

A COMPUTER-CONTROLLED DISCHARGE UNIT FOR THE TESTING OF NICKEL-CADMIUM CELLS AND BATTERIES

W. G. MARSHALL, R. LEEK and M. J. PILKINGTON

Department of Electrical and Electronic Engineering, University of Technology, Loughborough, Leicestershire LE11 3TU (U.K.)

N. A. HAMPSON

Department of Chemistry, University of Technology, Loughborough, Leicestershire LE11 3TU (U.K.)

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Summary

The study of Ni-Cd cells and batteries has led to the requirement for an automated method of removing fixed amounts of charge and logging voltages accurately. There are numerous possible sources of error in the manual approach, particularly when experiments are conducted on a continuous basis over several days. In this paper the design of a microcomputer-controlled unit which can discharge up to eight cells or batteries, apply load pulses, and log voltages is described. All possible discharge parameters are under the control of the program and no operator intervention is necessary. Each channel is independent, but they may be paralleled for constant-current discharge at up to 40 A.

Introduction

During work on a residual charge test unit for nickel-cadmium cells and batteries [1], it became obvious that we needed to automate the process of removing known amounts of charge from the devices. We had been discharging manually through a resistor for a measured time. Not only was this tedious, but it was inaccurate when small voltages were measured at precise intervals. We also needed to run tests overnight to discharge cells completely from full charge. Measured parameters depend heavily on charge "history", and in order to study this effect we wished to discharge several cells or batteries simultaneously.

Hardware development

A microcomputer can provide all the necessary automatic control functions. A complete discharge instrument could be built in a single case,

including a computer designed from scratch, but we rejected this for the following reasons:

(1) A relatively large amount of heat is produced in the equipment and we thought that it was desirable to keep as much of the digital circuitry as possible out of this environment.

(2) The extra development time was unnecessary when commercial microcomputers are available.

In this type of application the choice of computer is determined by the need for continuous operation and ease of interfacing. To meet these two requirements we chose to use a Kemitron 3000 with program and data storage on two 1 Mbyte "floppy" disks. Use of a microcomputer makes the control of several cells easy, and allows different discharge rates and intervals to be applied independently and at the same time. One cell or battery was deemed to be connected to one system "channel".

The specification is as follows:

(1) Each channel applies a constant-current load, programmable in the range 0 - 5 A in 20 mA steps. It is also possible to connect channels in parallel to extend this current range (up to 40 A with eight channels).

(2) Terminal voltage is "read" into the computer in the range 1 V for a discharged single cell to 30 V for a fully charged 24 V battery.

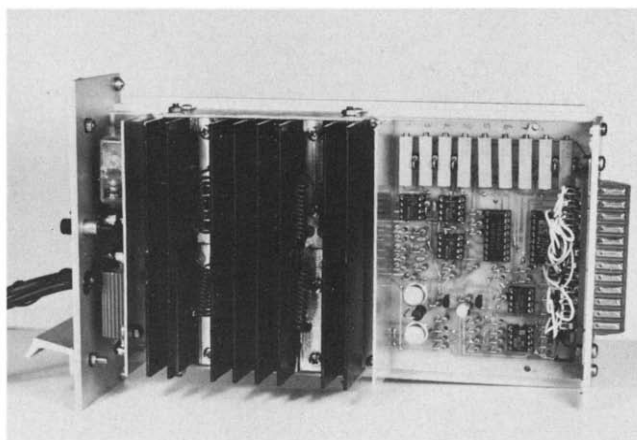
(3) A real-time clock chip provides accurate timing for all discharges.

(4) Temperature sensing for each channel is available. Owing to thermal and space limitations we decided to use only eight channels. The heavy current components for each channel reside on 2 inch wide modules (Figs. 1(a) and (b)), leaving space for a single interface board to one side of the rack and forced air cooling. The major part of the discharge equipment is contained in a 6U (19 in. wide) rack unit and joined to the controlling computer/interface board by a 26-way ribbon cable, as shown in Fig. 2. Interface boards both in the computer and in the discharge unit allow all signals in the interconnecting ribbon cable to be digital, thus reducing the possibility of errors with analogue signals in long lengths of wire.

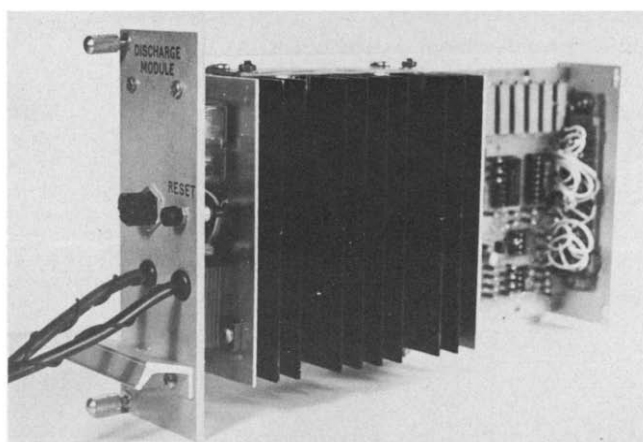
In our experiments the computer interface board did some of the address decoding, and contained the real-time clock chip. The rest of the address decoding, to produce individual channel select signals, was carried out on the discharge unit interface board in order to reduce the number of lines in the ribbon cable.

The discharge unit interface board also contains a single analogue-digital convertor chip (ADC) and handled the voltage input from all eight channels with an 8-way analogue multiplexer. This is an 8-bit device, digitizing the 0 - 10 V signals from each module with a resolution of 20 mV (1 bit). The battery voltages can go up to 30 V, so some sort of voltage "conditioning" was required. This conditioning was performed by circuitry on each discharge module.

Each channel requires one discharge module, a block diagram of which is given in Fig. 3. The various ranges of input voltages were converted to a single range, 0 - 10 V, using an amplifier having a gain which was set by the



(a)



(b)

Fig. 1. (a) A 5 A discharge module; (b) a discharge module showing the front panel.

computer program software according to the sensed input. To get the desired resolution, it was assumed that for a single Ni-Cd cell the only portion of the voltage range of interest lies between 1.0 and 1.5 V. Below 1 V the cell was considered to be fully discharged. The conditioner then gave a 0 V output for an input of 1.0 V and 10 V for a 1.5 V input, hence the 2 mV resolution of the 8-bit ADC. This principle was extended to the 12 and 24 V battery ranges which were 10 - 15 V and 20 - 30 V respectively. Program software restores the figures to their "real" values before screen display.

The discharge circuit translates an 8-bit data signal into one of 256 possible voltages via a digital-analogue converter (DAC). This control voltage drives the constant-current load circuit connected to the cell. Com-

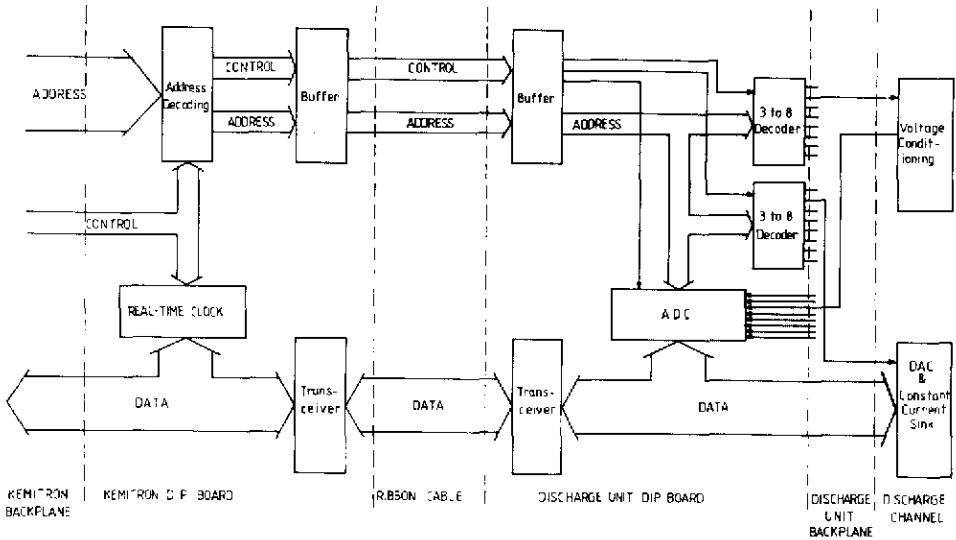


Fig. 2. Block diagram of an eight-channel discharge system.

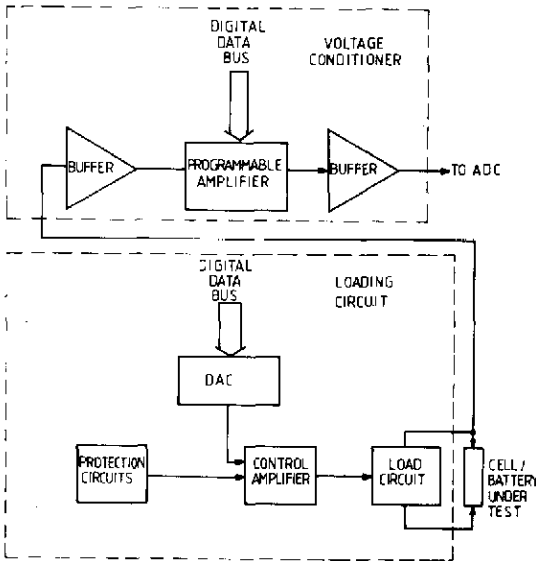


Fig. 3. The main parts of a discharge module.

ponents are included to protect both cell and circuit against reverse connection, overvoltage and overheating. Any of these conditions operates a relay trip which can only be reset manually (Figs. 1 (a) and (b)). Automatic reset was thought to be unnecessary as the results from a test run during which the circuit tripped would be useless.

Software development

The program has been written in FORTH, a high level language which operates at a relatively high speed. The speed is necessary for the program to monitor all eight channels simultaneously. The source code is contained in the computer main memory all the time, along with a simple editor, allowing rapid changes and recompilation.

A major problem was timing the various intervals without using a timing "interrupt" system. The latter allows easy timing but was avoided because it would make the program specific to this computer. To overcome this, each channel was provided with a set of starting data in a Parameter Array which may be examined or modified before a run commences. This array contains the "target time", which is the interval between the start of the run and the next event on that channel — read voltage, load on/off, etc. The real-time clock chip was set to zero at the start of a run and then started. During a run, the program constantly compares, in turn, each channel's target time against the clock. When there is a match, the required operation is carried out and the next interval — usually extracted from the parameter array — is added to the target time. To avoid unnecessary time tests, channels with nothing connected may be disabled. FORTH is ideal for this type of situation, with a single word definition (TGT+) to add to target time and another (TGTM) to test for a target being reached.

The basic pattern of readings and loads is determined by the definition of another single word, EXEC. This is modified in the source code followed by recompilation, but the parameters governing currents, discharge rates, etc. may be set from a menu while the program is operating. On first running the program, the operator may examine all of the channel parameters, a typical display being illustrated in Fig. 4. The cell(s) can be discharged in steps, with variable length "rest" periods, taking voltage readings under heavy load pulse conditions at varying, even random, intervals. These readings are stored in the computer memory as single bytes, and also printed out as voltages onto paper and/or the visual display screen. Results were not stored directly on disk, but the whole data array can be stored at the end of a run. This is done for security in case of power failure or some other di-

Parameter Menu for Channel 1

1. Starting Charge	100 (%)
2. Cell/Battery Potential	1250 (mV)
3. Nominal Capacity	4000 (mAh)
4. Test Current	4000 (mA)
5. Test Pulse Length	4 (sec)
6. Initial Discharge Rate	400 (mA)
7. 1st. Test Interval	60 (mins)
8. 2nd. Test Interval	0 (hrs)
9. Discharge this Run	5 (%)

Fig. 4. Typical parameter menu display for channel 1.

saster. The printed data may be re-entered manually, usually into a graph plotting and analysis program. When a machine is left running for days, or even weeks, this method provides further confidence in the system.

Conclusion

The repetitive and continuous accurate measurement of electrical storage cells is a demanding task. The application of modern microcomputer control to carry out this task appears to be the ideal solution to the problem of time scheduling of a job requiring accurate parameter measurements to form a reliable data base. The data generated by the system are adequate for the establishment of a residual charge testing procedure.

The advantages of the system described here are reliability, accuracy, speed and economy of operation, together with a minimization of operator involvement (and fatigue). Figure 5 shows some typical discharge characteristics obtained automatically using this equipment.

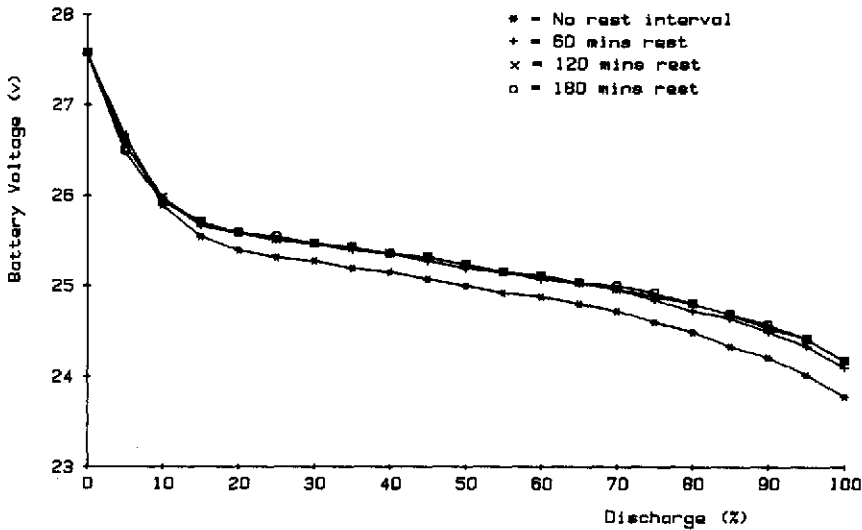


Fig. 5. 24 V discharge characteristics with pulse tests and rest intervals.

For the low-impedence Ni-Cd (alkaline) systems the control of cell cycling and testing regimes is vital because of the small parametric changes with the state of the charge. Results of an investigation into the latter will be published in the near future.

Reference

- 1 W. G. Marshall, R. Leek, N. A. Hampson and G. R. Lovelock, *J. Power Sources*, 13 (1984) 75 - 81.

Appendix

Program listing

Screen No:0

```

0
1      DISCHARGE UNIT MK.1 PROGRAM LISTINGS Vsn.1
2
3
4          W.G.Marshall 1985
5
6
7
8
9
10     This program is designed to run under 'LUT-FORTH Vsn.3.0'
11     Modification will be necessary in order to use other
12     types of FORTH. To run, type: BAT <return>
13
14     N.B. All numbers within the program are in HEX.
15

```

Screen No:1

```

0 ( DISCHARGE TEST PROGRAM T3 )
1 : ARRAYW CREATE DUP , * 2* ALLOT DOES>      ( ALLOWS 2-DIM WORD)
2 ROT OVER @ * ROT + 2* + 2 + ;              ( ARRAYS TO BE CREATED)
3 : ARRAYB CREATE DUP , * ALLOT DOES>        ( ALLOWS 2-DIM BYTE)
4 ROT OVER @ * ROT + + 2 + ;                ( ARRAYS TO BE CREATED)
5
6 : IPID 0F A2 OUTPUT 0F A3 OUTPUT ;          ( INITIALISE CLOCK PIO)
7 : OCLOCK 0F A3 OUTPUT A1 OUTPUT            ( OUTPUT TOS TO CLOCK)
8 03 A0 OUTPUT 02 A0 OUTPUT 03 A0 OUTPUT ;   ( CHIP ROUTINE)
9 : INCLOCK CF A3 OUTPUT F0 A3 OUTPUT A1 OUTPUT ( INPUT FROM)
10 01 A0 OUTPUT A1 INPUT 10 / 03 A0 OUTPUT ;   ( CLOCK ROUTINE)
11 : ICLOCK DUP INCLOCK DUP F =              ( CLOCK I/P, NO ERRORS)
12     IF DROP INCLOCK ELSE SWAP DROP THEN ;
13 : CLKON 1E OCLOCK 00 OCLOCK ;             ( SWITCH CLOCK ON)
14
15 -->

```

Screen No:2

```

0 ( SOME MORE INITIAL DEFINITIONS )
1 : TIME D 1 DO      ( DUMPS 1 SWEEP OF CLOCK REGS 1-12 WITH)
2     I ICLOCK      ( TOS=TENS OF MONTHS)
3     30 +          ( ADD ASCII OFFSET)
4     LOOP ;
5
6
7 : DISPTM TIME ." Date:" ROT DROP ROT EMIT ROT ( DISPLAY TIME)
8 EMIT 2F EMIT EMIT EMIT 5 SPACES ." Time:" EMIT EMIT ( AND DATE)
9 3A EMIT EMIT EMIT 2DROP DROP ;
10
11 : SELGAIN B0 + OUTPUT ; ( SET GAIN, TOS=CHANNEL, TOS-1=GAIN)
12
13 : DAC AB + OUTPUT ; ( SET CURRENT, TOS=CHANNEL, TOS-1=CURRENT)
14
15 : VOILT B8 + INPUT ; ( READ ADC, TOS=CHANNEL/TOS=VOLT (0-255) -->

```

OK

Screen No:3

```

0 ( FURTHER BASIC DEFINITIONS )
1 : INITCLK BEGIN 00 OCLOCK 0E OCLOCK      ( CLEAR CLOCK REGS)
2   D 1 DO I OCLOCK LOOP
3   I ICLOCK 4000 0 DO LOOP              ( WAIT A WHILE)
4   I ICLOCK = NOT
5     WHILE CR ." Clock Fault" CR KEY DROP
6     REPEAT ;
7
8 : GETNO 0 BEGIN                          ( RETURNS NO FROM TERMINAL, EXIT)
9   KEY DUP 2F > OVER 3A < AND           ( ON ANY NON-DIGIT)
10  WHILE
11    30 - SWAP A * +
12    REPEAT
13    DROP ;
14
15 -->

```

Screen No:4

```

0 ( FURTHER BASIC DEFINITIONS )
1 : GETDG BEGIN                            ( RETURNS SINGLE DIGIT FROM TERMINAL)
2   KEY DUP 30 < OVER 39 > OR           ( REJECTS ALL ELSE)
3   WHILE DROP
4   REPEAT 30 - ;
5
6 : AUTOV B 0 DO 1 I SELGAIN               ( MEASURE ADC VOLTAGE)
7   I VOLT FD >                          ( AND SET GAIN)
8   IF 2 I SELGAIN
9   I VOLT FD >
10  IF 4 I SELGAIN
11  THEN
12  THEN
13  LOOP ;
14
15 -->

```

Screen No:5

```

0 ( PARAMETER & DATA ARRAY INITIALISATION )
1 12 B ARRAYW PD                          ( SET UP PARAMETER ARRAY 18 X 8 )
2 1A4 B ARRAYB VD                         ( SET UP DATA ARRAY 420 X 8 )
3
4 VARIABLE VI                              ( USED FOR LOOP COUNTER STORAGE)
5
6
7 : SYSCLR 0 0 0 VD D20 FILL 0 9 0 PD 90 FILL ; ( CLEAR ARRAYS)
8 ( ARRAY ACCESS WORDS)                   : INITCH 0 VI @ PD ;
9 : POTENTIAL 1 VI @ PD ;                 : CRATE 2 VI @ PD ;
10 : TESTCU 3 VI @ PD ; : TESTD 4 VI @ PD ; : DISCU 5 VI @ PD ;
11 : TSTFREQ 6 VI @ PD ;                 : RESTIN 7 VI @ PD ;
12 : %DISC 8 VI @ PD ; : IDAYS 9 VI @ PD ; : THRS A VI @ PD ;
13 : TMIN 8 VI @ PD ;                   : DFLAG C VI @ PD ;
14 : AFLAG D VI @ PD ; : TCOUNT E VI @ PD ; : DCOUNT F VI @ PD ;
15 : DATAP 10 VI @ PD ; : PFLG 11 VI @ PD ;      -->

```


Screen No:6

```

0 ( PARAMETER MENU )
1 : MENU 1A EMIT
2 1A SPACES ." Parameter Menu for Channel " VI ? CR
3 1A SPACES ." -----" CR CR
4 ." 1. Starting Charge " INITCH @ 5 .R ." (%) " CR
5 ." 2. Cell/Battery Potential " POTENTIAL @ 5 .R ." (mV)" CR
6 ." 3. Nominal Capacity " CRATE @ 5 .R ." (mAh)" CR
7 ." 4. Test Current " TESTCU @ 5 .R ." (mA)" CR
8 ." 5. Test Pulse Length " TESTD @ 5 .R ." (sec)" CR
9 ." 6. Initial Discharge Rate " DISCU @ 5 .R ." (mA)" CR
10 ." 7. 1st. Test Interval " TSTFREQ @ 5 .R ." (mins)" CR
11 ." 8. 2nd. Test Interval " RESTIN @ 5 .R ." (hrs)" CR
12 ." 9. Discharge this Run " ZDISC @ 5 .R ." (%)" CR
13 1A SPACES ." -----" CR CR ;
14
15 -->

```

Screen No:7

```

0
1 : MENUT 8 0 DO I VI !
2 BEGIN MENU
3 CR 19 SPACES ." Anything to be Changed (Y/N)?" KEY 59 =
4 WHILE CR 21 SPACES ." Parameter No.?" GETDG
5 CR 23 SPACES ." New Data:" GETNO
6 SWAP 1- I PD !
7 REPEAT
8 LOOP ;
9
10 : DISCALC ( CALCULATE DISCHARGE INTERVAL)
11 CRATE @ ZDISC @ 64 */
12 3C DISCU @ */
13 3C /MOD SWAP ; ( TOS=MINS, TOS-1=HOURS)
14
15 -->

```

Screen No:8

```

0 ( CON DISPLAYS VOLTAGE AS "FLOATING-POINT")
1 ( TOS=CHANNEL NO., TOS-1=DATA)
2 : CON DUP 1 SWAP PD @ 05DE < ( SINGLE CELL?)
3 IF DROP 1F4 100 */ A /MOD A /MOD 1
4 ELSE DUP 1 SWAP PD @ 2EE2 < ( 12V BATTERY?)
5 IF DROP 0 SWAP 1F4 100 */ A /MOD A /MOD 31 EMIT
6 ELSE DROP 0 SWAP ( THEN 24V BATTERY)
7 3EB 100 */ A /MOD A /MOD 32 EMIT
8 THEN
9 THEN
10 30 + EMIT 2E EMIT 30 + EMIT 30 + EMIT 30 + EMIT ;
11
12
13 : TESTINT ( CALCULATE NO. OF TESTS/REST PERIOD)
14 RESTIN @ 3C * TSTFREQ @ / TCOUNT ' ;
15 -->

```

OK

Screen No:9

```

0 ( CHANNEL ACTIVITY STATE DEFINITIONS )
1
2 : CHAN 1A EMIT CR CR CR 21 SPACES ." Channel Status" CR
3   21 SPACES ." -----" CR CR
4   B @ DO
5     22 SPACES ." Channel " I . D I PD @      ( CHANNEL ACTIVE)
6     IF ." ON" ELSE ." OFF" THEN CR
7     LOOP CR ;
8
9
10 : SETCHAN BEGIN CHAN 20 SPACES ." Any Change (Y/N)?"
11       KEY 59 =
12       WHILE CR 22 SPACES D ." Channel No.:" GETD6 CR
13         PD DUP @ NOT SWAP !
14       REPEAT ;
15 -->

```

Screen No:10

```

0 ( TARGET TIME DEFINITIONS )
1 : TGT+ TMIN$ +! THRS +! TDAYS +!      ( ADD TOP 3 STACK ITEMS)
2   TMIN$ @ 3B >                          ( MINS > 59?)
3   IF TMIN$ @ 3C - TMIN$ ! 1 THRS +!
4   THEN
5     THRS @ 17 >                          ( HOURS > 23?)
6     IF THRS @ 18 - THRS ! 1 TDAYS +!
7     THEN ;
8
9 : TGT@ 4 ICLOCK 5 ICLOCK A * + TMIN$ @ = ( MINS MATCH ?)
10  IF 6 ICLOCK 7 ICLOCK A * + THRS @ =   ( THEN HOURS MATCH ?)
11  IF 8 ICLOCK 9 ICLOCK A * + TDAYS @ =   ( THEN DAYS MATCH ?)
12  IF NOT                                  ( THEN TARGET TIME REACHED)
13  THEN
14  THEN
15  THEN ;                                -->

```

Screen No:11

```

0 ( SINGLE PULSE TEST DEFINITION )
1 : TEST
2   1 ICLOCK
3
4   TESTCU @ 33 3EB */ VI @ DAC           ( TURN ON DAC)
5   TESTD @ 1- 0 DO
6     1000 0 DO LOOP                       ( DELAY)
7     BEGIN DUP 1 ICLOCK =                 ( WAIT 1 SEC)
8     UNTIL
9     LOOP DROP
10    VI @ VOLT
11    32 1 DO VI @ VOLT + LOOP 32 /        ( AVERAGE READINGS)
12    0 VI @ DAC DATAP @ VI @ VD C!      ( SAVE DATA, TURN OFF DAC)
13    1 DATAP +! ;                          ( INCREMENT DATA POINTER)
14
15 -->

```

OK

Screen No:12

```

0 ( VOLTAGE PRINTOUT )
1 : PRINT CR 10 SPACES DISPTM CR ( PRINT TIME)
2 B 0 DO 11 I PD @ D I PD @ AND
3 IF 10 I PD @ 1- I VD C@ I CON 2 SPACES ( PRINT VOLTAGE)
4 ELSE D I PD @ ( ACTIVE BUT NO OUTPUT?)
5 IF ." ----- "
6 ELSE 7 SPACES ( NOT ACTIVE)
7 THEN
8 THEN
9 LOOP CR ;
10
11
12
13
14
15 -->

```

Screen No:13

```

0 ( MAIN MENU & CHARGE VALUE PRINT DEFINITIONS )
1 : CMENU 1A EMIT CR 1C SPACES
2 ." Discharge Unit Program 1." CR
3 24 SPACES ." WGM 1984" CR CR
4 1A SPACES ." Press 1 to Set up Parameters" CR CR
5 1A SPACES ." 2 to Commence Test" CR CR
6 1A SPACES ." 3 to EXIT Program" CR CR ;
7
8
9
10 : PRINTC 0 8 0 DO 11 I PD @ + LOOP ( ANYTHING TO OUTPUT?)
11 IF CR 8 0 DO D I PD @ 11 I PD @ AND ( ACTIVE & READY?)
12 IF 0 I PD @ SPACE . 25 EMIT 2 SPACES ( PRINT CHARGE)
13 ELSE 7 SPACES ( OR BLANKS IF INACTIVE)
14 THEN LOOP
15 PRINT 8 0 DO 0 11 I PD ! LOOP THEN ; ( CLEAR FLAGS) -->

```

Screen No:14

```

0 ( MAIN EXECUTION LOOP )
1 : EXEC BEGIN
2 B 0 DO I VI ! AFLAG @
3 IF TGTM
4 IF TEST -1 PFLG ! DFLAG @ 0=
5 IF 1 DFLAG ! 0 0 TSTFREQ @ TGT+
6 . INITCH @ %DISC @ - INITCH !
7 ELSE -1 TCOUNT +! TCOUNT @ 0=
8 IF 0 DFLAG !
9 DISCU @ 33 3EB */ I DAC
10 TESTINT 0 DISCALC TGT+
11 ELSE 0 0 TSTFREQ @ TGT+
12 THEN THEN
13 THEN I VOLT 2 < IF 0 I DAC 0 AFLAG !
14 THEN THEN LOOP
15 PRINTC ?TERMINAL UNTIL ; -->

```

OK

Screen No:15

```

0 ( START DISCHARGE OPERATION ROUTINE )
1
2 : STARTEX INITCLK SETCHAN
3   B 0 DO I VI ! AFLAG 0
4   IF 0 TDAYS ! 0 THRS ! 0 TMIN5 ! 1 DFLAG ! 1 TCOUNT !
5
6   THEN
7   0 PFLG !
8 LOOP
9   1E OCLOCK CR CR 12 SPACES
10  ." Test Discharge Running ~ Press any key to Stop" CR CR
11 EXEC
12   B 0 DO 0 I DAC LOOP ;           ( TURN OFF ALL UNITS)
13
14
15 -->

```

Screen No:16

```

0 ( MAIN COMMAND LOOP )
1
2 : BAT SYSCLR IPID
3   BEGIN
4   AUTOV CMENU KEY 30 -
5   DUP 1 =           ( PARAMETER MENU)
6   IF MENUT
7   ELSE DUP 2 =     ( START OPERATION)
8   IF STARTEX
9   ELSE DUP 3 =     ( EXIT PROGRAM)
10  IF DROP 0
11  THEN
12  THEN
13  THEN
14  WHILE REPEAT ;
15

```

OK