History and current status of valve-regulated lead/acid batteries in Japan

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Abstract

The valve-regulated design of the sealed lead/acid battery (VRB), developed in the first half of the 1960s in Japan for use in portable television sets, has achieved successful market growth. This paper reviews the history of development of VRBs during the past thirty years, present production models, production quality, major applications, and technical problems.

Introduction

Today, valve-regulated lead/acid batteries (VRBs) are used in a number of storage applications, the starting, lighting and ignition of motorcycles and agricultural machines, and the powering of golf carts. The batteries are maintenance free, do not suffer from liquid leakage, do not require topping up, and have a lower unit price per W h than nickel/cadmium counterparts. In Japan, a small portable lead/acid system was developed in the 1950s as a cigarette lighter battery, or was sold as a rechargeable equivalent to the D-size carbon/zinc battery. Full-scale development commenced in the 1960s, and is continuing today.

Sealed nickel/cadmium batteries were manufactured using the Neuman patent for the gas-recombination cycle principle, but the cost per W h was high. Batteries ranging from the D-size to 400 A h capacity have been developed, but at present the majority are of the AA size.

Lead/acid batteries have high economic advantage in that the unit cell voltage is high and the principal materials are low in cost. Hence, the cost per W h is low. Large-capacity batteries were developed to meet the market needs, and improvements were achieved in the high-rate discharge performance. About 50 battery models are currently marketed with capacities between 0.5 and 3000 A h per cell. In Japan, both absorptive glass mat (AGM) and gelled-electrolyte types of sealed batteries were produced initially, but the former have now gained dominance.

The production technology of VRBs developed in Japan has been successively transferred to other countries. This has allowed the power sources for electric/electronic devices to become maintenance free and has accelerated the development of portable electronic devices as reserve power sources with high security and reliability. The history of the development of VRBs in Japan is reviewed in this paper, and the current status of production and applications is discussed.

0378-7753/92/$5.00

History of VRB development

First period

One of the drawbacks of lead/acid batteries is the leakage of sulfuric acid. This can cause hazards to both ancillary equipment and people. There has therefore been a long-standing desire to prevent these hazards by developing a sealed design of battery. Initial attempts were aimed at improving the mechanical construction of the battery ventilation system. Typical results of this work were safer batteries for miners' caplamps and signalling lamps. The application of electrolyte-retaining materials was investigated in the 1940s. In the 1950s, the characteristics of the existing synthetic resin allowed a battery container to be made with sufficient elasticity to cope with the gas pressure generated during charging. This resulted in the emergence of a small battery for cigarette lighters [1], as well as a D-size version that used a gelled electrolyte. Unfortunately, these batteries exhibited wide differences in capacity and cycle life and, consequently, were withdrawn from the market. Although the batteries were labelled 'leak-free', the majority required water replenishment, had a small volumetric A h capacity, and could tolerate only a small charge current. Around 1959, Yuasa developed a battery (6 V, 3 A h) for a portable television set that was manufactured by Sharp [2]. The negative plates of this battery were wrapped with rubber separators, the bottom ribs were eliminated to maximize the retention of electrolyte in the plate groups, and part of the group was exposed to air so that the negative plates could absorb the evolved gas.

Second period

In the 1960s, a wide variety of portable electric devices was rapidly developed. At first, carbon/zinc batteries were used as the power source, but because of the frequent need to replace the batteries, it became more convenient to employ sealed nickel/cadmium batteries. Nevertheless, the high cost of the latter forced the requirement for cheaper sealed lead/acid batteries. As a consequence, Yuasa developed a maintenance-free battery using a non-woven fibreglass retainer. This design was supplied to Crown for portable television sets, and to Akai Electric for powering those companies' products. At the same time a cylindrical lead/acid battery was produced by Yagishita, but the sales were less than 100 000 units per annum. The Yuasa battery used lead-plated Pb–Sb grids for cycle service applications and gave 100 to 150 cycles. The battery models ranged from 1 to 8 A h [3]. Batteries using a gelled electrolyte made from a mixture of silica and sulfuric acid were also developed in Japan [4].

Third Period

The first half of the 1970s saw the expansion of battery applications to fire alarms and emergency lights. This required batteries with a capability for float or trickle-charge service. Initially, gelled-electrolyte batteries were preferred, but gradually a shift was made to AGM batteries. The latter were adopted by Yuasa [5–7] and had capacities of 3 to 8 A h. To improve the overcharge performance, the partially exposed negative electrode system was used and Pb–Ca alloys were introduced [8]. At that time, battery chargers were either constant current–voltage systems or two-step constant voltage systems.

Fourth period

In the mid to late 1970s, the use of VRBs was extended to crime prevention devices, UPS [9, 10], telecommunications and medical equipment, and video tape recorders [11–13]. The expanded demand created the need for a battery that could be used for both cyclic and trickle-charge service [14]. This was realized by preventing softening of the positive active material and the use of Pb–Ca–Sn alloy to reduce grid growth. In addition, alkali metal ions were added to the electrolyte to improve charge characteristics [15].

Fifth period

In the 1980s, the success of the small VRBs [16, 17] prompted the sealing of the large-size flooded batteries, Yuasa was at the forefront of this development. Telecommunications applications have accelerated the use of these batteries. A particular advantage is that battery rooms can be eliminated. Batteries with capacities from 100 to 3000 A h have been developed under cooperative work with NTT [18–22]. A version of VRB technology has been introduced for motorcycle starting and lighting in order to guarantee safety when the machines fall over [23–27]. Specifications included an assurance of a starting performance at low temperatures, and reduced cost based on standardized mass production. In order for the battery supply to match the conventional motorcycle battery distribution system, it was necessary to ship the batteries in a dry-charged condition. The batteries are filled with electrolyte and sealed immediately prior to service. To meet these requirements, vigorous advancement of mass-production facilities was undertaken, and a method was developed to fill a certain amount of electrolyte both accurately and reliably. The success of a motorcycle VRB was achieved through the cooperation of the vehicle maker in standardizing the alternator voltage. The battery charger employed a switching regulator circuit.

Sixth period

From 1990 to the present date, VRB applications were further expanded. An increase in the high-rate capacity per unit volume was requested for portable use, as well as extended service life for UPS applications. These demands necessitated an enhancement of the precision in battery-plate manufacture and quality, as well as in other components [28]. Flame retardation was also requested in the case of synthetic resin containers in order to assure safety towards the end of battery life. In order to gain even better product consistency and cost reduction, further progress has been made in raising the precision of battery production facilities. At the same time, the market demand has increased for thin-type batteries for video tape recorders. Microcomputers have been introduced for the control of battery chargers.

The transitions in VRB design discussed above are summarized in Fig. 1.

Current status of VRBs in Japan

Production model

The following types of VRB are in production in Japan:

Large-size battery	100 A h/2 V		3000 A h/2 V
Medium-size battery	15 A h/2 V	38 A h/2 V	65 A h/2 V
Small-size battery	1.2 A h/6, 12 V		10 A h/6, 12 V
Thin-type battery			

The small-size battery includes the 'H' type battery that has a high-rate discharge capacity.

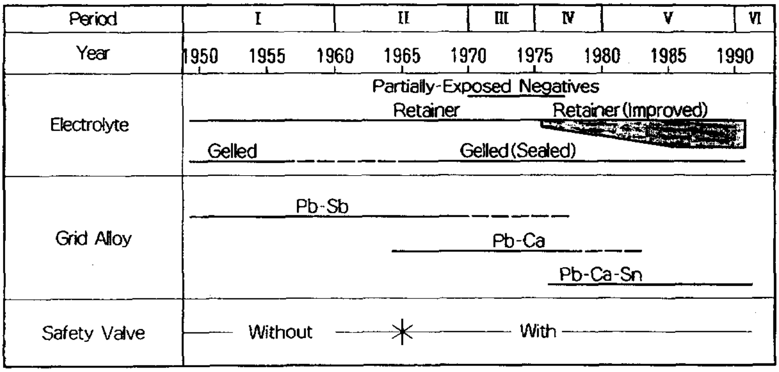

Fig. 1. Development of small-sized lead/acid batteries in Japan.

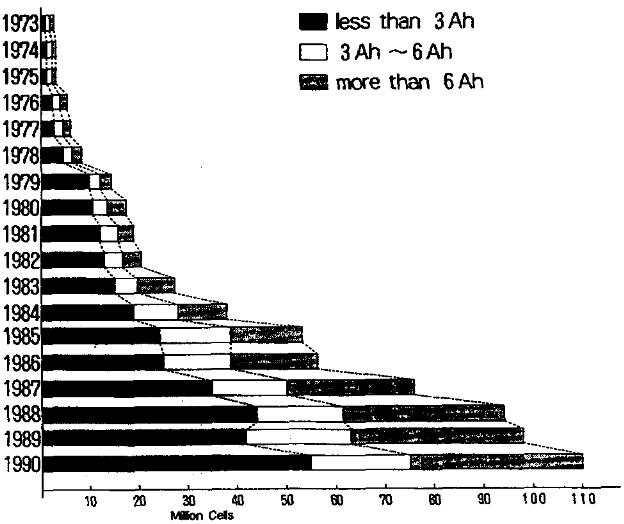

Fig. 2. Production of small-sized VRBs in Japan (data obtained from Japan Storage Battery Association).

Production and shipment quantities

Recent trends (Fig. 2) in VRB development in Japan show that Yuasa is positively transferring the technology and manufacture of these batteries to other countries, that the production of batteries in the 3 to 6 A h class has become nearly constant, and that the production of small-sized batteries is increasing with thin-type batteries as the main item. Both the latter technology and the large-sized batteries (converted from conventional flooded-electrolyte type) have been transferred less to other countries. In terms of metallic lead tonnage, the VRBs as a whole surpass that for traction batteries, and are now ranked second to automotive batteries. About 60% of the VRBs are exported.

Applications

Figure 3 shows the distribution of applications for small-sized batteries from 1985 through 1990. The major changes during these five years are the increase of use in

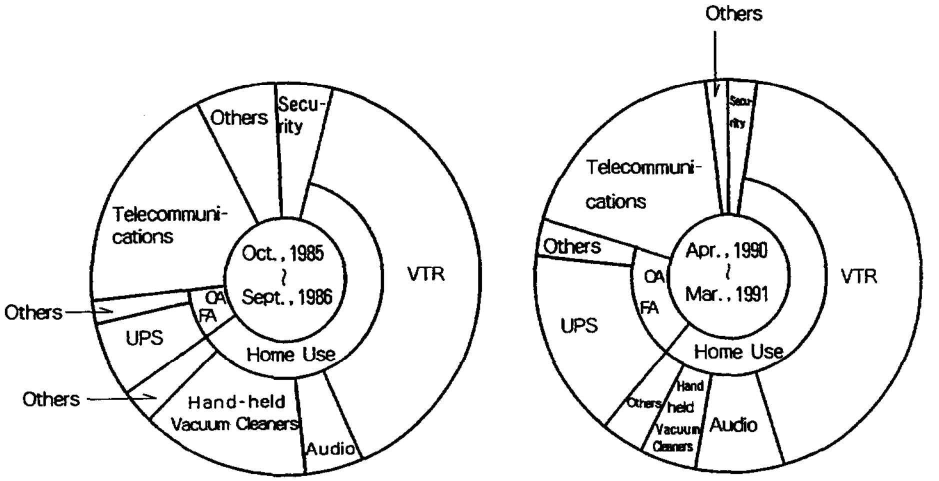

Fig. 3. Applications of small-sized VRBs in Japan (estimation).

UPS systems and audio devices (e.g., walkie-talkies), and the decrease in hand-held vacuum cleaners. Taking account of new applications, other areas exhibit approximately the same ratio.

The production of large batteries is increasing due to the growth in demand for UPS installations. The general trend is that conventional batteries are being replaced by VRBs in order to achieve maintenance-free operation, and that no new applications other than UPS, are being developed.

For vehicle use, the motorcycle market is undergoing a gradual increase. By contrast, no VRBs are being formally employed in automobiles; only trials are in progress. Agricultural machines, particularly those subject to tilting and vibration, are beginning to use VRBs for engine starting. Finally, it is expected that VRBs will be made suitable for electric road vehicles.

Problems to be solved

Volumetric reduction. This is necessary to meet the size requirements of portable devices and stationary facilities, or those situations where there is restricted floor space for the battery installations.

High-rate discharge performance. When used for UPS systems, a short-time compensation feeding is more useful because of the demand for reduced power-failure times and, therefore, enhanced commercial power-supply reliability.

Charge-acceptance performance. Following on from the last requirement, short-time deep discharges must be recovered quickly (within 1 h).

Longer life. Batteries must last for more than ten years in UPS applications.

High-temperature performance [29] and flame retardation. The batteries must use flame retardant parts.

Automotive use. Batteries must guarantee their performance even if the charge voltage varies over a wide range.

Conclusions

The production of VRBs in Japan and other countries has promoted the development of devices using such batteries, has helped to expand battery applications, has brought about increased lead consumption, and has given users products with added convenience and safety. Japanese battery development engineers, who have maintained continuous efforts to improve VRBs, take great pride in the success of the technology. It should be remembered that the products are rarely used as 2 V units, but rather as 12 V, 48 V, or even as high as 300 V batteries in high-precision electronic devices that require a high degree of safety and reliability.

Given the above features of VRBs, production facilities with a high level of automation and precision have been developed. Very strict quality control methods have also been implemented. It should be noted that VRBs can be produced to meet the requirements of quality, cost and delivery time only when production technology, manufacturing technology and quality control technology are comprehensively combined and operated at the production site. In this respect, the quality-control methods represented by the TQC system developed in Japan have greatly contributed to the expansion in demand for these batteries.

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