4.0 NiCd Batteries

4.1 NiCd Principles of Operation

In the uncharged condition the positive electrode of a nickel-cadmium cell is nickelous hydroxide, the negative is cadmium hydroxide. In the charged condition, the positive electrode is nickelic hydroxide, the negative metallic is cadmium. The electrolyte is potassium hydroxide. The average operating voltage of the cell under normal discharge conditions is about 1.2 volts.

4.2 NiCd Charging Discharging Chemical Reaction

Figure 4.1 NiCd Chemical Equations

Positive Electrode: $Ni(OH)_2 + OH^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftarrows}} NiOOH + H_2O + e^-$

Negative Electrode: $Cd(OH)_2 + 2e^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftarrows}} Cd + 2OH^-$

Overall Reaction: $Cd(OH)_2 + 2Ni(OH)_2 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftarrows}} Cd + 2NiOOH + 2H_2O$

4.3 NiCd Charge Chemical Reactions

During the latter part of a recommended charge cycle and during overcharge, nickel-cadmium batteries generate gas like Nickel Metal Hydride batteries. Oxygen is generated at the positive (nickel) electrode after it becomes fully charged and hydrogen is formed at the negative (cadmium) electrode when it reaches full charge. These gases must be vented from the conventional nickel-cadmium system. In order for the system to be over chargeable while sealed, the evolution of hydrogen must be prevented and provisions made for this reaction of oxygen within the cell container. These things are accomplished by the following:

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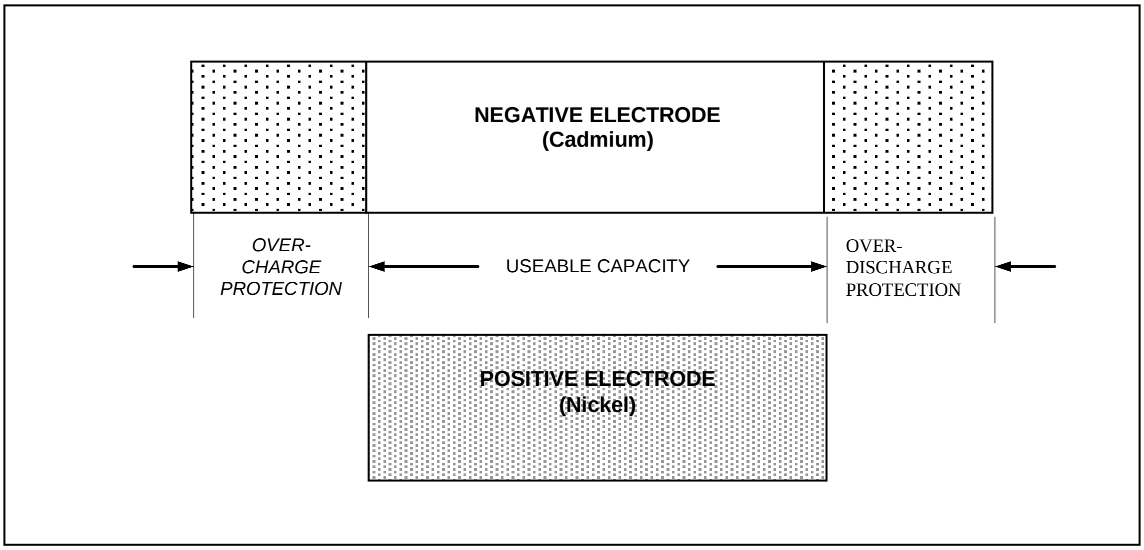
4.3.1 Overcharge Protection

Figure 4.2 Useable Capacity Diagram



- The battery is built with excess capacity in the negative cadmium electrode
- This causes the positive electrode to reach full charge before the negative electrode and it starts to give off oxygen. Since the negative electrode has not reached full charge it will not give off hydrogen.
- The oxygen is absorbed by the nickel fast enough to offset input energy. This keeps the cell in equilibrium.

4.4 NiCd High Current Discharge

High rate nickel-cadmium cells will deliver exceedingly high currents. If the cells are discharged continuously under short circuit conditions, self-heating may do irreparable damage. The heat problems vary somewhat from one cell type to another, but in most cases internal metal strip tab connectors overheat or the electrolyte boils. In some instances, both events occur. General overheating is normally easy to prevent because the surface temperature of the battery can be used to determine when to rest, for cooling, is required. In terms of cutoff temperature during discharge, it is acceptable practice to keep the battery always below 60°C (140°F). The overheated internal connectors are difficult to detect. This form of overheating takes place in a few seconds or less, and overall cell temperature may hardly be affected.

Harding Energy recommends paying close attention to the heat generated by the pack. In special cases, where cooling of the cell or battery is likely to be poor, or unusually good, special tests should be run to check the important temperatures before any duty cycle adjustment is made. Output capacity that is composed of pulses is difficult to predict accurately because there are infinite combinations of current, "on" time, rest time, and endpoint voltage. Testing on a specific cycle is the simplest way to get a clear understanding of temperature issues for a pack design.

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4.5 NiCd Over Discharge

When cells are connected in series and discharged completely, small cell capacity differences will cause one cell to reach complete discharge sooner than the remainder. The cell, which reaches full discharge first, might be driven into reverse by the others. When this happens in an ordinary nickel-cadmium sealed cell, oxygen will evolve at the cadmium electrode and hydrogen at the nickel electrode. Gas pressure will increase as long as current is driven through the cell and eventually it will vent. This condition is minimized in some sealed nickel-cadmium cells by special construction features. One technique uses a reducible material in the positive in addition to the nickel hydroxide, to suppress hydrogen evolution when the positive expires. Discharging to the point of reversal should be avoided.

4.6 NiCd Voltage Depression (Memory Effect)

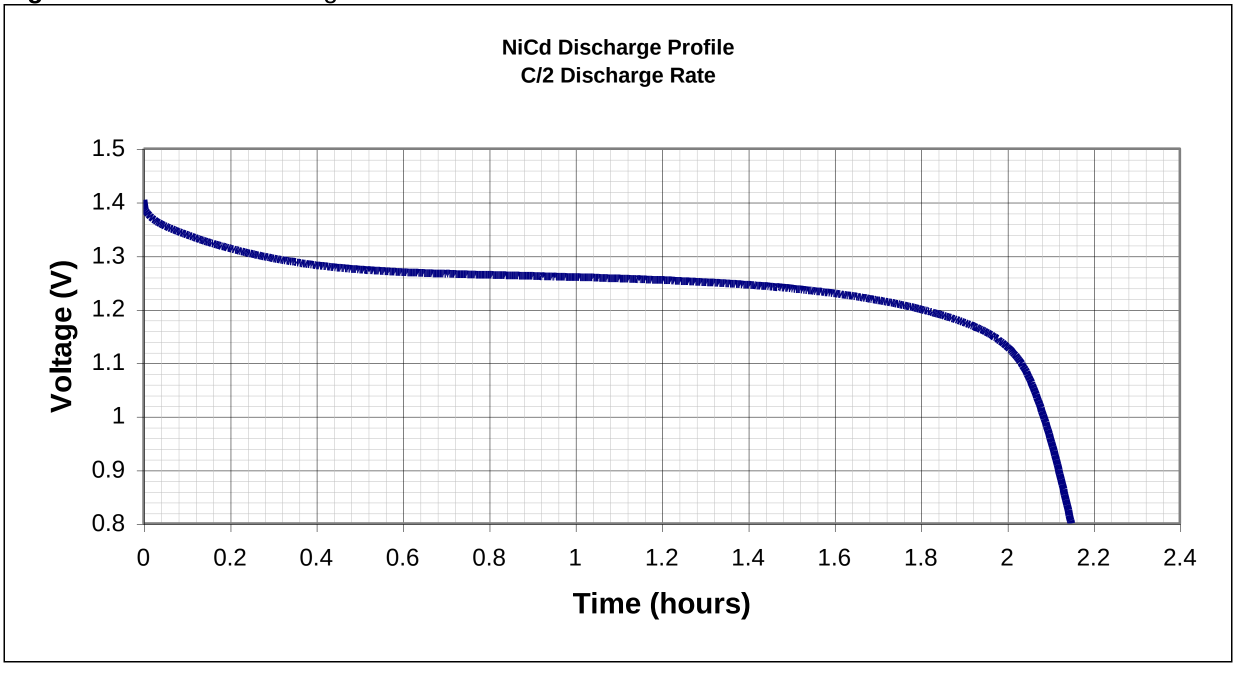
Voltage depression is the characteristic attributed to nickel-cadmium cells wherein the cell retains the characteristics of the previous cycling. After repeated shallow depth discharges the cell will not provide a full depth discharge. The cell remembers the level of discharge and the voltage of the cell emulates that of a fully discharged cell. This is reversible by conditioning the cell with several deep discharges.

4.7 NiCd Discharge Characteristics

4.7.1 Voltage

The voltage output curve on NiCd Cells nearly is identical to the NiMH. See Figure 4.7.1. The only difference is the knee of the NiCd voltage profile tends to be steeper.

Figure 4.7.1 NiCd Discharge Profile



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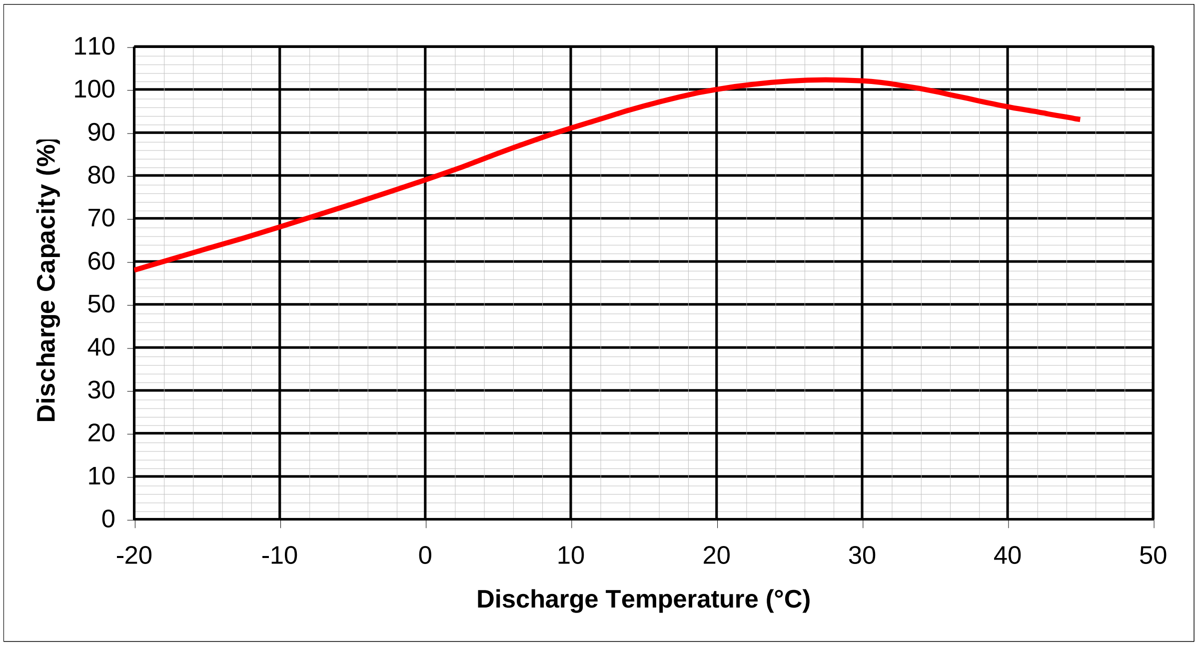
4.7.2 Temperature

The affect of temperature on NiCd cells is not as dramatic as on NiMH but it is still a significant factor as can be seen in the Figure 4.7.2. This is for a 0.2C discharge rate.

Figure 4.7.2



4.8 NiCd Charge Characteristics Overview

Constant current charging is recommended for sealed nickel-cadmium cells. The C/10 rate should not be exceeded unless overcharge is acceptable. The recharge efficiency of sealed nickel-cadmium cell is dependent on a number of things, but it is most important to remember that charging becomes more difficult as temperature increases and charge rate decreases. It is possible, under certain conditions, to charge at rates much higher than the C/10 charge rate, but control devices which prevent high rate over-charge are typically required.

The nickel-cadmium battery can be trickle charged but floating and constant voltage charging are not recommended. For maximum performance in situations of long term trickle charge, the current required to keep the battery fully charged is approximately C/30 to C/50.

4.8.1 Charging Temperature requirements

C/7 to C/10 Charge Rate

- Cells should not be charged below 0°C
- At 45°C charge efficiency will be about 50%

C/1 to C/3 Charge Rate

- Cells should not be charged below 15°C at the 1 hour rate
- Cells should not be charged below 10°C at the 3 hour rate
- At 45°C efficiency will be about 90%

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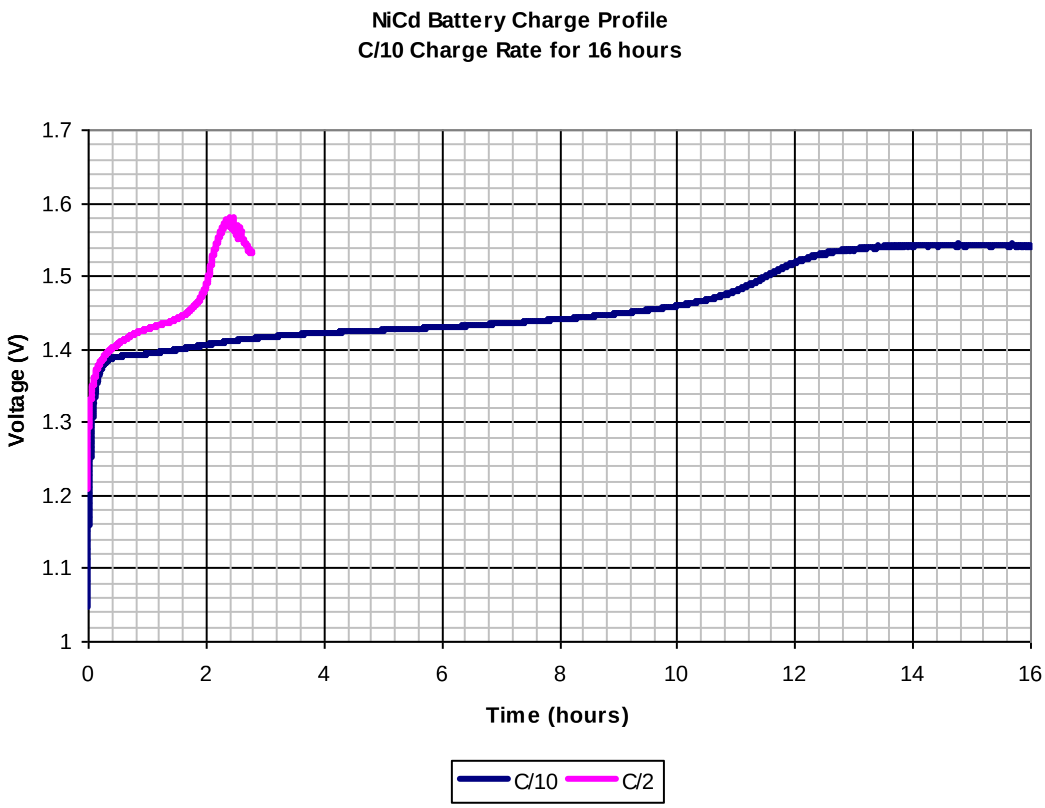
Figure 4.8.1 Typical NiCd Charge Curve



4.8.2 NiCd Charge Termination

Properly controlling the charging of a NiCd battery is not as critical to achieving optimum performance as in NiMH. Charge control incorporates proper charge termination to prevent overcharging the battery. The overcharging of a battery refers to the state at which the battery can no longer accept (store) the energy entering the battery. As a result pressure and temperature builds up within the cell. If a cell is allowed to remain in the overcharge state, especially at high charge rates, the pressure generated within the cell can be released through the safety vent located within the positive terminal. This may cause damage to the battery reducing cycle life and capacity.

To prevent damage occurring to the battery, charge termination is one of the most critical elements to be applied to any method of charge control. Charge control may utilize one or more of the following charge termination techniques. The three primary techniques of charge termination are time, voltage, and temperature.

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4.8.2.1 Time

Time-based charge control techniques terminate charging of the battery after a predetermined length of time. This technique should be used when slow charging to avoid excessive overcharge, and used as a backup secondary termination for all fast charge methods.

4.8.2.2 Voltage

Charge control techniques that are voltage-based are attractive because of the predictable charge voltage profile of a NiCd battery (see Section 4.8.3 NiCd Charge Termination Nomenclature). The charge voltage profile of a NiCd battery is consistent regardless of the batteries state of charge. However, the voltage-based charge termination techniques generally occur after a battery has already reached the overcharge state. Depending on charge rate, it may also be necessary to include temperature-sensing devices to terminate the charge if the temperature becomes too high. Such devices include thermostats and PTC resettable fuses.

Negative Delta V (-ΔV)

Negative delta V (-ΔV), senses the drop in battery voltage after the battery has reached its peak voltage. The change or drop in voltage is to 10 to 15 mV per cell before the charge is terminated. This technique allows the battery to be exposed to longer periods of overcharge and is not normally recommended. See Section 4.8.3 Charge Termination Nomenclature

4.8.2.3 Temperature

The temperature-based charge termination senses this temperature rise and terminates the charge when the battery has reached a temperature that indicates when overcharge has begun. This type of charge termination is recommended because of its reliability in sensing overcharge, yet it requires care in the selection of set points in the charge circuitry to avoid premature charge termination or failure to detect the overcharge when the battery is exposed to extreme temperature environments.

Change in Temperature (ΔT)

Change in temperature or ΔT is the technique that measures the difference of the rise in battery temperature above the starting (ambient) temperature during charge. The charge is terminated when the rate of change in temperature reaches a predetermined value. See Section 4.8.3 NiCd Charge Termination Nomenclature

Change in Temperature/Change in time (dT/dt)

The recommended technique for temperature-based charge termination for all fast-charging methods is dT/dt (see Section 4.8.3 NiCd Charge Termination Nomenclature). This technique monitors the change in temperature T verses the change in time t, and is considered most accurate because it senses the start of overcharge earlier than other techniques. Standard dT/dt temperature termination is between 0.5 to1°C per minute depending on pack

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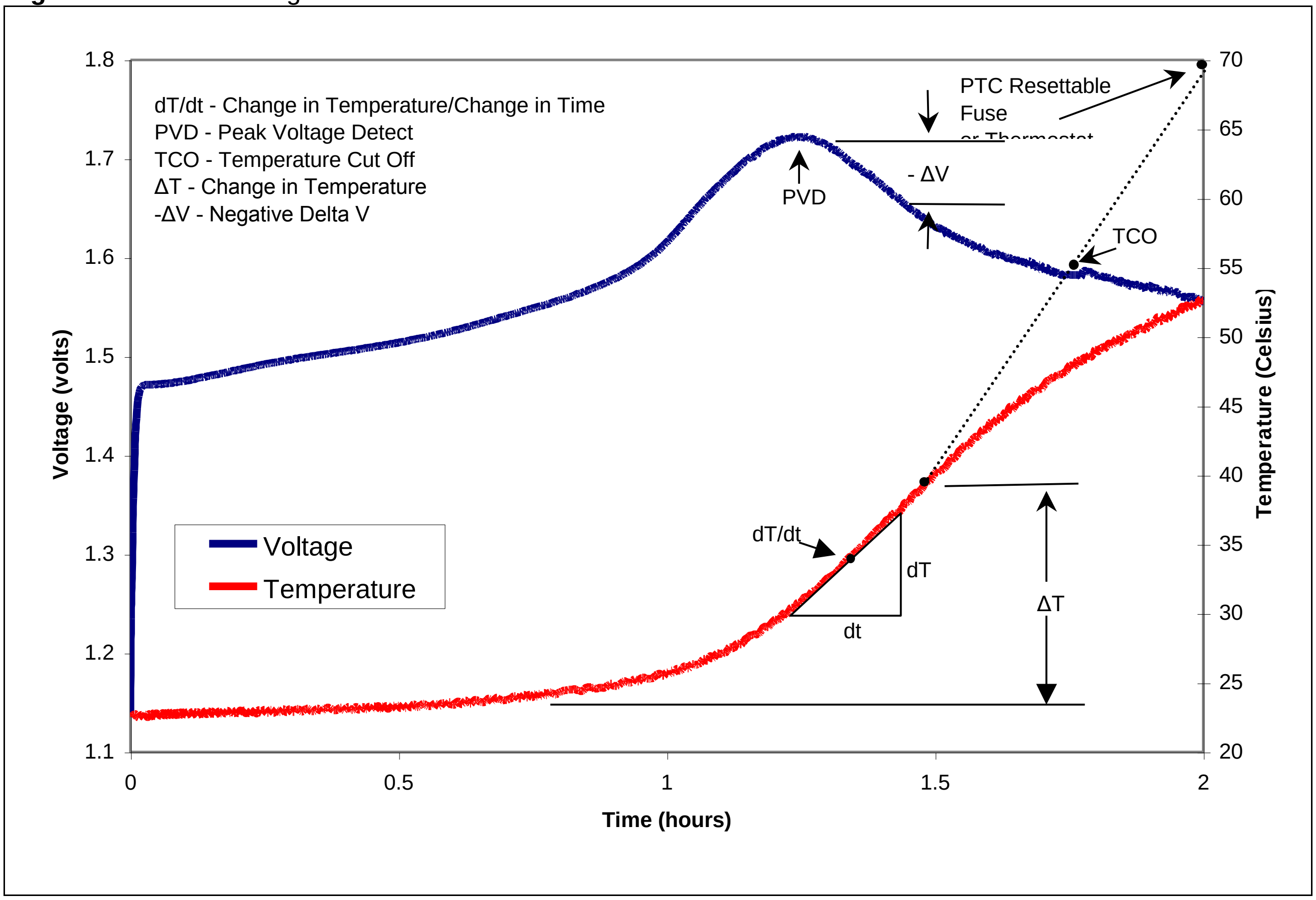
configuration and charge rate. When using a dT/dt termination, a top-off charge is suggested in order to fully charge the battery (see Section 4.8.6.5 Top-Off Charge).

Temperature *Cut Off (TCO)*

Temperature cut off or TCO is a secondary termination required for all fast-charging methods using dT/dt or -ΔV. This technique is based on the absolute temperature of the battery and is recommended only as a fail-safe strategy to avoid destructive heating in case of failure of any or all other charge termination technique(s). See Section 4.8.3 NiCd Charge Termination Nomenclature

4.8.3 NiCd Charge Termination Nomenclature

Figure 4.8.3 NiCd Charge Termination Nomenclature



4.8.4 NiCd Temperature and Charge Efficiency

The recommended charging temperature is between 10°C (50°F) and 40°C (104°F). If a NiCd battery is exposed to high temperatures (above 40°C, 104°F) due to overcharging or external heat sources, the charge efficiency (increase in stored cell capacity per unit of charge input) will be decreased. In order to avoid decreased charge efficiency, batteries should have charge control methods applied to limit the amount of overcharge heat that is generated. In addition, it is critical not to place batteries in close proximity to other sources of heat or in compartments with limited cooling or ventilation.

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At temperatures below 10°C (50°F) charge efficiency will also decrease resulting in an increase in the amount of time need for charging. Low temperatures inhibit transport capabilities (the ability to move ions within the electrodes) causing the low charge efficiency (see Section 2.1.5, Principles of Operation and Construction; Rate Capability). Charging below 0°C (32°F) is not advisable.

4.8.5 NiCd Charge Methods

Not all charge methods are recommended for all NiCd cell chemistries, since they are not designed the same. Different materials are used in various NiCd cells to achieve certain desired performance characteristics. The selection of these materials also affects the charging characteristics of the batteries. Therefore, any method that could cause problems with some batteries has been noted for each charge method. See Figure 4.8.5 Charge Method Specifications for recommended charge currents and charge terminations.

Figure 4.8.5 Charge Method Specifications

Charge Method	Charge Current	Charge Termination	Comments
Slow	0.02-0.1C	1. None[1] or Timer	Timer rated at 160%C.
Time	0.1-0.2C	1. Timer, and 2. TCO = 55°C	Timer rated at 160%C @ 0.1C to 120%C @ 0.2C.
Rapid[2]	0.25-0.5C	1. dT/dt, or ∆T, and 2. Timer, and 3. TCO = 55°C	-∆V of 10-15 mV/cell dT/dt = ~1°C/1 min rise. Timer rated at 140%C @ 0.2C to 120%C @ 0.5C.
Fast[2]	0.5-1.0C	1. dT/dt, or ∆T, and 2. Timer, and 3. TCO = 55°C	-∆V of 10-15 mV/cell dT/dt = ~1°C/1 min rise. Timer rated at 125%C.
Maintenance	0.002-0.008C	1. None	5-10%C per day at C/128 to C/512 pulse recommended.
[1] Not all batteries can be charged without a termination. [2] See Rapid/Fast Charging Procedure (Section 6.6).			

4.8.5.1 Slow Charge

When charge time is not an issue and maximum rechargeable capacity is desired, the slow charge method is often used. This method uses a charge that is less than 0.1C and for more than 16 hours (see Figure 4.8.5 Charge Method Specifications). Yet, with the recent developments of some NiCd cell chemistries to be better suited to faster charging methods, slow charging is not recommended for all NiCd batteries.

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4.8.5.2 Time Charge

For the faster timed charge method, batteries can typically be charged in 6 to 16 hours. This method of charging NiCd batteries requires the most attention before selection. Since this method uses higher rates of current (see Figure 4.8.5 Charge Method Specifications), two methods of termination are needed: timed and TCO. The later of the two terminations would require the battery to include a thermistor to detect the temperature during the charge cycle. If only a timed charged termination was used, the battery may be pushed into overcharge, especially if a partially discharged battery was charged using this method. For some NiCd cell chemistries this would significantly deteriorate battery performance.

4.8.5.3 Rapid Charge

The Rapid Charge method is good for applications needing a faster charge, but the battery compartment or housing does not allow for good heat dissipation. Rapid charge methods typically charge in 2.5 to 6 hours using charge rates of 0.25C to 0.5C (see Figure 4.8.5 NiCd Charge Methods). This method of charging uses - ΔV, dT/dt or ΔT with time backup. For further charging details see Section 4.8.6 Rapid/Fast Charging Procedure. This system usually uses a temperature backup to ensure against overcharging.

The advantage of this charge method is the ability to safely charge batteries that are at any state of charge. In other words, a partially discharged battery can be charged without the risk of being overcharged. The disadvantage to this type of system is the added complexity and expense of the charger.

4.8.5.4 Fast Charge

When time is a limited resource and there is good heat dissipation, Fast Charge methods are the best approach. Fast Charge methods will charge batteries in 2.5 hours or less. Like the Rapid Charge method, this method has increased charge rates and requires three separate charge terminations (see Figure 4.8.5 Charge Method Specifications).

As with the Rapid Charge, the advantages of the Fast Charge method is the ability to safely charge batteries that are at any state of charge in a short period of time. The disadvantages are, again, the added complexity of the charger and expense.

4.8.5.5 Maintenance Charge

Unlike the previous methods the Maintenance Charge method is not considered a means of charging a discharged battery to full capacity. Rather, this method is used to counteract the occurrence of battery self-discharge when the battery is not in use. See Section 4.9 NiCd Storage Guidelines.

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4.8.6 NiCd Rapid/Fast Charging Procedure

The following procedure outlines the six steps for fast or rapid charging a NiCd battery. These steps will provide insight into what the charger chip manufacturers have tried to incorporate into their designs.

4.8.6.1 Initialization Charge

Before fast or rapid charging a battery, a trickle charge is recommended. Starting with a pulsed C/10-C/50 trickle charge is good for two reasons. First, to bring up the temperature if the batteries are cold, and second, to verify there are no problems with the batteries or charging circuitry.

4.8.6.2 Temperature Measurement

Before fast or rapid charging can begin, the temperature needs to be above 10°C. Furthermore, take note that the dT/dt parameters will be reached at the beginning of a fast charge on a cold battery, thus resulting in the premature termination. Many chargers incorporate a low temperature inhibit to nullify this event.

4.8.6.3 Pack Voltage Measurement (PVM)

The measurement of the battery pack voltage is also part of the trickle charge step. A pack voltage measurement (PVM) can be used to verify that the battery is at the proper voltage level and to verify there is current available for charging. Time (few seconds to 10 minutes) and voltage (1.1 volts x # of cells) are dependent on the type and number of cells used. If the voltage of the battery is not reached in the set time (usually about 20 minutes) the charge is terminated. For PVM, a pulse charge at a rate of C/10 to C/50 is recommended, but a constant charge rate of C/10 to C/50 can be used. Pack temperature must be raised to between 10°C and 40°C. This is done as part of the trickle charge step.

4.8.6.4 Rapid/Fast Charge

Rapid charge or fast charge methods require three modes of termination:

1. $-\Delta V$, or dT/dt, or ΔT
2. Timer
3. Temperature Cut Off (TCO).

See Table 4.8.5 Charge Method Specification for charge rate information.

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4.8.6.5 Top-Off Charge

Top-off charging is only used if the fast charge or rapid charge does not fully charge the batteries. This occurs with some dT/dt and ΔT terminations. Before using a dT/dt or ΔT fast charging, the charging and termination parameters need to be tested inside the device. The top-off charge is best to be done as a pulse charge. The top off charge is terminated by time and is some fraction of the rapid charge rate.

4.8.6.6 Maintenance

A maintenance charge will retain a full charge on the battery until it is removed from the charger. During the first 24 hours after a battery has been charged, it will lose about 5% of its energy caused by the battery's self-discharge. A standard maintenance charge at a C/128 rate is designed to counter this self-discharge. Some NiCd chemistries are able to handle maintenance charge rates up to a C/10 rate. Continuous charging at low rates is not very efficient, therefore, pulse charging is recommended.

4.9 NiCd Storage Guidelines

There are no detrimental effects of storing between –20 °C and 40°C. However, above 32°C self-discharge will be considerably higher than at room temperature. It is recommended that batteries be stored at 21°C (70°F) or lower for this reason.

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