Knowing when to replace a Battery

Using Capacity as Benchmark

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A battery is a corrosive device that begins to fade the moment it leaves the assembly line. Its stubborn and unpredictable behaviour has left many users in awkward situations. Battery failure is common and up to 50 percent of system breakdowns are attributed to a failing battery. Much of this is avoidable, but even with the best of care, some batteries die early and scientists don't know why. Batteries exhibit human-like characteristics and the health rests on the genetic makeup, environmental conditions and user pattern.

The manufacturer specifies the runtime of a device on a battery performing at 100 percent capacity, but most operate at less. As time goes on, the performance declines further and the battery gets smaller in terms of storing energy. Most batteries deliver 300 to 500 full discharge/charge cycles, more on a partial discharge.

In the first year, most batteries work well, but the confidence fades in the second and third year. As batteries begin to lose capacity, new packs are added and in time, the battery fleet becomes a jumble of good and failing batteries. This is when the headache begins. Unless date stamped or other quality controls are in place, the user has no clue about the history of a battery, much less its performance.

The energy in a battery can be divided into three segments: *available energy,* the *empty zone* that can be refilled, and the *unusable part* or rock content that has become dormant. Figure 1 illustrates these three sections graphically.

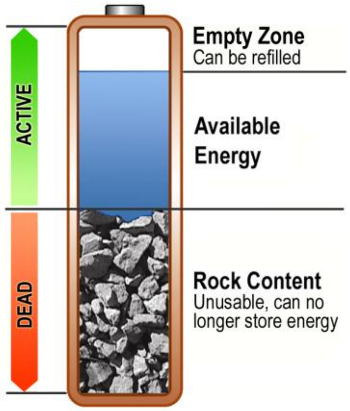

Figure 1: The three segments of a battery

The runtime on a device is measured on a 100% battery; most packs deliver less.

The "ready" light on a charger cannot verify the "health" of a battery. Ready only reveals that the battery is fully charged. As the active space of a battery declines with age, charge times also decrease. This can be compared to topping a water jug that's filled with rocks. Many battery users are unaware that weak batteries charge faster than good ones. The low performers gravitate to the top and become disguised to the unsuspecting user who trusts the "green light." A short charge time is not only reserved to a poor battery, a pack with a partial charge also charges quickly because there is little to add.

A battery needs constant care and feeding. Even if fully charged, self-discharge consumes valuable energy. This is not a manufacturing defect but a battery characteristic, although poor manufacturing and improper handling can elevate the problem. Table 2 shows the self-discharge of common batteries.

Battery System	Estimated Self-discharge
Lithium-metal (primary)	10% in 5 years
Alkaline (primary)	2-3% per year (7-10 years shelf life)
Lead-acid	5% per month
Nickel-based	10-15% in 24h, then 10-15% per month
Lithium-ion	5% in 24h, then 1-2% per month (plus 3% for safety circuit)

Table 2: Percentage of self-discharge in years and months. Primary batteries have considerably less self-discharge than secondary (rechargeable) batteries.

The amount of self-discharge varies with battery type and primary cells retain the energy longer than rechargeable systems. The energy loss is asymptotical, meaning that the self-discharge is highest right after charge and then tapers off. The self-discharge on all battery chemistries increases at higher temperature and the rate typically doubles with every 10°C (18°F). High cycle count and aging also increase the self-discharge.

The care and feeding of a battery begins with the acceptance from the supplier and continues to its rightful retirement. Battery service includes the following:

Incoming inspection: All batteries should be checked before field deployment; packs that fail to meet performance criteria should be returned. The open circuit voltage of a lead acid battery should be at least 2.10V/cell. Nickel-based batteries may need priming to get the full capacity, especially if they had been in storage for a while. After charging, lithium-based batteries out-of-box should be close to 100 percent.

Periodic capacity check: Batteries must be treated like any other medical device. While date stamping offers an alternative to analyzing batteries, this method does not guarantee reliable performance because some packs fail before the expiry date, but most last longer. Modern batteries properly maintained tend to outlive the date stamp. Longevity is a function of cycle count and depth of discharge. Capacity, and not the manufacturing date, is the leading health indicator of a battery.

Retirement: The battery capacity decreases with usage and time. Medical staff may be unaware of capacity fade and continue using the battery. A battery should be replaced when the capacity drops to 80 percent, in some cases this may be 70 percent, and restoration is not possible. Do not retire batteries too soon. Discarding good batteries increases operational cost and raises environmental concerns. Battery analyzers save money in predicting the correct replacement time.

Some batteries are in daily use, others are mainly on standby. Table 3 shows the recoverable capacity after one year of storage. Recovered capacity defines the remaining full-charge capacity after storage. Batteries deteriorate faster at higher temperature and with a full charge; this phenomenon is especially apparent with Li-ion.

Temperature	**Lead acid** at full charge	**Nickel-based** at any charge	**Lithium-ion** (Li-cobalt) 40% charge	100% charge
0°C	97%	99%	98%	94%
25°C	90%	97%	96%	80%
40°C	62%	95%	85%	65%
60°C	38% (after 6 months)	70%	75%	60% (after 3 months)

Table 3: Recoverable capacity after one year of storage. Elevated temperature hastens permanent capacity loss. Depending on battery type, lithium-ion is also sensitive to charge levels.

Battery analyzers have made critical inroads into the medical industry. The Cadex C7400ER illustrated in Figure 4, for example, services four batteries independently. Battery adapters permit plug-and-play, automated programs provide hands-off service and manual operation enables the setting of unique parameters. PC-BatteryShop™ software allows operation from a PC; a simple mouse click or swiping the bar code label on the battery configures the analyzer.

Figure 4: Cadex C7400ER Series battery analyzer

Each station is programmable to 30V and 6A; batteries connect by battery adapters or the programmable Smart Cable; PC-BatteryShop™ allows operation from a PC.

Battery labeling offers a simple and practical way to manage a battery fleet. PC-BatteryShop™ generates labels showing capacity, service date and due date. The system is self-governing in that the user will only pick a battery with a valid service date and sufficient capacity. Batteries reaching the service due date are removed and run on a battery analyzer. Figure 5 illustrates a printer with a sample label.

Figure 5: Battery management with labels

The label reveals the battery information at a glance and hints to the next service date.

A speaker at a battery conference said, “The battery is a wild animal and artificial intelligence domesticates it.” He wanted to make the battery intelligent. While adding a SMBus assists in battery management, it comes with baggage. “Smart batteries” are not standardized and the fuel gauge shows state-of-charge without reference to the actual capacity. In addition, a battery equipped with a fuel gauge needs periodic calibration to correct the tracking errors that occur with time. The error is about one percent with each cycle. To calibrate, apply a full charge/discharge and repeat the service every three months or after 40 partial cycles. A non-calibrated battery will still work but will provide false state-of-charge readings. Figure 6 explains the calibration process.

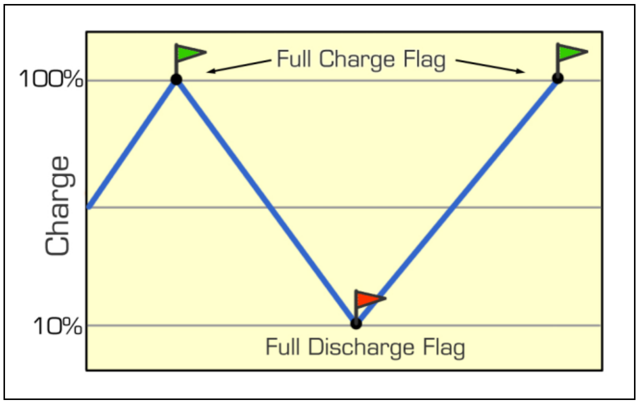

Figure 6: Charge/discharge flags

Calibration occurs by applying a full charge, discharge and charge in the equipment or with a battery analyzer as part of maintenance.

A technical expert at a hospital commented on his personal experience regarding smart batteries and said: “I have more problems dealing with the *smart part* of the battery than the actual cells. Many medical batteries have logic problems, memory errors, glitches or low voltage recovery issues.” Smart batteries for specialty applications have more anomalies than packs in laptops and other consumer products.

To eliminate system failures, authorities have implemented strict maintenance and calibration guidelines, but the battery enjoys immunity and escapes the inspector’s scrutiny as being “uncontrollable.” To satisfy regulatory requirements, the inspectors may validate logistic issues such as the model number and service dates and ignore the capacity, the leading health indicator.

Battery performance is difficult to estimate. Measuring capacity with discharge is time-consuming and rapid-test methods are not always dependable. It appears as if battery testing is stuck in medieval times. There are no simple solutions but progress is being made and Cadex is playing a role in this development.

Summary

The user is at the mercy of the battery. Charge-and-run without maintenance does not guarantee sufficient reliability. To avoid unnecessary risks, many hospitals and paramedics are taking a proactive approach towards battery maintenance. There is also a strong interest in cutting costs to keep each pack in service for the full duration of the useful life, and modern battery analyzers make this possible. Advanced battery analyzers also provide rapid-test methods that sort batteries into *good*, *suspect* and *poor* in a few seconds.

About the Author

Isidor Buchmann is the founder and CEO of Cadex Electronics Inc. For three decades, Buchmann has studied the behavior of rechargeable batteries in practical, everyday applications, has written award-winning articles including the best-selling book “Batteries in a Portable World,” now in its third edition. Cadex specializes in the design and manufacturing of battery chargers, analyzers and monitoring devices. For more information on batteries, visit www.batteryuniversity.com; product information is on www.cadex.com.