

Battery-Powered Traction—The User's Point of View

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5.1 INTRODUCTION

To transport people and material growing transportation systems are needed. More and more of the energy for these systems is drawn from secondary batteries. The reason for this trend is economic, but there is also an environmental need for a future chance for electric traction. The actual development of electrochemical storage systems with components like sodium–sulfur, sodium–nickel chloride, nickel–metal hydride, zinc–bromine, zinc–air, and others, mainly intended for electric road vehicles, make the classical lead-acid traction batteries look old-fashioned and outdated. Lead-acid, this more than 150-year-old system, is currently the reliable and economic power source for electric traction.

The main application of the lead-acid battery is vehicles for materials handling, such as forklift trucks, transporters, and so on, inside manufacturing plants and warehouses. Passenger transportation in areas where no pollution from exhaust gases can be tolerated is a further field of application for electric vehicles powered by batteries. Special machinery for lifting, cleaning, and other uses as well as electric boats, golf carts, and wheelchairs use and need the proven lead-acid traction battery.

In the following, battery design and operating conditions are described with a special view on economy and reliability. Optimal purchasing conditions are not always found from a central office with the responsibility for selection of products, but more information and exchange of experience are the bases for the preparation of sound decisions.

5.2 GENERAL REMARKS

Suppliers of traction batteries and electrical charge and control equipment today offer a large product scale, not easily comprehensible to a normal user. Users of only a few electric vehicles for materials handling or other battery-powered systems ask trustworthy suppliers for advice. But calling a second or third supplier results in varying offers and variants of application possibilities creating insecurity and difficulty in decisionmaking.

As a rule, for large users of traction batteries it is economic to handle things in a central office to collect information on available technologies and materials. Purchasing and acceptance, maintenance, and disposal responsibilities by internal specialists are effective. Smaller users can participate in the experience of these experts.

For investment of electric vehicles for materials handling it has to be regarded that in a normal use the costs of a traction battery during its useful life are between 50 and 75% of the costs of the vehicle (without the battery). Here is one example: the price for a forklift truck was 12,000 EUR; the service life was 8 years. In this time two to three traction batteries, each for a price of 3000 EUR had to be procured. This very simple comparison shows that it would have been more economical to purchase only two batteries instead of three. It has to be noticed that the extension of life of a battery depends on design and quality of the battery and the charging method and charging equipment.

Therefore it is indispensable for every user—from a middle- and a long-term view—to aspire to specialized knowledge for optimal system design. The user has to be informed on the market and the state-of-the-art technologies to form intelligent opinions.

Assistance to get the optimal operation of materials handling with all components is given by the recommendations of the VDI (Verband Deutscher Ingenieure), member of IEEE, the German Battery Manufacturers Association, and the relevant standards edited by DIN (Deutscher Industrie Normen) and EN (European Norm), the latter mentioned later in this chapter.

5.3 ADVANTAGES OF BATTERY-POWERED TRACTION

5.3.1 Impacts of Operation and Environmental Concerns

The alternative of battery-powered traction is the internal combustion (IC) engine. It has to be noticed that there are fields of operation where the former or the latter has to be preferred. [Table 5.1](#) points out some differences. This relatively simple listing shows that the domain of battery-powered traction is indoor service, while economy can be expected up to 3–4 tons. The German regulation for hazardous goods (TRGS 554) claims in addition that the employment of battery-powered traction avoids emissions by IC engines (see [Figure 5.1](#)). The domain for IC-powered traction is outdoor service and extremely high demands of performance. Newly reached positive results in cleaning the exhaust gases by filtering carbon particles and catalysts allow partial indoor service, but the competition of electric-powered vehicles with increased performance is high.

Table 5.1 Traction battery type for different kinds of service.

Kind of service	Kind of traction battery		
	Electric	Diesel	Liquid gas
Indoor service			
Food industry and food handling	+	—	o ^a
Basement operation	+	— ^a	—
Places with sufficient fresh air	+	o ^a	o ^a
Working areas	+	—	—
Places with no or little fresh air	+	—	—
Outdoor operation			
Cross-country-operation	—	+	+
Roadways in good condition	+	+	+
Working areas	+	o ^a	o ^a
Criteria for indoor and outdoor-operation			
High tonnage and high driving performance	—	+	+
Extreme temperatures	o	+	+
High rate of ascent	o	+	+
Explosive surrounding	+	—	—

+ = suitable; o = conditionally suitable; — = not suitable.

^aNeed for filtering the exhausted gases by particle filters and catalysts.

In principle the selection of the kind of traction has to be based on the kind of service and the environmental demands.

5.3.2 Physical Advantages of Battery-Powered Traction

Battery-powered traction means low noise generation, no pollution of gases, no vibration, simple mechanical propulsion components, simple electrical control and steering, usage of energy conforming to environmental demands, and last but not least lighter weight. This results in optimal conditions to fulfil environmental requirements and to make working areas healthier.

The relatively heavy weight of lead-acid batteries in relation to the useable performance has advantages for forklift trucks and other tractors (as counterweight or ballast), but is a great disadvantage for other traction systems such as electric road vehicles and mobile electric power supplies. Results in development with the aim to increase the specific energy and performance of battery systems and the minimization of their maintenance also have an impact on the employment of vehicles for materials handling.

5.3.3 Survey on Service Cost Calculation

Important factors to be regarded for the selection of the kind of traction battery to use are the fixed and running costs of the system. The guideline VDI 2695 “Ermittlung der Kosten für Flurförderzeuge” (Estimation of Costs for Vehicles for

4.12 Limitation of operation

The local authorities can restrict the operation of diesel-powered vehicles in partly or totally closed rooms, if the same operation can be performed by traction systems free of pollution, e.g. electric traction. . . . Such restrictions can be ordered for the following cases:

- Driving in containers and partially closed trucks, railway wagons and ships.
- Driving in cold-storage houses and other storage houses.
- Supply of working places in factory buildings.
- Operation of drilling-equipment in mines.

4.7.1 Vehicles for materials' handling

Before purchasing of vehicles for materials' handling the user has to check whether the operation of diesel-powered vehicles can be partly or totally avoided in closed rooms. The operation of diesel-powered vehicles can be tolerated corresponding to the German legal regulation GefStoffV § 16.2-2, if:

- The transport task with electric powered vehicles needs less than one battery charge per shift, because
 - a) A tonnage of less than 5 t is needed
 - b) Seldom level differences of more than 1 m have to be overcome
 - c) Average ranges less than 80 m per transport activity
 - No extreme stress of the battery is expected, because
 - a) No long breaks of operation occur (e.g. in seasonal operation)
 - b) No extreme vibration occurs
 - c) No extreme temperature exists (e.g. by operation in foundry)
-

Figure 5.1 Extract of survey on special regulations for the employment of internal combustion and battery-powered vehicles. Translation of German regulation TRGS 554.

Materials Handling), edited by VDI-Gesellschaft Materialfluss und Fördertechnik (VDI working group on materials handling and conveyance), is based on long-term practical experiences and enables—not only for forklift trucks—a relatively simple calculation for vehicles for materials handling. The guideline includes for a wide area of operation costs and calculation factors. The cost calculation concerns the following areas:

Time-dependent costs as to investment, write-offs, and interest, and *operational costs* as to energy consumption and maintenance, resulting in costs for 1 h of operation, in practice a useful and realistic estimate.

Table 5.2 shows an example of cost calculation based on the current VDI guideline. Not regarded is a calculating factor later on explained, the factor can be taken into account for different categories of service.

Category I—low duty

- Smooth and even surface of the roadway without essential ascent (up to 3%)
- Normal environmental conditions (e.g., temperature and humidity)
- Usage up to 50% (half the nominal load and half the time of service during one shift per working day)

Category II—normal (medium) duty

- Roadways with fastened surface, in addition to outdoor service on uneven roadways (ascents up to 6%)
- Increased pollution (dust, changing and higher temperatures)
- Usage up to 100% of the offered performance per 1-day shift

Category III—heavy duty

- Bad road conditions, cross-country operation (ascents > 6%)
 - High pollution by dirt, temperature, aggressive atmosphere
 - Usage mainly at 100% and two or three shifts
-

These categories of duty have direct impact on the economy of the relevant traction system. Generally the electric traction powered by batteries, e.g., for forklift trucks up to 3 tons, has the best economy for low and normal (medium) duty. Investment costs for electric vehicles are normally higher than those for IC-powered vehicles, but longer service life and lower operational costs compensate the higher rates for write-offs.

In practice an experienced user will not steadily calculate the costs, but will regard for the choice of the system company internal records and conditions of usage. Therefore, battery-powered and IC-powered systems will have their specific area of employment.

For the employment of special types of traction batteries the manufacturer can supply the client documents enabling practical cost calculations. As an example, see in [Figure 5.2](#) a cost comparison for the Hagen battery types PzS and CSM-ECON. In any example all parameters have to be regarded resulting in such presentations.

5.4 DEMANDS ON BATTERIES

From the users' point of view, there are the following demands:

- High electric performance by reasonable weight and volume
- Long service life and minimal maintenance
- Relatively low purchase costs
- High reliability guaranteed by optimal finishing, not insensible to casual overload, deep discharge, or higher temperature
- Type-spectrum of a manageable size

These demands cannot be realized at the same time. The physical properties of a lead-acid battery are limiting some combinations, e.g., long service life and service at high temperature.

Discussion of current technology regarding these parameters follows.

Table 5.2 Example of cost calculation based on current VDI Guideline 2695.

Investment	Factor	EUR	Service (years)	
Brand XXX, type YYY				
Basic equipment		5087.35	8	
Battery				
V =	24	1022.58	4	
Ah =	160			
Charger			16	
Special features			8	
Total investment		6109.93		
Operation duty category II	II			
Hours of service per year	600			
Fixed costs			EUR/Year	EUR/h
Write-offs			891.56	
Interest of 50% of the investment	11		672.09	
Calculated upkeep costs (fixed)	20%		127.06	
Safety check			102.26	
Calculated service costs			306.78	
Annual Fixed Costs			2099.75	
Fixed Costs per Operation Hour				3.50
Operation-dependent costs				
Battery traction				
Upkeep $0.8F (1.1+1.4)-2.4/2$				
F = 0.12, category I				
F = 0.15, category II				
F = 0.17, category III	0.15		559.35	
Electr. energy per charge =				
(V)(Ah)(0.8)(1.8)/1000 (kWh)	6			
Electricity costs (EUR/kWh)	0.12			
Service hours per charge	3			
Energy costs per year			132.71	
Energy costs per service hour				0.22
IOC—traction				
Upkeep $0.8F (1.1+1.4)-2.4/2$				
F = 0.15, category I				
F = 0.19, category II				
F = 0.22, category III			-51.13	
Specific fuel consumption (L/h)				
Costs for fuel (EUR/L)				
Sum per year			0.00	
Sum per service hour				0.00
Annual operation-dependent costs			640.93	
Sum of operation-dependent costs				
per service hour				1.07
Total annual costs			2740.68	
Total costs per service hour				4.57

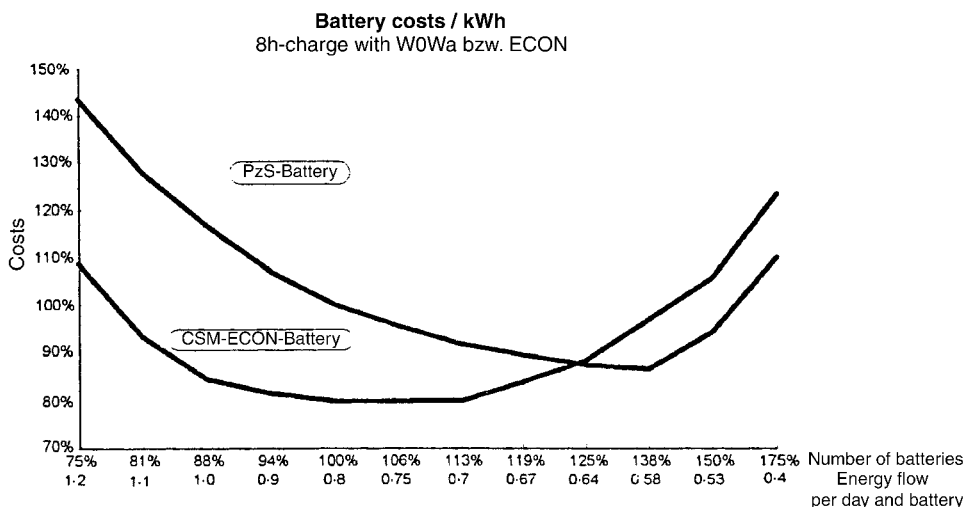


Figure 5.2 Comparison of costs for two different battery types.

5.4.1 Increase of Electrical Performance

The increase of electrical performance will be up to 20% by installing higher specific capacities by optimizing the grids and using the complete volume of a cell and increasing the electrolyte density. This requires more material (higher price), and the higher electrolyte density is restrictive to life expectancy.

5.4.2 Service Life

The service life of a lead-acid battery is influenced by several facts besides the quality of manufacturing, mainly by the kind of use. For example, deep discharges, higher temperatures, wrongly dimensioned chargers and charging methods, and high discharge currents reduce service life.

The temperature has the most important influence. A lead-acid battery can perform up to 10 years if the temperature is limited to 20 °C, while the same battery reaches the end of its life after only 1 year when operated at temperatures around 60 °C. Therefore all practicable measures should be performed to avoid higher temperatures if a long service life is wanted.

ZVEI has created a diagram ([Figure 5.3](#)) to determine the expected service life of a lead-acid traction battery with positive tubular plates; this diagram is a good basis for calculation, but it has to be noted that this diagram is only applicable for cells with a liquid electrolyte. For other cell types, e.g., the VRLA types, the diagram cannot be used.

5.4.3 Maintenance

Maintenance consists of two elements: servicing and upkeep, resulting in running (operating) expenses that get more and more expensive. Upkeep costs can sometimes

be avoided, but servicing costs are calculable. To look for a maintenance-free design is important for the choice of a traction system.

5.4.4 Purchasing Costs

Purchasing costs of battery systems are regulated by competition. There are two procedures:

- Purchasing the battery and the charger as a package from the supplier of the vehicle or truck
- Buying and providing the battery and the charger by the user

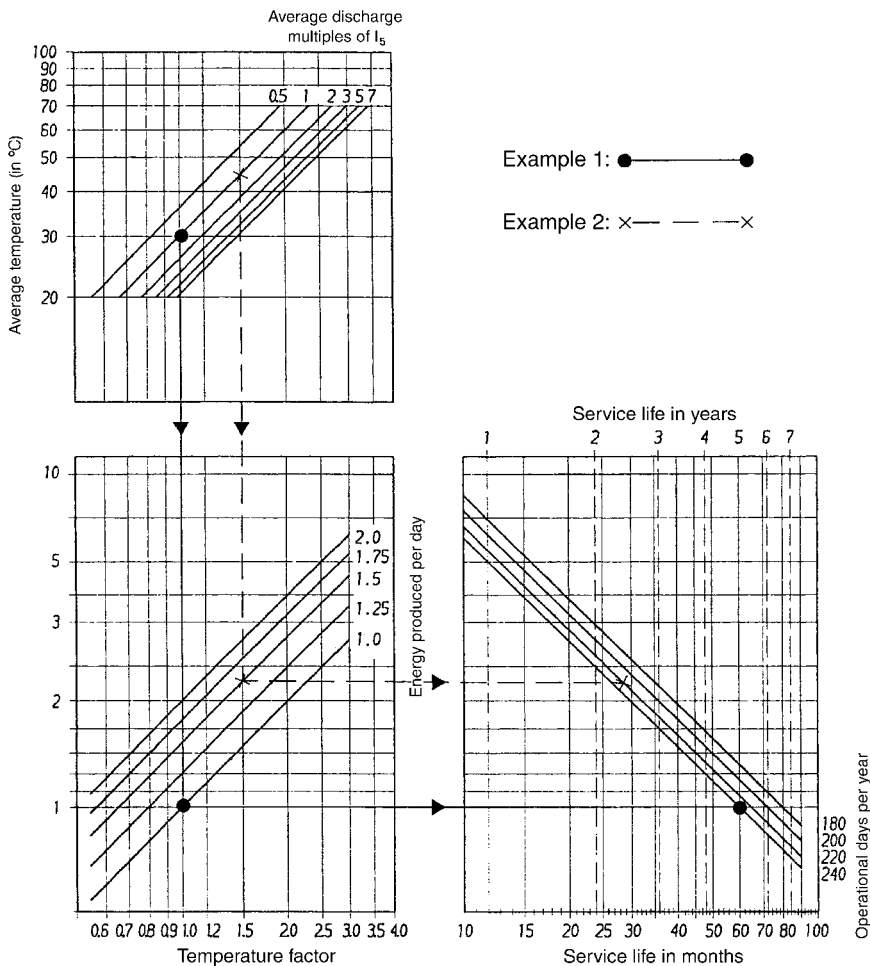


Figure 5.3 Diagram for calculation of the expected service life of a traction battery (type PzS with positive tubular plates).

Providing directly by the user makes more sense when better price conditions can be performed, depending on the quantity. Therefore central purchasing offices of big users have advantages. But also smaller users should check possible cost advantages of direct purchasing.

5.4.5 Safety of Operation

Safety of operation depends on the reliability of the components of a battery system. Falling outs of a battery system create quickly increasing costs for the user. Therefore a good mixture of demands on quality and price has to be found. The limits are between absolute quality not regarding the price level and the lowest price dominating, with risks of falling outs by low quality.

Looking at peripheral costs, as for installation, mounting, shipping, and fallout, today's recommendation must regard economy and ecology resulting in the choice of a product with high quality and a reasonable price.

To judge the operational safety a maximum of resistance against falling outs has to be noticed. Despite all planning in practice it cannot be avoided that from time to time a battery is deep discharged, overloaded, not sufficiently recharged, or operated at high temperature. Change of the kind of operation, failure of the mains, or other technical disturbances can be the cause. The higher the risks during operation, the higher should be the reserve in battery systems and vehicles. Today risks are often not calculated in order to keep the investment costs low. This can have a negative result as soon as a minimum of reserve is not at hand and when preventive servicing is not given. In general the outer limits are known by the suppliers and should be combined with the service schedules. Experiences of the user sometimes differ from the supplier's recommendations, but they have the higher priority.

5.4.6 Destinations of Types

Only standardized types should be chosen. The current states of the standards will be later demonstrated. In our region two standard types are established: DIN and BS, while in Germany the DIN types are dominating.

The selection of materials handling equipment should always include the right selection of the battery, especially when the user is the one who will order the batteries and the replacement batteries. Standardized batteries are cheaper and have shorter delivery times compared with specially designed batteries. This goes not only for the cells, but also for the trays. Here the vehicle suppliers often offer sophisticated solutions. To avoid extra costs for replacement the user should not accept such design.

It should also be mentioned that standardizing has disadvantages, because standards follow the state of the art of techniques with delay. Therefore a check is needed when purchasing new systems regarding how far a standard is necessary. Other disadvantages in application of the existing standards are that they are a compromise on a low level. But using the standards is always better than to accept the individual design of one supplier.

5.5 CONSTRUCTION AND SELECTION CRITERIA OF TRACTION BATTERIES

Notable manufacturers of traction batteries and chargers offer a wide scale of different constructions and designs making it difficult for the user to find an optimal solution. Cells with positive tubular plates (PzS) are most common in our region. Such cells perform between 1500 and 2000 cycles conforming to EN respective to DIN testing procedures. These cells are highly developed. So they are often chosen because of their high quality and long service life.

When only small traction performance is required, cells with flat plates (pasted plates) are used because of the lower price compared with the tubular cells. Cycles of 800 to 1000 can be performed. These types are on the market with a voltage of 24 V and capacities between 200 and 250 Ah.

In any case all advertising brochures of the suppliers should be read critically, and if arguments and figures are not plausible, the supplier should be asked for an explanation.

The following sections survey today's offering of systems and their classification to operational demands.

5.5.1 Standard Design of Cells Conforming to an Older Standard DIN 43 567

The lids of cells with positive tubular plates (PzS) are sealed with compound or the lids have a soft-rubber sealing; the terminals (poles) also have a soft-rubber sealing. That means this kind of cell is not electrolyte-tight. The cell connectors are from leaded copper bolted on the poles. Poles and connectors are insulated. These types of cells still have a relatively high content of antimony in the grids. The cells need maintenance such as cleaning and controlling of the cell connections. Therefore this standard has been withdrawn and is mentioned here only to give a complete survey. The use of this kind of design is no longer recommended.

5.5.2 Low-Maintenance Cells (Closed, but Not Sealed)

This "wet" design conforms to the older DIN 43 595 (dimensions conform to IEC 60254-2) and is the most popular type with tubular positive plates (PzS). The antimony content in the grids is very low; the cell covers and pole sealing are electrolyte-tight. The poles and cell connectors are insulated. The connectors' band end terminals can be delivered welded or bolted. This design is the today's European state-of-the-art of technology and basis for the following description of improved cell design.

Several manufacturers have developed special processes to produce cell connections to demonstrate product advantages against their competitors. Established manufacturers supply a good quality level, so the user finds no reason for a preference.

These low-maintenance cells are also available with high quality plug-in covers. This design only makes sense if the user has reason to open cells, e.g., for replacement of plate stacks or to remove mud from the cells to extend service life. This method is no longer of significant interest because of the high running costs and new better internal cell design (e.g., pocket separators) to avoid mud and short

circuits. Last but not least environmental demands require high expense to ensure safe handling of sulfuric acid and its disposal, including the mud. So economical reasons together with improved cell design brought the end of this type for long-term usage.

The difference between welded and flexible bolted cell connectors cannot only be judged by looking at the manufacturing costs. The welded cell connector, made from lead, can only be removed by a drill process and be replaced by welding through educated personal (trained in hydrogen–oxygen welding). Easy removable bolted cell connectors ensure an optimal end terminal connection with no loss of material when cells have to be replaced. This design has economical advantages if the user performs maintenance and replacement in his own facilities. Figure 5.4 shows an end terminal design (Hagen patent).

5.5.3 Low-Maintenance in Improved Cell Design with Higher Capacities

Low-maintenance and enclosed cells with tubular positive plates (PZS) conforming to the older DIN 43 595 are also offered with improved capacities, up to 20% compared to the normal design. This could be performed by increasing the electrolyte density from 1.27 to 1.29–1.31 kg/L, enlarged plates and reduced space for mud collection, and a lower electrolyte level above the plates. These measures reduce service life, and therefore these cells should be used only if the higher capacity per volume is really needed, e.g., if a second battery per shift is no longer needed.

Very special among this kind of design are cells with the so-called CSM technique, delivered by the manufacturer Hagen. Instead of lead grids in the plates, leaded expanded copper sheets are used. This means a lower internal resistance,

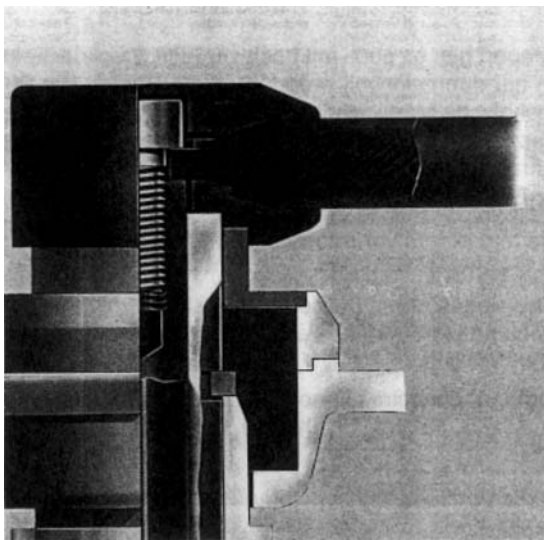


Figure 5.4 End terminal design, bolted and fully insulated (Hagen patent).

leading to a better voltage level, especially for higher voltage cells. For the use of this design the same argument pertains as mentioned before for cells with improved capacities.

5.5.4 Special Design for Heavy Duty

The demands for higher specific electrical performance, e.g., for operation in two or three shifts at elevated temperatures and the trend toward extremely reduced maintenance, were the reason to create batteries with battery water cooling and electrolyte circulation.

In cells with electrolyte circulation an air-pumping device is installed to mix the electrolyte of higher density in the bottom of the cell with electrolyte on top of the cell, where the electrolyte has a lower density. This means that the charging factor can be reduced from 1.2 to 1.03 with the effect that the charge time and the energy demand are reduced, while the water consumption is so low that water replenishment is only necessary after 200 to 250 cycles. The service life is as good as with normal vented cells. (See [Figure 5.5.](#))

A further increase of performance for heavy duty operation with higher discharge currents can be performed by water cooling of the cells, leading to normal service life despite elevated environmental temperatures and heat generated by the higher discharge currents. The higher costs for this special design need technical consultation by the battery manufacturer to check if the application is economical.

5.5.5 Maintenance-Free Design—Valve Regulated Cells

In cells in maintenance-free design the electrolyte is immobilized. The immobilization of the electrolyte reduces water losses when charged only with a limited voltage. Two designs are on the market: cells with a gelled electrolyte and cells where the electrolyte is fixed by a fleece between the plates. The cells are not totally sealed, because a vent is needed to regulate the internal air pressure of the cells. For more details see Chapter 1. The charging factor is lower as with normal cells: 1.05. Traction cells with gelled electrolyte have been introduced into the market by Sonnenschein in 1987 called dryfit. Other manufacturers followed and now there exists a standard and the design is well established for low and middle duty operation.

To get positive results with this design, the following rules should be regarded:

Operation only with low and middle discharge load and no extra stress by higher temperature; this means about 3.5 h of operation per day.

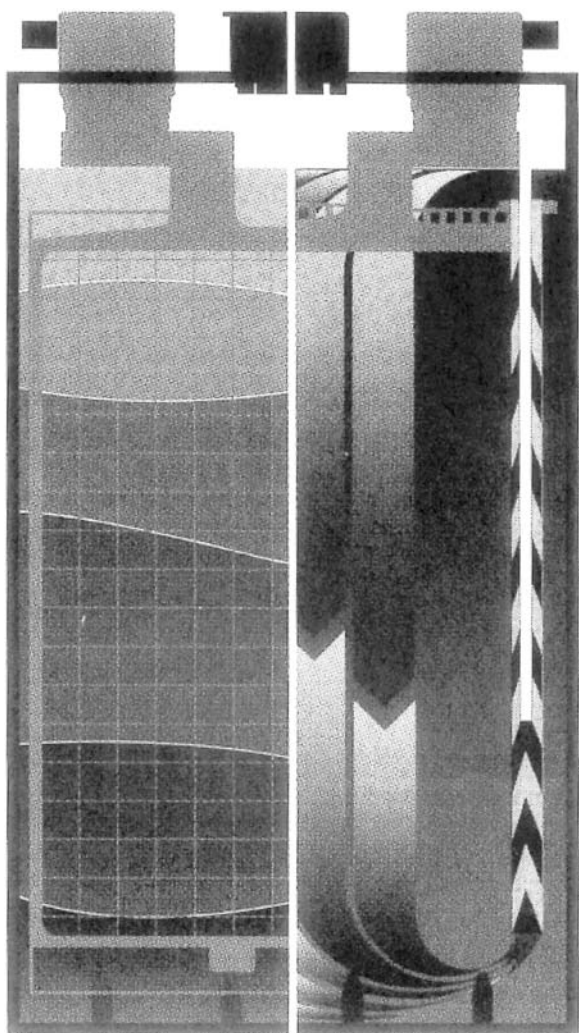
The depth of discharge should not be below 60 to 70% C_5 .

The battery temperature should always be below 45 °C.

Charge methods and chargers conform to the battery manufacturer's specifications.

If these rules are regarded, the user will have good operational results.

Substantial for the economical success of this design is the maintenance-free operation. Water replenishment of wet cells to be managed by the driver of the vehicle is a critical procedure. Often the cells were overfilled resulting in spillage into



Electrolyte stratification

VARTA electrolyte circulation
at the airlift principle

Figure 5.5 Cell with electrolyte circulation.

the trays with corrosion; or, if there was no replenishment in due time, the cells dried out and were damaged by heat.

For cells with immobilized electrolyte by fleece the same rules have to be regarded as for the gelled type. As an advantage it can be seen that in case of failure (water loss by overcharging), water can be added to continue with the service of the cells. Cells with fleece normally have pasted grid plates, while gelled types also with positive tubular plates operate with good results. Cells with fleece are offered mainly in smaller sizes as monoblocs.

5.6 CHARGING OF TRACTION BATTERIES

Besides the right selection of a battery to conform to the operational demands, the charging methods and chargers have a great influence on safety during service and service life. Optimal charging always means careful treatment but nevertheless effective for the battery and the operation.

The following demands on charging methods have to be regarded:

Limiting the temperature rise during charging

Switch-off when the battery is fully charged

Exact adaptation to the battery system to be charged

Enabling of booster charges and equalizing charges

Safe automatic switch-off to protect the battery in case of disturbances

5.6.1 Regulations and Manuals

Regulations concerning charging of batteries are numerous; only the important ones are mentioned here:

DIN/VDE 0510, Part 3	Accumulators and battery plants, traction batteries for electric vehicles
DIN 41 772	Rectifiers, shape and designation of charge characteristics
DIN 41 773, Part 1	Rectifiers, chargers with constant current/constant voltage characteristics
DIN 41 773, Part 3	Examples of characteristics
DIN 41 774	Rectifiers, chargers with taper characteristics
AGI	Working instructions: J 31: electrical facilities, buildings and rooms for battery service J 31, Part 2; charging stations, battery rooms

5.6.2 Chargers with Taper Characteristics

The most common chargers have taper characteristics, marked as W characteristics. (W for *Widerstand* in German, i.e., resistance). The internal resistance of the battery and the function of the transformer and rectifier control voltage and current during the charge process.

The simplest type is the **Wa characteristics** (a stands for switch-off). A charger of this type needs exact classification of the battery. To conform to the relevant standard the nominal current is $0.8 \times I_5$ (16 A/100 Ah) at 2.0 V/cell, decreasing when the battery voltage rises. When the gassing point of 2.4 V/cell is reached, the current has to be maximally $0.4 \times I_5$ (8 A/100 Ah) decreasing continuously to $0.2 I_5$ (4 A/100 Ah). The charging time for an 80% discharged battery is about 11 h, limited by a timer. The simple design and the low price are reasons for the widespread use of these chargers.

A great disadvantage of this type of charger is the influence of the variation of the mains's voltage on the charge current and, corresponding to that, the variation of the charge time. Mainly overcharge can be observed together with elevated water consumption reducing the service life of the battery. Charging is normally performed at night after one-shift-per-day operation, a time when the mains has little load and an elevated voltage. (10% overvoltage of the mains

means about a 50% elevated charge current.) Further on, batteries often are not discharged to 80%.

An improved characteristics is **WoWa** (o stands for switching from the first to the second taper characteristics). The first starts with a current $1.6 \times I_5$ (32 A/100 Ah). When the gassing point is reached (2.4 V/cell) by automatically switching with the second characteristic, the charge continues to conform to the above-mentioned Wa characteristic. By this method the charge time is reduced to 8 h, enabling shift operation. The same disadvantages as described before have to be regarded.

Chargers with W characteristics can be delivered with some improvements reducing the above-mentioned disadvantages. So a regulation of the main voltage stabilizes the charge current and the charge time. This kind of charger is cheaper than the chargers with voltage and current regulation.

When long service life and no maintenance is required, this type of charger should not be chosen.

5.6.3 Chargers with Regulated Characteristics

Chargers with regulated characteristics control current, voltage, and charging time corresponding to the data given by the battery. Originally this characteristic served as a means to get short charging times; now the reason for application is to get a smooth kind of charge. Therefore the range of application could be substantially extended. The price is not (or is only a little) higher than for modern taper chargers.

In the following section the functions of the regulated characteristics are briefly described. See also Chapter 12.

5.6.3.1 IU Characteristic—Charging with Constant Voltage

This characteristic limits the current I or the power P to the nominal values until the gassing voltage (max. 2.40 V/cell) is reached. Then the voltage is held constant with a little tolerance, so the charge current decreases.

This characteristic is applied in vehicles with IC engines (charged by generator) and as constant voltage charging for traction batteries. An advantage is the low gassing rate and the possibility for parallel charging of batteries having different capacities with the same nominal voltage. The application of relative high charge currents ($1.5\text{--}2 \times I_5$) enables booster charging to 80% in a short time (3–4 h). The time to get a fully charged battery is very long (30–70 h), so for daily operation the amount of charge is not sufficient. Therefore every 5 days an equalizing charge has to be performed.

A disadvantage of the IU characteristic is that the individual battery cannot be controlled. Therefore it has to be regarded that only faultless batteries are charged by this method. This cannot be performed in practice, because failures of single cells can be overcharged and dry out by high temperatures.

5.6.3.2 IUla Characteristic Enables the Optimal (Full) Charge

This characteristic has three steps, while variants work by the same basic principle. The U-step is held constant as long as the charge current drops to limited value,

tolerable for the end period of charging. This current then is held constant while the voltage rises. The charge is switched off, controlled by a timer.

This characteristic offers a wide range of operation for all systems, charging the batteries very smoothly. A full charge can be performed in less than 8 h using a nominal current of 25 A/100 Ah. If there is no need for a very short charging time, the nominal current can be reduced to 10 A/100 Ah, corresponding to a charging time of 12–14 h. In any case the time available for the recharge always should be used to get the advantages of a lower purchasing price of the charger and the smooth charging.

The right correlation of the nominal current and the charge current for the third step has to be regarded. These values are independent of the charge time wanted and only dependent on the type of battery and its capacity. The controller is very flexible, able to be adjusted to the specifications of different battery types.

Figure 5.6 shows an example of the IUa characteristic; voltage and current have to be between specified tolerances.

The technical and operational demands on a modern charger are as follows.

All electrical functions include a faultless operation supplied by the mains as a TN/TT net with the allowed tolerances regarding disturbances or pulses (conforming with the specification VDE 0160). In addition the following properties can be specified: control of the electrolyte pumping system, the automatic replenishment system, and registration of all battery data during operation by computer management.

The design of the chargers is defined as a housing of steel sheet (protection class IP 21) with clear announcement of the corresponding class of battery (nominal voltage, nominal capacity and type of battery, nominal charge current). The front plate has to show the charge current, the charge voltage, and the following steps: “Charge,” “Charge determined,” and “Failure.” Maximal length of cables to connect the charger with the mains and the battery with the charger is 3 m.

The factory code in the manual of the device shows the correlation of the charger to the battery. Later in the plant during operation, if necessary, an adjustment can be performed, but only by educated staff.

Modern electronic controllers offer additional information regarding different functions and failures regarding the given charge characteristics by the manufacturer.

From the author’s point of view it is not the right way to have prescriptions for charge characteristics for all different battery trademarks and types. The better way is standardization.

5.6.3.3 Characteristics and Chargers for Special Charges

Float charge is a continuous charge with constant voltage—about 0.1 V higher than the open battery voltage (DIN 2.23 V/cell)—to compensate losses by self-discharge or in cases when a battery is out of order for longer time. Self-discharge is dependent on the type and the age of a battery. Maintenance-free cells are more insensible and can stay active up to around 1 year without any charge. Also low-maintenance batteries with liquid electrolyte may be stored without any charge up to 6 months. A precondition is always a fully charged battery. Aged batteries show self-discharge rates up to 1% per day.

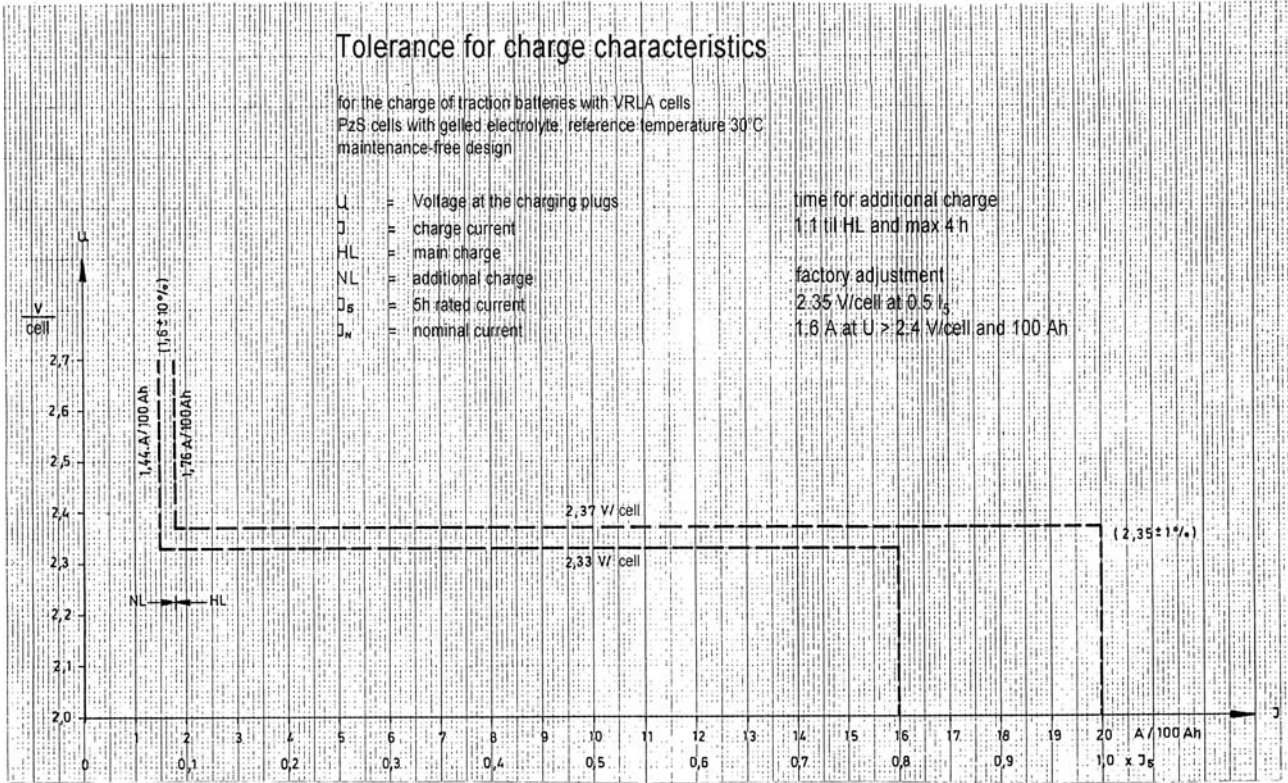


Figure 5.6 Diagram of the IUa characteristic.

To compensate self-discharge, constant voltage chargers (e.g., the IU1a type) may be used. The battery shall be connected to the charger in intervals of 6–8 weeks. The advantage of this method is that no special charger is needed.

Maintenance-free cells need careful float charge, best by an automatic charger to avoid extreme loss of water. This method is preferred if not all batteries are steadily in operation (rotation principle).

Equalizing charges are necessary to eliminate sulfate in the active material in cases when during operation phases of some days (e.g., 5 working days) no full charge can be performed by the constant voltage method. Further on the electrolyte stratification has to be equalized by charging in the gassing phase above 2.4 V/cell. Valve-regulated lead-acid (VRLA) cells show no electrolyte stratification, but the sensibility of these cells has shown that weekly equalizing charges are necessary because the normal charge is not a full charge.

Modern single chargers have characteristics performing automatically in long-time operation breaks to equalize charges, e.g., during the weekend. Educated staff can do it manually, e.g., with constant current 2 A/100 Ah for vented cells and 0.8 A/100 Ah for valve-regulated cells.

The measure for a successful equalizing charge is the electrolyte density, which only can be measured on vented cells. Valve-regulated cells need control of the open voltage after charge or a capacity test.

Booster charges are quick charges limited by the gassing voltage. Booster charges are a kind of “biberonage” to widen the range of a vehicle by an additional given capacity during pauses of operation. By this method in many cases the number of batteries can be reduced. It has to be considered that the service life of batteries often undergoing such booster charges is shortened, but the capacity in total taken out of the battery during operation is not shortened. Normally performing booster charges will reduce the battery costs.

Important for the realizing of booster charges with lead-acid batteries is a minimum time of 30 min; further beyond that the gassing point will not be passed over, and the maximum tolerable electrolyte temperature of 50 °C is observed. These parameters are difficult to plan and need experienced analysis at the scene.

The most critical charge is a charge to eliminate sulfurization. When deep discharge occurs often, re-maining of batteries in a discharged condition results in sulfurization of the active material. Often sulfurization cannot totally be eliminated by normal equalizing charges. Indications for sulfurization are losses of capacity and performance, rapid voltage, and temperature rise during charge.

With vented cells the sulfurization effect can be observed by measuring the electrolyte density when the nominal density cannot be reached. Vented cells need critical judgment of the open voltage or the result of a capacity test.

The measures to totally eliminate sulfurization are not economically possible. A controlled procedure—charging with a current between 0.1 and 0.15 A/100 Ah until a charge factor of 1.5 is reached—can be successful. This procedure needs days or weeks of time; therefore a decision on the scene is needed to do it or not. External service personnel for this task is very expensive; therefore sulfurization has to be avoided by regarding the manufacturer’s instructions for charging and battery operation.

5.7 ORGANIZATION OF CHARGE OPERATION

Operational conditions of materials handling and the kind of buildings determine the course of battery charging. Only breaks during work periods can be used to recharge the batteries, either by a short booster charge or by a full charge with duration of 7 to 14 h. Normally the charging procedure is not watched over, so some measures to ensure operational safety and protection against accidents have to be regarded. DIN VDE 0510, Part 3, describes the safety regulations, in addition with DIN 0115, Parts 1 and 2, DIN VDE 0117, and DIN VDE 0122. In special cases, e.g., when explosion protection is required, additional regulations have to be regarded, prescribed in DIN VDE 0115, Parts 1 and 2, and DIN VDE 0170/0171. All the mentioned standards undergo harmonization by CEN and CENELEC resulting in European standards EN.

In the following section practical advice is given.

5.7.1 The Battery Room (Charging Room)

In battery rooms batteries and/or electric vehicles with batteries are temporarily placed to be charged. The chargers are placed in another nearby room, a “separate electric operation room.” In the battery room the electrical plugs for the connection to the batteries are placed, protected by fuses. Control boards have signals for the steps of operation and for failures and breaks of the charging procedure. At any time by special switches the charge can be interrupted. This arrangement has the advantage that batteries and vehicles can be placed to provide ease of service. Installations of air ventilation can be centralized. All technical measures such as change of batteries, overhaul, and maintenance can be performed clearly. Educated personnel are necessary.

The chargers in the separate room are protected against aggressive gassing by the batteries, but longer cables and more equipment are needed for the remote serving of the plugs in the battery room. The voltage drop in the cables has to be calculated during planning. If extension of the charging time cannot be tolerated, special cabling for measurement only has to be installed; the installation of regulated transformers to compensate the voltage drop is more expensive.

The battery and vehicle manufacturers can provide special instruction sheets for the erection of battery rooms. (See recommendations J31, edited by Arbeitsgemeinschaft Industriebau e.V.–AGI.)

Rooms where batteries shall be charged are not under the rules for rooms with explosive atmosphere. The electrical installation and illumination equipment have to correspond to the standards for wet room installation. A minimum distance of 0.5 m between cells and electric spark–generating sources is strictly required.

Water outlets in the floor are very critical because acid separation from the water is required for the installation of a neutralization with no break control. These measures are very expensive and nowadays no longer practicable. Therefore no water outlets should be installed so sulfuric acid contaminated with lead cannot flow into the public sewer. To solve the problem of acid spillage the ground floor can be designed as a “tube” with a capacity to take the electrolyte of the biggest battery. Material to neutralize the electrolyte has to be in place. Proper disposal according to the legal regulations is necessary.



Figure 5.7 Charging station for batteries.

For air flow and ventilation see DIN VDE 0510, Part 3.

5.7.2 Battery Charging Station

A battery charging station is a room where batteries to be charged as well as chargers are placed together (Figure 5.7). Compared with the battery room the cables can be as short as possible for safe handling. Modern low-maintenance and valve-regulated types of lead-acid traction batteries—if sufficient airflow specified by DIN VDE 0510 is guaranteed—generate no corrosion of the chargers. This design is more economic as the one described in Section 7.7.1. The previous discussion of design and operation is similar.

5.7.3 Single Charge Point

To charge batteries in any working plants or storage rooms a single charging point can be installed. This is the most economic installation for the following reasons: There is no transport to the battery rooms or battery charging stations and no expense for the erection of battery rooms and charging stations. Booster charges are easily performed. This means dramatic cost reduction.

To realize such single charge points the following preconditions have to be regarded:

- Sufficient room for the electric vehicle and the charger.

- The single charge point has to be clearly marked as such; the place for the single charge point has to be free of other traffic and open for service.

- A protection against other traffic in the neighborhood is recommended.

The charger has to be placed so it cannot be damaged.

Airflow and ventilation corresponding to DIN VDE 0510 has to be guaranteed.

No open fire, welding, or grinding in the neighborhood of the single charge point is allowed.

Batteries and chargers have to be protected against direct contact to dangerous voltage.

Modern types of low-maintenance and valve-regulated traction batteries fulfill the requirements so battery charging can be performed safely and under optimal economic conditions. In any case for overhaul, repairs, and maintenance there should be a workshop for internal or external educated personnel; the single charge point is not the right place for this.

5.7.4 Mobile Charge Stations

Mobile chargers are used to charge various batteries in different places. This application can be recommended only for special cases and the above-described rules are valid. The question of what shall be transported, the battery or the charger, has only one answer: preferably the battery. A special application is charging batteries in rail-bounded vehicles. Another special case is the electric vehicle with on-board charger. This design is very flexible in use, because a simple connection to the mains is sufficient. The user has to be advised that sufficient airflow is available when the battery is on charge. Preferably for small vehicles on-board chargers are in use.

But disadvantages of this design should also be mentioned. By installing the charger supplied by the mains in a vehicle the regulations of DIN VDE 100, Part 410 (DIN 57 100) have to be regarded; that means repair and overhaul can be done only by educated personnel. In addition the charger has to fulfill the specified requirements for vibration and shock resistance as for a nonspringy vehicle.

5.7.5 Protection Methods and Specifications

With all charging operations protection against accidents has to be regarded; the following main points are important:

Explosive gases generated by the batteries during charge are dissolved by normal or forced airflow. The battery charging area is a nonsmoking area!

Danger of short circuits from handling with current-conducting and noninsulated tools requires a total insulation of the battery intercell connectors and end terminals.

Danger of fire must not be underestimated. Defects and harms are rarities, but when they occur the costs are high. To avoid fire by high temperature, short circuits (due to defects on the cables, perhaps damaged by passing vehicles), etc., means prophylactic controlling and maintenance and keeping the batteries dry and in proper condition.

5.8 PERIPHERAL EQUIPMENT

Many different demands of users and variants of operation combined with different opinions about their realization forces suppliers to have high flexibility. This is demonstrated by the huge array of peripheral equipment offered for traction batteries. Not all of this equipment makes sense. In the following section some peripheral equipment is described and evaluated.

5.8.1 Venting Plugs

Venting plugs are a must for low-maintenance cells with liquid electrolyte. Simple plug-in vents with a 35 mm diameter have substituted bayonet caps. More solid is a hinged lid instead of one with a plastic film lid. Inserts to the plugs exist in many variants. Important is that the maximum and minimum electrolyte level can be watched easily. Electrolyte proof should be possible when the level is below the minimum. Good experience has been had with antispilling inserts to keep back the electrolyte in the cell during the gassing phase.

5.8.2 Electrolyte Level Indicator

Electrolyte level indicators are made from acryl rods fixed or bolted in the cell covers. They indicate the electrolyte level without the need of removing the vent plugs. The function can be explained by different brightness, depending on the deepness of the rod dipped in the electrolyte. The advantage is that watching the battery surface allows seeing the electrolyte level and the need for refill with water. Also there is an indication of the maximum electrolyte level to avoid overfill. The disadvantage is that annually this appliance has to be cleaned to remain at full functionality. This kind of appliance is until now seldom in use.

5.8.3 Regulating Vents

Vents in use on valve-regulated lead-acid cells with immobilized electrolyte instead of normal venting plugs have to be designed in a way such that the user cannot open or remove them.

5.8.4 Cell Connectors

Connectors between the cells have different designs depending on the manufacturer and are normally not interchangeable. If the user has its own repair facilities, this is a disadvantage in case single cells have to be replaced. Welded connectors can be replaced depending on the manufacturer's design; bolted connectors need original spare parts.

5.8.5 Water Refill Equipment

For a long time automatic refilling devices for purified water have made maintenance easier; these are well known and reliable ([Figure 5.9](#)). There are two systems. The first is controlled by a vent plug with a mechanical working level indication, allowing

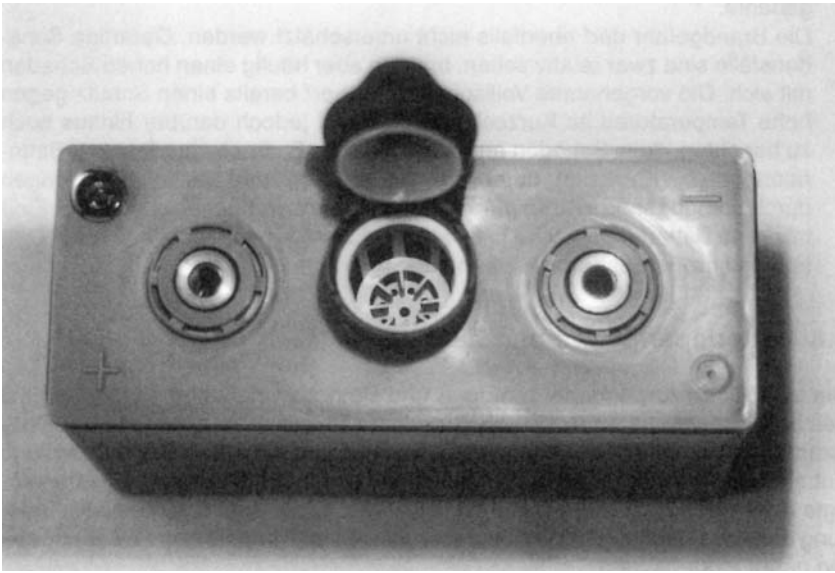


Figure 5.8 Cell with electrolyte level indicator, open vent plug with insert.

the check of the electrolyte density. There is a certain risk for overfilling, sensitivity to mechanical stress, and impurity of the water. The second one works with a so-called dipping pipe and is more precise allowing the check of the electrolyte level and density and is less sensitive to mechanical stress. In the case of mechanical defects both systems include the risk of overflowing the battery.

In any case refilling should start at the end of the charge. Water containers need a room free of frost. For large batteries with a high number of cells such water refill equipment is economical.

5.8.6 Recombination Plugs

Recombination plugs with a catalyst recombine the gases—hydrogen and oxygen—generated during charge to water flowing back into the cells. This method reduces the water loss to an extreme minimum, resulting in long maintenance intervals. In addition charging characteristics can also be influenced by the gassing rate, increasing the efficiency of the charge process. Important for the effective use of recombination plugs is the limitation of the surrounding temperature; otherwise the recombined water will not be condensed and escapes as vapor.

Recombination plugs have a fixed market share on stationary batteries as well as on mobile batteries. The mounting of the plugs has to be done very carefully, ensuring that cables do not move them from the right place disturbing their function by leakage. This point is the reason that recombination plugs have a limited field of application.

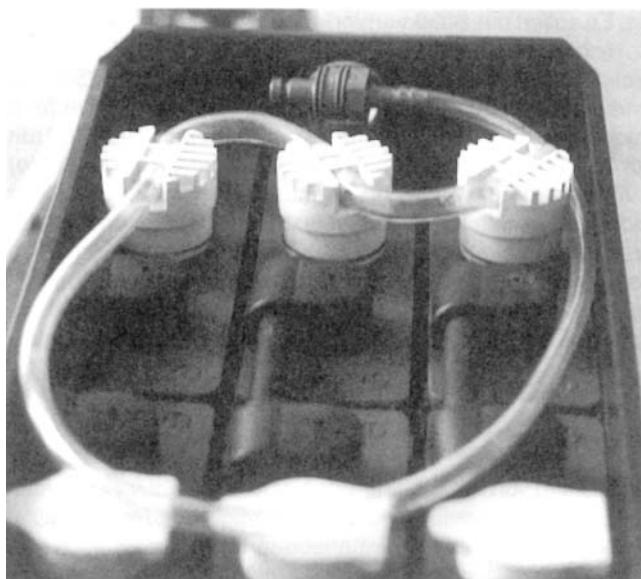


Figure 5.9 Watermaster refill plug.

5.8.7 Connections

Electrical plugs for traction batteries, chargers, electric vehicles, etc., exist in many variants. The European harmonized standard EN 1175-1 specifies required properties.

5.8.8 Capacity Indicators

Capacity indicators for traction batteries are on the market in many variants, of different reliability, and adapted to different battery types. This is understandable since the useful capacity of a lead-acid battery is dependent on several parameters, such as physical and chemical impacts, design and type of the battery, aging, temperature, and load. The user's demand in any case is to have a capacity indicator, comparable with a fuel indicator in a motorcar.

The very simple versions show only the battery voltage as a very rough indication of the capacity. Booster charges, aged batteries, and different battery types show a widespread scale of capacity values. The indication is not meant to avoid deep discharges.

Improvements in the development of electronics have allowed devices more accurate and easier for the user ([Figure 5.10](#)). These devices need only the battery voltage for indication, but show on a display the residual capacity, in percentage, of the nominal capacity and the remaining operation. The adjustment follows the individual characteristics of lead-acid batteries (low-maintenance or maintenance-free) or of nickel-cadmium batteries. Automatic switch-off breaks the operation of the lifting device of a forklift truck when there is danger for a deep discharge of the



Figure 5.10 Battery and time controller.

battery. The driver of a forklift truck can insert the right parameters in the capacity indicator in relation to a specific battery.

Another way to calculate the residual capacity of a traction battery is based on the evaluation of voltage and current. Both parameters have to be measured continuously, and the typical performance characteristics of a battery type have to be inserted in the calculation process. Often this type of capacity indication is part of the electronic control of a vehicle.

Normally the capacity indicator is a fixed part of a vehicle and is not considered by the buyer. The vehicle manufacturer makes the choice. Often during operation the indication is not watched because it seems not reliable enough. The vehicle is operated until a trouble occurs, e.g., the switch-off of the lifting device. This is to the debit of the safety of operation and the battery lifespan. Therefore the user should think about the expenses to get the right reliable capacity indicator.

5.8.9 Electronic Controllers

More and more costly control systems for batteries and charging equipment are of interest. Data collection and data transmission are used to identify a battery and to register the electric parameters under operation during discharge and charge. This enables the vehicle management of a plant a central controlling and steering of the electric vehicle fleet to identify the right time for service, maintenance, and replacement. Also this system has a great impact for leasing and rental systems.

Systems such as BICaT collect data via a microprocessor, a current measuring shunt, and a temperature sensor placed on a modified intercell connector and via a connection with the terminals of a traction battery. The transmission of all data is performed by a modern to a mobile data collector, e.g., a notebook.

[Figure 5.11](#) shows the principle of the BICaT (**B**attery **I**nformation **C**ontroller and **T**ransmitter), a joint project of the following battery manufacturers: Hagen Batterie AG, Hoppecke Batterien, Sonnenschein GmbH, and Varta Batterie AG.

A system like this offers optimal organization, supervision, and steering of a battery fleet. It can be clearly understood that only successfully tested equipment has

a chance on the market and this system is only for plants with major numbers of electric vehicles in use.

5.9 QUALITY ASSURANCE OF BATTERIES AND CHARGERS

To check qualified products the manufacturer has to install an efficient quality assurance system that guarantees the realization of all specified properties of a product. The best way for the manufacturer is to follow ISO 900. The purchaser can trust this system combined with a proven reputation of a product. If the purchaser defines the properties of the product, e.g., in technical terms of delivery, he has to also give detailed instructions for quality control. This goes for chargers as well as traction batteries, but it is easier for chargers than for batteries because capacity and life are the most important characteristics of a battery. These characteristics cannot be defined and measured easily. The main characteristics are defined in EN 60 241, Part 1, and the buyer of a battery can trust the supplier if he guarantees that he has tested the batteries corresponding to this standard with the following characteristics: (nominal) capacity or rated capacity, endurance in charge/discharge cycles, self-discharge, and water loss.

Regarding the expense of quality testing controlling quality characteristics, this can essentially be performed only in facilities of big users. Smaller users can profit from the testing of the big users; that means a product that is qualified by Deutsche Bahn AG, Deutsche Telekom, Bundeswehr, Mercedes Benz, or Volkswagen, just to mention some of the big users, is recommended for use also for smaller users.

Technische Lieferbedingungen (TL) are the technical purchasing conditions and *Technische Baurichtlinien* (TB) are the technical design rules that contain the modalities for quality assurance, both for qualification and for acceptance tests.

The tests for qualification are performed by the manufacturer and can be defined as a type test, e.g., that a battery shall have 100% of the nominal capacity

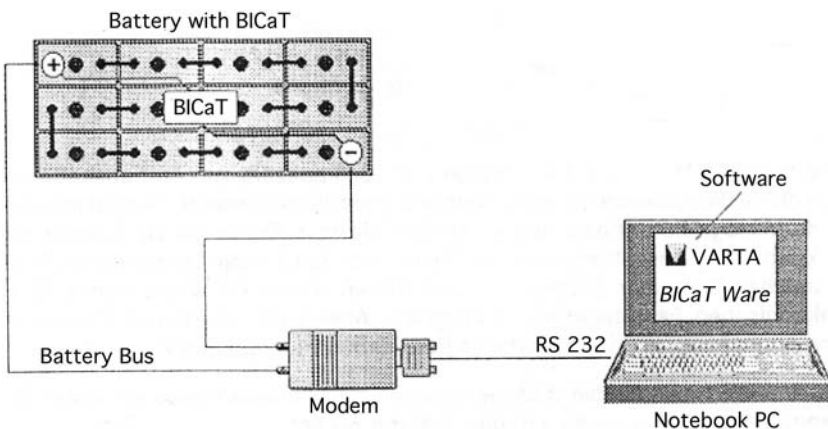


Figure 5.11 BICaT system. BICaT is mounted in the middle of the battery replacing an intercell connector.

after 10 discharge cycles with a DOD (depth of discharge) of 80%. New products require in addition a practical operation test of 12 months with a capacity test at the end of this period; the battery shall then have 100% of the nominal capacity.

Quality tests can be performed during acceptance tests and include optical control of the design and workmanship, dimensions, cabling, and accessories together with electrical tests. The electrical tests can be performed as sample tests.

Experience in practical use shows that not all manufacturers can guarantee the initially required performance data, but in all cases they can learn about and make improvements on their products to complete successfully.

Also the quality assurance of chargers make sense; worth mentioning is a type test and a sample test to check the main electrical and technical functions.

5.9.1 Capacity Tests

The capacity test of a traction battery is performed not only for quality assurance, but also to evaluate the endurance of the battery during operation. The capacity test is the only way to get a view of the electrical power of a battery. The test is described in EN 60 451, Part 1, as a discharge with a constant current I_5 (A), compensation of the temperature by 0.6% per degree if the electrolyte temperature differs from 30 °C. To execute a test qualified testing equipment and educated staff are needed.

Informative is the result if each cell of a battery is checked so that at the end of the test the capacity of all individual cells is known. This test can be performed annually and be limited on the second lifespan of the battery. This kind of surveillance will result in longer service life of the batteries in use. The test is only economic if enough samples can be chosen and the expenses for electronically controlled equipment (rectifier/alternator) are relatively low compared with the investment costs of the battery fleet. The normal user cannot run this kind of test.

5.10 MAINTENANCE AND UPKEEP

Besides the quality and the charge technique, maintenance and upkeep has an important impact on the service life of batteries. Regarding the investment costs for replacement batteries, upkeep reduces cost and prolongs battery service life. Upkeep includes all measures to preserve and to restore initial performance. In any case, inspection and maintenance are the first things to do.

Inspection and maintenance rules are set by the manufacturer and can differ from product to product, but the following daily inspection is always recommended:

- Inspection of the vehicle for safe operation (tires, steering, brakes, lights, and state of charge of the battery)
- In-time connection of the battery with the charger and control of the functions of the charger at the beginning of the charge
- Electrolyte level and refill with purified water
- Reporting of disturbances, especially those that can generate accidents, to the responsible office

To enable the operator or driver to take over the personal responsibility for the function of the vehicles and batteries, he has to be educated regularly and carefully.

Maintenance includes

- Cleaning (removal of dust and other substances)
- Preservation (measures to ensure endurance)
- Lubrication
- Refilling (e.g., water)
- Replacement of defective parts
- Adjustment (regulation in case of deviations),

Inspection includes

- Check of technical data compared with nominal values by measuring instruments
- Functional tests
- Optical check

Upkeeping includes

- Repair of parts
- Replacement of parts

When these tasks cannot be performed by the user but shall be the responsibility of the supplier, contracts on all details such as costs and scheduling should be arranged, keeping in mind competitive offers. Regarding the legal regulations to avoid accidents, the appointed times for inspection and maintenance remain the responsibility of the user.

If in the user's plant vehicles supplied by different manufacturers are operated, it can make sense to educate internal staff to perform maintenance and upkeep. Internal staff enables quick reaction on disturbances and shorter down times. Splitting routine work to performed internally and bigger upkeep tasks performed by external personnel also makes sense.

For upkeep by the user some advice is given in the following sections.

5.10.1 Traction Batteries

A critical check of the manufacturers' recommendations for maintenance is recommended because the operational conditions often require modifications. Normally for light duty operation the maintenance effort can be reduced. The type of battery and the peripheral accessories give important differences. Following is an example of the range of tasks for maintenance.

5.10.1.1 Daily Tasks of Operation/Charge

Charge the cell and keep the vent plugs of low-maintenance cells closed; remove cover mats; and limit electrolyte temperature to a maximum of 55 °C (random measurement by thermometer and density meter). Check the starting functions of the charger. After the end of charge control of the signal board of the charger, check the electrolyte level and remove moisture from the cell covers and connection of the battery to the vehicle.

5.10.1.2 Additional Weekly Tasks

Check the electrolyte level of all cells and refill with water if necessary. Remove moisture from the battery.

5.10.1.3 Additional Monthly Tasks

Check the electrolyte density of all cells; check the electrolyte temperature of a cell placed in the middle of the battery and make a written report. Control the fastening of the terminals.

5.10.1.4 Additional Tasks Every Three Months

Clean the battery; dry the wet surface of the battery; check the fastening of all intercell connectors; and grease if necessary.

5.10.1.5 Additional Tasks Every Half-Year

Check corrosion protection in the battery room. Clean the battery. Check the cables and plugs. Check the vent plugs. Check the open voltage of all cells and make a written report.

5.10.1.6 Additional Yearly Tasks

Clean the electrolyte level indicators. Check of the isolation of the battery (corresponding to DIN/VDE 0510) and make a written report. Perform capacity test (to be performed only in the second part of the lifespan of the battery) and make a written report.

5.10.1.7 Other Additional Tasks

Perform float charge for batteries stored out of operation (or every 2 months a normal charge for vented batteries, and an equalizing charge every 6 months for valve-regulated batteries).

Weekly perform an equalizing charge of batteries that are not normally fully recharged, e.g., batteries weekly charged by chargers with IU characteristics.

Perform equalizing charges of batteries showing sulfurization (if the nominal electrolyte density cannot be measured after a normal recharge).

Note: Maintenance work should be defined in technical instructions regarding the specific methods of operation for cleaning, all measurement procedures, capacity tests, and special charges.

5.10.2 Chargers

Maintenance of chargers is negligible. Optical control and a technical random check of the correctness of the charge characteristics are recommended.

For example, on a charger with IUIa characteristics and equalizing phase the following measurements should be performed:

- Voltage and current to the gassing point
- Voltage at half the nominal current

- Current in the third constant current period
- Equalizing current

If the charger is not operated in surroundings with extreme conditions, such as outdoor operation in wet or hot climate or in dusty atmosphere, a yearly inspection is sufficient. The tasks are as follows:

- Clean inside with airflow.
- Check the connection plugs.
- Check the fuses.
- Check all electrical functions and make a written report.
- Safety test corresponding to VDE 0100.

When battery-controlled systems are in use, there is no need to check the electrical functions because all data of the charger are registered by the system. It has to be noticed that upkeep inside the charger may be performed only by educated personnel (see VDE 0100). These recommendations are also valid for mobile and on-board chargers.

5.11 LEASING OF BATTERIES

Leasing and renting of batteries with full service provided is common nowadays. Complete batteries can be leased with full service avoiding any management problems for the user. These methods are economic for certain cases of operation.

After having read the previous sections, one may like the idea of leasing/renting with full service. There is no need for choosing the system and its components unaided, no need to organize maintenance; upkeep and disposal of spent material are taken care of. Such offers for leasing with full service, however, should be checked to see whether the technical service is qualified and financial conditions are appropriate.

In many cases, though, the user gains advantage by doing things internally when experienced staff is available and the distribution of this work with other work can be organized flexibly. Other users will see economies in external service.

5.12 DISPOSAL OF BATTERIES

The need for recycling of spent lead-acid batteries has been obvious for long time and did not need a political push. The recycling rate is near 100%, a result of contracts between user and supplier. The time when the user got reimbursement for lead batteries has passed because the recycling costs have increased partly due to the fact that the smelters have to fulfill many expensive measures against pollution. But this should be no reason for the user not to return the batteries and to avoid pollution despite the costs.

Recycling is not limited to the lead content of a battery. Plastic materials and metal parts can be recycled as well. Handling of sulfuric acid has to be done very carefully. Therefore normally the returned batteries will contain the electrolyte and the electrolyte is disposed of during the recycling process. Nowadays dismounting of plates and replacement of plates is no longer recommended because of environ-

mental legislation demanding to keep wastewater clean. Neutralization and disposal of the electrolyte needs very expensive equipment.

5.13 FUTURE OUTLOOK

In the beginning of this chapter it was mentioned that the lead-acid battery, especially as a traction battery, will continue to maintain its premier position in the foreseeable future. Improvements are still possible. Besides improvements in performance and service life, we can expect the following coming improvements of traction batteries:

Maintenance requirements will be minimized.

There will be six instead of five even surfaces. All peripheral parts are hidden and protected against damage and dirt.

The electrical connections of the black box battery will be simplified, but technical internal tasks will be left to the experts.

Batteries with immobilized electrolyte having a cooling system and electrolyte circulation will be improved to a high degree of reliability and become more economical.

Battery controlling equipment will get a reliable finish, featuring easy data reading with a normal PC or notebook at an acceptable price.

European standards will be the basis for the improved design under fair conditions.

5.14 CONCLUSIONS

The lead-acid traction battery is the most important part for materials handling systems, but it needs optimal usage conditions, including product-specific training of its functions by qualified and educated personnel. This chapter gives the perspective of a large user of operating electric vehicles and trucks. Certainly, critical comments from other points of view are possible. There are as many opinions about operation, application, and maintenance as there are battery products. The common bases are the physical and chemical properties together with the electric behavior of a lead-acid battery, combined with the aim for economical and pollution-free operation.

REFERENCES

1. European Norm (EN) Standards (as listed in chapters 2 and 14).
2. Deutsche Institut für Normung (DIN) Standards (German Institute for Standardization) (as listed in chapters 2 and 14).