Short Communication

Developments in lead/acid stationary batteries

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Abstract

Valve-regulated designs of the lead/acid system are securing significant shares of the markets for stationary batteries. This paper discusses the major problems that have been encountered with the introduction of valve-regulated technology. Areas that have provided particular difficulties include: acid leakage (container-cover, post-seal and vent leaks); adverse effects of ripple current; variations in float voltage, and initial value of recharge current.

Purpose-made valve-regulated batteries

It would be generally true to say that the majority of the efforts in the development of lead/acid stationary batteries lies in the area of valve-regulated designs and that although manufacturers still continue to improve their flooded-cell products, they do so as a result of operating experience.

Valve-regulated lead/acid batteries (VRBs) have now been developed to suit specific applications or to have characteristics that make them more appropriate for particular applications (Fig. 1). In general, there are four categories: (i) batteries with a design life of 20 years and intended for medium-duration discharge periods from 1 to 10 h, such as required in telecommunications and emergency lighting; (ii) batteries with a 10-year design life, intended for high-rate, short-discharge period applications of 1 to 60 min and, specifically intended for UPS applications; (iii) batteries with a 20-year design life and excellent high-rate performance that are specifically designed for UPS applications but also required to compete with nickel/cadmium batteries, and (iv) batteries with the above characteristics and good cycling capability.

The most significant difference between these different types of battery, is the design of the positive plate which can vary in terms of grid alloy (Fig. 2), as well as in geometry, thickness and quantity. High-rate performance is obtained by the use of a greater number of thinner plates to increase the total surface area. This characteristic is obtained, however, at the expense of life, unless a more suitable grid alloy than conventional lead–calcium is used. All aspects of the design must minimize internal and external voltage drops in order to maximize the output of the complete battery on load. The relevant features include grid-frame, take-off lugs, top lead, separator arrangement, terminal material, contact surface area, and intercell-connector voltage drop.

Purpose-designed batteries provide a smaller, lighter and more cost-effective way of obtaining the required performance compared with the use of larger general-purpose

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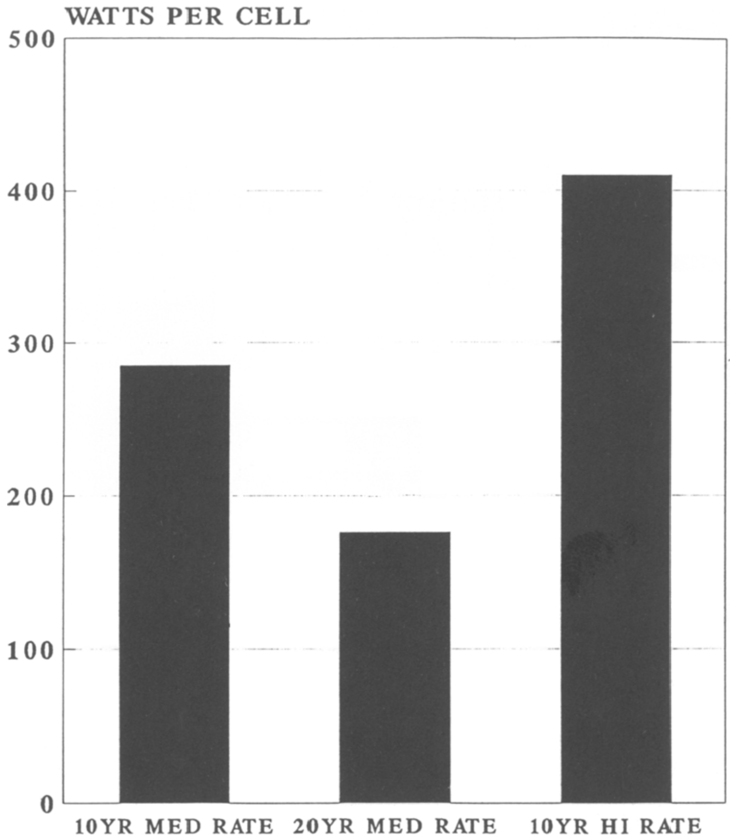


Fig. 1. Performance of different designs of value-regulated battery: 15 min to 1.67 V/cell.

cells. The former batteries provide high energy-density packages and use less floor space, particularly when mounted horizontally.

Problems experienced with valve-regulated batteries

Since the appearance on the market of VRBs, a number of problems have been experienced. This is not unusual with new technologies and, of course, corrective actions have been made. Problems associated with incompatible alloys seem to have disappeared and the major concern is probably now related to acid leaks. Valve-regulated batteries operate at a positive internal pressure in order to facilitate the gas-recombination effect. Although there should be no free acid in a properly-conditioned cell, there will be an acid film throughout the internal surfaces and any acid leaks will originate from this source.

Acid leaks can occur via three different modes, namely: (i) container-to-cover-seal leaks; (ii) post-seal leaks, and (iii) vent leaks.

Container-to-cover leaks

Most cells use heat sealing to fix the cover to the container. In this process, the edges of both the cover and container are heated and melted and then forced together

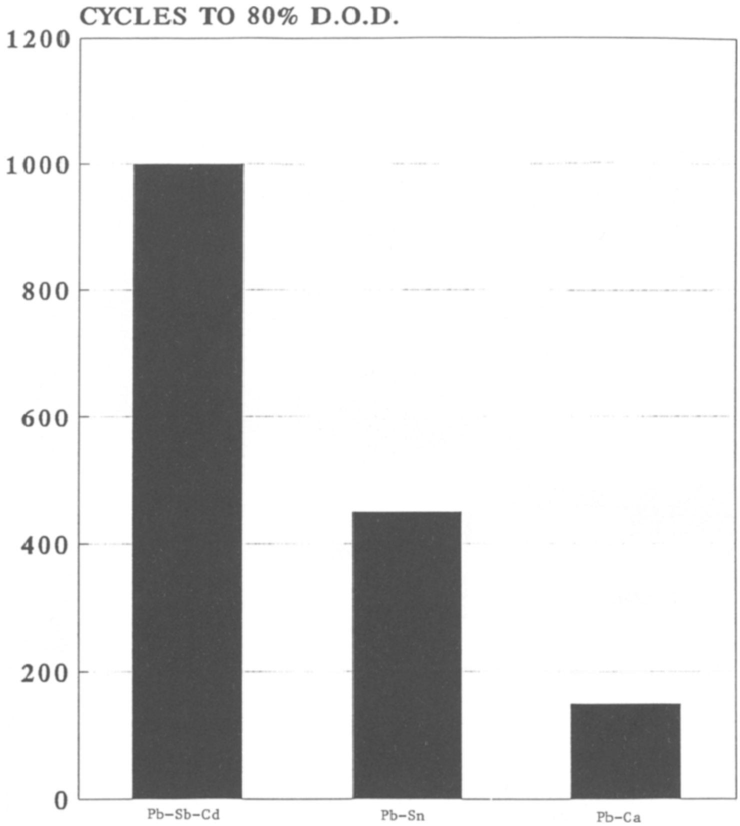


Fig. 2. Effect of positive grid alloy on cycle life of valve-regulated batteries.

to form a seal. This provides a strong bond between the two parts. If the seal is cut open and examined, however, a honeycomb effect can exist in the case of flame-retardant ABS (acrylonitrile/butadiene/styrene) materials. Usually, this does not create a problem, but it does provide the opportunity for a leak track to be produced. Although the honeycomb effect is not evident with flame-retardant polypropylene materials, leak paths can still develop when using such materials.

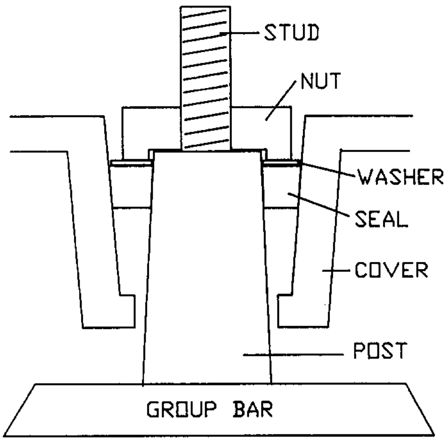
Post-seal leaks

Post seals are made in a number of different ways and two different methods are illustrated (Fig. 3). Both designs are known to have produced leaks, but only under abnormal conditions. With type 1 (Fig. 3(a)), leaks can originate from: a badly moulded post; incorrect torque on the nut; inadequate or incorrect sealing lubricant, and external pressure on the post. For seal type 2 (Fig. 3(b)), porosity of the die cast bushing and faulty post-to-bush burn can give rise to leakage problems.

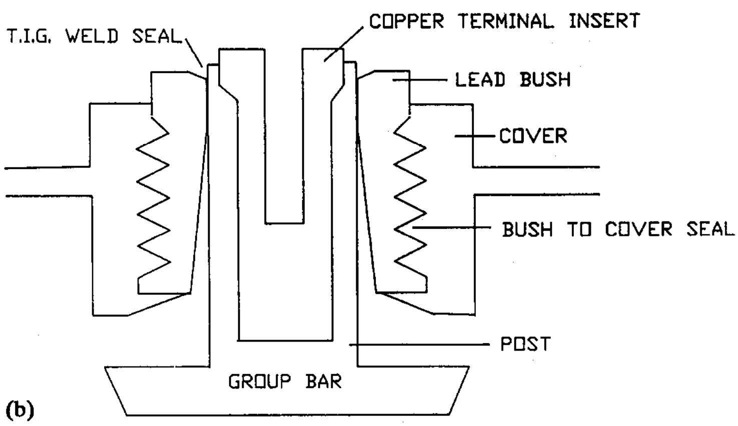
Vent leaks

This form of leak is rare and, in most cases, is attributable to a faulty valve. It has also resulted from an undetected acid-overfill.

Obviously, the aim is to prevent the occurrence of leaks of any type through the adoption of a good design and quality control procedures. It is particularly important,



(a)



(b)

Fig. 3. Two different designs of post seal: (a) type 1, and (b) type 2.

however, to be able to test adequately for leaks in order to ensure that any faulty cell is found during the manufacturing stage.

Figure 4 depicts the distribution of leaks in terms of the number of leaks as a function of the leak rate. THe latter is expressed as ml s^{-1} under a pressure of 1 atm using helium gas as the test medium.

Other issues with valve-regulated batteries

The following are several points that are commonly raised by users of VRBs.

Ripple current

Since nearly all charging systems are derived from the a.c. mains, the output of the charger, although filtered, will still contain some a.c. ripple voltage. The latter will, in turn, impose an a.c. ripple current in the battery circuit. The impedance of fully-charged batteries to an a.c. impressed voltage component is quite low and,

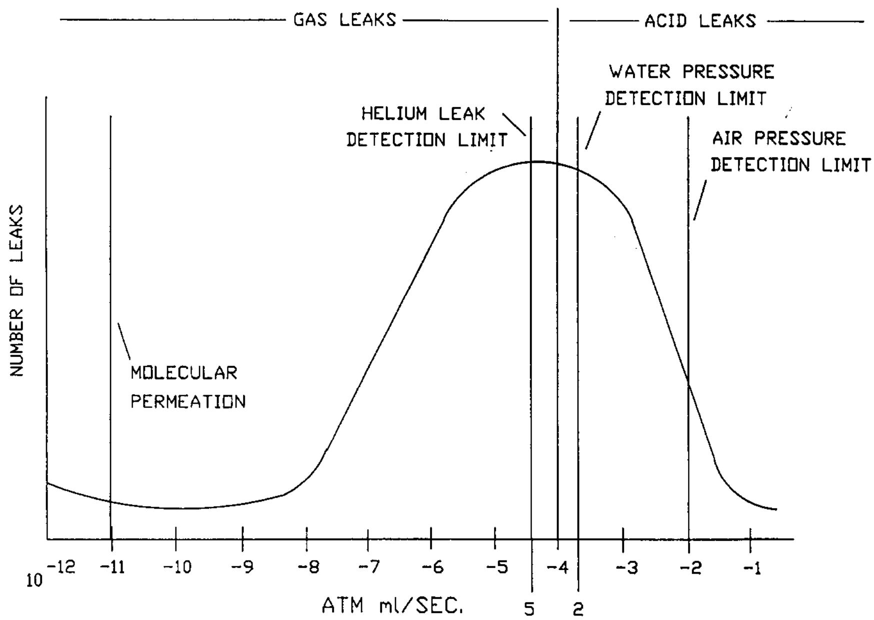


Fig. 4. Leakage rate at 1 atm pressure using helium gas as the leakage medium.

therefore, small voltage variations cause significant a.c. current in the battery circuit. Since the amount of filtering in the charger is a compromise between cost and performance, the battery will always experience and a.c. current component. The value of the latter is generally influenced more by the load than by the charger. This is particularly true for nonlinear loads. The inverter of a UPS is the commonest example of this type of condition and has been the cause of severe grid-corrosion failure that has been witnessed in a number of VRBs.

Manufacturers quote a range of maximum values of a.c. current that are related to the nominal Ah capacity of the battery. Values of up to 10% are common; this means 10 A rms for a 100 Ah battery. The graphs in Fig. 5(a) demonstrate the significance of this effect by showing the ripple current (assuming a sine-wave current) superimposed on the float current. Ripple current has two detrimental effects. First, it always increases the temperature of the battery and, second, it has been seen to contribute to severe, and sometimes localized corrosion of the positive grid and also positive-post failure in flooded cells. This is not a subject on which comprehensive information is readily available, but there is certainly clear evidence that premature battery failure has occurred in association with inverter loads that involve both flooded and valve-regulated lead/acid batteries, as well as nickel/cadmium batteries. From the point of view of the battery manufacturer, ripple current is not wanted in the battery, since it is obviously not going to assist battery life. In practice, however, since there will normally be some ripple current, this should be kept to a minimum.

It is also desirable that the instantaneous current in the battery does not reverse cyclically to produce an alternating current as this creates a repetitive charge/discharge cycle at the ripple frequency (Fig. 5(b)).

The IEEE recommendation on determining the limits of ripple current is that the temperature measured at the negative terminal is not more than 3 °C above

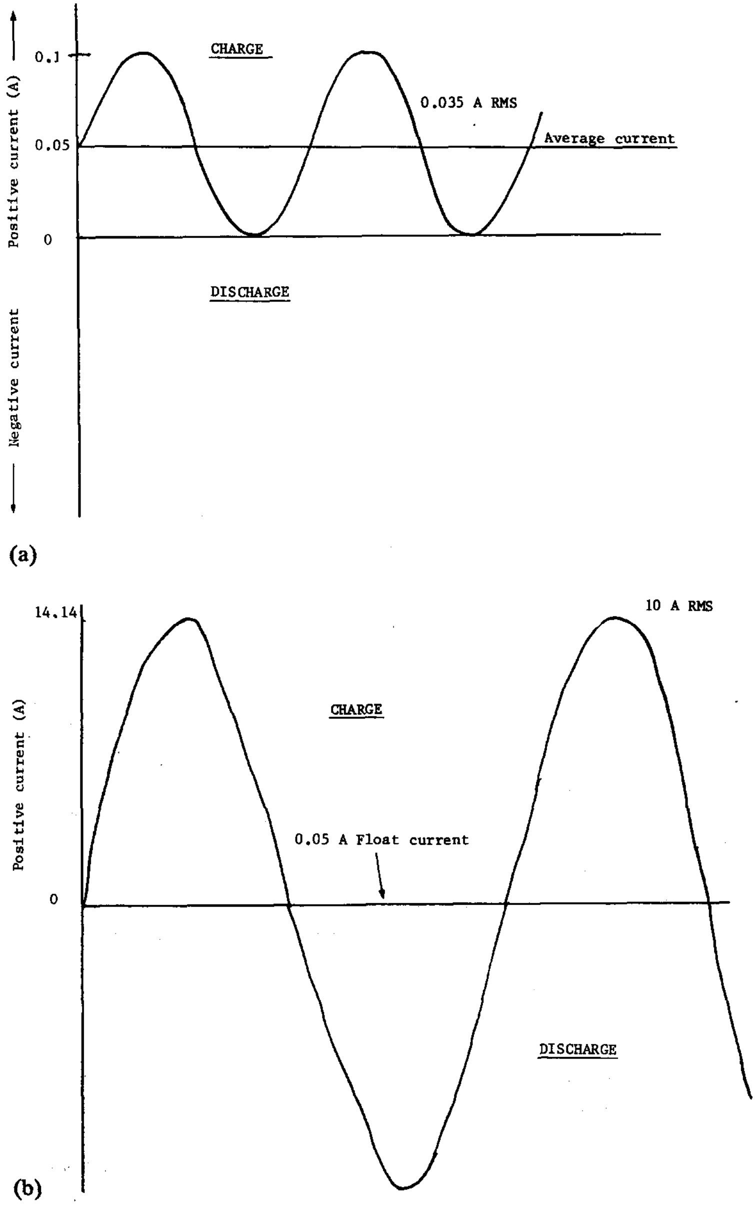


Fig. 5. Schematic of ripple current superimposed on float current (a) low ripple current, no battery current reversal, and (b) high ripple current, battery current reversal.

ambient in a fully-charged float condition. This method provides a relatively easy way of quantitatively approaching the problem; it is based on the fact that ripple causes heating irrespective of what else it may do.

There is now strong evidence to show that premature failure in some VRBs has actually been caused by excessive a.c. current in the battery that has arisen from both the charger and the load.

Variations in float voltage

It is well known that the float voltages of individual cells in a series string of VRBs frequently differ significantly from each other, particularly during the early stages of service life. This effect causes considerable concern to many users who are more accustomed to flooded cells. Nevertheless, when a battery in this condition is discharged, the individual cells generally track each closely.

The current in each cell in a string is the same and the voltages vary for two main reasons. The most significant factor is differences in the level of saturation of the separators. A cell that is oversaturated will exhibit a high voltage compared with an equivalent cell of low saturation. During initial conditioning, the cell behaves as a flooded cell and water is driven off to bring the separators to the correct saturation point. Slight variations in separator saturation produce concomitant effects in the negative-plate voltage. Cells in this condition will continue to lose water and therefore the problem is self-correcting. The problem has been reduced by the use of more accurate acid-filling systems. These ensure that correct quantities of acid are added to each cell. Variations in charge conditioning is normally not a problem since cells are conditioned in series strings and, therefore, all receive the same Ah input.

The second significant factor that gives rise to differences in cell voltage is variation in the degree of plate formation. Cells with slightly underformed plates will float low. Again, this condition is self-correcting. For these reasons, new cells in a series string that is connected to a constant-voltage charger will move closer together with the passage of time.

Initial value of recharge current

The maximum value of current used for recharge is a contentious point. Manufacturers quote figures ranging from 'unlimited' to *C*/4 to *C*/10. Normally, the 'unlimited' value is qualified as being at the float-voltage limit of about 2.25 V/cell.

Flooded lead/acid batteries can become out of step, but because in most cases the batteries are recharged to above the float-voltage level, the problem is not serious. It is not unusual, however, to charge a single cell, or cells, in a bank in order to bring them into line.

With VRBs, boost charging is not usually recommended as it will unnecessarily increase drying out of the separator. Provided the battery is not deep-discharged, there are generally no problems on recharge. If the battery has been deep-discharged and high recharge currents are applied, the battery will rise quickly to the constant-voltage level. Some cells will be at very high voltages and others will still have a low voltage. The problem is that, at this point, the recharge current drops off and the low cells do not recharge fully. Continuous cycling causes the situation to become worse and eventually, a cell will go into reverse. This causes the cell quickly to become very hot and to be generally irrecoverable.

The lower the recharge current, the more efficient the recharge becomes. Recharging at around 10% of *C*/10 is an efficient level. By way of example, tests carried out on recharging at *C*/2.5, i.e., 40 A per 100 Ah, from a fully-discharged state, on a healthy battery gave a useable capacity of only 9.5% at the point the battery reached the constant-voltage float level. Recharging at *C*/10 will give about 80% at the point of reaching the constant-voltage float level.