2

Batteries for Electrically Powered Industrial Trucks

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2.1 INTRODUCTION

Electrically powered road vehicles are currently more and more debated and many new prototypes of vehicles and batteries have been presented, e.g. at the 18th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition in October 2001 in Berlin, Germany, the world's largest event on this topic under the motto "*Clean and efficient mobility for the millennium*". While for materials handling battery-powered trucks, elevating trucks, forklifts, and other vehicles for internal factory transportation have been used for decades, today the market for electric road vehicles seems to be open only in some niches, because of the relative higher initial costs. As environmental laws tighten and oil and gasoline become more expensive, battery-powered machinery gains importance in more than one regard. Table 2.1 gives a view of the variety of battery electric powered vehicles. For more on electric road vehicles see Chapter 4.

2.2 DEMANDS OF THE MARKET

The demands concerning batteries can be listed in short as follows:

- Easy service, long service intervals, maintenance freedom, highest possible performance at unchanged weight and size. All of the above are expected in connection with optimized service life.

Table 2.1 Battery powered vehicles.

Type of vehicle	Traffic range					
	Rooms in buildings	Outdoor	Roads and streets	Rails	Water	Air
Land operating vehicles						
Materials handling trucks	•	•	(•)			
– Forklift trucks	•	•	(•)			
– Pedestrian and pallet trucks	•	•				
– Tow tractors	•	•	(•)			
– AGVs	•	(•)				
Special operating machines	•	•	•			
– Cleaning machines	•	•	•			
Rail vehicles				•		
– Locomotives				•		
– Mining locomotives				•		
– Railway coaches				•		
Electric road vehicles		•	•			
– Bicycles, motorcycles		•	•			
– Wheelchairs	•	•	•			
– Passenger cars	•	•	•			
– Vans		•	•			
– Lorries, trucks		•	•			
– Motor coaches, buses		(•)	•			
Ships					•	
Aircrafts						•

- The vehicles must be of rugged design; the same goes for the batteries powering them; they should be indifferent to exhaustive discharge and low temperatures. On top of all that there is the demand for economy in comparison with other energy sources or powering systems.

This package of demands is presently almost fulfilled.

Sophisticated battery systems do already exist, such as the battery of a MAN-bus, which continuously checks its state by a number of well-tested peripheral devices, such as a centralized water refilling system, a centralized gas disposal, a temperature-controlling device, and a discharge/charge surveying apparatus.

In the German city of Düsseldorf buses powered by such batteries have covered in 16-hours-per-day regular service more than 140,000 km per battery before the end of service life.

Battery systems are presently available for industrial trucks, easily recharged by new-generation control circuits that also permanently survey the batteries' state of charge.

All these batteries are of tubular cell design, commonly employed in industrial trucks throughout Europe. Three reasons for this are: their overwhelming life expectancy, which has been practically determined to be greater than 5 years; their low weight/power ratio and high power density; and last but not least their favorable lifetime/costs ratio and the experienced economy. Only smaller, especially hand-directed vehicles are preferably fitted with monobloc batteries or grid-type plate cells.

Apart from the standardized battery sizes there are innumerable battery designs due to the variety of industrial trucks being in action, that differ only in small details such as lifting eyelets, terminals, and locking catches for fixing in the truck.

Not only experts, but also the users of the manifold types of battery vehicles know that this is a simpler system compared to vehicles powered by internal combustion engines. This means battery/electric materials handling is highly economic and avoids pollution in the surroundings where exhausted gasses and noise cannot be tolerated, e.g. in warehouses, food markets, and factories where workers want a healthy atmosphere.

2.3 STANDARDIZED DESIGNS

As it is important for the applicant to know the present situation of the standards, a survey of the presently standardized cells and batteries shall be given.

DIN (Deutsche Industrie Normen) and VDE standards (Verein Deutscher Elektriker) are valid only inside national borders; more and more they are substituted by European Norm (EN) Standards and international standards, the IEC Standards (International Electrotechnical Commission) and ISO standards (International Standardization Organization), as for instance for battery voltages. Generally all batteries must be designed and manufactured in accordance with the VDE directions (VDE 0501/.1.77). See, for example, Table 2.2.

These directions for instance cover the classification and the consistency of the electrolyte and of refill water and how batteries must be fitted in containers for safety reasons (VDE 0510 is at present time under revision). See also Chapter 6 and 14.

Concerning the single-cell designs of tubular plate cells two standards sheets inform of nominal capacities and main dimensions:

1. DIN 43 595: Tubular plate cells for land- and water-bound vehicles, low maintenance type.
2. DIN 43 567 part 2: Tubular plate cells for land- and water-bound vehicles.

DIN 43 595 concerns cells of the low maintenance type with compound sealed or welded cell lids. The connector bars are permanently attached to the terminals by means of welding or crimping on. The main dimensions only vary slightly from the earlier DIN 43 567. DIN 43 595 recently has been drawn back, while the dimensions are still valid and conform to the international standard IEC 60 254-2. New types with higher capacities will be listed in a new standard, having the same dimensions (see Table 2.3).

DIN 43 567 concerns tubular plate cells with bolted connectors, with flat terminals and with conical terminals for the ex types up to VDE 0170/0171 for explosion-safe types. The lids of these types can be removed and are sealed by a flexible rubber seal.

The overall dimensions of these tubular plate-type cells also accord to the IEC Standard 60 254-2, "Lead-acid traction batteries, part 2, cell dimensions for traction batteries".

Table 2.2 Survey of the PzS standard cells to DIN 43 595.

Plate size	Cell height (mm) (max.)	Cell width (mm) (max.)	Nominal capacity K_5 (Ah) with varying number of positive plates								
			2	3	4	5	6	7	8	9	10
PzS 55	365		110	165	220	275	330	385	440	—	—
PzS 70	425		140	210	280	350	420	490	560	—	—
PzS 80	505	198	160	240	320	400	480	560	640	—	800
PzS 100	595		200	300	400	500	600	720	800	900	1000
PzS 120	752		—	360	480	600	720	840	960	—	1200
length of cells (mm)			47	65	83	101	119	137	155	174	192

[a] Including terminal end with mounted intercell connectors.

Table 2.3 Survey on capacities of plates type PzS (normal) and PzS-H (high capacity).

Cell height (max) [mm]	Capacity C/PzS plate [Ah] series L (new) PzS...L	DIN (old) PzS	Capacity increase %
370	60	55	9
440	80	70	14
510	90	80	13
605	110	100	10
750	140	120	17

DIN 43 595 is preferred more and more as it has the following advantages:

- High operational safety through complete insulation.
- Improved cyclic durability through optimized masses and plate geometry.
- Great number of cycles through lowering of the mud fallout rate.
- Substantially higher maintenance intervals through electrolyte-tight cells.

Cells of these types undergo not only severe testing in practical applications, but also tests to the DIN 43 539 part 3, as well as the lEC tests of the same content and extent in laboratories for quality improvement, with endurance tests demanding over 1500 cycles in cyclic charging/discharging operation (see IEC 60 254-1).

Each standard needs an update following the technical development. So when the new international standard for dimensions of traction lead-acid cells IEC 60 254-2 was published and harmonized in the European Union to a European standard EN 60 254-1, DIN 43 595 was drawn back. In an additional technical information sheet, published by the German Battery Manufacturers Association, the (nominal) capacities in use were listed in relation to the cell dimensions. Table 2.3 shows the range of cell heights conforming to IEC (respective EN 60 254-2) together with the new series of higher capacities.

Compared with cells of the older design the "high-capacity cells" have an increased capacity between 9 to 17%. Table 2.4 shows the data for the new series of PzS cells.

Standards sheets also have existed apart from the above mentioned for battery trays for several years. In certain intervals standards sheets must be revised to consider new developments.

In the past, standardization of parts making up a battery such as cells, connectors, trays, parts of installation and terminals was ascribed a great advantage by the users' side because of the great number of combinations possible to assemble a battery. Modification and repair of batteries was common then.

The main disadvantage of the single parts standards is that this leads to a huge amount of types and variants, as changed details can be accepted for new batteries, but by no means from the spare parts side.

Designers and manufacturers of industrial trucks and battery manufacturers have developed a standard of the 24-V and the 80-V standard batteries to take over

Table 2.4 Lead-acid traction cells with tubular plates, series L, dimensions conforming to IEC 60 254-2.

Designation code			Nominal capacity C_5[a] (Ah)	Code[b] tubular plate	Dimensions[d] a 0 −2	(h) (max.)	Weight including electrolyte (kg) (± 5%)	Lead content[c] (kg) (± 5%)
2	PzS	120 L	120		47		8.4	6.2
3	PzS	180 L	180		65		11.8	8.8
4	PzS	240 L	240		83		15.5	11.5
5	PzS	300 L	300	PzS 60	101	370	19.0	14.1
6	PzS	360 L	360		119		22.5	16.8
7	PzS	420 L	420		137		26.1	19.4
8	PzS	480 L	480		155		29.8	22.2
2	PzS	160 L	160		47		9.8	7.3
3	PzS	240 L	240		65		14.0	10.4
4	PzS	320 L	320		83		18.1	13.5
5	PzS	400 L	400	PzS 80	101	440	22.6	16.8
6	PzS	480 L	480		119		26.6	19.8
7	PzS	560 L	560		137		31.1	23.1
8	PzS	640 L	640		155		35.2	26.3
2	PzS	180 L	180		47		12.0	9.0
3	PzS	270 L	270		65		16.9	12.6
4	PzS	360 L	360		83		21.6	16.1
5	PzS	450 L	450	PzS 90	101	510	26.3	19.5
6	PzS	540 L	540		119		31.1	23.1
7	PzS	630 L	630		137		36.1	26.9
8	PzS	720 L	720		155		40.8	30.3
10	PzS	900 L	900		192		50.3	37.4
2	PzS	220 L	220		47		14.3	10.6
3	PzS	330 L	330		65		20.3	15.1
4	PzS	440 L	440		83		26.0	19.4
5	PzS	550 L	550		101		31.8	23.6
6	PzS	660 L	660	PzS 110	119	605	37.9	28.2
7	PzS	770 L	770		137		43.8	32.6
8	PzS	880 L	880		155		49.8	37.0
9	PzS	990 L	990		174		55.7	41.5
10	PzS	1100 L	1100		192		61.5	45.7
3	PzS	420 L	420		65		25.4	18.9
4	PzS	560 L	560		83		32.9	24.5
5	PzS	700 L	700		101		39.9	29.7
6	PzS	840 L	840	PzS 140	119	750	47.2	35.2
7	PzS	980 L	980		137		54.8	40.8
8	PzS	1120 L	1120		155		62.3	46.3
10	PzS	1400 L	1400		192		76.7	57.1

[a] $C_5 = 5\,h$ rated capacity = nominal capacity (see IEC 60 254–1).
[b] Code of a plate with a capacity of, e.g. 60 Ah: PzS 60.
[c] Loss during production of 7% included.
[d] Width 198 mm −2.

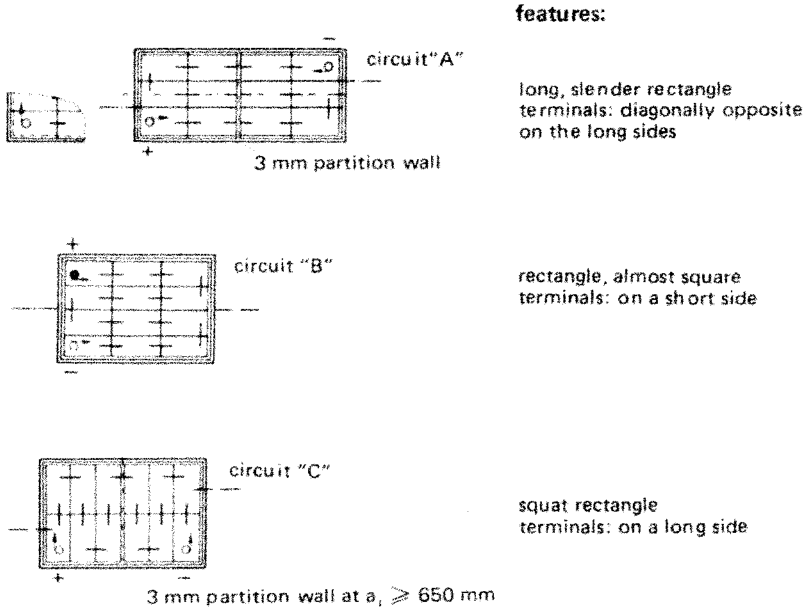

Figure 2.1 Circuits of 24-V traction batteries to DIN 43 535.

the older "component standards" (see Figures 2.1 and 2.2). The sheets in question are

- DIN 43 535 Lead-acid accumulators; traction batteries 24 V for industrial trucks.

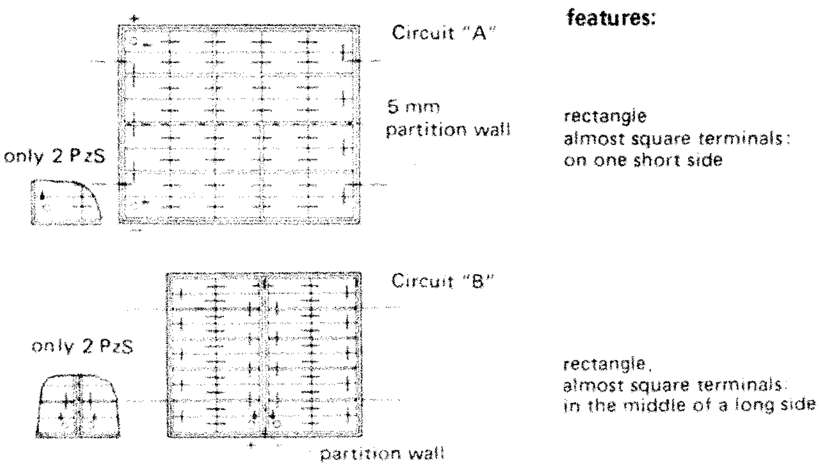

Figure 2.2 Circuits of 80-V traction batteries to DIN 43 536.

- DIN 43 536 Lead-acid accumulators; traction batteries 80 V for industrial trucks.

DIN 43 535 mentions three main circuits of type A, B, C:

- 19 batteries of the A circuit type.
- 15 batteries of the B circuit type.
- 12 batteries of the C circuit type.

that have been standardized, in all 46 batteries of 24 V.

DIN 43 536 mentions two main circuits of the types A and B:

- 18 batteries of type A.
- 6 batteries of type B.

that have been standardized, in all 24 battery types of 80 V.

In other countries 48-V and 72-V batteries are more popular and standardized. So it was necessary to complete the line of battery standards with DIN 43 531 for the 48-V traction batteries to conform to the two other above-mentioned standards for 24 and 80 V.

These standard batteries (see Figure 2.3) have the following in common:

- The battery trays are all of the same design.
- Length, width, and height are standardized.
- The design and location of the lifting eyes are standardized.
- The connecting terminals are described in a special informal sheet published by the German Battery Manufacturers Association.

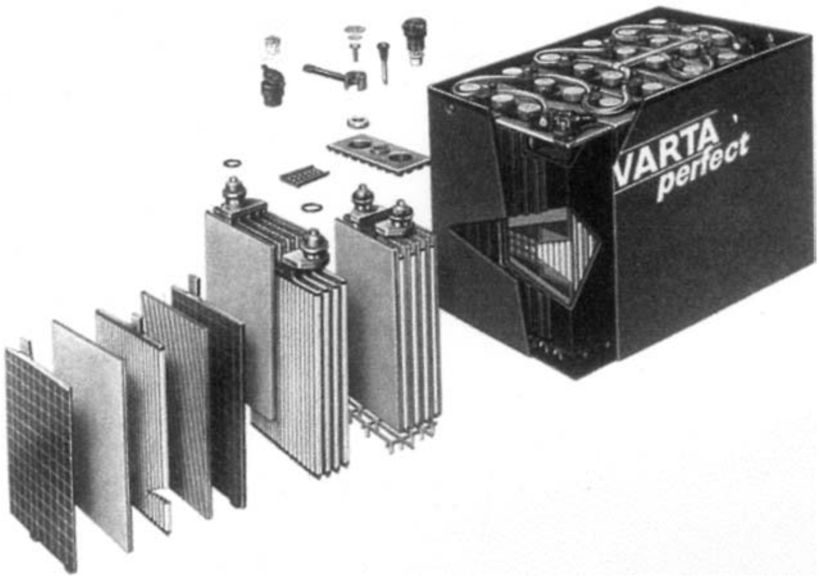

Figure 2.3 Design of a modern traction battery.

- Insulation of the tray (mostly a plastic coating) accords to VDE 0510-standards.
- Battery trays are always fitted with the greatest possible cell capacity.
- No ballast weights are employed.

Figure 2.3 shows the design of a modern 24-V traction battery with positive tubular plates to DIN 43 535.

With this step toward a reasonable standardization of batteries two substantially important aspects for future developments have come into close range:

- Following a certain transitional period a noticeable reduction of variants and types of cells and trays.
- Introduction of new technologies in battery design resulting in less maintenance.

Standard voltages for traction batteries for industrial trucks are fixed by the ISO 1044 standards as follows:

- Series I: 12, 24, 36, 48, 60, 72, and 96 V.
- Series II: 40 and 80 V.

In Germany only 24 V and 80 V are common values.

The above-mentioned traction batteries in grid plate design for smaller vehicles are treated by DIN 43 594. A revised standard will be edited for monobloc batteries in plastic containers (containers as in use for automotive batteries). The pasted plates are thicker; the batteries have a special separation between the plates (see Table 2.5).

A parallel new standard, DIN 43 598, is in preparation: Part 1 for small traction batteries with positive tubular plates in monoblocs corresponding to DIN 43 594. Part 2 for small traction cells in plastic trays. (See Tables 2.6 and 2.7.)

2.4 ENERGY/WEIGHT AND ENERGY/VOLUME RATIOS

The display of standardized values may create the impression of a power level being cemented or fixed. The applicant of lead-acid traction batteries today may not realize the improvements that have made concerning energy/weight and energy/volume ratios.

Forerunners of these more powerful batteries of the tubular plate type and also of the grid plate type have been tested in electric road vehicles. Naturally the classic lead-acid battery has a limit which lies far below the theoretical value of 161 Wh/kg. By showing the shares of weight of conductive material, excess mass, and excess electrolyte and inactive material, Figure 2.4 explains why the possibilities for improvement of the energy/weight ratio are so few.

The values for the energy/weight and the energy/volume ratios (like the above values) are related to a 5-hour discharge.

Figure 2.5 displays the specific drawable energy per kg dependent on the currents drawn in a much-simplified manner. At a load of the 5-hour discharge current, the PzS cells yield about 30 Wh/kg. Only about 50% of this value is available if the cell is drained with the 1-hour discharge current value. This amounts to only 10% of the theoretical value of 161 Wh/kg. This entitles the developer and the user to expect severe improvements, at least on the high-drain sector.

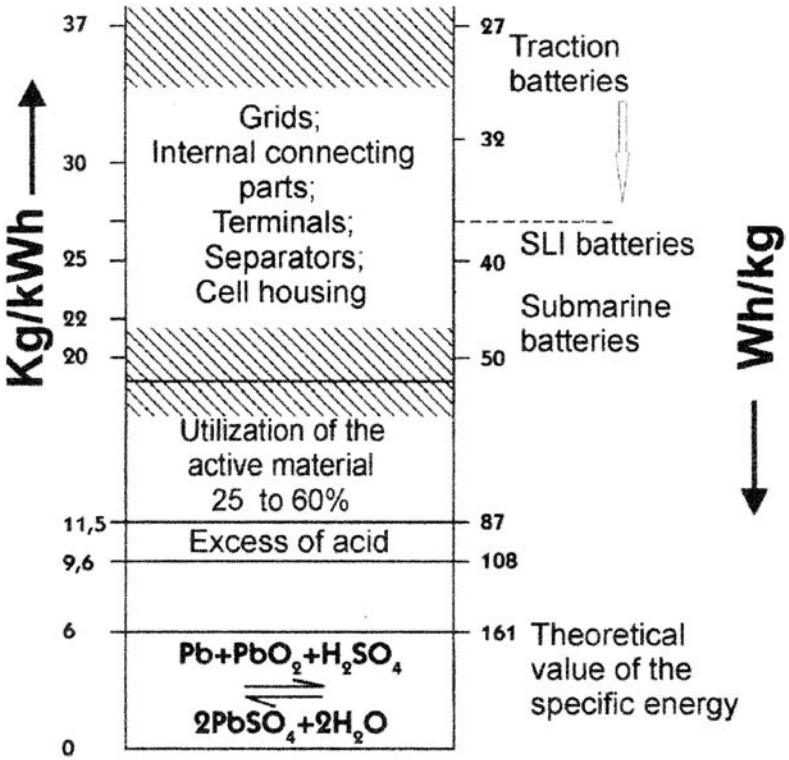

Figure 2.4 Theoretical and practical energy/weight ratio of lead-acid cells.

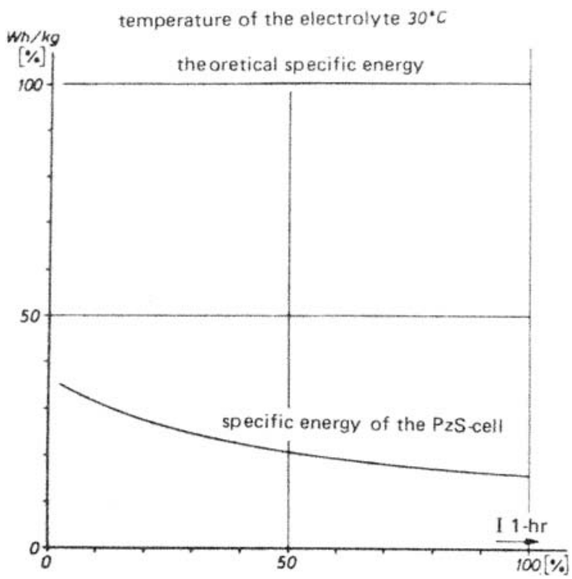

Figure 2.5 Comparison of specific energy yield of PzS cells.

Table 2.5 Lead-acid traction batteries, monobloc battery with pasted plates (DIN 43594).

Battery marking		Voltage	Nominal	Nominal	Dimensions			
Short designation	Type no.	(V)	capacity[a] (Ah)	Monobloc type	a (max)	b (max)	h (max)	
6 V GiS 180	9 180.1	6	180	M 13	244	190	275	30
12 V GiS 40	9 540.1	12	40	H 4	211	175	190	14
12 V GiS 50	9 550.1	12	50	H 5	246	175	190	16
12 V GiS 60	9 560.1	12	60	H 6	306	175	190	20
12 V GiS 75	9 575.1	12	75	H 8	381	175	190	24
12 V GiS 105	9 605.1	12	105	M 20	513	189	223	40
12 V GiS 135	9 635.1	12	135	M 25	513	223	223	48
12 V GiS 180	9 680.1	12	180	M 33	518	291	242	64

[a]Nominal capacity after 10 discharges; electrolyte density 1.28 ± 0.01 kg/L; electrolyte temperature 25 °C.

Table 2.6 Lead-acid traction batteries, monobloc batteries with positive tubular plates (DIN 43 598 part 1).

Short designation	Nominal voltage (V)	Nominal capacity[a] (Ah)	Monobloc type	Dimensions a (max)	b (max)	h (max)	Total weight (kg ± 5%)
6 V PzS 170	6	170	M 13	244	190	275	30
12 V PzS 75	12	75	M 20	513	189	223	34
12 V PzS 100	12	100	M 20	513	189	223	40
12 V PzS 130	12	130	M 25	513	223	223	48
12 V PzS 150	12	150	M 33	518	291	242	61
12 V PzS 170	12	170	M 33	518	291	242	64

[a]Nominal capacity after 10 discharges electrolyte density 1.28 ± 0.01 kg/L; electrolyte temperature 25 °C.

Table 2.7 Lead-acid traction batteries in plastic trays with single cells and positive tubular plates (DIN 43 598 part 2).

Short designation	Nominal capacity C_5[a] (Ah)	Circuit	Dimensions a_1 (max)	a_2 (max)	b_1 (max)	b_2 (max)	h (max)	Total weight filled (kg ± 5%)
6 V PzS 104 H	104	A	248	253	168	168	235	22.7
6 V PzS 130 H	130	A	303	318	168	168	235	27.8
6 V PzS 172 H	172	A	245	251	194	194	280	34.2
12 V PzS 104 H	104	B	486	506	168	168	223	45.1
12 V PzS 130 H	130	B	486	506	205	205	223	55.3
12 V PzS 172 H	172	C	486	506	199	199	279	68.4

[a]Nominal capacity after 10 discharges; electrolyte density 1.28 ± 0.01 kg/L; electrolyte temperature 25 °C.

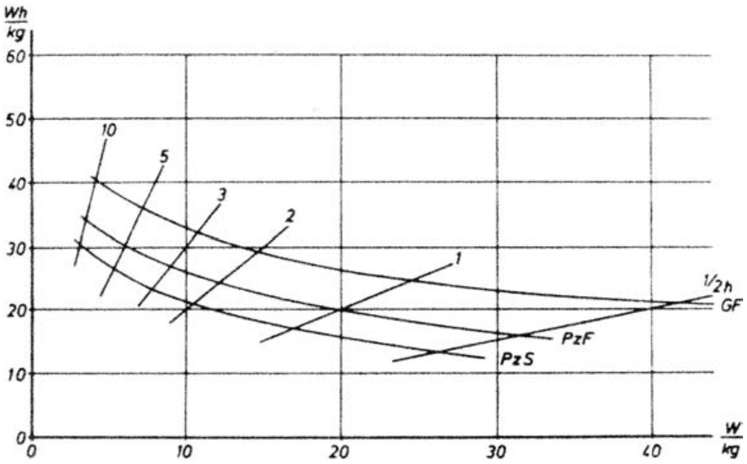

Figure 2.6 Useable fraction of the energy/weight ratio in Wh/kg of lead-acid PzS cells, PzF cells, and GF cells (GF = flat plate type).

Figure 2.6 shows the specific drawable energy of lead-acid traction batteries of different designs. The lower graph represents the capacity of the common PzS cells. Further development of this cell type for application in electric road vehicles of the PzF type yields accordingly higher values.

2.5 SERVICE LIFE AND ECONOMY

The service life of traction batteries, depending on the average load during operation, is located somewhere between 3 to 9 years. The average lifespan thus is 5.5 to 6 years, corresponding 1500 to 1600 discharges to 80% of the nominal capacity. It is understandable that no "standard" service life value can be given independent of the load profile. The following can influence lifetime and economy:

- Choice of a too small battery resulting in frequent or even permanent exhaustive discharges.
- Severe on-duty conditions and resulting permanent temperatures over 50 °C.
- Permanent overcharging because of faulty charging technique or maladjusted charging devices.
- Storage of uncharged batteries.

Especially the choice of too small battery capacity generally leads to bad results in service life. For further details see information sheet published by the German Battery Manufacturers Association.

2.6 CHARGING TECHNIQUES

Demands on charging techniques and monitoring systems include:

- Choice of a preserving charge method.
- Controlling of the charge process regarding the condition of the battery (electronic diary).
- Indication of the actual capacity.
- Current limitations.
- Deep discharge protection.
- Control of voltage and temperature of the battery and charging.

Charging devices should have a characteristic curve following DIN 41 773 and be equipped with a charge-control switch that limits the charging period, as shown in Figure 2.7 after gassing voltage of 2.4 V/cell has been reached.

The charging-control "Poehlertronic" switch actuates the additional charge considering the batteries age and temperature and compensates the mains' fluctuations optimally. This charging timer also prolongs the life span of a battery and facilitates maintenance as there is less water consumption, and overcharging is impossible even with older batteries (see Figure 2.8).

Apart from this, other principles for controlling the charging process of a battery are operational, such as the controlling of the charging process by measuring the gas adsorption rate with recombinators (HOC charging device from Hoppecke) and by monitoring the charging current (Belatron system from the Benning Corporation).

Several devices, ranging from a simple voltage controller to a sophisticated electronic apparatus minutely balancing the Ah household, can monitor state of charge. A type of safety switch has reached a high level of distribution as it automatically switches off the lifting fork when 20% of the nominal capacity is reached, and the driver is forced to charge the vehicles batteries.

For more details see Chapters 12 and 13 where charging methods and charger characteristics are described in detail.

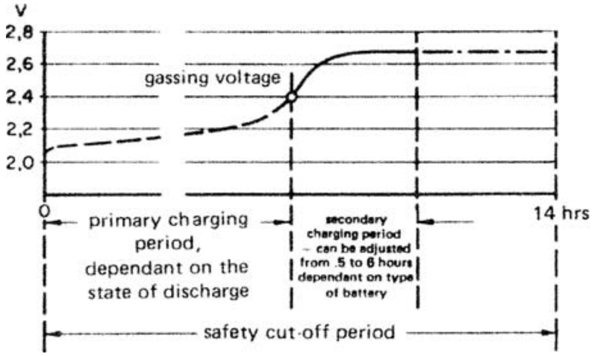

Figure 2.7 Switching timetable of a "Poehler" switch.

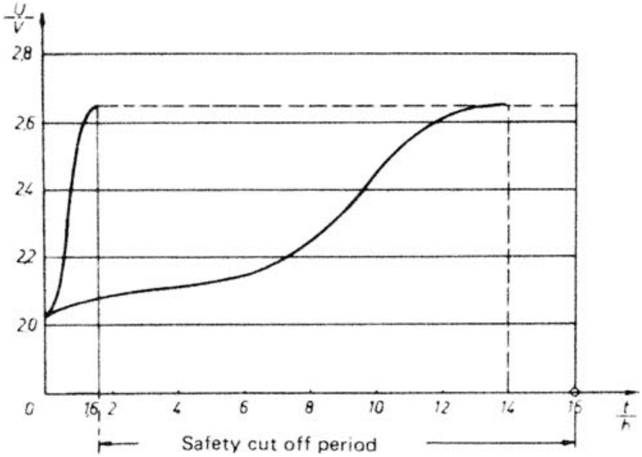

Figure 2.8 Switching periods of the charge-control "Poehlertronic" switch; duration of charge dependent on battery condition.

2.7 MAINTENANCE

Only very few details must be respected:

- Refill water at the end of charge.
- Keep the battery clean and dry.
- Recharge the battery immediately after discharge.
- Do not discharge a battery exhaustively (more than 80%).
- Do not overcharge the battery (charging factor maximum 1.2).
- Battery temperature must not exceed 55 °C.
- In case of malfunction, contact your local service office; they will gladly also check your charging devices and controllers.
- Use only safe and adequate lifting equipment.

2.8 SUMMARY AND OUTLOOK

The present lead-acid traction battery of the PzS type represents the highest standard of performance. Further development is possible, whereas the attainable limit for power density in the near future will in practice be around 35 to 40 Wh/kg.

Development on the forklift truck sector for higher transport performance naturally leads to greater stress on the battery. This could lead to shorter charging intervals of the vehicles. In connection with the limited space inside forklift trucks energy density of traction batteries will have to be improved. Most of the German battery manufacturers introduced a new generation of batteries averaging 15% more capacity than with the presently standardized types.

Total freedom of maintenance cannot be realized without peripheral devices because of the necessity of water replenishment. Even so, plastic housings totally electrolyte-tight, welded-on plastic lids, as well as totally sealed terminals make a new generation of batteries with high insulation resistances that are totally dry on the outside. Good insulation resistance is a demand that must be met, especially for modern impulse-guided vehicles, for resistance deficiency could cause malfunctions with these systems.

A higher grade of perfection can be attained through peripheral devices, such as a central water-refilling system or "puridrier" plugs, which make these batteries almost totally maintenance free. (See Figure 4.5 in Chapter 4.)

For a few years "enclosed" valve-regulated and maintenance-free traction batteries have been offered to the market. The electrolyte is immobilized, soaked in a fleece or as a gel (See Chapter 1). During the recharge, with limited voltage below 2.40 V/cell, the oxygen developed on the positive electrode is recombined on the surface of the negative electrode. Therefore gassing of this kind of battery is extremely low resulting in no need to refill water. Because the cells of such batteries are valve regulated, no water can be added, but gas can escape in the case of incorrect charging (overcharge with high voltage). At all times during recharge a small rate of hydrogen is developed, therefore battery containers must be vented. Future experience with this new generation of batteries will answer questions as to their duration and economy.

Figure 2.9 shows a 24-V traction battery in maintenance-free design (dimensions of DIN 43 535) and a special charger.

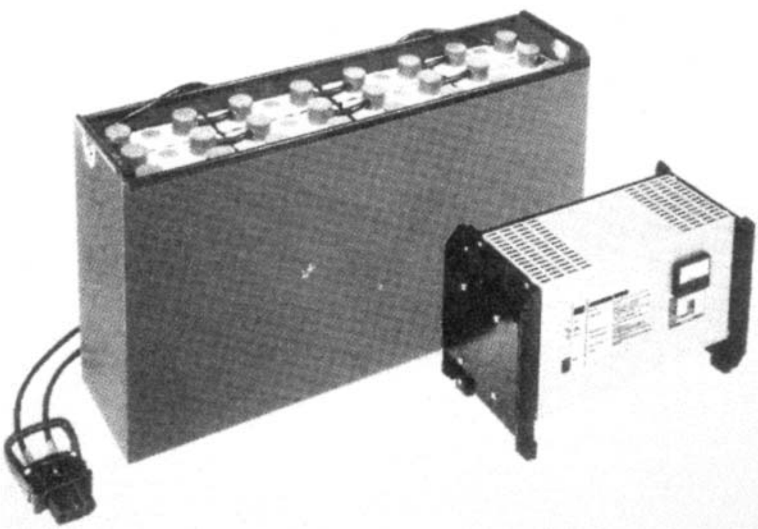

Figure 2.9 Traction battery 24 V (Dimensions DIN 43 535) in maintenance design, cells with positive tubular plates and charger.

A further possibility to increase the performance of lead-acid traction cells is electrolyte circulation, as proved in batteries for electric road vehicles and batteries for submarines. The principle is an airlift pump installed in each cell. The results are

- No electrolyte and temperature stratification.
- Extremely efficient charge acceptance and equalized load of the plates.
- Shortened charging time up to 30% and therefore less energy from the mains is needed.
- Shorter gassing period, less slugging of active mass of the positive plate, and less water consumption.
- Less temperature rise during the charge (up to 10 °C), therefore batteries applicable in so-called atmosphere with elevated temperature.
- Time of no use of the batteries is drastically reduced, an advantage for the application in plants working on two or three shifts.
- Booster charging enables heavy duty service.
- Maintenance intervals are longer which lowers costs.

Figure 2.10 shows a modern lead-acid traction cell designed by Varta with electrolyte circulation compared to a cell with electrolyte stratification. There are many electrochemical systems that will yield favorable accumulators (see Chapters 1 and 10), some of which have reached a very promising state of development. They will have to prove their versatility in practical application, especially with the aspect of economy in the future.

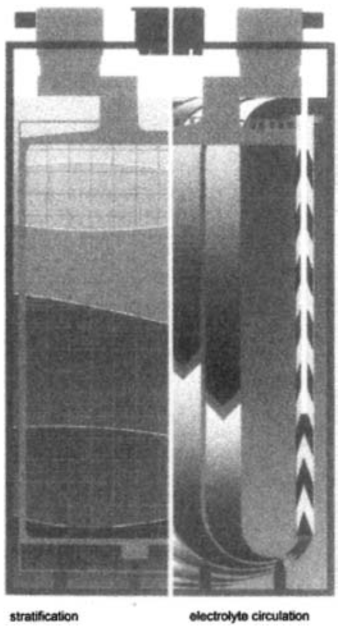

Figure 2.10 The principle of electrolyte circulation.

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