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Batteries in a Portable World

A Handbook on Rechargeable Batteries for Non-Engineers

Isidor Buchmann

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Third Edition

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Chapter 9 | **Testing and Monitoring**

Difficulties with Battery Testing

A German manufacturer of luxury cars points out that one out of two starter batteries returned under warranty is working and has no problem. It is possible that battery testers used in service garages did not detect the batteries correctly before they were returned under warranty. ADAC* reported in 2008 that 40 percent of all roadside automotive failures are battery-related. In Japan, battery failure is the largest single complaint among new car owners. The average car is driven 13km (8 miles) per day and mostly in congested cities. The most common reason for battery failure is undercharge. Battery performance is important; problems during the warranty period tarnish customer satisfaction.

Battery malfunction during the warranty period is seldom a factory defect; driving habits are the culprits. A manufacturer of German-made starter batteries stated that factory defects account for only 5 to 7 percent of warranty claims. The battery remains a weak link, and is evident when reviewing the *ADAC 2008 report* for the year 2007. The study examines the breakdowns of 1.95 million vehicles six years old or less, and Table 9-1 provides the reasons.

Percentage of Failure	Cause of Failure
52%	Battery
15%	Flat tire
8%	Engine
7%	Wheels
7%	Fuel injection
6%	Heating, cooling
5%	Fuel systems

Table 9-1:
Most common car failures

Batteries cause the most common failures requiring road assistance.

Source: ADAC 2008

The cellular phone industry experiences an even more astonishing battery return pattern. Nine out of 10 batteries returned under warranty have no problem or can easily be serviced. This is no fault of the manufacturers but they pay a price that is ultimately charged to the user.

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* The ADAC (Allgemeiner Deutscher Automobil-Club e.V.) originated in Germany in 1903 and is Europe's largest automobile club, with over 16 million members.

Part of the problem lies in the difficulty of testing batteries at the consumer level, and this applies to storefronts and service garages alike. Battery rapid-test methods seem to dwell in medieval times, and this is especially evident when comparing advancements made on other fronts. We don't even have a reliable method to estimate state-of-charge — most of such measurements using voltage and coulomb counting are guesswork. Assessing capacity, the most reliable health indicator of a battery, dwells far behind.

The battery user may ask why the industry is lagging so far behind. The answer is simple: battery testing and monitoring is far more complex than outsiders perceive it. As there is no single diagnostic device that can assess the health of a person, so are there no instruments that can quickly check the state-of-health of a battery. Like the human body, batteries can have many hidden deficiencies that no single tester is able to identify with certainly. Yes, we can apply a discharge, but this takes the battery out of service and induces stress, especially on large systems. In some cases, even a discharge does not provide conclusive results either, as we will learn later (see "Discharge Methods" on page 221).

As doctors will examine a patient with different devices, so also does a battery need several approaches to find anomalies. A dead battery is easy to measure and all testers can do this. The challenge comes in evaluating a battery in the 80 to 100 percent performance range. This chapter examines current and futuristic methods and how they stand up. One thing to remember is this: batteries cannot be measured; the appropriate instruments can only make predictions or estimations. This is synonymous with a doctor examining a patient, or the weatherman predicting the weather. All findings are estimations with various degrees of accuracies.

How to Measure Internal Resistance

The resistance of a battery provides useful information about its performance and detects hidden trouble spots. High resistance values are often the triggering point to replace an aging battery, and determining resistance is especially useful in checking stationary batteries. However, resistance comparison alone is not effective, because the value between batches of lead acid batteries can vary by eight percent. Because of this relatively wide tolerance, the resistance method only works effectively when comparing the values for a given battery from birth to retirement. Service crews are asked to take a snapshot of each cell at time of installation and then measure the subtle changes as the cells age. A 25 percent increase in resistance over the original reading hints to an overall performance drop of 20 percent.

Manufacturers of stationary batteries typically honor the warranty if the internal resistance increases by 50 percent. Their preference is to get true capacity readings by applying a full discharge. It is their belief that only a discharge can provide reliable readings and they ask users to perform the service once a year. While this advice has merit, a full discharge requires a temporary disconnection of the battery from the system, and on a large battery such a test takes an entire day to complete. In the real world, very few battery installations receive this type of service and most measurements are based on battery resistance readings.

Measuring the internal resistance is done by reading the voltage drop on a load current or by AC impedance. The results are in ohmic values. There is a notion that internal resistance is related to capacity, and this is false; the resistance of many batteries stays flat through most of the service life. Figure 9-2 shows the capacity fade and internal resistance of lithium-ion cells.

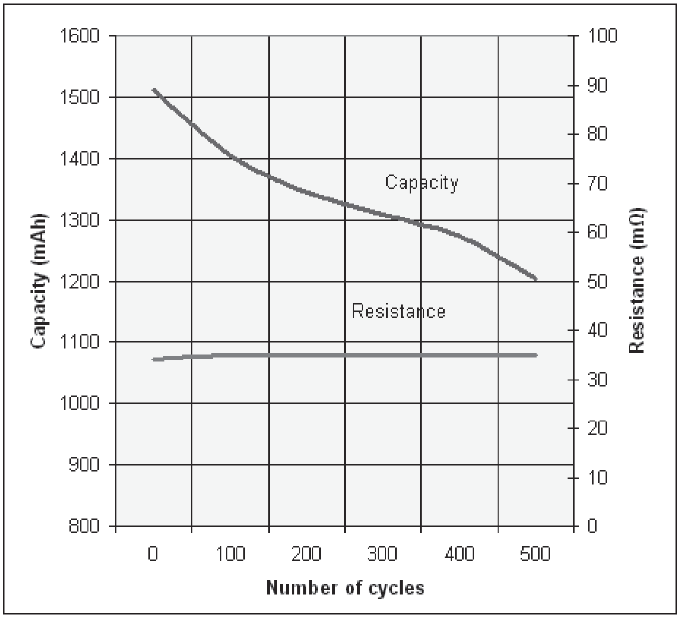

Figure 9-2: Relationship between capacity and resistance as part of cycling

Resistance does not reveal the state-of-health of a battery. The internal resistance often stays flat with use and aging.

Cycle test on Li-ion batteries at 1C:
Charge: 1,500mA to 4.2V, 25°C
Discharge: 1,500 to 2.75V, 25°C

Courtesy of Cadex

What Is Impedance?

Before exploring the different methods of measuring the internal resistance of a battery, let's examine what electrical resistance means, and let's differentiate between a pure *resistance* (R) and *impedance* (Z) that includes reactive elements such as coils and capacitors. Both values are given in Ohms (Ω), a measure formulated by the German physicist Georg Simon Ohm, who lived from 1798 to 1854. (One Ohm produces a voltage drop of 1V with a current flow of 1A.) The difference between resistance and impedance lies in the *reactance.* Let me explain.

The electrical resistance of a pure load, such as a heating element, has no reactance. Voltage and current flow in unison and there is no advancing or trailing phase shift that would occur with a reactive load, such as an electric motor or a florescent light fixture. The ohmic resistance on a pure resistive load is the same with direct current (DC) as is with alternating current (AC). The Power Factor (pf) is 1, which provides the most accurate metering of the power consumed.

Most electrical loads, as well as a battery as power source, have reactance. They consist of *capacitive* reactance (capacitor) and *inductive* reactance (coil). The resistor of a reactance varies with the frequency of the electrical power. The capacitive resistance decreases with higher frequency while the inductive resistance increases. (To explain resistance change with frequency, we compare an oil damper that has a stiffer resistance when moved fast. See also Chapter 1, "Watts and Volt-amps (VA)," on page 32.) A battery has resistive, capacitive and inductive resistance, and the term *impedance* includes all three in one.

Impedance can best be illustrated with the Randles model. Figure 9-3 illustrates the basic model of a lead acid battery, which reflects resistors and a capacitor (R1, R2 and C). The inductive reactance is commonly omitted because it plays a negligible role in a battery, especially at a low frequency.

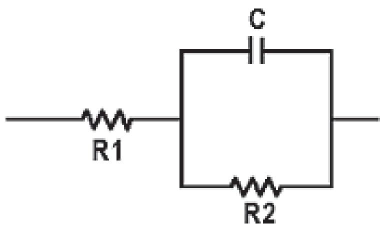

Figure 9-3: Randles model of a lead acid battery

The overall battery resistance consists of ohmic resistance, as well as inductive and capacitive reactance. The schematic and electrical values differ for every battery.

Now that we have learned the basics of internal battery resistance and how they can be applied to rapid-test batteries at different frequencies, this section examines current and future battery test methods. It also discusses advantages and shortfalls.

DC Load Method

Ohmic measurement is one of the oldest and most reliable test methods. The battery receives a brief discharge lasting a few seconds. A small pack gets an ampere or less and a starter battery is loaded with 50A and more. A voltmeter measures the voltage drop and Ohm's law calculates the resistance value (voltage divided by current equals resistance).

DC load measurements work well to check large stationary batteries, and the ohmic readings are very accurate and repeatable. Manufacturers of test instruments claim resistance readings in the 10 micro-ohm range. Many garages use the carbon pile to measure starter batteries, and with experience mechanics familiar with this loading device get a reasonably good assessment of the battery. The invasive test is in many ways more reliable than non-invasive methods.

The DC load method has a limitation in that it blends R1 and R2 of the Randles model into one combined resistor and ignores the capacitor (see Figure 9-4). "C" is an important component of a battery that represents 1.5 farads per 100Ah capacity. In essence, the DC method sees the battery as a resistor and can only provide ohmic references.

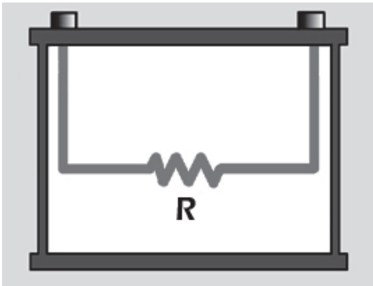

Figure 9-4: DC load method

The true integrity of the Randles model cannot be seen. R1 and R2 appear as one ohmic value.

Courtesy of Cadex

The *two-tier DC load* method offers an alternative method by applying two sequential discharge loads of different currents and time durations. The battery first discharges at a low current for 10 seconds, followed by a higher current for three seconds (see Figure 9-5), and Ohm's law calculates the resistance values. Evaluating the voltage signature under the two load conditions offers additional information about the battery, but the values are strictly resistive and do not reveal SoC and capacity estimations.

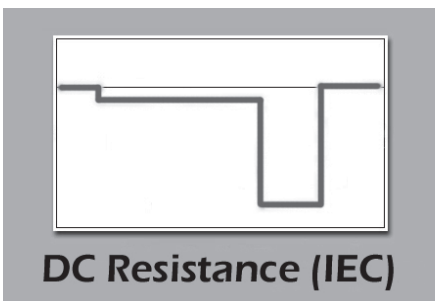

Figure 9-5: Two-tier DC load

The two-tier DC load follows the IEC 60285 and IEC 61436 standards and provides lifelike test conditions for many battery applications. The load test is the preferred method for batteries powering DC loads.

Courtesy of Cadex

AC Conductance

The AC conductance method replaces the DC load and injects an alternating current into the battery. At a set frequency of between 80 and 90 hertz, the capacitive and inductive reactance converge, resulting in a negligible voltage lag that minimizes the reactance. Manufacturers of AC conductance equipment claim battery resistance readings in the 50 micro-ohm range, and these instruments are commonly used in North American car garages. The single-frequency technology as illustrated in Figure 9-6 sees the components of the Randles model as one complex impedance called the *modulus of Z.*

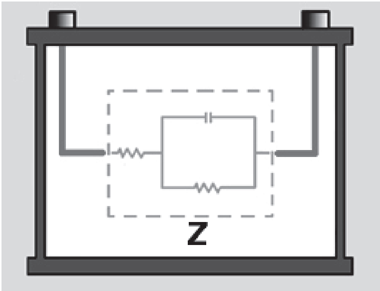

Figure 9-6: AC conductance method

The individual components of the Randles model are molten together and cannot be distinguished.

Courtesy of Cadex

Smaller batteries often use the popular 1000-hertz (Hz) ohm test method. A 1000Hz signal excites the battery, and the Ohm's law calculates the resistance. It is important to note that the AC method shows different values to the DC load, and both are correct. For example, Li-ion in an 18650 cell produces about 36mOhm with a 1000Hz AC signal and roughly 110mOhm with a DC load. Since both readings are correct, and yet are so far apart, the user needs to consider the application. The pulse DC load method provides the best indication for a DC application such as driving a motor or powering a light, while the 1000Hz method better reflects the performance of a digital load, such as a cellular phone that relies to a large extent on the capacitor characteristics of a battery. Figure 9-7 illustrates the 100Hz method.

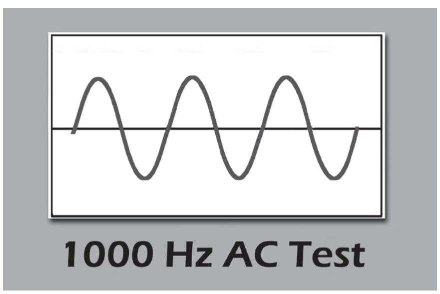

Figure 9-7: 1000-hertz method

The IEC 1000-hertz is the preferred method to take impedance snapshots of batteries powering digital devices.

Courtesy of Cadex

Electrochemical Impedance Spectroscopy

Electrochemical impedance spectroscopy (EIS) enables more than resistance readings; it can estimate state-of-charge and capacity. Research laboratories have been using EIS for many years to evaluate battery characteristics, but high equipment cost, slow test times and the need for trained professionals to decipher large volumes of data have limited this technology to laboratory environments. EIS is able to read each component of the Randles model individually; however, analyzing the value at different frequencies and correlating the data is an enormous task. Fuzzy logic and advanced digital signal processor (DSP) technology have simplified this task. Figure 9-8 illustrates the battery component, which EIS technology is capable of reading.

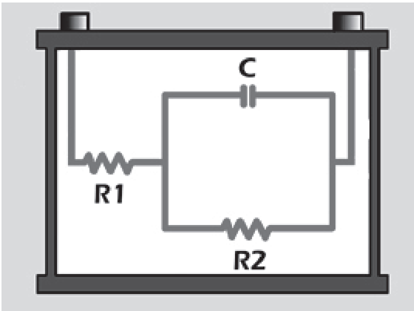

Figure 9-8: Spectro™ method

R1, R2 and C are measured separately, which enables state-of-charge and capacity measurements.

Courtesy of Cadex

How to Measure State-of-charge

Voltage Method

Measuring state-of-charge by voltage is the simplest method, but it can be inaccurate. Cell types have dissimilar chemical compositions that deliver varied voltage profiles. Temperature also plays a role. Higher temperature lowers the open-circuit voltage, a lower temperature raises it, and this phenomenon applies to all chemistries in varying degrees.

The most blatant error of voltage-based SoC occurs when disturbing the battery with a charge or discharge. This agitation distorts the voltage and no longer represents the true state-of-charge. To get accurate measurements, the battery needs to rest for at least four hours to attain equilibrium; battery manufacturers recommend 24 hours. Adding the element of time to neutralize voltage polarization does not sit well with batteries in active duty. One can see that this method is ill suited for fuel gauging.

Each battery chemistry delivers a unique discharge signature that requires a tailored model. While voltage-based SoC works reasonably well for a lead acid battery that has rested, the flat discharge curve of nickel- and lithium-based batteries renders the voltage method impracticable. And yet, voltage is commonly used on consumer products. A "rested" Li-cobalt of 3.80V/cell in open circuit indicates a SoC of roughly 50 percent.

The discharge voltage curves of Li-manganese, Li-phosphate and NMC are very flat, as 80 percent of the charge is stored in a tight voltage window. This profile assists applications requiring a steady voltage but presents a challenge for designers relying on voltage to read SoC. The only practical use of the voltage method on these batteries is to indicate "low charge."

Lead acid has diverse plate compositions that must be considered when measuring SoC by voltage. Calcium, an additive that makes the battery maintenance-free, raises the voltage by 5–8 percent. Temperature also affects the open-circuit voltage; heat lowers it while cold causes it to rise. Surface charge further fools SoC estimations by showing an elevated voltage immediately after charge; a brief discharge before measurement counteracts the error. Finally, AGM batteries produce a slightly higher voltage than the flooded equivalent.

When measuring SoC by voltage, the battery voltage must be truly "floating," with no load attached. If the battery is installed in a car, any parasitic load can quickly falsify the readings. In spite of the notorious inaccuracies, most SoC measurements rely on the open circuit voltage (OCV) because it's simple, whereas alternative methods are too expensive and need calibration. Voltage-based state-of-charge is popular for wheelchairs, scooters and golf cars.

Hydrometer

The hydrometer offers an alternative to measuring SoC, but this only applies to flooded lead acid and flooded nickel-cadmium. Here is how it works: As the battery accepts charge, the sulfuric acid gets heavier, causing the specific gravity (SG) to increase. As the SoC decreases through discharge, the sulfuric acid removes itself from the electrolyte and binds to the plate, forming lead sulfate. The density of the electrolyte becomes lighter and more water-like, and the specific gravity gets lower. Table 9-9 provides the BCI readings of starter batteries.

Approximate state-of-charge	Average specific gravity	Open circuit voltage 2V	6V	8V	12V
100%	1.265	2.10	6.32	8.43	12.65
75%	1.225	2.08	6.22	8. 30	12.45
50%	1.190	2.04	6.12	8.16	12.24
25%	1.155	2.01	6.03	8.04	12.06
0%	1.120	1.98	5.95	7.72	11.89

Table 9-9: BCI standard for SoC estimation of a maintenance-free starter battery with antimony. The readings are taken at room temperature of 26°C (78°F); the battery had rested for 24 hours after charge or discharge.

While BCI specifies the specific gravity of a fully charged starter battery at 1.265, battery manufacturers may go for 1.280 and higher. When increasing the specific gravity, the SoC readings on the look-up table will adjust upwards accordingly. Besides charge level and acid density, the SG can also vary due to low fluid levels, which raises the SG reading because of higher concentration. Alternatively, the battery can be overfilled, which lowers the number. When adding water, allow time for mixing before taking the SG measurement.

The specific gravity also varies according to battery type. Deep-cycle batteries use a dense electrolyte with an SG of up to 1.330 to get maximum runtime; aviation batteries have a SG of 1.285; traction batteries for forklifts are at 1.280; starter batteries come in at 1.265 and stationary batteries are at a low 1.225. Low specific gravity reduces corrosion. The resulting lower specific energy of stationary batteries is not as critical as longevity.

Nothing in the battery world is absolute. The specific gravity of fully charged deep-cycle batteries of the same model can range from 1.270 to 1.305; fully discharged, these batteries may vary between 1.097 and 1.201. Temperature is another variable that alters the specific gravity reading. The colder the temperature is, the higher (more dense) the SG value becomes. Table 9-10 illustrates the SG gravity of a deep-cycle battery at various temperatures.

Temperature of the Electrolyte		Gravity at full charge
40°C	104°F	1.266
30°C	86°F	1.273
20°C	68°F	1.280
10°C	50°F	1.287
0°C	32°F	1.294

Table 9-10: Relation of specific gravity and temperature of deep-cycle battery

Colder temperatures provide higher specific gravity readings.

Errors can also occur if the acid has stratified, meaning the concentration is light on top and heavy on the bottom (Figure 8-15 on page 187). High acid concentration artificially raises the open circuit voltage, which can fool SoC estimations through false SG and voltage indication. The electrolyte needs to stabilize after charge and discharge before taking the SG reading.

Coulomb Counting

Laptops, medical equipment and other professional portable devices use coulomb counting as a SoC indication. This method works on the principle of measuring the current that flows in and out of the battery. If, for example, a battery was charged for one hour at one ampere, the same energy should be available on discharge. This is not the case. Inefficiencies in charge acceptance, especially towards the end of charge, as well as losses during discharge and storage reduce the total energy delivered and skew the readings. The available energy is always less than what had been fed to the battery, and compensation corrects the shortage.

Disregarding these irregularities, coulomb counting works reasonably well, especially for Li-ion. However, the one percent accuracy some device manufacturers advertise is only possible in an ideal world and with a new battery. Independent tests show errors of up to 10 percent when in typical use. Aging causes a gradual deviation from the working model on which the coulomb counter is based. The result is a laptop promising 30 minutes of remaining runtime and all of a sudden the screen goes dark. Periodic calibration by applying a full discharge and charge to reset the flags reduces the error. (See Chapter 6, “Calibration,” on page 148.)

There is a move towards electrochemical impedance spectroscopy (page 214), and even magnetism (page 219) to measure state-of-charge. These new technologies get more accurate estimation than with voltage and can be used when the battery is under load. Furthermore, temperature, surface charge and acid stratification do not affect the readings noticeably.

Impedance Spectroscopy

Impedance spectroscopy evaluates the battery on the impedance values of the Randles model and works on flooded and sealed lead acid. The battery does not need to rest before taking the reading and parasitic loads do not affect the outcome. Figure 9-11 illustrates an incorrect SoC reading because of voltage drop when a load is applied; Figure 9-12 shows the correct result under the same conditions with impedance spectroscopy.

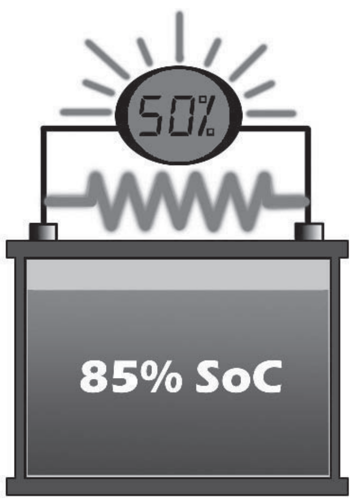

Figure 9-11: BCI*-based SoC reading. A parasitic load distorts voltage-based SoC readings. Voltage recovery takes 4–8 hours.

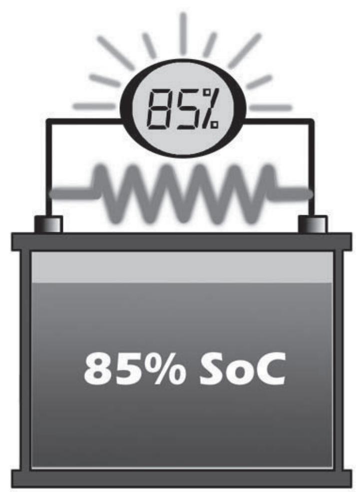

Figure 9-12: SoC based on impedance spectroscopy. A parasitic load does not affect the SoC reading.

* BCI (Battery Council International) measures state-of-charge by open circuit voltage. The voltage methods works well if the battery has no load and has rested after charge or discharge.

Courtesy of Cadex

Quantum Magnetism

In pursuit of a better way to measure battery state-of-charge, researchers are exploring radically new methods, one of which is *quantum magnetism* (Q-Mag™). Q-Mag by Cadex reads magnetism through spin-dependent tunneling. Here is how it works.

When discharging a lead acid battery, the negative plate changes from lead to lead sulfate, which has a different magnetic susceptibility to lead. Measuring the resulting change of the magnetic field with a sensor responding to magnetism provides linear SoC information. The magnetic change also works with lithium-ion, and the feedback is more pronounced than with lead acid. Figure 9-13 shows the concept on a starter battery.

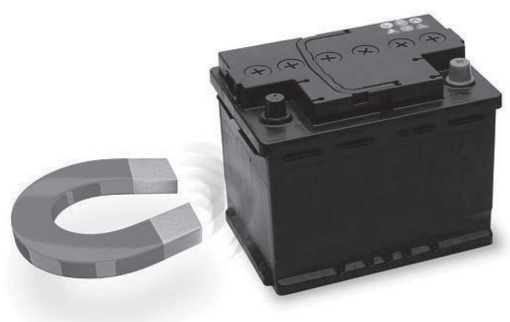

Figure 9-13: State-of-charge measurement by quantum magnetism

Lead fights the applied magnetism less than lead sulfite, allowing SoC measurement by magnetism. Li-ion also responds well to magnetic SoC measurement.

Courtesy of Cadex

The sensor consists of two metal alloys separated by a thin insulator in the nanometer range (thickness of few atoms). The electrons in a magnetic field tunnel through the insulator more easily than in a neutral state, leading to a resistive change. Q-Mag™ interprets state-of-charge using mathematical models. The error is +/–7 percent over the entire SoC range, an accuracy that is unthinkable with voltage measurement, hydrometer and coulomb counters.

All batteries behave in a similar way in that the composition of the electrodes changes, which affects the magnetic characteristics. Q-Mag works on new as well as aged batteries and the technology is immune to voltage distortion caused by loading, charging or surface charge on lead acid. Figure 9-14 shows how magnetic measurements can track discharge/ charge activities of a lead acid battery independent of voltage. The circles represent the voltage under charge and the triangles reveal the state-of-charge.

Measuring the intrinsic state of a battery rather than relying on voltage enables more precise full-charge detection. This feature can be used to improve charge methods and diagnose battery deficiencies, including predicting end-of-life by measuring battery capacity. Q-Mag works also with lithium-ion in non-ferric enclosures. Many of these technologies are proprietary and are in various experimental stages at Cadex.

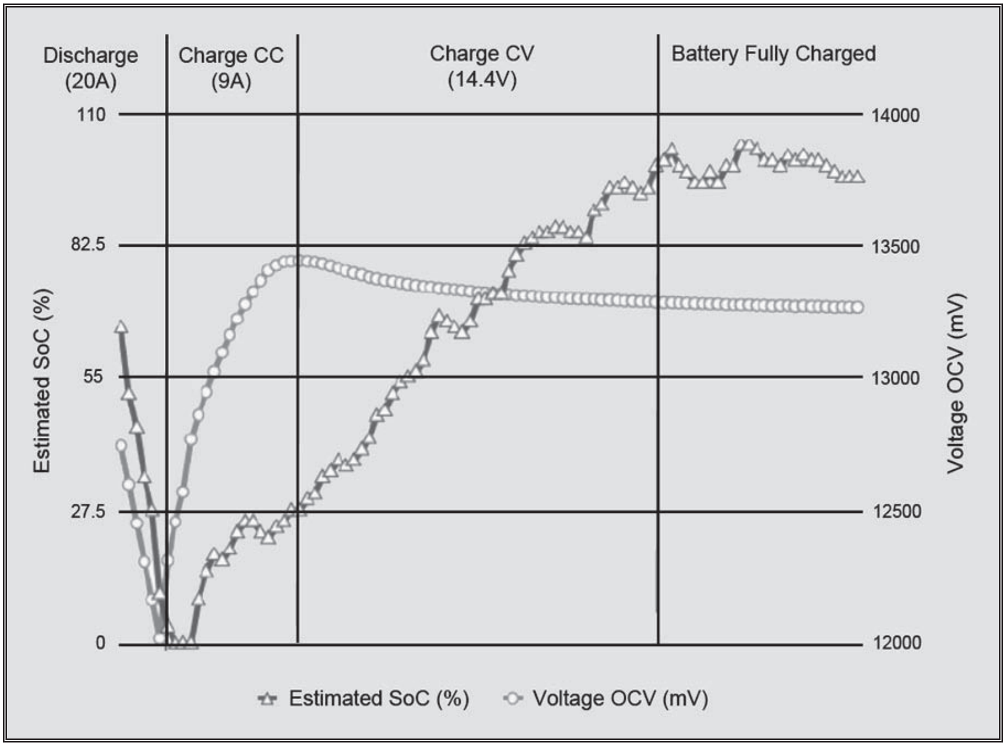

Figure 9-14: Discharge/charge profile of a starter battery
Magnetism traces SoC from 0 to 100% against voltage.

Test method: The battery was first discharged at 20A, followed by a constant charge of 9A to 14.4V and subsequent float charge. (October 2009)

Laboratories of Cadex

How to Measure Capacity

The traditional charge/discharge/charge cycle still offers a dependable way to measure battery capacity. Alternate methods have been tried but none deliver reliable readings. Inaccuracies have led users to adhere to the proven discharge methods even if the process is time-consuming and removes the battery from service for the duration of the test.

While portable batteries can be discharged and recharged relatively quickly, a full discharge and recharge on large lead acid batteries gets quite involved, and service personnel continue to seek faster methods even if the readings are less accurate. This section explains what's available in new technologies, but first we look at the discharge method more closely.

Discharge Method

One would assume that capacity measurement with discharge is accurate but this is not always the case, especially with lead acid batteries. In fact, there are large variations between identical tests, even when using highly accurate equipment and following established charge and discharge standards, with temperature control and mandated rest periods. This behavior is not fully understood except to consider that batteries exhibit human-like qualities. Our IQ levels also vary depending on the time of day and other conditions. Nickel- and lithium-based chemistries provide more consistent results than lead acid on discharge/charge tests.

To verify the capacity on repeat tests, Cadex checked 91 starter batteries with diverse performance levels and plotted the results in Figure 9-15. The horizontal x-axis shows the batteries from weak to strong, and the vertical y-axis reflects capacity. The batteries were prepared in the Cadex laboratories according to SAE J537 standards by giving them a full charge and a 24-hour rest. The capacity was then measured by applying a regulated 25A discharge to 10.50V (1.75V/cell) and the results plotted in diamonds (Test 1). The test was repeated under identical conditions and the resulting capacities added in squares (Test 2). The second reading exhibits differences in capacity of +/–15 percent across the battery population. Other laboratories that test lead acid batteries experience similar discrepancies.

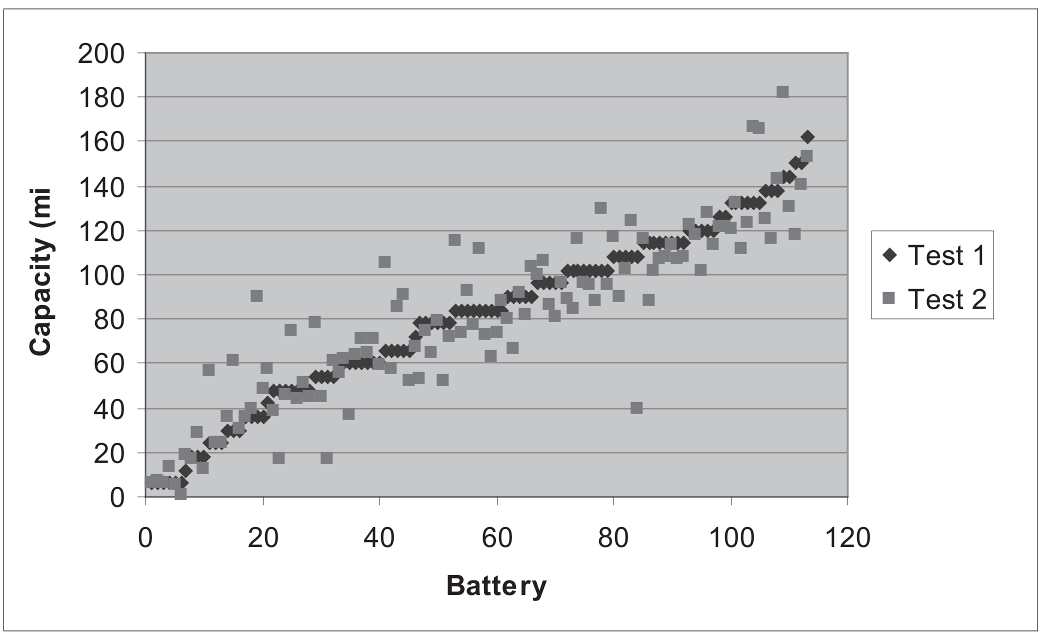

Figure 9-15: Capacity fluctuations on two identical charge/discharge tests of 91 starter batteries. The capacities differ +/–15% between Test 1 and Test 2.

Courtesy of Cadex (2005)

Capacity vs. CCA

Starter batteries have two distinct values, *CCA* and *capacity.* These two readings are close to each other like lips and teeth, but the characteristics are uniquely different; one cannot predict the other. (See Chapter 8, "How Age Affects Capacity and Resistance," on page 188.)

Measuring the internal battery resistance, which relates to CCA on a starter battery, is relatively simple but the reading provides only a snapshot of the battery at time of measurement. Resistance alone cannot predict the end of life of a battery. For example, at a CCA of 560A and a capacity of 25 percent, for example, a starter battery will still crank well but it can surprise the motorist with a sudden failure of not turning the engine (as I have experienced).

The leading health indicator of a battery is *capacity,* but this estimation is difficult to read. A capacity test by discharge is not practical with starter batteries; this would cause undue stress and take a day to complete. Most battery testers do not measure capacity but look at the internal resistance, which is an approximation of CCA. The term *approximation* is correct — laboratory tests at Cadex and at a German luxury car manufacturer reveal that the readings are only about 70 percent accurate. A full CCA test is seldom done; one battery can take a week to measure.

The SAE J537 CCA test by BCI mandates to cool a fully charged battery to -18°C (0°F) for 24 hours, and while at subfreezing temperature apply a high-current discharge that simulates the cranking of an engine. A 500 CCA battery would need to supply 500A for 30 seconds and stay above 7.2V (1.2V/cell) to pass. If it fails the test, the battery has a CCA rating of less than 500A. To find the CCA rating, the test must be repeated several times with different current settings to find the triggering point when the battery passes through 7.2V line. Between each test, the battery must be brought to ambient temperature for recharging and cooled again for testing. (For CCA with DIN and IEC norms, refer to "Test Method" on page 223)

To examine the relationship between CCA and capacity, Cadex measured CCA and capacity of 175 starter batteries at various performance levels. Figure 9-16 shows the CCA on the vertical y-axis and reserve capacity* readings on the horizontal x-axis. The batteries are arranged from low to high, and the values are given as a percentage of the original ratings.

The table shows noticeable discrepancies between CCA and capacity, and there is little correlation between these readings. Rather than converging along the diagonal reference line, CCA and RC wander off in both directions and resemble the stars in a clear sky. A closer look reveals that CCA gravitates above the reference line, leaving the lower right vacant. High CCA with low capacity is common, however, low CCA with high capacity is rare. In our table, one battery has 90 percent CCA and produces a low 38 percent capacity; another delivers 71 percent CCA and delivers a whopping 112 percent capacity (these are indicated by the dotted lines).

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* North America marks the reserve capacity (RC) of starter batteries in minutes; RC applies a 25A discharge to 1.75V/cell and measures the elapsed time in minutes. Europe and other parts of the world use ampere-hours (Ah). The RC-to-Ah conversion formula is as follows: RC divided by 2 plus 16.

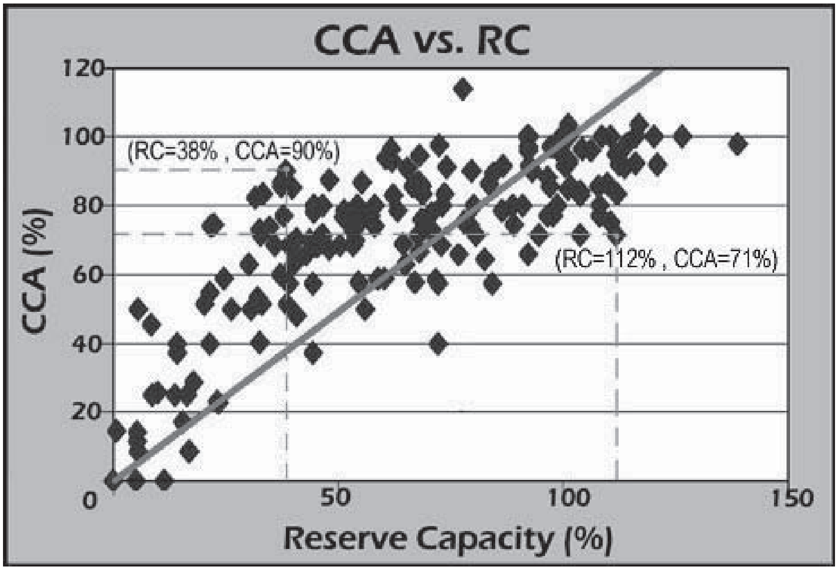

Figure 9-16: CCA and reserve capacity (RC) of 175 aging starter batteries

The CCA of aging starter batteries gravitates above the diagonal reference line. (Few batteries have low CCA and high capacity.)

Courtesy of Cadex

Test method: The CCA and RC readings were obtained according to SAE J537 standards (BCI). CCA (BCI) loads a fully charged battery at –18°C (0°F) for 30s at the CCA-rated current of the battery. The voltage must stay above 7.2V to pass. CCA DIN and IEC norms are similar with these differences: DIN discharges for 30s to 9V, and 150s to 6V; IEC discharges for 60s to 8.4V. RC applies a 25A discharge to 1.75V/cell and measures the elapsed time in minutes.

As discussed earlier, a battery check must include several test points. An analogy can be made with a medical doctor who examines a patient with several instruments to find the diagnosis. A serious illness could escape the doctor's watchful eyes if only blood pressure or temperature was taken. While medical staff are well trained to evaluate multiple data points, most battery personnel do not have the knowledge to read a Nyquist plot and other data on a battery scan. Nor are test devices available that give reliable diagnosis of all battery ills.

Testing Lead Acid

Many manufacturers of battery testers claim to measure battery health on the fly. These instruments work well in finding battery defects that involve voltage anomalies and elevated internal resistance, but other performance criteria remain unknown. Stating that a battery tester based on internal resistance can also measure capacity is misleading. Advertising features that are outside the equipment's capabilities confuses the industry into believing that multifaceted results are attainable with basic methods. Manufacturers of these instruments are aware of the complexity involved, but some like to add a flair of mystery in their marketing scheme, similar to a maker of a shampoo product promising to grow lush hair on a man's bald head. Here is a brief history of battery testers for lead acid and what they can do.

The *carbon pile,* introduced in the 1980s, applies a DC load of short duration to a starter battery, simulating cranking. The voltage drop and recovery time provide a rough indication of battery health. The test works reasonably well and offers evidence that power is present. A major advantage is the ability to detect batteries that have failed due to a shorted cell (low specific gravity in one cell due to high self-discharge). Capacity estimation, however, is not possible, and a battery that simply has a low state-of-charge appears as *weak.* In addition, the tester must rely on voltage to estimate state-of-charge. A skilled mechanic can, however, detect a faulty battery based on the voltage signature and loading behavior.

The *AC conductance* meters appeared in 1992 and were hailed as a breakthrough. The non-invasive method injects an AC signal into the battery to measure the internal resistance. Today, these testers are commonly used to check the CCA of starter batteries and verify resistance change in stationary batteries. While small and easier to use, AC conductance cannot read capacity, and the resistive value gives only an approximation of the real CCA of a starter battery. A shorted cell could pass as good because in such a battery the overall conductivity and terminal voltage are close to normal, even though the battery cannot crank the motor. AC conductance testers are common in North America; Europe prefers the DC load method.

Critical progress has been made towards *electrochemical impedance spectroscopy* (EIS). Cadex took the EIS technology a step further and developed battery specific models that are able to estimate the health of a lead acid battery. *Multi-model electrochemical impedance spectroscopy,* or Spectro™ for short, reads battery capacity, CCA and state-of-charge in a single, non-invasive test. Figure 9-17 illustrates the Spectro CA-12 handheld battery tester.

Figure 9-17: Spectro CA-12 battery tester

Compact battery rapid tester displays capacity, CCA and state-of-charge in 15 seconds.

Courtesy Cadex

The Spectro CA-12 handheld device, in which the Spectro™ technology is embedded, excites the battery with signals from 20–2000Hz. A DSP deciphers the 40 million transactions churned out during the 15-second test into readable results. To check a battery, the user simply selects the battery voltage, Ah and designated matrix. Tests can be done under a steady load of up to 30A and a partial charge, however, if the state-of-charge is less than 40 percent, the instrument advises the user to charge and retest.

The Spectro method is a further development of EIS, a technology that had been around for several decades. What's new is the use of multi models and faster process times. Cost and size have also shrunk. Earlier models cost tens of thousands of dollars and traveled on wheels. The heart of Spectro is not so much the mechanics but the algorithm. No longer do modern EIS devices accompany a team of scientist to decipher tons of data. Experts predict that the battery industry is moving towards the multi-model EIS technology to estimate batter performance

Nowhere is the ability to read capacity more meaningful than with deep-cycle batteries in golf cars, aerial work platforms and wheelchairs, as well as military and naval carriers. Getting a readout in seconds without putting the vehicles out of commission allows for a quick performance check on a suspect battery before deployment in the field. Figures 9-18, 9-19 and 9-20 show typical battery problems and how modern test technologies can detect them.

Figure 9-18: Low charge

Drive is sluggish; Spectro™ reads low SoC. Capacity estimation is correct in spite of low charge.

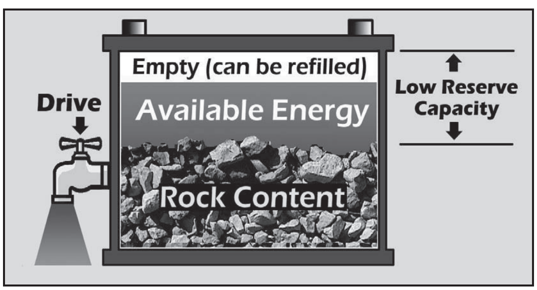

Figure 9-19: Low capacity

Battery has good drive but short runtimes. Spectro™ reads good impedance but low capacity.

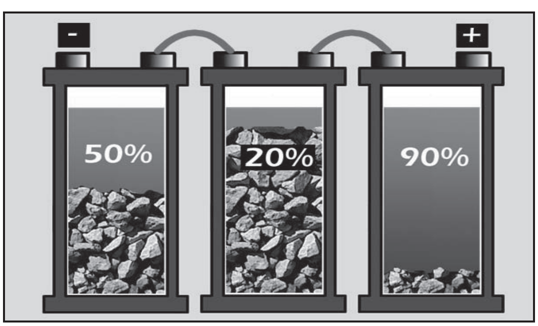

Figure 9-20: Faulty set

Spectro™ finds low performing and shorted blocks in a string. Good batteries can be regrouped and reused.

All figures Courtesy of Cadex

Matrices
Measurement devices, such as the Spectro CA-12, are not universal instruments capable of estimating the capacity of any battery that may come along; they require battery specific matrices, also known as pattern recognition algorithm. A matrix is a multi dimensional lookup table against which the measured readings are compared. Text recognition, fingerprint identification and visual imaging operate on a similar principle in that a model exists, with which to equate the derived readings.

This book identifies three commonly used measuring methods. The principle in all is to take one or several sets of readings and compare them against known reference settings or images to disclose the characteristics of a battery. The three methods are as follows.

Scalar: The *single value scalar test* takes a reading and compares the result with a stored reference value. In battery testing this could be measuring a voltage, interrogating the battery by applying discharge pulses or injecting a frequency and then comparing the derived result against a single reference point. This is the simplest test, and most DC load and single-frequency AC conductance testers use this method.

Vector: The *vector method* applies pulses of different currents, or excites the battery with several frequencies, and evaluates the results against preset vector points to study the battery under various stress conditions. Typical applications for this one-dimensional scalar model are battery testers that apply multi-tier DC loads or inject several test frequencies. Because of added complexity in evaluating the different data points and limited benefits, the vector method is seldom used.

Matrix: The *matrix method*, which was introduced on page 224, scans a battery with a frequency spectrum as if to capture the image of a landscape and compare the imprint with a stored model of known characteristics. This multi-dimensional set of scalars, which form the foundation of Spectro™, provides the most in-depth information but is complex in terms of evaluating the data generated. With a proprietary algorithm, the Spectro™ technology is able to estimate battery capacity, CCA and SoC.

Matrices are primarily used to estimate battery capacity, however, CCA and state-of-charge also require matrices. These are easier to assemble and serve a broad range of starter batteries. While the Spectro™ method offers an accuracy of 80 to 90 percent on capacity, CCA is 95 percent exact. This compares to 60 to 70 percent with battery testers using the scalar method. Service personnel are often unaware of the low accuracy; verifications are seldom done, as this would involve several days of laboratory testing.

A further drawback of scalar battery testers is obtaining a reading that is neither resistance nor CCA. While there are similarities between the two, no standard exists and each instrument gives different values. In terms of assessing a dying battery, however, this method is adequate as it reflects conductivity. The larger disadvantage is not being able to read capacity. Table 9-21 illustrates test accuracies using scalar, vector and matrix methods.

Measuring units	Scalar Single value	Vector One-dimensional set of scalars	Matrix Multi-dimensional set of scalars
CCA	60–70% accurate		90–95% accurate
Capacity	N/A		80–90% accurate
SoC	Voltage-based; requires rest after charge and discharge		90–95% accurate (with new battery)

Table 9-21: Accuracy in battery readings with different measuring methods
Scalar and vector provide resistance with references to CCA on starter batteries. The matrix method is more accurate and provides capacity estimations but needs reference matrices.

To generate a matrix, batteries with different state-of-health are scanned. The more batteries of the same model but diverse capacity mix are included in the mix, the stronger the matrix will become. If, for example, the matrix consists only of two batteries, one showing a capacity of 60 percent and the other 100 percent, then the accuracy would be low for the batteries in between. Adding a third battery with an 80 percent capacity will solidify the matrix, similar to placing a pillar at the center of a bridge. To cover the full spectrum, a well-developed matrix should include battery samples capturing capacities of 50, 60, 70, 80, 90 and 100 percent. Batteries much below 50 percent are less important because they constitute a fail.

It is difficult to obtain aged batteries, especially with newer models. Forced aging by cycling in an environmental chamber is of some help; however, age-related stresses from the field are not represented accurately. It also helps to include batteries from different regions to represent unique environmental user patterns. A starter battery in a Las Vegas taxi has different strains than that of a car driven by a grandmother in northern Germany.

Different state-of-charge levels increase the complexity to estimate battery health. The SoC on a new battery can be determined relatively easily with impedance spectroscopy, however, the formula changes as the battery ages. A battery tester should therefore be capable of examining new and old batteries with a charge level of 40 to 100 percent. With ample data, this is possible because natural aging of a battery is predictable and the scanned information can be massaged to calculate age. This is similar to face recognition that correctly identifies a person even if he or she has developed a few wrinkles and has grown gray hair.

Simplifications in matrix development are possible by grouping batteries that share the same chemistry, voltage and a similar capacity range into a generic matrix. This simplifies logistics; however, the readout is classified into categories rather than numbers. Figure 9-22 illustrates the classification scheme of Good, Low and Poor. Good passes as a good battery; Low is suspect and predicts the end of life; and Poor is a fail that mandates replacement.

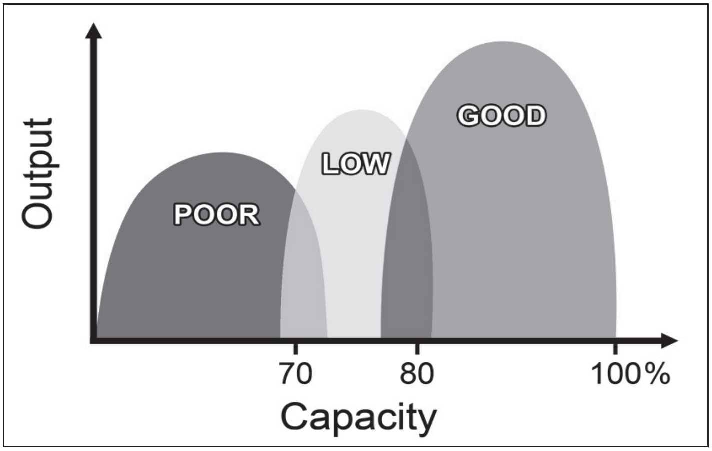

Figure 9-22: Classifying batteries into categories

The classification method provides an intelligent assessment of what constitutes a usable battery for a given application. Some classifications have pass/fail; others provide GOOD, LOW and POOR.

Courtesy of Cadex

Service personnel appreciate the classification method because it gives them an intelligent assessment of what constitutes a usable battery for a given application and eliminates customer interference. If numeric capacity readings are mandatory for a given battery type, a designated matrix can be developed and downloaded into the tester from the Internet.

Testing Nickel-based Batteries

Nickel-based batteries have unique properties, and Cadex developed a rapid-test method for these battery systems called *QuickTest*™. The process takes three minutes and uses an inference algorithm. Figure 9-23 illustrates the general structure of the algorithm applied.

QuickTest™ fuses data from six variables, which are capacity, internal resistance, self-discharge, charge acceptance, discharge capabilities and mobility of electrolyte. A trend-learning algorithm combines the data to provide a dependable state-of-health (SoH) reading in percentage. The system uses battery-specific matrices stored in battery adapters of a designated battery analyzer (Cadex). The user can create a matrix in the field by scanning two or more batteries on the analyzer's *Learn* program. The battery must be at least 20 percent charged.

Among other parameters, QuickTest™ relies on the internal resistance of a battery pack, and the welding joints between the cells might cause a problem, especially on packs with 10 cells or more. Although seemingly insignificant in terms of added resistance, mechanical linkages behave differently to a chemical cell and this causes an unwanted error. The linkage error is not seen on a conventional discharge test or when doing a resistance check but interferes with rapid-test methods on voltages above 20V. It is also possible that each cell of a multi-cell pack behaves on its own when excited with a common signal and the result gets muddled.

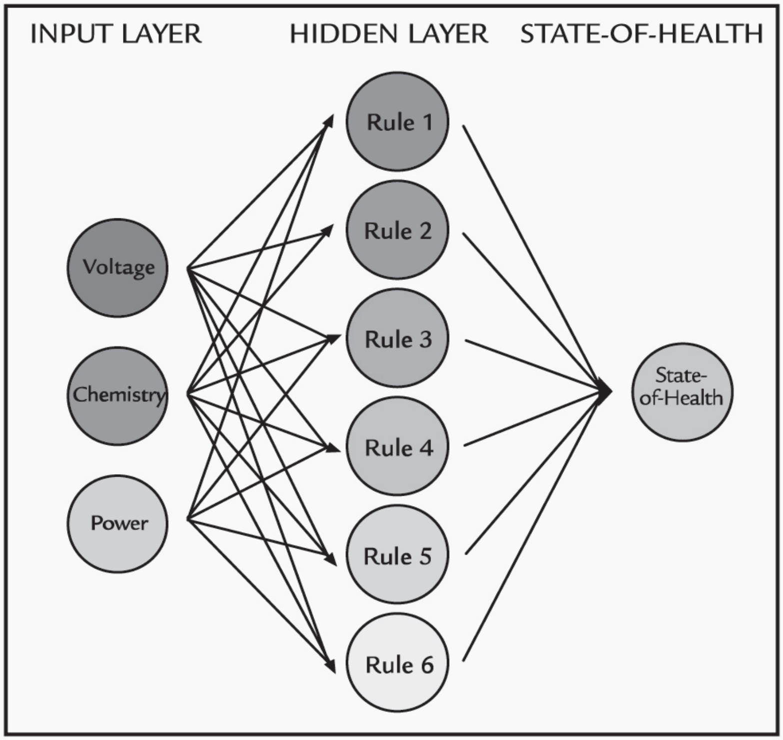

Figure 9-23: QuickTest™ structure

Multiple variables are fed to the micro controller, "'fuzzified" and processed by parallel logic. The data is averaged and weighted according to battery application.

Courtesy of Cadex

Testing Lithium-based Batteries

With the large number of lithium-ion batteries in use and the population growing rapidly, developing an effective testing method has become an urgent task. *QuickSort*™ (Cadex) is a further development of QuickTest™ using a generic matrix. The simplification was made possible by limiting the battery population to single-cell Li-ion from 500 to 1,500mAh. (Larger cells and higher voltages will need a different generic matrix.) Rather than capacity readout in percentage, QuickSort™ classifies the battery health as Good, Low or Poor.

Electrochemical dynamic response, the method used for QuickSort™, measures the mobility of ion flow between the electrodes on a digital load. The response can be compared with a mechanical arm under load. A strong arm resembling a good battery remains firm, and a weak arm synonymous to a faded battery bends and becomes sluggish under load.

The test takes 30 seconds, is 90 percent accurate regardless of battery cathode material and can be performed with a state-of-charge range of between 40 and 100 percent. QuickSort™ requires the correct mAh, and setting a wrong value does not shift the reading on a linear scale from good to poor, as one would expect, but makes the sorting less accurate. The system does not rely on internal resistance per se. This would produce unreliable readings because modern lithium-ion maintains low resistance with use and time (see Figure 9-2 on page 211). An overall resistance check is only done at the conclusion of the test. Figure 9-24 shows the concept.

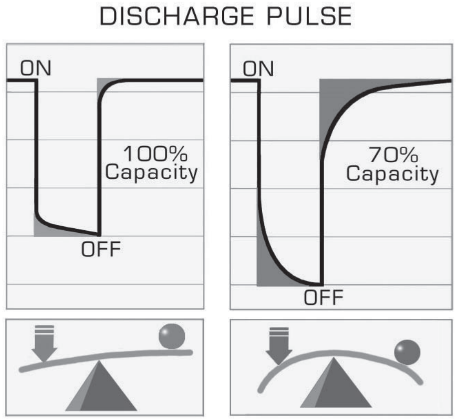

Figure 9-24:
Electrochemical dynamic response

The electrochemical dynamic response measures the ion flow between the positive and negative plates. This process can be compared to a mechanical arm under load.

Courtesy of Cadex

Lithium-ion batteries have different diffusion rates, and in terms of electrochemical dynamic response, Li-ion polymer with gelled electrolyte appears to be faster than Li-ion containing liquefied electrolyte. Li-polymer may need a different matrix to produce accurate readings.

Scientists explore new ways to evaluate the health of a battery with scanning frequencies ranging from several kilohertz to milihertz. High frequencies reveal the resistive qualities of a battery, which presents a bird-eye's view in landscape form. By lowering the frequency, diffusion begins to provide insight into unique battery characteristics that allow capacity estimation, sulfation detection and revealing of dry-out condition.

Evaluating batteries at sub one-hertz frequency needs long test times. At one milihertz, for example, a cycle takes 1,000 seconds and several data points are required to assess a battery with certainty. Low-frequency tests can take several minutes for one measurement, however, with clever software simulation, the duration can be shortened to just a few seconds.

Research engineers at Cadex are working on a technique called *Low Frequency Pulse Train* (LFPT), also known as *diffusion technology*. Diffusion works with most chemistries and the information retrieved provides vital information relating to battery capacity and underlying deficiencies. This knowledge enables the all-important *state-of-life estimation*, the ultimate goal for advanced battery management systems (BMS).

There is a critical need for practical battery testers that can examine the state-of-health of batteries in medical equipment, military instruments, computing devices, power tools and UPS systems. There are currently no instruments that can reliably predict battery state-of-life on the fly, although many device manufacturers may claim their instruments will do so.

How to Monitor a Battery

One of the most urgent requirements for battery-powered devices is the development of a reliable and economical way to monitor battery state-of-function (SoF). This is a demanding task when considering that there is still no dependable method to read state-of-charge, the most basic characteristic of a battery. Even if SoC were displayed accurately, charge information alone has limited benefits without knowing the capacity. The objective is to identify *battery readiness,* which describes what the battery can deliver at a given moment. SoF includes capacity (the amount of energy the battery can hold), internal resistance (the delivery of power), and state-of-charge (the amount of energy the battery holds at that moment).

Stationary batteries were among the first to include monitoring systems, and the most common form of supervision is voltage measurement of individual cells. Some systems also include cell temperature and current measurement. Knowing the voltage drop of each cell at a given load reveals cell resistance. Cell failure caused by rising resistance through plate separation, corrosion and other malfunctions can thus be identified. Battery monitoring also serves in medical, defense and communication devices, as well as wheeled mobility and electric vehicle applications.

In many ways, present battery monitoring falls short of meeting the basic requirements. Besides assuring *readiness*, battery monitoring should also keep track of aging and offer end-of-life predictions so that the user knows when to replace a fading battery. This is currently not being done in a satisfactory manner. Most monitoring systems are tailored for new batteries and adjust poorly to aging ones. As a result, battery management systems (BMS) tend to lose accuracy gradually until the information obtained gets so far off that it becomes a nuisance. This is not an oversight by the manufacturers; engineers know about this shortcoming. The problem lies in technology, or lack thereof.

Another limitation of current monitoring systems is the bandwidth in which battery conditions can be read. Most systems only reveal anomalies once the battery performance has dropped below 70 percent and the performance is being affected. Assessment in the | all-important 80–100 percent operating range is currently impossible, and systems give the batteries a good bill of health. This complicates end-of-life predictions, and the user needs to wait until the battery has sufficiently deteriorated to make an assessment. Measuring a battery once the performance has dropped or the battery has died is ineffective, and this complicates battery exchange systems proposed for the electric vehicle market. One maker of a battery tester proudly states in a brochure that their instrument "Detects any faulty battery." So, eventually, does the user.

Some medical devices use date stamp or cycle count to determine the end of service life of a battery. This does not work well either, because batteries that are used little are not exposed to the same stresses as those in daily operation. To reduce the risk of failure, authorities may mandate an earlier replacement of all batteries. This causes the replacement of many packs that are still in good working condition. Old habits are hard to break, and it is often easier to leave the procedure as written rather than to revolt. This satisfies the battery vendor but increases operating costs and creates environmental burdens.

Portable devices such as laptops use coulomb counting that keeps track of the in- and out flowing currents. Such a monitoring device should be flawless, but as mentioned earlier, the method is not ideal either. Internal losses and inaccuracies in capturing current flow add to an unwanted error that must be corrected with periodic calibrations.

Over-expectation with monitoring methods is common, and the user is stunned when suddenly stranded without battery power. Let's look at how current systems work and examine up-and-coming technologies that may change the way batteries are monitored.

Voltage-Current-Temperature Method

The Volkswagen Beetle in simpler days had minimal battery problems. The only management system was ensuring that the battery was being charged while driving. Onboard electronics for safety, convenience, comfort and pleasure have greatly added to the demands on the battery in modern cars since then. For the accessories to function reliably, the state-of-charge of the battery must be known at all times. This is especially critical with start-stop technologies, a mandated requirement on new European cars to improve fuel economy.

When the engine stops at a red light, the battery draws 25–50 amperes of current to feed the lights, ventilators, windshield wipers and other accessories. When the light changes, the battery must have enough charge to crank the engine, which requires an additional 350A. With the engine started again and accelerating to the posted speed limit, the battery begins charging after a 10-second delay.

Realizing the importance of battery monitoring, car manufacturers have added battery sensors that measure voltage, current and temperature. Packaged in a small housing that forms part of the positive clamp, the *electronic battery monitor* (EBM) provides useful information about the battery and provides an accuracy of about +/–15 percent when the battery is new. As the battery ages, the EBM begins drifting and the accuracy drops to 20-30 percent. The model used for monitoring the battery is simply not able to adjust. To solve this problem, EBM would need to know the state-of-health of the battery, and that includes the all-important capacity. No method exists today that is fully satisfactory, and some mechanics disconnect the battery management system to stop the false warning messages.

A typical start-stop vehicle goes through about 2,000 micro cycles per year. Test data obtained from automakers and the Cadex laboratories indicate that with normal usage in a start-stop configuration, the battery capacity drops to approximately 60 percent in two years. (See Figure 8-19 on page 191.) Field use reveals that the standard flooded lead acid lacks robustness, and carmakers are reverting to a modified version lead acid battery.

Automakers want to ensure that no driver gets stuck in traffic with a dead battery. To conserve energy, modern cars automatically turn off unnecessary accessories when the battery is low and the motor stays running at a stoplight. Even with this measure, state-of-charge can remain low if commuting in gridlock conditions because motor idling does not provide much charge to the battery, and with essential accessories like lights and windshield wipers on, the net effect could be a small discharge.

Battery monitoring is also important on hybrid vehicles to optimize charge levels. Intelligent charge management prevents stressful overcharge and avoids deep discharges. When the charge level is low, the internal combustion (IC) engine engages earlier than normal and is left running longer for additional charge. On a fully charged battery, the IC engine turns off and the car moves on the electrical motor in slow traffic.

Improved battery management is of special interest to the manufacturers of the electric vehicle. In terms of state-of-charge, a discerning driver expects similar accuracies in energy reserve as are possible with a fuel-powered vehicle, and current technologies do not yet allow this. Furthermore, the driver of an EV anticipates a fully charged battery will power the vehicle for the same distance as the car ages. This is not the case and the drivable distance will get shorter with each passing year. Distances will also be shorter when driving in cold temperatures because of reduced battery performance.

Magnetic Method

Under "How to Measure State-of-charge" in this chapter on page 219 we explored an improved way to measure state-of-charge by using magnetism. We now take this technology further and apply it to battery monitoring. Figure 9-25 illustrates the installation of the Q-Mag™ sensor on the side of a starter battery in close proximity to the negative plate. The technology works for lead- and lithium-based batteries.

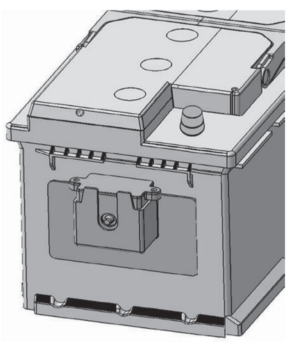

Figure 9-25:
Q-Mag™ sensor installed on the side of a starter battery

The sensor measures the SoC of a battery by magnetism. When discharging a lead acid battery, the negative plate changes from lead to lead sulfate. Lead sulfate has a different magnetic susceptibility to lead, which a magnetic sensor can measure.

Courtesy of Cadex (2009)

The potential of the Q-Mag™ technology is multifold, and this book addresses only the most basic functions. A key advantage is measuring SoC while the battery is being charged or is under load. In a charger, this allows optimal service under all conditions, including hot and cold temperature charging. Knowing the true SoC and tailoring the charge to best charge acceptance is of special interest to automotive and uninterruptible power supply (UPS) markets.

A Q-Mag-controlled charger can prolong the life of chronically undercharged lead acid batteries by applying maximum current when the opportunity arises without causing undue damage to the battery. Being relieved of voltage feedback, an intelligent charger based on Q-Mag™ can balance the state-of-charge of a fully charged battery by only replenishing the current that is lost through loading and self-discharge. Maintaining a "neutral" charge state saves energy and prolongs battery life by eliminating sulfation or overcharge.

As battery supervisor, Q-Mag™ can recognize sulfation and acid stratification on lead acid batteries. Coupled with an intelligent charger, the system can apply a corrective charge to fix the battery before the condition becomes irreversible. Furthermore, an imbalance between the terminal voltage and the Q-Mag-estimated SoC points to a battery with high self-discharge (partially shorted cell). Observing the SoC level during rest periods allows the assessment of self-discharge and the estimation of battery end of life.

The ability to measure SoC while a battery is on charge or on a load enables the estimation of battery capacity. Several proprietary techniques are possible, all of which offer a critical improvement to present systems. The voltage and impedance methods used today reveal only an anomaly when the battery is failing, and coulomb counters lose accuracy as the battery ages. One of the most critical measuring requirements of a battery test system is to know the usable capacity between 70 and 100 percent capacity.

Battery monitoring without touching the poles of the individual cells makes Q-Mag™ attractive for stationary batteries. The installation involves placing the sensors between the batteries and collecting SoC data, among other battery information, with the help of a controller on low voltage. It is conceivable that battery manufacturers in the future will include the sensors in the housing as part of production. Economical pricing at high volume and small size could make this feasible.

Q-Mag™ works across several battery chemistries, and the magnetic measuring technique may one day solve the critical need for improved battery monitoring in hybrid and electric vehicles. Research engineers at Cadex will also examine nickel-based batteries; however, the ferrous enclosure of the cylindrical cells may pose limitations. A solid aluminum enclosure on Li-phosphate does not inhibit the magnetic measurement, as the tests at Cadex are showing.

Q-Mag™ may one day also assist in the consumer market to test batteries by magnetism. Placing the battery on a test mat, similar to charging a battery, may one day be possible.

Battery Test Equipment

Conventional battery test methods measure the stored energy through a full discharge. This procedure is time-consuming and stresses the battery. There is a move towards methods that take only seconds instead of hours; however, rapid testing provides only estimated state-of-health values, and the accuracies vary according to the method used. Public safety, medical and defense organizations still depend on tests involving periodic full discharge/charge cycles.

Battery Analyzer

Battery analyzers became popular in the 1980s and 1990s to restore nickel-cadmium batteries affected by "memory," as well as to prolong battery life as part of maintenance. The Cadex C7000 Series serves the industry well and set new standards for what a battery analyzer could do. These workhorses accommodate lead-, nickel- and lithium-based batteries, and operate stand-alone or with a PC. Figure 9-26 illustrates a C7400 battery analyzer servicing a variety of batteries in configured adapters that set the analyzer to the correct setting. Each of the four independent stations allows unique service programs.

Figure 9:26:
Cadex C7400 battery analyzer

Two- and four-station analyzers service batteries from 1.2 to 15V, programmable up to 4A per station. The extended version goes to 36V and 6A charge and discharge currents. The service programs include QuickSort™ for rapid-test of Li-ion batteries.

Courtesy of Cadex

Connecting various shapes and forms of batteries has always been a challenge, and technicians have invented unique contraptions with springs and levers so complicated that only the inventor dares to touch. There is no simple way to connect batteries, especially when dealing with small packs that have tiny surface contacts.

Cadex solved the battery interface challenge with *custom adapters* for common batteries and *universal adapters* for specialty packs. The custom adapters are easiest to use; they are specially designed and the batteries go in only one way. The adapters are smart and are able to hold configuration codes for up to 10 different battery types. This allows the servicing of batteries with identical footprints but different electrical values. The user can edit the parameters with the menu function on the analyzer or with the PC.

The universal adapters consist of user-programmable *Smart Cables* that accommodate virtually any battery type. With the proliferation of cellular batteries and the need for a quick and simple battery interchange, Cadex developed the *RigidArm*™ (Figure 9-27). This adapter features spring-loaded arms that meet the battery contacts from the top down and apply correct pressure to the contacts. Lockable mechanisms allow quick and repetitive testing of same-type batteries. The retractable floor holds the battery in a vertical position, and magnetic guides keep the battery in place if laid horizontally. For added safety, a temperature sensor monitors the battery during the test.

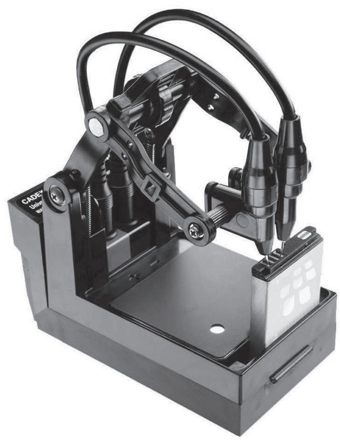

Figure 9-27:
RigidArm™ for cellular batteries

The universal adapter simplifies the interface with small batteries. The adapter holds 10 of the most commonly used mAh ratings and is compatible with Cadex battery analyzers.

Courtesy of Cadex

Servicing Cellular Batteries

Advancements made in battery test equipment make it feasible to service the over four billion cellular batteries in global use at storefronts while the customer waits. Hooking up the battery still needs some skill, and once the contacts are established the service technician may need to enter the capacity in mAh and other battery specifications.

Most cellular batteries have three or four contacts. The positive [+] terminal is normally at the outer edge and the negative [–] one is positioned towards the inside. The third contact is the thermistor measuring the battery temperature, and unless the battery adapter is specially made for the battery type, the thermistor is normally not hooked up for the test; a universal adapter often has its own temperature protection. The fourth contact, if available, may offer code identification for configuration. Figure 9-28 illustrates a typical contact positioning.

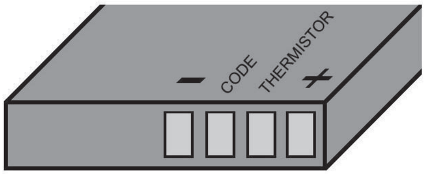

Figure 9-28:
Typical contacts on a cellular battery

The positive [+] is normally at the outer right and the negative [–] is on the inside. Most batteries have a thermistor; some also offer a code.

Returned batteries are either discarded or shipped to service centers where they are tested and redistributed as Class B packs. Looking closer at the tonnage of these returned batteries reveals that nine out of 10 packs have no problem and can be serviced. Seeing an opportunity for business, large refurbishing centers have sprung up in the USA that test 400,000 batteries per month, with volumes anticipated to increase to one million per month.

Storefront testing reduces waste, and the motto goes: "To the storefront and no further." Battery analyzers featuring rapid-test programs are offered that give a clear assessment of a battery in a few seconds while the customer waits. Figure 9-29 illustrates a service concept for storefront testing while the customer waits. If the battery needs charging or has a genuine fault, an alternate pack is given from the pool of previously tested batteries.

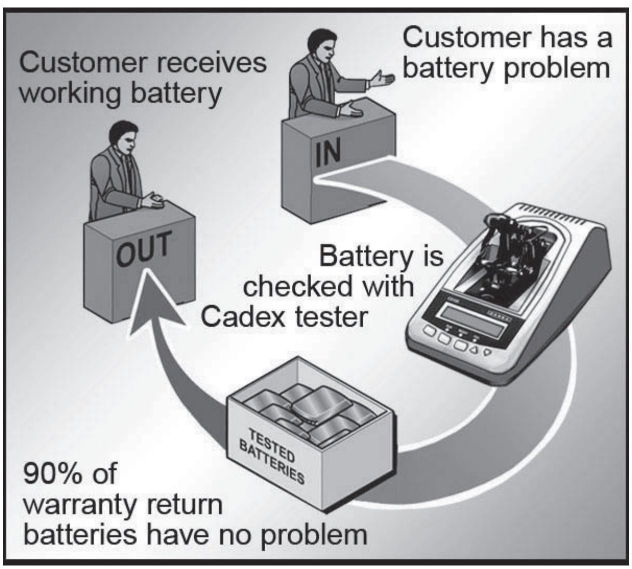

Figure 9-29:
Storefront service

Batteries are serviced while the customer waits. A faulty pack is replaced from the pool of previously serviced batteries. Storefront testing reduces handling, lessens disposal and improves customer satisfaction.

Courtesy of Cadex

One of the difficulties of storefront testing has been the availability of suitable battery diagnostic equipment. The older units lacked accuracy in rapid testing, and had a predictive capacity that resembled a ticket in a Las Vegas lottery; many potential users hesitated to buy such equipment. QuickSort™ provides 90 percent accuracy across the population of cellular batteries. (See "Testing Lithium-based Batteries," on page 229.) With a PC, some analyzers allow service reports to be printed, and the Internet enables a central manager to monitor the activity of each store. Figure 9-30 illustrates a battery analyzer designed for storefront use.

Figure 9-30: Cadex C5100 analyzer for lithium-ion batteries

This analyzer rapid tests, charges and cycles batteries. The RigidArm™ adapter allows easy interface to cellular batteries; also accepts preprogrammed adapters. QuickSort™ tests batteries in 30 seconds.

Courtesy of Cadex

Maintaining Fleet Batteries

A battery analyzer assures that fleet batteries meet the minimum performance standards. The device also helps to restore low performers, if such a service is possible with the battery types in question. In addition, a battery analyzer supervises the all-important function of a timely replacement at the end of a productive life. Manufacturers of portable equipment support battery maintenance because well-performing batteries reflect positively on the equipment, a win-win situation for both manufacturer and user.

Many battery analyzers come with PC application software. With BatteryShop™ (by Cadex), for example, the PC becomes the command center and all functions are processed through the keyboard, as well as other input devices. Clicking the mouse on any of the 2,000 batteries listed in the database configures the analyzer to the correct setting, eliminating the need for further programming. The user has the liberty to add, remove and edit the batteries listed should the specification change.

Labeling each fleet battery with a permanent ID number simplifies logistics and traceability. A printer connected to PC BatteryShop™ generates these labels in bar code format. The user simply scans the label, which in turn configures the analyzer and retrieves the performance history for review. Besides capacity readings and service dates, purchasing date, vendor information and pricing can also be entered. Figure 9-31 illustrates the battery scan, service and data examination.

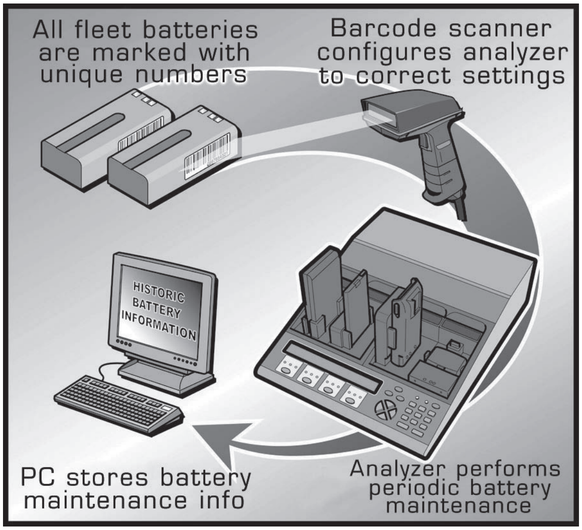

Figure 9-31:
Fleet battery management

Labeling each battery with a unique number simplifies battery service. Swiping the barcode label reveals the history of the battery.

Courtesy of Cadex

Another tracking method for fleet batteries is attaching a removable label that shows the battery information at a glance between services, as illustrated in Figure 9-32. The system is self-governing in that all batteries must regularly be serviced as part of quality control. This is made possible by providing a time period between the last service and the new date due. With this information on hand, the prudent battery user only picks a battery that has been serviced and meets this quality assurance (QA) test protocol. Setting up the maintenance system is simple and managing it requires only about 30 minutes per day.

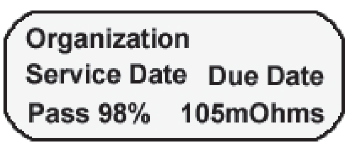

Figure 9-32: Sample of removable battery label

The label shows battery information at a glance and includes name of organization for traceability, capacity in percent, as well as past and future service dates.

Setting up a battery maintenance system requires a battery analyzer that is capable of printing battery stick-on labels. The analyzer should also offer a program that automatically restores nickel-based batteries if the set capacity threshold cannot be met. Cadex analyzers meet these requirements and go one step further by offering adjustable capacity target settings to select the minimum performance criteria for the given operation.

Most fleet operations use 80 percent as their battery pass/fail criterion. Increasing the threshold to 85 percent tightens the performance tolerance but passes fewer batteries; lowering the settings extends service life but offers less stringent performance standards. When choosing the setting, the organization must ensure that the lowest-level battery in the fleet is able to fulfill its assigned duty. Figures 9-33, 9-34 and 9-35 illustrate the battery label system.

Rechargeable batteries do not die suddenly but gradually get weaker with time. A service every one to three months offers plenty of confidence that all batteries will meet the minimum required capacity and last through the shift with some energy to spare.

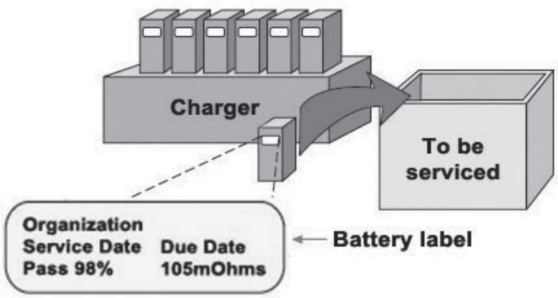

Figure 9-33: Sorting batteries for servicing

When taking a battery from the charger, the user checks the service date, and if expired the battery is placed in the “To be serviced” box.

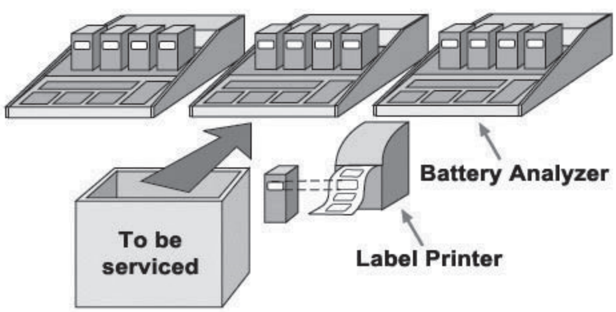

Figure 9-34: Servicing expired batteries

The analyzers service the batteries and recondition them if low in capacity (only nickel-based batteries receive recondition). Passing batteries are relabeled showing capacity and the next service date.

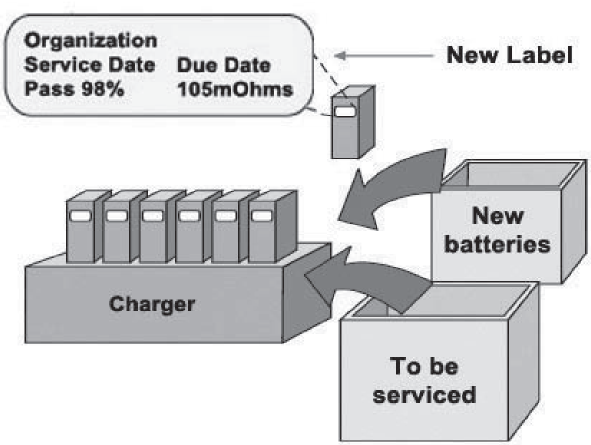

Figure 9-35: Reinstating batteries

The failed batteries are removed from service and replaced with new packs. The new and serviced batteries go back into service by being charged.

All figures Courtesy of Cadex

Battery Test Systems

While battery analyzers are tools to service batteries; battery test systems provide multi-purpose test functions for research laboratories. Typical applications are life cycle testing and verifying cell balance in field imitation. Such tests can often be automated with a custom program. *Load capture* allows storing load signatures for playback simulations. Many battery test systems also control external load units and environmental chambers. Other uses of such systems are quality inspections and verifying warranty claims. Figure 9-36 illustrates a typical battery test system.

Figure 9-36:
Cadex C8000 Battery Test System

Four independent channels provide up to 10A each and 36V. Maximum charge power is 400W, discharge is 320W. The discharge power can be enhanced with external load banks.

Courtesy of Cadex

The alternate to a battery test system is a programmable power supply controlled by a computer. Such a platform offers flexibility but requires careful programming to prevent stress to the battery and possible damage or fire if an anomaly were to occur. A battery test system, such as the Cadex C8000, offers protected charge and discharge programs that identify a faulty battery and terminate a service safely. The system can be overridden to do destructive tests.

Simple Guidelines to Choosing a Battery Test System

- Similar to a medical test or the weather forecast, battery testers provide only estimations. No single instrument can do it all; several methods are needed to attain a full assessment.
- Most batteries keep a low internal resistance while the capacity drops gradually with age.
- Battery resistance provides only a snapshot and cannot provide the end-of-life prediction.
- Capacity is the leading health indicator but this measurement is difficult to estimate.
- A charge or discharge agitates the voltage and the battery needs several hours of normalize.
- Coulomb counting requires periodic calibration to keep accuracy.
- Battery management prevents surprise failure and allows for a scheduled retirement.
- Storefront battery testing provides on-site troubleshooting to verify performance.