Batteries Association

ZVEI – Die Elektroindustrie

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Lead-acid starter batteries in systems
Usage information

Preliminary note:
This information leaflet aims to help to choose batteries and develop design solutions and operating manuals by providing general information on the usage of lead-acid batteries in vehicles, which extend beyond the relevant standard specifications. This information serves as a recommendation only, and not as a substitute for the battery user's responsibility to make appropriate decisions. By pooling all gained experience to date, however, it should make the decision easier.

Contents

This leaflet was prepared by the Working Group Starter Batteries of the
ZVEI – German Electrical and Electronic Manufacturer's Association

1. General

Lead-acid batteries as defined by this recommendation fulfil their function during engine start-up, when supplying power to the on-board electrical system, and while smoothing the system's voltage. A series of instructions must be followed when using lead-acid batteries to ensure customer satisfaction in terms of maximum product reliability. These instructions are based on the battery's dependence on mechanical, thermal and electrical influences, and take into account safety aspects.

This information leaflet contains recommendations for safe handling of these batteries. It does not replace the industrial work instructions issued by the OEM, the usage instructions provided by the vehicle manufacturer, or the vehicle operating manual.

Following a wide range of requirements, optimised batteries are used for special usage conditions in addition to standard batteries. Special usage conditions include high mechanical loads, high thermal loads and specific electrical loads. Particular attention must be paid to the safety-related properties.

The installation location, operating conditions and choice of battery must all be in tandem with one another. These guidelines are designed to help with this and explain the finer details.

2. Mechanical loads

2.1. Battery installation

2.1.1 The battery tray

The battery tray is the designated battery receptacle on the vehicle. It must be mechanically stable, and fastened firmly to the vehicle. The fastened battery tray must be attuned to the dynamic loads. Excess mechanical loads on the batteries must be avoided. It is beneficial to have a support running around the entire outside of the battery base. In the area where the battery is fixed in, the tray must be designed in such a way so as to enable the multiplied battery weight resulting from strong vibrations or a crash to be absorbed.

The various battery types enable different installation options:

2.1.2 Base hold-down bars as per EN 50342-2

This European standard describes base hold-down bars running around the long and front sides. These standardised base hold-down bars have a clearly specified profile. They also have standardised beading at set locations. The structural elements required to affix the battery, such as terminal strips, clamps etc., are responsible for positioning the battery in the tray, fastening it down and protecting it from sliding to the side. The fastening devices must be mechanically stable, and screwed snugly into the base plate. The fastening devices and elements must be designed in such a way so as to absorb any forces applied to the battery. Slide protection is ideally provided using lugs which protrude into the base hold-down bars' beading. The fastening devices must be able to prevent any damage to the battery. See 2.1.5 for the permitted clamping forces.

2.1.3 Covers as per EN 50342-2

This European standard describes batteries with covers, whose tops have defined recessed sections on both of the long sides. The resulting section is ideal for top-down fastening. Typical fastening devices include brackets running crossways to the battery with tie rods. The fastening devices must be mechanically stable, and screwed snugly into the base plate. The fastening devices must be designed in such a way so as to absorb any forces applied to the battery. Additional protection against sideways sliding is required. See 2.1.5 for the permitted clamping forces.

2.1.4 One-piece cover as per EN 50342, parts 2 and 4

These European standards describe batteries with flat covers. In these batteries, the end terminals, and in some cases also the cell cap stopper, sit beyond the cover. Typical fastening devices include full frames or brackets with tie rods running vertically to the battery's transverse axis. The fastening devices must be mechanically stable, and screwed snugly into the base plate. The fastening devices must be designed in such a way so as to absorb any forces applied to the battery. Additional protection against slipping sideways is required. See 2.1.5 for the permitted clamping forces.

2.1.5 Permitted clamping forces

The battery cases are generally made from polypropylene. EN 50342-5 establishes the requirements for materials, battery boxes and covers. One of the properties of polypropylene is that it yields under loads. This means that it takes only a change in temperature to significantly reduce the clamping force applied by initial fastening. Even high clamping forces will not change this, resulting in plastic deformation in the case walls. When fastening the battery using the base hold-down bars, a certain degree of plastic deformation in the base hold-down bars is required in order to permanently fasten the batteries. Excessive deformation destroys the case. For this reason, bottom-bar deformation should not exceed 15% of the bottom bar's height during assembly.

NOTE: Bottom-bar battery fastening is a hyperstatic system to which the construction rules of mechanical engineering cannot be applied in relation to plastic deformation. The following structural features must be fine-tuned in theory and through experiments: The rigidity of the bottom bar in terms of construction and materials, the size of the clamp area, the deformation trajectory and the tightening torque in relation to the screw-thread diameter (thread pitch depends on thread diameter).

When fastening using the cover, the surface loading depends on the respective construction's cover (battery cover design, and location and design of the holder), and must be designed separately for each individual case. It is important to ensure that the battery's total load is generally no more than 10 times the battery weight, and that the surface load does not exceed 1 N/mm² for unsupported cover areas and a maximum of 6 N/mm² for cover areas supported by a partition.

2.1.6 Protection against lateral movement

The battery should be fastened in such a way that any movement in an X/Y and Z direction is prevented. In addition to being held down, the battery should also be protected against lateral movement. Batteries installed next to one another must be kept far enough apart so that their covers do not touch. Any height differences of batteries standing next to each other should be taken into account.

In the event of fastening using base hold-down bars, lateral movement can be prevented by lugs in the clamps and/or terminal strips which grip firmly into the base hold-down bars' ribbing.

2.1.7 Battery behaviour in a crash

Due to its large mass, the battery can pose a particular risk to persons directly or indirectly involved in a crash. The following measures help reduce these risks:
- Choose a suitable installation location,
- Allow the battery to be pinned by the bodywork, or
- If necessary, secure the battery additionally.

2.2. Vibration stress

The battery tray transfers the vehicle vibrations directly to the battery. The stress is determined by the frequency spectrum and associated amplitudes. Frequencies close to the battery's resonance frequency have a particularly critical effect

As a result of its structural design the battery itself constitutes an active resonant system. This is made up of the elastic plastic case, the plate packs affixed in the case, and the acid moving freely within the cells. The three-component system generally displays two distinct resonance frequencies which vary depending on the respective battery's design.

Typical resonance frequencies lie within the following ranges:
- 10 to 30 Hz (for the acid resonance)
- 90 to 120 Hz (for the plate pack resonance)

If the acid resonates, it may leak out of the battery. If the plate pack resonates, the plates may break and/or the bridge between the electrodes and affixed pole may crack. Internal sparking may then cause the battery to explode.

Structural arrangements on the vehicle can influence the impact of the vibration. Batteries with higher vibration resistance can be used if necessary:
- Batteries with a fixed electrolyte (sealed VRLA technology) absorb a lot of the resonance in the plate pack and the acid.
- In the case of conventional batteries, the plate pack's vibrations can be absorbed through suitable engineering measures. EN 50342-1 defines the various requirement categories.

3. Thermal stress

Batteries are electrochemical energy storage devices. Chemical processes are known to depend heavily on temperature. In a first-order approximation, the reaction speed doubles per 10 K temperature increase and halves with a 10 K temperature reduction.
Major temperature differences in the battery or battery pack cause the cells to work unevenly, resulting in an early failure of the battery.

The battery's optimum operating temperature is between +20 and +40 °C. Lower temperatures limit both its charging capacity and its performance, while higher temperatures increase self-discharge, wear-out, and water consumption.

The battery can heat up through external heat sources via heat conduction, radiation and/or convection, or through a loss of heat within the battery.

Extreme temperatures cause specific risks:
- In the event of overheating, it is important to note that, in addition to greater aging/wear out, VRLA batteries in particular can fail as a result of the "thermal runaway" effect. This is the term used to describe the battery's thermal self-destruction, as power input rises uncontrollably when overheated batteries are charged, causing the extra heat released to escalate. Acid may leak as a result.
- For temperatures below zero, power intake drops to almost nil, meaning the amount of power withdrawn from the battery is not recharged quickly enough. It must also be noted that the battery acid's freezing point increases as the acid density decreases. The acid's density drops during discharge when the depth of discharge increases. Typical values include:
  - a fully charged battery freezes only at around -70°C,
  - a half-charged battery will freeze at -20°C, and
  - a fully discharged battery will freeze at just 0°C.

Caution: Frozen batteries can burst, and acid will leak out once it is thawed. Charging frozen batteries can also cause explosions.

The battery should thus be kept at a charge which prevents it from freezing, in accordance with the expected operating temperatures.

	Flooded batteries	Valve-regulated lead-acid batteries – VRLA
Upper temperature	60°C	55°C
Difference within battery/within battery assembly	10 K	6 K
Lower temperature	- 40°C Note chargeability and freezing point.	

1) Cumulative temperature peaks of 80°C over 3 hours of usage are permitted.
2) It is important to note that, in the same ambient conditions, VRLA batteries heat up faster than flooded batteries due to the internal recombination cycle.
3) If, based on design, the VRLA is suitable for operation in temperatures above 55°C, the temperature provided by the battery manufacturer is used as a recommendation, e.g. 60°C

Table 1: Operating temperature range inside the battery

3.1. Battery temperatures

In keeping with the general information above, the batteries should be used within the operating temperature range (acid temperature) shown in *Table 1*:

3.2. Possible measures regarding thermal loading

3.2.1 Measures combating battery problems at high temperatures

Possible measures to combat high battery temperatures may include the following – either individually or in combination:
- Cool installation location (note the location of the cooling and exhaust system),
- Ventilated installation system preventing external and internal heating, heat shield, water traps/cooler traps, complete heat protection for the battery (insulation, provide space for insulation), or
- Battery-temperature-controlled charging using a charging voltage gradient of -24 mV/K per 12 V unit (see point 4.2.1).

3.2.2 Measures combating battery problems resulting from low temperatures

Possible measures to combat low battery temperatures may include the following – individually or in combination:
- Thermal insulation,
- A warm installation location (use heat sources in the vehicle, additional heating), or
- Battery-temperature-controlled charging using a charging voltage gradient of -24 mV/K per 12 V unit, see point 4.2.1.

3.2.3 System measures

The system itself can also help compensate for extreme temperatures or the consequences thereof:
- Choice of battery (technology, internal design, acid density),
- System tuning (generator, on-board electrical system, battery),
- Temperature monitoring using active temperature management of the battery,
- Charge status monitoring with active energy management for the battery, or
- Ensure easy battery removal so that the battery may be recharged externally.

3.2.4 Servicing measures

In regions involving extreme climatic conditions, users may be recommended to take the following measures:
- Battery maintenance (acid level checks, water refills, external charging, external temperature controlling),
- Adjusting maintenance intervals, or
- Limiting usage time.

4. Electrical loads

4.1. Electrical battery integration into the vehicle

The battery has preferred terminal locations and shapes to ensure safe integration into the on-board electrical system. The connection elements on the battery cables must be attuned to the shapes and material properties of the terminals in such a way so as to guarantee a permanent, force-locked connection.
The shape and location of the terminals are largely established in the standard EN 50342, part 2 (for cars) and part 4 (for commercial vehicles).

The battery terminals are made from lead or a lead alloy. The terminal bushing is partially hollow, and the ductile behaviour of lead under permanent mechanical loading must be taken into account. When building the connection clamps and defining the associated tightening torques, it is therefore important to ensure extensive, consistent compression of the terminal which causes minimal deformation. When building the clamps it is also important to note that the loosening and connection process may need to be repeated several times. The fact that the terminal gets narrower with every connection process must be taken into account. When using terminal grease, check to see how it affects the clamp's fit.

The design of the terminal clamp and the fastening tool must be attuned to one another in such a way that the terminal, battery cover and plate groups are not damaged when the battery is connected by laypersons. Using force to open the clamp (hammer) or applying a bending or torsional moment (leverage) beyond 10 Nm is not permitted.

Depending on features, a vehicle model will generally contain different sized batteries. The following is thus recommended:
- Ensure the length of the electrical cable is such that the battery can only be connected to the terminals of correct polarity,
- Ensure the length and flexibility of the cables are such that no excessive bending moments can statically or dynamically be applied to the battery terminals,
- Ensure the dimensions of the wiring harness are such that the charging voltage stated in point 4.2.1 is upheld.
- Cables and hoselines touching the engine must be kept in a safe distance from the battery, otherwise engine vibrations can cause the battery case to wear through, resulting in possible acid damage to the vehicle parts.

Non-grounded terminal connections must be protected against short circuits.

4.2. Battery voltage

During charging, the optimum charging voltage depends on the battery design, battery temperature and load profile. Excessively high charging voltages create more gassing in the battery, resulting in the risk of acid leakage. At the same time, water consumption is increased and lifetime reduced. Excessively low charging voltages lead to insufficient charging, persistent sulfation and the risk of freezing.

To protect the battery, lead batteries should not be discharged below current-dependent voltage limits. On the other hand, supplying safety-related devices takes precedence over battery protection.

4.2.1 Charging voltages

Figure 1 shows a charging-voltage characteristic curve optimised for the battery and

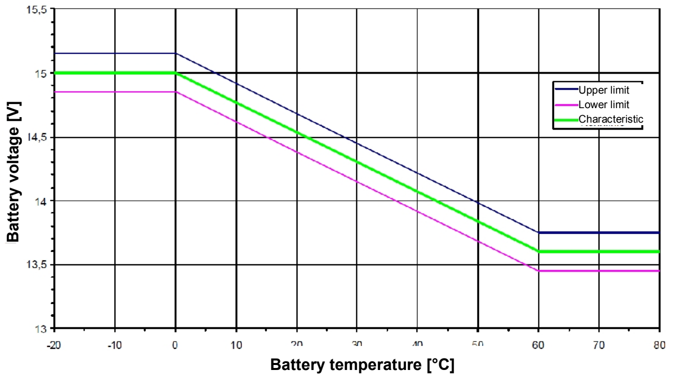

Figure 1:
Double kinked characteristic curve for 12 V batteries when charging in the vehicle (Characteristic curve gradient: -24 mV/K).

dependent on temperature (voltage measured at the battery terminals, temperature measured inside the battery).

System-optimised charge characteristic curves should be discussed with the battery manufacturer. Special charges, such as recuperation (recovery of braking energy, recovery of actuators) or external charges should also be discussed with the battery manufacturers if they lie outside the aforementioned charge characteristic curve (Fig. 1).

NOTE: The battery is not an electric component in the sense of ISO 16750-2.

4.2.2 Superimposed alternating current

The battery operates as a buffer in the electrical system of the vehicle. The generator and alternating devices create an additional AC-current load on the battery, giving the charging or discharging current the properties of an AC current. Depending on charge balance, the battery's charge status, battery temperature and battery design, the amplitude and frequency of the AC-current can affect the battery's durability. They have been known to cause various types of damage, dramatically reduce battery life but also produce positive effects.

An additional AC-current load during the charging phase always results in extra battery heating. Current experience has shown that sealed, fully charged batteries are more sensitive to AC-current loads than batteries containing liquid electrolytes.

Depending on the shape of the current curve and on the basic charge status, frequencies up to 500 Hz can, even with low charge flow, cause microcycling in the battery, which can lead to acid stratification, early wear-out of the active materials and reduced battery life. AC-current loads within the kHz range are relatively harmless.

Measures combating AC-current loads include:
- Adjusting battery size and battery technology,
- Adjusting the on-board electrical system (avoiding battery overload, using inductance and/or additional capacities).

4.2.3 Discharge voltages

The battery's minimum state of charge is generally determined by the start-up requirements, and is thus usually more than 50%, based on the battery's nominal capacity. Lower battery discharges are possible, but negatively affect the battery lifetime. Discharges over 80% of the rated capacity should particularly be avoided. Staying permanently at low state of charge also causes damage and early failure. Occasional current peaks, e.g. at start-up, are not critical and do not require the discharge voltage to be limited in any way.

The end voltages tuned to an 80 % depth of discharge depend on the respective load current. The final discharge voltages

Specific discharge current I_E per C_{20} [A/Ah]	0.0005	0.005	0.05	0.25	1	3	5
Final discharge voltage UES [V]	11.7	11.7	11.7	11.6	11.3	10.2	9.3

Table 2: Final discharge voltages

(UES) shown in *Table 2* apply to 12 V batteries and the load currents standardised at a rated capacity of C_{20}. For batteries with a rated voltage differing from 12 V, the end voltages must be converted linearly in accordance with the rated voltages.
The permitted voltage limits stated in ISO 16750 have to be considered for the electric components.

The following measures are recommended to prevent any prohibited voltage drops:
- On-board electrical system layout (Generator/electric components/wires)
- Battery size and design,
- Disconnect individual devices,
- Increase rate of rotation.

4.3. Battery currents

Car batteries are not short-circuit-proof. During a short circuit in an unprotected part of the on-board electrical system (battery main, starter line, generator line), batteries can release very high output over extended periods of time. Excessively high currents, such as those occurring during a short circuit in the on-board electrical system, may cause the battery's internal lead connections to melt and break connection. The resulting sparks can lead to battery explosion.

Experience has shown that the load currents and load times stated in *Table 3* are non-critical.

Load time [s]	0.5	2	10	30	> 30
Load current [Icc]	3	2	1.3	1	0.6

Table 3: Load current/Load times

4.3.1 Measures combating excessively high battery currents

Various measures can be taken on the vehicle individually or in combination with each other in order to prevent short circuits in wiring and batteries:
- Suitable installation space,
- Protected cable routing,
- Using terminal covers,
- Using main fuses,
- Multi-battery on-board electrical system,
- Using suitable batteries

4.4. Limits of cyclical loading

Cyclical loading means the alternation of charges and discharges. A battery's capacity for cyclical loading is defined as the number of charge and discharge cycles before the battery fails. With optimum temperature and charge, the achievable number of cycles is essentially determined by the average depth of discharge. The product of the number of cycles and the capacity lost per cycle is an first-order approach to setting a characteristic cycle lifetime for a specific battery.

The cycle lifetime actually achieved in the vehicle is determined by charging voltage, charging balance, battery design and battery temperature.

Batteries which
- are permanently operated in a low charging state,
- are charged with excessively low or high charging voltages,
- are cycled under extreme battery temperatures,

have heavily reduced cycle lifetimes.

Possible measures for combating early failure caused by cyclical loading:
- Co-ordinating the generator and electric components;
- Quiescent current management to avoid excessively low discharges;
- Charging voltage adjusted to battery temperature;
- Choice of battery (size, design, charging dynamics) or
- Avoid extreme battery temperatures.

5. Installation space of the battery

5.1. Battery ventilation

A mixture of hydrogen and oxygen is generated in the battery as a result of water electrolysis and self-discharge. This process occurs under all operating conditions (charging, discharge and quiescent phases), and particularly arises when the battery is charged beyond the so-called gassing voltage.
The battery under all circumstances needs a gas exchange with the surrounding atmosphere. The battery degases through the cap or plugs on each individual cell or through the side opening of the central degassing unit. Acidic droplets can escape with the gases, and these aerosols can cause corrosion in the area around the battery. These gases are usually explosive, depending on their composition.

5.1.1 Formation of battery gases

The gassing voltage marks the voltage at which substantial gassing begins. This voltage depends on the battery's technology, age and temperature. 14.4 V (= 2.4 V/cell) is considered a reference value for a new battery's gassing voltage at room temperature.

In a fully charged battery, almost all of the charging power is used to decompose electrolyte water. The charge quantity of one ampere hour thus decomposes 0.34 g of water, forming 0.42 L of hydrogen and 0.21 L of oxygen at 20°C and 1013 hPa.

Towards the end of battery life, short circuits may also form in one or more battery cells. In this case, the generator's charging voltage remains the same but is spread over just a few non-short-circuited cells, meaning it may significantly exceed the gassing voltage in the remaining cells. A defective regulator can also cause the charging voltage to rise incorrectly, and more gassing and corrosive aerosols to be produced.

A hydrogen/oxygen mixture can be ignited within a hydrogen concentration range of 4 % to 96 %. Ignition energy of just 0.01 joules will suffice. The escaping gas mixture can generally be ignited, and the ignition can potentially continue straight into the battery.

It is therefore necessary to take measures which minimise the risk of battery explosions. These measures must remain effective for the entire duration of vehicle usage. This also applies to the replacement battery, which must meet at least the same requirements as the original battery.

5.1.2 Measures to avoid damage from battery gases

Possible measures to prevent damage caused by battery gases/aerosols near ignition sources and/or corrosion-sensitive components are:
- Suitably designing the installation space (see 5.1.2.1),
- Maintaining an adequate distance from ignition sources (see 5.1.2.2) or
- Specific discharge of battery gases (see 5.1.2.3),

Additional measures to reduce damage:
- Choosing suitable batteries,
- Inhibiting re-ignition in the battery (see 5.1.2.4),
- System co-ordination (regulator, battery),
- System for collecting leaking acid (droplet trap, tray),
- No corrosion-sensitive components near the battery, or
- Battery cover systems with acid collection/separation function.

5.1.2.1
Suitable installation place design

Installation spaces should be designed in such a way so as to keep hydrogen concentration below the ignition limit of < 4 % when diluting escaping gases.

Possible measures for doing so are:
- Designing the installation space so that natural ventilation will suffice,
- Ensuring adequate external ventilation in the installation space, or
- Discharging the battery gases from the installation space.

See also the relevant safety requirements in standards EN 50272 or IEC 62485.

5.1.2.2
Adequate distance from ignition sources

It is important to maintain an adequate distance from ignition sources in order to keep hydrogen concentration below the ignition limit. This requires suitable inspections or calculations. The standards EN 50272 and IEC 62485, respectively, provide the relevant information.

5.1.2.3
Specific discharge of battery gases

Collecting the battery gases in a central degassing pipe enables the gases and aerosols to be directed out of the battery environment or battery box in a controlled manner through a standardised degassing vent in the cover, combined with a gas diversion hose.

It is important to note the following here:
- Ensure unimpeded degassing through straight, non-kinked piping.
- Lay the hose in a continuously downward sloping position to avoid water collecting (this could affect degassing in the event of frost).
- Do not let the hose opening end in areas of intensely low or high pressure.
- Maintain an adequate distance between the hose end and ignition sources.
- Add a note that the hose must be reinserted after maintenance work.
- Use batteries whose cell plugs or caps remain leak-proof for the battery's entire lifetime, or which have plugless battery covers.
- Add a note that, in the event of battery replacement, only batteries with the same design can be used.
- Some vehicles are equipped with a hose with an attached connector to drain off the battery gases. If this is the case in that vehicle, the hose must be inserted into the corresponding degassing opening of the battery via the connection piece. If an additional degassing opening is provided on the other side, this must be closed with a closure plug. Under no circumstances must both openings be closed.

5.1.2.4
Prevent flash-back

Preventing flash-back means taking additional measures to reduce the risk of explosion during external ignition. It involves using a special “filter” to prevent a spark outside the battery from crossing into the battery. Despite this clear benefit, it is also important to note that this filter delays the venting of explosive gases from the battery.

5.2. Protecting against corrosion caused by battery acid

Batteries contain highly corrosive, diluted sulphuric acid as an electrolyte. When batteries are installed in a vehicle's interior (the boot is also classified part of the interior in the event of fold-down back seats), it is important to avoid physical injury caused by leaking battery acid. The possibility of people being contaminated with battery acid can be reduced or prevented by measures at both the vehicle and battery level.

5.2.1 Vehicle-based measures

Corrosion caused by battery acid can, for example, be prevented by housing the battery in a completely covered compartment.

5.2.2 Battery-based measures

The batteries mentioned below are designs featuring specific properties. In the event of replacement, users must be instructed to use a battery with at least the same design features as the original (e.g. on a sign near the battery or in the vehicle's operating manual).

5.2.2.1
Optimised tilt-angle batteries

Batteries with optimised tilt angle meet special requirements. For example, they retain the liquid electrolyte even when turned upside down and while being charge, and so reduce the risk of acid leakage for a limited time.

5.2.2.2
Batteries with a fixed electrolyte

It makes sense to use batteries with a fixed electrolyte, a so-called VRLA battery (VRLA = Valve Regulated Lead Acid; collective term for AGM and gel batteries).

5.3. Electrostatic discharge (ESD)

The hydrogen/oxygen mixture, almost always present in the battery's gas compartment, is explosive and may be ignited by a spark. An ignition spark may also arise as a result of electrostatic discharge.

As the battery case is made of plastic and is an electric insulator, the inside of the battery can have a different potential than its surrounding environment. This difference in potential is equalised as electrostatic discharge.

People or objects are electrostatically charged through charge separation or transfer. Charge separation can occur as a result of friction by/on chargeable surfaces or objects, e.g. by cleaning the battery case with a dry cloth, dragging the battery over carpet, or rubbing surfaces/objects in the battery's immediate environment. Friction causes electrons to move from one surface to another, thereby electrostatically charging the surfaces or objects.

This is only possible with non-conductive materials/objects. Very high electrical voltages or potentials in the multi kV range can develop, and, depending on the conditions (type of materials, friction and air humidity), the charge may be equalised by an ignition spark (electrostatic discharge, ESD). The sparking occurs through the air as a result of a charge equalisation between two surfaces with differing electron concentrations. The air is ionised, meaning conductive, due to the high electrical potential. As a rule of thumb, every 1kV of potential difference can pass an air gap of 1 mm. This value is heavily influenced by air humidity.

Sparking can also occur by entrance of a charged person or object coming into close proximity of the battery.

The ignition spark energy needed to ignite the gas mixture inside the battery is so low that the spark may not necessarily be perceptible to the human eye. Due to the complexity of this topic, it is referred to the relevant literature.

5.3.1 Battery-based measures

At the battery level, the ESD risk can be reduced by using batteries with a high contact resistance between their exterior and interior. The main factors are:
- Material thickness of the battery case;
- Refraining from using cell plugs or caps, or
- Cell plugs or caps with a high contact resistance around the seal;
- Sticking a non-conductive label over the cell stoppers;
- Spraying the batteries with antistatic spray (temporary effect).

5.3.2 Measures in the battery's surrounding environment

The environment can also help keep ESD away from the battery mounted in the vehicle:
- People need to be sufficiently discharged, e.g. by touching conductive parts connected to the bodywork material.
- In the battery's immediate surroundings, the charge is diverted through materials with a minimum conductivity of 10^{-4} Sm^{-1} and contact with the vehicle material or battery terminal.

5.4. Splashing water

If large amounts of splashing water hit the battery, they quickly cause the battery's gas compartment to cool down. This creates low pressure in the battery, which sucks water flowing over the battery's cover into the battery through the side opening of the central degassing unit or through unsealed plugs or caps. If this process is repeated multiple times, the overfilled battery may leak acid.

It is important to prevent the battery from being constantly flooded with splashing water.

Protective measures include:
- Choosing an installation location with no splashing water,
- Sealing the central degassing unit's opening with an elbow fitting or similar,
- Use a cover hood for the battery, or
- Choose batteries protected against flooding (cell plugs with sealing ring, batteries without cell plugs or whose cell plugs have been covered, degassing hose, protected terminals)

5.5. Direct light exposure (UV)

The UV components in sun light cause the battery case to become brittle, potentially resulting in case ruptures and acid leaks.

Possible protective measures include:
- Choosing an appropriate installation location,

- Installation the battery in a separate box or in a light-stabilised battery case, and
- Ensuring light protection during storage.

5.6. Battery environment

The battery should be mounted into the vehicle in such a way so as to maximise the ease of installation and dismantling (e.g. accessibility, short circuits, ESD).

The battery's surrounding environment must not contain any pointy or sharp objects which could destroy the battery's case during usage, installation or dismantling.

5.7. Battery installation direction in the vehicle

In the case of wet-cell batteries with built-in measures to prevent acid stratification, it is important to follow the manufacturer's recommendation for installation.

Horizontal installation in the vehicle is recommended for wet-cell batteries.

5.8. Signs and warnings

In accordance with EN 50342, batteries must be labelled with safety symbols. The symbols should remain visible, or have reference made to them, even when working on installed batteries. These symbols are explained in the battery's usage manual, together with other safety-related information.

6. Instructions for interconnecting batteries

Batteries in vehicles are always connected parallel to the charger and electric components. Depending on the requirements of the vehicle's on-board electrical system, batteries are connected
- in series to increase voltage, or
- parallel to increase total capacity and/or combine various functions.

6.1. Batteries connected in series

To avoid reduced battery lifetime, it is important to ensure the following when connecting multiple batteries in series:
- The charging voltage stipulated by the battery manufacturer should be present at every battery's terminals;
- The individual batteries should have the same operating temperatures wherever possible (otherwise use temperature-controlled battery management);
- The individual batteries should be loaded as consistent as possible (use intermediate taps with equalising charge and/or discharge management).

6.2. Parallel battery connections

To avoid a reduced battery lifetime, it is important to ensure the following when connecting multiple batteries in parallel:
- Only batteries with the same voltage, design and (as close as possible) age should be connected, and
- The same charging voltage (or as similar as possible) should be present at every battery's terminals (either by equalising the cable lengths and cross-sections or through a special charging circuit), and
- The individual batteries should have the same operating temperature (or as similar as possible) and
- Unwanted interaction between batteries (e.g. unintentional compensating current flows resulting in uncontrollable battery and cable warming and loss of charge) should be reduced through suitable connection measures.

6.3. Combined series and parallel connections:

Combined series and parallel connections can cause early failure due to uneven charging of individual batteries. Appropriate compensation measures must therefore be stipulated in such cases.

7. Repair and maintenance information

The following information should be appropriately included in the workshop service instructions and vehicle operating manual.

7.1. Frozen batteries

The freezing process damages batteries, which is why it is not recommended to use a frozen battery. If, despite all care taken, a battery should still freeze, it is important to note the following:
- Wherever possible, dismantle the battery before it thaws;
- Thaw the battery in an acid-proof container, collect any leaking acid;
- Dispose of the defective battery and any leaked acid appropriately.

7.2. Installation and dismantling batteries

The battery manufacturer's manual should serve as a guideline for the vehicle manufacturer's documentation (operating manual, workshop service instructions).

7.3. Checking and correcting electrolyte levels

Batteries consume water during operation. A distinction is made between batteries which allow maintenance and those which do not.

Batteries with excessively low electrolyte levels must be maintained or replaced.

Operating batteries with excessively low electrolyte levels can result in considerable damage.

Electrolyte levels should be regularly checked, and should be corrected by a specialised workshop. In the case of batteries which permit maintenance, it is important to note that:
- The electrolyte must only be topped up with demineralised water, and by no later than at the time the minimum on an acid level indicator or similar is reached, and

- The liquid must not be topped up beyond the maximum mark (otherwise acid can leak).
- When filling the battery with demineralised water, make sure no foreign matter or fluids get into the battery.
- The battery surface and environment must not be contaminated with acid.

Even when using batteries which do not enable maintenance, it is important to note changes in electrolyte levels during usage. If the minimum indicator is reached, the battery needs to be replaced. If the levels cannot be checked, a maximum usage duration needs to be defined.

No electrolytes or water must be refilled in the case of sealed batteries (VRLA).

7.4. External charging

External charging should only be performed by a specialised workshop.

Only suitable chargers must be used. Users should be instructed as follows:

- Follow the charger manufacturer's or battery manufacturer's usage instructions and
- Check electrolyte levels before charging, and equalise if necessary (see 7.3). Batteries with excessively low electrolyte levels must not be recharged.

Charging information must be included in the operating manual/service instructions.

7.5. External start-up

A description of an external start-up must be included in the vehicle's operating manual.

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