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Journal of Power Sources 116 (2003) 236–242
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

High integrity VRLA batteries for telecommunications service☆

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Abstract

Telecommunications power requirements continue to evolve and to meet new patterns of use, new battery configurations have been developed to maximise energy density, optimise space utilisation and provide for ease of installation and maintenance. Front-access terminal batteries are well-matched to these requirements and are now widely applied in rack-mounted power supplies for telecommunications.

A new range of sealed lead–acid batteries are described which embody front-access terminals but adopt a somewhat different approach where applications issues have been brought into sharper prominence rather than established design and manufacturing criteria. This range uses absorptive glass mat separators and state-of-the-art electrochemical designs to produce a range of batteries that has strong user benefits and enhanced performance.

The technical characteristics of these batteries are described and compared to other constructions to demonstrate their behaviour under a wide range of operational conditions.

Keywords: Lead–acid batteries; Industrial batteries; Valve-regulated; Front-access

1. Introduction

Valve-regulated lead–acid (VRLA) batteries have continued to develop for telecommunications applications and to ensure performance and reliability, a careful balance between design requirements and operational needs is essential. Telecommunications power requirements have also continued to evolve and to meet new patterns of use, new battery configurations have been developed to maximise energy density, optimise space utilisation and provide for ease of installation and maintenance. Front-access terminal batteries are well-matched to these requirements and are now widely applied in rack-mounted power supplies for telecommunications.

Telecommunications operators require a 48 V power supply. The standby battery that is used to back up this power supply is generally comprised of 2, 4, 6 or 12 V units as cells or monoblocs. Front-access types have become increasingly important for installation in industry standard racks as they permit easy installation and access for maintenance inspection.

These are generally 12 V units and follow design principles that have been well-established for larger automotive batteries for truck applications. The user, however, simply requires a 48 V battery and there are benefits in using 16 V monoblocs. This reduces the number of blocs per battery from four to three, simplifying installation and maintenance. The battery design (Fig. 1) is improved insofar as a smaller number of plates per cell with a profile closer to square rather than the tall, thinner plates used in 12 V designs.

The design and construction of these batteries are described and a study of battery life both in laboratory and in field service conditions is summarised.

2. Battery design

The design of VRLA cells is much more critical than flooded cells but the principles for reliable operation and battery integrity have been clearly established in recent years. There are several factors that determine performance and reliability and these are discussed later.

2.1. Grid alloys

Given that other factors do not limit battery life, corrosion of the positive grid in floating service becomes the life limiting parameter. This is affected, first, by the selection

☆ Eighth European Lead Battery Conference.

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0378-7753/03/$ – see front matter
doi:10.1016/S0378-7753(02)00696-1

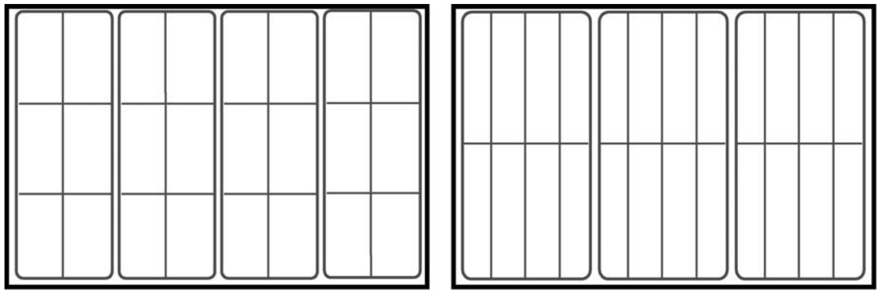

Fig. 1. 48 V battery systems with 4 × 12 and 3 × 16 V blocs.

and processing of the lead alloy and, second, by the grid design. Pb–Ca–Sn alloys have generally proved to be most successful in terms of production uniformity, high temperature resistance and actual service life. These alloys have small amounts of aluminium added to control the formation of dross during casting and help stabilise the calcium content in the alloy which tends to be lost by preferential oxidation. The calcium content is critical; too much leads to undesirable microstructures which can suffer accelerated corrosion, but too little results in soft alloys that are difficult to process. Calcium forms intermetallic compounds with lead and tin that produces a finely dispersed age hardening precipitate. The thermal processing of the grids affects the dispersion of the precipitate and has been developed to produce good levels of hardness with lower calcium levels with beneficial effects on corrosion behaviour. Tin assists in improving the corrosion resistance and in the cyclic performance of the cell. It also takes part in the age hardening of the grid by also forming an intermetallic compound with calcium and improves the castability of the grids. Other elements need to be carefully controlled to low levels. Antimony and to a lesser extent arsenic even in very small amounts affect the float current and, hence, dry-out. In addition, they can lead to corrosion of the top lead in the battery. For this reason, alloys for VRLA batteries need to be clean in terms of key impurity levels to optimise life. Over time, there has been an evolution to alloys with higher tin levels and lower levels of calcium as the materials of choice for the highest levels of integrity.

Grid design in very simple terms relies on an adequate grid profile to ensure a full life. The manufacturer can, however, improve the efficiency by adjusting the wire section and the distribution of metal in the grid. This will have a significant impact on corrosion resistance and the performance of the battery.

2.2. Electrochemical design

The electrochemical design of the cell depends on the balance between the positive and negative active material and the acid quantity. The density of active masses, particularly the positive, will affect the durability of the battery on cycling but needs to be traded off against high-rate performance. The acid quantity is closely balanced with the available active materials and separator volume.

2.3. Separators

The separator needs to have an adequate level of fine fibres and a reasonably high level of compression. Recombination efficiency is high over a range of separator formulations and compressions provided there is good contact at all times but cyclic performance is improved significantly at higher levels of compression and with separator formulations that have higher fine fibre content.

2.4. Battery case materials

The battery case serves not only to contain the cell elements but needs to be designed to ensure a fixed compression of the plate group throughout the service life. The internal pressure varies during operation and combined with a variety of service temperatures leads to a need for a high-integrity case both in terms of design and material selection. An adequate wall thickness backed up with reinforcing ribs is essential for good performance. Materials selection is generally from acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), or polyvinylchloride (PVC). The characteristics required are a high strength and high modulus with a high softening point to avoid distortion at elevated service temperatures with a sustained internal pressure and end-wall load. Flammability rating and impermeability to water are also required. ABS, PC and PVC have a higher rigidity than PP and, therefore, PP tends to bulge unless it is designed with very extensive ribbing or uses an external containment system. ABS has better fracture toughness than PVC. Higher levels of flame retardancy are more easily and economically achieved with ABS, PC and PVC than with PP. Water permeability is lower with PP compared to PVC and significantly higher with ABS but with the wall thickness needed for good performance, water transmission through the case is a negligible contribution to longer term dry-out. Overall, ABS or for some applications ABS alloyed with PC is the preferred base material for the battery case. It should also be noted that PVC presents some difficulties for recycling.

2.5. Battery sealing

The case to cover seal for ABS cased batteries is easily and reliably made by heat sealing. This provides a seal with an integrity and strength close to the base polymer.

The post seal is critical and needs to be carefully controlled as it operates in an aggressive internal environment. Compressed grommets or moulded bushings can be effective but are not completely tolerant of manufacturing variations. Epoxy resin seals in combination with a grommet seal provide a more reliable solution combined with treatment to modify the surface properties of the components and a high level of control of the manufacturing process.

2.6. Valve design

The correct operation of the one-way valve for a VRLA cell is necessary to avoid ingress of oxygen from the external environment and to limit the internal pressure to a safe level. There are a variety of designs in use but the Bunsen valve provides a simple and reliable solution. It can also be adapted to permit a progressive characteristic such that in the event of an abusive overcharge, an increased flow of gas can be achieved.

2.7. Battery configuration

Batteries for front-access installation need to comply with telecommunications industry standard 19 in. and 23 in. racks. There are a variety of sizes required and little standardisation. The range of 12 V batteries from 100 to 150 Ah has, however, become a popular offering with a common footprint and varying heights depending on capacity (Fig. 2; Table 1). For lower capacities, the relatively long and narrow containers are a less efficient package than a conventionally designed battery, where clearly, a cube would be most efficient. As a result, the use of a 16 V battery provides a better solution. There are three batteries rather than four for each 48 V supply, the plates are closer to a square shape which is better for battery performance and there are fewer plates per cell.

Fig. 2. Front-access terminal VRLA batteries.

Table 1
Typical dimensions for rack-mounted front-access VRLA batteries

Battery type	Voltage (V)	Nominal capacity (Ah)	Dimensions (mm)			Rack type (in.)
			l	*w*	*h*	
UMTB 1630	16	30	144	280	185	19
UMTB 1650	16	50	144	280	280	19
UMTB 1665	16	60	144	395	230	19
UMTB 1685	16	80	155	395	295	19[a]
UMTB 12100	12	100	126	558	230	23
UMTB 12100	12	125	126	558	270	23
UMTB 12155	12	155	126	558	320	23

[a] Special customer rack.

One of the advantages of 12 V front-access batteries is a better thermal behaviour because they have a relatively high external surface area for heat dissipation compared to a conventional design. The 16 V types move closer to a conventional 6 × 1 design with a 4 × 2 arrangement rather than a 2 × 3 arrangement but studies of the thermal behaviour of these types [1] have shown that they are not subject to increased internal temperatures to any significant degree.

The battery terminals are arranged for easy interconnection and voltage measurement with adaptors to permit current take-off to the rear of the cabinet or end cells. Gas collection may be used where required for safe venting in enclosed installations.

3. Battery operation

There are a wide variety of environments in which telecommunications batteries are installed. These range from large central plants to small remote installations. The operational configuration has a strong impact on battery life and it is important to ensure adequate spacing between monoblocs for good convective ventilation and to site the battery correctly with regard to other heat generating equipment. The float voltage, temperature of the local environment and maintenance operations are all keys to reliability and durability in service. The batteries need to be selected and matched for each specific installation and the battery layout optimised for each battery compartment. In addition, the charging equipment must have the necessary characteristics to ensure that the recommended conditions can be met in full.

3.1. Voltage and capacity matching

There are benefits for reliability in ensuring that the voltage and capacity of individual blocs are held within close tolerances. Manufacturing tolerances are fully capable of maintaining high levels of consistency but the history of individual monoblocs from manufacture to installation will alter their behaviour and characteristics. Monoblocs will exhibit a spread of voltages within the same battery string.

A limited spread is acceptable and will not have an adverse effect on battery life but a larger spread can result in imbalances that adversely affect life. Procedures have been developed to match the capacity and voltage of groups of monoblocs and this assures the capability of these groups of monoblocs to float correctly. Correctly applied, this procedure will result in each bloc being within very close tolerances on float and the procedure will also reduce the spread of capacities in the population. A number of years of experience in the use of this approach has provided benefits in overall battery life.

3.2. Temperature correction of float voltages

It is critically important to maintain VRLA cells at their correct float voltage to achieve the full service life. At higher voltages, corrosion tends to be accelerated and, at lower voltages, the state-of-charge will fail to be maintained or the time taken to recover on float after discharge will be unacceptably extended. Use of higher voltages for rapid charging is acceptable but only for limited periods. Temperature correction also needs to be applied. Constant current charging should never be used and for installations where VRLA cells are a direct replacement for sealed nickel–cadmium cells with constant current charging, a device capable of shunting current around the cell in order to maintain a constant and correct potential at top-of-charge needs to be installed.

3.3. Thermal management

Thermal management of VRLA batteries is important in order to avoid the effects of high temperatures in severely reducing battery life and in extreme cases of thermal runaway. Good installation design with correct spacing of monoblocs for convective ventilation and siting the battery away from other heat sources provides a good level of security, balanced by an intrinsically sound battery design.

3.4. Battery maintenance

The need for battery maintenance is not eliminated with VRLA batteries and it remains necessary to check battery voltages, correct operation of the charger and the security of the connections. Incorrect floating conditions will rapidly lead to premature failure and it is vital that these are verified from time to time.

4. Battery life

Battery life may be assessed by accelerated life testing at elevated temperatures under a constant float voltage. A wide variety of battery types have been tested over time and the data may be combined to show a strong statistical validity over a full product range having positive and negative plates with similar profiles, using similar electrochemical designs and other features.

A standard procedure was used for all tests in which the battery was held in a temperature controlled oven at ±1 °C and a relative humidity of 20%. A float voltage of 2.27 V per cell was used and at an appropriate interval the batteries were removed from the test chamber, allowed to equilibrate to room temperature, checked for capacity, fully recharged and then returned to the test chamber for a further interval. Weight loss was also recorded.

Test temperatures of 50, 60, 71, and 82 °C were used. For the 82 °C test, a steel fixture was used to maintain the compression of the plate group since the ABS used for the container moulding tends to soften at this temperature. It was considered that an additional level of capacity loss will occur under these conditions and, for this analysis, an end-of-life 50% figure of the nominal capacity was used rather than the normal 80% figure used for other levels.

The mean capacity against time is shown in Figs. 3–6 and the time taken for the battery to reach end-of-life as defined is shown in Table 2.

Using the Arrhenius equation to interpret the results,

$$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R((1/T_1) - (1/T_2))}$$

where k_1 and k_2 are the rates of degradation at temperatures T_1 and T_2 (K), E_a is the activation energy and R the gas constant (1.987 cal/(mol °C)). The data are plotted in Fig. 7. This shows the projected life was 10.4 years at 25 °C with an activation energy of 15.5 kcal/mol.

More recent tests have confirmed these data also show an increase in capacity in the early part of the battery life in a more consistent manner.

4.1. Life tests in real time

A number of tests were also carried out in real time on different float voltages at 25 °C. In these tests, an upper limit

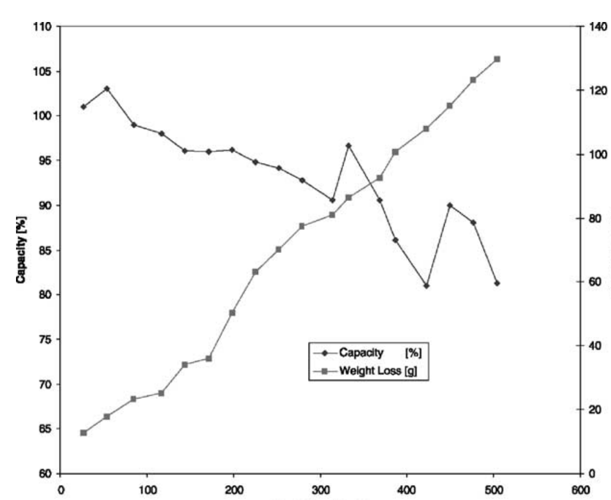

Fig. 3. The 50 °C accelerated life test.

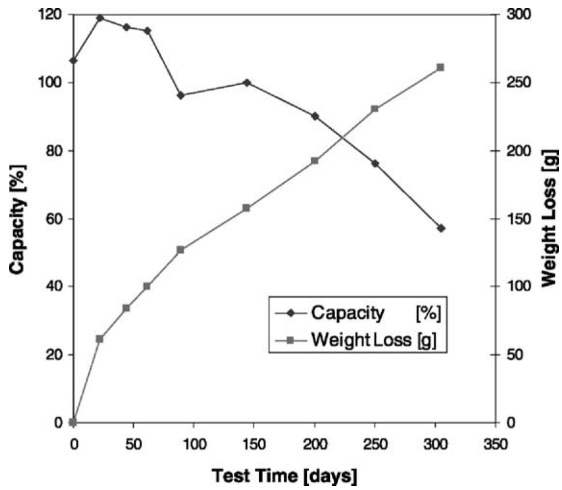

Fig. 4. The 60 °C accelerated life test.

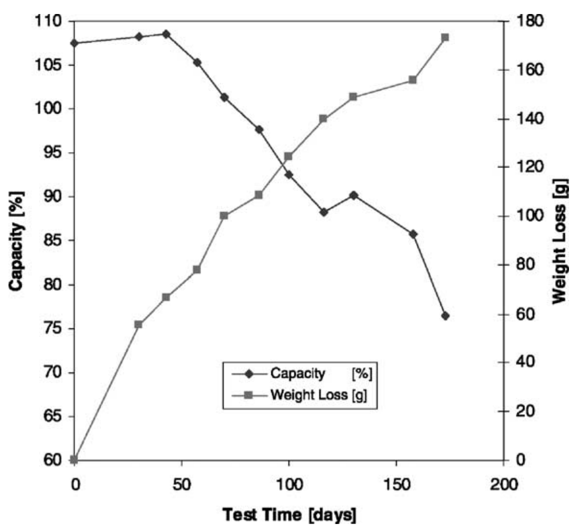

Fig. 5. The 71 °C accelerated life test.

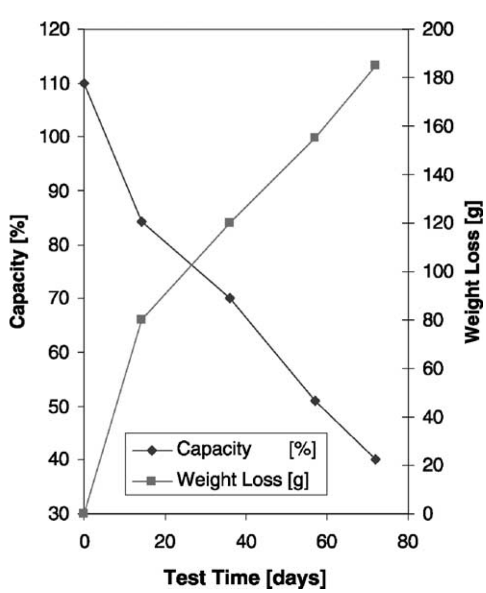

Fig. 6. The 82 °C accelerated life test.

Table 2
Accelerated life test summary

Test temperature (°C)	Time to end-of-life (days)
50	504
60	240
71	162
82	58

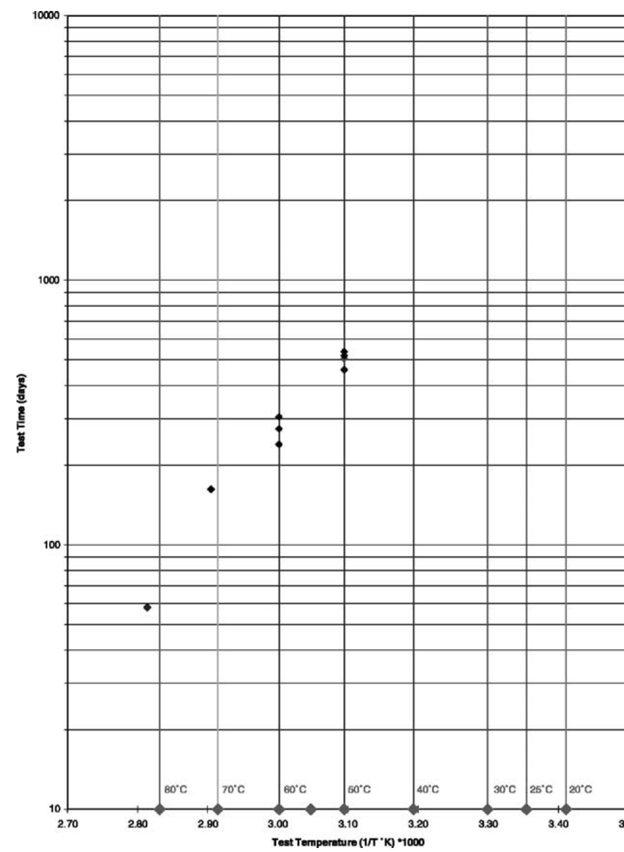

Fig. 7. Arrhenius plot.

of 2.31 V per cell, a normal value of 2.27 V per cell and a lower limit of 2.23 V per cell were used. Capacity, float current and weight loss were recorded (Figs. 8–10) [2].

At the higher level of float voltage there is an earlier capacity loss and this is readily correlated with the higher float current and weight loss. The lower level of float voltage does not have a significant effect on retained capacity although the float current and weight loss are lower. If higher service temperatures are likely and voltage compensation is not applied, a slightly lower float voltage might be beneficial but with batteries in long series strings the normal float voltage needs to be applied to ensure there is no risk of undercharging and that the cell capacity is balanced.

4.2. Field service

A recent evaluation of a number of batteries which have been in field service for ~6 years has shown very satisfactory

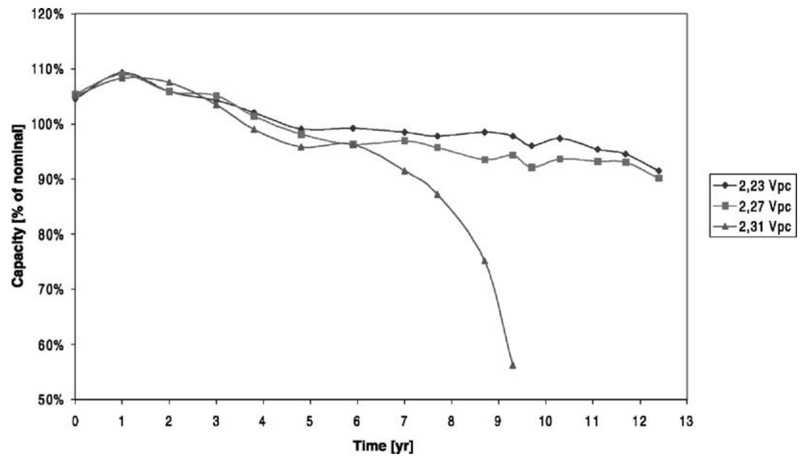

Fig. 8. Capacity change with time on float at ambient temperature at various voltages.

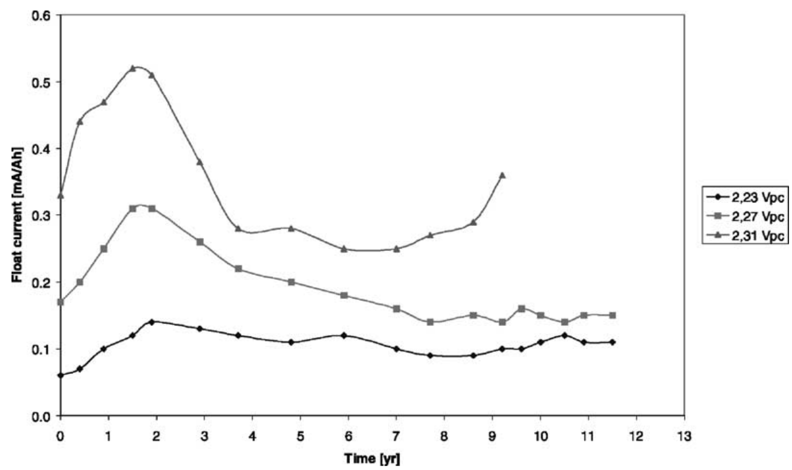

Fig. 9. Change of float current with time at ambient temperature at various voltages.

capacities after this period. These were in environmentally controlled remote terminals and although all the sites are now air conditioned, they were not environmentally controlled at the outset and the batteries spent a significant part of their life in non-controlled environments as the air-conditioning was a later addition. These sites were all in WI, USA and although this is a relatively northern location, summer ambients can be

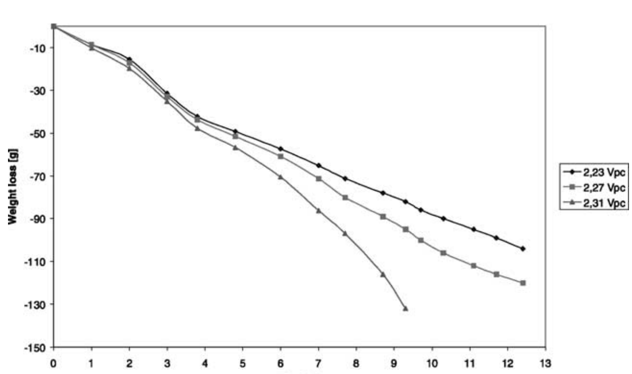

Fig. 10. Weight change with time at ambient temperature at various floating voltages.

high for extended periods. Air conditioning is a prerequisite for maximum service life to be obtained and the initial period of operation will have an adverse affect on overall life. The rectifiers were not temperature compensated. The ambient temperatures during the testing varied from 25 to 30 °C and the internal temperatures inside the remote terminal from 21 to 33 °C.

The average capacity was $114 \pm 11\%$ of nominal at an average age of 6.3 years. The majority of sites had multiple strings of 24 cells and this then represents a substantial sample size in terms of the number of cells.

Battery impedance measurements were taken on all sites. Expressed as a percentage of the initial value for each monobloc the average was 96% with a spread of 8% which is consistent with the capacity test data.

The average capacities of those cells were significantly in excess of the expected level based on the accelerated life test data where a decline to $\sim$90% of the nominal capacity occurs at approximately half the time to failure. There is greater consistency with the ambient temperature life tests. In fact, the accelerated life test data shows that the capacity tends to increase in the early part of life which is consistent with the behaviour observed. Further testing is planned and as a result and notwithstanding further test results, a life well in excess of 10 years under these conditions may be assured.

Recent improvements have been demonstrated by accelerated life testing and the principal factor is the use of alloys with improved corrosion resistance. This has been achieved by the adjustment principally of the tin and calcium levels of the positive grid and improved metallurgical processing, together with a number of detailed improvements to battery design and construction.

5. Conclusions

The requirements for back-up power for telecommunications equipment can be fully met with VRLA batteries. These have evolved and matured over a number of years to a level where service lives in excess of 10 years under a variety of conditions may be assured. This has been adequately demonstrated by accelerated and real time life testing.

The application has evolved to more efficient battery configurations in terms of space utilisation and to ensure easy installation and maintenance through the use of batteries with front-access terminals. These are accommodated in industry standard 19 in. and 23 in. racks. A new range recently introduced to commercial production and a combination of 12 and 16 V blocs has been used to provide maximum energy density in the space available. These batteries have good thermal characteristics because their external surface area is larger than conventional batteries, thus improving heat dissipation.

In the future, VRLA batteries will continue to improve and become more precisely adapted to particular applications but this is a technology that has reached a high level of reliability and will continue to meet the power requirements of existing and new networks in the years to come.

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