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A NICKEL–CADMIUM CELL RESIDUAL CHARGE ANALYSER

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Summary

This paper describes a portable unit for measuring the charge remaining in nickel–cadmium secondary cells Exhaustive frequency response tests have confirmed that cell impedance varies very little with charge state, with the possible exception of that at very low frequencies (<50 mHz) In the interim before further work in this area is carried out, a microprocessor-based test unit has been built which uses a current pulse discharge method to arrive at a residual charge reading When the cell is discharged according to a particular regime, the unit produces results accurate to within 10 - 15% over the entire range of charge Further development involving the inclusion of cell history parameters promises to make the unit useful for military and other applications.

Introduction

There has long been a requirement in the military, commercial and domestic fields for an instrument capable of measuring reliably the state-of-charge of a battery Such a unit should be cheap, robust, and above all, believable Work on zinc–carbon, lithium and mercury primary cells has led to the development of a range of non-destructive charge testers [1]. These make use of a relationship between charge state and cell impedance at one or two selected spot frequencies A reasonable correlation for part of the charge range was found in each case, and it was hoped that similar techniques could be used with nickel–cadmium secondary cells Cell impedances were so low and variation with charge state so minor at 'reasonable' frequencies (>1 Hz), however, that the prototype test sets use a cell loading

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technique very similar to the familiar ‘loaded voltmeter’ test, rather than direct signal injection The results of a lengthy investigation into Ni–Cd cell characteristics will soon be published [2] The cell selected for initial investigation was the SAFT type VR1 2RR with a nominal 1 2 A h capacity

Cell frequency response tests

Initial tests on a cell were carried out using a microcomputer controlled Solartron 1250 Frequency Response Analyser coupled to an 1186 Electrochemical Interface The cell was held in equilibrium by a polarising voltage and an a c perturbation of 3 mV amplitude applied This level allowed a c. impedance measurements to be made without disturbing the cell chemistry A typical plot covering the frequency range 60 kHz - 5 mHz is shown in Fig. 1 Note that the capacitive reactance is shown above the real axis, with inductive reactance below We can see a near-vertical inductive reactance line between 60 kHz and 300 Hz leading into a steep Warburg line above the axis The calibration marks on the graph indicate how low an impedance was being measured, a problem which is worse with larger cells

Stray capacitance, inductance, and resistance in connecting leads, and within the interface itself, probably accounted for the bulk of the impedance above 1 kHz and, given the available equipment, looking for a variation with the charge state above 1 kHz seemed to be a fruitless exercise. Even so, tests

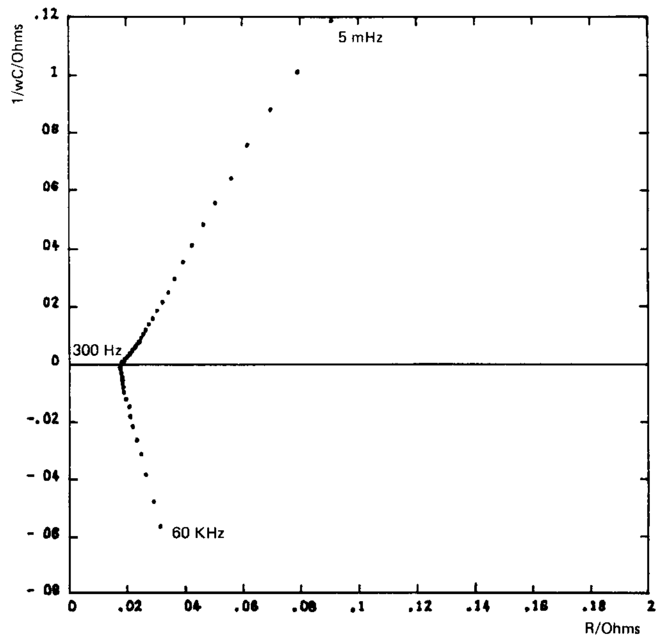

Fig 1 Impedance plot Ni–Cd, VR1 2RR, 75% discharged

were carried out on cells discharged to various levels from fully charged to fully discharged, as indicated by the load voltage falling to 1 V. The data was then processed to remove estimated stray inductance effects, and the resistance at 300 Hz subtracted from all values to bring the graph origin to the base of the Warburg line

Results for various charge levels are shown superimposed in Fig 2 A possible relaxation of the Warburg line at the low frequency end is discernable. The problem is that the change in resistance was so small that variations due to manufacturing tolerances, temperature, etc , render these results useless as far as a practical state-of-charge tester is concerned

These results were confirmed by similar tests carried out on 23 A h aircraft cells of even lower impedance [2]

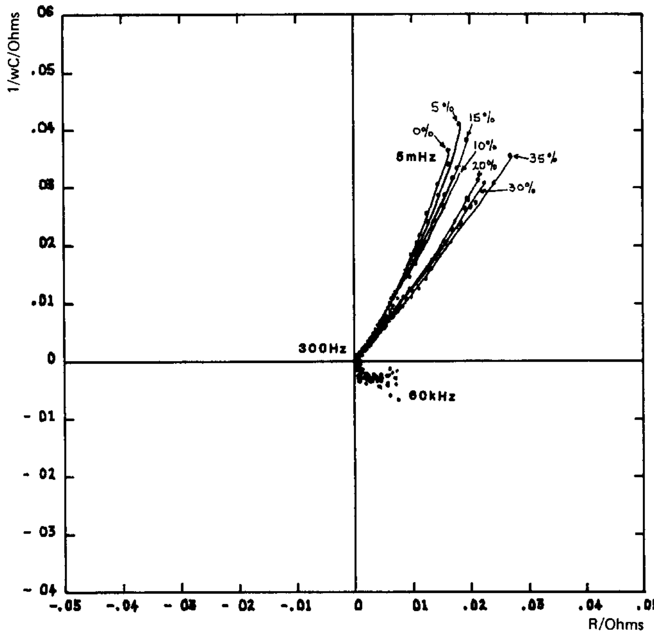

Fig 2 Impedance plots Ni–Cd VR1 2RR, 0 - 35% discharged after processing

A current step test

An analysis of the cell impedance data suggests that charge state is related to ‘zero frequency resistance’, with the result that a practical test cannot be based on simple a.c signal injection Using standard techniques, the test unit would take a time approaching infinity to arrive at a value as the test frequency approached zero Work at Loughborough is continuing on pulse techniques using Fast Fourier analysis methods to extract charge data more quickly, but a simple solution has also been developed which yields useful results

The basis of the test is to load the cell at its '*C*' rate (1.2 A for the VR1 2RR) and note the terminal voltage after several seconds. This current pulse effectively applies a wide range of test frequencies simultaneously, including the important low ones The pulse duration allows the minor high frequency effects due to stray capacitance and inductance to be ignored, leaving a voltage level related to the charge state It is normally considered that on-load voltage is not a reliable indicator of residual capacity, but accurate voltage measurement, timing, and comparison with pre-programmed data have enabled a portable, microprocessor-based unit to produce 'believable' readings under certain cell discharge conditions The use of a microprocessor system allowed us to develop the test with increased sophistication in program software rather than hardware

The residual charge prototype unit

A block diagram of the prototype is given in Fig 3. The test unit is a purpose built, single-board microcomputer housed in a portable steel case This portability is essential in that development of test software will involve 'on-site' experience with cells in a real world environment. Programs are written in the high-level language FORTH, and compiled code produced on a disk based laboratory computer Transferred to non-volatile EPROM, the code then runs under the control of a resident interpreter contained in the prototype unit This dialect of FORTH has been especially written for this application, allowing changes to be made to the charge calculator algorithm with the minimum of effort Accurate timing of events is crucial, so a real-time, battery driven, clock chip is included in the hardware A cell's capacity is greatly influenced by discharge rates and patterns, and the equipment has the ability to take into account the cell operational conditions Battery backed-up memory in the unit is used to record discharge parameters so that repeated entry for a particular cell batch is not required The capability of handling varying conditions is vital if the results from the test unit are to be reliable The microprocessor-based system is ideal for this purpose

A 2 mV resolution on voltage measurement is achieved using an 8-bit analogue-digital converter working over a range of 1 - 1 5 V A voltage of less than 1 V means a dead cell and accurate measurement in this area is pointless

The prototype in use

The plot of Fig. 4 is a comparison between the nominal charge remaining in a cell deduced from the amount discharged, and the value obtained using the test unit In this case, fully charged cells were subjected

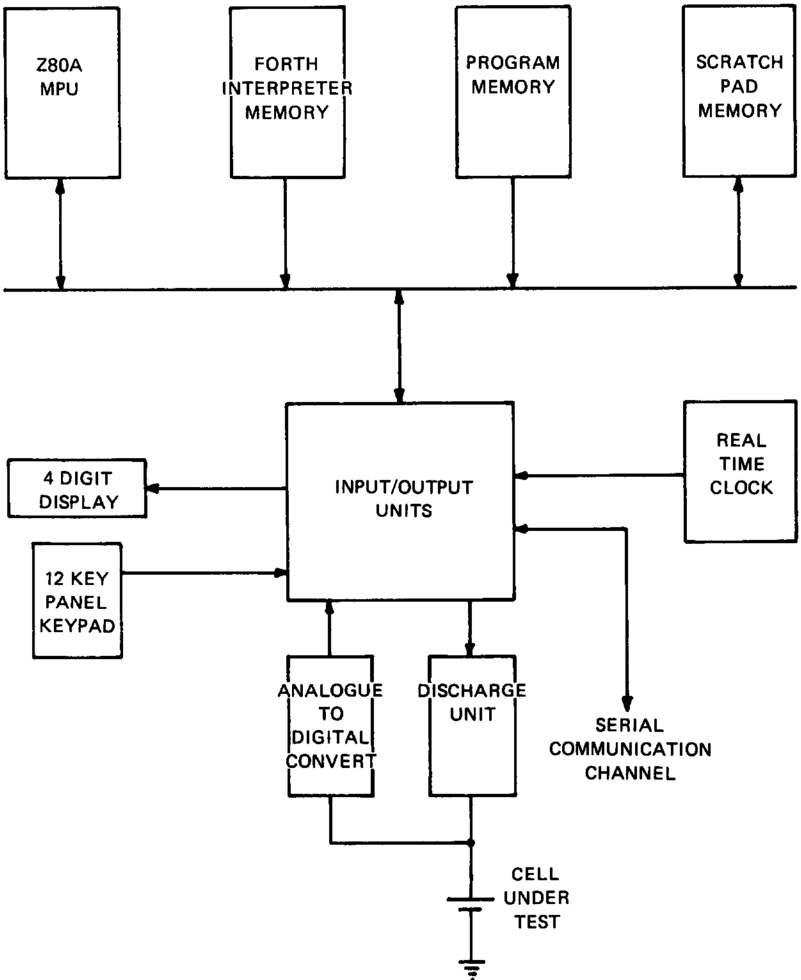

Fig 3 Block diagram of prototype Ni–Cd cell test unit

to a steady discharge of 240 mA for periods of 30 min with a 30 min 'rest' between each A reading of charge was taken immediately after the discharge period, and also after the half-hour of no load. It can be seen that there is good correlation over the entire charge range for readings taken immediately after a period of discharge, with a vertical shift in readings as the cell recovers off-load

It can be argued that such a discharge pattern is hardly typical of real-world conditions, and this is why information based on cell history must be included in the calculation. The simple algorithm used here does not take this factor into account. In the test example given, the correction for a no-load interval is incorporated fairly easily, but varying loads will also modify the algorithm. In the military environment, batteries of these cells are used

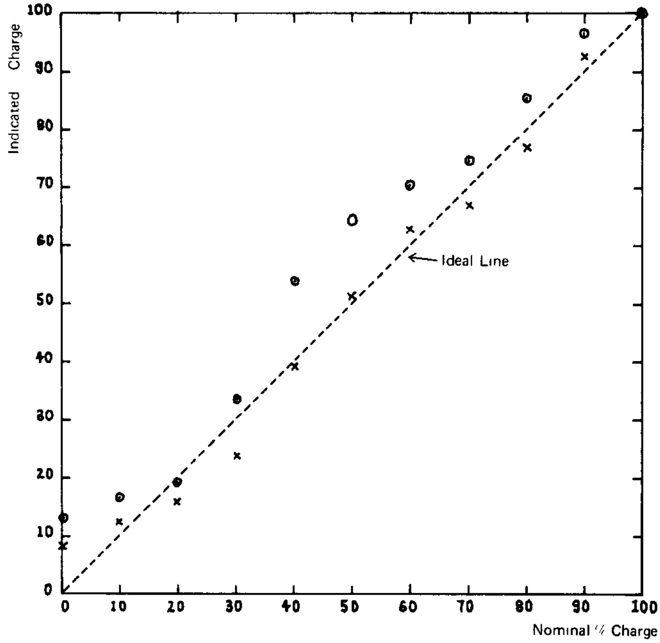

Fig 4 Prototype unit output Ni–Cd VR1 2RR, discharged at 240 mA ×, test result immediately after period of discharge, ○, test result after 30 min no load

in portable radio equipment, and are sent for recharging when their ability to complete a mission is doubted. In use, the battery sees fairly constant low discharge rates when the set is in receive mode, with bursts of heavy load on transmit. Developing a test based on these data will be very difficult, but a field instrument capable of giving reliable readings to within 10 - 15% should be possible.

It has been found that the test consumes less than 0 2% of the nominal capacity

Conclusion

The Ni–Cd secondary cell is very 'well-behaved', a feature which makes it ideal for many applications, but which causes some problems when it comes to finding a measurable parameter which varies with the charge state While efforts will continue to be made to devise a test which consumes zero charge, the interim solution described here takes a great deal of the guess-work out of checking cells The microprocessor technology used in these prototype testers will be used in only slightly modified form in the more sophisticated models

Acknowledgement

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