

Choosing a battery that will last

Isidor Buchmann

Cadex Electronics Inc.

isidor.buchmann@cadex.com

www.buchmann.ca

April 2001

What causes a battery to wear down — is it mechanical or chemical? The answer is “both”. A battery is a perishable product that starts deteriorating right from the time it leaves the factory. Similar to a spring under tension, a battery seeks to revert back to its lowest denominator. The speed of aging is subject to depth of discharge, environmental conditions, charge methods and maintenance procedures, or the lack thereof. Aging and user-conditions affect each battery chemistry differently.

As part of an ongoing research program to find the optimum battery system for wireless applications, Cadex has performed life cycle tests on Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH) and Lithium Ion (Li-ion) batteries. All tests were carried out on the *Cadex C7000* battery analyzers in the test labs of *Cadex Electronics Inc.*, Vancouver, Canada.

The batteries received an initial full-charge, and then underwent a regime of continued discharge/charge cycles. The internal resistance was measured with Cadex’s proprietary *OhmTest* method, and the self-discharge was obtained from time-to-time by reading the capacity loss incurred during a 48-hour rest period. The test program involves 53 batteries of different models and chemistries.

When conducting battery tests in a laboratory, it should be noted that the performance in a protected environment is commonly superior to those in field use. Elements of stress and inconsistency that are present in everyday use cannot always be simulated accurately in the lab.

Battery performance as a function of cycling

In terms of life cycling, the standard NiCd is the most enduring battery. In Figure 2 we examine the capacity, internal resistance and self-discharge of a 7.2V, 900mA NiCd battery with *standard* cells. Due to time constraints, the test was terminated after 2200 cycles. During this period, the capacity remains steady, the internal resistance stays flat at 75 milliohms (mΩ) and the self-discharge is stable. This battery receives a grade 'A' for almost perfect performance.

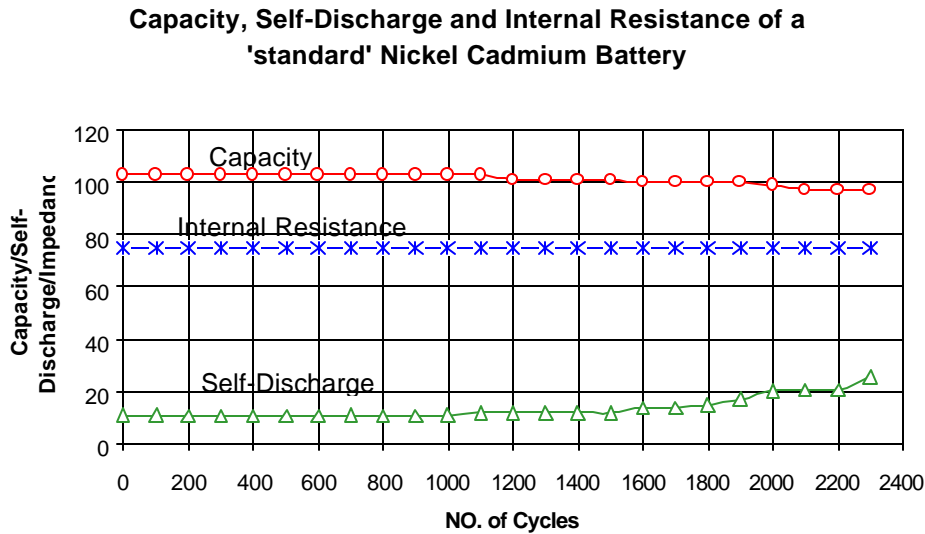


Figure 1: Characteristics of a standard cell NiCd battery.

This battery deserves an 'A' for almost perfect performance in terms of stable capacity, internal resistance and self-discharge over many cycles. This illustration shows results for a 7.2V, 900mA NiCd.

The readings on an *ultra-high capacity* NiCd are less favorable but still better than other chemistries in terms of endurance. Although up to 60% higher in energy density than the standard NiCd version, Figure 3 shows a steady drop of capacity during the 2000 cycles delivered. At the same time, the internal resistance rises slightly. A more serious degradation is the increase of self-discharge after 1000 cycles. This deficiency manifests itself in shorter runtimes because the battery consumes some energy, even if not in use.

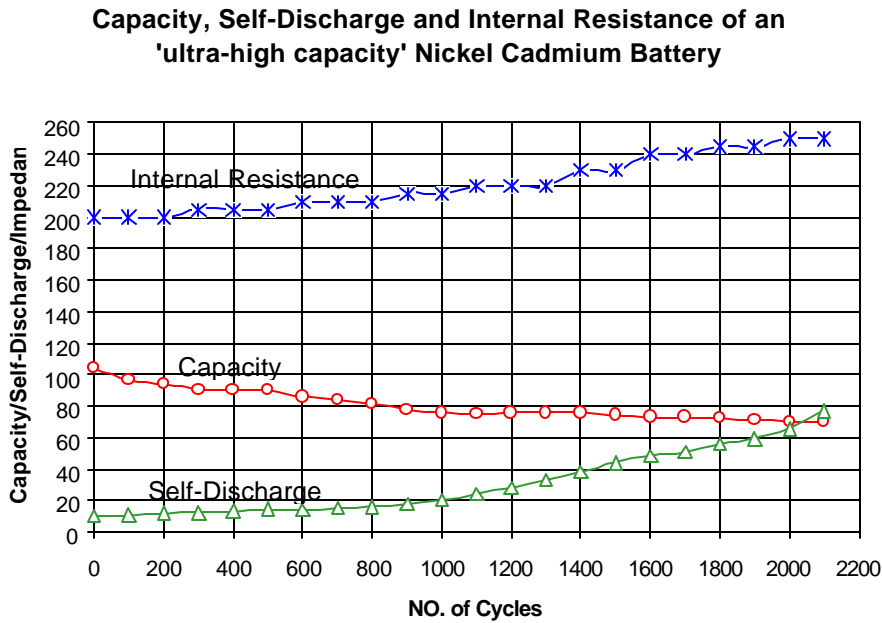


Figure 2: Characteristics of a NiCd battery with ultra-high capacity cells.
 This battery is not as favorable as the standard NiCd but offers higher energy densities and performs better than other chemistries in terms of endurance. This illustration shows results for a 6V, 700mA NiCd.

Figure 4 examines the NiMH, a battery that offers high energy density at low cost. We observe good performance at first but past the 300-cycle mark, the performance starts to drift downwards rapidly. One can observe the swift increase in internal resistance and self-discharge after cycle count 700.

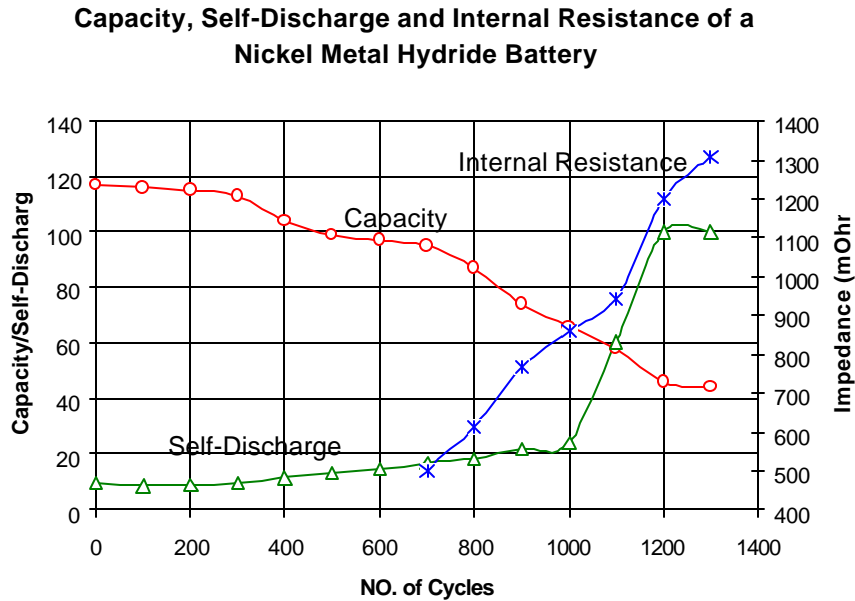


Figure 3: Characteristics of a NiMH battery.

This battery offers good performance at first but past the 300-cycle mark, the capacity, internal resistance and self-discharge start to deteriorate rapidly. This illustration shows results for a 6V, 950mA NiMH.

The Li-ion battery offers advantages that neither the NiCd nor NiMH can meet. In Figure 5 we examine the capacity and internal resistance of a typical Li-ion. A gentle and predictable capacity drop is observed over 1000 cycles and the internal resistance increases only slightly. Because of low readings, self-discharge has been omitted on this test.

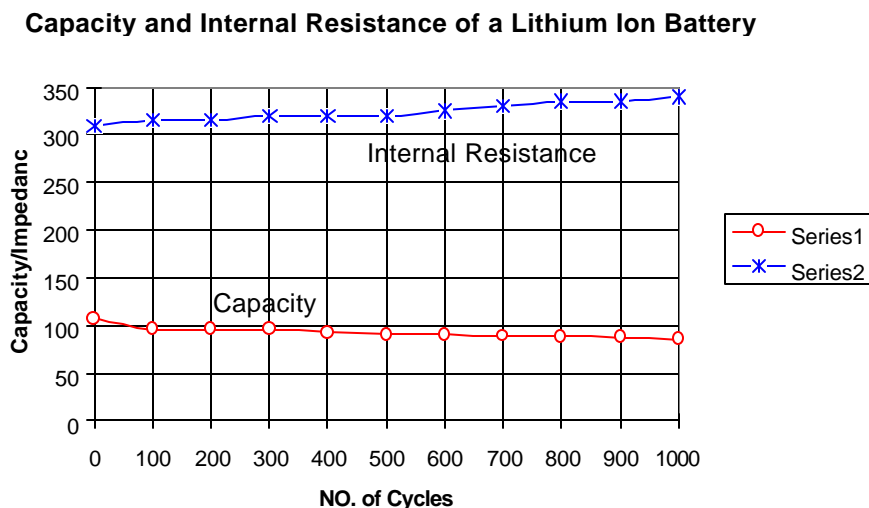


Figure 4: Characteristics of a Li-ion battery.

The above-average performance of this battery may be due to the fact that the test did not include aging. This illustration shows results for a 3.6V, 500mA Li-ion battery.

Is the Li-ion truly superior?

Today’s battery research focuses heavily on lithium systems, so much so that one could assume that all future applications will be lithium based. This lithium hype is especially apparent when attending battery conferences where battery manufacturers from all corners of the world meet to present their latest achievements. Just a few years ago, the argument was NiCd against NiMH; then the speakers argued on the benefit of Li-ion over NiMH and today the emphasis is on Li-ion Polymer. The Nickel Cadmium (NiCd) and Nickel Metal Hydride (NiMH) are hardly mentioned.

In many aspect, the Li-ion is superior to nickel or lead based batteries. There is one weak point with the Li-ion that, for unknown reasons, is seldom mentioned by the battery manufacturer. It is aging. Capacity deterioration is noticeable after one year, whether the battery is in storage or use. Past two years, the battery frequently fails.

Although less of a concern in the fast moving cell-phone and notebook market, storage at operational readiness is an important factor in most industrial applications. In Figure 6 we examine the capacity loss as a function of charge level and storage temperature.

Temperature	40% charge level (recommended storage charge level)	100% charge level (typical user charge level)
0°C	98% after 1 year	94% after 1 year
25°C	96% after 1 year	80% after 1 year
40°C	85% after 1 year	65% after 1 year
60°C	75% after 1 year	60% after 3 months

Figure 5: Non-recoverable capacity loss on Li-ion batteries after storage.

High charge levels and elevated temperatures hasten the capacity loss. Improvements in chemistry have increased the storage performance of some Li-ion batteries.

It is not recommended to keep Li-ion batteries in storage for a long time. Instead, the packs should be rotated like perishable food. The buyer should be aware of the manufacturing date when purchasing a replacement Li-ion battery. Unfortunately, this information is often encoded in an encrypted serial number and is only available to the manufacturer. The recommended charge level is 40% and the storage temperature should be 15° C or less.

How much battery maintenance is needed?

The NiMH and NiCd are considered *high maintenance* batteries that require regular discharge cycles to prevent memory. Although the NiMH was originally advertised as memory-free, both NiCd and NiMH are affected similarly by memory. The nickel plate, a metal that is shared by both battery systems, is the main contributor to crystalline formation. Memory may not be as visible on the NiMH because of its shorter cycle life as compared to the NiCd.

The Li-ion is a *low maintenance* battery that does not require periodic discharges. No trickle charge is applied once the battery reaches full charge and the Li-ion may remain in most chargers until used.

With newer battery systems such as Li-ion, battery maintenance shifts from applying periodic discharges to quick testing. Quick testing is possible by reading the battery's internal resistance, also known as impedance. Measured in milliohms (mΩ), the impedance is the gatekeeper of the battery that, to a large extent, determines the runtime. The lower the resistance, the less restriction the battery encounters in delivering the needed power.

The impedance readings only takes a few seconds to complete and work best with Li-ion batteries because the performance degradation follows a linear pattern with cell oxidation. The performance of NiMH batteries can also be measured with the impedance method but the readings are less dependable. There are instances when a poorly performing NiMH battery can also exhibit a low mΩ reading.

Testing a NiCd on resistance alone is unpredictable. A low resistance reading does not automatically constitute a good battery. Elevated impedance readings are often caused by memory, a phenomenon that is reversible.

A more reliable method of measuring the state-of-health of a battery is through quick-test methods. Several universities, research organizations and private companies, including *Cadex Electronics*, are striving to find a workable solution to battery quick testing. When studying the characteristics relating to battery state-of-health, some interesting effects can be observed. Unfortunately, these properties are cumbersome, nonlinear and unique to each battery type. This inherent complexity makes it difficult to create a formula that works for all batteries.

Cadex Electronics has found ways to alleviate these seemingly insurmountable challenges. The system uses an inference algorithm to test battery capacities. The Quicktest algorithm is made battery specific by using a trend-learning algorithm that resembles the thinking process of the human brain.

The first stage of the analysis uses a waveform to gather battery information under certain stresses. A probability is established to which the battery is best suited. Since there are many battery types with several variables interacting, a set of rules is applied to further evaluate the data. The results are averaged and a predicted battery capacity is estimated. The initial inference to categorize the batteries is computed from a set of specialized shapes called membership functions. These membership functions are unique to every battery model and are developed using a specialized trend-learning algorithm.

The Cadex Quicktest can be performed with a charge level of between 20 and 90 percent. If the battery is insufficiently charged, or has too high a charge, the analyzer automatically applies the appropriate charge or discharge to bring the battery within testing range. Within this range, different charge levels do not affect the readings. The test lasts about two minutes and supports Li-ion/Polymer, NiMH and NiCd batteries.

The Cadex Quicktest is added to the Cadex 7200 and 7400 battery analyzers. These platforms feature interchangeable battery adapters that contain the battery configuration codes and matrix for the quick test.

Summary

Research has brought about a variety of battery chemistries, each offering distinct advantages but none providing a fully satisfactory solution. However, with today's selection of battery systems, better choices can be made to tailor to specific user applications.

Relentless downsizing has pressured manufacturers to invent smaller battery sizes. By packing more energy into a pack, other qualities may be neglected, one of which is longevity.

Long service life and predictable low m \dot{U} reading are found in the NiCd family. However, this chemistry is being replaced, where applicable, with systems containing higher energy density. In addition, negative publicity about the memory phenomenon and concerns of toxicity on careless disposal are causing equipment manufacturers to seek alternative choices.

Once hailed as the superior battery system, the NiMH has also failed to provide the universal battery solution for the twenty-first century. Shorter than expected service life remains a major complaint by users.

For a fast-moving consumer market that replaces the equipment every two years, the Li-ion battery is the best choice. However, for applications that need fully charged batteries that often must be kept in warm storage conditions, the Li-ion does pose a problem in terms of longevity.

So far, the emerging lithium polymer system has been unable to overcome the shortcomings of the Li-ion. Other than lighter and thinner designs, the cost-to-energy ration of Li-Polymer is among the highest of rechargeable batteries.

With the rapid developments in technology occurring today, battery systems may soon become viable that use neither nickel, lead nor lithium. Fuel cells, which do not rely on electro-chemical process but allow refueling similar to a vehicle, may solve the portable energy needs for the future. Instead of a charger, the user carries a bottle of liquid energy. Although still many years from practical reality, such a battery would truly change the way we live and work.

This article contains excerpts from the second edition book entitled Batteries in a Portable World — A Handbook on Rechargeable Batteries for Non-Engineers. In the book, Mr. Buchmann evaluates the battery in everyday use and explains their strengths and weaknesses in laymen's terms. The 300-page book is available from Cadex Electronics Inc. through book@cadex.com, tel. 604-231-7777 or most bookstores. For additional information on battery technology visit www.buchmann.ca.

About the Author

Isidor Buchmann is the founder and CEO of Cadex Electronics Inc., in Richmond (Vancouver) British Columbia, Canada. Mr. Buchmann has a background in radio communications and has studied the behavior of rechargeable batteries in practical, everyday applications for two decades. The author of many articles and books on battery maintenance technology, Mr. Buchmann is a well-known speaker who has delivered technical papers and presentations at seminars and conferences around the world.

About the Company

Cadex Electronics Inc. is a world leader in the design and manufacture of advanced battery analyzers and chargers. Their award-winning products are used to prolong battery life in wireless communications, emergency services, mobile computing, avionics, biomedical, broadcasting and defense. Cadex products are sold in over 100 countries.