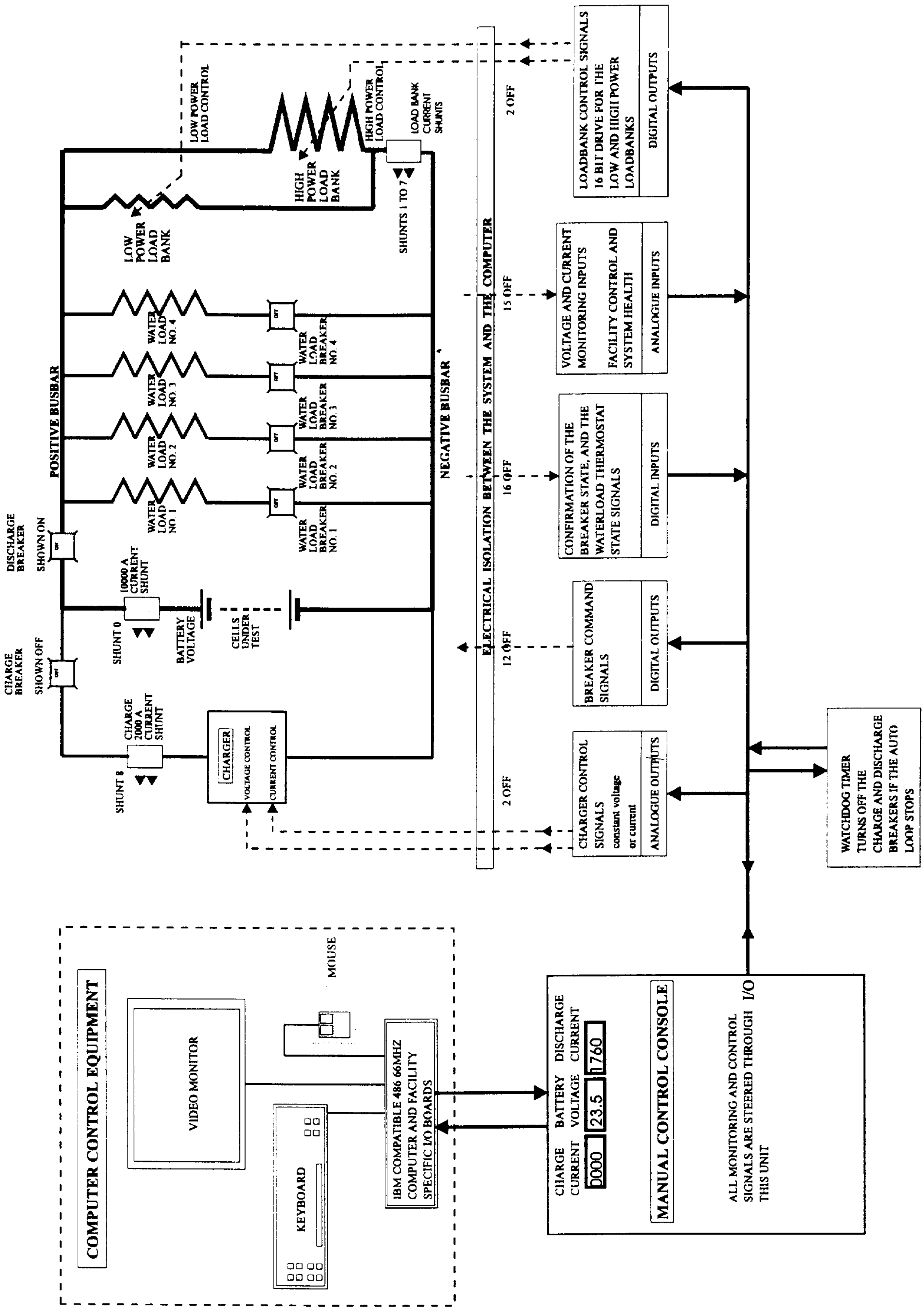

Fig. 1. A schematic overview of the automatic battery test facility.

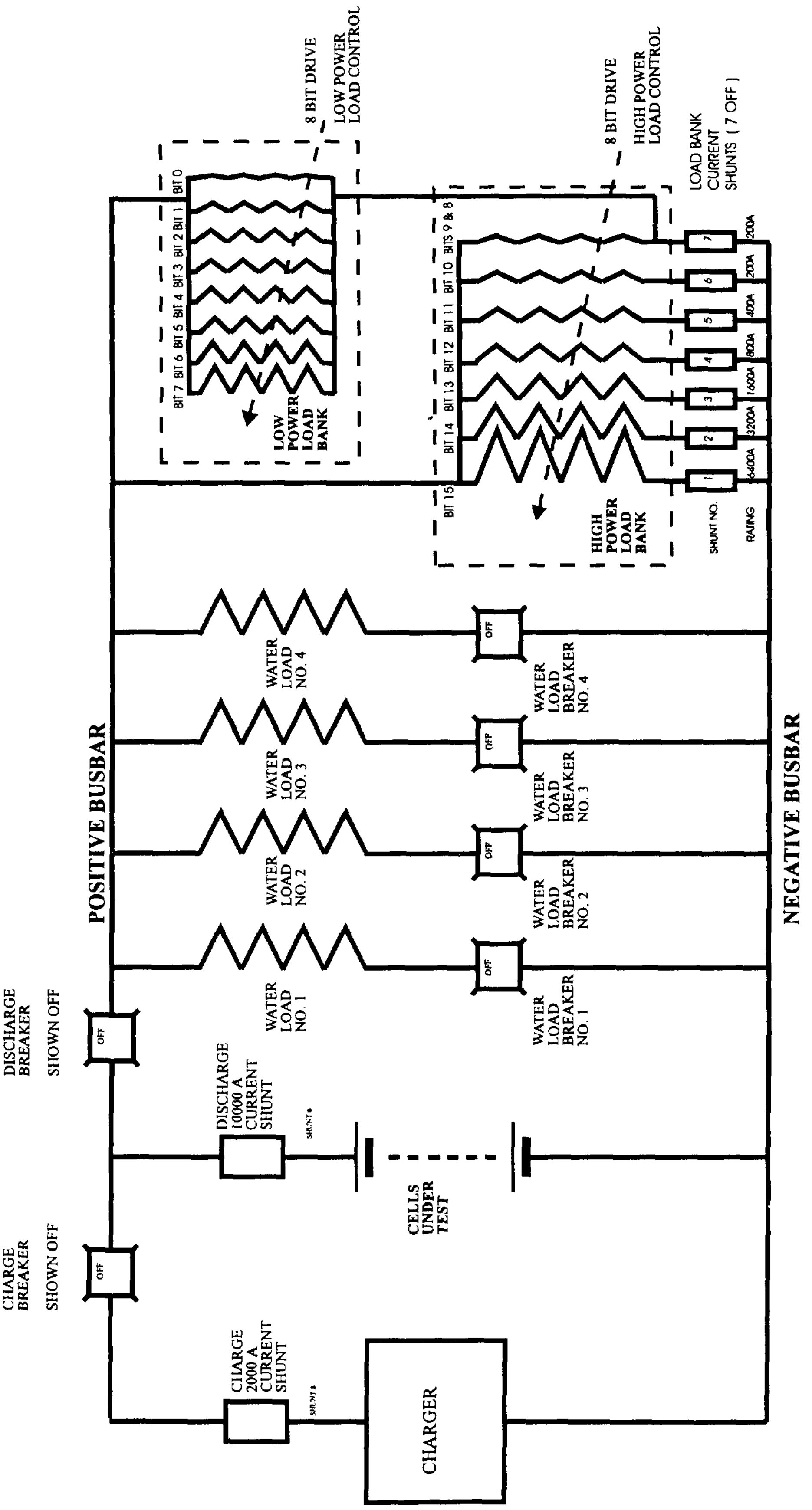

Fig. 2. A schematic diagram of the battery test facility hardware.

(ii) it can be used to operate the facility under manual supervision from switches on its control panel.

All commands and data are passed through this unit. Switches on the MCC determine whether the system is operated manually or automatically. Output commands to the system are transferred via a digital output rack, containing solid-state relays for the discharge load bank drive, and coil-operated relays for circuit breaker control. An additional solid-state relay propagates the 'watchdog' timer pulse, a fail-safe device ensuring SCC control under automatic operation.

The system is monitored by a digital input rack, containing optical couplers to monitor the operation of the circuit breakers and the thermostats on the water-cooled resistive loads (see below).

Analogue signals are processed by an analogue input/output rack, containing sixteen isolating instrumentation amplifiers to monitor voltage and current. Voltage and current command signals, from the MCC or SCC, are sent to the charger via separate isolating buffer amplifier modules.

2.1.2. The discharging unit

The discharge current is controlled through two resistive loads, consisting of individual resistive elements connected in 8-bit binary pattern groups, one high power and the other low power. The high-power load bank is schematically shown in Fig. 3. Control of the overall 16-bit discharge unit is effected through solid-state relays located in the MCC. For very high current/power applications, water-cooled resistive loads can be operated in parallel with the 16-bit system. Because of the unique nature of the discharge unit, it will be described in greater depth in Section 2.2.

2.1.3. The charging unit

Charging is effected using a thyristor-controlled power rectifier with a continuous rating of 3000 A at up to 50 V, current being measured using a single, thermally-compensated, precision (better than $\pm 0.2\%$ of reading) shunt. This device has an internal analogue, closed-loop current control system which can be controlled locally, from the front panel, or remotely. In the remote mode, the charger can be controlled by the SCC or from the MCC front panel. Because the SCC also controls the discharge unit, automatic operation allows the programmable control and data logging for both simple and complex tests involving variable charge/discharge cycles.

2.2. The discharging unit

This unit comprises a 16-bit resistive load, divided into two 8-bit modules, one high power the other low power. For very high-power tests, this load is supplemented by four water-cooled resistive loads connected in parallel.

For the high-power 8-bit load, power MOSFET heat sink modules are used to switch 0.4 Ω, > 1.5 kW resistors using an 8-bit data control signal. The partially uncovered resistor bank is shown in Fig. 4, the power MOSFET modules are shown in close-up in Fig. 5, and an overall view is shown in Fig. 6. These allow the discharge current to be varied between 0 and 10 000 A in 40 A steps at 16 V.

The high-power load bank comprises 255 such modules. Each module consists of a heat sink, a terminal block and three MOSFETs connected in parallel to achieve the desired power rating. The drain to source terminals of the power MOSFETs of each module are protected by a capacitor and transient absorber. Resistor networks on the transistor gates ensure current control sharing, and improve removal of gate to source charge. The transistors are protected from high voltages by a zener diode and transient absorber connected across the copper bus bars.

The low-power load bank unit (Fig. 7) comprises power MOSFET drivers switching 50 Ω, 25 W resistors. These are controlled by an 8-bit data control signal to vary the discharge current between 0 and 50 A, in 160 mA steps at 16 V. The least significant bit controls a single 100 Ω resistor.

The data bit drive data are summarised in Table 1, and show the resistance values and the approximate current at 20 V. Control precision is maintained by routing resistor groups corresponding to bits 10 to 15 through individual shunts, at the current rating shown in Table 1; bits 0 to 9 are routed through a single 200 A shunt. The shunt arrangement is shown in Fig. 8; each one is high precision (better than $\pm 0.2\%$ of reading) and thermally compensated. For ease of build, these shunts have been connected between the power MOSFET source and the negative bus bar. This means that the non-battery current drain of up to 6 A, from switching the power MOSFETs, has to be compensated for in the control software.

The discharge current/power capability is supplemented by water-cooled resistive loads (water loads), which can draw up to approximately 8000 A, in parallel with the 16-bit load bank. These are switchable in four steps of 2000 A each, as outlined in Fig. 1. Fig. 9 shows the water-cooled loads, which are made from round-section steel conduit and have a resistance of 2.9 mΩ. Each is controlled by a circuit breaker, two of which are shown in Fig. 10. When these are in use, the overall discharge current is measured using a single precision shunt.

2.3. Computer/hardware interfaces

The major concerns when operating high-power systems are safety and reliability. Isolation of the high-power and low-level control signals from each other,

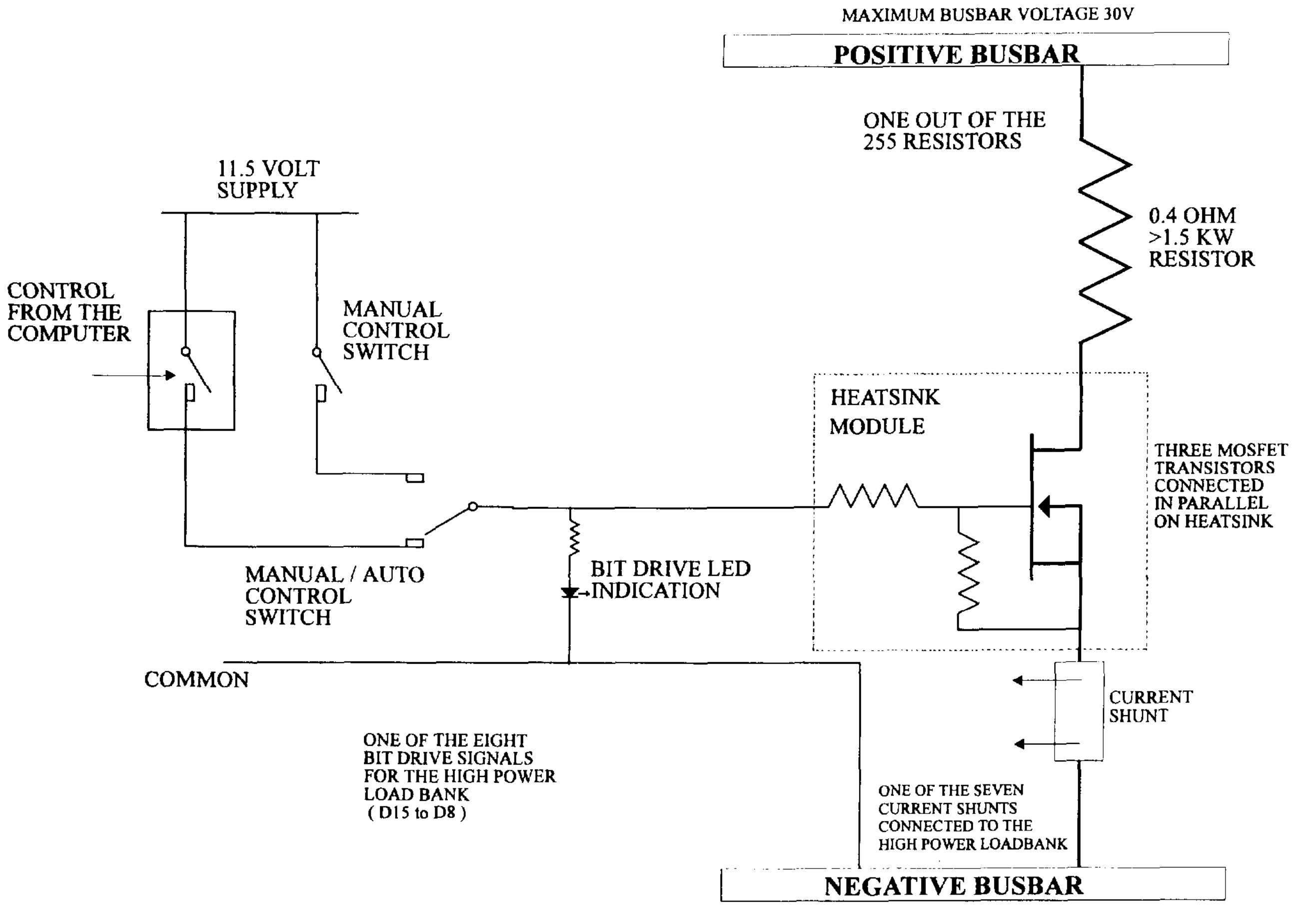

Fig. 3. A diagram of the high-power load bank.

Fig. 4. Photograph showing the partially uncovered high-power resistor load bank; the load bank comprises 255 0.4 Ω resistors.

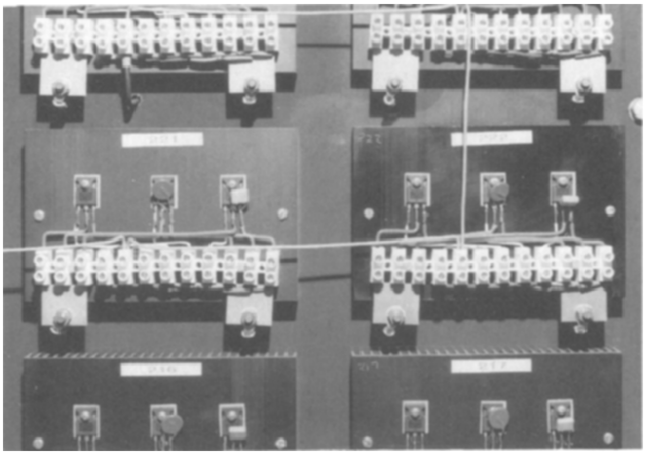

Fig. 5. A close-up photograph of the power MOSFET modules.

and the computer hardware is essential. To minimise the possibility of earth loops, signal interference, and system damage, all the interfacing between the SCC and the rest of the system is either optically, capacitively, inductively or relay isolated.

The system has been designed to be operationally versatile, under manual or automatic control; the control type is selected by switches on the MCC.

System safety has been addressed by:

(i) monitoring the on/off state of all breakers;

(ii) using electrical interlocks to prevent simultaneous closure of charge/discharge breakers;

(iii) a thermostatic control of water loads to prevent overheating;

(iv) a watchdog timer that stops charge or discharge when control is lost;

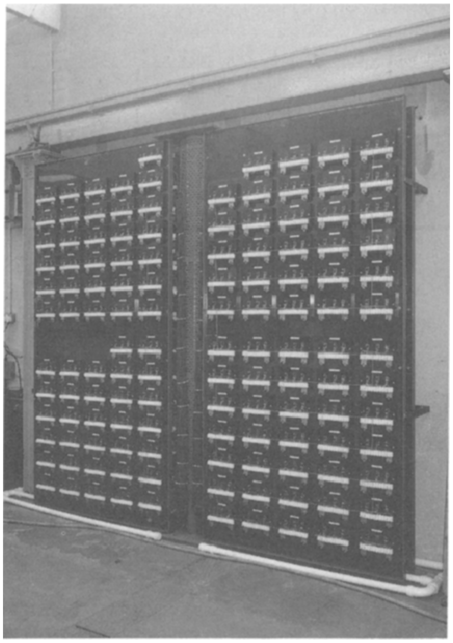

Fig. 6. A photograph showing an overall view of the power MOSFET modules.

Table 1
Data bit drive related to loadbank parameters

Data bit drive	Resistance value (Ω)	Approximate current at 20 V	Parallel driven resistors
a) High-power load bank			0.4 Ω resistors
D15	0.003	6400	128
D14	0.006	3200	64
D13	0.012	1600	32
D12	0.025	800	16
D11	0.05	400	8
D10	0.1	200	4
D9	0.2	100	2
D8	0.4	50	1
b) Low-power load bank			50 Ω resistors
D7	0.78125	25.6	64
D6	1.5625	12.8	32
D5	3.125	6.4	16
D4	6.25	3.2	8
D3	12.5	1.6	4
D2	25	0.8	2
D1	50	0.4	1
D0	100	0.2	2 in series

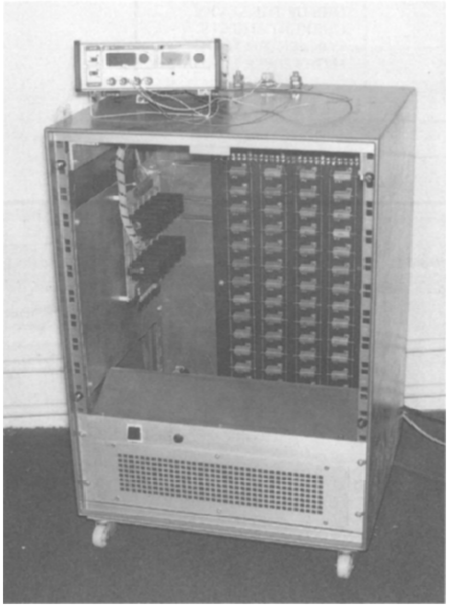

Fig. 7. The low-power resistor load bank unit.

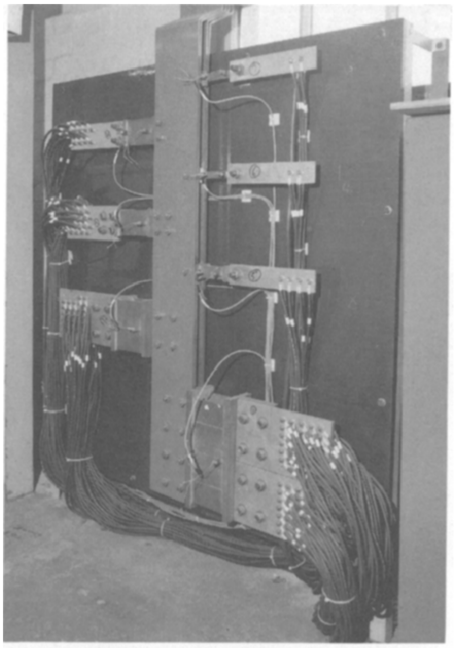

Fig. 8. Photograph showing the arrangement of current measuring shunts in the discharge control circuit.

(v) an emergency 'stop' button on the manual control console.

The measurement and control functions are effected by the SCC via two plug-in cards. One card has 12 A/D inputs, 2 D/A outputs, 16 digital inputs, 16 digital outputs and a counter/timer. The resolution of the A/D's and D/A's is 14-bit. The second card has 64 channels of digital I/O.

2.4. Software

The facility control software was written in 'C' language to run under Microsoft DOS, with embedded 'assembler' routines for communication to the two plug-in cards that provide the interface between the SCC and the system hardware.

There are three main variable arrays, which contain the system set-up values, run-time mathematical and logical variables and the 'autoloop' control data for

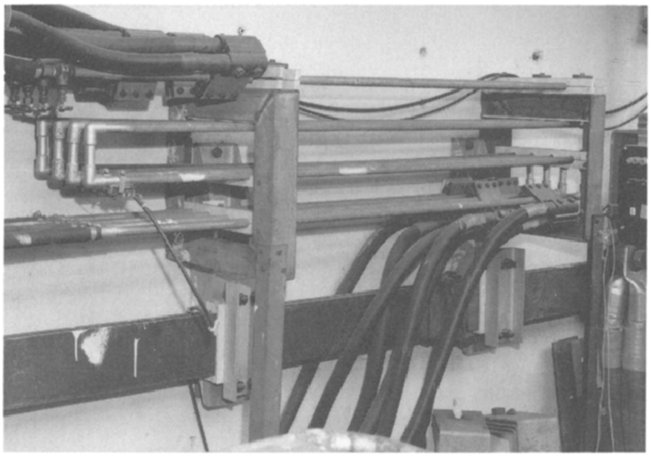

Fig. 9. Photograph showing the four, water-cooled resistive loads used in parallel with the main load bank.

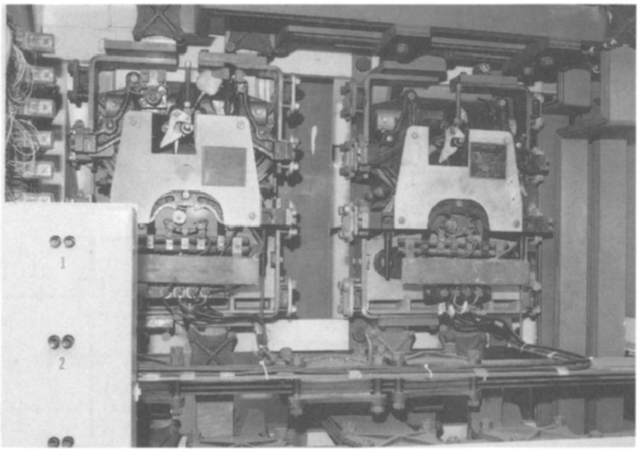

Fig. 10. Photograph showing two of the control breakers for the water-cooled resistive loads.

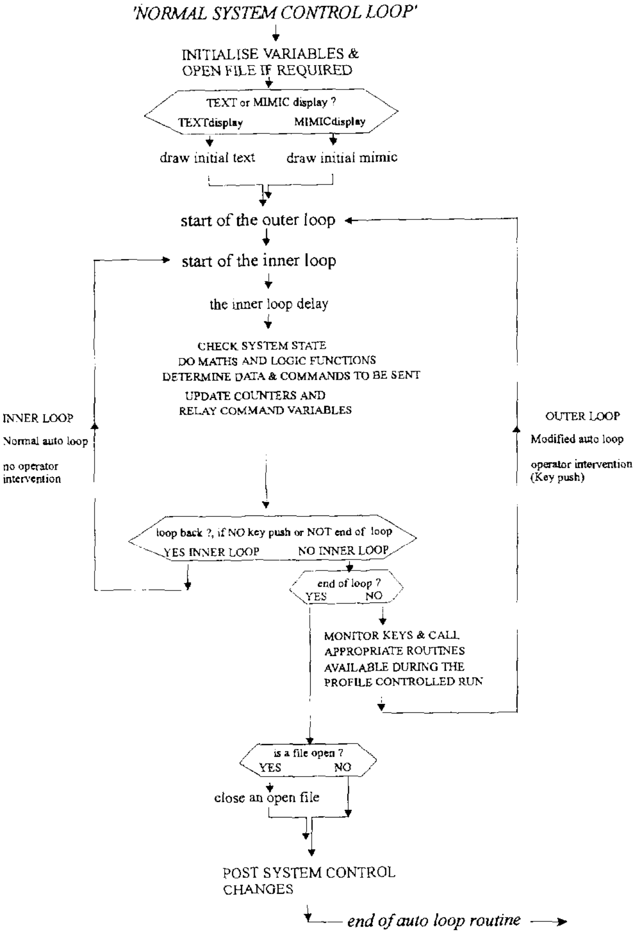

Fig. 11. An overview of the normal system control loop of the automatic battery test facility software.

eventual logging to disc. The majority of the variables are globally available to improve access by all routines.

An overview of the normal system control loop is shown schematically in Fig. 11; some 100 routines and subroutines are called within the inner loop. The discharge and charge current data drive control equations, which operate within the inner loop, are summarised in Figs. 12 and 13, respectively.

The routines to communicate with the system hardware have embedded assembler code to provide the low-level interface to absolute addresses on the SCC motherboard. The charge is controlled by two analogue voltage outputs, whereas the load banks and breakers are driven by digital outputs.

2.5. Functionality

The software operates at its quickest in the text screen display mode; during an automatic discharge, the screen is updated at 200 ms intervals. However, for better visual ergonomics, there is a graphic mimic screen display option. In mimic mode, the set and actual run-time parameters are displayed at the top of the screen.

On discharge, the information displayed on screen and logged to disc includes: set and measured current, set and measured power, minimum set battery voltage, measured battery voltage, measured Ah, measured kWh, step number, step time, requested mode, profile step, profile number, run time, and number of data samples logged. The discharge can be terminated on measured overall battery voltage, kWh or Ah. Options are built in so that, if required, individual cell voltages, temperatures, and another measurable parameter (e.g., gas evolution rate), can be monitored and logged and the discharge terminated. The desired control parameters are entered by keyboard and saved to disc. All measurable parameters are also independently monitored by a 16-bit data logging system with fully isolated inputs. This system has the capability to terminate charge or discharge on any measured parameter.

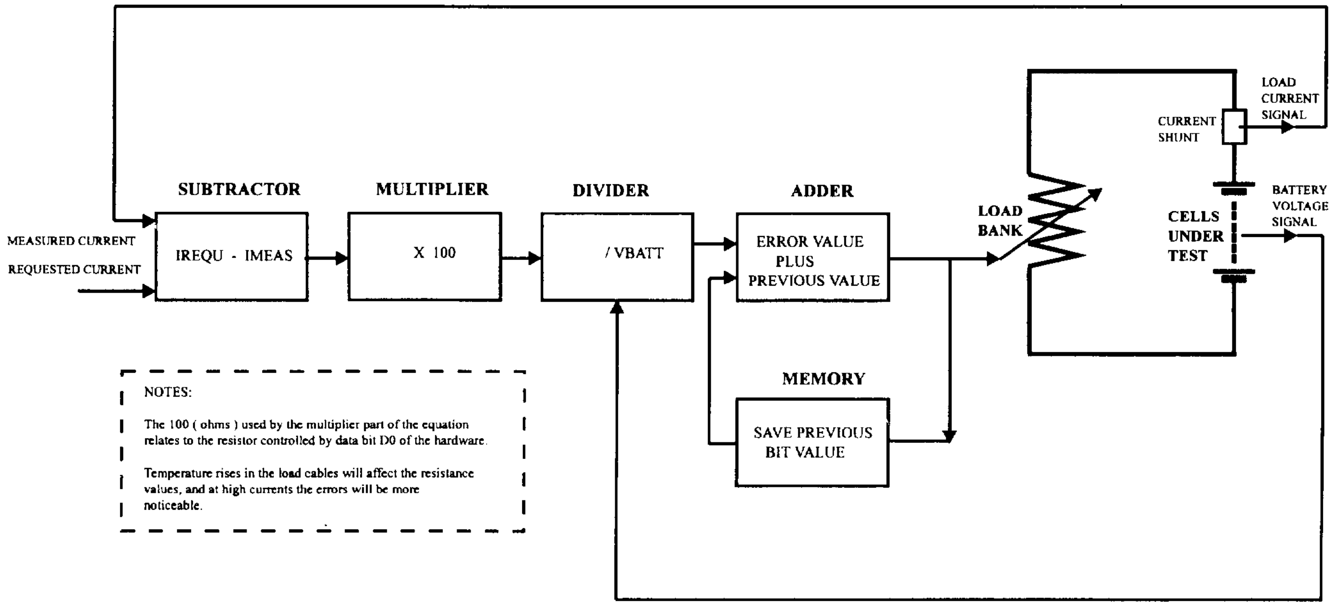

Fig. 12. Diagram showing the discharge current data drive control equation for the automatic battery test facility software; bit drive = previous bit drive + current difference × 100/V batt.

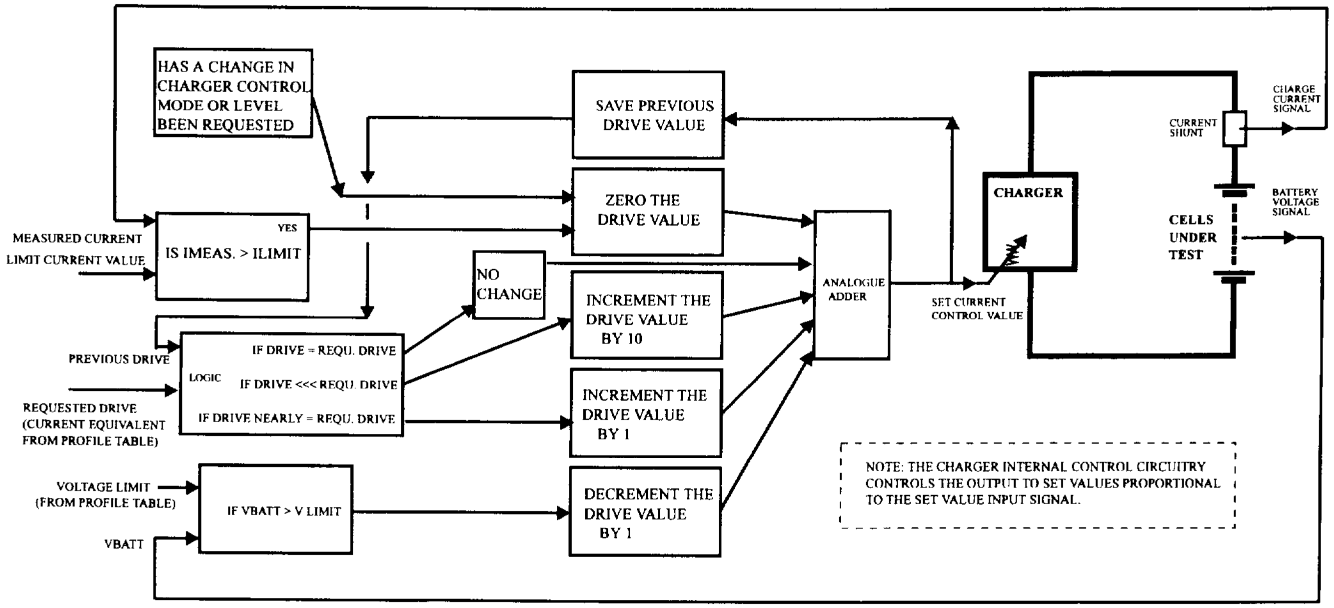

Fig. 13. Diagram showing the charge current data drive control equation for the automatic battery test facility software; drive = previous drive + logically chosen increment or decrements value.

On charge, the displayed and logged information is similar to the discharge function, except that a maximum battery voltage is set, and there is no constant power option. Under manual control, voltage, charge current and discharge current can be read from LCDs on the MCC front panel. However, the system software can also be used to display more comprehensive data on the SCC monitor.

Alarm state data displayed includes: error in supplies, incorrect breaker state, water load over-temperature, amount of random access memory (RAM) used exceeds 50%, and load bank approaching maximum capability. Other data displayed relate to the 'watchdog' timer, the water load on/off state, and keypress information for changing functions.

All measured data are logged to hard disc and Bernoulli drive at user-settable intervals. The data are stored in a comma separated variable (CSV) format, so that further processing using off-the-shelf software is conveniently achieved.

3. Facility operation

3.1. High-power battery testing

Fig. 14 shows an 8-cell battery of submarine propulsion cells connected to the test facility. The cells are contained in a thermostatically controlled water tank of which there are three. A typical discharge at a constant current of 6080 A, followed by a three-stage charge is summarised in Fig. 15. The graph shows the monitored current, and the resultant battery voltage, for a 10-cell battery of submarine propulsion cells. Charging is carried out at three levels of constant current: 1900, 950 and 325 A, respectively. A voltage limit of 2.4 V/cell is set at the first two charge rates in order that cell gassing is minimised [2].

Fig. 16 shows the voltage response of a 10-cell battery discharged at four levels of constant power; 45.3, 53.6, 68.7 and 53.4 kW, respectively. The control precision of the 16-bit discharge system is excellent, and should be compared with the output of the thyristor-controlled analogue charge depicted in Fig. 15.

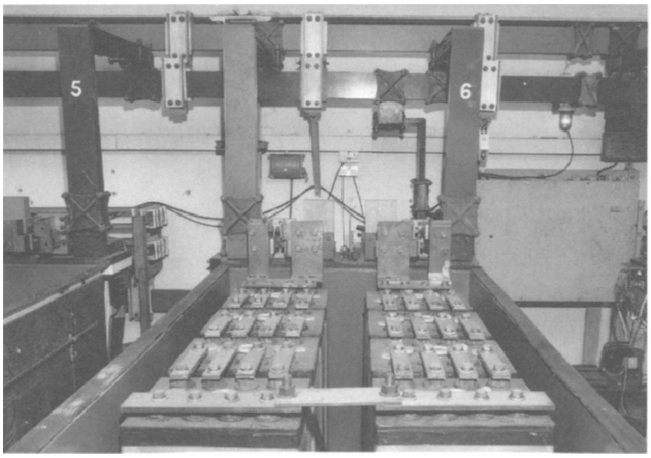

Fig. 14. Photograph showing an 8-cell battery of submarine propulsion cells installed in the circuit of the automatic battery test facility.

In all cases, the cell electrolyte temperature, individual cell voltages, and gas evolution rate and composition can be monitored and recorded at all stages of charge and discharge. These parameters can be used as inputs to control the test profile.

3.2. Testing of d.c. power sources

Fig. 17 illustrates the results of using the 16-bit discharge system as a load simulator for a transformer-rectifier unit (TRU) used for helicopter engine starting. The graph shows the measured TRU output current from two sets of double pulses separated by a 30 s delay. Each pulse is triangular in shape, and the current decays from 1500 to 200 A over 15 s. The resultant output voltage response of the nominal 28 V TRU is also shown. The pulse shaping is achieved by using the 45 software-programmable steps. Higher pulse shape resolution is readily achieved by increasing the number of these steps.

The above results indicate that the automatic battery test facility can be used for the precision testing, using complex operational profiles, of all types of d.c. power sources at up to 16 kA and approximately 30 V. By uprating the power MOSFETs and ancillary connections, the power rating of the facility can be increased when submarine propulsion power sources of improved performance are developed.

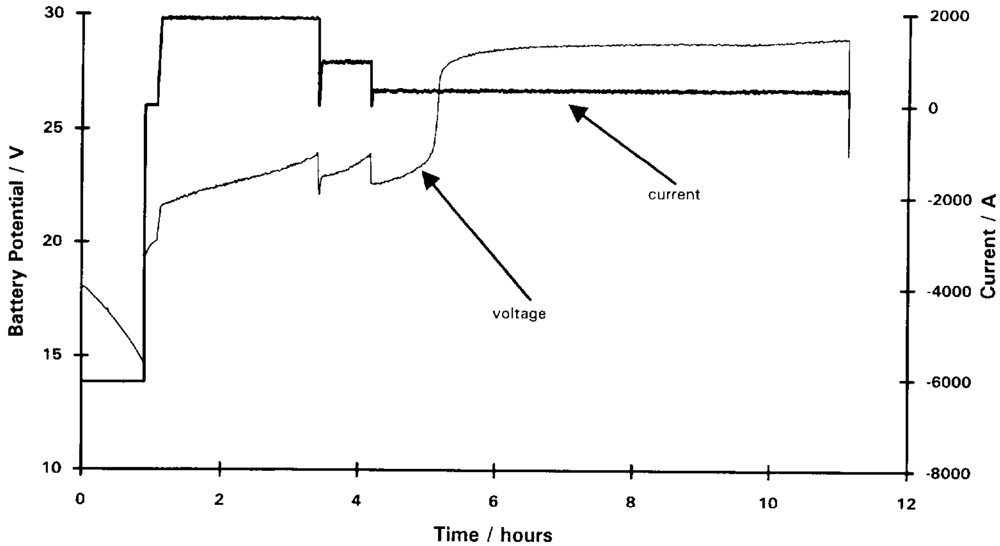

Fig. 15. Graph showing current and battery potential against time for a 10-cell battery of lead/acid submarine propulsion cells discharged at a constant current of 6080 A and then constant current charged at 1900, 950 and 325 A, respectively.

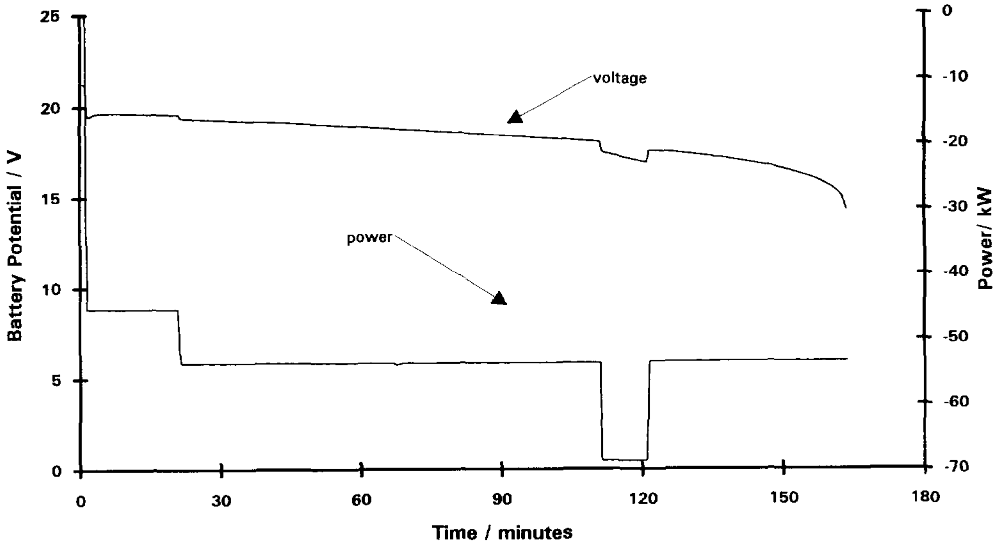

Fig. 16. Graph showing discharge power and potential against time for a 10-cell battery of lead/acid submarine propulsion cells.

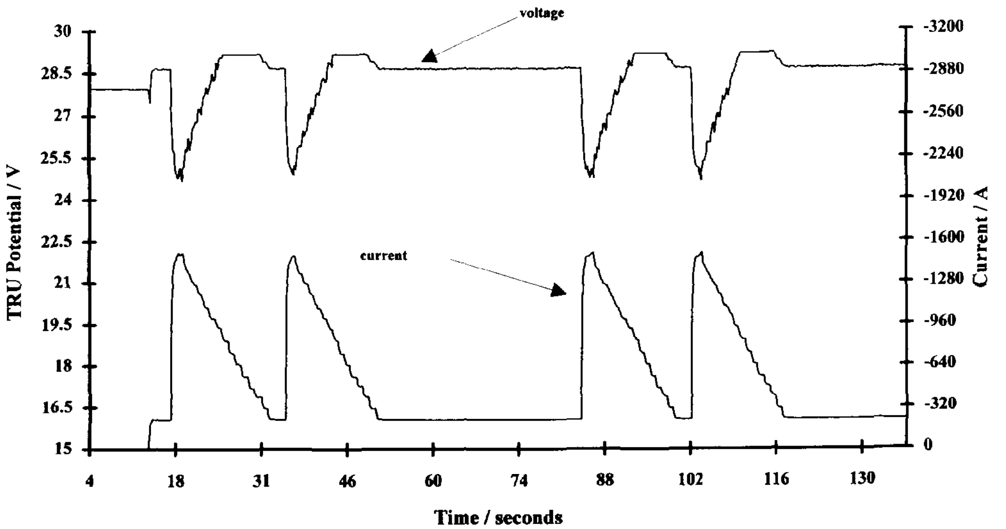

Fig. 17. Graph showing measured current and transformer-rectifier unit (TRU) potential against time with the 16-bit discharge system acting as a load simulator for a helicopter engine starter.

4. Summary

A high-power automatic battery test facility is described, which provides features hitherto only available on small capacity systems. This facility was developed, using existing hardware where possible, so that submarine propulsion batteries could be tested to realistic and complex operational profiles, with a high degree of precision and control. A high degree of flexibility was built-in, in order that a wide range of cell sizes and types could be assessed. Other types of d.c. power sources, including fuel cells and transformer-rectifier units, can also be investigated.

The system provides the ability to achieve constant current and constant voltage charging, constant current, constant power and constant resistance discharging, each with shaped programmable profiles and automatic cycling. The data are output in a DOS file format for further possible processing using commercially available software.

Experimental data are reported which demonstrate the precision and versatility of the system.

References

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