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Progress in the design and development of improved lead/acid batteries for electric buses and vans

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Abstract

Transit and shuttle buses are certainly amongst the most suitable of all road vehicles to move by electric power. The restricted operational areas, nearly constant driving range and, in many cases, fleet operation, makes this application ideal for high-performance lead/acid batteries. This paper summarizes the practical experience gained from the operation of batteries in electric buses. It then describes the technical background to the products used and gives a view on future improvements and developments.

Keywords: Electric vehicles; Lead/acid batteries; Design

1. Introduction

During the last decade, CMP Batteries (part of the CEAC Group) has continued to support electric-vehicle programmes and progress the development of advanced lead/acid batteries. The technology base for this progress has been the use of thin, tubular, positive plates. These have been employed to get maximum cycle life and reliability, whilst maintaining good energy density.

Currently, as a consequence of environmental considerations, there is a significant worldwide increase in the development and promotion of the electric-vehicle concept. This is especially so in the USA, where the Government and other agencies are contributing considerable support and funding. There is also a large impetus being generated by an increasing awareness of real commercially viable projects such as vans and, especially, buses. In these applications, the lead/acid battery can be optimized to make best use of its specific attributes. Consequently, CMP is continuing its development of products for these applications. These products include a matched package of high energy-density batteries, efficient and specialized chargers, control systems and other accessories.

2. Lead/acid batteries and electric-vehicle applications

When comparing EV applications, a superficial view on the general demands of the small car and a bus can be made. This is shown in Table 1. It is evident that lead/acid bus batteries are not inflicted with the apparent contractions on battery specification that the car generates, i.e., every conceivable requirement at lowest cost. This is what makes the bus application so attractive. This, together with a potential worldwide market place for transit and shuttle buses in 2-V cell terms, is equivalent to half the conventional motive-power material-handling business.

The suitability for electric drive is further enhanced when it is realized that the majority of buses are used in urban areas and other range-restricted districts such as airports and leisure parks. This means:

- inner city routes
- fleet operation
- maintenance staff
- restricted range
- often the existence of workshops and maintenance facilities
- skilled workers available

In summary, the suitability of buses for electric drive is shown in Fig. 1.

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Table 1
Comparison of battery requirements of small cars and buses

Battery demands	Small cars	Buses
Low battery weight	necessary	desirable
Energy density	high – desirable	medium – acceptable
Valve-regulated, maintenance free	necessary – desirable	desirable – not necessary
Cycle life	medium – desirable	long – necessary
Very fast charge	necessary	desirable – not necessary
Energy package cost	low	cost effective for large capital investment

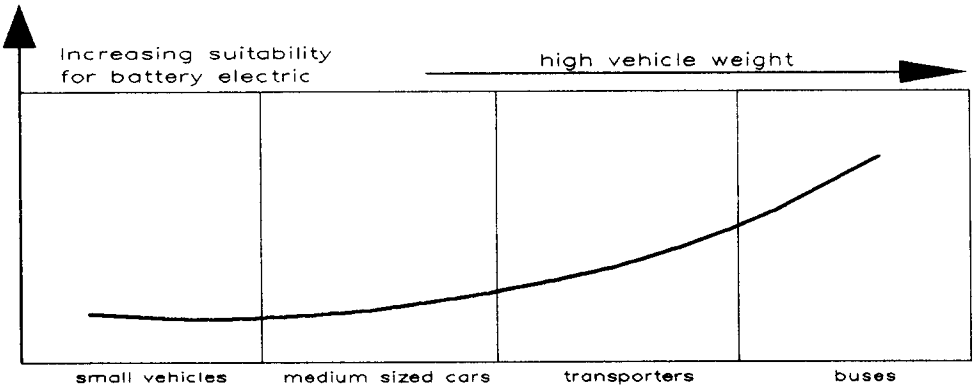


Fig. 1. Suitability of buses for electric drive.

3. Technical background and field experience

Association with major electric vehicle programmes during the past decade has provided considerable battery-related experience. A significant factor that has contributed to the evolution of the bus battery has been the successful performance and life characteristics of the thin, tubular, positive-plate technology. Table 2 shows the transition to thinner positive plates with smaller tube and spine diameters and its effects on both energy density and cycle life.

The 6-V, ET 215 Ah ($C_5/5$ rate) is the ideal battery for vans, small trucks and hybrid cars; the domain of the Classic 25 range is buses and trucks. During the last five years, more than 6000 2-V cells and 4000 6-V monoblocs have been delivered to power almost 200 buses and vans. At present, the largest fleets of buses using this technology are at CARTA in Chattanooga, TN and Santa Barbara, CA by SBMTD, which also has the longest experience. The first bus has over 50 000 miles running experience. The eight buses in service have given over 250 000 miles in total with a range of 44–75 miles per day. Moreover, 800–1100 battery cycles have been achieved. Almost all the buses are equipped with 216-V batteries in three or four trays. The battery capacity varies between 260 and 380 Ah ($C_5/5$ rate).

Table 2
Development of high energy-density electric-vehicle batteries

Battery designation	Standard performance (Classic)	High performance (Classic 25)	Advanced EV 3 ET 215[a]
Acid gravity	1.280	1.300	1.320
Plate pitch (mm)	15.9	13.5	11.4
Number of tubes	19	24	30
Tube diameter (mm)	7.5	6.1	4.9
Spine diameter (mm)	3.2	2.3	1.85
Energy density (Wh kg^{-1}) ($C_5/5$ rate)	28	36	40
Cycle life	1500	1000	800

[a] 6-V monobloc battery.

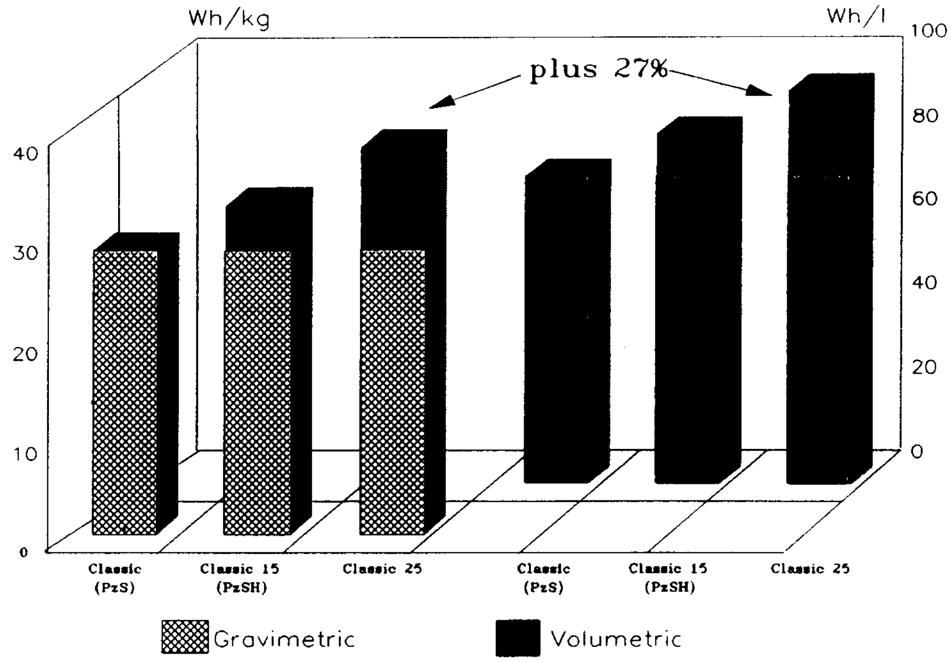


Fig. 2. Performance of motive power cells.

4. Battery technology and its development

The background to the thin, tubular, positive plate has been given. This evolution is based firmly on market needs and field experience. The performance of motive power cells in volumetric and gravimetric terms is given in Fig. 2.

There are three main areas of product development of the thin, tubular, positive-plate element. These are: (i) enhancement of capacity; (ii) reduction of watering frequency (the so-called low-maintenance technologies); (iii) conversion to a valve-regulated product (normally termed maintenance free).

4.1. Enhanced capacity

There are a number of possibilities for increasing the capacity of a DIN-sized cell that accommodates a thin, tubular, positive-plate design. In the main they are based upon increasing electrolyte availability by reducing acid displacement. For example, the performance of any motive power cell can be improved by reducing the separator volume. Conventional polyethylene (55% porous) can improve its porosity, polyethylene can be replaced by higher porosity polyvinylchloride (75% porous) or, ultimately; the use of some 'paper' at 90–95% porosity can be used. The geometry of the separator has also to be considered. A ribbed material of 1.3 mm thickness and with a backweb of 0.64 mm has a relatively small apparent volume. Papers at 1.3–1.5 mm thickness have relatively large apparent volumes. The real improvement can only be seen if thin papers can be substituted for existing separators.

In conjunction with higher-porosity separators, increasing the plate lengths to maximum by reducing to a minimum the pillar height and mud space is a technique that can be employed. The compromise here is that more frequent watering may be necessary, although this could be partially counter-balanced by the use of low-maintenance technology. Plates would also have to be completely wrapped with a high-integrity bottom seal or enveloped. The reduction in mud space is a very high-risk area.

The two developments described together with the most efficient balance of active material by possibly reducing positive and negative active materials, whilst increasing electrolyte specific gravity, could lead to significant improvements in capacity. These could be as much as 10–15%. This would give a Classic 25 (PzS H higher capacity) battery a gravimetric and volumetric energy density of 40–44 Wh kg^{-1} and >100 Wh l^{-1}, respectively. Such performance, together with a cycle life estimated at 750–1000 cycles, would considerably enhance the performance of the bus.

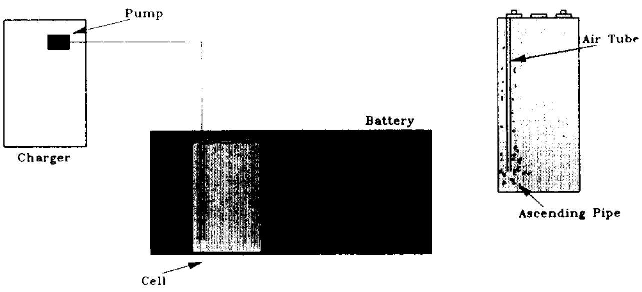
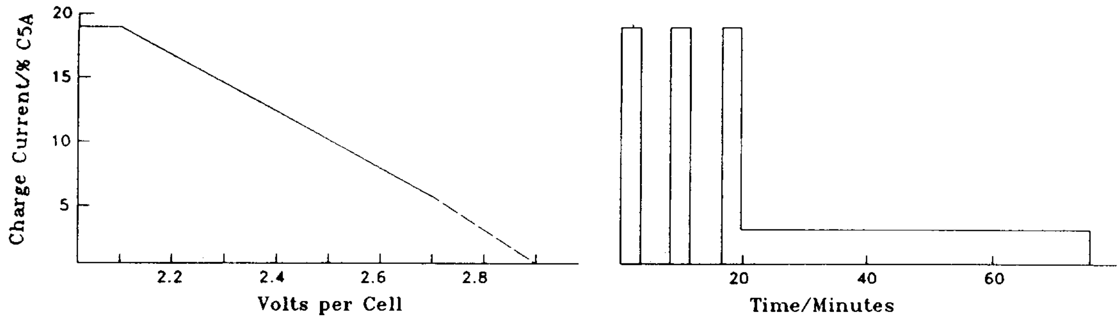


Fig. 3. Air agitation principle.



Phase 1 – 19% C5 Amps taper
terminated by dV/dt
At charge factor = 1.05

Phase 2 – Three two minute pulses at
19% C5 followed by one hour
at 2% C5

Fig. 4. Low-maintenance charging characterization.

Table 3
Development of high energy-density electric-vehicle batteries

Battery parameter	Classic 25	Classic 25 New flooded	Classic 25 MF
Working electrolyte (sp. gr.)	1.300	1.310	1.300
Plate pitch (mm)	13.5	13.5	13.5
Number of tubes	24	24	24
Tube diameter (mm)	6.2	6.2	6.2×4.9
Spine diameter (mm)	2.3	2.3	2.3
Separator type	polyethylene	polyethylene	glass microfibre mat envelope
Tube shape	round	round	rectangular
Energy density (Wh kg^{-1})	36	39	34.5
Cycle life	1000	1000	750

4.2. Low maintenance

Low charge-factor charging, or extended maintenance charging, techniques have been used for some time now in the conventional materials-handling business. Basically, a low charge-factor is used to minimize water loss through electrolysis, whilst electrolyte stratification is controlled by mixing the electrolyte either by air-pumped agitation or by relatively high current pulses of gassing charge. Using these techniques, watering periods can be extended and, additionally, the improved charge efficiency reduces the operating cost. The techniques are shown schematically in Figs. 3 and 4. The use of these techniques for electric vehicle applications has been previously cited in a paper by Stevenson and Dyson [1].

4.3. Valve-regulated maintenance-free technology

Although in conventional motive-power products this technology still has to be shown to be successful, there is some merit in developing its use with thin tubular positives. Two major differences exist between the materials-handling applications and electric-vehicle usage. These are as follows.

(i) The materials-handling industry is dominated by a 1500 cycle-life requirement with inconsistent battery maintenance checks. On the other hand, the electric-vehicle application for buses can be very controlled in battery maintenance terms, and cycle life will be what is acceptable by the user. A cycle life of 500–1000 cycles could be commercially acceptable by the user within a given route/application.

(ii) The use of thin tubular plates is not a common design or production reality for most battery manufacturers. Thicker plates are normally used with a view to very long abuse-resistant cycle life and ease of manufacture. Again, the advantage that the bus application generates is that plate design can be more flexible and, therefore, thin tubular positives can be incorporated to make the best use of their higher capacity performance. Indeed, this allows for a certain loss of capacity due to the use of recombination technology to be off-set by the increases in capacity gained through the employment of thinner plates.

The two technologies used for maintenance-free batteries are absorptive glass-microfibre (AGM) and gelled electrolyte. This discussion does not cover the merits of the two technologies. For the Classic 25 product, AGM is to be employed, together with a thin rectangular-tube profile. The development of this product is shown in Table 3.

The maintenance-free product described here would take advantage of the maximum plate lengths and minimum head and mud spaces. Increased plate heights of 7–10% and the use of higher specific gravity would be expected to be the maximum improvement obtainable. There are, however, drawbacks in the use of maintenance-free technology. The depth-of-discharge must be controlled, as well as the not insignificant prolonged charging time. The effect of these can be minimized by virtue of the nature of the bus application. A management system can be used to control the high-voltage batteries. The charging time can be acceptable for day-time bus use.

In conclusion, it can be stated that 'thin', tubular, positive-plate technology, when used in either flooded or recombination mode, can be applied with confidence to designs for lead/acid bus batteries. The application is also ideal for the use of low-maintenance technologies. Anticipated improvements to these technologies will consolidate their use in this field of electric vehicles.

Reference

[1] J.M. Stevenson and J.I. Dyson, *Proc. EVS 11, Florence, Italy, Sept. 1992.*