ELSEVIER

Journal of Power Sources 73 (1998) 146–151

JOURNAL OF POWER SOURCES

Field experience and improvements with thin tubular-plate lead/acid technology

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Received 11 August 1997; accepted 20 December 1997

Abstract

The Classic 25 is the product name for a motive-power lead/acid cell using thin positive tubular plates. This cell was developed for use in electric vehicles and other applications where high specific energy and reliable cycle life is required. It would appear that the best approach is to provide a lead/acid battery that has the highest specific energy while still maintaining excellent cycle life. This technology was implemented by use of 6 V modules, followed by a 2-V design. Since this was first introduced in 1989, more than 20000 cells and monoblocs have been delivered to various electric vehicle applications such as vans, trucks, and buses. The field experience with this product is therefore excellent, and development is continuing on the battery design and manufacturing techniques to improve performance and life even further. Today, a wide range of products using this technology is available, and the latest developments are a new 6 V monobloc and some maintenance-free cells. © 1998 Elsevier Science S.A. All rights reserved.

Keywords: Electric vehicle; Lead/acid battery; Tubular plate; Specific-energy monobloc

1. Design and construction

The standard motive-power cell and the majority of traction batteries use the positive tubular plate design. The positive active-material is fixed by a gauntlet, either in woven or non-woven material, to the spine or collector (see Fig. 1).

In comparison to flat-plate construction, where the active material is pasted onto a grid, the construction of the tubular-plate design allows a reduced amount of active material, but nevertheless the average specific energy of such blocs or cells is between 28 and 32 W h kg^{-1} depending on the density of the active material and the acid volume and gravity. It is well known that the specific energy can be increased by enhancing the surface of the electrodes and lowering the density of the active material, but this affects the life of the battery (Fig. 2).

2. Monoblocs, 3ET range

The demand for electric-vehicle (EV) applications is high specific energy and good cycle life. The best compromise needs to be found to meet these two demands. The most promising and most practical solution seems to be a thin, tubular, positive-plate design. CMP Batteries started the development of a thin tubular plate in 1986 to be used in a monobloc to power an electric van. The result was a 6 V flooded lead/acid battery called the 3ET205 (Fig. 3).

The specific energy of this product is almost 40 W h kg^{-1} and is still the highest among all other lead/acid batteries for deep-cycle applications. The initial monobloc incorporated a plate with 21 tubes and 6 mm inside diameter. The thin-plate version use a 30-tube plate with 4.9 mm i.d. (Fig. 4). The separator is, in both cases, polyethylene but is a thinner for the new type, viz., 0.5 vs. 0.65 mm.

Some technical data are listed as follows.

Specific energy	34 W h kg^{-1} at $C_3/3$ rate
	38 W h kg^{-1} at $C_5/5$ rate
Power	67 W kg^{-1} at 80% DoD
Energy density	82.6 W h l^{-1}
Discharge capacity	$C_3/3$ rate: 180 A h
	$C_5/5$ rate: 205 A h
Dimensions	316 mm × 183 mm × 214 mm
Volume	12.38 l
Weight	32 kg

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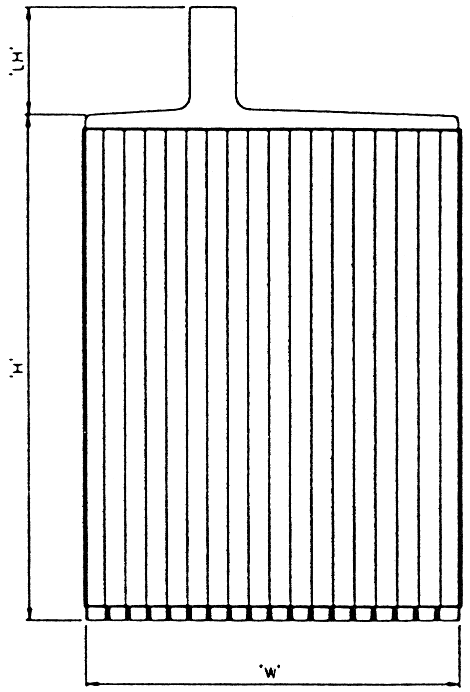

Fig. 1. Schematic of tubular positive plate (19 tubes).

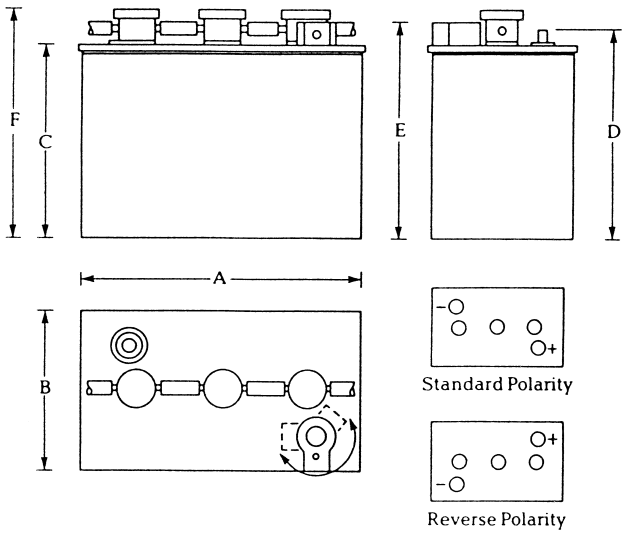

Fig. 3. Design of 3ET205 battery.

A further advantage, besides the good performance, is the low height of this bloc which makes this battery very attractive in EV applications. It can be easily fitted in a low-floor bus or van, or can be suspended underneath the vehicle as done in the Bedford van and the G-Van.

One parameter to receive special attention was cycle life. Due to the smaller spines, a lower cycle life was expected. Two cycling tests have been carried out: a 3-h (62 A test) and a 75 A discharge test. The cycle lives achieved in these bench tests have been much better than expected; the battery gave 80% of the rated capacity after more than 1450 cycles Fig. 5.

3. 2 V cells, classic 25 range

Based on the good field experience of the 3ET monobloc in electric vans and forced by an increasing demand for larger EVs such as truck and buses, the decision was made to implement this technology to the 2 V cell design to achieve higher specific energies. The thin tubular plate was designed to fit into the standard DIN box (200 mm width), which provides a wide range of cells with different heights and lengths. The positive tubular plate was thinned in such a way that the number of spines could be increased from 19 to 24 (Fig. 6).

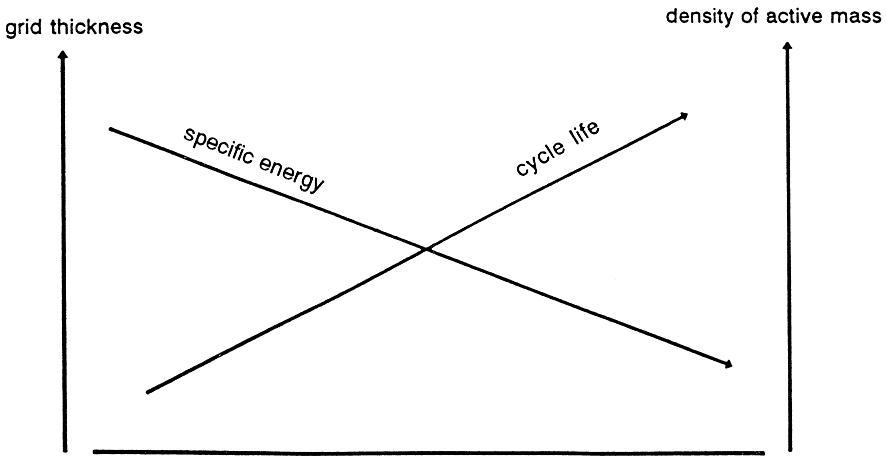

Fig. 2. Principal relation of active mass and grid to cycle life and energy density.

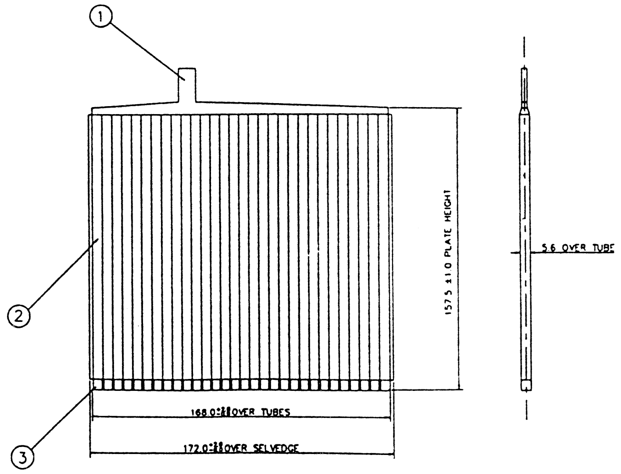

Fig. 4. Schematic of their version of tubular positive plate (30 tubes) for 3 ET range of batteries.

Table 1 provides some technical data of the Classic 25 cell compared with the standard Din Classic cell.

Today, a wide range of about 50 cells with different heights and capacities from 200 to 1000 A h are available. The first cell type made for electric buses in Santa Barbara, USA, in 1990 was the Classic 25 S32Y11. This was a 2-V 320-A h cell, assembled into a 216-V battery with a total energy of almost 70 kW h. Since then, more than 15 000 cells have been delivered to such applications and the field experience has been excellent.

4. Field experience with 3ET monobloc and classic 25 cells

Since 1985, more than 30 000 monoblocs and cells have been manufactured to be used in electric vans, trucks and buses. Experience has shown that the thin tubular positive plate has good performance and reliability.

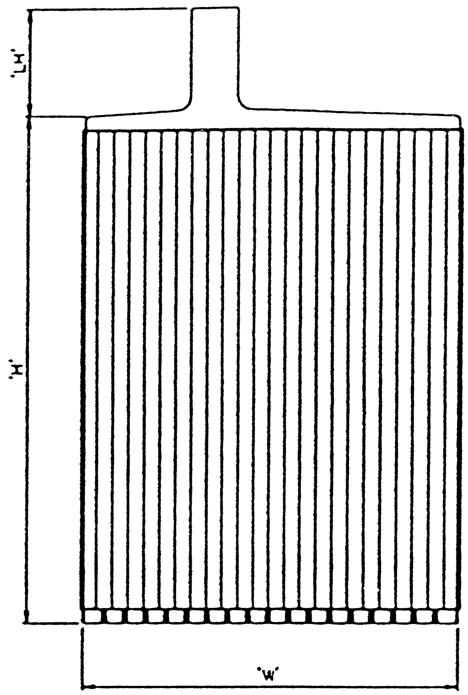

Fig. 6. Schematic of Classic 25 thin tubular plate (24 tubes).

In such applications, the average cycle life of the 6-V monobloc and the 2-V cell design is between 800 and 1100 cycles depending on factors such as ambient conditions, charging technology, maintenance, etc. The applications, where this technology has performed very successfully, are:

Santa Barbara, CA	Electric shuttle busClassic 25

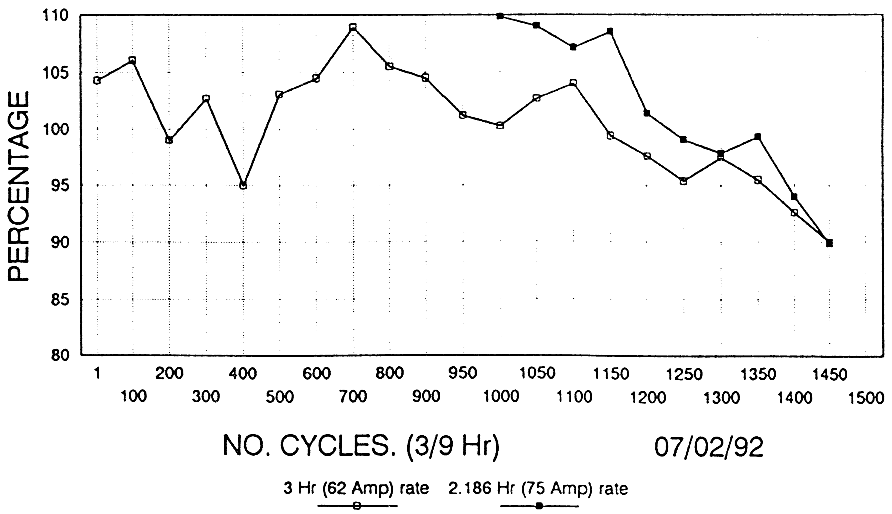

Fig. 5. Cycle life of thin tubular plate battery under given cycling tests.

Table 1
Technical data for Classic 25 batteries

Battery designation	Standard performance Classic	High performance Classic 25	Advanced EV 3ET215
Acid gravity (SG)	1.280 g cm^{-3}	1.300 g cm^{-3}	1.320 g cm^{-3}
Plate pitch	15.9 mm	13.5 mm	11.4 mm
Number of tubes	19	24	30
Tube diameter	7.5 mm	6.2 mm	4.9 mm
Spine diameter	3.2 mm	2.3 mm	1.85 mm
Specific energy (C_5)	28 W h/kg	36 W h/kg	40 W h/kg
Cycle life	1500	1000	800

Chattanooga, TN	Electric shuttle busClassic 25
Various places in USA	G-Van3ET205
Scandinavia	ELCAT Van3ET205
Florence, Italy	Electric shuttle busClassic 25
Hongkong, various vans and buses	3ET205/Classic 25

Today, buses and vans with this battery technology are operating on all continents and the number of vehicles is increasing rapidly.

Santa Barbara MTD was the first authority to start an EV project and therefore has the longest experience with electric buses and the thin tubular-plate batteries. Results obtained for the cycle life of Classic 25 batteries in SBMTD electric buses are presented in Table 2.

The number of cell replacements during cycle life are shown in Fig. 7. Its obvious that after 800 to 900 cycles, the single-cell failure rate increases rapidly, and repair of these cells is not practical. Thus, after 4 to 5 years of operation, the batteries are exhausted.

To gain a successful implementation and operation of electric vehicles, it is necessary to compare the economic effect and operation costs in comparison to those of ICE vehicles.

Fig. 8 shows a comparison of the operational costs of various lead/acid systems and nickel/cadmium (Ni/Cd) batteries which are the major battery systems used in commercial vehicles.

Table 2
Battery usage history at Santa Barbara MTD

Battery	Date placed in service	Miles driven	Driving cycles
Chloride 216V S32Y11	19/12/90	27668	639
Chloride 216V S32Y11	10/4/91	25083	531
Chloride 216V S32Y11	21/1/92	27961	766
Chloride 216V S32Y11	21/1/92	36151	884
Chloride 216V S32Y11	15/2/92	32992	921
Chloride 216V S32Y11	27/2/92	20797	607
Chloride 216V S32Y11	15/5/92	26738	708
Chloride 216V S32Y11	15/5/92	27839	572
Chloride 216V S32Y11	9/4/93	13749	358
Chloride 216V S32Y11	20/5/93	20597	528
Chloride 216V S32Y11	5/8/94	4918	102
Chloride 216V S32Y11	5/8/94	4045	104
Totals		268538	6720

5. New products with thin tubular positive plates

The ever-changing nature of vehicle technology and infrastructure are placing ever-changing demands on batteries and battery accessories. Some new basic requirements are:

- higher voltage > 300 V,
- lower capacity,
- maintenance-free product, and
- control and management systems for depth-of-discharge, charging and temperature.

To fulfil these demands from the battery point of view, it is necessary to develop another monobloc with at least the same performance as the existing 3ET205, but with lower costs and maintenance-free operation.

5.1. Monobloc 3ET200

The 3ET monobloc consists of three, 15-plate elements that utilize the latest positive tubular plate technology. The technical data are as follows.

Filled weight	32 kg
Acid specific gravity	1320
C_5 capacity	200 A h
Overall height	269 mm
Width	181 mm
Length	261 mm

This 3ET 200 monobloc gives 14% increased capacity which equates to 20% extra running time, and thus greatly increases the flexibility of the application.

Since the product was only launched in March 1997, data on cycle life are not yet available, but because the construction is almost the same as that of the 3ET205, almost the same life is expected. At present, there are six different applications of the product: two are hybrid applications and the batteries perform well.

5.2. Classic 25MF

The ideal battery for EVs, whatever the system, is definitely a maintenance-free system. But such technology still has some drawbacks, namely: (i) lower specific energy, (ii) lower life time, (iii) greater sensitivity to abuse and (iv) higher cost.

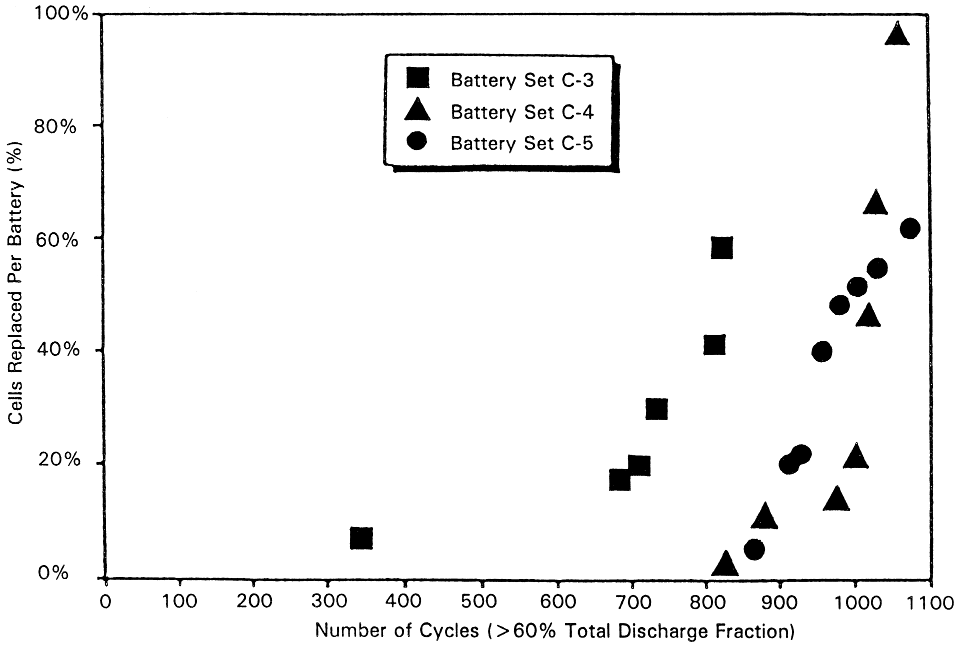

Fig. 7. Cell replacement during service life.

Nevertheless, in many applications, the maintenance-free (MF) battery is the only choice. Flooded systems are not suitable for small vehicles such as scooters and small cars (Fig. 9). The reasons for this are basically operating conditions, maintenance facilities and access to the battery.

With larger vehicles, safety reasons are the main reason to use MF products. Since CMP Batteries has a long-term experience in manufacturing VRLA batteries in AGM (absorbed glass microfibre) technology using rectangular tubes, it was considered appropriate to combine both technologies, V13, AGM and thin tubular plates. This resulted in the Classic 25 MF cell (Table 3). The first product, the Mark I design, still used round tubes, just to obtain initial data on capacity and power, but the lifetime was not encouraging.

The development of the Mark II design, using thin rectangular tubes was completed in May 1997, and the first three sets of batteries have been produced. All three batter-

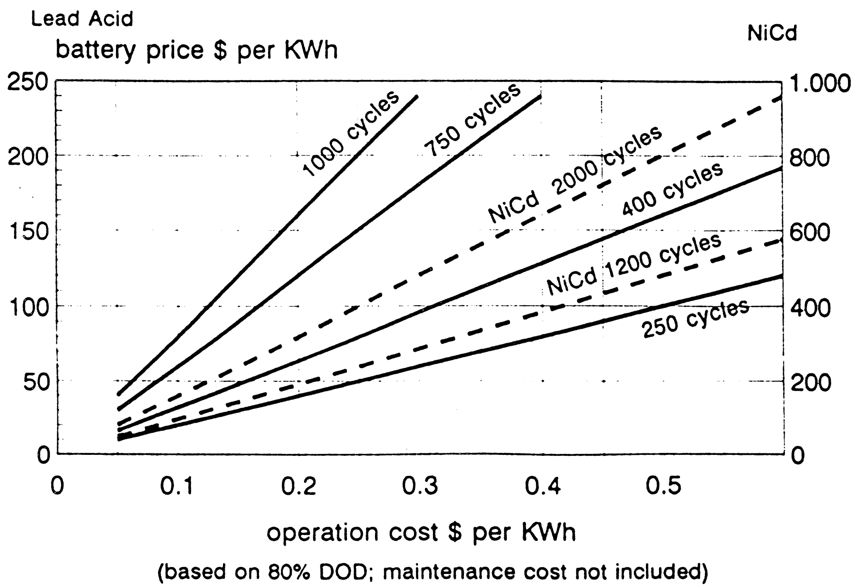

Fig. 8. EV batteries—cost evaluation of lead/acid in comparison with nickel/cadmium.

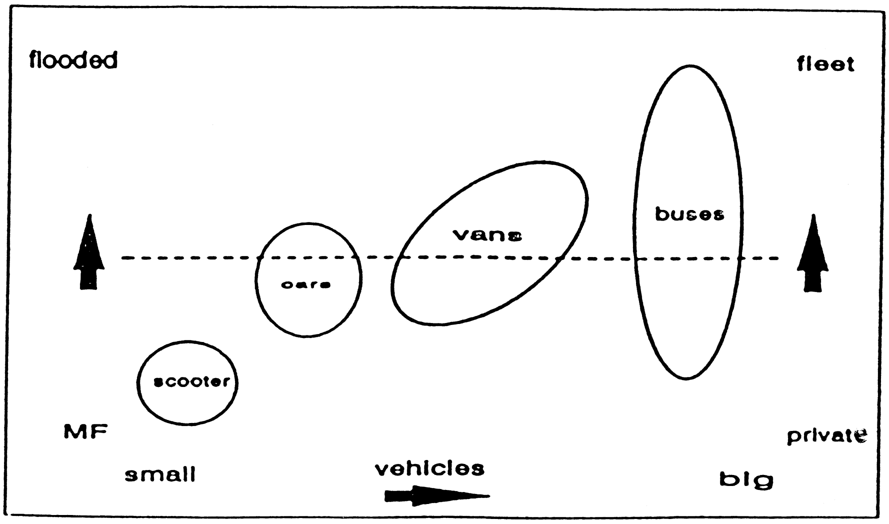

Fig. 9. Battery selection for different electric vehicles.

ies have been delivered to Santa Barbara in California to for testing with fast-charging technology and various management systems.

6. Future activities

It is understood that the performance and life of batteries depends strongly on the recharging process. CMP manufactures more than 25 000 chargers per year for traction applications and has started the manufacturing of special chargers for EV applications, both standby and on-board chargers.

The development of cells and monoblocs is continuing and a new monobloc is already under development in a flooded and a maintenance-free version.

Due to the long-term experience in the EV business and the countless contacts with manufacturers and users of EVs worldwide, CMP Batteries plays more and more of an important and influencing role when city councils, fleet operators and other authorities show an interest in using EVs in certain applications. Our overall knowledge of EV technology and components, as well as our experience of existing applications, is of great assistance to such organisations. Our support in the design and management of complete EV applications is an increasing part of our work.

Table 3
Technical data for flooded and MF Classic 25 batteries

Battery designation	Classic 25	Classic 25 new flooded	Classic 25 MF
Working electrolyte	1.300 sg	1.310 sg	1.300 sg
Plate pitch	13.5 mm	13.5 mm	13.5 mm
Number of tubes	24	24	24
Tube diameter	6.2 mm	6.2 mm	6.2 mm × 4.9 mm
Spine diameter	2.3 mm	2.3 mm	2.3 mm
Separator type	Polyethylene	Polyethylene	Glass microfibre mat envelope
Tube shape	Round		Rectangular
Energy density	36 W h/kg	39 W h/kg	34.5 W h/kg
Cycle life	1000	1000	750