Copyright Notice

NICKEL CADMIUM BATTERIES - A SURVEY

By: A N Holdstock

For as long as there have been rechargeable batteries in use they have in many respects been a liability. It is difficult to arouse interest in battery maintenance and consequently these batteries normally get the minimum of attention necessary to keep them functioning. At times even this minimum is not maintained and the battery is then more trouble than it is worth. This state of affairs naturally has serious operational and economic consequences.

The nickel cadmium batteries which have been used for many years to provide power for Pack and Pocket sets are no exception. In fact because of their size, construction and variability of use, they are more liable to premature failure than larger and more robust types.

One of the main problems stems from the battery's most useful property, namely its extremely low internal resistance; this results in the "on load" potential difference being almost equal to the electromotive force which is therefore almost constant over the whole discharge cycle. The potential difference between a cell which is 30% charged and one which is 80% charged is approximately .05 volt, this voltage being substantially independent of load current.

The variation of the potential difference of a cell corresponding to a temperature change of 30°C is approximately .03 volt. Thus one could be left with .02 volt per cell as the indication of a 50% change in charge.

In addition there are other factors which affect voltage, such as the age and condition of the battery, and whether the battery had been removed from a charge or discharge cycle.

We conclude from these facts that relating "state of charge" to potential difference is unreliable and this fact is borne out in practice.

Work carried out by manufacturers, CCE, RWD Hannington, Bishops Cleeve and Weyhill all show conclusively that even if a high grade instrument is used for measurement, no reliance can be placed on a potential difference/state of charge relationship except at the point where the battery is almost discharged.

Throughout the normal charge discharge cycle of a Nickel Cadmium battery the electro-chemical reaction does not result in the release of any gaseous product. The battery can thus be hermetically sealed, this being the simplest and cheapest method of ensuring that there is no leakage of electrolyte. Once a battery has reached a fully charged state however, a continuation of the charging process results in the release of oxygen and hydrogen from the positive and negative electrodes respectively, ie electrolysis takes place.

It is extremely difficult to dispose of any hydrogen produced, but the oxygen can be recombined electro-chemically provided it can be routed from the positive plate where it is produced, to the negative one, and that the rate of release is small.

In order to ensure that hydrogen is not released as a result of overcharge, it is arranged that the negative electrode has a quantity of uncharged cadmium hydroxide left after the positive electrode has exhausted its ability to absorb further charge.

As the cells which make up a battery have slightly different capacities, completely discharging a battery will result in a reversed polarity of the cells with a lower capacity. This process results in the release of gases in reverse to the overcharge condition,and arrangements must once more be made to prevent the production of hydrogen by adding to the positive electrode a quantity of negative active material. Since these additional masses are electro-chemically ineffective they play no part in the normal charge/discharge processes, but as they are limited in quantity, so is the amount of overcharge and overdischarge which the battery can absorb without producing excess gas. Research carried out by Ever Ready has shown that an excess current equivalent to 0.2 of the 10 hour charge rate is sufficient to cause significant amounts of gas to be released. The rate at which the battery is charged is its ampere hour capacity divided by 10.

If gas released within the cell cannot be disposed of chemically it builds up a pressure which either leaks out through imperfect or damaged seals, and may well take with it some of the elctrolyte; or alternatively it may distend the casing making the battery too large for its housing. In either event the battery structure becomes damaged, the life of the battery is shortened and its capacity reduced.

Used in a pocketfone receiver producing no speech output, a battery under a normal 1 in 5 cycling condition will last well in excess of 20 hours, whereas if the receiver were producing a continuous tone output the battery life could be reduced to 3 hours. These are extreme cases, but if the conditions of use of a pocketfone in a small rural scheme, where very few messages are passed, is compared with that in a busy scheme with say 100 pocketfones where many messages are being passed, it will be appreciated that the length of time taken to discharge the batteries will be vastly different.

Consider also the difference between a Police Officer on duty for a full spell of 8 hours with one who spends part of his time in court or writing reports; it is evident that at the end of a "tour of duty" batteries will have different amounts of unspent charge.

The transmitter battery on the other hand is subjected to a completely different set of conditions. When a Nickel Cadmium battery is discharged at a rate in excess of its 10 hour rate its capacity is reduced. Thus a battery discharged at 13 x I/10, as in the case of the transmitter battery, may have a capacity of only 50% of the nominal. Since the nominal capacity of the battery is 75 milliampere hours and the transmitter uses some 100 milliamperes during use, it would be completely discharged in 0.375 hours.

As the transmitter is used intermittently an assessment must be made as to what percentage of time it will be in use, and although it is difficult to be accurate we know that at least 50 units can be accommodated on one scheme. If messages were being continuously received at control each set would be in use for 2% of the time, but we know that this is not so and we can therefore assess the operational time of a transmitter as being about 1% of the on duty time.

Returning to the original calculation therefore the battery should last for 100 x 0.375 hours or 37.5 'on duty' hours. As one tour of duty is normally not more than 8 hours it would seem that a battery of little more than 1/5 of this capacity would suffice or alternatively that the battery could remain in use for at least 4 tours of duty.

Neither of these seemingly attractive propositions is possible because:-

a. A battery of 15 milliampere hour capacity could not satisfactorily produce the required heavy current.

and

b. The transmitter power output is proportional to the square of the battery voltage and a reduction in battery capacity will cause the terminal voltage to fall resulting in a loss of transmitter output power.

If it were possible to accurately assess the amount of charge left in the battery, the amount lost could be made up by a charge of the correct duration. (This was the principle behind the "test" fitted to all chargers in Service), but as was shown earlier there is no reliable method of determining the "state of charge" of a sealed nickel cadmium battery.

In addition to this problem there are two others which have to be taken into account:-

a. It is not practicable to rely upon a busy 'duty constable' to test and "mark up" all batteries and to extract them as they reach a charged state.

b. When Nickel Cadmium batteries are continuously "cycled" between two points in their overall capacity, say, between 60% and 100% charge, the battery develops a "memory" and the overall capacity becomes nearer 40% of the original. The battery can be restored to normal efficiency by a succession of deep charge/discharge cycles. The reason for this is not known, but the phenomenon has been described by workers both in America and in Europe, and it may be a process similar to sulphation in lead acid batteries.

Certain batteries are subjected to this topping up process under present charging arrangements and there is reason to believe that this is the cause of some of our battery problems. The answer to this problem is to remove the human element by introducing a fully automated system so that batteries are "processed" and not simply "charged". This automated process is in fact very simple; it makes use of the discernable discharge state when this can be related to potential difference, at a point just before complete discharge. The battery is discharged to this point and then fully charged (1.4 x charge rate) the discharge/charge process being timed automatically.

If a battery consists of anumber of cells in series it is necessary to halt the discharge process before the battery is completely discharged.The reason is that the cells of the battery will have slightly different capacities, the difference depending on manufacturing inaccuracies. When the capacity of the cells is small, quite small inaccuracies produce fairly large percentage differences and consequently by the time some cells become discharged others will have taken on a reverse charge. After recharge, a reverse charged cell regains its normal polarity but the process shortens cell life.

A current controversy concerned with charging rates is likely, if not seen in context, to completely obscure the problem with which we alone are faced. The Directorate is the only organisation in the world with experience in manipulating 120,000 nickel cadmium batteries and must therefore consider problems from its own experience. We should not accept, without reservation, the solution offered by those without parallel experience, who would solve the whole problem by a system which charges a battery, by means of a pulse or short duration heavy current, in 1 to 10 minutes.

NOTE - For the purposes of the arguments put forward in this paper the charging rate is completely irrelevant.

There could be merit for instance in reducing the charging time from 11 hours or approximately 2 tours of duty duration to something under 8 so that 2 sets of batteries instead of 3 would suffice for 24 hours continuous duty. If a reduction in charging time below this figure would enable the battery to be charged during the "set changeover period", it could result in only one set of batteries being required. As a result the battery would become part of the set which could present operational difficulties.

In any case the gain resulting from a reduced number of batteries per set is not by any means all profit as a battery in use continuously would last only 1/3 as long as a battery in use for 1/3 of the time.

Rapid charging does not overcome the difficulty of overcharging. Unless it can be shown conclusively that rapid oversharging does not cause battery damage or batteries can be made which are immune to damage from overcharge, a method is still needed whereby the battery can be safely brought to a discharged state before subjecting it to a charging process. If it is shown that future batteries can be reliably charged without damage, whatever their initial state of charge, a processing system will still be required to ensure that each battery is satisfactorily charged irrespective of initial conditions.

A battery is often rendered unserviceable because one or more cells have failed in an otherwise good battery and it is worth relating this premature failure to the overcharge and overdischarge problem.

If we consider a cell which has an initial capacity slightly below others, it is obvious that this cell will be subject to more overcharge than others, furthermore, every time the battery is fully discharged the same cell will inevitably be reverse charged, (a known contributory factor to premature failure). This process is cumulative and must hasten the process in respect of the cell in question. One might say that (neglecting other reasons for failure) the cells most likely to fail first are determined when the battery is first assembled.

The reasons which make it necessary to radically change the present system of battery charging are as follows:-

a. Most Police Officers are now concerned about the repercussions that battery charging has on set reliability; if they were more conversant with the true number of set failures which are attributable to battery condition their desire for a change would certainly be pursued with more vigour.

Those officers most concerned and technically inclined construct "battery testers," some of which appear from time to time for evaluation.

b. At recent Regional Crime Squad Officers Conferences every officer voiced a complaint regarding the reliability of his Cub set. An investigation has shown that most failures are due to faulty batteries although this reason was not suspected by the officers.

c. Many Fire Service Officers suspect that their Packset batteries are responsible for unreliability of the equipment.

Some officers clearly believe that alerter batteries are the cause of lost calls. The fact that these batteries do not always last a full day may be due to the differing domestic habits of the officers and the use of a standardised system of charging.

d. Many technician man hours are wasted on "call-outs" where no faults are found, and on Pocketfones returned for service when the faults have been either wholly, or (more difficult to determine) partly due to battery problems.

e. Added to these reasons is the situation that is apparent whenever a pocketfone control is visited. In general, little or no information can be extracted regarding the position in respect of batteries.

Manufacturers Solutions

Very little work seems to have been carried out in the United Kingdom aimed at providing foolproof charging systems for Nickel Cadmium batteries. Work carried out in America mainly by P R Mallory and Company to produce safe fast charge systems, was aimed at popularising Nickel Cadmium batteries for toothbrushes, shavers etc and resulted in the investigation of 6 systems:-

a. Third electrode:- an auxiliary electrode incorporated in the battery recombines the oxygen that is present on overcharge and produces a voltage which switches off the charger. Batteries of this type are said to cost five times as much as normal batteries, but the system is effective.

b. Pressure Sensing:- a pressure sensitive switch operates when pressure, caused by gas, starts to build up in the battery. It is expensive and unreliable.

c. Voltage Monitor:- the very small voltage changes during charge are monitored and used to switch off the charge. Because battery voltage depends upon ambient temperature, the system must be temperature compensated. The circuitry is critical and the system unreliable.

d. Cell temperature sensing:- the rise in cell temperature obtained when full charge is reached is used to operate a switch. The high thermal mass delays temperature rise detection until too late, especially if high charge rates are used, and the circuitry has to take account of ambient temperature. Because of these problems the system is not considered viable.

e. Coulometer Sensing:- a chemical coulometer determines the amount of discharge and the result is used to determine re-charge. This method is expensive and difficult to track across the temperature range of the charge cycle.

f. Diode monitored charger:- in this system each cell of the battery on charge is bridged by a zener diode which acts as a low resistance, by-passing heavy charging current when the cell voltage reaches a pre-determined level. This system is complex, needs temperature compensation, but nevertheless was accepted as the best of a poor bunch.

As stated earlier, the problem facing the Directorate has been to some extent unique in that very large numbers of batteries are involved, there is little point therefore in expecting to find a solution, proposed or produced by others who have not yet encountered the problems.

Directorate's Solution

The main features of the system proposed by the Directorate are shown in Figure 1. By using the cell or battery voltage at the discharge point as the control for the processing system, a degree of reliability is achieved which no other system can offer, and in addition, by cycling the cell over the full maximum capacity required, there is no question of residual active material becoming electrochemically inactive.

The discharge circuit is via D1, relay I, S5, S1 and R1 etc. A level detector senses the voltage across bus bars and causes Relay I to open when the voltage is 1 volt per cell. The charging circuit is via R4 and S4 etc. Switches S4 and S5 control the charge/discharge functions and are operated by a motor driven timer, so arranged that in any period of 16 hours S4 is closed for 12 hours and S5 for 4 hours.

The discharge rate in the system described is 2.5 x the ten hour charge rate, and the charge rate a little below the ten hour rate.

The charge rate if maintained for 12 hours will achieve an 80% charge. There is little point in increasing this to 100%, since the battery will obviously be required to give satisfactory service when its capacity has dropped to 80%. This approach will prevent overcharge of a battery after its capacity is reduced by deterioration.

S1, S2, S3 are microswitches; they bring into circuit discharge resistors R1, R2, R3 and are operated by insertion of the batteries. Any number of batteries can be connected into the system which may therefore be extended as required. Two such banks of chargers are required for each charging location and they are controlled by two level detectors and one time motor. Timewise the system is a replica of that in use at present and the same number of batteries are required.

As described earlier a faster charge rate resulting in an 8 hour process time would reduce the number of batteries required from 3 to 2 per set, but this would only produce an economic advantage if the battery life span was not subsequently reduced.

The recommended routine for a charging location would be:-

a. When coming on duty remove all batteries from the appropriate charger and place in a dispenser.

b. Put into the charger all batteries used during the previous 8 hour spell of duty, and depress the start button.

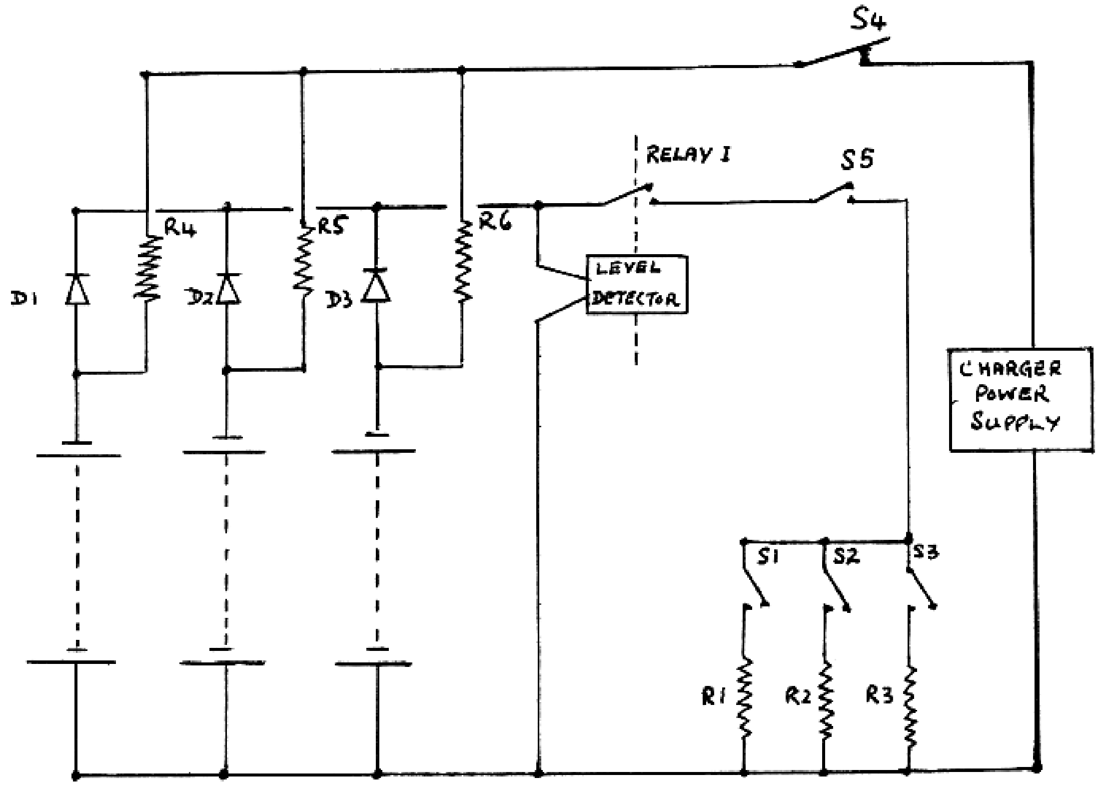
c. Assemble all batteries which have been in use during the duty spell, but do not put them into the charger, this will be done by the officer coming on the next duty spell.

d. Batteries for use should be taken from the dispenser and once a battery is put into a set it should be left in, irrespective of the fact that the set may be returned from duty and re-issued during the duty spell.

The basic control system herein described can be used, with appropriate numbers and types of battery positions, to process large batches of batteries or individual units for UBP officers and Fire Brigade alerter users. Provided resistors R1, R2, R3, and R4, R5, R6, are included in the battery socket unit, the control system can process a mixture of battery types, capacities, and voltages.

The economics of this type of battery processor will obviously depend upon whether the control system is used to process a large number of batteries simultaneously, or individual batteries as used by UBP officers working from home or Fire Officers with alerters. The cost of parts used in the control would be in the region of £10 and when spread over a number of batteries would be very much less than the battery "test" system used at present. At the same time battery life would be extended to at least twice that achieved at present, and the financial result of this would be recovery of cost of the controller in a month or so for large installations, and 3 to 4 years for single battery units.

Added to this are the very great advantages, difficult to quantify, which will accrue from greatly increased customer satisfaction, scheme reliability, and reduced technician attendance.



BATTERY PROCESSING UNIT Fig 1