# State of Health (SOH) Determination

**What is the SOH?**

The State of Health is a "measurement" that reflects the general condition of a battery and its ability to deliver the specified performance compared with a fresh battery. It takes into account such factors as charge acceptance, internal resistance, voltage and self-discharge.

During the lifetime of a battery, its performance or "health" tends to deteriorate gradually due to irreversible physical and chemical changes which take place with usage and with age until eventually the battery is no longer usable or dead.

The SOH is an indication of the point which has been reached in the life cycle of the battery and a measure of its condition relative to a fresh battery.

Unlike the SOC which can be determined by measuring the actual charge in the battery there is no absolute definition of the SOH. It is a subjective measure in that different people derive it from a variety of different measurable battery performance parameters which they interpret according to their own set of rules. It is an estimation rather than a measurement. This is fine so long as the estimate is based on a consistent set of rules but it makes comparisons between estimates made with different test equipment and methods unreliable.

Battery manufacturers do not specify the SOH because they only supply new batteries. The SOH only applies to batteries after they have started their ageing process either on the shelf or once they have entered service. The SOH definitions are therefore specified by test equipment manufacturers or by the user.

**What is the SOH used for?**

Its purpose is to provide an indication of the performance which can be expected from the battery in its current condition or to provide an indication of the how much of the useful lifetime of the battery has been consumed and how much remains before it must be replaced. In critical applications such as standby and emergency power plant the SOC gives an indication of whether a battery will be able to support the load when called upon to do so. Knowledge of the SOH will also help the plant engineer to anticipate problems to make fault diagnosis or to plan replacement. This is essentially a monitoring function tracking the long term changes in the battery.

**SOH for Electric Vehicle (EV) applications**

For EV applications, the ability to achieve the range when called upon to do so is most important, hence the SOH is based on a comparison of current capacity with capacity when new.

**SOH for Hybrid Electrical Vehicle (HEV) applications**

For HEV applications the ability to deliver the specified power is most important and so SOH is based on a comparison of the DC resistance (or 1 kHz impedance) now with DC resistance (or 1 kHz impedance) when new.

If the recorded usage history of the battery is used to determine the SOH, as in the Log Book Function below, then this same data can be also used to validate warranty claims. This is particularly useful for assessing the condition of high cost EV and HEV batteries which may have been subject to abuse.

**How is the SOH determined?**

Any parameter which changes significantly with age, such as cell impedance or conductance, can be used as a basis for providing an indication of the SOH of the cell. Changes to these parameters will normally signify that other changes have occurred which may be of more importance to the user. These could be changes to the external battery performance such as the loss of rated capacity or increased temperature rise during operation or internal changes such as corrosion.

Because the SOH indication is relative to the condition of a new battery, the measurement system must hold a record of the initial conditions or at least a set of standard conditions. Thus if cell impedance is the parameter being monitored, the system must keep in memory as a reference, a record of the initial impedance of a fresh cell. If counting the charge / discharge cycles of the battery is used as a measure of the battery usage, the expected battery cycle life of a new cell would be used as the reference. In a Lithium ion battery, since the cell capacity deteriorates fairly linearly with age or cycle life, the expired, or remaining cycle life, depending on the definition used , is often used as a crude measure of the SOH.

In practice some people estimate the SOH from a single measurement of either the cell impedance or the cell conductance. (See Impedance and Conductance Testing). In pursuit of accuracy, others advocate measuring several cell parameters, all of which vary with the age of the battery, and making an estimation of the SOH from a combination of these factors. Examples are capacity, internal resistance, self-discharge, charge acceptance, discharge capabilities the mobility of electrolyte and cycle counting if possible. The absolute readings will depend on the cell chemistry involved. Weighting is added to individual factors based on experience, the cell chemistry and the importance the particular parameter in the application for which the battery is used. If any of these variables provide marginal readings, the end result will be affected. A battery may have a good capacity but the internal resistance is high. In this case, the SOH estimation will be lowered accordingly. Similar demerit points are added if the battery has high self-discharge or exhibits other chemical deficiencies. The points scored for the cell are compared with the points assigned to a new cell to give a percentage result or figure of merit.

Such complex measurements and processing need the help of a microprocessor to deliver the results. For automated measurements the initial conditions and the "experience" can be encapsulated in memory to facilitate this process. The "experience" can be modified in a learning process as more data becomes available to refine the estimations. Fuzzy Logic is used to combine the experience with the measurements to improve the accuracy of the results.

The sentence on the cell - Pass or Fail -. is based on an arbitrary limit based on experience with the application, expedience and whatever safety factors are required.

This method uses an external measuring device to provide an estimate of the current / actual SOH. It does not require any modifications to the cells.
Proprietary equipment is available for measuring the SOH.

**The Log Book Function**

An alternative method of specifying the SOH is to base the estimation on the usage history of the battery rather than on some measured parameter. The number of charge - discharge cycles completed by the battery is an obvious measure, but this does not necessarily take into account any extreme operating conditions experienced by the battery which may have affected its functionality. It is however possible to record the duration of any periods during which the battery has been subject to abuse from out of tolerance voltages, currents or temperatures as well as the magnitude of the deviations. From this data a figure of merit representing the SOH can be determined by using a weighted average of the measured parameters.
Battery usage (or abusage) data can be stored in memory in the BMS in a "History Chip" and downloaded when required. This alternative method does not use any external test equipment but it adds complexity and cost to the battery.