

Batteries for Stationary Power Supply

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7.1 INTRODUCTION

Today the most important electrochemical storage systems for stationary applications are the lead-acid and the nickel/cadmium systems. Both of them have advantages and disadvantages which carefully have to be considered for best selection.

Batteries for telecom applications are specially designed for long service life and hours of discharging time. Batteries for UPS applications are designed for discharges with high current over short times (minutes). Special battery constructions are offered for the different requirements. In case of high safety demands, stationary batteries that ensure long service life are preferred.

Already today valve-regulated lead-acid batteries are in widespread use in many applications, and this trend will increase in the future since the reduction of maintenance is a significant advantage. This battery system requires high quality of all parameters that influence the performance and other characteristics. Valve-regulated lead-acid batteries that are installed in cabinets require sufficient air circulation to achieve equal temperature for all cells or monoblocs. Monitoring or control systems may be used.

For selection of the correct size of a stationary battery, manufacturers issue data curves and tables with the performance dates and installation rules to their customers. Most tables are calculated by special computer programs, and they include applications with varying current profiles during discharge.

Monitoring of stationary batteries is especially important to ensure a safe energy supply and the desired service life of the battery:

- For vented batteries there are many proven service methods.
- For valve-regulated batteries new methods of measurements and monitoring are necessary. Quite a number of automatic monitoring systems have been developed in the past; their reliability must be proved in the future.

7.2 STATIONARY BATTERIES

Stationary batteries have been applied for more than 100 years. During this time they have reached a technical design of very high reliability; they are the most reliable back-up power sources. Nevertheless, the application requirements for stationary batteries are quite different to a traction battery:

- A traction battery in general will be charged by a charger and then discharged, e.g. by a forklift. Thus the moment when it has to be ready for discharging is well known, e.g. the beginning of a shift, and the battery can be put into the required condition. Also the time for recharging can be adjusted. Thus the working cycle of the battery is determined.
- Stationary batteries, on the other hand, must do their work when the main power fails, and nobody can forecast when this will happen and how long the failure will last.

Many investigations have been made to find out how often and how long the main power network fails, but all of them are only statistics (see [Figure 7.1](#)). To accomplish such unexpected challenges stationary batteries need a high grade of reliability. Experience by important battery customers shows a failure rate below 0.25% per year. For example, when 8000 battery plants are installed by one customer, less than 20 of them will endure a failure during a year. Other investigations by a UPS manufacturer show mean time between failures (MTBF) of more than 100,000 hours, which means more than 11 years.

From the multitude of available storage systems – some of them only in a theoretical state – in stationary applications, mainly lead-acid and nickel/cadmium batteries are applied in a large scale. ([Figure 7.2](#) shows examples of possible battery systems.) There is a wide field of application for stationary batteries. [Figure 7.3](#) shows the most important applications for nickel/cadmium and lead-acid batteries. More than 90% of them employ the lead-acid systems.

The required discharge times are quite different: they can vary between some seconds in applications like diesel starting up to a month in solar plants. In some special cases there are further requirements, e.g. for UPS devices the connected power supply requires constant power. That means when the battery output voltage decreases, the discharge current automatically is increased. This has to be considered when selecting the battery.

In general, most applications can be divided in the following groups:

- Equipment for communication and information systems.
- Equipment for memory protection.
- Equipment to protect human lives.

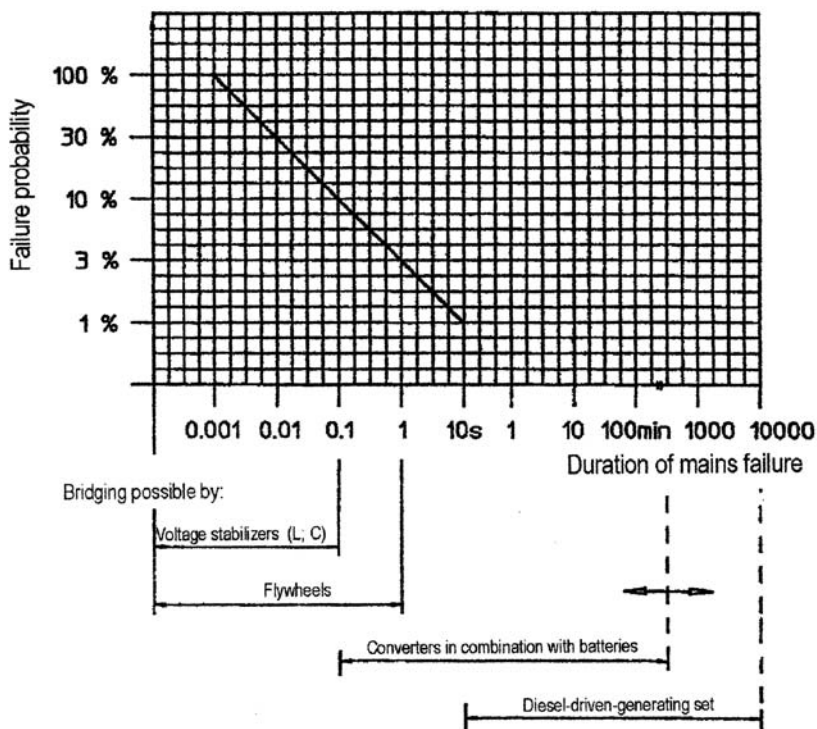


Figure 7.1 Power failure characteristic.

PbO₂/Pb		Ca/NiF ₂	Li/J ₂	Zn/Cl ₂	Na/Al ₂ O ₃ Br ₂	Ni/Cd
		Al/FeS ₂	Na/Al ₂ O ₃ S	Ag/PbJ ₂	Ag/RbJ	
		MnO ₂	Li/S	Li/Se		
		Be ₂ O ₃ /Li	Cf/Li			
Sb		CnF/Li	AgF/Li	H ₄ N ₃ O ₂	CH ₃ OH/O ₂	
Glycol/O ₂	Na/O ₂	Cl ₃ N ₂ C ₃ O ₃ Al	DNB/Mg	Ca/CaCrO ₄	AgCl/Zn	
PbCl ₂ /Mg	MnO ₂ /Zn	PbO ₂ Zn	AgCl/Mg	MnO ₂ /Cd	HgO/Cd	
AgO/Cd	AgO/Pb	O ₂ /Fe	O ₂ /Cd	O ₂ /H ₂	AgCl/Mg	
CuCl/Mg	Ni/Zn	Ag ₂ O/Zn	AgO/Zn	HgO/Zn	O ₂ /Zn	
Ag/NI ₂	Ni/Fe	Li/Fe				

Figure 7.2 Examples of possible battery systems. Some of them are hypothetical, some important for today's portable applications like nickel/metal hydride or lithium-ion systems are not shown.

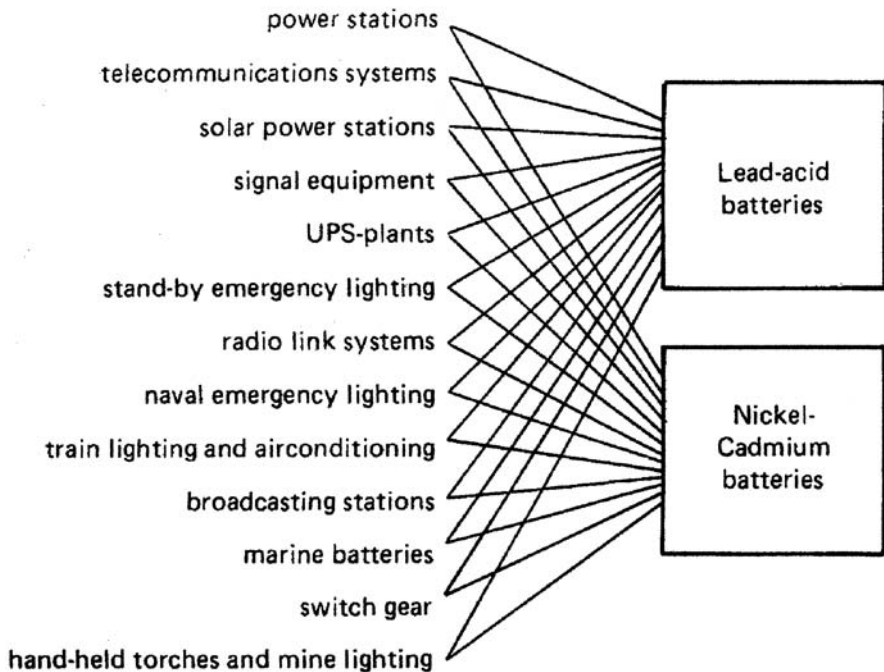


Figure 7.3 The most important applications for stationary lead-acid and nickel/cadmium batteries.

- Equipment for emergency power supply of technical facilities and processes.

Today stationary batteries are mostly connected in parallel with the DC power equipment and the consumers (see [Figure 7.22](#)). In case of emergency lighting also switching devices are usual. Batteries with additional cells that are switched in during discharge are more seldom seen, predominantly in older installations.

7.3 CELL AND PLATE DESIGN

Lead-acid and nickel/cadmium batteries differ in plate design, as shown in [Figure 7.4](#). In lead-acid batteries the type of the *positive* plate designates the cell type. The *negative* plate always is a grid plate. In traditional nickel/cadmium cells and batteries the *positive* and the *negative* plates are of the same construction.

[Figure 7.5](#) is a general survey of the different plate types and their combination in cells of both systems. In [Figure 7.6](#) and [Figure 7.7](#) the most usual plate construction for lead-acid batteries are shown, in [Figure 7.8](#) today's construction of plates for nickel/cadmium cells.

[Figures 7.9, 7.10, and 7.11](#) show examples for single cells and bloc batteries with lead and lead-dioxide electrodes; in [figure 7.12](#) a nickel/cadmium cell with pocket plates is shown housed in a steel container.

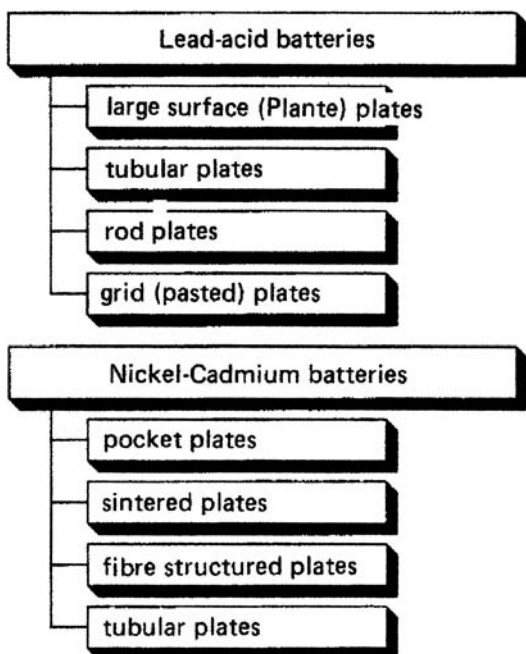


Figure 7.4 Different plate designs for lead-acid and nickel/cadmium batteries.

All cell constructions discussed above are of the *vented* type that have covers with openings that allow the escape of gas. Through this opening also water or electrolyte can be refilled. To reduce evaporation, usually the opening is closed by a vent cup.

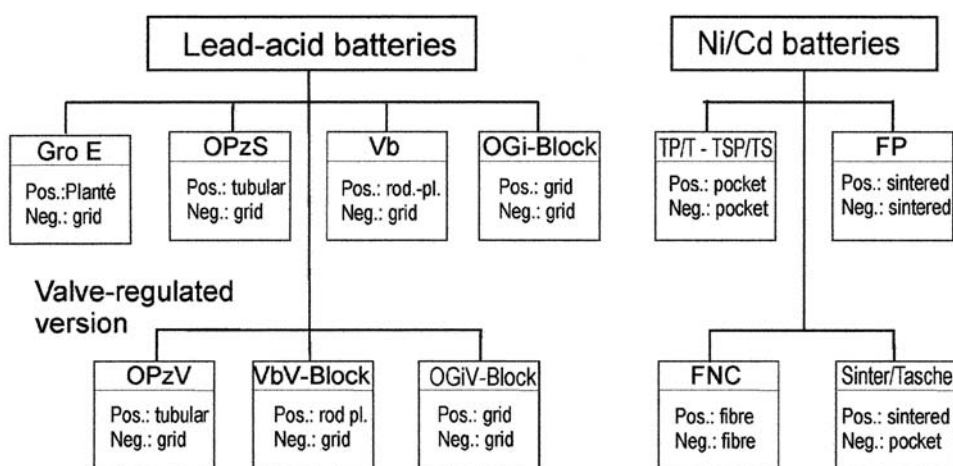
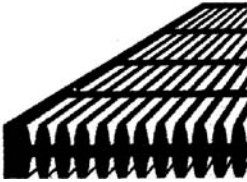


Figure 7.5 Cell types and plate combinations that are mostly used in stationary batteries. The top line in each box shows the termination according to DIN.

Gro or Planté plate
(large surface area covered
by electrochemical formed PbO_2)



Grid plate
(casted or punched
and then filled with
active material)

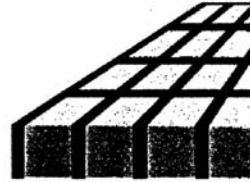


Figure 7.6 Planté and grid plate design.

Since the 1970s also maintenance-free valve-regulated lead-acid batteries have been in widespread use in the field of stationary applications. Sometimes they are called “*recombination cells*” or “*sealed lead-acid cells*”. Their correct designation, however, is in accordance to DIN 40 729 *valve-regulated lead-acid batteries (VRLA batteries)*.

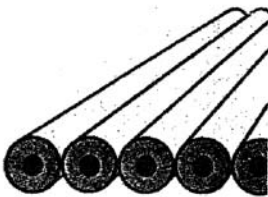
The various designations for the different cell constructions are formulated in the “International Electrotechnical Vocabulary, Chapter 486: Secondary cells and batteries”. Valve-regulated cells are closed by a valve. It prevents the admission of air into the cell, but opens during normal operation when the internal pressure has increased to the opening value of the valve.

Stationary batteries are designed for special application, e.g. high current density or installation within electrical devices or in cabinets. Therefore each battery is more or less characterized by special construction elements.

Figure 7.13 compares the plate arrangement in different cell types:

- Left: a *vented* lead-acid bloc battery: Varta bloc (Vb).
- Right: a *valve-regulated* lead-acid bloc battery: Varta bloc V (VbV).

Tubular plate
(always the
positive one)



Rod plate
(positive one
in VARTA design)

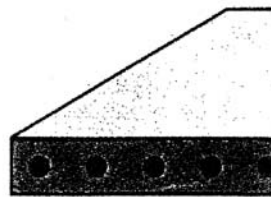


Figure 7.7 Tubular and rod plate design. The first one is used in OPzS cells, the latter one in Varta bloc and VbV batteries.

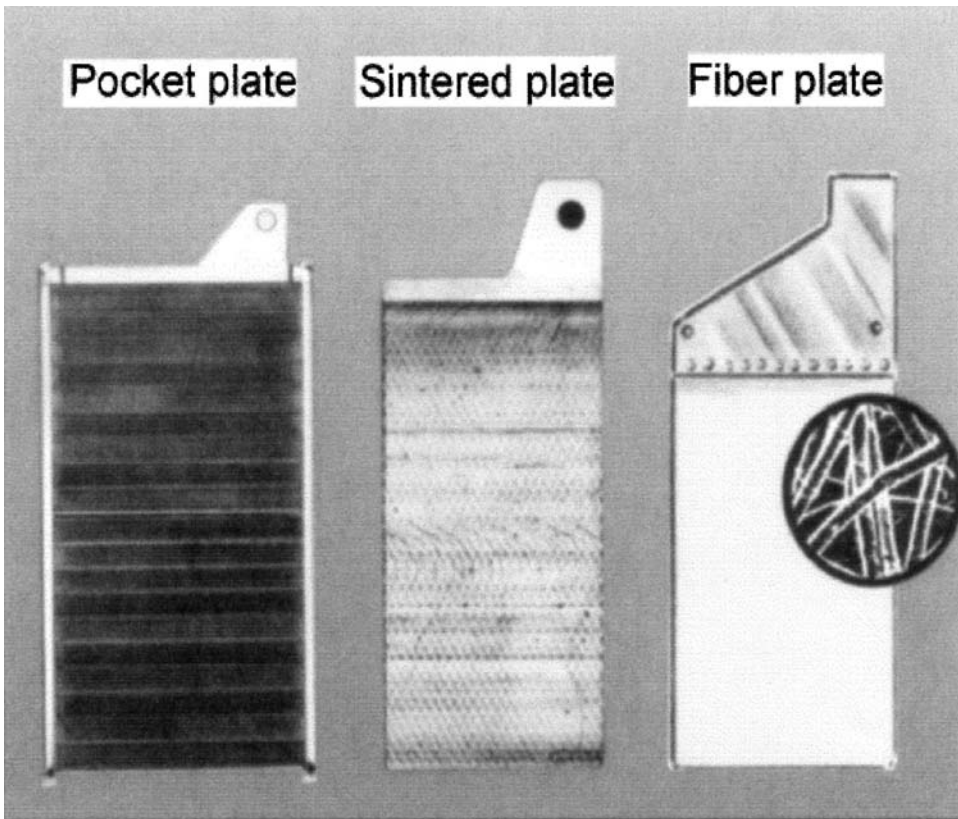


Figure 7.8 Various plate designs that are used in stationary nickel/cadmium batteries.

The Vb as well as the VbV batteries can be used in any stationary application. The UPS version is the result of optimizing work: plate thickness, internal connectors, new vents, and new dimensioning of the battery container – especially for application in UPS systems.

7.4 CHARACTERISTICS

A result of the different plate, cell, and battery designs and construction is the internal resistance of the battery. [Figure 7.14](#) shows average values of the internal DC resistances for various cell designs, always referred to the nominal capacity of 100 Ah. Depending on various parameters, like electrode design and spacing, the observed internal resistor for *vented* cells is between 0.3 mOhm and 3.0 mOhm. A similar range applies for *valve-regulated* lead-acid cells and monoblocs, since their main construction elements are quite similar to those for the vented version. The internal resistance has a significant influence on the performance of the different designs, as is illustrated in [Figure 7.15](#).

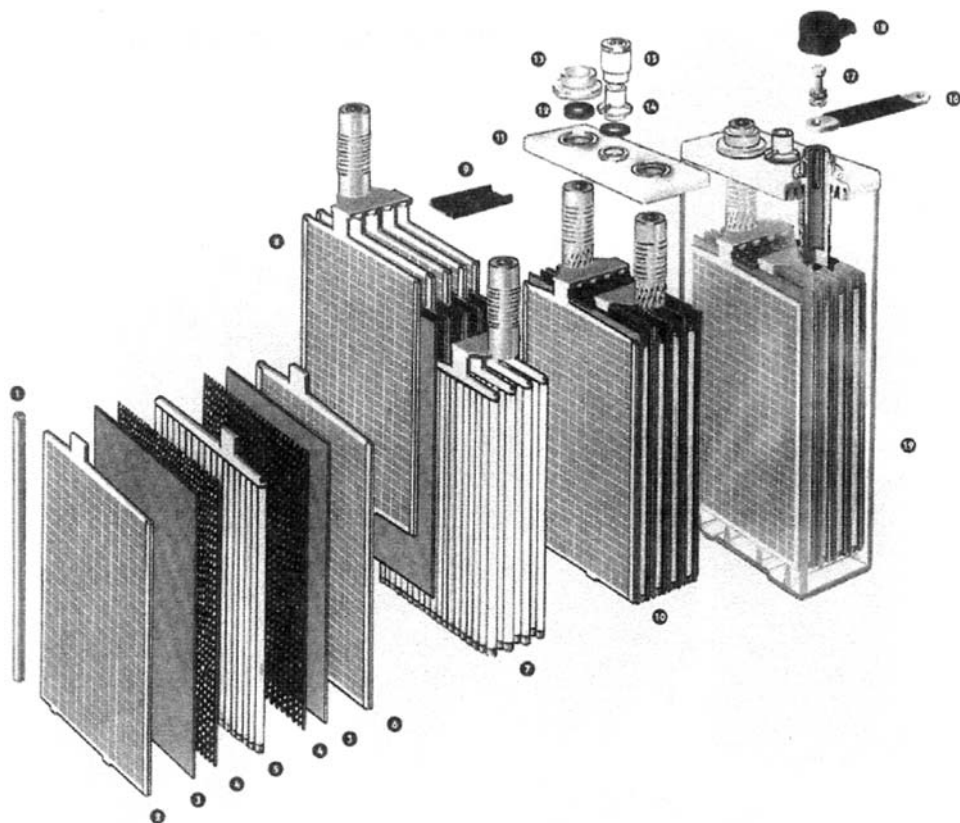


Figure 7.9 Exploded view of an OPzS cell (stationary battery with tubular plates). 1: Edge insulation (enlarged); 2: Negative end plate; 3: Microporous separator; 4: Perforated and corrugated PVC separator; 5: Positive tubular plate; 6: Negative plate; 7: Positive plate group with bus bar and Varta safety terminal; 8: Negative plate group with bus bar and Varta safety terminal; 9: Plastic cover plate; 10: Plate group; 11: Cell lid; 12: Pole sealing; 13: Washer; 14: Vent plug with washer; 15: Gas dehydrator; 16: Cell connector; 17: Connecting screw with locking device; 18: Pole cap; 19: Complete OPzS cell in transparent container.

For long discharge durations (in the range of 5 to 10 hours and correspondingly low current rates) no difference is observed, since all batteries reach their nominal capacity, but there is a large difference between the different types at high loads: the lower the internal resistance, the larger is the drawable amount of current.

For valve-regulated lead-acid batteries only one curve is shown in [Fig. 7.15](#) that concerns a low resistance battery designed for high rates. However, dependent on their design also valve-regulated types would show a wide scattering, as indicated by the wide range of their internal resistance in [Figure 7.14](#).

For many applications short discharge times are demanded. Then large differences are observed as indicated by the following comparison for a 10-minute discharge:

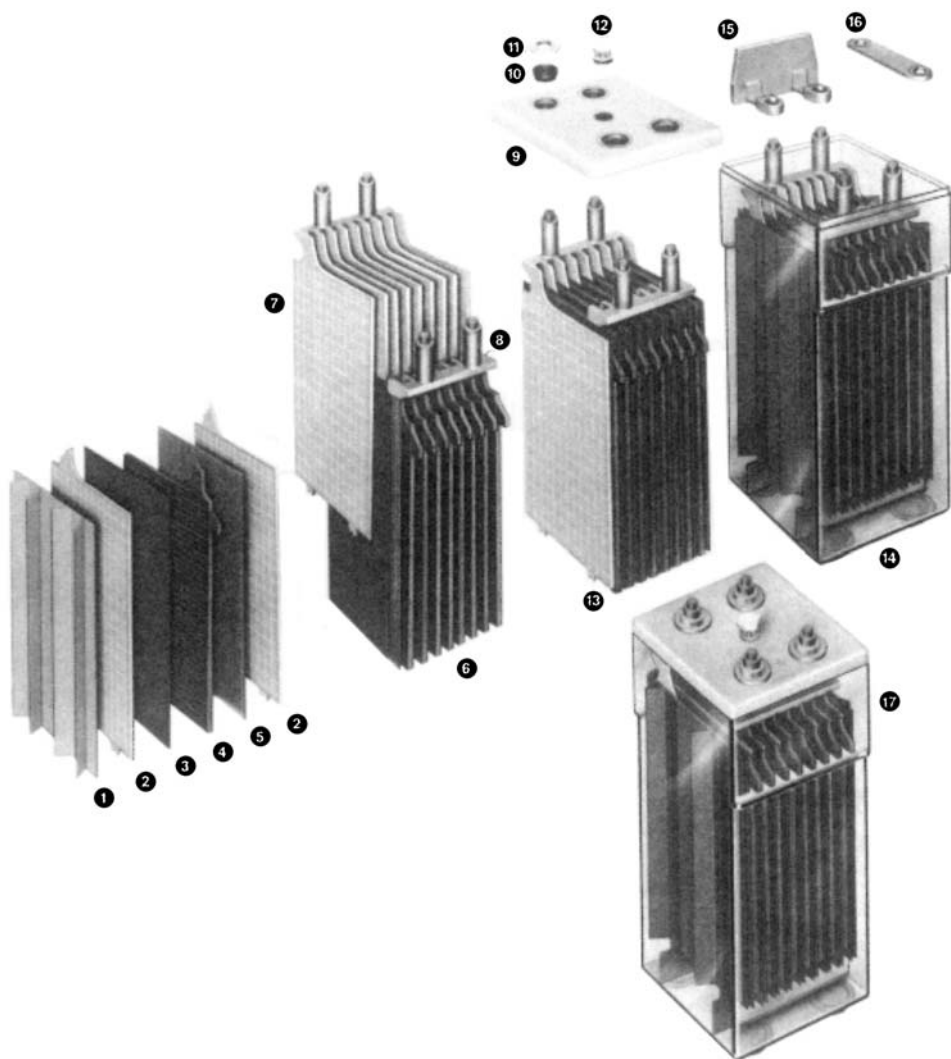


Figure 7.10 Exploded view of a Gro-E cell (with positive Planté plates). 1: End spacer; 2: Negative grid plate; 3: Microporous separator; 4: Positive Planté plate; 5: Corrugated plastic separator; 6: Positive plate group; 7: Negative plate group; 8: Bus bar and pole; 9: Lid with slot for glued joint; 10: Soft rubber seal; 11: Washer; 12: Vent plug with cap; 13: Plate group; 14: Complete Gro E cell in a transparent container.

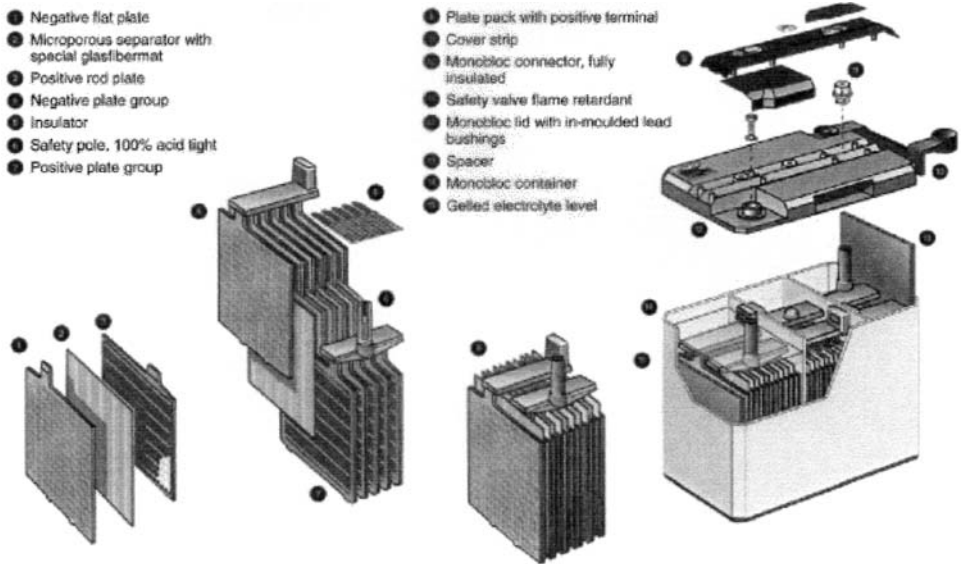


Figure 7.11 Exploded view of a Varta bloc battery (6-V monobloc).

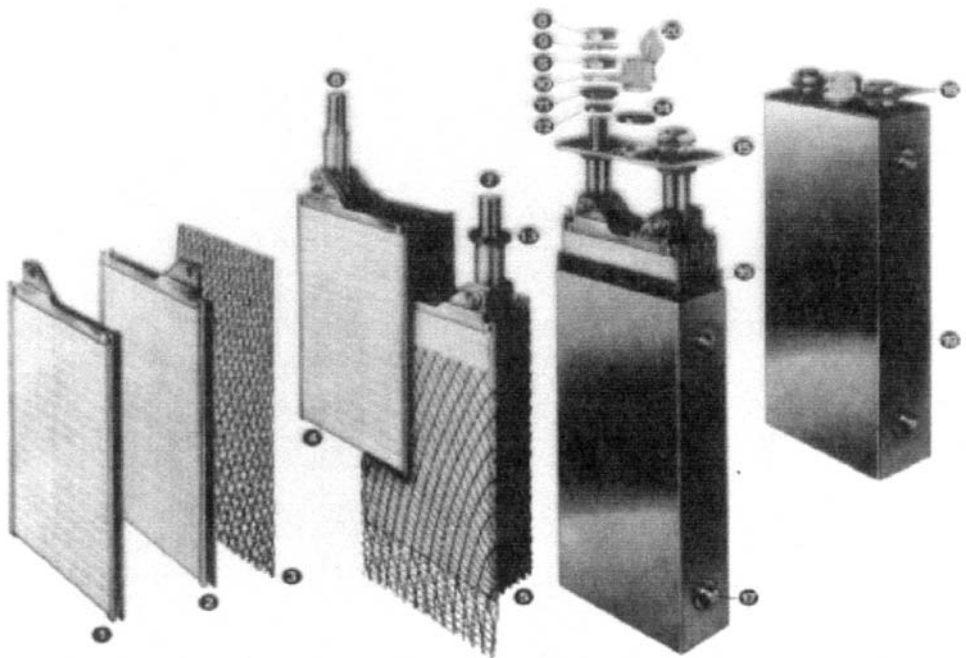


Figure 7.12 Exploded view of a nickel/cadmium cell with pocket plates. 1: Positive plate; 2: Negative plate; 3: Netlike PVC separator; 4: Positive plate group; 5: Negative plate group; 6: Positive post terminal; 7: Negative post terminal; 8: Washer; 9: Cell lid (welded); 10: Gas dehydrator plug; 11: Cell container; 12: Flat washer; 13: Pole nut; 14: Insulated cell connector; 15: Lock washer; 17: Connector nut; 18: Insulating cap.

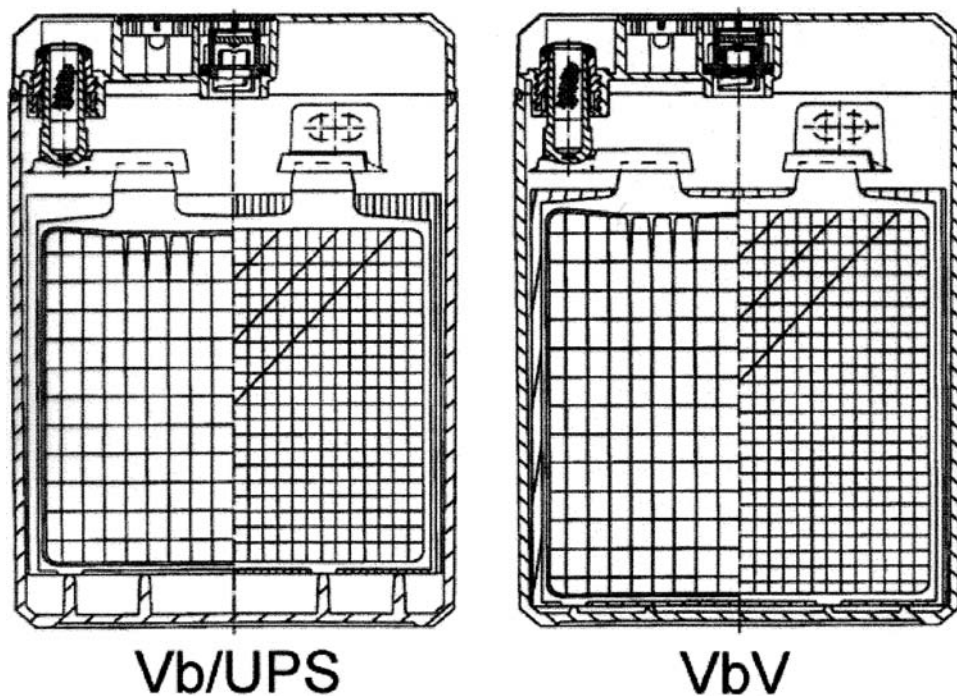


Figure 7.13 Plate group arrangement in a vented (Vb or UPS) and a valve-regulated lead-acid battery.

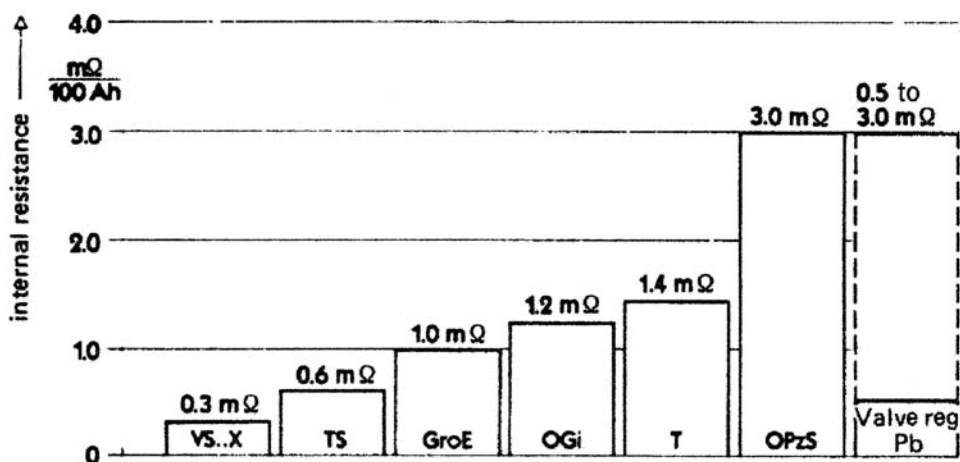


Figure 7.14 Specific values of the DC internal resistance for various cell types. To compare the different designs and construction, all dates and figures are related to 100 Ah nominal capacity.

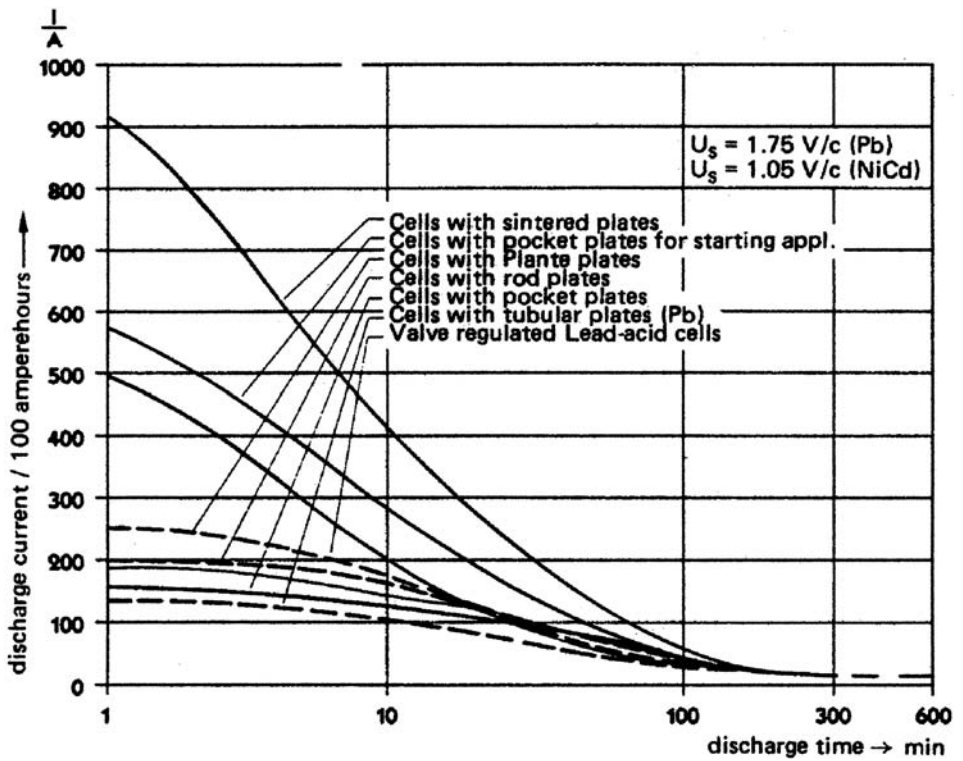


Figure 7.15 Discharging current per 100 Ah of nominal capacity versus discharge duration with an end-of-discharge voltage of 1.75 V/cell and 1.05 V/cell for lead-acid and nickel/cadmium batteries, respectively.

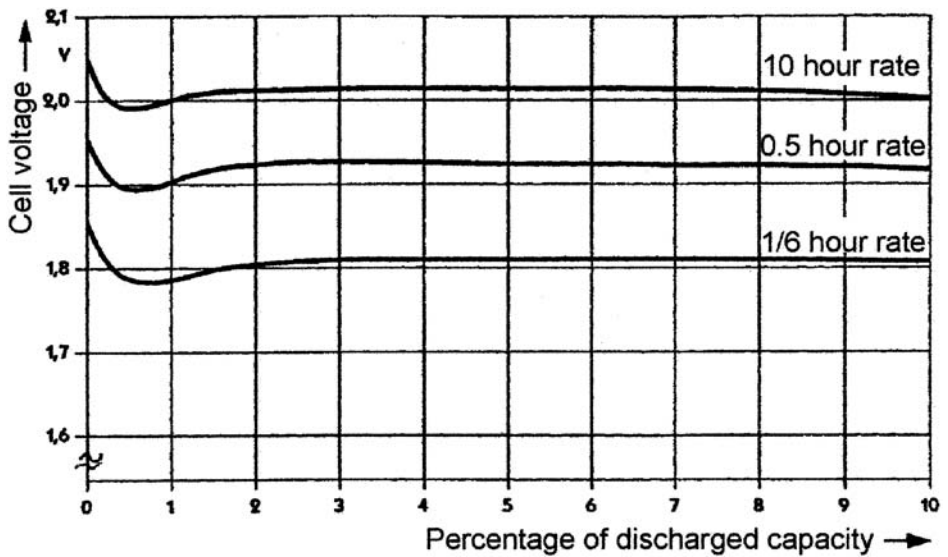


Figure 7.16 Coup de fouet at the beginning discharge of a fully charged lead-acid battery.

- 100 Ah OPzS cell = 100 A for 10 minutes
- 100 Ah Vb cell = 170 A for 10 minutes
- 100 Ah Ni/Cd sinter cell = 400 A for 10 minutes

Apart from the above mentioned – mostly design-dependent – characteristics, there are a number of further parameters that are to be observed and may cause advantages or disadvantages of the concerned battery system. The following examples are by no means complete but represent a selection of important properties that have to be recognized:

- Lead-acid batteries show a voltage drop – the *coup de fouet* – when discharged from the fully charged state, e.g. after a certain period of float charging. This voltage drop occurs within the first 1 to 2% of capacity drawn and is current dependent and must be respected, especially when high voltages are demanded and the voltage minimum determines the cut-off voltage (see [Figure 7.16](#)).
- Another important parameter is the dependence of the float current on float voltage and the temperature. Both parameters markedly influence the float current and thereby the water loss by electrolysis. Furthermore, both parameters also influence corrosion of the grid and all conducting elements that are connected to the positive plate.

Note: A quantity of 3 Ah that flows into the cell as an overcharging current decomposes approximately 1 cm³ of water from the electrolyte!

[Figure 7.17](#) shows the so-called Tafel – lines which more or less are valid for the float situation of lead-acid batteries. Such drawings allow quantified fundamental considerations concerning float charging:

- If the float voltage increases only up to 200 mV, the float current increases by a complete decade; with 50 mV voltage increase – that is approximately only 2.5% of the nominal float voltage – the float current will double! In valve-regulated batteries this increase is even higher, since the negative electrode is hardly polarized, and a voltage increase of only about 140 mV causes the current increase by one order of magnitude.
- [Figure 7.17](#) also shows the great influence of the electrolyte temperature: Temperature rise by 10 °C approximately doubles the float current, and therewith also water consumption will be doubled.

As a consequence the accuracy of the float voltage has strictly to be observed, especially with devices that employ valve-regulated lead-acid batteries, since this type contains no surplus of electrolyte and water cannot be refilled. Therefore most of the battery manufacturers give directions (tables and curves) for float charging of their products.

But not only the float voltage, also the cell capacity depends on the electrolyte temperature, as shown in [Figure 7.18](#).

The broken section in the curve for the lead-acid battery indicates that discharge may not be possible at such a low temperature since ice may be formed and dramatically increase the internal resistance. This is caused by acid consumption during discharge, which means that the acid density in a completely or deep discharged battery approaches the density of 1.00 kg/L. Therefore the operation of lead-acid batteries can be limited at very low temperatures.

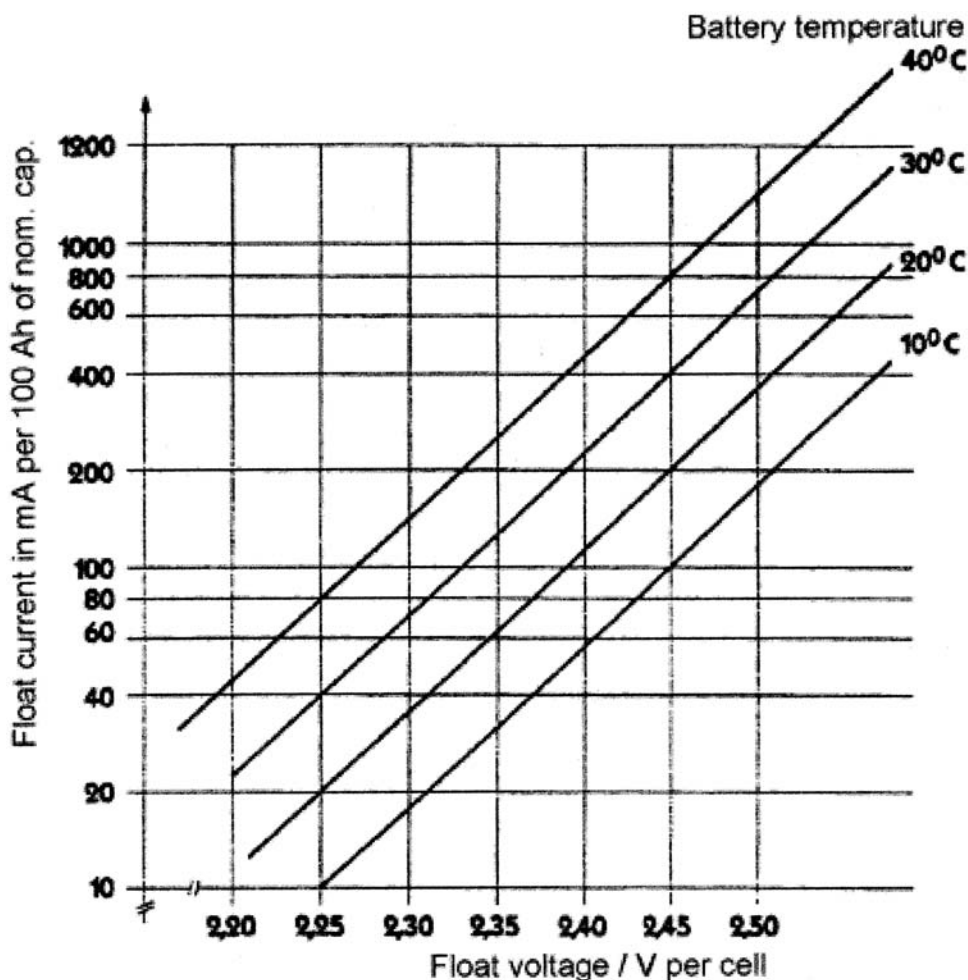


Figure 7.17 Float current versus float voltage of an aged OPzS battery at various temperatures referred to 100 Ah of nominal capacity.

In nickel/cadmium batteries the concentration of the electrolyte does not appreciably change and thus the problem of freezing does not exist. Usually freezing forms a sludge of frozen water in more concentrated acid, but at a very low acid concentration a solid ice can be formed that may destroy the container by its increased volume. Valve-regulated lead-acid batteries are advantageous, because of their immobilized electrolyte in a glass mat or as a gel which can never form a block of ice.

Many efforts have been made to keep the amount of the water consumption as low as possible. One way to reach this goal is to reduce the antimony content in the grid alloy, preferably in positive electrodes, or to eliminate antimony at all:

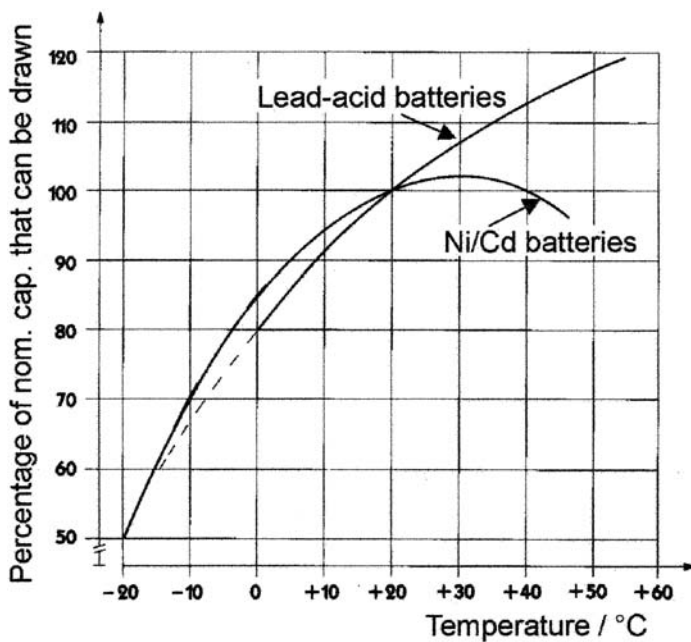


Figure 7.18 Actual discharge capacity of lead-acid and nickel/cadmium batteries at different temperatures (nominal capacity referred to 20 °C).

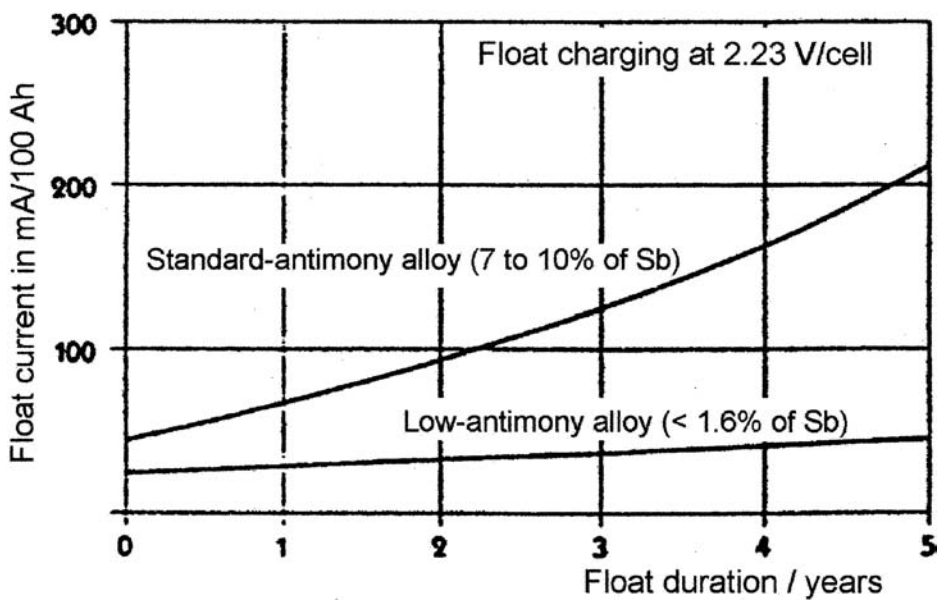


Figure 7.19 Alloy-dependent current increase during float charging.

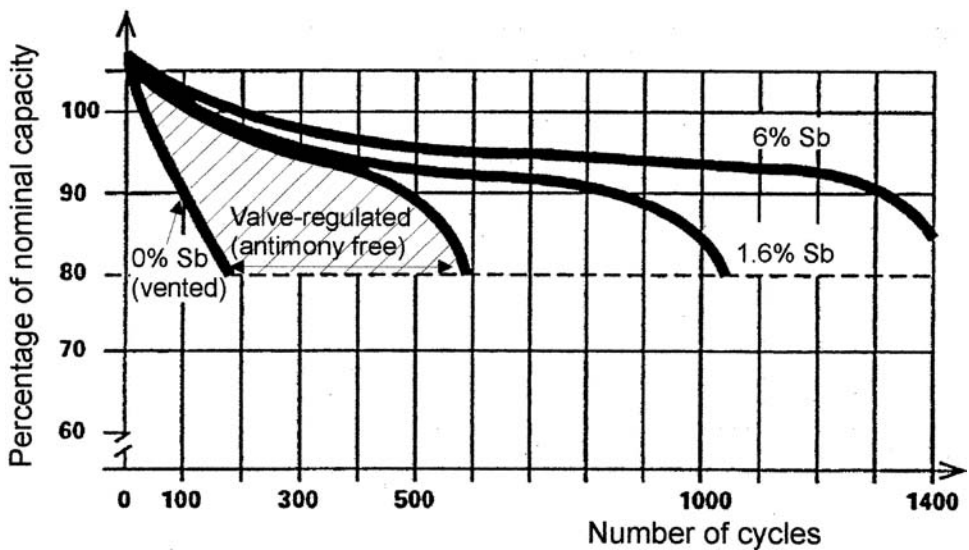


Figure 7.20 Influence of the alloy on cycle performance of vented and valve-regulated lead-acid batteries (rough approximation).

- The lead alloy used influences the float current (see [Figure 7.19](#)).
- The higher the antimony content in the grid of the *positive* electrodes, the higher is the float current – even for new batteries.
- The higher the antimony content in the grid of the *positive* electrodes, the higher is the increase of the float current during the float charging.

The best remedy would be to avoid the use of antimony. However, this would cause disadvantages for batteries that are used in “cycle applications”. This almost never happens in applications where the battery mainly is used in standby operation, namely when the power supply is designed smaller than the load requires, e.g. for motors or switches. Then the back-up battery will repeatedly be discharged for short periods.

[Figure 7.20](#) shows that normal lead-acid batteries with antimony-free alloys (e.g. Gro E cells have a cycle life of less than 200 cycles (DIN/IEC cycles)).

The immobilized electrolyte in valve-regulated lead-acid batteries favors cycle life. High quality stationary lead-acid batteries, e.g. the Varta bloc type (Vb), reach a cycle life up to 1400 cycles before the capacity falls below 80% of the nominal capacity. High quality *valve-regulated* lead-acid batteries, e.g. the type OPzV, reach more than 600 cycles.

Sometimes the *internal resistance* of a battery is required to calculate fuses in the DC power supply.

[Figure 7.21](#) shows the internal AC resistance for lead-acid and Ni/Cd cells. It can be seen that up to more than 50% of discharge the resistance largely remains constant and then increases – more suddenly in the Ni/Cd battery.

Reliable emergency power supply requires an adequate combination of the electrical equipment and the back-up battery. [Figure 7.22](#) shows various possibilities:

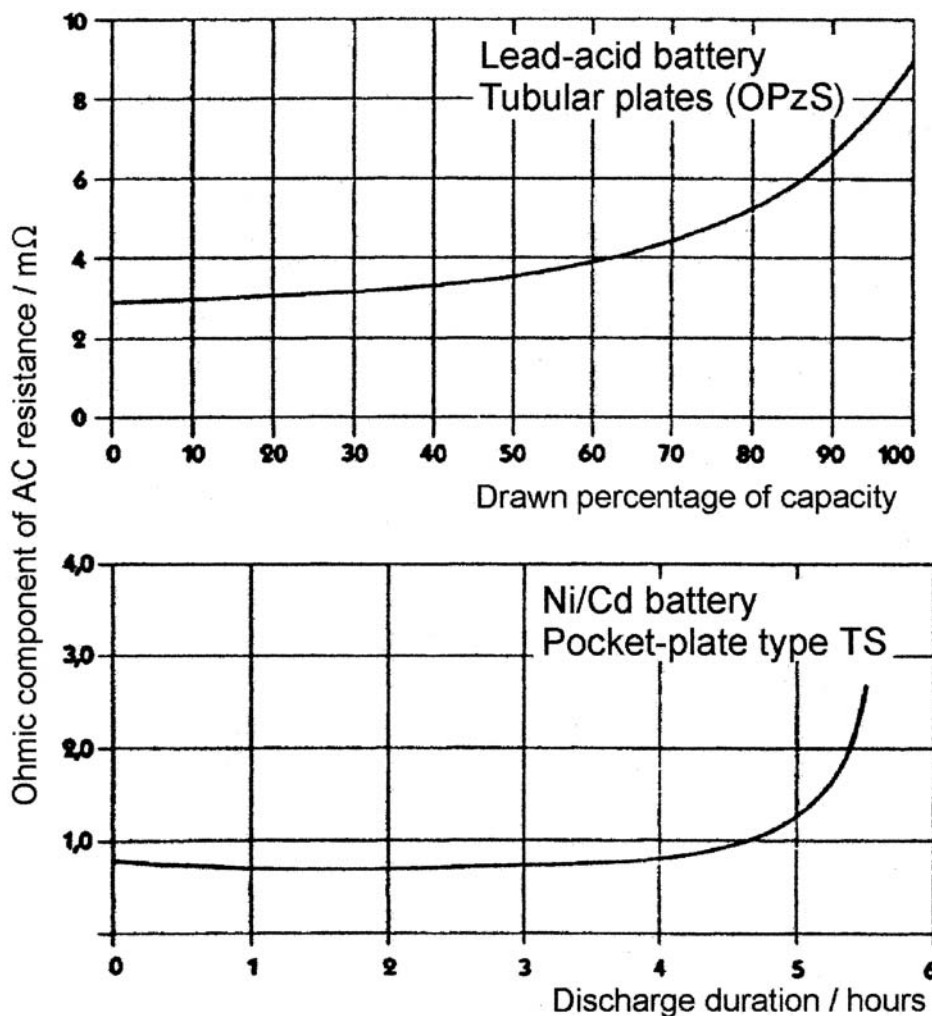
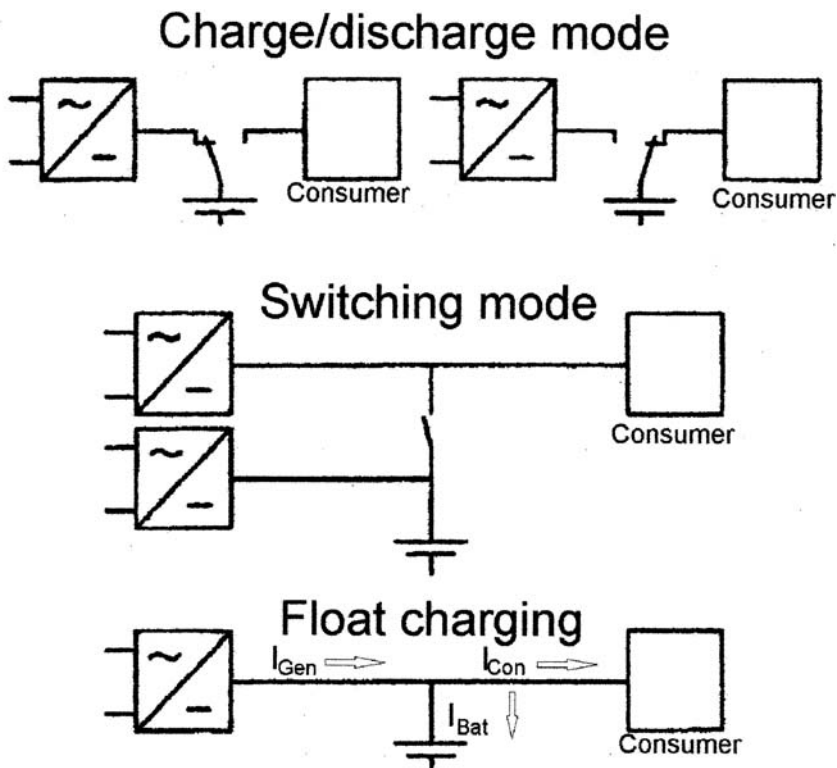


Figure 7.21 Internal resistance (ohmic component of 1000 Hz AC resistance) referred to 100 Ah of nominal capacity; 5 hour rate discharge.

- Most usual is the parallel connection, shown at the bottom in [Figure 7.22](#). Under normal conditions the output of the power source is sufficient to supply the consumer and simultaneously keep the parallel connected battery in the fully charged state by slight overcharging (“float charging”). In the “buffered mode” the parallel connected battery has to serve power peaks of the load that cannot be balanced by the power supply. In practice, this situation sometimes occurs unnoticed.
- Today the switching mode is only seldom used, e.g. in emergency light devices. It is only possible in devices that can tolerate short voltage interruptions.



Float charging: $I_{Gen} = I_{Con} + I_{Bat}$ (continuous overcharging)

Buffered mode: periodical $I_{Con} = I_{Gen} + I_{Bat}$ (Discharging)

Figure 7.22 Possible methods to connect a stationary battery, the current supply, and the consumer.

- Today the use of main and additional cells to minimize the gap between charging and discharging voltage is observed only in older installations.

The rather simple charging technique for lead-acid batteries is advantageous compared to that of Ni/Cd batteries (see [Figure 7.23](#)):

- Lead-acid batteries in general are charged in parallel connection to the consumer, i.e. according to IU characteristics (at the low charging voltage of 2.23 V/cell). Also recharge can be achieved at this float voltage, but it may take more than 24 hours to reach the state of full charge.
- The charging technique for nickel/cadmium batteries demands far more expenditure. Charging is conducted according to the IU characteristics at a comparatively high voltage level for the time being. After the fully charged state has been reached, the charger switches over to a substantially lower

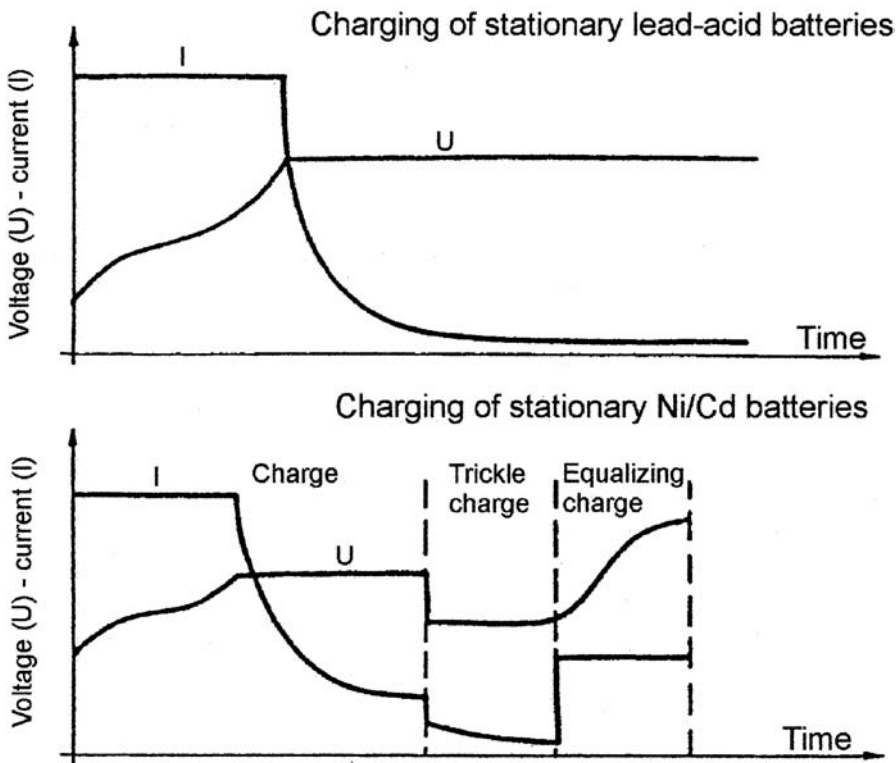


Figure 7.23 Charging schedules that are applied for stationary lead-acid and nickel/cadmium batteries.

voltage, which is applied for floating. Full capacity, however, is only preserved when periodically equalizing charges are applied at increased voltage (after about every 6 months). Otherwise, the battery has to be oversized by about 20% of nominal capacity.

- Nevertheless nickel/cadmium systems are economic under certain conditions, e.g. at very low temperatures.

The accuracy of the float voltage is very important. [Figure 7.17](#) indicates the strong increase of the float current with cell voltage. For this reason all relevant standards give a tolerance of not more than $\pm 1\%$ for the charger output voltage.

In strong connection to the accuracy of the voltage is the maximum value of charge current and also the ripple current. German and also European standards allow a *maximum ripple* of *5 A per 100 Ah of nominal capacity*. Future European standards will even stronger restrict the allowed ripple for valve-regulated lead-acid batteries.

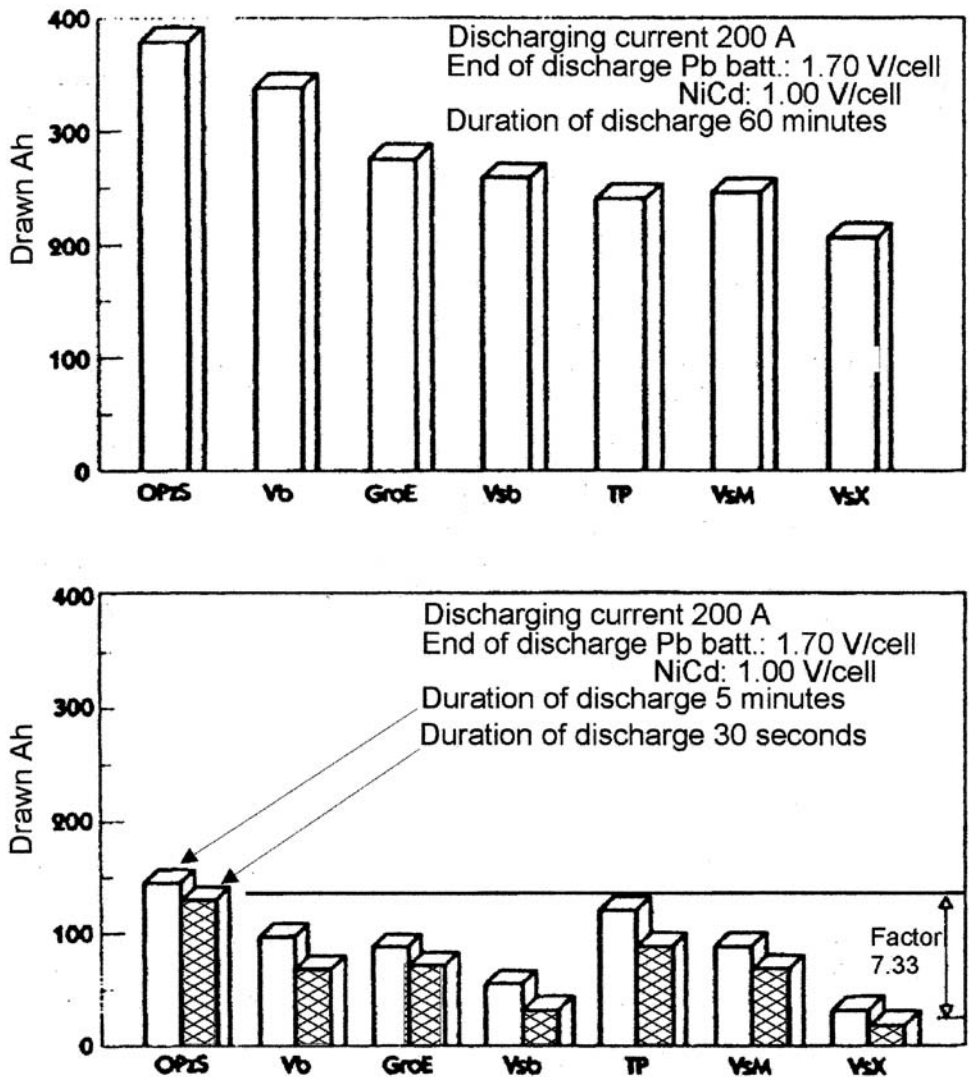


Figure 7.24 Comparison of the Ah that can be drawn from the various battery types under various discharge conditions.

7.5 SELECTION OF STATIONARY BATTERIES

Under consideration of these general facts it is already possible to make a selection of battery type, battery design, and battery size for a normal application. For the choice of batteries for simple constant current discharge, the manufacturers issue performance data as curves or tables. Tables have the advantage that the relation between bridging time, required current, and minimum voltage can directly be seen and thus easy comparison is possible of the performance data of the various battery systems offered.

UPS power: 60kVA

DC output: 51.1 kW

DC voltages:

Nominal: 360 V

Minimum: 306 V

Maximum: 432 V

Bridging time in minutes:

Number of cells	Vsb 12501	Vsb 12502	Vsb 12503	Vsb 12504	Vsb 12505	Vsb 12506	Vsb 6604	Vsb 6605	Vsb 6607	Vsb 6610
189			2.1	4.5	7.0	9.5	15.2	21.5	33.8	59.1
186			1.6	4.0	6.5	8.9	14.5	20.5	32.9	57.0
183			1.1	3.5	5.9	8.3	13.7	19.6	32.1	55.0
180				2.9	5.2	7.7	12.9	18.9	30.3	52.5
177				2.5	4.9	7.2	12.3	18.1	29.5	51.2
174				1.9	4.3	6.6	11.5	17.2	28.5	49.6

Figure 7.25 Bridging times that would be reached by various numbers of cells of the concerned cell type under the given conditions of nominal, minimum, and maximum voltage. Such tables allow the selection of the battery that fits best the given conditions also in view of its price.

In [Figure 7.24](#), a comparison is shown of the performance data for three different but typical applications:

- Required discharge duration 1 hour, discharge current 200 A (e.g. emergency light)
- Required discharge duration 5 minutes, discharge current 200 A (e.g. UPS application)
- Required discharge duration 5 seconds, discharge current 200 A (e.g. diesel starting)

With experience, based on the mentioned tables, battery sizing can also be calculated for more complex discharge schedules, e.g. for a two step discharging. But it is also possible (and recommended) to use the manufacturers' calculating computer programs.

In many applications, like a UPS, the stationary battery will be discharged with constant power. For this case battery and UPS manufacturers commonly issued curves and tables for the customer which consider the specific aspects of the concerned UPS equipment. Such documents allow the optimization of the battery by comparing alternatives of different cell size and cell numbers (as shown in [Figure 7.25](#)).

On request of the customer, stationary batteries can be installed on steel or wooden racks. More and more bloc batteries – especially valve-regulated lead-acid batteries – will be installed into battery cubicles. That minimizes the required footprint. But it is very important that there is sufficient air circulation inside the cubicles to equalize the temperature.

To avoid the formation of an explosive gas mixture within the cubicle, a certain quantity of airflow is required to attain sufficient ventilation. Relevant standards are to be found in the German Standard VDE 0510 Part 2.

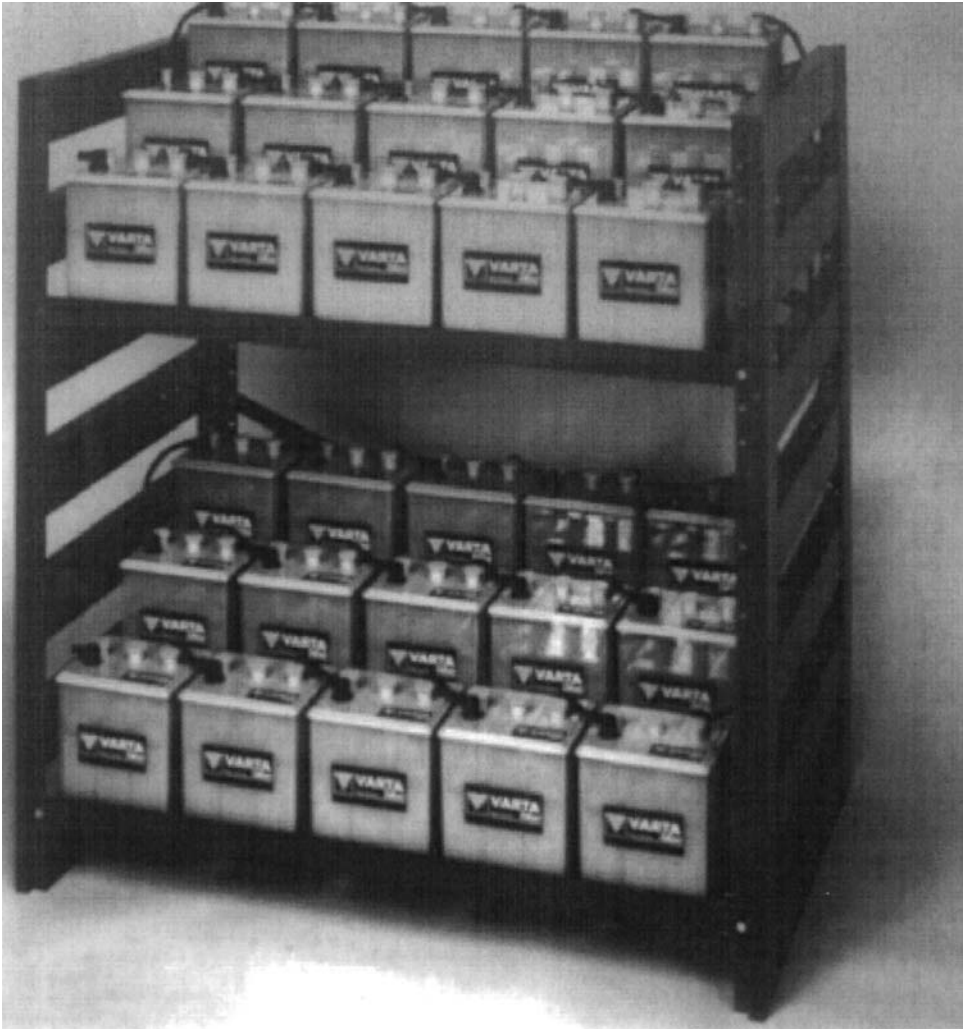


Figure 7.26 Steel rack in double-decker design for vented or valve-regulated batteries.

A special case of battery installation is a rack in double-decker design, according Figure 7.26.

Figure 7.27 shows a way to minimize the necessary floor space that is necessary with valve-regulated batteries. In the shown rack 64 bloc batteries are arranged in eight rows one above the other, installed in horizontal position. That makes service very simple because the terminals and connectors are in front of the rack and voltage readings can easily be taken.

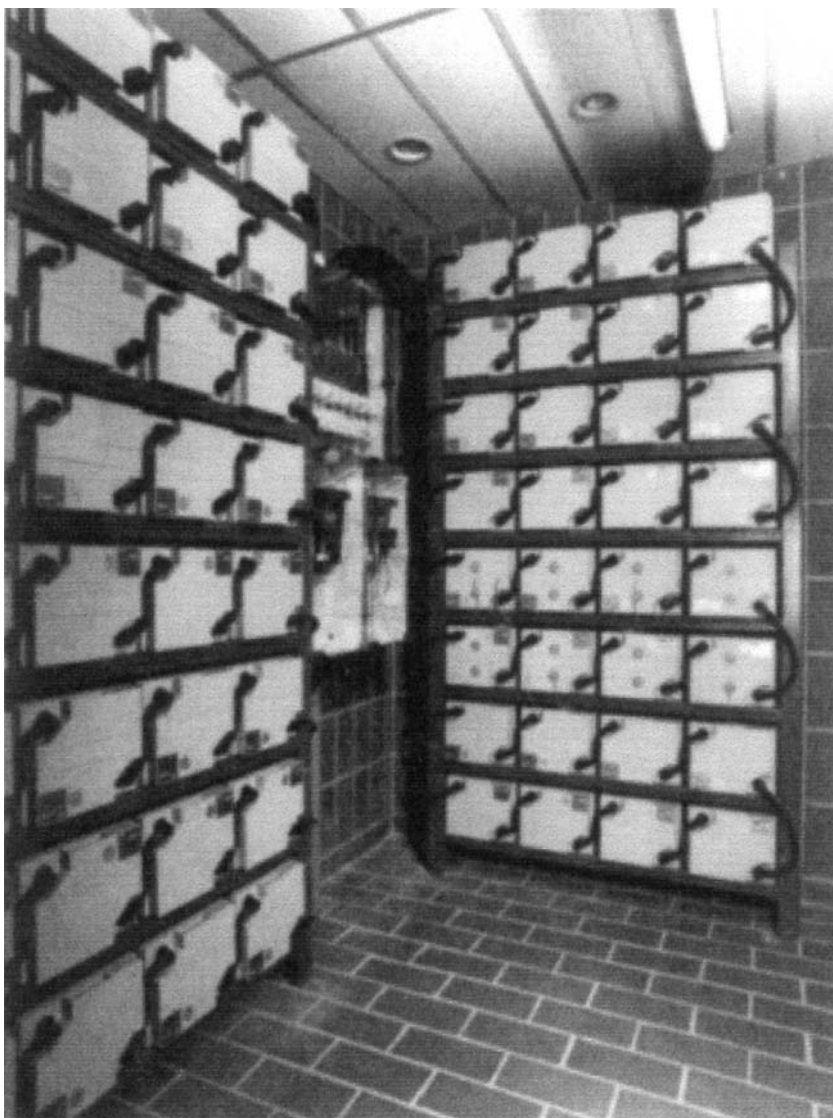


Figure 7.27 Valve-regulated monoblocs installed in horizontal position.

7.6 MAINTENANCE

A general problem with standby batteries is how to find out their state of charge and state of health, since in case of emergency the battery will fulfill its task only when it is sufficiently charged and when all cells are in proper state. As a consequence the battery must regularly be controlled, and with vented systems water loss has to be balanced by refilling.

The use of valve-regulated lead-acid batteries reduces maintenance expenditures markedly, since the refilling of water is no longer required. But the possibility



Figure 7.28 Manual service equipment that automatically registers the results and forms files that can be transferred into a PC for further processing.

to monitor such batteries is limited, since the acid density cannot be measured, and the amount of electrolyte left in each cell cannot be determined. Furthermore, in bloc batteries it is only possible to measure the bloc terminal voltage but not each cell voltage. With normal equipment it is a problem to attain reliable information about the state of charge and the general situation of the battery and its parts, except by testing its capacity. But this is not only expensive, it also means that during the period of discharge and subsequent recharge the battery is not available as emergency power supply. The only possibility to control the state of the battery is to monitor cell or monobloc voltages regularly and register any changes that might indicate problems within the concerned cells or monoblocs.

As a consequence, most battery manufacturers and also many electronics companies are developing monitoring systems and service equipment. The automatic

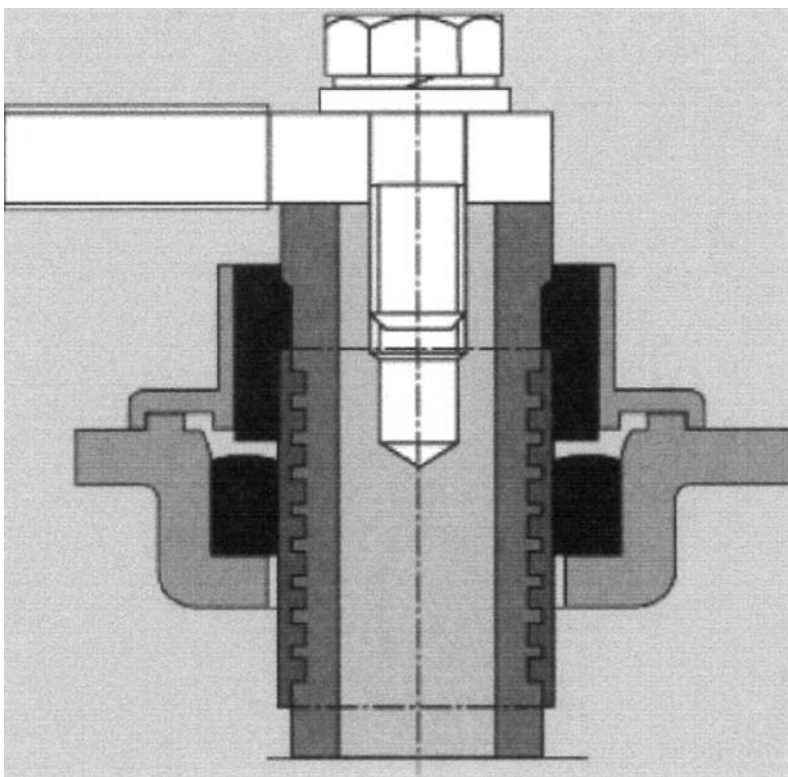


Figure 7.29 Durable electrolyte-tight safety pole.

surveillance of each cell in a battery is very expensive, especially in batteries with many cells. Usually the battery is divided into groups that are controlled and comparison of the group voltages often indicates problems in an early stage. Less expensive are manual methods like that shown in [Figure 7.28](#).

Today in many cases the battery-monitoring equipment is integrated into the monitoring system of the complete equipment, e.g. the UPS. For remote monitoring many systems have special modem connectors.

7.7 POLE SEALING

A long service life of a lead-acid cell or bloc battery presupposes to have durable electrolyte and gas-tight pole sealing. Otherwise, in case of vented lead-acid batteries corrosion will take place at the connecting parts outside the cell. When valve-regulated lead-acid batteries have a pole leakage, oxygen from the surroundings can diffuse into the cells and will oxidize the *negative* plate and so influence the balance of the internal oxygen circle.

Thus, in valve-regulated lead-acid batteries electrolyte- and gas-tight pole bushings are a must, and vented batteries allow the use of copper inserts and screws for cell and battery connectors and thus install the battery as usual in electrotechnics.

Fully insulated connectors represent another safety aspect, especially when batteries are installed in racks.

A durable electrolyte and gas-tight pole bushing (the safety pole bolt) is shown in [Figure 7.29](#). Its special design is

- Copper insert with inside thread.
- Fully insulated screw-on cell connector.
- Sealing rings around and injected plastic wrapper.
- Durable elastic sealing to the cell cover.
- Optical monitoring is possible.
- Plug connectors for external monitoring and test equipment.
- Connector for service equipment.

7.8 DELIVERY DESIGN

State of the art of the battery manufacturers is that vented cells and batteries are delivered in a dry charged condition. Such cells and batteries can be stored in their original wrapping for very long time. They will be activated when filled with acid and will deliver about 80% of the nominal capacity without any preceding charge. A 24-hour initial charge by the charging device at the plant (e.g. with 2.23 V per cell) is sufficient to attain a 100% charge. The issued battery manual gives corresponding information.

Today valve-regulated lead-acid cells and batteries are delivered to the customers in *filled and charged state*, and in most cases they have the filling date on it. That is the “birthday” of the battery, since with the filling of the acid all chemical and electrochemical reactions have started.

7.9 FUTURE ASPECTS

Battery development is ongoing. The lead-acid and nickel/cadmium systems will hold their dominant position in the field of stationary batteries. In the field of small portable power the *nickel/metal hydride system* has advantages because of its higher energy density compared to nickel/cadmium.

There are developments of nickel/metal hydride batteries with very high power density for application in hybrid road vehicles.

Valve-regulated lead-acid batteries already have displaced the vented types in many applications.

The technique for automatic battery monitoring will develop further. New technology and price decrease will open more applications.

Nevertheless, in very critical cases – e.g., nuclear power station – mostly vented lead-acid cells and batteries will also in future be used as standby, because of the better ability for controlling and monitoring, which are important safety aspects.

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