



Battery Basics

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In the design of any portable, battery operating equipment, battery model selection requires consideration of ratings, conditions of use, temperature operating and storage conditions as well as the voltage requirements, equipment space and battery mounting methods. While most of Symbol's batteries are Nickel Metal Hydride (NiMH) and Lithium Ion (Lilon), we still have a number of the designs where NiCd cells are used. The following information the principals, operating conditions, storage details and other essentials about our battery solutions, which will help anybody, working with these types of batteries, including NiCd.

Q. What types of batteries do we use in our products?

A. While battery manufacturers make loose **cells**, Symbol puts them together into different types of packages by connecting cells together and encasing them with plastic housing with a few external gold plated contacts. Also, as a rule, there are some electronic components inside a pack, such as thermistors, fuses and, in case of Lithium Ion battery, quite complicated protection circuitry. Very often we call substitute the term "battery packs" with just batteries for short.

Q. What are Rechargeable NiCd batteries?

A. Rechargeable NiCd batteries are the type of alkaline storage devices that are classified as a secondary (rechargeable) battery. NiCd cells use nickel hydroxide as a positive electrode, cadmium as the negative, and alkaline (potassium hydroxide – KOH) electrolyte. First invented in Sweden in 1899, the basis for practical application was made possible about 50 years later, but the mass production was started in the 60's with the development of portable electronic devices

Q. What about NiMH and Lilon batteries?

A. NiMH batteries are very similar to NiCd in terms of basic structure and applications. They utilize different chemical reactions and the major difference is in the negative plate, composed of hydrogen-absorbing alloys. NiMH batteries have about twice the energy density and a similar operating voltage as that of NiCd batteries. Lilon batteries are very different from chemical principles, structure and operation from those of nickel base.

They use either lithium cobalt oxide (most popular), or manganese dioxide as the positive electrode and a highly crystallized special carbon as the negative one. Lithium in the positive electrode is ionized during charge and moves from layer to layer in the negative electrode during charge. Lithium ions (mold back) to the positive electrode during discharge. Lightweight and high operating voltage (3.7V – 3.6V) makes them a popular choice for portable products.

Q. How do batteries generate electrical current?

A. There are three types of electro-chemical reactions employed in the generation of the power, accompanied by gas generation:

- Discharge reaction which supplies electrical power to the load
- Charge reaction which restores that electrical power

- Gas generation
 - For NiCd and NiMH batteries – resulting from electrolysis of water on the positive electrode which occurs after completion of charge during overcharge
 - During these reactions both active material goes through chemical conversions and the gas generated at the positive electrode is absorbed by reacting with the “un-exercised” part of the negative electrode thus making it possible for the battery to be sealed. However, in the case if some excess gas is been generated, every cell has a vent mechanism with safety valve.
 - For Lilon batteries, gas-generating reaction is different, but vent mechanism is similar.
 - Electrolyte does not contribute directly to the reaction and is used to support the flow of ions between electrodes.

Q. What are the performance characteristics of these batteries?

A. There are five main characteristics of every battery: charge, discharge, cycle life, storage and environmental operation conditions.

Charge

For NiCd and NiMH batteries:

The current, time, temperature, and age of the battery as well as other factors affect the charge characteristics of the battery. Charge, especially with a high current, generates heat, thus causing the battery temperature to rise and internal pressure build-up. Charge efficiency also varies depending on those parameters. It is never 100%, but can reach 85% or higher with the high charge rate.

However, for the rapid charge, the charge termination control system, (like negative ΔV cut-off, dT/dt , coulomb counting and others) should be implemented. Since NiMH batteries do not have a well-pronounced peak voltage/ voltage drop during the charge, temperature termination method is more reliable than negative ΔV one. Also, the temperature rises faster in NiMH batteries than in NiCd; therefore, NiMH battery packs use some type of temperature sensitive and temperature protection devices.

During charging, the cell voltage increases to approximately 1.48-1.6 volts per cell for Ni based cells (depending on the construction and the manufacturer), then decreases slightly (a few tens of the millivolts) in the final stage of the process, eventually reaching equilibrium at about 1.45V/cell.

For Lilon batteries:

Charging of Lilon cells is very different from NiCd or NiMh ones. Typical charging regime is constant current until cell voltage reaches about 4.15V – 4.2V, then switching to constant voltage. The charge is done when a current drops down to less than pre-determines current level, typically between 50 mA and 100mA, depending on the size of the cell.

As we already mentioned, during charging, the cell voltage increases to approximately 4.2 volts per cell for Lilon ones (depending on the construction and the manufacturer), and then decreases slightly (a few tens of the millivolts) in the final stage of the process, eventually reaching equilibrium at about 4V/cell.

For All Types:

The cell voltage also varies widely according to the charge current, ambient temperature and the age of the cell. Reverse charging must be avoided.

Reverse charging can cause a reversal in a battery polarity, causing gas pressure inside the battery to rise, which can activate the safety vent. All these events can lead to electrolyte leakage, rapid deterioration in battery performance, battery swelling and rupture. Overcharging batteries (charging a battery when it is already fully charged) can lead to deterioration in battery performance and, in extreme cases, to a leakage of electrolyte.

Discharge:

Although the operating voltage of the batteries varies slightly, depending on the discharge current, it is maintained at approximately 1.2V for 90% of the discharge period for a discharge current (3.6V for Lilon cells) of up to 1C. With higher constant current discharge rate, flat portion of the discharge curve becomes significantly shorter, it develops well pronounced slope and the capacity of the cell is decreased to about 80% of the nominal or even less, depending on the value of a discharge current.

When a battery has gone through several hundreds of charge/discharge cycles, the batteries voltage during discharge will decrease due to the increase in internal impedance. Discharge should be stopped at 0.9V – 1V per cell for NiCd and NiMH, cells and about 2.75V - 3V per cell for Lilon.

Discharge capacity drops at temperatures below –20C (down to 50% or less for the temperatures below –25C) or above +60C. Also, over discharging (discharging batteries bellow 0.9V per cell) negatively effects battery characteristics.

Self-discharge:

Of the Ni-based cells: self-discharge is about 1% - 1.5% per day at room temperature, up to 2% - at 40C – 45C and less then 0.5% at 0C.

For Lilon cells, self-discharge rate is lower.

Cycle life:

The cycle life of batteries will vary according to the charge and discharge conditions, the temperature and other usage conditions. When used in accordance with the IEC charge and discharge specifications (slow charge and discharge of about 0.2C at the room temperature), over 500 charge/discharge cycles are possible. However, typical cycle life of a battery is between 300 and 400 cycles.

Shallow discharge can increase cycle life, but might present other negative consequences, like “memory effect” for Ni based cells – see below for further details.

The industry accepted definition of the end of the cycle life is when battery delivers only 80% of their nominal capacity. However, if the application uses less than 80% of the capacity, a customer might not notice degradation of the performance till it reaches the point interfering with the application, which might occur significantly later than 500 cycles limit.

Storage characteristics:

Because batteries are chemical products involving internal chemical reactions, performance deteriorates not only with the use but also during prolonged storage. Cell voltage and capacity are usually reduced after the storage. The largest accelerating factor is the temperature. However, the capacity can be subsequently restored by slow charge. Even if the batteries are stored for an extended length of time, if the storage conditions are appropriate (storage in cool places), the capacity can be restored to almost 100% after a few subsequent charge and discharge cycles.

Batteries should be stored in a dry location with low humidity no corrosive gases and at temperature range of -20C to + 45C.

Storing batteries in a location where the humidity is high or where the temperatures fall below -0C or rise above +45C can lead to the rusting of metallic parts and battery leakage due to the expansion or contraction in parts composed of organic materials.

Storage in the charged or discharged condition does not significantly effect permanent capacity loss. However, if a battery is stored inside the unit, the discharge process is accelerated due to the additional discharge current path on the top of the normal self-discharge current. In this case, cells can go the reverse, which may cause irreversible capacity loss or even loss of the electrolyte, which can be observed as a greenish-yellowish residue around safety vent. These cells should not be used.

Long-term Storage:

Long storage (1year – 2 years) can accelerate battery self-discharge and lead to the deactivation of reactants. Locations where the temperature ranges between 0C and +20C are best suitable for long-term storage. When charging for the first time after the storage, deactivation of the elements might lead to increased battery voltage and decreased capacity. Repeating several charge-discharge cycles can restore the original performance. When storing batteries for a year or so, batteries should be charged at least once every 6 - 8 months to prevent leakage and deterioration in performance due to self-discharge.

Safety:

If pressure inside the battery rises as a result of improper use, such as overcharge, short-circuit or reverse charge, a resettable safety valve will function to release the pressure, thus preventing bursting of the battery. If the charge or discharge conditions are not appropriate, not only will the

batteries not display their full performance potential , but also the cycle life will be shortened, and in the extreme cases, electrolyte leakage could damage the device in which the batteries are used.

Q. What is the best charging temperature range and what happens if batteries are charged outside this range?

A. Batteries should be charged at room temperature or, if this is not practical for some application, the temperature range should be above 0C and below 40C. Charging at high temperatures might provide customers with the capacity higher than nominal but significantly decreases their cycle life. Also, it affects all the battery parameters (rate of temperature rise, voltage profile etc.), which are part of a charging mechanism. As a result the termination mechanism might fail. The same is true for charging at lower temperatures, except cycle life effect. Also, we have to keep in mind that the temperature inside the pack can exceed the ambient one by quite a few degrees Centigrade – up to 7C-8C.

Q. Capacity is one of the most important characteristics of a battery performance. What is the difference between nominal, minimum and other definitions of a capacity

A. Unfortunately, there is no standard definition of the capacity. Different manufacturers rate their batteries by using words “nominal”, “average”, “typical” etc.

When you read specification, the attention always should be given to the conditions under which cells are rated, i.e. temperature, discharge rate, charge conditions and others. But even if all these conditions are satisfied, there are still a number of batteries that can exhibit the performance better or worse than rated. For a capacity' variations analysis, normal distribution is usually assumed. If manufacturer is provided “minimum capacity” values it means that with certain deviation (most likely 3 sigma) all the batteries will provide a capacity equal to or higher than listed. Also, all the capacity values are given for loose cells. Capacity of a pack is usually smaller than the capacity of a single cell by a few percent (we can assume 5% difference) due to added resistance of the connections, safety element, like PTC etc.

Q. What is “memory effect” (a known problem with NiCd Batteries only)?

A. Some people believe that batteries “remember” the level of discharge they reached during previous discharge cycles and “drops dead” if we are trying to go beyond that level. What happens in reality is a little different. After a number of repeated shallow charge/discharge cycles, batteries exhibit so called voltage depression phenomena (a.k.a.”memory”). The voltage drop of between a few tens to a few hundreds millivolts characterizes this event. This happens when the certain portion of the active material, which has left “un-exersized” during previous shallow discharge cycles, is reached. This area has a higher resistance than other parts of the material, which have gone through chemical conversion process during previous cycles. A battery can still deliver its full capacity , but on slightly lower voltage level. The real problem is that this voltage drop might be big enough to reach the level of pre-set “low” (or even “dead”) battery voltage, thus triggering appropriate reaction, like displaying warning messages,

executing safe routine or even switching the unit off. Lilon batteries are not known for exhibiting any “memory” like problems.

Q: How does shallow discharge increase "cycle life

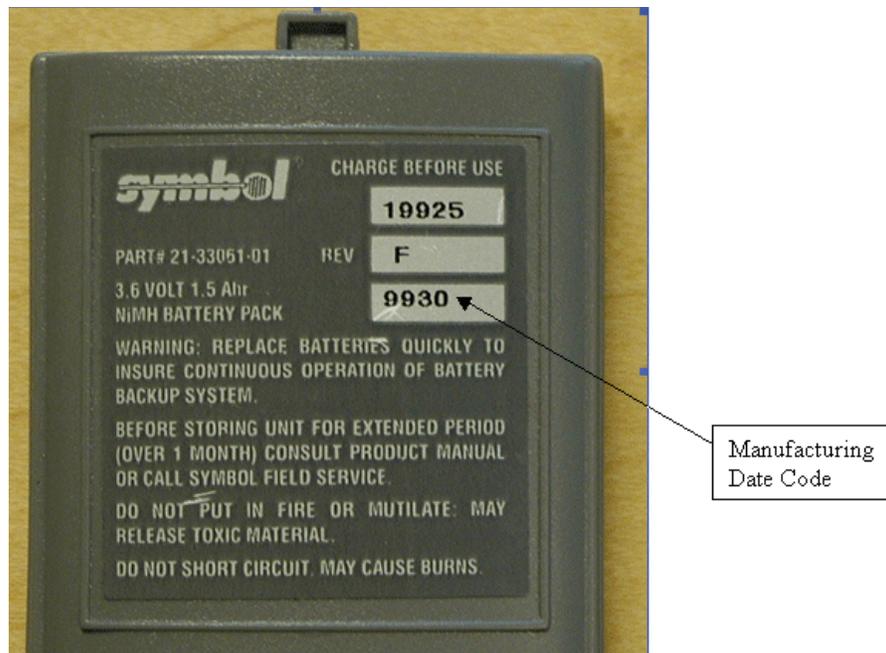
A. It’s very difficult to quantify the effect of shallow discharge on the cycle life of a battery. In general, we might see about two-three fold increase vs. typical 300 –400 cycles, but in the case of NiCd or NiMH batteries we have to be aware of “memory effect” typically associated with shallow discharge/charge modes.

Q. What constitutes a full cycle?

A. Industry accepted definition of a full cycle is 100 discharge followed by 100% charge.

Q. How do you know what the date of manufacture of a particular battery is?

A. The date of manufacture of the battery is given as a four digit code on the face of the battery where the first two digits represent the year of manufacture and the second two digits represent the week of manufacture. For example, (see Figure 1 below), the manufacturing date for this battery with date code 9930 would be the 30th week of 1999.



Q. Are NiMH or Lilon batteries better than NiCd

A. It depends on the application. NiCd batteries feature the lowest internal impedance among these three chemistries; therefore in the applications, which require high discharge currents, NiCd, is still the better choice. NiCds can withstand significantly higher overcharge than NiMH. Also, NiCds offers a largest variety of sizes and there the cost is lower than other chemistries.

But the capacity of the NiMH is higher than of NiCd and Lilon can deliver significantly higher energy density. Also, cadmium is been recognized as environmental hazard, therefore a number of countries and states imposed a significant limitation on the usage, transportation and collection of NiCd batteries.

On the other hand, power delivered by Lilon batteries is the highest among all three chemistries due to three times higher voltage than the one delivered by Nickel based batteries.

Q. What is the function of protection circuitry in any Lilon battery?

A. It is advisable to put some form of a protection into any battery pack, i.e. fuse, PTC, etc, but because of some qualities associated with Lilon (high energy, possibility of metallic lithium plating during overcharge, chemical composition of electrolyte) this chemistry requires more sophisticated methods of protection from any external equipment malfunctioning. The typical functions of protection circuitry are overcharge, over discharge and over current safety functions. There are a number of standard designs of protection circuitry available from cells manufacturers or from different electronic companies.

Q. What is Lithium Polymer battery?

A. Lithium Polymer battery is practically identical to a Lithium battery, except one difference: electrolyte is not liquid any more. Separator, soaked with special “gel” has an additional function of being “electrolyte” to support ionic conductivity. Being practically identical to their “liquid” counterparts in terms of voltage, charging and discharging methods etc. they typically have a very thin profile, thus making them very suitable for portable application. Also, theoretically, they have higher gravimetric and volumetric densities that will make them lighter and smaller than traditional Lilon batteries.

Q. Are we going to use NiCd batteries for the future Symbol products?

A. It is very unlikely, because of the reasons mentioned above. However, we still have a number of older devices utilizing NiCd chemistry. Also, we cannot exclude the possibility that for some future applications requiring high currents, NiCd can still be our choice.

General Warning:

Because batteries utilize chemical reactions, they are to be actually considered chemical products. As such, battery performance will deteriorate over time if stored for a long period of time without being used. In addition, if the various usage conditions such as charge, discharge, ambient temperature, etc. are not maintained within specified ranges, the life expectancy of the battery may be shortened or the device in which a battery is used may be damaged by electrolyte leakage. If batteries cannot maintain a charge for long period of time, even when they are charged and used correctly, this may indicate it is time to change a battery.

Nickel Cadmium (NiCd) Overview

The following is a brief overview of proper Nickel Cadmium (NiCd) battery handling, storage, usage & disposal.

Handling & Storage

New and unused batteries should be stored in a cool dry place (-20°C to 35°C) for up to 2 years, and remain in original shipping bag or container until ready to use. Batteries last longer if they are stored in cooler temperatures. Their self-discharge rate is much lower when cooler. Batteries should never be immersed in water or any other liquids.

Charging & Usage

New batteries should be allowed several charge and discharge cycles before full capacity is expected. This is a normal process that activates the chemistry and properly forms the cell.

Batteries should be charged using only Symbol Technologies authorized charging solutions, including charge cradles, terminals, and universal battery charger adapters.

Batteries can be expected to last a minimum of about 400 cycles, or one calendar year, provided that proper maintenance and usage is followed. In some cases batteries can last longer, depending on the usage profile, the system settings established, and the deployment of a regular battery maintenance regime.

Batteries that sit for extended periods without charge activity may experience what is called a memory effect. This effect is not unusual, and is caused by the self-discharging of the cell and the growth of cadmium hydroxide crystals inside the cells. Establishing a conditioning program whereby the battery is deep discharged and cycled once a month can prevent this effect. Symbol Technologies presently has a charge solution that can accommodate this requirement. This unit is known as a Universal Battery Charger (UBC) used in conjunction with battery pack and program specific adapters.

Batteries should never be conditioned more than once a month, and done so only if the battery sees regular charge and discharge cycling.

Batteries of different capacities may require varying lengths of time to charge. The higher the capacity, the longer the time needed to reach full charge. In some cases the charger will take the same amount of time for higher capacity batteries as for lower capacity batteries. Universal Battery Charger (UBC) has an intelligent "quick" charge solution, automatically detecting when to terminate charging. See your Symbol Technologies charger, terminal or cradle guide for details on charge time and termination.

End of Life & Disposal

Batteries should be considered for replacement only when the discharge capacity reaches 80% or less of minimum rated capacity, the battery has been properly maintained, and periodically conditioned as part of a regular battery maintenance regime. Batteries that are found to be at end of life and have been in service for more than 300 or 400 cycles should be disposed of properly. NiCd batteries contain cadmium, and require a strict disposal policy ensuring they are properly recycled. Do not dispose of NiCd batteries in trash. There is an organization established specifically to address recycling and disposal of batteries. They can be reached at the following web address: RBRC (Rechargeable Battery Recycling Company, www.rbrc.org).



Glossary Of Terms

Un-exercised - batteries that have not gone through complete charge/discharge cycle, therefore proper chemical reactions did not take place.

Charge - is the process when electrical energy applied to a cell or a battery is converted into chemical energy within a cell or a battery

Discharge - conversion of the chemical energy of a cell or a battery into electrical energy and withdrawal of an electrical energy into a load

Cycle life - number of charge/discharge cycles under specified conditions before a cell or a battery fails to meet specified criteria as to performance

Storage - the time during which battery is not used

Environmental operation conditions - temperature, humidity, drop, vibration, etc.

Negative - everything that is smaller than 0

Delta - difference

Cut-off – threshold level upon reaching which a process must be terminated.

DT/dt - rate of change of a temperature over time

3 sigma - statistical characteristics of the deviation

Internal impedance - the opposition or resistance of a cell or battery to an alternating current of a particular frequency or to a constant current