Conductance Monitoring of Recombination Lead Acid Batteries
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ABSTRCT

BT has been using VRLA batteries since 1984 and is now replacing those installed in early years. The large number in service make it impossible to test discharge all batteries to detect end of life or imminent failure of other sorts. AC impedance and conductance monitoring are currently being promoted as an indicator of battery state of health and capacity. Described is BT's own evaluation of conductance monitoring of 100Ah 6V monoblocs. The results show high correlation of conductance with capacity but suggest the correlation may depend on discharge rate. While there are some limitations conductance monitoring is a useful process and will play a useful role improving reliability of installed batteries.

INTRODUCTION

In the middle of 1984 BT introduced the Power Equipment Rack (PER) as the dc power source for the new System X digital telephone exchanges. The philosophy behind the PER was to increase system reliability, reduce accommodation requirements and reduce cost by putting the DC power source and standby backup on the equipment floor 'on suite' with the switch equipment.

The PER incorporates switch mode rectifiers and valve regulated lead acid (VRLA) batteries without which the whole design philosophy would not have been possible. Each PER can accommodate up to three 100 Ah batteries connected in parallel. Each battery consists of eight, three cell monoblocs connected in series to form a 48 volt string. The batteries are float charged at 54.5 volts and at full load give one hours standby in the event of a public power supply failure. Similar philosophies were adopted for other exchange digital switches. All together BT now has approximately 40,000 VRLA batteries, some 438,000 monoblocs/cells in service.

Up to now BT has relied on the time and trusted method of test discharging batteries to determine their state of health. A power management system installed on each PER can, on remote command, instigate and monitor a test discharge 'on line' to the connected load. However, this pre-supposes the batteries are in a fairly good state of health otherwise the system is put at risk by the test itself.

BT is now replacing its early VRLA batteries. The main failure modes have been group bar corrosion and earlier than expected 'end of natural life' probably due to operating temperatures. The end of natural life was seen as capacity loss due to positive grid corrosion and growth. Problems of dryout and thermal runaway have not been exhibited in BT installations.

Changes in manufacturing technique now appear to have eliminated group bar corrosion and improvements in plate technology have improved temperature sensitivity and increased life.

Group bar corrosion has proved notoriously difficult to discover. The cell has to be near to failure and the network put at risk before problems can be identified. Even discharging at high rates will not show corroding bars until failure is imminent. If such corrosion is suspected off line testing must be applied.

Loss of capacity with age does not present the same catastrophic failure risk as group bar corrosion. System failures are rarely attributable to capacity loss alone. Prediction of end of life, though, is important. Batteries have to be removed from service before the grid break up or growth causes internal short circuits.

Replacement programmes of large numbers of batteries have to be planned well in advance. Budgeting and manpower restraints do not allow battery replacement on an adhoc basis. Predictions of battery life therefore are also necessary to manage such a programme. At present BT predicts the end of battery life by testing discharging, to external load, large statistical samples of batteries of each age of manufacture. This is both time consuming and expensive and alternative methods of test are required.

Recently much has been made of the relationship between conductance and cell capacity. This paper presents data obtained so far from BT's own study of conductance testing using 100 Ah 6 volt monoblocs of various ages. Laboratory and field units are reported, including cells suspected of group bar corrosion and cells which had been abused in other tests.

BACKGROUND

Various papers have been written showing a relationship between available capacity and both cell impedance and conductance. Work by DeBardelaben [1] using lead antimony 7,000 Ah cells showed a strong inverse correlation between capacity and either cell impedance or its resistive real part. Further studies by Vaccaro and Casson [2] on a limited number of cells also showed a degree of correlation between impedance and capacity but only at high rates. Feder, Croda, Champlin and Hlavac [3] presented findings of a study of 500 field and laboratory VRLA cells and monoblocs to Intelec 92. The study included cells ranging from 200 to 1000Ah in size and some 200 Ah 6V monoblocs. They concluded that "correlation of conductance with capacitance was universally high and sufficiently good to allow statistical prediction of capacity to be made from individual cell conductance values."

Following Intelec studies by Misra, Hoveske, Holden and Mraz [4] of C&D Charter Power Systems gave conflicting results. They, like Vaccaro and Casson, concluded that there was poor correlation between ac impedance at low discharge rates but it was shown to improve at high rates. Good correlation was also observed where the cells were processed as an identical group.

EXPERIMENTAL

For conductance testing to be of any use to BT there must be correlation at the 1 hour rate which is our normal dc standby period. This correlation must also be apparent to our end voltage of 1.917 vpc. This equates to the System X lower working voltage limit. All timed discharges reported in this paper were therefore made at the 1 hour rate to 1.917 vpc.

Conductance measurements were made using a Midtronics 2600 Conductance meter. This meter measures the conductance by injecting a low amplitude test signal of 25 Hz. It uses a four wire technique to minimize the conductance variations in connecting cable and at the connection point.

The monoblocs used were all 100 Ah 6V blocs of ages from 1982 to 1991. Those used in the timed discharge tests were all from the same source of manufacture. Measurements were always made with the batteries at top of charge. All batteries had been on long term float, those in the laboratory in simulated field conditions but perhaps at lower temperatures.

In all cases the measurements were taken in a manner thought most likely to stimulate use of the meter as a field maintenance tool. Batteries were disconnected and measurements made within 2 to 3 minutes of disconnection. In the field, time and service restraints will not permit batteries to be left open circuit for long periods. Batteries were then discharged as a 50 volt string at 50 amps constant current (nominal 1 hour rating to 1.917V) and the time recorded for each monobloc voltage to fall to 5.75 volts (1.917 vpc).

Conductance/timed discharge measurements were made at battery temperatures ranging from 9°C to 28° C. The temperature of each battery was measured between adjacent blocs at the start of each test. No attempt has been made to apply corrections for temperature. If conductance is proportional to capacity then temperature should affect both in a similar way. Also previous work had shown temperatures rise of less than 2° C during 50 amp discharges of up to 70 minutes duration so no corrections were made here either. The starting temperature of the batteries ± 1° is shown on each chart.

Batteries suspected of group bar corrosion were not test discharged. After their conductance was measured they were torn down and examined internally for signs of corrosion. The level of corrosion was catalogued.

The conductance results are displayed as a percentage. The meter was calibrated to 100% = 1700 mhos after measuring the conductance of nearly new monoblocs. The average conductance reading for 24 new monoblocs float charged for 3 months was 1598 mhos (94%). This was rounded up to the nearest scale graduation.

RESULTS AND DISCUSSION

Conductance v. Capacity measurements

Figures 1 to 8 show the results of conductance/discharge time measurements for monoblocs from 21 batteries. Each string of 8 monoblocs is identified as a battery (Bat 1 to 21). Batteries connected in parallel in the same PER are displayed together on the same chart. Figure 9 plots all measurements (164 monoblocs) on the same chart. Best fit and standard error curves are derived from figure 9 and are copied to each individual chart. No attempt has been made to calculate best fit curves for each individual battery. A sample six of 8 monoblocs is too small.

Figures 1 & 2 show 1984 and 1986 batteries. With a wide range of capacity monoblocs from batteries 1 and 4 fit the curve remarkably well. Batteries 2 and 3 show a tightly grouped scattering of readings mostly within the error bands.

Figure 3 shows measurements made on pre-production prototypes made in 1982. Some terminal corrosion had occurred which may account for the wide scatter of results. Four monoblocs could not be measured because of the corrosion. Tear down of two monoblocs shortly after these tests showed positive grids to be brittle, with little lead left, but no growth. Unfortunately the initial weights of the monoblocs had been mislaid during a test move, so weight loss and dry out could not be measured. The batteries had been discharged during the previous 12 months.

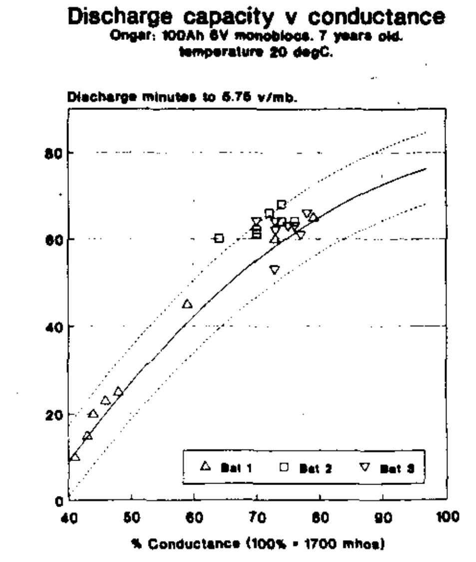


Fig.1

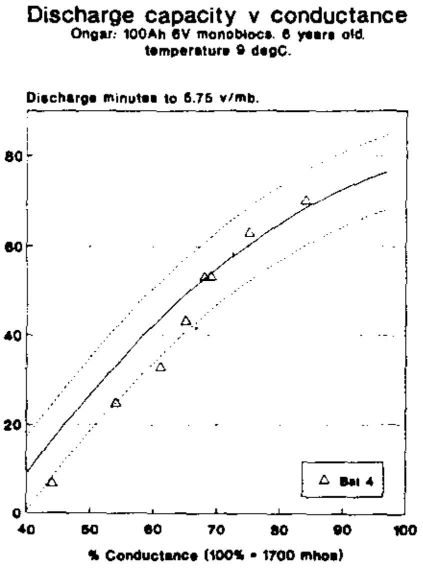


Fig.2

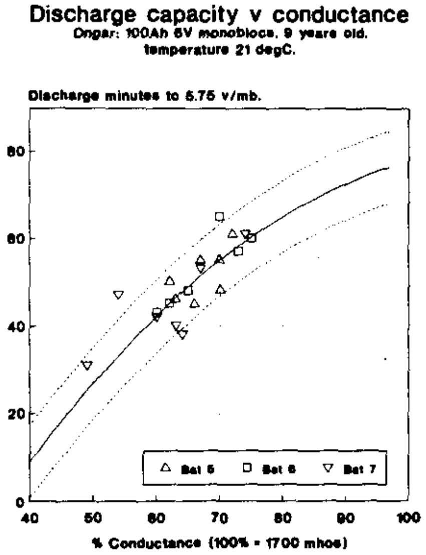


Fig.3

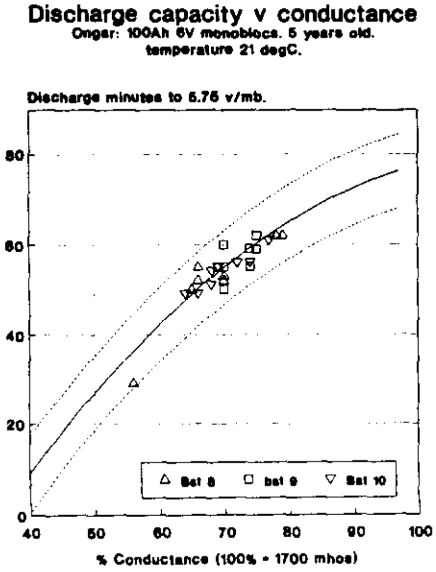


Fig.4

Figure 4 shows the results of monoblocs made in 1987. They were installed positioned on their side with the plates vertical. A relatively good curve fit can be seen for batteries 8 and 10. Again they had been discharged during the last 12 months.

Figures 5 & 6 show monoblocs made in 1985. They had been used in a number of PER short circuit tests and a 10 month open circuit test. They had only been back on float for 30 days prior to these measurements. One discharge at the 1 hour rate had been carried out during the 30 days. Tear down revealed no obvious problems with little corrosion and plenty of lead in the positive grids.

The field batteries shown in **figure 7** were nearing end of life. Tear down revealed positive grid corrosion and moderate growth. Float current on battery 18 was higher than normal at 350 mA.

Batteries 19, 20, and 21 shown in **figure 8** were manufactured in 1991. They were being used in float current v. temperature tests and had been running at 28° C for 8 weeks prior to the measurements shown here. The low capacity monobloc in battery 21 is of interest. The valve caps were removed from monobloc No.1 battery 21 to measure the effect on battery float current. The monobloc float voltage dropped from 2.266 vpc to 2.22 vpc within 24 hr with little change to the float current. The drop in float voltage was due, perhaps, to self discharge of the negative plate. Six weeks later the valve caps were replaced and the battery continued on float charge. The float voltage of monobloc No. 1 remained at 2.22 vpc and did not return to normal, indicating sulphation of the negative plate. Twelve weeks after the caps were replaced the conductance measurements and discharge results shown in figure 8 were taken. The measurement falling outside the error band giving poor performance for a good conductance reading is monobloc 1. This suggests the relationship of conductance to capacity for a partially discharged cell is different to that normally shown by aging. It also suggest that failure of the valve cap, ie. air leaks, may be difficult to find by conductance testing alone.

A few odd field cells are reported as giving low capacity but high conductance readings. These are being investigated but at first sight it appears they have not fully recharged after a discharge. Studies [3] have shown that the correlation of conductance and capacity is different for discharged cells. The same studies show the conductance of a partially discharged cell to be higher than on fully charged.

The various temperatures at which measurements were made ie. 9°C, 12°C, 20°C, 24°C and 28°C have not affected the correlation of measurements. For instance monoblocs from batteries 16,17, & 18 at 24°C plot to the same area of the chart as monoblocs from batteries 11, 12, & 13 at 12°C for the same performance. This implies that temperature has the same effect on conductance as on available capacity.

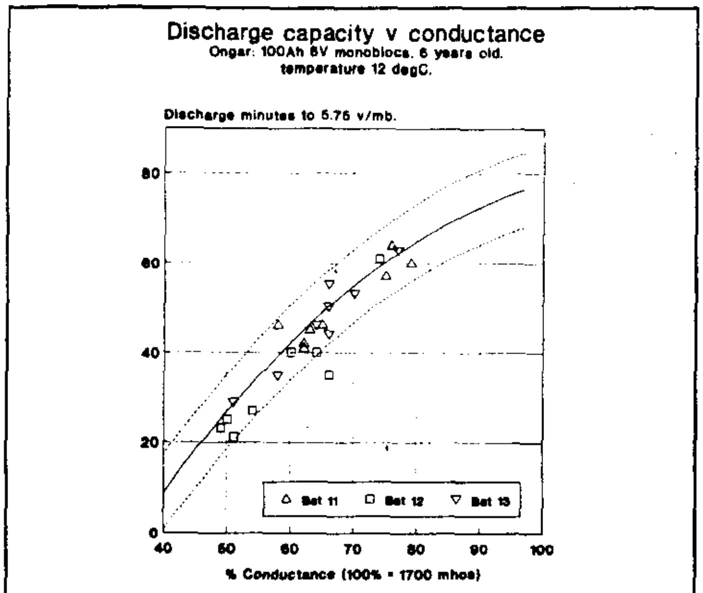

Discharge capacity v conductance
Ongar: 100Ah 6V monoblocs. 6 years old.
temperature 12 degC.

Fig.5

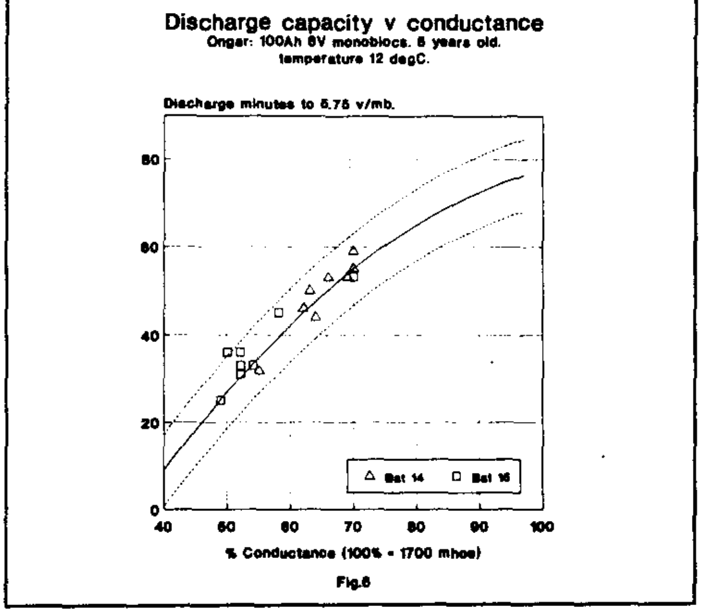

Discharge capacity v conductance
Ongar: 100Ah 6V monoblocs. 6 years old.
temperature 12 degC.

Fig.6

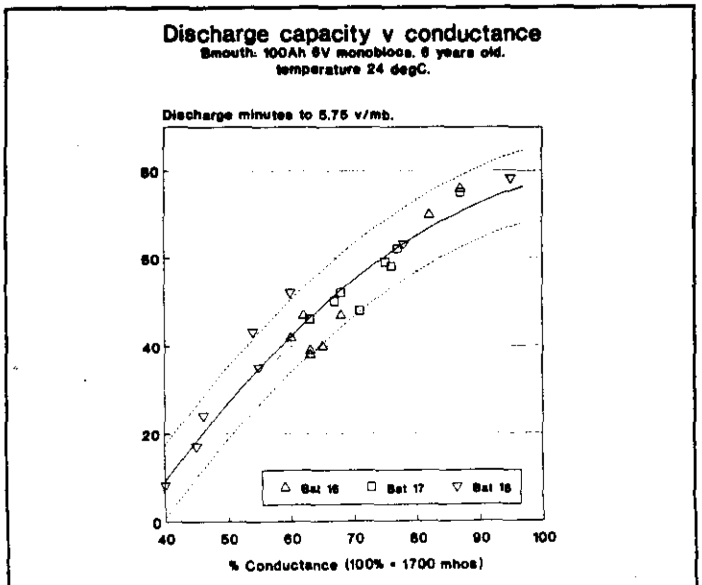

Discharge capacity v conductance
Smouth: 100Ah 6V monoblocs. 6 years old.
temperature 24 degC.

Fig.7

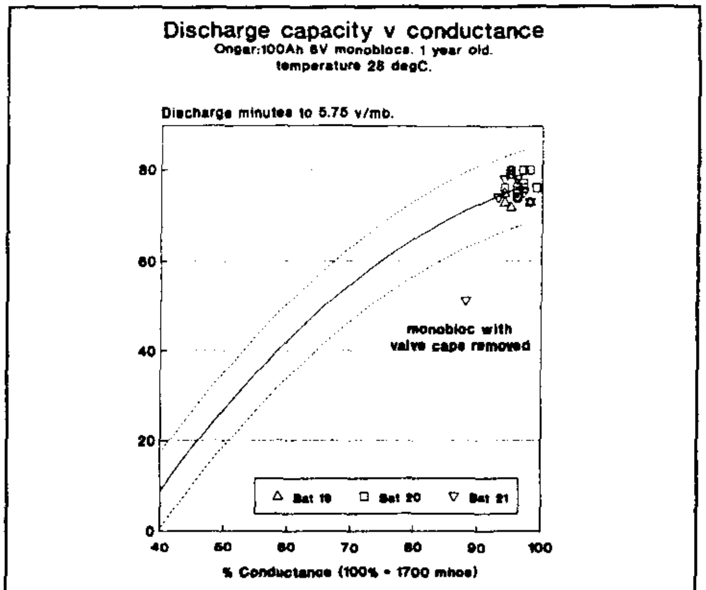

Discharge capacity v conductance
Ongar:100Ah 6V monoblocs. 1 year old.
temperature 28 degC.

Fig.8

Best Fit Curve

Figure 9 shows the correlation of conductance with capacity for all 164 monoblocs. The best fit curve is a second order equation:

$y = 2.949X - 0.0129X^2 - 88.313.$

High correlation factor, r^2, of 0.91.

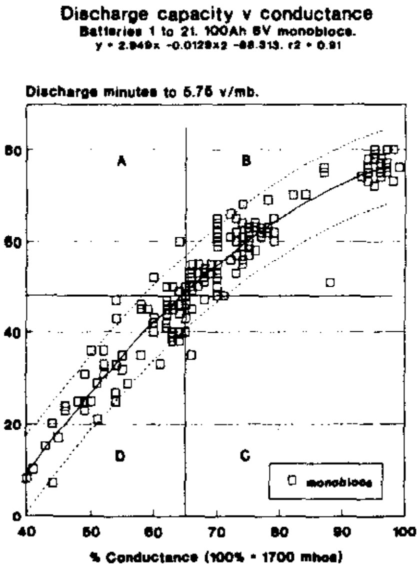
Standard error for y = 4.8 minutes.

90% within ± 1.7 standard error (shown dashed).

Most authors have shown linear correlation between conductance or impedance and capacity so why the difference. The relationship between the conductance and capacity of a cell is complex. Many factors will effect impedance, electrolyte dry out, grid corrosion, loss of paste structure, etc. All these occurring to various degrees, are unlikely to produce a linear correlation.

As study of past papers[1,2] shows linear correlation lines with good fit drawn for various samples. Best linear correlation is at vary high discharge rates[2] ie. 10 minutes, where dry out has a marked effect on performance. Tests by BT suppliers have also shown this to be true. At lower rates dry out has less effect. For instance, initial dry out of new cells causes little variation in capacity at the 1 hour rate. Perusal of papers comparing long discharge times[3] show a non linear function, similar to the one shown in figure 9 might fit best, even though linear correlations have been plotted. Does the function of correlation depend on the discharge rate? If so calibration for each type of use may be required.

A cursory glance at field results for the same sized monobloc, but not yet entered on the data base, show good correlation with figure 9. Results of other manufacturers product also show good fit.

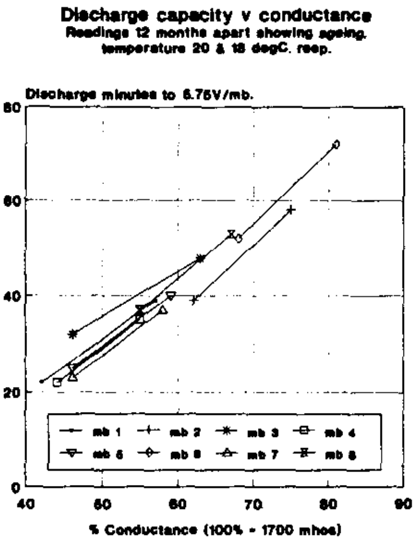


Discharge capacity v conductance

Batteries 1 to 21. 100Ah 6V monoblocs.

y = 2.949x -0.0129x2 -88.313. r2 = 0.91

Fig.9



Discharge capacity v conductance

Readings 12 months apart showing ageing.
temperature 20 & 18 degC. resp.

Battery 22: age 7 & 8 years resp.
Fig.10

Tracking Age By Conductance

Figure 10 shows measurements tracking the fall of capacity of 8 monoblocs over a twelve month period near to end of life, from 7 years age to 8 years age. The range of capacities is surprising with one monobloc as good as new when first measured. However, the similar loss of performance of each bloc over the period suggests the same mechanisms at work. Tear down revealed the same extent of positive grid corrosion and growth in all monoblocs. The differences in overall performance explained, perhaps, by variations in loss of contact with paste and breakage of grid wires. Field experience using discharge tests has shown similar results with some monoblocs holding 90% of nominal capacity up to the last 6 months of life and then falling rapidly. (This makes life prediction difficult). Unfortunately the best fit trend does not follow the curve calculated for figure 9. It is difficult to draw conclusions as this was only a very small sample. BT has started more field tests to monitor this application.

Conductance v. Group Bar Corrosion

Figure 11 shows measurements made on 25 monoblocs from a batch suspected of group bar corrosion. Tear down of other monoblocs from the same batch had shown top down sulphation of the negative bar. After measuring the conductance the monoblocs were opened and the group bar corrosion catalogued as light (surface corrosion), medium (50% corrosion) or heavy (75% corrosion) for intact bars and as fault categories where faults had occurred.

No apparent correlation between conductance and the level of corrosion is evident. Differences are not apparent until the bar starts to fail or drop plates. The two high readings for cracked group bars may be genuine. For example, test on other monoblocs with cracked group bars have shown monoblocs behaving normally on float, but failing when subjected to high load currents. The meter generally picks these out. The already weak bars may also, of course, have been cracked by the effort of removing the lid.

Conductance readings for monoblocs
with group bar corrosion

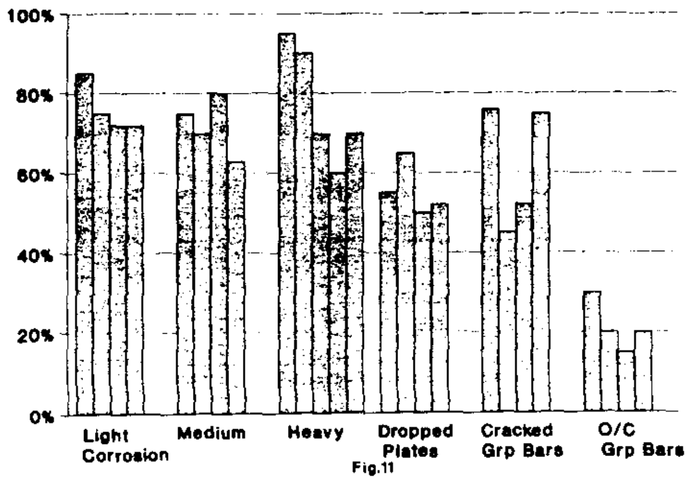


Fig.11

Test discharging does not fare any better with group bar corrosion. In field situations, test discharges at 50 amps failed to find batteries which failed only two to three later in service and at a lower connected load. There have also been reports of monoblocs failing halfway through a discharge, up to which point voltages appeared normal.

If group bar corrosion is suspected testing, whether by conductance or discharge, needs to be carried out frequently.

REJECTION OF MONOBLOCS USING CONDUCTANCE

There is little doubt that conductance can identify very low capacity cells and those which have suffered catastrophic failure. Its use in detecting cells at end of life, 80% of nominal capacity, depends on how sensitive the particular installation is to standby time. If as, in figure 9, errors in the region of ±9 minutes are acceptable then conductance monitoring could be used with little test discharging.

Figure 9 shows how this might work. The chart has been divided into four segments. A horizontal line bisects the chart at 48 minutes (end of life as 80% of 60 minutes). Where this bisects the best fit curve gives the conductance value below which all cells would be rejected, in this case 65%. All monoblocs in segment B are good and would be kept, all those in segment D are poor and would be rejected. However we also reject good blocs in segment A and keep poor blocs in segment C. Whether this matters is up to the particular user. Other safeguards could be used like test discharging those batteries which have conductance readings near the reject level.

Remember though this pre-supposes that all blocs are top of charge and as we have seen this may not always be the case.

INITIAL SETTINGS

The shape of the correlation curve could make monitoring of new cells prone to error, with changes in conductance for little or no change in capacity. This practically rules out quick commissioning tests using conductance, although obviously low values can be rejected. Care must be exercised when initially calibrating the meter. I have seen readings as high as 120% (against 1700 mhos) on some new monoblocs. This could obviously cause errors if used as the initial setting. It is recommended that initial calibration for new cell types should be carried out on conditioned cells.

CONCLUSIONS

This study carried out on 100Ah 6V has shown:
1. A high degree of correlation (0.91) exists between timed discharge and conductance at the one hour rate for fully charged cells of the type used in this study.

2. The correlation function may depend on the discharge rate. For the one hour rate to 1.917 vpc it is of a second order function.

3. Within the limitations described conductance can be used to reject cells at the end of life.

4. Catastrophic failure can be detected by conductance monitoring.

5. It is not possible to detect the extent of group bar corrosion by conductance or test discharge until partial failure has occurred.

6. Errors may arise if conductance is used to monitor new cells.

7. Initial calibration should only be made against conditioned cells.

8. Some cell faults such as air leaks or self discharge fall outside the correlation band.

ACKNOWLEDGEMENTS

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