Ni-Cd Memory: myth or fact?

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The word 'memory' was originally derived from 'cyclic memory', meaning that a Nickel Cadmium (NiCd) battery can remember how much discharge was required on previous discharges. Improvements in battery technology have virtually eliminated this phenomenon.

The problem with NiCd is not the cyclic memory but the effects of crystalline formation. The active cadmium material is present in finely divided crystals. In a good cell, these crystals remain small, obtaining maximum surface area. When the memory phenomenon occurs, the crystals grow and drastically reduce the surface area. The result is a voltage depression, which leads to a loss of capacity. In advanced stages, the sharp edges of the crystals may grow through the separator, causing high self-discharge or an electrical short.

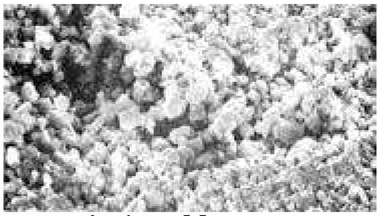
Another form of memory that occurs on some NiCd cells is the formation of an inter-metallic compound of nickel and cadmium, which ties up some of the needed cadmium and creates extra resistance in the cell. Reconditioning by deep discharge helps to break up this compound and reverses the capacity loss.

The memory phenomenon can be explained in layman's terms as expressed by Duracell: "The voltage drop occurs because only a portion of the active materials in the cells is discharged and recharged during shallow or partial discharging. The active materials that have not been cycled change in physical characteristics and increase in resistance. Subsequent full discharge/charge cycling will restore the active materials to their original state."

When Nickel Metal Hydride (NiMH) was first introduced there was much publicity about its memory-free status. Today, it is known that this chemistry also suffers from memory but to a lesser extent than the NiCd. The positive nickel plate, a metal that is shared by both chemistries, is responsible for the crystalline formation.

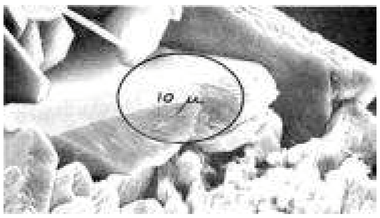
In addition to the crystal-forming activity on the positive plate, the NiCd also develops crystals on the negative cadmium plate. Because both plates are affected by crystalline formation, the NiCd requires more frequent discharge cycles than the NiMH. This is a non-scientific explanation of why the NiCd is more prone to memory than the NiMH.

The stages of crystalline formation of a NiCd battery are illustrated in three figures below. The enlargements show the negative cadmium plate in normal crystal structure of a new cell, crystalline formation after use (or abuse) and restoration.



New NiCd cell.

The anode is in fresh condition (capacity of 8.1Ah). Hexagonal cadmium hydroxide crystals are about 1 micron in cross section, exposing large surface area to the liquid electrolyte for maximum performance.



Cell with crystalline formation.

Crystals have grown to an enormous 50 to 100 microns in cross section, concealing large portions of the active material from the electrolyte (capacity of 6.5Ah). Jagged edges and sharp corners may pierce the separator, which can lead to increased self-discharge or electrical short.

Restored cell.

After pulsed charge, the crystals are reduced to 3 to 5 microns, an almost 100% restoration (capacity of 8.0A). Exercise or recondition are needed if the pulse charge alone is not effective.

Three figures Above: Crystalline formation on NiCd cell.

Illustrations courtesy of the US Army Electronics Command in Fort Monmouth, NJ, USA.

How to restore and prolong nickel-based batteries

The effects of crystalline formation are most pronounced if a nickel-based battery is left in the charger for days, or if repeatedly recharged without a periodic full discharge. Since most applications do not use up all energy before recharge, a periodic discharge to 1V/cell (known as exercise) is essential to prevent the buildup of crystalline formation on the cell plates. This maintenance is most critical for the NiCd battery.

All NiCd batteries in regular use and on standby mode (sitting in a charger for operational readiness) should be exercised once per month. Between these monthly exercise cycles, no further service is needed. The battery can be used with any desired user pattern without the concern of memory.

The NiMH battery is affected by memory to a lesser degree. No scientific research is available that compares NiMH with NiCd in terms of memory degradation. Neither is information on hand that suggests the optimal amount of maintenance required to obtain maximum battery life. Applying a full discharge once every three months appears right. Because of the NiMH battery's shorter cycle life, over-exercising is not recommended.

Exercise and Recondition — Research has shown that if no exercise is applied to a NiCd for three months or more, the crystals ingrain themselves, making them more difficult to break up. In such a case, exercise may no longer be effective in restoring a battery and reconditioning is required.

Recondition is a slow, deep discharge that removes the remaining battery energy by draining the cells to a voltage threshold below 1V/cell. Tests performed by the US Army have shown that a NiCd cell needs to be discharged to at least 0.6V to effectively break up the more resistant crystalline formation. During recondition, the current must be kept low to prevent cell reversal. Figure 2 illustrates the battery voltage during a discharge to 1V/cell, followed by the secondary discharge, know as recondition.

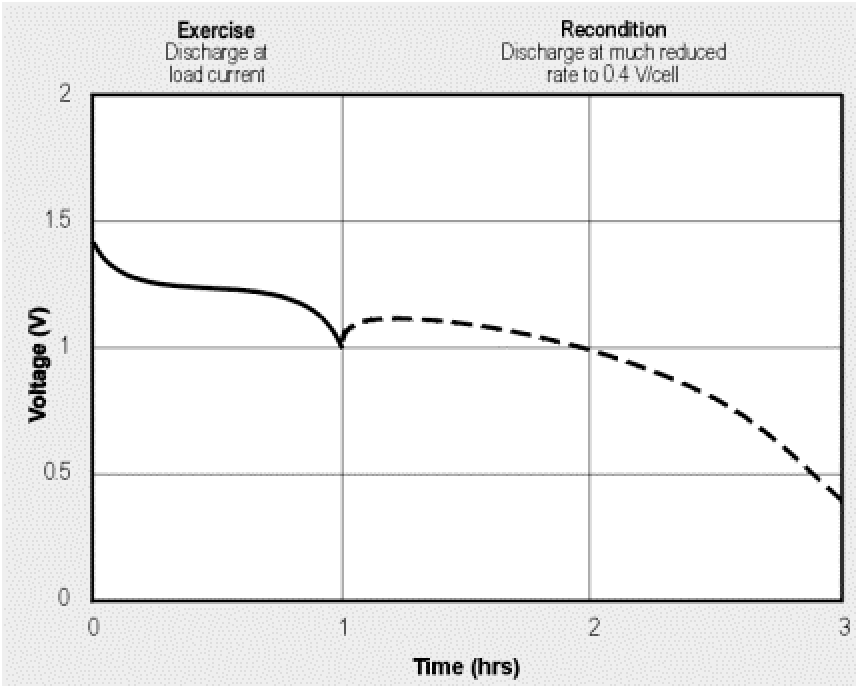


Figure 2 above: Exercising and reconditioning batteries on a Cadex battery analyzer.

If no exercise is applied to a NiCd for three months or more, exercise may no longer be effective in restoring a battery and reconditioning is required. Recondition is a slow, deep discharge to 0.4V/cell.

Figure 3 illustrates the effects of exercise and recondition. Four batteries afflicted with various degrees of memory are serviced. The batteries are first fully charged, then discharged to 1V/cell. The resulting capacities are plotted on a scale of 0 to 120 percent in the first column. Additional discharge/charge cycles are applied and the battery capacities are plotted in the subsequent columns. The solid black line represents exercise, and the dotted line recondition. On this test, the exercise and recondition cycles are applied manually at the discretion of the research technician.

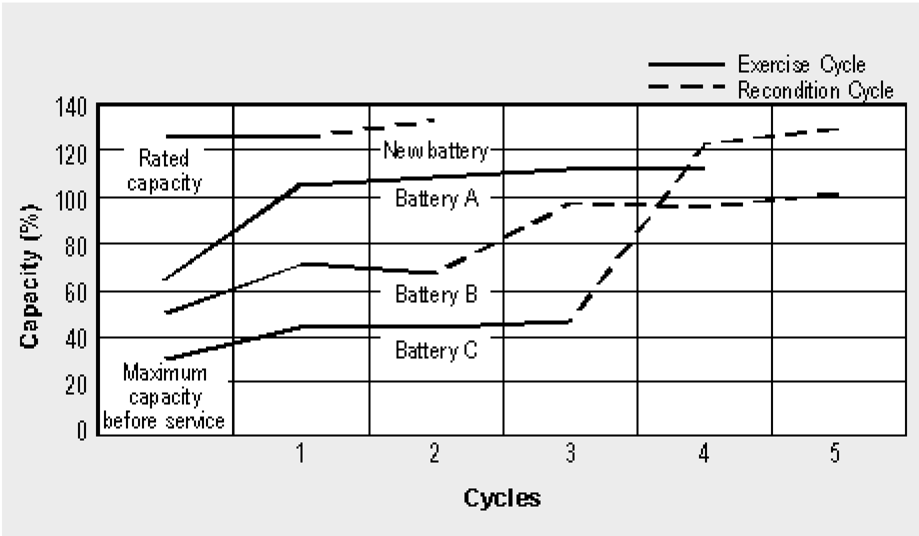


Figure 3 above: Effects of exercise and recondition.

Four batteries afflicted with various degrees of memory are serviced. Battery ‘A’ improved capacity on exercise alone; batteries ‘B’ and ‘C’ required recondition. The new battery improved further with recondition.

Battery ‘A’ responded well to exercise alone and no recondition was required. This result is typical of a battery that has been in service for only a few months or has received periodic exercise cycles. Batteries ‘B’ and ‘C’, on the other hand, required recondition (dotted line) to restore their performance. Without the recondition function, these two batteries would need to be replaced.

After service, the restored batteries were returned to full use. When examined after six months of field service, no noticeable degradation in the restored performance was visible. The regained capacity was permanent with no evidence of falling back to the previous state. Obviously, the batteries would need to be serviced on a regular basis to maintain the performance.

Applying the recondition cycle on a new battery (top line on chart) resulted in a slight capacity increase. This capacity gain is not fully understood, other than to assume that the battery improved by additional formatting. Another explanation is the presence of early memory. Since new batteries are stored with some charge, the self-discharge that occurs during storage contributes to a certain amount of crystalline formation. Exercising and reconditioning reverse this effect.

Case studies

A certain organization continually experienced NiCd battery failure after a relatively short service time. Although the batteries performed at 100 percent when new, their capacity dropped to 20 percent and below within one year. We discovered that their two-way radios were under-utilized; yet the batteries received a full recharge after each short field use.

After replacing the batteries, we advised the organization to exercise the new batteries once per month by discharging them to one-volt-per cell with a subsequent recharge. The first exercise took place after the batteries had been in service for four months. At that stage, we were anxious to find out how much the batteries had deteriorated. Here is what we found:

On half of the batteries tested, the capacity loss was between 25 to 30 percent; on the other half, the losses were around 10 to 20 percent. With exercise — and some needed recondition cycles — all batteries were fully restored. Had maintenance been omitted for much longer, the probability of a full recovery would have been jeopardized.

The importance of exercising and reconditioning NiCd batteries is emphasized by a study carried out by GTE Government Systems in Virginia, USA, for the US Navy. To determine the percentage of batteries needing replacement within the first year of use, one group of batteries received charge only, another group was exercised and a third group received recondition. The batteries were used for two-way radios on the aircraft carriers USS Eisenhower with 1500 batteries and USS George Washington with 600 batteries, and the destroyer USS Ponce with 500 batteries.

With charge only (charge-and-use), the annual percentage of battery failure on the USS Eisenhower was 45 percent (see Figure 4). When applying exercise, the failure rate was reduced to 15 percent. By far the best results were achieved with recondition. The failure rate dropped to 5 percent. Identical results were attained from the USS George Washington and the USS Ponce.

Maintenance Method	Annual Percentage of Batteries Requiring Replacement
Charge only (charge-and-use)	45%
Exercise only (discharge to 1V/cell)	15%
Reconditioning (secondary deep discharge)	5%

Figure 4 above: Replacement rates of NiCd batteries.
The annual percentage of NiCd batteries requiring replacement when used without any maintenance decreases with exercise and recondition. These statistics were drawn from batteries used by the US Navy on the USS Eisenhower, USS George Washington and USS Ponce.

The GTE Government System report concluded that a battery analyzer featuring exercise and recondition functions costing $2,500US would pay for itself in less than one month on battery savings alone. The report did not address the benefits of increased system reliability, an issue that is of equal if not greater importance, especially when the safety of human lives is at stake.

Another study concerning NiCd batteries for defense applications was performed by the Dutch Army. This involved battery packs that had been in service for 2 to 3 years during the Balkan War. The Dutch Army was aware that the batteries were utilized under the worst possible conditions. Rather than a good daily workout, the packs were used for patrol duties lasting 2 to 3 hours per day. The rest of the time the batteries remained in the chargers for operational readiness.

After the war, the batteries were sent to the Dutch Military Headquarters and were tested with Cadex 7000 Series battery analyzers. The test technician found that the capacity of some packs had dropped to as low as 30 percent. With the recondition function, 90 percent of the batteries restored themselves to full field use. The Dutch Army set the target capacity threshold for field acceptability to 80 percent. This setting is the pass/fail acceptance level for their batteries.

Based on the successful reconditioning results, the Dutch Army now assigns the battery maintenance duty to individual battalions. The program calls for a service once every two months. Under this regime, the Army reports reduced battery failure and prolonged service life. The performance of each battery is known at any time and any under-performing battery is removed before it causes a problem.

Summary

Each battery system has a few shortcomings: The lithium family ages and has limited load current; the NiMH has a relative shore service life; the lead acid family is bulky and requires long charge times; and the NiCd has memory. But the NiCd makes up by being the most enduring battery. In addition, it has the lowest cost-to-energy-ratio of all commercial rechargeable batteries.

To achieve long life, some simple guidelines must be observed. They are:

- Do not leave a nickel-based battery in a charger for more than a day after full charge is reached.
- Apply a monthly full discharge cycle. Running the battery down in the equipment may do this also.
- Do not discharge the battery before each recharge. This would put undue stress on the battery.
- Avoid elevated temperature. A charger should only raise the battery temperature for a short time at full charge, and then the battery should cool off.
- Use quality chargers

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.

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