SEALED LEAD-A

SLAs still going strong

Lead-acid batteries still form an essential part of the on-board power systems in cars, motorcycles, boats and caravans. In its new form, featuring a fixed electrolyte and a sealed enclosure, this veteran battery technology (invented in 1850!) is now more versatile than ever.

Sealed batteries with a fixed electrolyte have been in production for more than forty years. The electrolyte (dilute sulphuric acid) is fixed either using silica gel (lead-gel, or 'dryfit' battery) or using a glass fibre mat (AGM or 'absorbed glass mat' technology). This allows the oxygen produced at the positive electrode when the battery is overcharged to diffuse to the negative plate where it can recombine into water. This cycle of recombination makes the battery emit practically nothing in the way of gases, and so it can be built into a sealed enclosure. To prevent rupture in the event of the pressure getting too high, the cells (as in almost every sealed battery) are equipped with self-closing safety valves. The combination of fixed electrolyte and a sealed enclosure allows operation in any orientation (although AGM batteries must not be charged upside-down). The most important advantages of sealed lead-acid batteries, besides their low price, are their low self discharge, simple charging method, and long life, especially when continuously charged.

Although the basic principles of operation of the sealed lead-acid battery have not changed, steady development over the years has led to significantly better battery characteristics:

- Improved behaviour when overcharged
- Relatively low sensitivity to deep discharge
- Improved life
- Higher specific capacity
- Improved cycle life
- Quicker charging
- Improved current output

CID BATTERIES

Manufacturers such as Yuasa, Panasonic and Sonnenschein/Exide offer various ranges of batteries optimised for one (or more) different applications. So, for example, there are batteries available optimised for long life designed to last for 20 years and 1500 cycles.
The most important application areas today are emergency power supplies of various types (for example for alarm systems, IT equipment, lighting, and medical devices), electric vehicles (such as golf buggies and wheelchairs), electric starter motors, on-board power supplies in boats, caravans and gliders, and, last but not least, solar power systems that are independent of the mains.

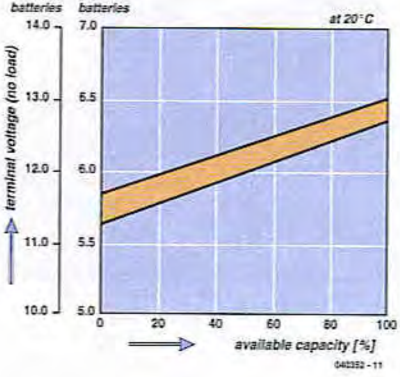


Figure 1. Relationship between measured open-circuit voltag and remaining capacity.

Voltage, current and capacity

The state of charge of a lead-acid battery can be determined by measuring its no-load voltage. **Figure 1** shows typical values for sealed 6 V and 12 V batteries. The figure also indicates the accuracy that can be expected using this measurement: the voltage varies from around 2.2 V for a fully-charged cell to 1.9 V for a discharged cell. These values are valid at room temperature (20 °C). If the battery has recently been charged or discharged, the values are respectively higher and lower.
The usable capacity *C* of a sealed lead-acid battery, measured in amp-hours (Ah), depends to a great extent on the discharge current. The lower the discharge current, the lower the losses during discharge, and so the higher the usable capacity. For this reason, the discharge current is generally quoted in *C*A, giving the current as a fraction of the nominal capacity *C*. For example, a capacity *C* specified at *C*/10 (or 0.1 *C*A) for a 1 Ah battery means that the capacity given is valid for a discharge current of 0.1 A (100 mA). In this case the capacity may also be written as C_{10} (capacity for 10-hour discharge). Nominal capacities of lead-acid batteries quoted according to the German DIN standard are given for a 20-hour discharge (i.e., at 0.05 CA) and with a final discharge voltage of 1.75 V per cell.

Charging

In principle sealed lead-acid batteries can be charged at a constant voltage. The maximum charge voltage that can be used depends on the temperature, and it is important that this voltage is not exceeded during charging. **Figure 2** shows the relationship between temperature and voltage for two different charging regimes. The higher value is used for normal (cyclical) operation, while the lower value is for when the battery is trickle-charged to maintain its condition over a long period. In standby operation a voltage that is even only slightly too high will have a negative impact on the life of the battery, and so if the operating temperature will not be constant a temperature-compensated charging circuit is essential. What can happen if the charge voltage is not adjusted to suit the temperature is clearly shown in **Figure 3**.

Charging at constant voltage is very simple. Any regulated power supply can be used as long as its output voltage can be set to the correct value. At room temperature (20 °C) a value of 2.45 V (say between 2.4 V and 2.5 V) per cell is suitable for normal cyclical charging; for trickle charging a suitable value is 2.275 V (say between 2.25 V and 2.3 V) per cell. Cells should not be charged for too long at higher voltages. One criterion that can be used to determine when to stop charging is to test when the charge current, which falls continuously during the first few hours of charging, reaches 0.07 *C*A (or less) and remains unchanged for three further hours. If this test is not used, then time-controlled charging should be limited to a maximum of 16 to 20 hours.
The initial charge current is determined by the internal resistance (or, if available, current limiting) of the power supply. Raising the maximum initial current does not reduce the charge time as much as might be expected.

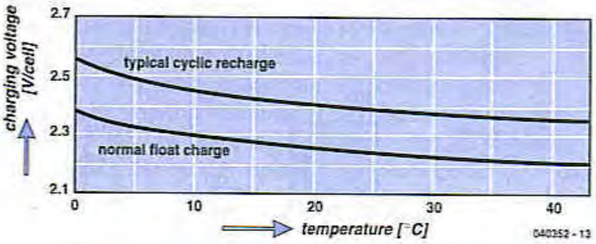


Figure 2. Charge voltage (per cell) in relation to temperature for cyclic charging (above) and trickle charging (below).

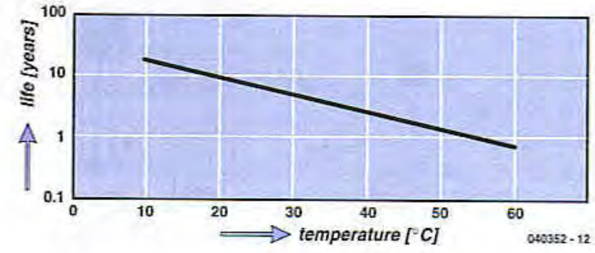


Figure 3. Effect of temperature on battery life with continuous charginc at a constant 2.275 V per cell.

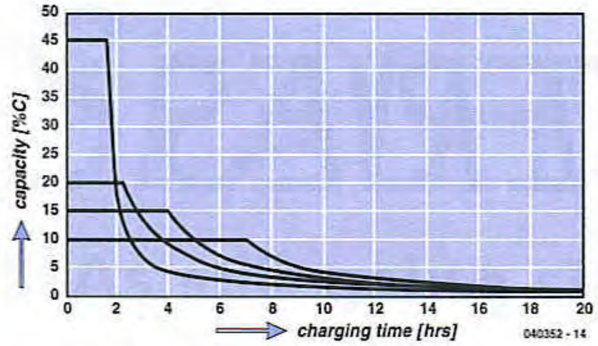


Figure 4. Charging behaviour at constant 2.275 V per cell at four different current limit settings.

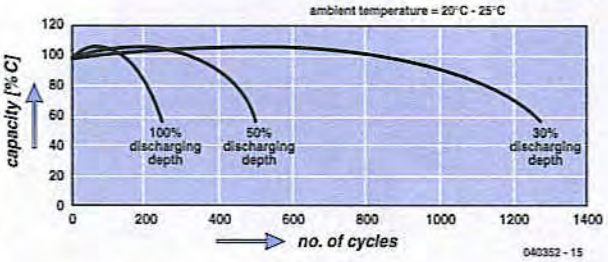


Figure 5. Effect of depth of discharge on life in cyclic operation.

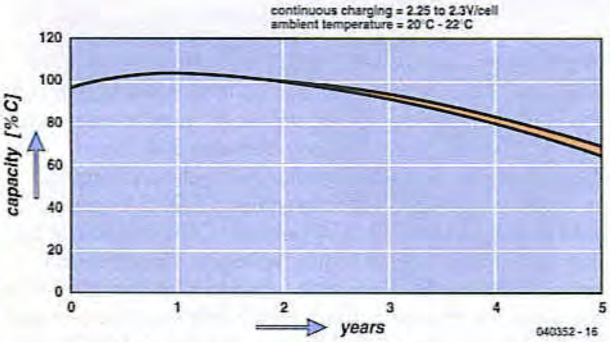


Figure 6. Typical fall-off in capacity in trickle-charged operation.

Figure 4 shows how the charge current changes when the charge voltage is set to 2.275 V using four different current limit settings. The charge current (in amps) is shown on the vertical axis as a percentage of the battery capacity C_{10}. If the C_{10} capacity is, for example, 1 Ah, then we are considering initial currents from 450 mA (or 45 % of C_{10}) down to 100 mA (10% of C_{10}). The figure shows that the initial limit current only flows at the beginning of the charge cycle. The current proceeds to fall off exponentially, almost to zero at the end of the charging procedure. Manufacturers recommend initial current limit values in the range from 0.25 CA to 0.4 CA; values above 0.5 CA are best avoided in the interests of preserving the life of the battery.

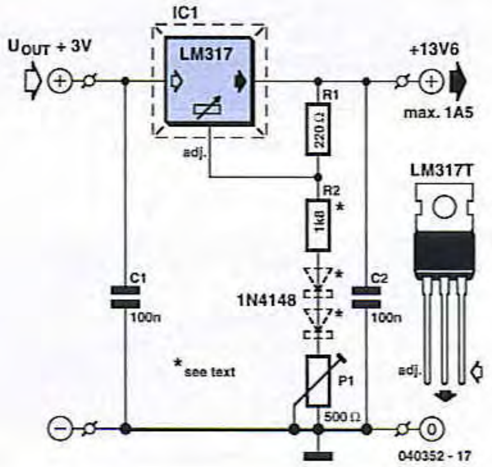


Figure 7. This simple circuit meets all the manufacturers' main recommendations for charging sealed lead-acid batteries.

Typical values

(all voltage data are per cell and at 20 °C)

Recommended charging voltage:

2.45 V (2.4 V to 2.5 V) for normal charging

2.275 V (2.25 V to 2.3 V) for trickle charging

Recommended current limit:

0.25 CA to 0.4 CA

Maximum charge time (normal charging):

16 h to 20 h

Final discharge voltage:

1.75 V

Open circuit voltage:

2.2 V (charged)

2.1 V (half-discharged)

1.9 V (discharged)

Battery life

The life of the battery depends to a great extent on the depth of discharge, expressed as a percentage of the nominal capacity. **Figure 5** gives an idea of the effect of cyclic operation on battery life. To maximise the number of useful cycles it is best to choose a battery with a larger capacity so that the depth of discharge is reduced.

Although discharge depth is the main factor, temperature also has an effect on life. Temperatures above 50 °C should be avoided, and below –15 °C there is a significant drop in capacity. Charging at too high a voltage, or for too long, will damage the battery.

Temperature and charging voltage are the main factors affecting life in continuously-charged operation.

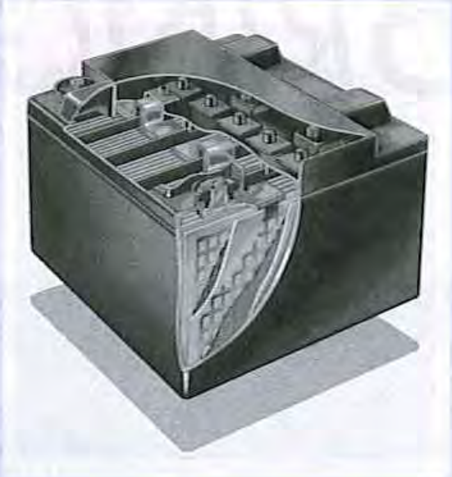
Figure 6 illustrates typical performance in this case, where 60 % of the battery's capacity still remains available after 5 years' use. The 60 % level is considered to mark the end of the useful life of the battery in industrial applications.

In addition to the factors mentioned above, the construction of the battery also affects its life. For example, in standby operation the small charge current that continuously flows results in the plates gradually becoming thinner and thinner. Batteries with sturdier plates last considerably longer in such use. There are also batteries available that are optimised for cycle life. Exact specifications for the various ranges can be found on the manufacturers' websites (see list).

Not recharging the battery after a deep discharge also has a negative effect. Sealed lead-acid batteries should

Gel and AGM-lead batteries

Conventional lead-acid batteries have a few decisive disadvantages: they are filled with highly acid and therefore hazardous liquids which may spill into the environment not just when the battery case is cracked but also when far from positioned upright. Also, these batteries are marked by a high degree of self-discharging and a limited number of charging cycles. This may be tolerable for a vehicle starter battery, but if the battery is to power a vehicle supply system (and be subject to complete charging cycles including deep discharging) then it will protest by developing amounts of sulphate.



With the above in mind, it is not surprising to see lead-acid batteries with fixed electrolytes used in such applications as back-up PSUs and solar systems. These variants are sealed, maintenance-free and will not easily spill their contents. Sulphation can hardly occur because the free sulphuric acids are 'captured' by the internal gel mass. Self-discharging is noticeably smaller, although charging instructions must be observed closely. Unfortunately sealed lead-acid (SLA) batteries exhibit considerably lower energy densities than their liquid acid counterparts, which makes them generally unsuitable for use as vehicle starter batteries.

Apart from the well-known lead-gel technology there is another method to fix electrolyte in a lead-acid battery: AGM. AGM stands for 'absorbent glass mat'; a separating layer pressed between the electrodes. The construction of an AGM battery is shown diagrammatically in the illustration (source: Hawker). The capillary action of the mat causes the electrolyte to be fully absorbed, preventing it from moving around freely. AGM batteries typically supply higher currents than gel types and are also cheaper. On the down side, they are marked by some excess electrolyte as well as worse heat dissipation — at high temperatures, AGM batteries are susceptible to drying out.

not be left in a deeply-discharged state for more than a few days, and should be recharged as soon as possible. The deep discharge capability of a battery indicates whether (and how quickly) it will accept charge again after being left discharged for a long period. Modern AGM-type batteries accept charging relatively quickly after a month in a deeply-discharged state and subsequently return to their normal charging characteristics. To avoid the possibility of leaving the batteries discharged for a long time, they should be stored in the charged state. Recharging is recommended when the open-circuit voltage reaches 2.1 V per cell, which corresponds to a self-discharge to about 50 % of the nominal capacity. A healthy battery at room temperature will discharge so slowly that this value will only be reached after about 18 months. At 30 °C it will take around 9 months to reach half capacity, and at 40 °C, around 4.5 months. At lower temperatures (down to –15 °C) charge is lost even more slowly than at room temperature. The low self-discharge and associated long storage life, along with long life in standby operation, are the most important advantages of sealed lead-acid batteries over other battery technologies.

In practice

Most battery manufacturers recommend charging using a constant voltage and current limiting, with temperature compensation. A simple charging circuit that satisfies these recommendations is shown in **Figure 7**. An LM317 is used as the voltage regulator with a current limit of 1.5 A. To ensure that the charge voltage is maintained at the level set by P1, the voltage at the input to the LM317 must be kept at least 3 V higher than that at the output. The input voltage can be provided from a (plug-in) mains adaptor (unregulated is fine) or from a 14 V boat power supply. The latter option is only suitable if the battery to be charged contains no more than four cells.

The charge voltage is set using P1 to the optimal value for the number of cells, battery type (see manufacturer's data) and type of charging (normal or trickle). The voltage at the output of the charger should be checked using a digital multimeter with the battery not connected. The range of voltages offered by P1 can be altered if necessary by changing R2 to suit the number of cells in the battery.

If charging is always to be carried out at room temperature, the temperature compensation diodes between R2 and P1 (shown dotted) can be dispensed with. Otherwise it is necessary to find out what temperature coefficient (TC) the manufacturer recommends for compensation. A TC value in the range from –2 to –5 mV/°C can be realised using our circuit as follows.

Inserting as many 1N4148 diodes in series between R2 and P1 as there are cells in the battery will give a TC of –2 mV/°C: for a 12 V battery, that means six diodes. If the number of diodes is doubled to 12, the TC value will be –4 mV/°C; with nine diodes, the value will be –3 mV/°C. As you can see, the TC can easily be adjusted by varying the number of diodes. In order to correct for the voltage drop across the diodes, the resistance of R2 must be decreased by about 120 Ω for each diode added.

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Web pointers:

http://www.yuasabatteries.com

http://www.networkpower.exide.com/

http://www.batterypoweronline.com/

http://www.panasonic.com/industrial/battery/

http://www.panasonic.com/industrial/battery/oem/chem/seal/index.html