The electrolyte density of maintenance-free batteries cannot be measured, nor does the battery need to be topped up with distilled water. The Bosch Silver battery provides an indication of the electrolyte density and therefore the charge via the "Power Control System" (Fig. 1). If the indicator in the transparent window is green, the battery is adequately charged. If the indicator is dark, the electrolyte density and therefore the state of charge is too low and the battery needs recharging. If the window is light, the electrolyte has dropped below the minimum level and the battery must be replaced.

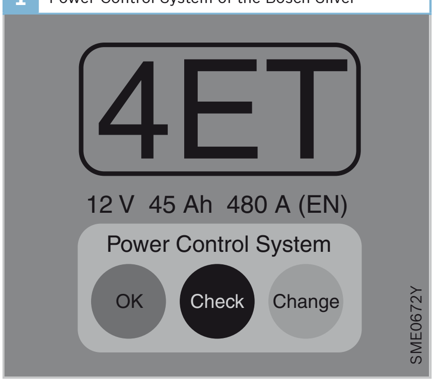
Battery storage

The following storage times are specified for new batteries on the aftermarket:

- Unfilled: unlimited
- Filled, conventional: 3 (max. 6) months
- Filled, completely maintenance-free: 18 months

If the battery is to be stored for longer periods, it must be regularly recharged following the normal charging procedure. Batteries must be stored in a cool and dry state and in a good state of charge. The older a battery gets, the less time it can be stored. As far as possible, the battery is to be trickle-charged with a very low current. If the battery is to remain in the vehicle during the storage period, its ground cable is to be disconnected.

1 Power Control System of the Bosch Silver



Battery charging

If it is impossible for the alternator to charge the battery adequately, a battery charger must be used. This applies when the battery has been out of use for a long time, or directly before it is removed from the vehicle and put into storage.

Charging methods

Normal charging

Generally speaking, normal charging takes place using a battery charge current of I_{10}, which corresponds to 10 % of the battery's nominal capacity:

$$I_{10} = 0.1 \cdot K_{20} \cdot \text{A/Ah}.$$

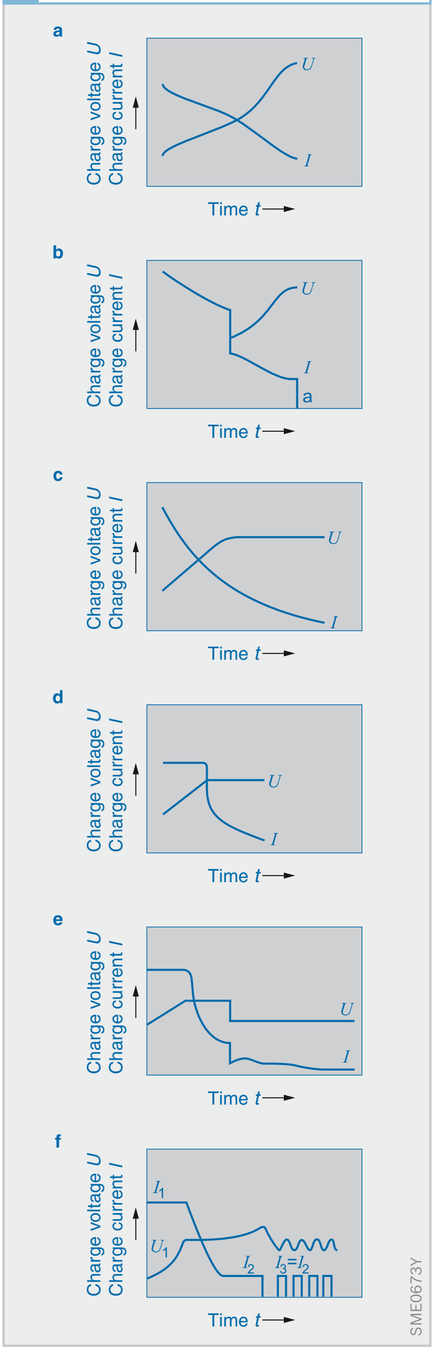
Depending upon the process used, the charging time can be up to 14 hours.

Boost charging

Boost charging can bring a discharged intact battery back up to about 80 % of its nominal capacity so that it can handle loadings which are typical in automotive applications. A high charging current can be used without problems below the gassing voltage – e.g. in the range of the numerical value for the nominal capacity (relative battery charge current $I_1 = K_{20} \cdot \text{A/Ah}$). Once the gassing voltage is reached, the boost charge must either be switched off or changed to normal charging.

The gassing voltage depends on the design of the battery, its age and the electrolyte temperature. If the charge voltage exceeds this value during charging, the battery starts to gas. This leads to water loss in the battery and the production of oxyhydrogen gas. Controlled chargers therefore restrict the charge to a typical 14.4 V (2.4 V/cell) with a cold battery and 13.8 V (2.3 V/cell) with a warm battery.

2 Charging characteristics



Trickle charging
To compensate for the self-discharge losses in stored batteries (for instance when caravan or mobile-home batteries are stored during the winter), the battery is left connected to a battery charger for an extended period of time, whereby charging current is limited to 1 mA/Ah.

Floating-mode operation
With floating-mode operation, the battery charger and the consumers are permanently connected to the battery. This means that energy is drawn from the battery by consumers during charging. The electronics of the charger prevent the battery from becoming overcharged.

Charging characteristics

There are various methods for charging the battery, each of which is characterized by its own charging characteristics (DIN 41 722):

- *W* Constant resistor (battery charge current drops when the charge voltage increases)
- *U* Constant charge voltage
- *I* Constant charging current
- a Automatic shut-off
- e Automatic restart
- o Automatic switch-over to other characteristic curve

The different characteristic curves can also be combined. For instance:

- W Like W characteristic curve but charge voltage remains constant above a given value (e.g. just below the gassing voltage)
- IU Constant charging current up to a value from which voltage remains constant and the charging current falls
- WoW Switch from one W characteristic curve to another

Fig. 2
- a W charging characteristic (normal charge)
- b WoWa charging characteristic
- c WU charging characteristic
- d IU charging characteristic (boost charge)
- e IUoU charging characteristic
- f $I_1U_1I_2aI_3$... charging characteristic

With the W charging characteristic (Fig. 2a) the charging current is determined by the charge circuit resistance and the driving voltage difference according to Ohm's law ($I = \Delta U/R$). Since the charge voltage slowly increases during charging, the driving voltage difference becomes smaller as does the battery charge current.

The W charging characteristic is easiest to achieve, i.e. it leads to cheaper chargers. However, the uncontrolled end of charging and the long charging time taken to fully charge the battery are a disadvantage. The battery charge current drops long before the gassing voltage has been reached.

Both disadvantages are avoided by using the IU charging characteristic (Fig. 2d). A constant high battery charge current I is maintained until the final charging voltage U is reached. This method permits a high level of charge in a short time whereby an overcharge is avoided.

With the IUoU charging characteristic (Fig. 2e) the system U (2.3 to 2.4 V per cell) is permanently switched to a lower voltage (2.23 V per cell) when the final charge voltage is reached (trickle charge).

Battery overcharging is also prevented on equipment with a limited charge voltage (WU characteristic curve, Fig. 2c) or which automatically switches to weaker W charging characteristics when a limit stress is reached (Fig. 2b) or stops charging altogether (Wa characteristic curve).

The $I_1U_1I_2aI_3aI_3$... charging characteristic (Fig. 2f) starts like IU charging. As soon as the battery charge current drops below a certain limit in the U-phase, the system switches to recharging with I_2. This is for a limited time and with a limited voltage. Batteries with defined electrolyte (mat or gel technology) are fully charged, and normal starter batteries with free electrolyte ("wet" batteries) undergo a defined gassing phase with electrolyte mixing. The final trickle charge (I_3aI_3a...) charges at approx. 1A/100 Ah until an upper limit stress is reached, and then shuts off. As soon as the battery voltage has reached a lower limit stress by means of self-discharging, the recharging current I_3 starts again.

Safety requirements

In order to avoid the risk of accidents the charger must have reliable potential separation between the 230V mains and the accessible charging terminals. Additional reverse-polarity protection prevents battery short-circuiting and the destruction of the battery charger if the battery terminals are wrongly connected.

Battery testers

The condition of installed starter batteries can also be checked with battery testers. They mainly measure and evaluate the high-current capability of the battery. The Bosch BAT121 battery tester also makes it possible to print out the result of the test on the built-in thermal printer.

The battery tester is connected to the battery via cables. The low-temperature test current of the battery is selected on the tester, then the test can be started. The digital display shows the following information when the test is complete:

- The available starting power as a percentage of the input value
- The battery voltage
- The evaluation "good" or "replace"
- A charge recommendation if a low state of charge has been detected

Battery chargers

Highly sensitive electronic components such as airbags, car telephones, car radios and electronic control units must be protected from voltage peaks when the battery is being charged. Previously, the battery had to be disconnected from the vehicle electrical system. However, when modern electronic chargers are being used, the battery can be charged with the consumers connected (floating-mode operation). Since charging is faster and there is no danger to the vehicle's electronic consumers, this is of course a considerable