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Eight years of experience with valve-regulated batteries for automotive use

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Abstract

In 1985, Matsushita developed a valve-regulated lead/acid (VRLA) battery with an expanded grid for automotive use. Since 1989, these batteries have been adopted as original equipment for cars. To take full advantage of their benefits, the batteries are installed away from the engine compartment, for example, in the boot of the car. Despite a steady market for automotive VRLA batteries, there are still a few problems that accompany their use. These must be solved in order to enhance reliability and improve customer satisfaction. The major areas of concern are life at high temperature, and recovery after over-discharge and long standing. Work in these areas is reported here.

Keywords: Automotive batteries; Lead/acid batteries; Valve-regulated lead/acid batteries

1. Introduction

The main criteria for automotive batteries are small size, long life, good reliability, and low cost. More recently, maintenance-free operation has also become important. The maintenance-free characteristics of automotive batteries have made rapid progress following the application of lead–calcium–tin alloys for the grids. It is well known [1,2] that valve-regulated lead/acid (VRLA) batteries exhibit ideal maintenance-free features, e.g., there is no requirement for water addition during normal life, the batteries are free from electrolyte spillage or release of gas or mist. Ideally, the batteries should be located well away from the engine compartment.

VRLA technology first made a major impact on industrial and consumer applications in the early to mid 1980s.

Eight years ago, we developed and introduced into the automotive market a VRLA battery with expanded-metal grids. After a few years, it was adopted as original equipment for cars. Now, it is expected to receive more widespread acceptance. At the beginning of the development, certain difficulties such as productivity, adaptability to the automotive charging system and recovery after over-discharge received special attention. The performance has been improved in many areas during the intervening period in order to reach a high level of battery reliability. The actions taken and the advances made are discussed in this paper.

2. Battery structure

In general, automotive batteries are produced with high productivity. Thus, their cost is lower than that of same-capacity VRLA batteries for industrial or consumer use. The latter batteries are expensive because of their special materials and more complex manufacturing method. In order to achieve comparity in production cost, a VRLA design has been developed that can be produced by present automotive-battery manufacturing equipment and from similar materials. The design of the battery is given in Fig. 1.

By virtue of their high productivity, lead–calcium–tin alloy expanded grids are used for both the positive and the negative plates. A mat separator that can be enveloped has been developed specifically for the battery. This separator is made from glass fibre, polyester fibre and inorganic powder. The container (with an end wall of reinforced shape) and the cover are made from polypropylene resin and are joined to each other by heat welding. These manufacturing methods are almost the same as those used for conventional automotive batteries. A vent valve is fitted in the cover; a flat, rubber-sheet device is found to be effective and to

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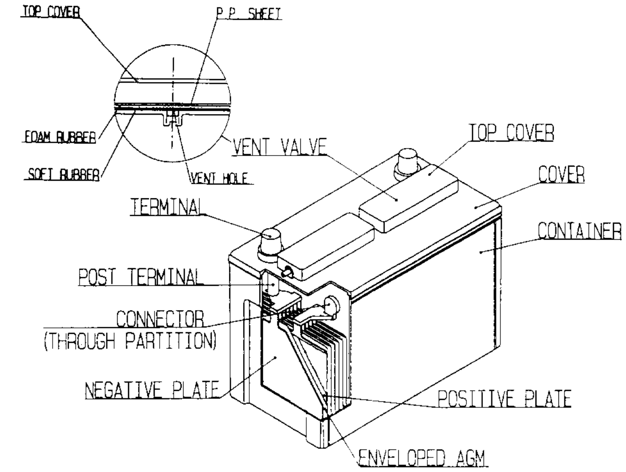

Fig. 1. Battery design.

Table 1
Dimensions, weight and performance of Panasonic VRLA batteries for automotive applications

Model	Size			Weight (kg)	RC (min)	CCA (A)
	h	*w*	*l*			
ACT50A19	170	127	187	7.0	30	250
ACT60B19	227	127	184	8.0	40	270
ACT80B24	227	129	238	10.8	60	360
ACT90D23	226	173	222	13.5	80	420
ACT100D26	226	173	259	16.0	95	460
S46A24	187	128	238	9.7	56	350
S55D23	226	173	222	13.8	85	450

simplify the construction. As a result of this approach, the VRLA batteries can be produced by present automotive battery equipment with high productivity.

To date, seven sizes of automotive VRLA batteries have been developed and marketed by Matsushita. The specifications of these batteries are given in Table 1. Models ACT50A19 to ACT100D26 are for the replacement market; models S46A24 and S55D23 are for the original equipment market.

3. General battery performance

Table 2 compares the dimensions, weight and specific performance of conventional flooded-electrolyte (type 46B24) and VRLA (type S46A24) automotive batteries. The data show that VRLA batteries give a 20% reduction in both volume and weight for the same cold-cranking (CCA) rating. Moreover, at high rates of discharge, the voltage is maintained at a higher level (Fig. 2). As expected, however, the low-rate (*C*/5) capacity and the reserve capacity (RC) are both lower for VRLA batteries.

Table 2
Comparison of VRLA and flooded-electrolyte types of automotive batteries

Type	Size			Vol. (l)	Wt. (kg)	RC (min)	*C*/5 (Ah)	CCA (A)
	h	*w*	*l*					
VRLA (S46A24)	187	128	238	4.9	9.7	56	32	350
Flooded (46B24)	227	129	238	6.2	12.0	70	38	350

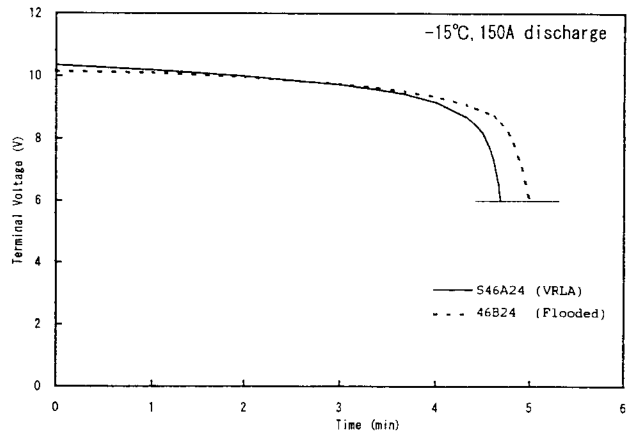

Fig. 2. High-rate discharge characteristics at 150 A (−15 °C).

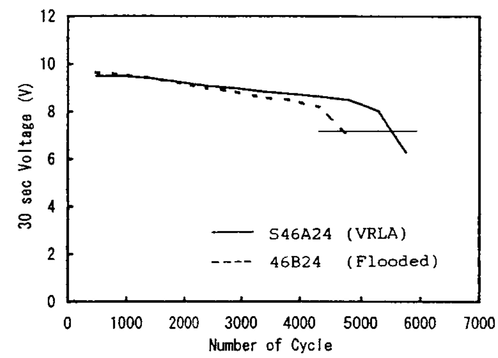

Fig. 3. SAE J 240 cycle-life test.

The results of SAE-J240 and JIS-D5301 endurance tests are given in Figs. 3 and 4, respectively. In both cases, VRLA type S46A24 units deliver better performance, especially for the JIS deep-cycle endurance test in which the battery depth-of-discharge is about 40%. It is concluded that the enhanced performance is due to the fact that the positive plates are held by the glass-mat separators (i.e., reduced active-material shedding).

The two types of battery designed specifically for original equipment, namely, S46A24 and S55D23, have been installed either in the luggage compartment of cars or at another place away from the engine compartment. Such locations are required for improved drivability, the adoption of aerodynamic vehicle design, etc. The relationship between the characteristics of

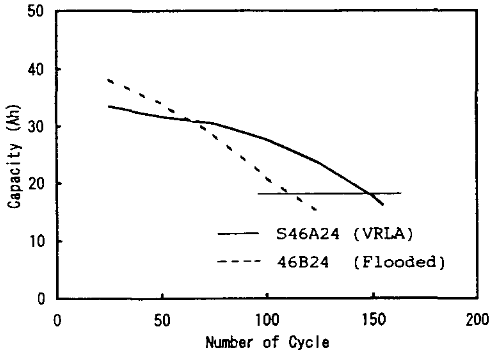

Fig. 4. JIS D 5301 deep cycle endurance test.

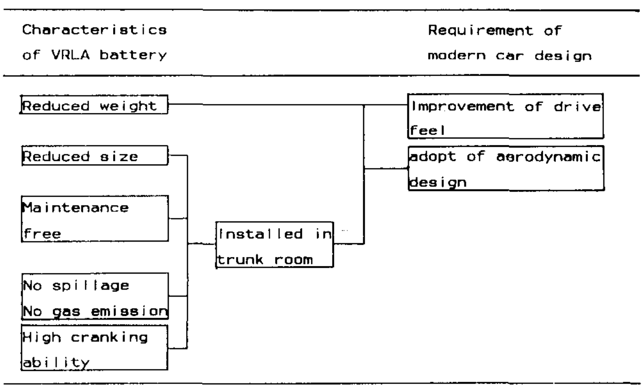

Fig. 5. Requirement of modern car design and characteristics of VRLA battery.

VRLA batteries and the requirements of modern car design are shown schematically in Fig. 5. In summary, the advantages of VRLA technology for automotive use are: (i) reduced size and weight; (ii) longer lifetime; (iii) high cranking ability; (iv) maintenance free operation; (v) suitable for installing at other locations within the car.

4. Overcoming some problems

As mentioned above, VRLA automotive batteries offer many advantages over conventional flooded-electrolyte batteries. Nevertheless, there have been some particular problems caused by the small amount of electrolyte used in the VRLA design and the gas-recombination characteristics. These include recovery after over-discharge and positive-grid corrosion at high temperatures.

4.1. Recovery after over-discharge

In general, non-antimony type batteries are inferior in rechargeability after over-discharge and long standing [3,4]. The problem is attributed to a passivation process at the thin interfacial layer between the active material and the calcium-alloy grid in the plates. This is caused by the combined effects of high potential due to the residual PbO_2 and high pH after over-discharge. These effects are critical in a VRLA battery because it contains small amounts of electrolyte, i.e., it has a high ratio of sulfuric acid to positive active material. When the VRLA battery is over-discharged, a large amount of PbO_2 is unconverted and the pH of the electrolyte rises.

In order to improve the poor recovery of antimony-free batteries after over-discharge, a tin-rich alloy clad to wrought sheet was developed [5]. Fig. 6 gives a schematic of the clad method, and Fig. 7 shows the grid design. This method has proved effective for VRLA batteries under typical over-discharge. For example, it protects against battery damage when an interior light is inadvertently left on in a car for about a month [5]. In more severe conditions, however (i.e., over-discharge by a small current for a long period) this method is not adequate for VRLA batteries. The tin content of the surface of the wrought lead–calcium–tin alloy sheet has to be increased. It is not sufficient simply to increase the tin content of the base alloy sheet. Experimental results are given in Fig. 8. The detailed phenomena and mechanisms of the process have been discussed previously [6].

4.2. Improvement of positive-grid corrosion

The overcharge current of a VRLA battery at constant voltage is more comparable to a flooded-electrolyte equivalent because of the gas-recombination reaction. Fig. 9 shows the relationship between the charging voltage and the charging current. Line C is for a typical flooded-electrolyte battery with a lead–calcium–tin alloy;

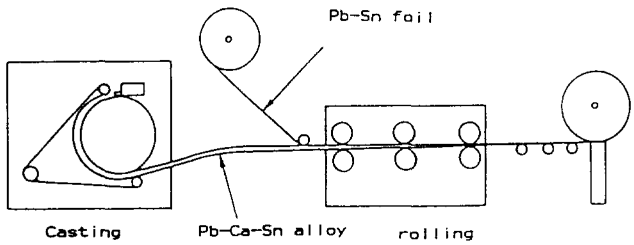

Fig. 6. Schematic representation of the clad process.

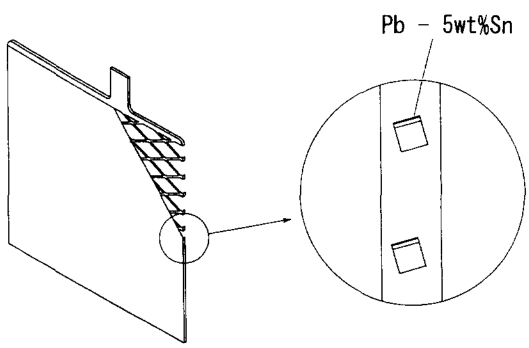

Fig. 7. Structure of grid with clad.

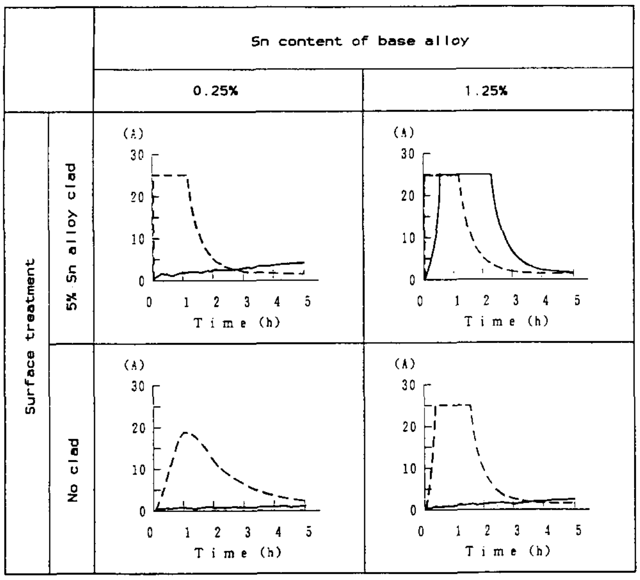

Fig. 8. Charging characteristics after overdischarge. Discharge condition (temperature 40 °C): C/5 discharge to 10.5 V. --- Discharge with 15 Ω resistor for 14 days, open circuit for 14 days; — discharge with 1 kΩ resistor for 6 months. Charge condition: 15 V constant voltage charge (max. 25 A).

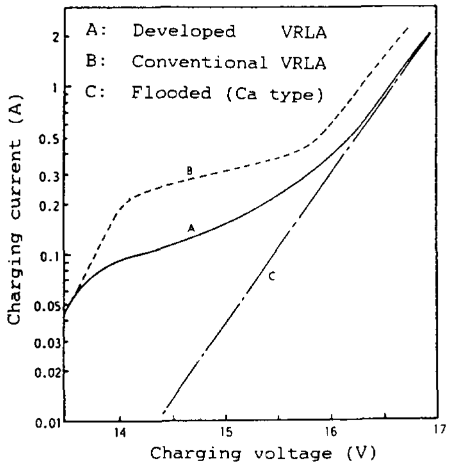

Fig. 9. Charging characteristics of VRLA and flooded-electrolyte batteries.

line B is for a typical VRLA battery with a conventional glass-mat separator. From the two performances, it can be concluded that the VRLA battery has the better charge-acceptance behaviour. From a different point of view, however, this means that the battery tends to be overcharged. Line A is an example of a VRLA developed for automotive use. The gas-recombination characteristics of this battery are restrained compared with those of a conventional VRLA battery. As a result of this, the charging current, which is associated with corrosion of the positive grid, is controlled and the developed VRLA battery can be adopted to the present automotive charging system. One of the reasons for this added control of the gas-recombination process is the properties of the newly developed glass-mat separator.

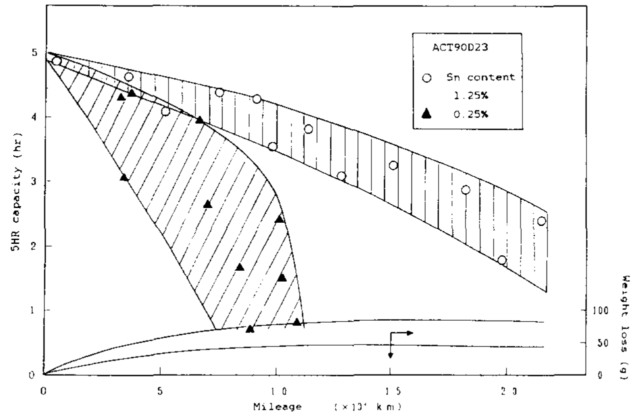

Fig. 10. Field test of VRLA batteries in taxis.

During the past decade, temperatures in the engine compartments of automobiles have risen [7]. Thus, the life of batteries subjected to these higher temperatures has become increasingly important. The main failure modes of non-antimony batteries at high temperatures are corrosion/growth of positive grids, and loss of contact between the grid and the positive active material. As these phenomena are accelerated by both high temperature and overcharge, high temperature influences the life of VRLA batteries more than that of flooded-electrolyte types. An increase in the tin content of the lead–calcium–tin alloy used for the positive grid is very effective in improving the corrosion resistance of the grids at high temperatures [8]. This approach is equally beneficial in the case of VRLA automotive batteries.

Fig. 10 shows the results of a field test that was performed in taxis. In this test, the battery temperatures were more than 75 °C during the summer season. Batteries that used grids with a high tin content gave a much longer lifetime than those with low tin contents. Moreover, drying out of the electrolyte, which was thought possible at high temperature, was not experienced. The gas-recombination efficiency of the developed VRLA battery was good in almost all cases.

5. Conclusions

Some advantages and problems (and related solutions) of VRLA batteries when used in automotive applications have been presented. The results are based on an experience of producing and selling these batteries for the last eight years. Advantages, such as the flexibility of being able to install the battery elsewhere than the engine compartment, have been appreciated in actual use.

Improvements have been sought for some of the problems that, to date, appear to be inherent with VRLA batteries or batteries with non-antimony alloy grids. As a consequence, the reliability of the battery has been increased remarkably.

Today, VRLA batteries for automotive use are gradually gaining ground. It is expected these batteries will become even more popular.

References

[1] E. Nann, *J. Power Sources, 33* (1991) 93.
[2] D. Calasanzio, G. Cecchinato and M. Marchetto, *J. Power Sources, 42* (1993) 247.
[3] D. Pavlov and B. Monakhov, *J. Electrochem. Soc., 133* (1989) 27.
[4] J. Garche, *J. Power Sources, 30* (1990) 47.
[5] K. Takahashi, N. Hoshihara and H. Yasuda, *J. Power Sources, 30* (1990) 23.
[6] K. Takahashi, H. Yasuda, N. Takami, S. Horie and Y. Suzui, *J. Power Sources, 36* (1991) 451.
[7] T. Ochiai, *J. Power Sources, 33* (1991) 291.
[8] K. Takahashi, H. Yasuda, K. Yonezu and H. Okamoto, *J. Power Sources, 42* (1993) 221.