

NICKEL-METAL HYDRIDE Application Manual

INTRODUCTION

Mobility is increasingly viewed as an essential attribute of today's lifestyles, both personal and professional. Advanced electronic devices such as cellular phones and portable computers now permit people on the go to operate more effectively than was possible in home and office-bound environments of a generation ago. But the price of mobility has been increasing demands and dependence on portable power sources.

Fortunately, with the development of new nickel-metal hydride (NiMH) battery options, improvements in electronics have now been matched by significant improvements in the batteries that power them. Nickel-metal hydride battery cells provide more power (in equivalently sized packages) than nickel-cadmium (NiCd) cells while also eliminating some of the concerns over use of heavy metals in the cells.

This manual provides an introduction to this exciting new battery technology while presenting recommendations for use of nickel-metal hydride cells that will provide optimum results in battery-powered products.

Advantages of the Nickel-Metal Hydride Cell

The three major benefits of the nickel-metal hydride cells to designers of portable electrical and electronic products are:

- ✦ Improved energy density (up to 40 percent greater than nickel-cadmium cells) which can be translated into either longer run times from existing batteries or reductions in the space necessary for the battery.
- ✦ Elimination of the constraints on cell manufacture, usage, and disposal imposed because of concerns over cadmium toxicity.
- ✦ Simplified incorporation into products currently using nickel cadmium cells because of the many design similarities between the two chemistries.

Typical Applications

The nickel-metal hydride cell is currently finding widespread application in those high-end portable electronic products where battery performance parameters, notably run time, are a major consideration in the purchase decision. First adoption of the nickel-metal hydride cell has occurred in two markets, cellular phones and portable computers, which are growing dramatically thanks to significant reductions in weight and volume coupled with major improvements in performance. Examples of the range of products currently powered by nickel-metal hydride batteries are shown in Figure 1.

Penetration of the nickel-metal hydride cell technology has been strongest in premium electronic products that require premium performance. As production volumes increase and the cell technology and production processes mature, nickel-metal hydride cells are expected to compete aggressively with nickel-cadmium cells in most markets with the possible exceptions of the very high discharge rate and high temperature specialty niches.

Comparison of NiMH and NiCd Cells

Nickel-metal hydride cells are essentially an extension of the proven sealed nickel-cadmium cell technology with the substitution of a hydrogen-absorbing negative electrode for the cadmium-based electrode. While this substitution increases the cell electrical capacity (measured in ampere-hours) for a given weight and volume and eliminates the cadmium which raises toxicity concerns, the remainder of the nickel-metal hydride cell is quite similar to the nickel-cadmium product. Many application parameters are little changed between the two cell types, and replacement of nickel-cadmium cells in a battery with nickel-metal hydride cells usually involves few significant design issues. Table 1 compares key design features between the two cell chemistries.

Table 1 - Summary Comparison of Nickel-Metal Hydride Application Features.

Application Feature	Comparison of Nickel-Metal Hydride to Nickel-Cadmium Batteries
Nominal Voltage	Same (1.25V)
Discharge Capacity	NiMH up to 40% greater than NiCd
Discharge Profile	Equivalent
Discharge Cutoff Voltages	Equivalent
High Rate Discharge Capability	Effectively the same rates
High Temperature (>35°C) Discharge Capability	NiMH slightly better than standard NiCd cells

Charging Process	Generally similar; multiple-step constant current with overcharge control recommended for fast charging NiMH
Charge Termination Techniques	Generally similar but NiMH transitions are more subtle. Backup temperature termination recommended.
Operating Temperature Limits	Similar, but with NiMH, cold temperature charge limit is 15°C.
Self-Discharge Rate	NiMH slightly higher than NiCd
Cycle Life	Generally similar, but NiMH is more application dependent.
Mechanical Fit	Equivalent
Mechanical Properties	Equivalent
Selection of Sizes/Shapes/Capacities	NiMH product line more limited
Handling Issues	Similar
Environmental Issues	Reduced with NiMH because of elimination of cadmium toxicity concerns.

CELL FUNDAMENTALS

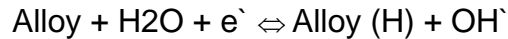
The nickel-metal hydride cell chemistry is a hybrid of the proven positive electrode chemistry of the sealed nickel-cadmium cell with the energy storage features of metal alloys developed for advanced hydrogen energy storage concepts. This heritage in a positive-limited cell design results in batteries providing enhanced capacities while retaining the well-characterized electrical and physical design features of the sealed nickel-cadmium cell design.

Electrochemistry

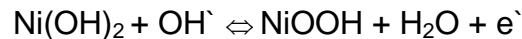
The electrochemistry of the nickel-metal hydride cell is generally represented by the following charge and discharge reactions:

Charge

At the negative electrode, in the presence of the alloy and with an electrical potential applied, the water in the electrolyte is decomposed into hydrogen atoms, which are absorbed into the alloy, and hydroxyl ions as indicated below.

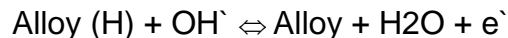


At the positive electrode, the charge reaction is based on the oxidation of nickel hydroxide just as it is in the nickel-cadmium couple.

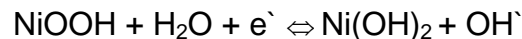


Discharge

At the negative electrode, the hydrogen is desorbed and combines with a hydroxyl ion to form water while also contributing an electron to the circuit.



At the positive electrode, nickel oxyhydroxide is reduced to its lower valence state, nickel hydroxide.



Cell Components

Nickel-metal hydride cells, with the exception of the negative electrode, use the same general types of components as the sealed nickel-cadmium cell.

Negative Electrode

The basic concept of the nickel-metal hydride cell negative electrode emanated from research on the storage of hydrogen for use as an alternative energy source in the 1970s. Certain metallic alloys were observed to form hydrides that could capture (and release) hydrogen in volumes up to nearly a thousand times their own volume. By careful selection of the alloy constituents and proportions, the thermodynamics could be balanced to permit the absorption and release process to proceed at room temperatures and pressures. The general result is shown schematically in Figure 2 where the much smaller hydrogen atom is shown absorbed into the interstices of a bimetallic alloy crystal structure.

Two general classes of metallic alloys have been identified as possessing characteristics desirable for battery cell use. These are rare earth/nickel alloys generally based around LaNi_5 (the so-called AB_5 class of alloys) and alloys consisting primarily of titanium and zirconium (designated as AB_2 alloys). In both cases, some fraction of the base metals is often replaced with other metallic elements. The AB_5 formulation

appears to offer the best set of features for commercial nickel-metal hydride cell applications.

The metal hydride electrode has a theoretical capacity approximately 40 percent higher than the cadmium electrode in a nickel-cadmium couple. As a result, nickel-metal hydride cells provide energy densities that are 20-40 percent higher than the equivalent nickel-cadmium cell.

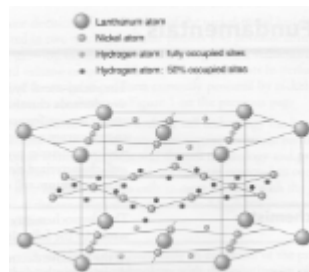


Figure 2.

Schematic of Metal-Alloy Crystal Structure Within Nickel-Metal Hydride Negative Electrode

Positive Electrode

The nickel-metal hydride positive electrode design draws heavily on experience with nickel-cadmium electrodes. Electrodes that are economical and rugged exhibiting excellent high-rate performance, long cycle life, and good capacity include pasted and sintered-type positive electrodes.

The balance between the positive and negative electrodes is adjusted so that the cell is always positive-limited as illustrated in Figure 3. This means that the negative electrode possesses a greater capacity than the positive. The positive will reach full capacity first as the cell is charged. It then will generate oxygen gas that diffuses to the negative electrode where it is recombined. This oxygen cycle is a highly efficient way of handling moderate overcharge currents.

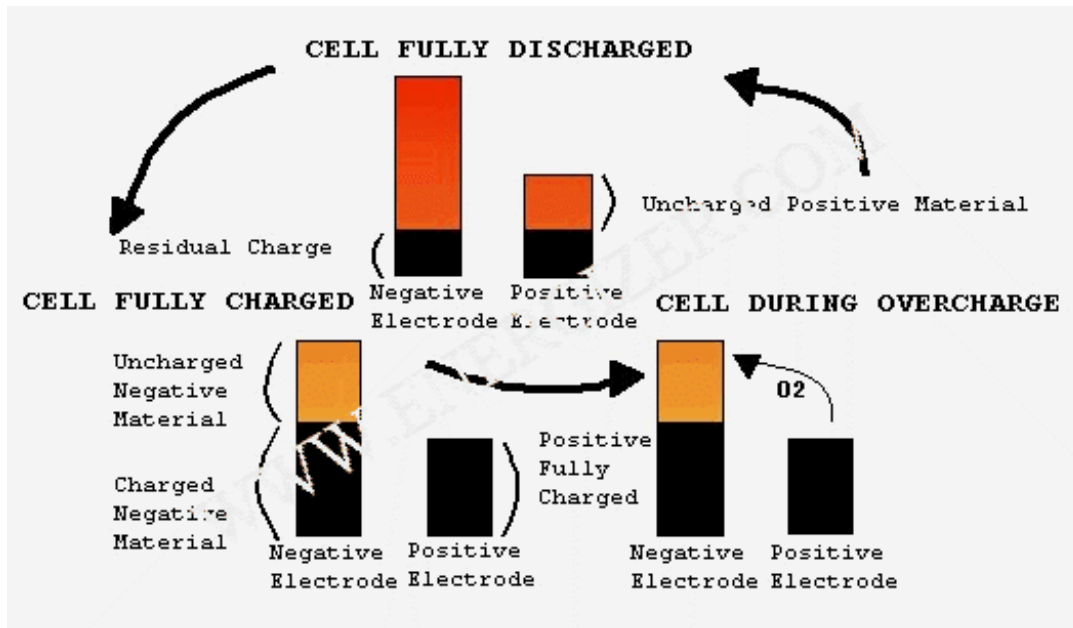


Figure 3.
 Relative Electrode Balances for Nickel-Metal Hydride Cell During Discharge/Charge/Overcharge

Electrolyte

The electrolyte used in the nickel-metal hydride cell is alkaline, a dilute solution of potassium hydroxide containing other minor constituents to enhance cell performance.

Separator

The baseline material for the separator, which provides electrical isolation between the electrodes while still allowing efficient ionic diffusion between them, is a nylon blend similar to that currently used in many nickel-cadmium cells.

Cell Construction

The nickel-metal hydride couple lends itself to the wound construction shown in Figure 4, which is similar to that used by present-day cylindrical nickel-cadmium cells. The basic components consist of the positive and negative electrodes insulated by separators. The sandwiched electrodes are wound together and inserted into a metallic can that is sealed after injection of a small amount of electrolyte.

In variation of this design, nickel-metal hydride cells are also being produced in prismatic versions such as that illustrated in Figure 5. The prismatic cells may fit more easily into volume-critical applications.

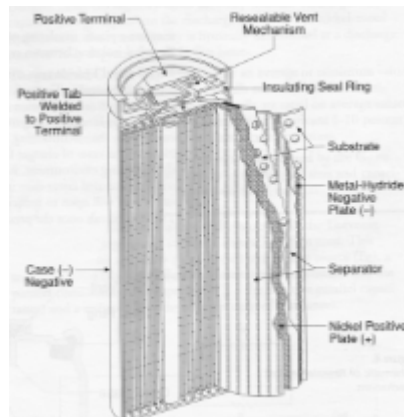


Figure 4.
 Schematic of Cylindrical Cell Construction

The general internal construction of the prismatic cell is similar to the cylindrical cell except the single positive and negative electrodes are now replaced by multiple electrode sets. Thus the trade-off for improved packaging in select applications is increased complexity in cell assembly with the corresponding increases in production cost.

Both cylindrical and prismatic nickel-metal hydride cells are typically two-piece sealed designs with metallic cases and tops that are electrically insulated from each other. The case serves, as the negative terminal for the cell while the top is the positive terminal.

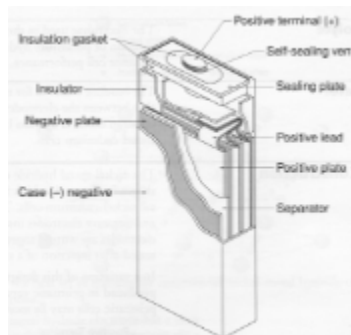


Figure 5.
 Schematic of Prismatic Cell Construction

Some finished cell designs may use a plastic insulating wrapper shrunk over the case to provide electrical isolation between cells in typical battery applications.

Nickel-metal hydride cells contain a resealable safety vent built into the top, as illustrated in Figure 6. The nickel-metal hydride cell is designed so the oxygen recombination cycle described earlier is capable of recombining gases formed during overcharge under normal operating conditions, thus maintaining pressure equilibrium

within the cell. However, in cases of charger failure or improper cell/charger design for the operating environment, it is possible that oxygen, or even hydrogen, will be generated faster than it can be recombined. In such cases the safety vent will open to reduce the pressure and prevent cell rupture. The vent reseals once the pressure is relieved.

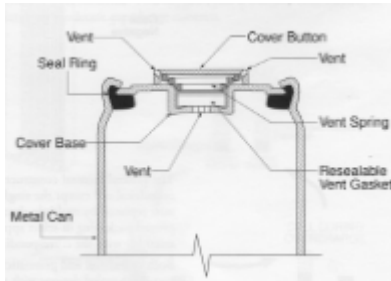


Figure 6.
Schematic of Resealable Vent Mechanism

DISCHARGE PERFORMANCE

The discharge behavior of the nickel-metal hydride cell is generally well suited to the needs of today's electronic products - especially those requiring a stable voltage for extended periods of operations.

Definitions of Capacity

The principal battery parameter of interest to a product designer is usually the run time available under a specified equipment use profile. While establishing actual run times in the product is vital prior to final adoption of a design; battery screening and initial design are often performed using rated capacities. Designers should thoroughly understand the conditions under which a cell rating is established and the impact of differences in rating conditions on projected performance.

The standard cell rating, often abbreviated as **C**, is the capacity obtained from a new, but thoroughly conditioned cell subjected to a constant-current discharge at room temperature after being optimally charged. Since cell capacity varies inversely with the discharge rate, capacity ratings depend on the discharge rate used. For nickel-metal hydride cells, the rated capacity is normally determined at a discharge rate that fully depletes the cell in five hours.

The published **C** value may reflect either an average or minimum value for all cells. Typically nickel-cadmium cells are rated based on minimum values while nickel-metal hydride cells are rated on average values. The difference between the two values may be significant (~ 10 percent) depending on the variability in the manufacturing process.

Many charge and discharge parameters are normalized by the **C** rate since cell performance within a family of varying cell sizes and capacities is often identical when compared on the **C** basis.

Equivalent Circuit

For purposes of electrical analysis of the battery cell, the Thevenin equivalent discharge circuit shown in Figure 7 is often used. This models the circuit as a series combination of a voltage source (E_o), a series resistance (R_h = the effective instantaneous resistance), and the parallel combination of a capacitor (C_p = the effective parallel capacitance) and a resistor (R_d = the effective delayed resistance).

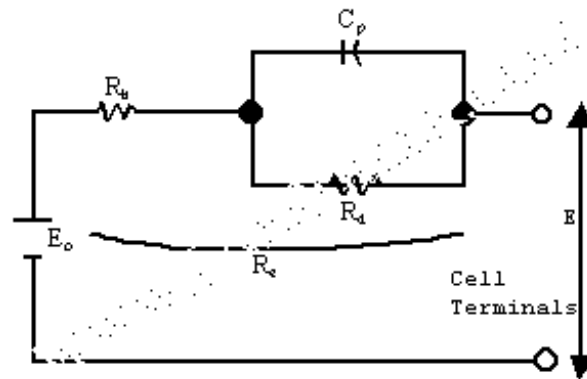


Figure 7.
Equivalent Discharge Circuit for a Nickel-Metal Hydride Cell

- E_o = effective cell no-load voltage
- $R_e = (R_h + R_d)$ = total effective internal resistance
- R_h = effective instantaneous resistance
- R_d = effective delayed resistance
- C_p = effective parallel capacitance
- E = cell termination voltage

For steady state purposes, the cell voltage at a given current is $E_o - iR_e$, where R_e , the effective internal resistance, is the sum of R_h and R_d . The transient response is shown in Figure 8 where the initial voltage drops immediately to $E_o - iR_h$ and then transfers exponentially (with a time constant = $C_p * R_d$) to the steady-state voltage. Obviously the process reverses when the load is reduced or removed. For many applications the steady-state voltage is adequate for describing cell performance since the time constant for most cells is small: usually less than 3 percent of the discharge time. When compared to a nickel-cadmium cell, the steady-state voltage for the nickel-metal hydride cell will be reduced since, although the instantaneous resistance is comparable, the delayed resistance will be on the order of 10 percent higher.

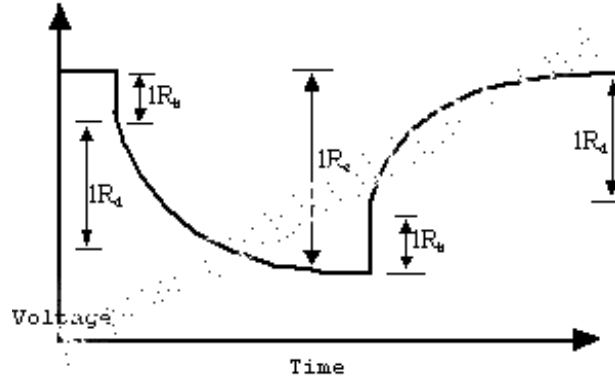


Figure 8.
Example of Transient Voltage Profile for a Nickel-Metal Hydride Cell

Voltage During Discharge

The discharge voltage profile, in addition to the transient effects discussed above, is affected by environmental conditions, notably discharge temperature and discharge rate. However, under most conditions the voltage curve retains the flat plateau desirable for electronics applications.

Shape of Discharge Curve

A typical discharge profile for a cell discharged at the 5-hour rate (the 0.2C rate) is shown in Figure 9. The initial drop from an open-circuit voltage of approximately 1.4 volts to the 1.2 volt plateau occurs rapidly.

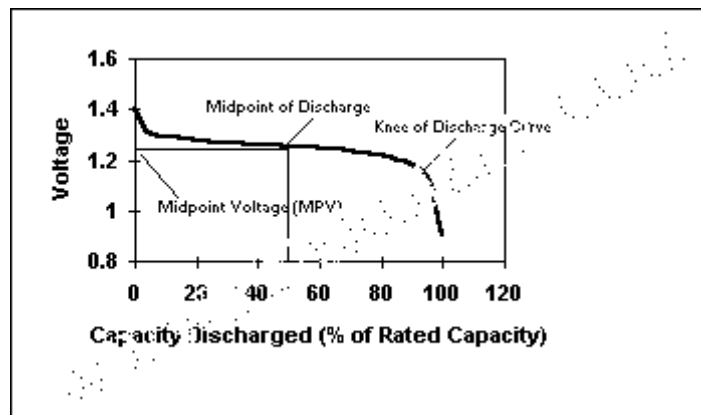


Figure 9.
Typical Discharge Voltage Profile for a Nickel-Metal Hydride Cell

Then, as with nickel-cadmium cells, the nickel-metal hydride cell exhibits a sharp "knee" at the end of the discharge where the voltage drops quickly.

As can be seen by the flatness of the plateau and the symmetry of the curve, the mid-point voltage (MPV - the voltage when 50 percent of the available capacity is discharged) provides a useful approximation to average voltage throughout the discharge.

Environmental Effects

The principal environmental influences on the location and shape of the voltage profile are the discharge temperature and discharge rate.

As indicated in Figure 10, small variations from room temperature ($\pm 10^{\circ}\text{C}$) do not appreciably affect the nickel-metal hydride cell voltage profile. However major excursions, especially lower temperatures, will reduce the mid-point voltage while maintaining the general shape of the voltage profile.

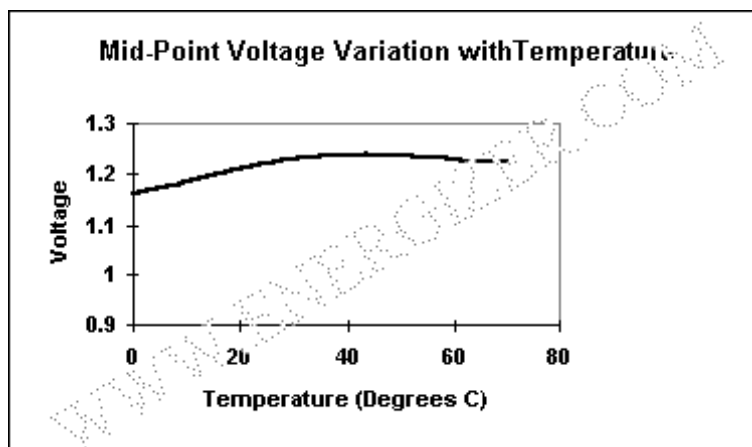


Figure 10.
Mid-Point Voltage Variation with Temperature

Discharge Rate

The effect of discharge rate on voltage profile is shown in Figure 11. There is no significant effect on the shape of the discharge curves for rates under 1C; for rates over 1C; both the beginning and ending transients consume a larger portion of the discharge duration.

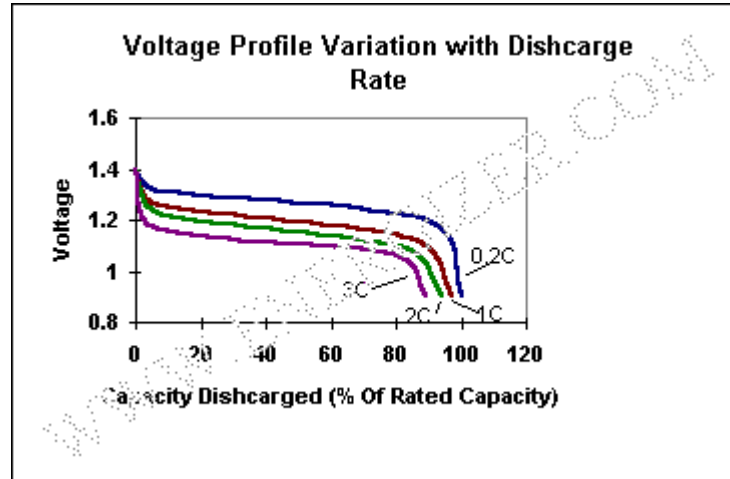


Figure 11.
Voltage Profile Variation with Discharge Rate

Discharge Capacity Behavior

As with the voltage profile, the capacity available during a discharge is dramatically affected by the cell temperature during discharge and the rate of discharge. The capacity is also heavily influenced by the operating history of the cell, i.e. the recent charge/discharge/storage history of the cell. Obviously a cell can only discharge the capacity which has been returned to it from the previous charge cycle less whatever is lost to self discharge. Charging/charge return issues are discussed in the next section while storage and self-discharge is addressed in a later section.

Effect of Temperature

The primary effects of cell temperature on dischargeable capacity, assuming adequate charging, are at lower temperatures ($<0^{\circ}\text{C}$) as shown in Figure 12. Use of nickel metal hydride cells in cold environments may force significant capacity derating from room-temperature values.

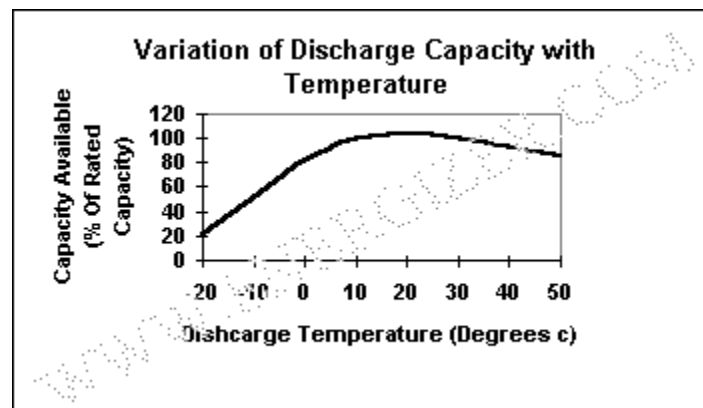


Figure 12.
Variation of Discharge Capacity with Temperature

Effect of Discharge Rate

Figure 13 illustrates the influence of discharge rate on total capacity available. There is no significant effect on capacity for discharge rates below 1C. At the discharge rates above 1C and below the current maximum discharge rate of 4C, significant reductions in voltage delivery occur. This voltage reduction may also result in capacity reduction depending on the choice of discharge termination voltage as discussed on page 11.

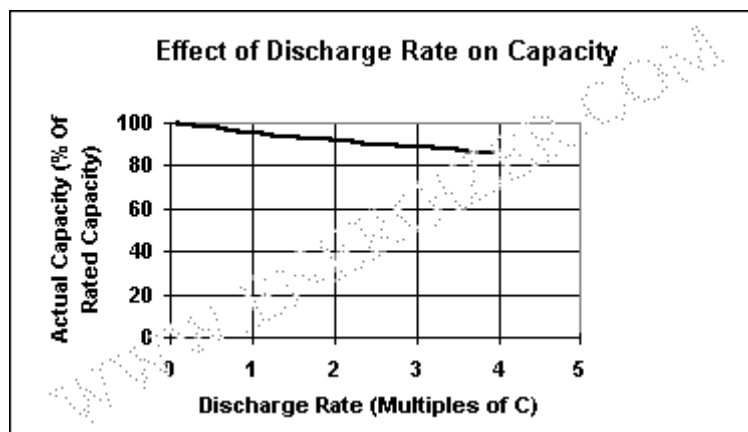


Figure 13.
Effect of Discharge Rate on Capacity

Discharge Application Considerations

In general, the discharge behavior of nickel-metal hydride cells closely follows that of similar nickel-cadmium cells used in the same environment. Thus much of the design expertise gathered for nickel-cadmium cells is directly applicable to nickel-metal hydride cells. Discussed below are some specific issues often raised by designers using nickel-metal hydride cells. As the nickel-metal hydride experience base builds, additional information that will help designers optimize the use of nickel-metal hydride cells is becoming available. For this reason, close consultation with the factory during the design effort is encouraged.

State-of-Charge Measurement

A major issue for users of portable electronics is the run time left before they need to recharge their batteries. Users of portable computers, in particular, expect some form of "fuel gauge" to help them determine when they need to save their work. A variety of schemes for measuring state-of-charge have been suggested. In general, experience with nickel-metal hydride cells indicates that, due to the flatness of the voltage plateau under normal discharge rates, voltage sensing cannot be used to accurately determine state-of-charge.

To date, the only form of state-of-charge sensing found to consistently give reasonable results is coulometry—comparing the electrical flows during charge and discharge to indicate the capacity remaining. Many devices already have the electronics available to perform sophisticated tracking of charge flows including estimation of self-discharge losses. Some off-the-shelf charging circuitry includes this form of charge tracking as part of the package. With careful initial calibration and appropriate compensation for environmental conditions, predictions accurate within 5 to 10 percent of actual capacity can be obtained.

Memory/Voltage Depression

The issue of "memory" or voltage depression has been a concern for many designers of devices, using nickel-cadmium cells. In some applications where nickel-cadmium cells are routinely partially discharged, a depression in the discharge voltage profile of approximately 150 mV per cell has been reported when the discharge extends from the routinely discharged to rarely discharged zones. While the severity of this problem in nickel-cadmium cells is open to differing interpretations, the source of the effect is generally agreed to be in the structure of the cadmium electrode. With the elimination of cadmium in the nickel-metal hydride cell, memory is no longer a concern.

Discharge Termination

To prevent the potential for irreversible harm to the cell caused by cell reversal in discharge, removal of the load from the cell(s) prior to total discharge is highly recommended. The typical voltage profile for a cell carried through a total discharge involves a dual plateau voltage profile as indicated in Figure 14. The voltage plateaus are caused by the discharge of first the positive electrode and then the residual capacity in the negative. At the point both electrodes are reversed, substantial hydrogen gas evolution occurs, which may result in cell venting as well as irreversible structural damage to the electrodes. It should be noted that the nickel-metal hydride cell, because it uses a negative electrode that absorbs hydrogen, might actually be somewhat less susceptible to long-term damage from cell reversal than the sealed nickel-cadmium cell.

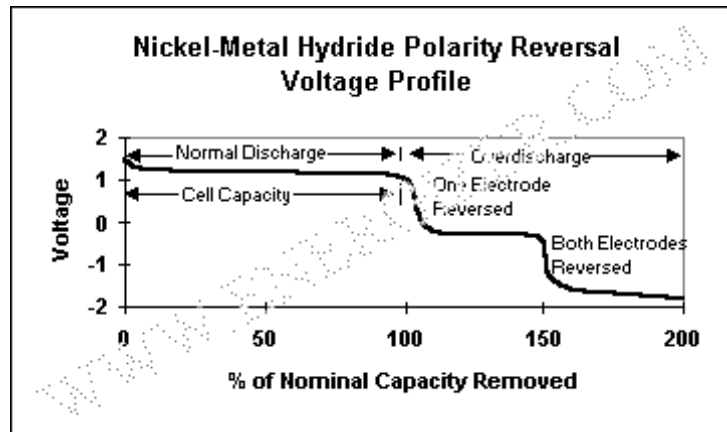


Figure 14.
Nickel-Metal Hydride Cell Polarity Reversal Voltage Profile

The key to avoiding harm to the cell is to terminate the discharge at the point where essentially all capacity has been obtained from the cell, but prior to reaching the second plateau where damage may occur. Two issues complicate the selection of the proper voltage for discharge termination: high-rate discharges and multiple-cell effects in batteries.

Voltage Cutoff at High Rates

Normally discharge cutoff is based on voltage drops with a value of 0.9 volts per cell (75 percent of the 1.2 volt per cell nominal mid-point voltage) often being used. As can be seen in Figure 11, 0.9 volts is an excellent value for most medium to long-term discharge applications (<1C).

However, again as seen in Figure 11, with high drain-rate usage (1-4C), the change in shape in the voltage curve with the more rounded "knee" to the curve means that an arbitrary 0.9V/cell cutoff may be premature, leaving a significant fraction of the cell capacity untapped. For this reason, a better choice for voltage cutoff in high-rate applications is 75 percent of the mid-point voltage at that discharge rate. Note, however, that this choice of end-of-discharge voltage (EODV) is dictated only by considerations of preventing damage to the cell. There may be end-application justification for selection of a higher voltage cutoff with the resulting sacrifice of some potential additional capacity.

Discharge Termination in Batteries

Normal manufacturing variation produces a range of capacities for battery cells. As these cells are combined in batteries, the effects of cell capacity variations are amplified by the number of cells in the battery. Use of termination voltage based on a simple multiple of 0.9V/cell times the number of cells may result in a weaker cell being driven into reverse significantly before the battery reaches the termination voltage. Both charging techniques that minimize the amount of overcharge applied to the cell and

frequent repetitive discharging of the battery may exacerbate the problem. The result may be premature battery failure due to the damage caused by reversal of the weak cell. Experience indicates selection of the EODV by the following formula provides acceptable margin to minimize battery failure from repeated cell polarity reversal:

$$\text{EODV} = [(\text{MPV} - 150\text{mV})(n - 1)] - 200\text{mV}$$

Where **MPV** is the single-cell mid-point voltage at the given discharge rate and **n** is the number of cells in the battery.

Selection of the proper discharge termination voltage, especially for large batteries or complicated application profiles, should be done in consultation with the cell manufacturer.

CHARGE CHARACTERISTICS

Proper charging of nickel-metal hydride cells is the key to satisfaction with their performance in any product. A successful charging scheme balances the need for quick, thorough charging with the need to minimize overcharging, a key factor in prolonging life. In addition, a selected charging scheme should be economical and reliable in use.

In general, the nickel-metal hydride cell appears to be more sensitive to charging conditions than the nickel-cadmium cell. It also has yet to develop the volume of operational data that guides design of nickel-cadmium chargers. For these reasons, charging strategies should be selected and charging parameters established in consultation with the cell manufacturer. One advantage today's application designers do have in developing chargers for nickel-metal hydride cells is the increasing availability of packaged charger circuits.

Charging Summary

The keys to successful charging of nickel-metal hydride cells are:

- ✦ Use a three-step charging strategy to speed return to service while minimizing excessive overcharge.
- ✦ Design for more subtle indications of entry into overcharge.
- ✦ Use redundant fast-charge termination techniques.
- ✦ Provide fail-safe charge-termination backup (thermal fuse, etc.).

When these guidelines are followed, nickel-metal hydride cells can be quickly and reliably charged while maximizing cycle life.

Cell Behavior During Charge

Unlike discharge performance where the behavior of nickel-metal hydride cells and traditional nickel-cadmium cells is very similar, there are significant differences in behavior on charge between the two cell types that relate to basic electrochemical differences. Specifically nickel-cadmium cells are endothermic on charge while nickel-metal hydride cells are exothermic. This difference is manifested in the interrelationships among voltage, pressure, and temperature as discussed below.

Voltage, Pressure, Temperature Interrelationships

Figure 15 sketches typical behavior of a nickel-metal hydride cell being charged at the **C** rate. These curves both indicate why charge control is important and illustrate some of the cell characteristics used to determine when charge control should be applied.

The voltage spikes up on initial charging then continues to rise gradually through charging until full charge is achieved. Then as the cell reaches overcharge, the voltage peaks and then gradually trends down.

Since the charge process is exothermic, heat is being released throughout charging giving a positive slope to the temperature curve. When the cell reaches overcharge where the bulk of the electrical energy input to the cell is converted to heat, the cell temperature increases dramatically.

Cell pressure, which increases somewhat during the charge process, also rises dramatically in overcharge as greater quantities of gas are generated at the **C** rate than the cell can recombine. Without a safety vent, uncontrolled charging at this rate could result in physical damage to the cell.

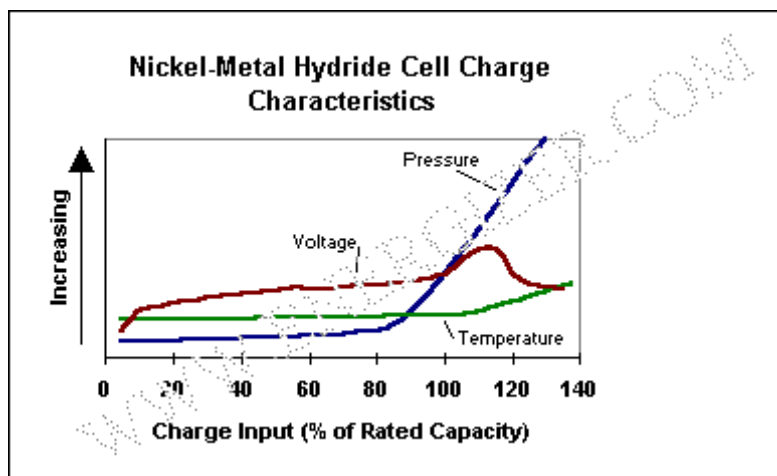


Figure 15.
Nickel-Metal Hydride Cell Charging Characteristics

Charge Acceptance at Temperature

The effect of temperature on charging efficiency (the increase in cell capacity per unit of charge input) is one area of difference between nickel-metal hydride and nickel-cadmium cells. Specifically charge acceptance in the nickel-metal hydride cell (as shown in Figure 16) decreases monotonically with rising temperature beginning below 20°C and continuing through the upper limits of normal cell operation. This contrasts with the nickel-cadmium cell, which has a peak in charge acceptance in the vicinity of room temperature. With either cell type, the drop in charge acceptance at higher temperatures remains a significant concern to product designers who are mounting the cells in close proximity to heat sources or in compartments with limited cooling or ventilation.

Rate Effect on Charge Acceptance

Figure 17 indicates that the charge acceptance efficiency for the nickel-metal hydride cell is improved as the charging rate is increased.

Overcharge Detection

Determining when overcharge has occurred is critical to charging schemes that minimize the amount of time spent at high charge rates in overcharge. In turn, these efficient charging techniques are a key to maximizing cell life, as will be discussed later. Primary charge control schemes typically depend on sensing either the dramatic rise in cell temperature illustrated in Figure 18 or the peak in voltage shown in Figure 19.

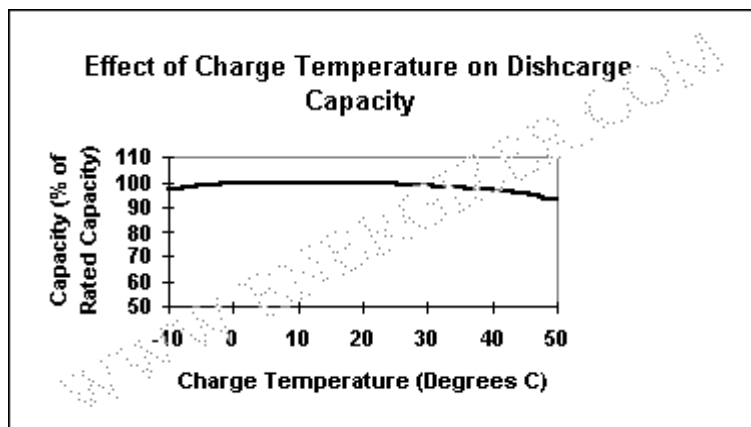


Figure 16.
Effect of Charge Temperature on Discharge Capacity

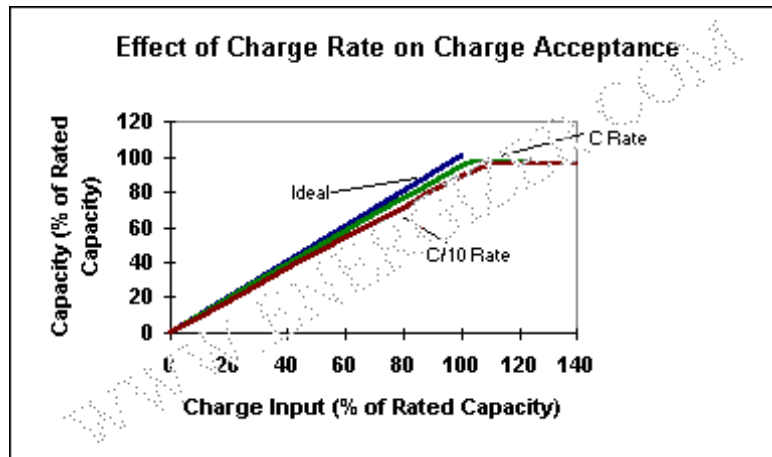


Figure 17.
Effect of Charge Rate on Charge Acceptance

Charge control based on temperature sensing is the most reliable approach to determining appropriate amounts of charge for the nickel-metal hydride cell. Temperature-based techniques are thus recommended over voltage-sensing control techniques for the primary charge control mechanism.

Recommended Charging Rates

Today's trend to faster charge times requires higher charge rates than the 0.1 to 0.3C rates often recommended for many nickel-cadmium charging systems. Both Figures 18 and 19 indicate that fast-charge rates serve to accentuate the slope changes used to trigger both the temperature and voltage-related charge terminations. A charge rate of 1C is recommended for restoring a discharge cell to full capacity. For charging schemes that then rely on a timed "topping" charge to ensure complete charge, a rate of 0.1C appears to balance adequate charge input with minimum adverse effects in overcharge. Finally a maintenance (or trickle) charge rate of 0.025C (C/40) is adequate to counter self-discharge and maintain cell capacity.

Effective Charging Strategies

Products using nickel-metal hydride cells often make use of the sophistication of today's chip-level packaged charging systems to tailor the charging profile to fast capacity recovery while minimizing overcharge stress. Two general classes of strategies have evolved:

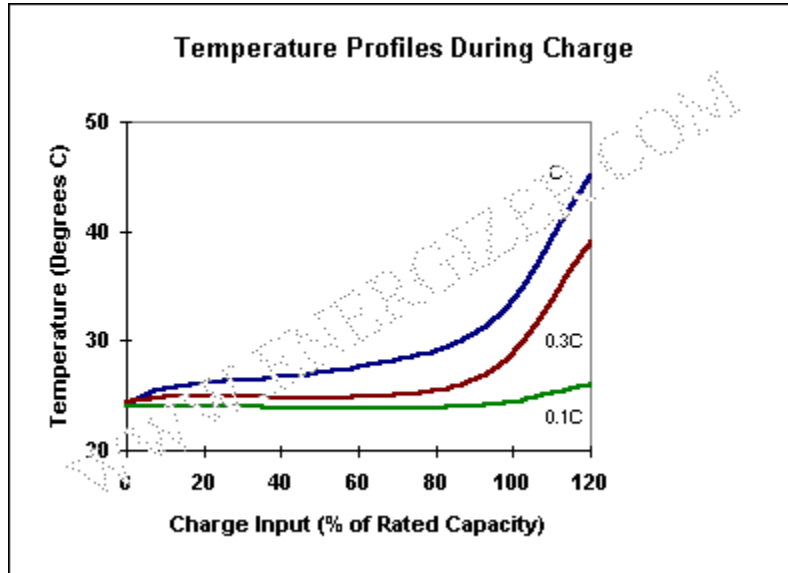


Figure 18.
Temperature Profiles During Charge

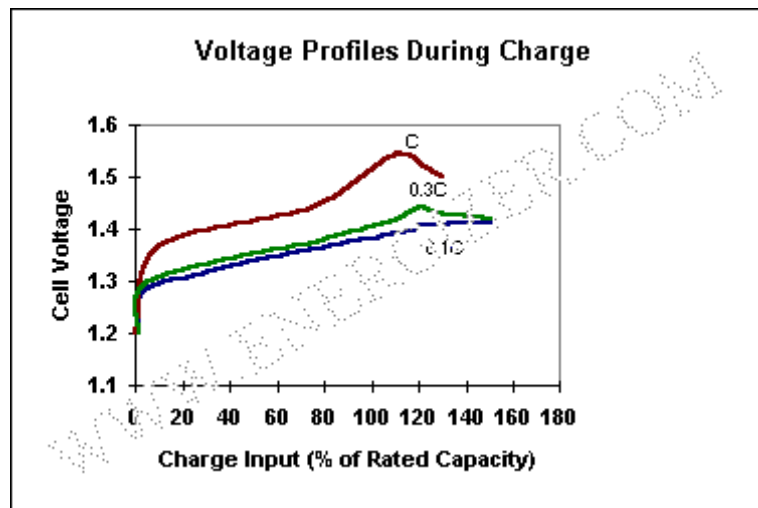
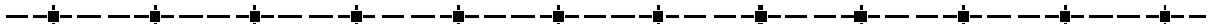


Figure 19.
Voltage Profiles During Charge

Two-Stage—This approach uses a timer to switch from the initial charge rate to the maintenance charge rate. Because there is no sensing of the cell’s transition into overcharge, the charge rate must be kept low (0.1C) to minimize overcharge-related impact on cell performance and life. Charge durations are typically set at 16 to 24 hours to ensure full recharge in cases of complete discharge. Although economical, since this scheme makes no allowance for the degree of discharge or for environmental conditions, its use is rarely recommended for typical nickel-metal

hydride applications.

✦ **Three-Stage**—Here a fast charge restores approximately 90 percent of the discharged capacity, an intermediate timed charge completes the charge and restores full capacity, then a maintenance charge provides a continuous trickle current to balance the cells and compensate for self-discharge. The fast charge (with currents in the $1C$ range) is typically switched to the intermediate charge using a temperature-sensing technique, which triggers at the onset of overcharge. The intermediate charge normally consists of a $0.1C$ charge for a timed duration selected based on battery pack configuration. This intermediate-charge replaces the need to fast-charge deeply into the overcharge region to ensure that the cell has received a full charge. Three-step charging, such as illustrated in Figure 20, requires greater charger complexity (to incorporate a second switch point and third charge rate), but reduces cell exposure to life-limiting overcharge.



Charging System Redundancy

Because of the sensitivity of cell life to overcharge history and the greater subtlety of some of the overcharge transitions, charge termination redundancy in charger design is recommended. This applies to both built-in redundant charge control techniques and fail-safe charge termination techniques such as thermal fusing. Both of these considerations are discussed in more detail in the cell and battery design sections.

Temperature-Based Charge Control

Use of charge control based on the temperature rise accompanying the transition of the cell to overcharge is generally recommended because of its reliability (when compared to voltage peak sensing techniques) in sensing overcharge. However, temperature sensing is typically more expensive to implement than voltage sensing since it requires additional sensors. The exothermic nature of the nickel-metal hydride charge process (as illustrated in Figure 18) results in increasing temperature throughout charging. This requires care in selection of setpoints to avoid premature charge termination.

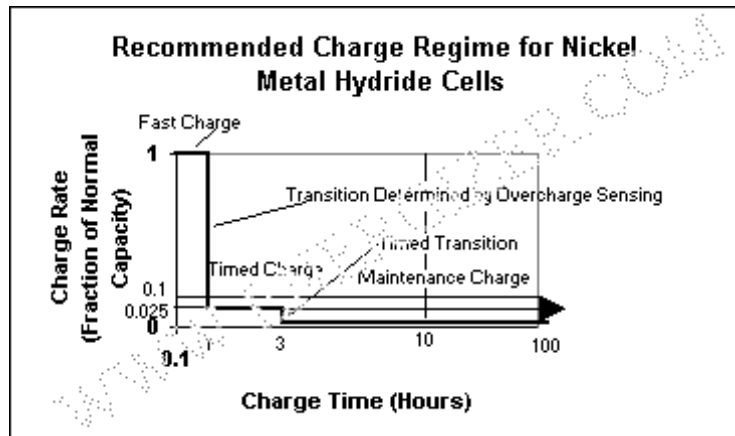


Figure 20.
Recommended Charge Regime for Nickel-Metal Hydride Cells

Charge switching based on the change in slope of the temperature profile eliminates much of the influence of the external environment and can be a very effective technique for early detection of overcharge in a three-step charging scheme.

The simple form of temperature-based switching is to use an absolute increment in temperature from the start of charging e.g. a 20°C increase in cell temperature from onset of charge. The chosen ΔT has to account for both normal temperature gain during charge and the spike at overcharge. Selection of the proper temperature increment can be greatly influenced by the environment surrounding the cell. Thus it should be done based on bench testing of the cell in the application and done after consultation with the cell manufacturer.

Maximum Temperature

Charge switching based on the absolute cell temperature (as opposed to temperature increment) is subject to varying use patterns—Alaska or the Sahara—and is recommended only as a fail-safe strategy to avoid destructive heating in case of failure of the primary switching strategy.

Voltage-Based Charge Control

Charge control based on voltage changes is attractive because it can be accomplished using only existing leads to the battery, eliminating the expense and complexity of additional temperature-sensing leads to the cell. However, the voltage peak typically occurs later in the overcharge process, the voltage overcharge is not as distinct as that seen with temperature, and the voltage behavior may change with cycling. For these reasons, most product designers choose to use voltage-sensing techniques only as backups to temperature-based control.

Despite the concerns voiced above, Figure 19 does indicate a significant knee to the voltage early in overcharge when charging at the 1C rate. Sensing this slope change in a dV/dt system can provide an effective economical approach to detecting early entry to overcharge.

Sensing the absolute voltage rise, if carefully performed, can be a useful charge control strategy. It can be most easily utilized if cells are usually fully discharged prior to recharge. This approach is subject to the same caveats mentioned previously regarding consultation and bench-level verification.

Since the voltage does peak during overcharge, switching on the voltage decrease is feasible. This eliminates the concerns faced in both voltage and temperature increment methods about determining the increment that ensures charge return without excessive overcharge.

Magnitude

Charge control through the absolute value of the voltage is relatively imprecise and unsuited for primary charge-control techniques. It can be used as a redundant control technique in, for example, a dV/dt scheme.

Time-Based Charge Control

Timer-controlled charging systems are the simplest and most economical of all charging strategies. However, to avoid adverse effects on cell life and performance, charging rates must be limited to 0.1C, which constrains time-based charging to those products where overnight return of charge is acceptable. In typical application scenarios where the degree of discharge varies widely, a charging system using time as the primary control variable will either undercharge or overcharge the battery. However, time-based redundant charge termination and/or time-based control of intermediate charging (topping charge) in a three-step system are often key elements of an integrated charge-control strategy.

Environmental Influences on Charging Strategy

The discussions above are most pertinent for devices operating in the room-ambient range. Designers of products predominantly operating at either temperature extreme should consult closely with their cell suppliers in designing their charging system.

High Temperature

Although high-temperature performance (in the 40 to 55°C range) is equivalent or even slightly better than the standard nickel-cadmium product, charging of nickel-metal hydride cells in high-temperature environments requires careful attention for two reasons: (1) the selection of setpoints, for both temperature and voltage-sensing systems, can be affected if the cells are already at elevated temperatures prior to

starting charge; and (2) charge duration may have to be extended due to the charge acceptance inefficiencies illustrated in Figure 16.

Low Temperature

Even though low temperature charge acceptance is better for the nickel-metal hydride cell than for nickel-cadmium cells, designers must ensure that low temperatures do not adversely affect their charge-control scheme. The charge time increases at lower temperatures so charge durations must be carefully considered to provide adequate low-temperature charging while avoiding excessive charge at normal temperatures. Charge rates must also be reduced at low temperatures. An upper limit of 0.1C is recommended below 15°C. Charging below 0°C is not advisable. Consult the factory for more details on low-temperature charging.

Available Battery Charging Systems

Traditionally, application designers tailored their charging system to their application. With the rapid evolution of chip-based charging circuitry, designers can now use standardized designs providing a sophisticated charging scheme while allowing the designer wide latitude in selecting charge parameters. Such systems are available from a variety of sources including both cell manufacturers and integrated-circuit design houses, in forms ranging from basic chip to complete charger packages.

STORAGE

Essentially all rechargeable battery cells gradually discharge over time whether they are used or not. This capacity loss is typically due to slow parasitic reactions occurring within the cell. As such, the loss rate (self-discharge rate) is a function of the cell chemistry and the temperature environment experienced by the cell. Due to the temperature sensitivity of the self-discharge reactions, relatively small differences in storage temperature may result in large differences in self-discharging rate. Extended storage with a load connected not only speeds the discharge process, but may also cause chemical changes after the cell is discharged, which may be difficult or impossible to reverse.

Cell and battery storage issues of concern to most application designers relate either to the speed with which the cells lose their capacity after being charged or the ability of the cells to charge and discharge "normally" after storage for some period of time. In both situations, general guidelines developed for nickel-cadmium cells will work acceptably for nickel-metal hydride cells.

Retained Capacity

Figure 21 illustrates the amount of capacity available from nickel-metal hydride cells after standing for a given number of days in four different thermal environments. The

common rule of thumb for nickel-cadmium cells that a 10°C increase in storage temperature halves the time required for a cell to self-discharge to a given level remains approximately correct for nickel-metal hydride cells.

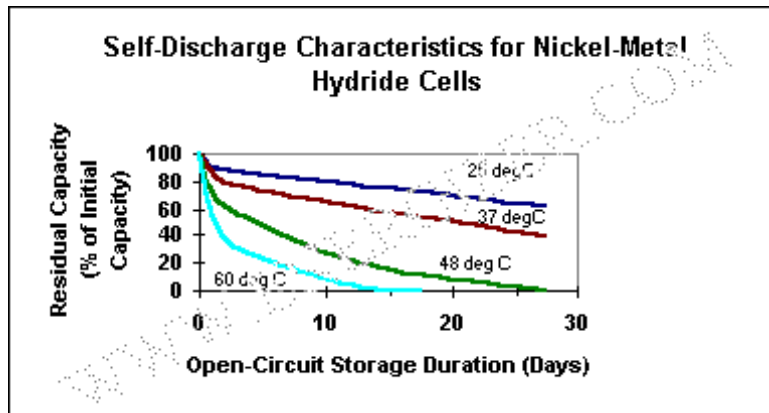


Figure 21.
Self-Discharge Characteristics for Nickel-Metal Hydride Cells

Recommended Storage Conditions

Storage recommendations for nickel-metal hydride cells parallel those for nickel-cadmium cells:

- ✦ Store at the lowest feasible temperatures (-20°C to 30°C being the generally recommended storage temperatures).
- ✦ Store cells/batteries open-circuit to eliminate loaded storage effects (see next page).
- ✦ Store in a clean, dry, protected environment to minimize physical damage to batteries.
- ✦ Use good inventory practices (first in, first out) to reduce time cells spend in storage.

Capacity Recovery After Storage

In normal practice, stored cells will provide full capacity on the first discharge after removal from storage and charging with standard methods. Cells stored for an extended period or at elevated temperatures may require more than one cycle to attain pre-storage capacities. Consultation with the manufacturer is recommended if prolonged storage and rapid restoration of capacity is planned.

Loaded Storage

Cells and batteries intended for storage for extended periods of time (past the point where they are fully discharged) should be removed from their load. In particular, many portable electronic devices place a very low-level drain requirement on their batteries even when in the "off" position. These micro-current loads may be sustaining volatile

memory, powering sense circuits or even maintaining switch positions. Such loads should be eliminated when storing devices for protracted periods.

When nickel-metal hydride cells are stored under load, small quantities of electrolyte can ultimately begin to seep around the seals or through the vent. This creep leakage may result in the formation of crystals of potassium carbonate, which detract cosmetically from the appearance of the cell. In extreme cases, creep leakage can result in corrosion of cells, batteries, or the adjoining componentry. Although such occurrences are rare, positive methods of electrically isolating the cell, such as an insulating tape over the positive terminal or removal from the product are suggested for applications requiring extended storage of cells.

LIFE

A key determinant of the economic and practical feasibility of using nickel-metal hydride cells and batteries in portable electronic applications is the cell's cycle life: the ability of the nickel-metal hydride cell to deliver acceptable capacity on a repetitive basis. Nickel-metal hydride cell cycle life has received intensive development attention with the result that operational life expectations are now competitive with those for nickel-cadmium cells.

Limiting Mechanisms

The life of any battery cell is determined by a combination of abrupt failure events and gradual cell deterioration. With the nickel-metal hydride cell, abrupt failures, typically mechanical events resulting in the cell either shorting or going open-circuit, are relatively rare and randomly distributed. Cell deterioration can take two forms:

- ✘ Oxidation of the negative active material that increases cell internal resistance resulting in reduction of available voltage from the cell (MPV depression). This also affects the balance between electrodes within the cell and may possibly result in reduced gas recombination, increased pressure, and ultimately, cell venting.
- ✘ Deterioration of the positive active material results in less active material being available for reaction with the consequent loss of capacity.

Both phenomena result in a loss of usable capacity, but pose differing design issues. Mid-point voltage depression requires that the application design be able to adapt to variations in supply voltage from cycle to cycle. Capacity reduction simply requires that initial cell selection be sized to provide adequate capacity at end-of-life for the desired number of cells.

The actual mechanism that will determine cell life may vary depending on application parameters and the cell characteristics. Development work has reduced oxidation in the negative electrode reducing the depression in MPV as the cell ages.

Factors Affecting Life

The way the nickel-metal hydride cell is designed into an application can have dramatic effects on the life of the cell. This is especially true of the design of the charging circuitry for the application to ensure adequate return of charge while minimizing overcharge. In fact, effective control of overcharge exposure, time and charge rate is the way of enhancing cell life.

Charge Regime

In general, tailoring the charge regime to the application use scenario is even more important with nickel-metal hydride cells than with nickel-cadmium cells because of the increased subtlety of the voltage and temperature indications of full charge and the greater sensitivity of cell life to overcharge history.

Degree of Overcharge

Establishing the appropriate degree of overcharge for a battery-powered application is dependent on the usage scenario. Some overcharge of the battery is vital to ensure that all cells are fully charged and balanced, but maintenance of full charge currents for extended periods once the cell has reached full charge can reduce life. The three-step charge process works to minimize some of the overcharge stress. Details of the charging process and the application context should be carefully reviewed with the cell manufacturer to ensure maximum cell life for the specific application.

Exposure to High Temperatures

In general, higher temperatures accelerate chemical reactions including those, which contribute, to the aging process within the battery cell. High temperatures are a particular concern in the charging process as charge acceptance is reduced. Sensing the transition from charge to overcharge is also more difficult at higher temperatures. Although early data indicate that nickel-metal hydride cells may tolerate high-temperature charging better than standard nickel-cadmium cells, close consultation with the cell manufacturer is encouraged to select a charging strategy that meets operational requirements while maximizing cell life.

Cell Reversal

Discharge of nickel-metal hydride batteries to the degree that some or all of the cells go into reverse can shorten cell life, especially if this overdischarge is repeated routinely.

Prolonged Storage under Load

Maintaining a load on a cell (or battery) past the point of full discharge may eventually cause irreversible changes in the cell chemistry and promote life-limiting phenomena such as creep leakage.

DESIGNING FOR NICKEL-METAL HYDRIDE CELLS

Incorporation of nickel-metal hydride cells into applications is generally straightforward, particularly for designers accustomed to designing with nickel-cadmium cells. Primary differences between the two cell chemistries are:

- ✦ Nickel-metal hydride cells offer higher energy densities.
- ✦ Environmental and occupational health issues relating to cadmium are eliminated with nickel-metal hydride cells.
- ✦ More care is required in design of nickel-metal hydride charging systems.
- ✦ Since nickel-metal hydride cells may emit hydrogen in heavy overcharge or overdischarge, both charge-control redundancy and location of the battery package in the product deserve careful scrutiny.
- ✦ Nickel-metal hydride cells have yet to offer the wealth of sizes and design variations found in the mature nickel-cadmium line.

Capacity Guide

A convenient aid to early analysis of battery systems is the cell selection guide shown in Figure 22.

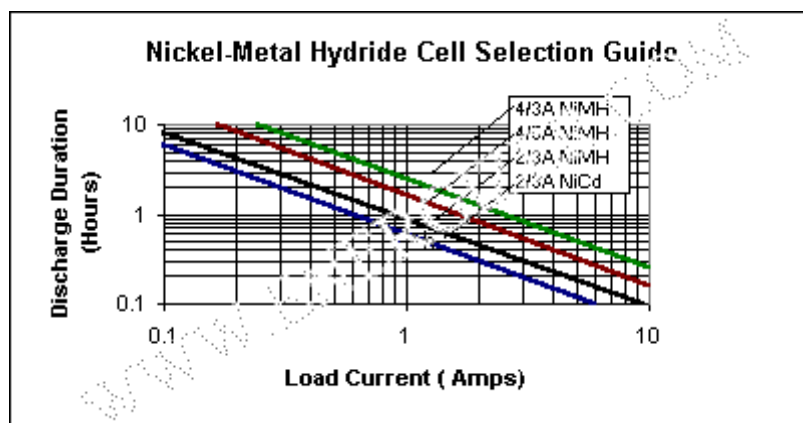


Figure 22.
Nickel-Metal Hydride Cell Selection Guide

This chart allows estimation of the run times available from specified cell sizes when exposed to a given constant discharge rate. Included on the chart are nickel-metal

hydride cell sizes available from the manufacturer at the publication date. Other sizes are being added rapidly; consult the manufacturer for an updated capacity guide covering existing offerings. Note that comparison information is also provided for one size of nickel-cadmium cell to allow estimation of the actual performance increment achieved with nickel-metal hydride cells.

Typical use for the capacity guide is to enter the guide with a given discharge rate. The intersection of that discharge rate with the performance line for each cell size then indicates the amount of run time nominally available from that cell. The values provided by this guide should be used for planning purposes only; final cell selection should be based on actual discharge times obtained from testing under realistic application scenarios.

Materials of Construction

The materials of construction for the nickel-metal hydride cell external surfaces are, like the nickel-cadmium cell, largely comprised of nickel-plated steel, and therefore, are resistant to attack by most environmental agents.

Orientation

Nickel-metal hydride cells will operate satisfactorily in any orientation.

Environmental Suitability

The nickel-metal hydride cell is designed to operate effectively in all environments normally experienced by portable electronic equipment. Application designers intending to use nickel-metal hydride cells in especially adverse environments should consult closely with the cell manufacturer to ensure design suitability.

Temperature

Like most other battery cells, nickel-metal hydride cells are most comfortably applied in a near-room-temperature environment (-25°C); however, with careful attention to design parameters, they can be successfully utilized when exposed to a much wider range of temperatures.

Operating

Nickel-metal hydride cells can be successfully applied in temperatures from 0 to 50°C with appropriate derating of capacity at both the high and low ends of the range. Design charging systems to return capacity in high or low temperature environments without damaging overcharge requires special attention.

Storage

Cells are best stored in temperatures from 0 to 30°C although storage for limited periods of time at higher temperatures is feasible.

Shock and Vibration

Expect nickel-metal hydride cells to easily withstand the normal shock and vibration loads experienced by portable electronic equipment in day-to-day handling and shipping. Consult with the cell manufacturer regarding applications required operation in more intense shock and vibration environments.

Ventilation and Isolation

The primary gas emitted from the nickel-metal hydride cell when subjected to excessive overcharge is hydrogen as opposed to oxygen for the nickel-cadmium cell. Although venting of gas to the outside environment should not occur in a properly designed application, isolation of the battery compartment from other electronics (especially mechanical switches that might generate sparks) and provision of adequate ventilation to the compartment are required to eliminate concerns regarding possible hydrogen ignition.

Isolation of the battery from heat-generating componentry and ventilation around the battery will also reduce thermal stress on the battery and ease design of appropriate charging systems.

Termination

Since the exterior of the nickel-metal hydride cell is nearly identical to that of the nickel-cadmium cell, all termination procedures accepted for the nickel-cadmium cell apply equally well to the nickel-metal hydride cell. The recommendation against use of mechanical (pressure) contacts in favor of welded terminations, especially to nickel-metal hydride cells. The prohibition against soldering directly to the cell to prevent heat damage to plastic seal components also applies.

Other Selections Considerations

To date, applications for nickel-metal hydride cells have been focused on electronics that have nominal drain rates of 2C or less. As a result, cell internal current-carrying components such as tabs and current collectors have not been designed for high currents such as found in portable tools and appliances. Although there appear to be no intrinsic constraints on discharge rates imposed by cell chemistry, existing cell designs are for applications with maximum currents of less than 4C.

BATTERY DESIGN

Nickel-metal hydride cells are versatile performers easily adapted to most application demands. Existing design libraries for nickel-cadmium cells can usually be easily

modified to incorporate nickel-metal hydride cells instead. Economical off-the-shelf designs can be tailored to the specific voltage, space, and termination requirements of an application.

Figure 23 illustrates a typical battery installation within a representative application, while Figure 24 diagrams many of the components recommended for a nickel-metal battery.

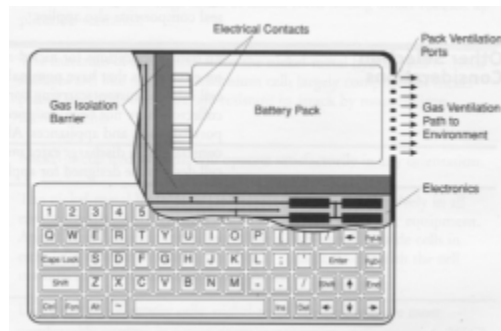


Figure 23.
Installation Within Typical Application (Notebook Computer)

Packaging Considerations

Nickel-metal hydride batteries are generally packaged in two forms:

Hard plastic cases are recommended for applications requiring the end-user to handle the battery. These cases offer greater protection against handling damage and shock and vibrations stresses. But depending on the design, thermal management may be more difficult within the hard case.

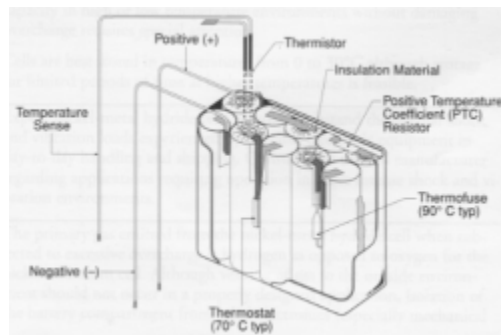


Figure 24.
Elements of Battery Assembly

Injection molding of hard cases requires a substantial investment for mold construction and is thus best suited for high volumes.

Lighter shrink-wrapped plastic packaging may be used when routine battery removal is not expected. These packs, as illustrated in Figure 24, usually consist of the cell assembly with insulators covering the exposed terminals. Plastic shrink tubing then covers the whole pack. Shrink-wrapped batteries have acceptable mechanical integrity for assembly, and when properly secured, withstand normal portable-product shock and vibration levels. Shrink packaging provides ample opportunity for hydrogen to diffuse and for internally generated heat to dissipate. Additional insulation from heat may be needed at the tangent points within the cell stacks (where they shrink material directly contacts the cell).

Either type of packaging must maintain adequate ventilation to the individual cells while providing room for cell interconnections, battery terminations, and requisite charge control sensors.

Shape

Battery shapes can be adjusted to fit application constraints. Among the most popular battery shapes are the following:

- ✳ Sticks—the terminal of one cells butts against the base of the next cell forming a long, slender battery.
- ✳ Linear—the cells are placed side by side in a straight line.
- ✳ Paired—cells are arranged in two (or more) symmetric rows.
- ✳ Nested—the cells of one row are nested within the indentations formed by the adjacent row.

Materials

Materials used in the assembly of nickel-metal hydride batteries must withstand the high temperature environment that accompanies venting of the cell. Because of the exothermic nature of the charging process, should cells vent in overcharge, the vented gases will be largely high-temperature hydrogen (>200°C). Although these gases will quickly disperse and cool, all materials used in cell construction must be capable of withstanding elevated temperatures while remaining inert in a hydrogen environment. Recommended materials for use in nickel-metal hydride battery construction include those below. Consult with the cell manufacturer regarding specific material specification details.

Wires: All wire insulation should be Teflon[®], Kapton[®], or other material with a minimum temperature rating of 200°C.

Sleeving: All shrink sleeving should be able to withstand 200°C. PVC sleeving is not generally recommended. Kraft paper or fishpaper sleeving should be approximately 0.007 inches thick.

Insulation: All cell insulation should be able to withstand 105°C for 24 hours. Vent shields must be constructed of Nomex[®] or other insulating material capable of withstanding 210°C.

Case Material: Plastic cases must meet UL 9V40. Case materials without a rating of 210°C DTUL (Deflection Temperature Under Load) must be provided with vent shields over the positive ends of the cells.

Interconnections and Terminations

Cell interconnections typically consist of nickel (Ni200) strip spot-welded from one cell terminal to the adjacent cell's case. Nickel bus strips offer good conductivity, ease of welding, and resistance to corrosion. Minimum recommended nickel strip size is 0.187 inches wide by 0.005 inches thick. Wire interconnections are rarely used because of the difficulty in attachment since soldering directly to cells is forbidden.

Battery terminations come in a variety of configurations ranging from simple flying leads (wires soldered to weld lugs which are then welded to the cells) in permanent installations to much more elaborate contact or connector systems on removable battery packs. Removable battery packs should be designed with a connection system that produces a minimum of 2 pounds of force while incorporating a wiping action on insertion to cut through oxide layers on the connection surfaces

Other Components

Nickel-metal hydride batteries typically require more components than nickel-cadmium batteries because of the emphasis on careful, redundant charge control including adequate fail-safe charge termination in case of excessive temperatures. These components include the follows:

PTC Resistor: Positive temperature coefficient resistors such as Raychem's PolySwitch[®] circuit protector provide a latching, but resettable device for protection against short-circuit conditions.

Thermostat: Thermostats or other resettable thermal control devices are typically used for backup to the primary charge control system to guard against extended overcharge and the resulting elevated temperatures.

Thermal Fuse: Thermal fuses that open at a suitably elevated temperature (nominally 90°C) are often used as a third tier of thermal protection (after the normal charge control system and thermostat). They are a fail-safe measure since the battery charging system will become inoperative.

Thermistor: Thermistors are normally used for the temperature sensing necessary for recommended charge control schemes.

Standard Configurations

A wide variety of standard battery configurations have been developed by cell manufacturers encompassing permutations of cell size/capacity, voltage, terminations, and charge control and termination sensors.

As a minimum, Energizer Power Systems recommends that the following be included in any standard battery design:

- ✘ Primary Charge Control System—The standard temperature or time-based charge control system to switch to maintenance charging.
- ✘ Backup Resettable Thermal Protection—Terminates charging if the primary control system should fail to switch prior to extended overcharge. Normally set to 70°C.
- ✘ Fail-Safe Thermal Fuse—Permanently opens charge circuit if battery temperature exceeds acceptable limits. Normally set to 90°C.
- ✘ Short-Circuit Protection—Provides protection in cases of excess discharge current.
- ✘ Vents and Vent Shielding—Gas management system to diffuse and cool a vented stream of hydrogen.

Location

While battery location is generally influenced by product design constraints such as available space, influence on center of gravity, and ease of access, battery locations should also provide adequate ventilation, isolation from ignition sources and separation from major heat generators.

CARE AND HANDLING

Nickel-metal hydride cells should be handled in much the same manner as nickel-cadmium cells. Major points are summarized below. Contact the cell manufacturer for additional information pertinent to specific applications.

General Safety Precautions

Nickel-metal hydride cells are generally well behaved; however, like any rechargeable cell, they should be treated with care. Issues in dealing with nickel-metal hydride cells include the following:

- ✘ Nickel-metal hydride cells operate on an exothermic, hydrogen-based charging and oxygen recombination process. Precautions should be taken to avoid venting. Should venting occur, the vent gases must be properly managed.
- ✘ Nickel metal hydride cells can generate high currents if shorted. These currents are

sufficient to cause burns or ignition of flammable materials.

- ✘ The active materials in the negative electrode can ignite on exposure to air. The electrolyte is also corrosive and capable of causing burns. For these reasons, the cell should be maintained intact and sealed.

Shipping and Handling

Shipping and handling of nickel-metal hydride cells is straightforward. The following suggestions ensure maximum performance, reliability, and safety in working with the cells:

- ✘ Ship cells only in fully discharged state.
- ✘ Provided proper packaging, considering the cells' and batteries' weight, to avoid transit damage, either to cells or adjacent items.
- ✘ Do not store cells or batteries in loaded or shorted condition.
- ✘ Use product on a first-in, first-out inventory management policy.
- ✘ Avoid keeping excessive product in inventory.
- ✘ Avoid excessive handling of charged cells and batteries outside the end-use product.

Disposal

Although disposal procedures for nickel-metal hydride cells are still evolving, as a minimum, observe the following precautions:

- ✘ Discharge fully prior to disposal.
- ✘ Do not incinerate.
- ✘ Do not open or puncture cells.
- ✘ Observe all national, state, and local rules and regulations for disposal of rechargeable cells.

Incoming Inspection

Normal incoming inspection techniques consist of physical examination of the cells for any dents, bulges, or leakage and selection of a representative sample for capacity testing. In general 100 percent capacity testing is discouraged because of the cost/schedule impact. Specialized incoming test procedures are normally developed for each application by consultation between the product designer and the cell manufacturer.

This reference manual contains general information on all Energizer/Eveready batteries within the Nickel Metal Hydride chemical system in production at the time of preparation of the manual. Since the characteristics of individual batteries are sometimes modified, persons and businesses that are considering the use of a particular battery should contact the nearest Energizer Sales Office for current information. None of the information in the manual constitutes a representation or warranty by Eveready Battery Company, Inc. concerning the specific performance or characteristics of any of the batteries or devices.