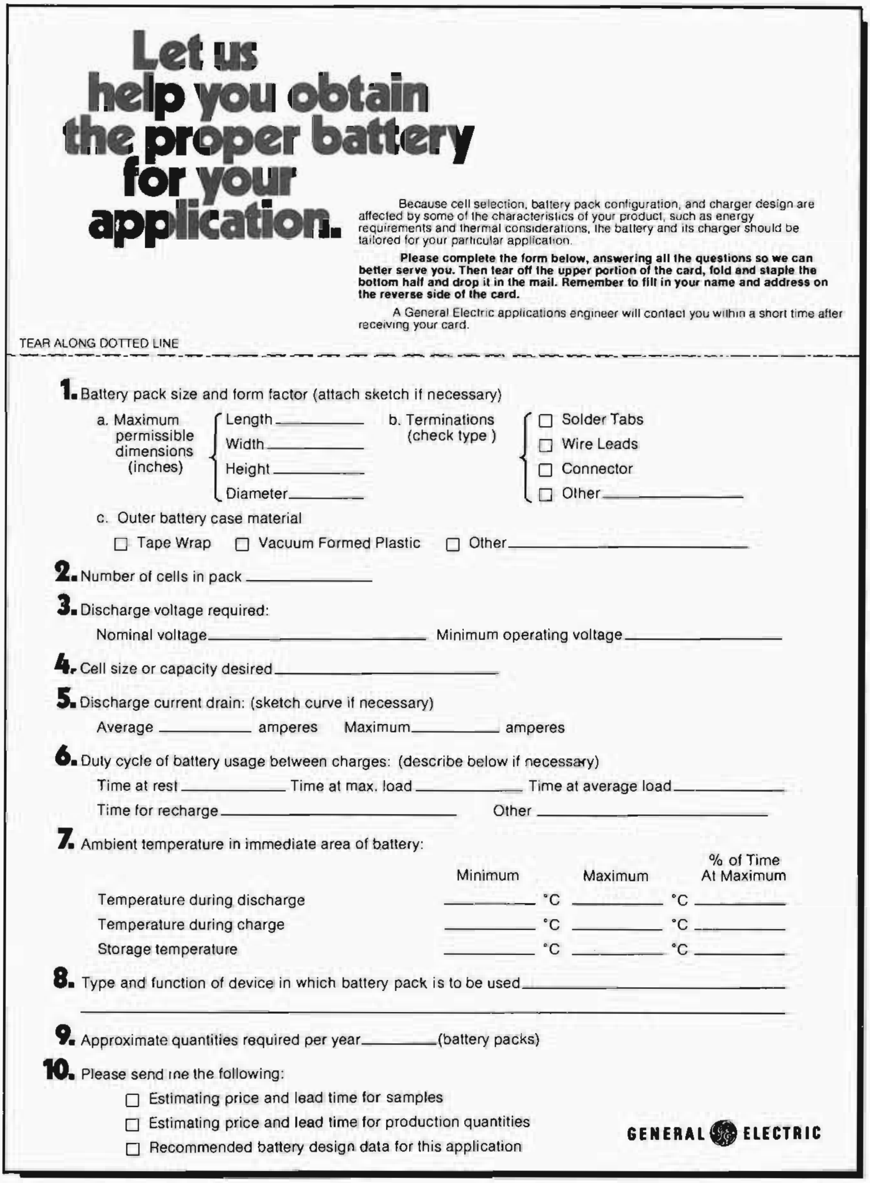
nickel-cadmium battery

APPLICATION ENGINEERING HANDBOOK SUPPLEMENT

GENERAL ELECTRIC



Let us help you obtain the proper battery for your application.

Because cell selection, battery pack configuration, and charger design are affected by some of the characteristics of your product, such as energy requirements and thermal considerations, the battery and its charger should be tailored for your particular application.

Please complete the form below, answering all the questions so we can better serve you. Then tear off the upper portion of the card, fold and staple the bottom half and drop it in the mail. Remember to fill in your name and address on the reverse side of the card.

A General Electric applications engineer will contact you within a short time after receiving your card.

TEAR ALONG DOTTED LINE

1. Battery pack size and form factor (attach sketch if necessary)

a. Maximum permissible dimensions (inches)
- Length ____
- Width ____
- Height ____
- Diameter ____

b. Terminations (check type)
- ☐ Solder Tabs
- ☐ Wire Leads
- ☐ Connector
- ☐ Other ____

c. Outer battery case material

☐ Tape Wrap ☐ Vacuum Formed Plastic ☐ Other ____

2. Number of cells in pack ____

3. Discharge voltage required:

Nominal voltage ____ Minimum operating voltage ____

4. Cell size or capacity desired ____

5. Discharge current drain: (sketch curve if necessary)

Average ____ amperes Maximum ____ amperes

6. Duty cycle of battery usage between charges: (describe below if necessary)

Time at rest ____ Time at max. load ____ Time at average load ____

Time for recharge ____ Other ____

7. Ambient temperature in immediate area of battery:

	Minimum	Maximum	% of Time At Maximum
Temperature during discharge	____ °C	____ °C	____
Temperature during charge	____ °C	____ °C	____
Storage temperature	____ °C	____ °C	____

8. Type and function of device in which battery pack is to be used ____

9. Approximate quantities required per year ____ (battery packs)

10. Please send me the following:
- ☐ Estimating price and lead time for samples
- ☐ Estimating price and lead time for production quantities
- ☐ Recommended battery design data for this application

GENERAL ELECTRIC

To obtain additional information on nickel-cadmium battery applications, fill out and return a copy of Form GEZ-5702, which appears above. Copies of Form GEZ-5702 are available from General Electric sales representatives.

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APPLICATION ENGINEERING HANDBOOK SUPPLEMENT

GENERAL ELECTRIC COMPANY
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SECTION 1

INTRODUCTION

The first edition of the Nickel-Cadmium Battery Application Engineering Handbook, GET-3148, was published by the General Electric Company early in 1971. Since that time the technology of nickel-cadmium sealed cells has been extended. The new developments have increased the utility of these rechargeable batteries by extending their capabilities.

The information in this publication, the Nickel-Cadmium Battery Application Engineering Handbook Supplement, GET-3148-S1, is devoted to these new extended capabilities. In combination with the original handbook, the supplement provides a ready reference for application design using the new extended capability batteries. These newly developed batteries are:

- Fast Charge Batteries – Charge in one hour or less
- Quick Charge Batteries – Continuous charge at the 3- to 4-hour rate
- High Temperature Batteries – Up to 65°C continuous operation
- Standby Power Batteries – Years of continuous charge

Each one of these new capability batteries is treated in depth in a separate section. In addition a product section provides detail application data for each of the General Electric extended capability cells.

Any handbook of this nature cannot treat all the specific questions that may arise for a particular application. If questions do arise, the reader is invited to contact our application engineering group at the following address for more information and assistance:

GENERAL ELECTRIC COMPANY
Electronic Components Europe
P.O. Box 265
Amstelveen – The Netherlands
Attn: Manager – Application Engineering

SECTION 2

FAST CHARGE BATTERIES

2.1 FAST CHARGING

2.1.1 General

Fast charge of nickel-cadmium sealed-cell batteries, as defined by General Electric, encompasses any battery/charger system that charges the battery at the one-hour rate, 1.0C or faster. (C is the value in amperes numerically equal to the rated ampere-hour capacity of the cell; e.g., the C rate for an AA cell rated 450 mAh is 450 mA; the 0.1C rate in this example is 45 mA.)

The benefits of having a fast charge battery/charger system in a cordless electrical product are:

- Ability to use the full capability of the battery several times each day.
- Products can be designed with smaller, lighter-weight batteries in place of large, bulky batteries, thus providing mobility and flexibility.
- Capability to recharge fast enough to permit use of the product without hours of advance planning.
- Products can be continually operated with just two batteries, one on charge while the other is in use.

Most nickel-cadmium sealed-cell batteries are capable of handling overcharge current (overcharge current is that current that flows into the battery after it is fully charged) at the 0.1C rate continuously. Some special batteries, described in Section 3, can be overcharged indefinitely at the quick-charge rate of 0.3C. But higher rates of charging current, such as the C rate or higher, must be terminated because extended overcharge at these rates causes the pressure and temperature developed in the cell to rise to excessive values. Hence, all fast charge systems must be designed to terminate the fast charge current before undesirable internal pressure and/or cell temperature conditions are reached.

A number of methods have been used to sense when the battery reaches the point at which the fast charge current should be terminated. Some of these include the independent sensing of:

- Cell temperature
- Battery voltage
- Internal cell pressure

Very accurate sensing and tight tolerances have been required in the control circuits of many fast charge systems based upon one of these indicators. This has raised the cost of these fast charge systems to the point of precluding their use in many commercial products. Two of these fast charge systems are discussed in the following pages:

- Temperature Cutoff – paragraph 2.2
- Voltage Cutoff – paragraph 2.3

2.1.2 PowerUp-15* Battery

A new concept in fast charge batteries, the General Electric PowerUp-15 battery, opens up new possibilities for cordless portable electric devices where power is needed fast. When charged at room temperature at the 4C rate for 15 minutes, the PowerUp-15 battery delivers close to its rated capacity. Special fast charge cells which feature a significant amount of overcharge capability at the 4C rate are used in the PowerUp-15 battery.

A new method of sensing when the battery is charged, combined with the newly developed cells are the two keys to the safety and reliability of the PowerUp-15 battery/charger system. The charger monitors both the cell temperature and the battery voltage. Earlier fast-charge systems have depended primarily upon the sensing of only one of these characteristics. However, in the PowerUp-15 system both indicators are fed into an "OR" logic circuit in the charger. Either characteristic, when it reaches the predetermined set point, is designed to trigger the charger to terminate the fast-charge current.

This new voltage/temperature cutoff (VTCO) technique is designed to protect the battery from damage at the high charge rate under all circumstances. Both charger cutoff points are set high enough to allow a high charge input, but low enough so there should be no damage to cells. This permits a reasonably economical 15-minute charge system. For more information on the PowerUp-15 battery, see paragraph 2.4.

2.1.3 Temperature, Voltage, Pressure Relationships

Nickel-cadmium sealed cells can be charged at very high rates. However, the amount of high rate overcharge they can sustain safely is limited. It is necessary to terminate the high charge rate before the cell is damaged. Fast charge termination controls utilize the inherent characteristics which the nickel-cadmium sealed cells display during high rate charging and overcharging.

The three cell parameters which may be used individually to control fast charging of nickel-cadmium sealed cells are internal pressure, cell temperature, and battery voltage. Combinations of these parameters may also be used to provide a reliable, low-cost charge control scheme.

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* Trademark of General Electric Company

The voltage, pressure, and temperature characteristics of nickel-cadmium sealed cells during charge and in overcharge are affected by cell design. Though the individual cell designs may be different, most sealed cell designs follow the general trends illustrated in Figure 2-1.

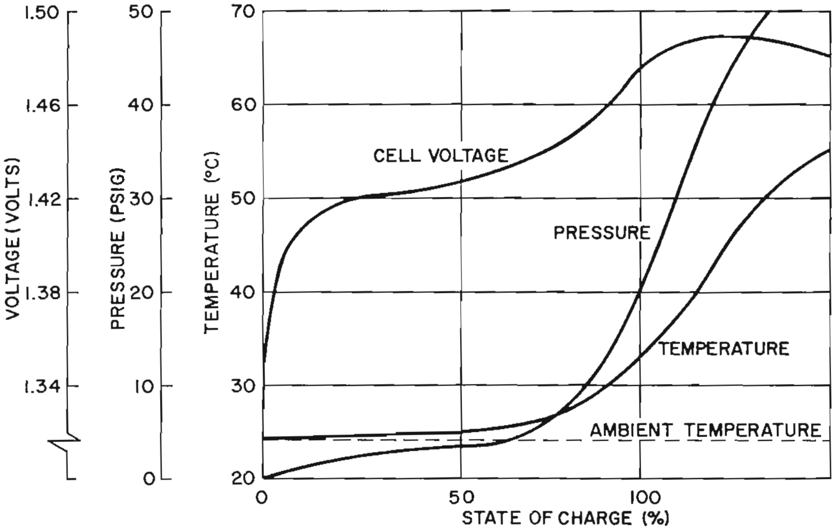


Figure 2-1. Characteristics of Voltage, Pressure, and Temperature Vs. State of Charge of a Sealed Cell at C Charge Rate

The area of interest in fast charge control is at high states of charge with the focus on how these parameters can act as indicators as the battery is approaching full charge and is starting into overcharge. The voltage, on a cell charged at the 1C to 4C rate, will slowly rise during the majority of the charge time. As the cell approaches full charge, the voltage will rise more sharply, reach a peak and then start to fall off. This rise in voltage can be utilized as a signal to terminate fast charge. The rate of rise and the maximum level of the peak voltage has a complex relationship with the cell design, the charge rate and the cell temperature. A more detailed discussion of the vagaries of the charging voltage characteristic which must be taken into account if it is to be used alone to control fast charge, is found in paragraph 2.3.

The temperature characteristic of a cell when exposed to a high rate charge is shown starting with a fully discharged cell stabilized at room temperature. There will be essentially no temperature change as the cell is charged until the cell goes into overcharge. As the cell becomes fully charged, all of the electrical power input is diverted to heating the cell, causing the temperature to rise rapidly. This rise in cell temperature, as the cell is overcharged at the fast charge rate, can be utilized as a signal to terminate the fast charge. A more detailed discussion of the temperature characteristic and how it can be used as a fast charge control signal is found in paragraph 2.2.

A third parameter which can be utilized to control a fast charge is the internal pressure of the nickel-cadmium sealed cell. Figure 2-1 illustrates that the pressure of a cell subjected to a high charge rate, rises very slowly until the cell goes into overcharge. The pressure is caused by the oxygen being generated on the positive electrode. At low states of charge only a very small portion of the charge current is used to generate oxygen. Most of the charge current is converting active material to a dischargeable state. As the cell approaches the fully charged state, an increasing proportion of the charge current contributes to gassing. When the cell becomes fully charged all the input energy goes into generating gas and the pressure rises rapidly. This rapidly rising internal pressure of a cell in overcharge at high rates can theoretically be utilized as a signal for terminating a fast charge. However, the sensing of internal cell pressure requires the use of a pressure switch. This complicates cell design sufficiently to discourage the use of pressure as a signal for controlling fast charge of sealed cells.

It must be recognized that the specific nature of the temperature, voltage, and pressure characteristics are dependent on a number of factors including charge rate, cell temperature, cell packaging, and cell design. The successful fast charge control design will take all of these factors into account.

Figure 2-1 reveals that the pressure of the cell rises before the temperature starts to increase, and that the pressure will continue to rise if the fast charge rate is continued. If the high rate charge is continued indefinitely one of two events will likely occur.

a. The internal pressure will reach a value exceeding the setting of the safety vent. If this occurs the gasses will vent and if charging at the high rate is continued, the electrolyte in the cell dries out and the cell becomes inoperative, or
b. The cell temperature rise will be sufficient to increase the recombination efficiency to the point that the gas pressure does not reach the safety vent setting. In this instance, the stabilized cell temperature will likely be high enough that the insulation and the separator will degrade at a very rapid rate which may ultimately lead to a massive short in the cell.

It is extremely important that any consideration of fast charging recognize that fast charge termination needs to be foolproof. Failure of a fast charge termination will very likely result in destructive cell venting and/or overheating of the cell. Charger designers must recognize these cause-effect factors and provide redundancy in the fast charge termination control circuit. The most common back-up safety feature is a one-time temperature fuse securely attached to the cell pack.

2.2 FAST CHARGE TEMPERATURE CUTOFF BATTERIES

2.2.1 Temperature Cutoff Concept

The method of fast charge control using cell temperature as the indicator is often referred to as fast charge temperature cutoff (TCO). In this concept, the battery temperature is sensed and the fast charge current is terminated when the temperature of a cell rises to a previously established cutoff value. The sensor monitors the temperature of one or more cells in the battery pack. Once it reaches the predetermined set point, the fast charge current is terminated and only a topping charge is allowed to flow.

Previous discussions point to the pressure-temperature relationship which exists in overcharge at high charge rates. If the pressure of the cell can be kept from rising too rapidly while the cell temperature is increasing, then temperature can be used as an effective and reliable signal for fast charge termination. The faster the cell temperature rises relative to the rise of internal cell pressure, the more reliable the temperature cutoff system will be. Hence, a prerequisite for a reliable temperature cutoff fast charge system is the use of a battery comprised of cells designed to enhance rapid oxygen recombination. The General Electric fast charge cells used for temperature cutoff systems incorporate design features which improve their oxygen recombination capability. These special cells are subject to processing, which also contributes to capabilities not found in conventional cells. The net result is a cell which is more tolerant of high rate overcharge. This tolerance takes the form of a more slowly rising pressure characteristic in the overcharge region. For any particular cell temperature and degree of high rate overcharge, the cell pressure will be lower in a GE special fast charge cell than in a cell of the same configuration, but incorporating conventional design and construction.

2.2.2 Considerations in Selecting the Charge Rate and Cutoff Temperature

The determination of the actual temperature cutoff point to be used should be made for each specific battery design and application. Three general factors which should be considered in selecting the temperature cutoff point are:

a. The temperature cutoff point should be set high enough to prevent premature cutoff in the highest ambient temperature in which the battery would normally be charged. For example, if the battery would often be at 35°C at the time a fast charge was desired, the charge termination temperature setting would obviously have to be above 35°C.

b. Some applications will require high discharge rates in which some cell heating will occur during discharge. This will keep the battery temperature above ambient during use. For the convenience of obtaining an immediate recharge, the cutoff temperature setting must allow for this discharge heating effect as well as for the ambient temperature range noted above.

These two factors generally guide the designer in his selection of the minimum temperature cutoff value.

c. The maximum temperature cutoff value must be established within the capabilities of the cell to handle overcharge at the fast charge rate. The amount of overcharge a GE fast charge cell can reliably tolerate depends on the charge rate and the cell temperature. The relationships between cell temperature, charge rate, and the packaging of the battery pack will be discussed in the following section.

The temperature characteristic of a particular battery pack during charge and in overcharge is illustrated in Figure 2-1, but to get a better understanding of the overcharge characteristic, the temperature scale must be expanded to show the entire temperature characteristic including the area of stabilization. See Figure 2-2.

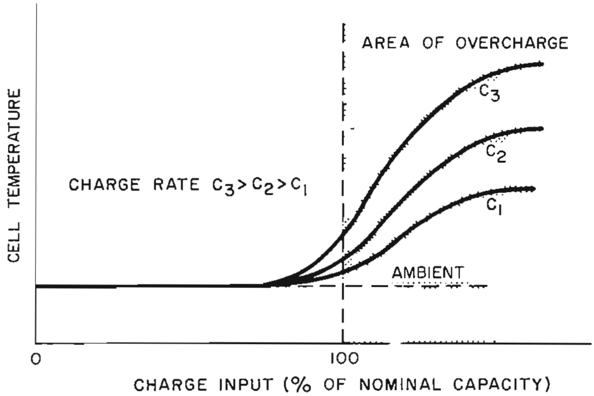


Figure 2-2. Effect of Charge Rate on Cell Temperature with Other Variables Being Held Constant

2.2.2.1 Effect of charge rate

Figure 2-2 illustrates the effect of charge rate on cell temperature. The cell temperature at low states of charge is nearly the same for each charge rate. But as the battery becomes fully charged, the temperature of the cells in the pack rises with the rate of rise reflecting the effect of gassing and energy conversion to heat as the cells enter the overcharge. The cell temperature continues to rise as long as the rate of heat generated by the overcharge current exceeds the heat loss to the surrounding ambient.

Eventually, the heat loss equals the heat generation and the cell temperature stabilizes. The temperature at which this stabilization occurs and the rate of temperature rise depends on the following variables:

- Overcharge rate
- Cell size and design
- Number of cells in battery pack
- Arrangement of the cells in the pack
- The type of battery case material
- The enclosure in which the battery pack is mounted
- The ambient temperature during charge
- Cell temperature at the start of charge

The variable which determines the heat generation rate is the overcharge current. The rate of heat generation in a fully charged battery is equal to the product of the overcharge current and the battery voltage. Since the battery voltage is only slightly affected by overcharge current, the overcharge rate is the most significant contributor to the temperature rise of the battery pack. The maximum overcharge rate for GE fast charge cells for temperature cutoff applications is the 2C rate. The minimum rate for reliable temperature cutoff depends on the heat loss characteristic and thermal time constant of the system, the ambient temperature during charge, and the minimum cell temperature expected at the start of charge.

2.2.2.2 Thermal characteristics of the battery pack

A number of the factors listed will affect the stabilized battery temperature in overcharge. These factors include cell size and design, the number of cells in the battery pack and their physical arrangement, the type of battery case material, and the enclosure in which the battery pack is placed. These factors which are also discussed in paragraph 3.2, are summarized below:

- A battery pack containing a large number of cells will tend to run hotter than a pack made up of only a few cells.
- A battery pack containing large ampere-hour capacity cells will tend to have a higher stabilized temperature than a pack having an equal number of low capacity cells (assuming same C rate of charging current).
- A battery pack with cells packed closely together will tend to run hotter than a pack with cells separated from each other.
- A battery pack enclosed in a heavy duty plastic case will tend to run hotter than a pack in a metal case which acts as a good heat exchanger.
- A battery pack mounted in a confined area will tend to run hotter than one mounted in a well-ventilated location.

The effect of these heat loss factors on the stabilized temperature in overcharge is illustrated in Figure 2-3. It is difficult to generalize which factors have the greatest impact on the thermal characteristics. Each application is unique. It is important to characterize each battery for each application (as

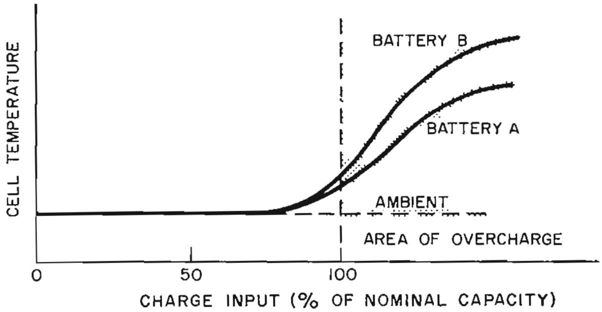


Figure 2-3. Effect of Heat Loss Factors on the Temperature Characteristic in Overcharge of Two Batteries Charged at the Same Rate (Batteries Have Same Electrical Rating But Differ in Configuration and Packaging)

has been done with battery A and battery B in Figure 2-3) to establish heat-loss characteristic. This should be done with the specific battery in the actual end product before a charge rate and cutoff point are selected.

These same heat loss factors affect the rate of temperature rise as well as the stabilized temperature in overcharge. Figure 2-4 illustrates these same two battery systems which are heated up to the same temperature and then allowed to cool down. Battery A in Figure 2-4 cools down toward room ambient faster than battery B because battery A loses its heat to the surrounding ambient faster than battery B. Battery B in overcharge will rise to a higher stabilized temperature than battery A for the same overcharge rate.

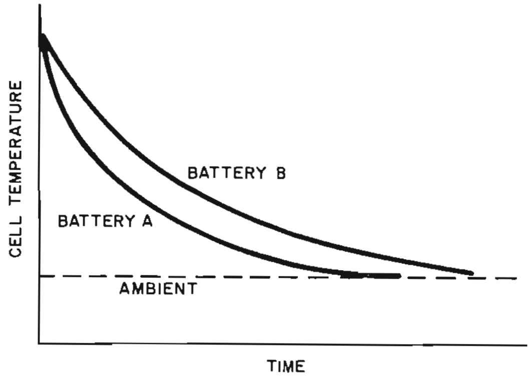


Figure 2-4. Thermal Characteristic of Two Batteries

2.2.2.3 Overcharge rate vs. thermal characteristics

The designer needs to consider the overcharge rate and the heat loss characteristics as both of them will affect the rate of temperature rise and the temperature at stabilization. It is desirable for the cutoff point to occur before the inflection point of the temperature rise characteristic is reached. (The inflection point is where the slope changes from increasing slope to decreasing slope.) This is illustrated in Figure 2-5.

The overcharge rate and thermal characteristics of the charger/battery systems represented by curves (1) and (2) in Figure 2-5 are a much better match for a reliable fast charge termination than that represented by curve (3). Curve (1) has a faster temperature rise which is due to a higher overcharge rate and/or a lower heat loss characteristic than the other two systems. The system represented by curve (1) will be quite reliable for temperature cutoff, but the available capacity after fast charge termination may be slightly less than the capacity of system (2) after its cutoff. The system represented by curve (2) is also very reliable. It has a lower overcharge rate and/or higher heat loss characteristic than system (1), but has a large enough safety margin to ensure cutoff under most environmental conditions. The system represented by curve (3) does not have a sufficient margin of safety to ensure reliable cutoff and may possibly not cutoff under the following circumstances:

a. If the battery is charged at a low rate caused by low ac line voltage conditions
b. If the battery is charged in lower than normal ambient temperature
c. If the battery is very cold at the start of charge, the system may eventually cut off, but not soon enough.

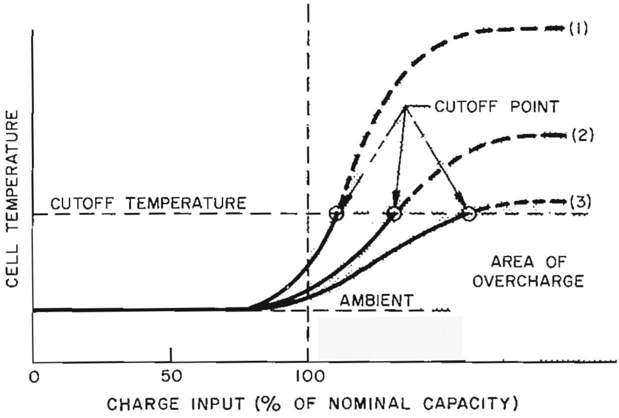


Figure 2-5. Slope of Temperature Characteristic at Cutoff

2.2.2.4 Effect of low charge rate

Too low an overcharge rate may cause a situation where the battery temperature stabilizes at a point below the predetermined cutoff value. The high rate overcharge current continues to flow and this condition, as described in paragraph 2.1.3, if continued for extended periods, can result in damage to the cell.

2.2.2.5 Effect of low ambient temperature

If the temperature characteristic of the system under normal charge conditions is similar to that represented by curve (3) in Figure 2-5, it may fail to cut off under low ambient temperature conditions. This may also lead to damaging overcharge. The two curves in Figure 2-6 illustrate the same battery and the same charge rate charged in two different ambient temperatures. The temperature rise is just barely enough to provide a cutoff in a 25°C ambient temperature but does not provide enough safety margin for charging in even a slightly lower ambient temperature or at a slightly lower charge rate.

2.2.2.6 Effect of a cold battery in a room temperature ambient

If the battery is cold at the start of charge, even if charged in a 25°C ambient temperature, the cutoff point may not be reached before pressure in the cell has reached an excessive value and venting has occurred. This would be more likely to happen for a system similar to that represented by curve (3) in Figure 2-5, than for curve (2).

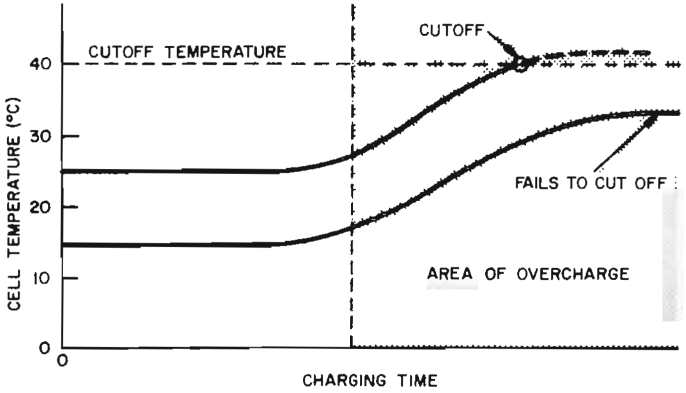


Figure 2-6. Effect of Low Ambient Temperature on Ability of System to Cut Off

If the battery had been soaked in a very cold winter temperature, for example, and then was brought into a 25°C ambient for immediate recharge, the temperature profile might look like curve B in Figure 2-7.

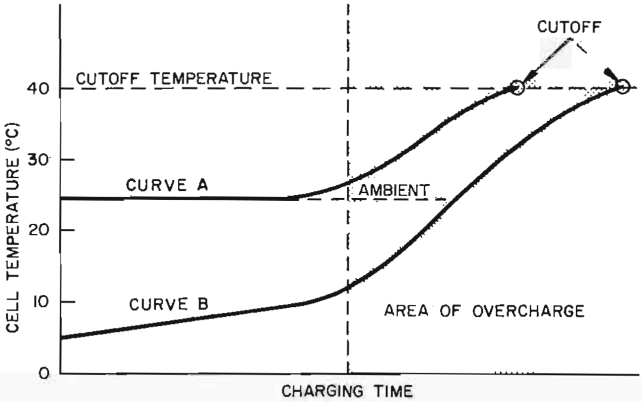


Figure 2-7. Effect of Cold Battery in Room Ambient on the Time to Reach Temperature Cutoff

The time in overcharge to reach temperature cutoff for curve B is considerably longer than for curve A. The system represented by curve A (which is the same as curve (3) in Figure 2-5) is marginally acceptable, provided the battery is not cold at the start of charge; but when the battery is cold at the start of charge it takes too long to reach cutoff. The cell pressure may rise to the setting of the safety vent causing venting.

2.2.2.7 Summary

To select the temperature cutoff value and the charge current most appropriate for a specific battery design for a given application it is recommended that tests be run to characterize the battery in the product at both the highest and the lowest fast charge rates which are anticipated. The temperature rise data obtained by tests can serve as the basis for selecting the nominal cutoff temperature value and establishing acceptable tolerances to assure cutoff under all conditions. The following limits should be observed in selecting the proper charge current and cutoff point:

- The maximum cutoff point (the nominal plus the tolerances of the sensor and the control circuit) should not exceed 120°F (49°C).
- The maximum input to cutoff in ampere-hours at the fast-charge rate should not exceed 100 percent overcharge in the worst case situation.
- The maximum overcharge rate should not exceed 2C.

If these conditions cannot always be met over the full range of environmental conditions expected in service, a redesign of the battery packaging to change its thermal characteristics is one choice. An alternative is to select a charge control system which uses a combination of signals (see paragraph 2.4) for fast charge termination.

2.2.3 Chargers and Sensors for Temperature Cutoff Batteries

2.2.3.1 Sensing cell temperature

The cell temperature of a battery pack is sensed by either a thermostat or a thermistor buried in the pack. The sensor is normally placed in the center of the pack where the hottest temperature is expected. Wherever possible, it is affixed to the cell metal casing to ensure the best conductivity of heat from the cell to the sensor. The sensor is frequently covered with epoxy to achieve close coupling to the cell and is thermally insulated so that the ambient temperature does not significantly influence the switching temperature of the sensor. The sensor can be connected into the circuit in a variety of ways. Most commonly, one terminal of the sensor is connected directly to one of the battery terminals and the other terminal is brought out separately to the charger. The temperature sensor in most applications is not wanted in the discharge circuit so provisions must be made for a separate current path from the battery to the load.

2.2.3.2 Thermostats

The simplest temperature sensor for fast-charge rate cutoff is the automatic reset thermostat. This device is a switch that opens when the rising cell temperature reaches the actuating temperature and automatically closes when the temperature falls below the reset temperature. The thermostat is thermally coupled to a selected cell and is electrically connected in series with the charging circuit. See Figure 2-8. A bypass resistor around the switch drops the charging current to the 0.1C topping charge rate when the thermostat is open.

The advantage of the thermostat is that it is a low cost approach to both the sensing and switching function. The thermostat not only senses cell temperature but also switches the fast charge current. There are two disadvantages of the common thermostat:

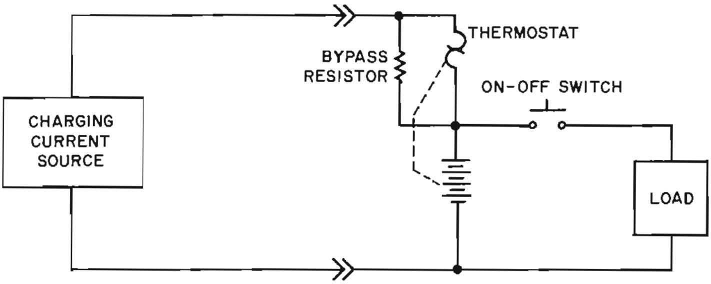


Figure 2-8. Thermostat Sensing Circuit

- "Dead" band
- "Bouncing" in overcharge

The "dead" band between opening and reclosing of the thermostat may present a limitation in the application if a fast charge is desired while the thermostat is in the "dead" band. This could occur if, during discharge or storage, the battery temperature had risen above the cutoff temperature and had not cooled down below the reclosing temperature of the thermostat. The battery would have to be cooled to the thermostat reclosing temperature before a fast charge could be initiated.

With the automatic reset thermostat an undesirable "bouncing" condition in overcharge can occur. After the battery becomes fully charged and the temperature rises to the cutoff point, it begins to cool down since the fast charge current has been terminated. The battery cools down through the "dead" band of the thermostat until the temperature reaches the reclosing point of the thermostat. This causes the fast charge current to flow again. The repeated on-off condition is illustrated in Figure 2-9.

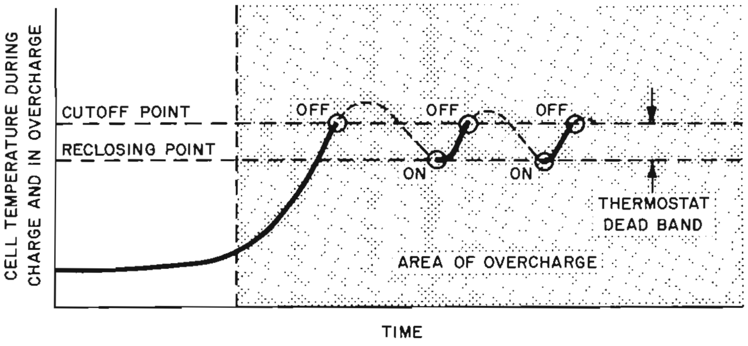


Figure 2-9. Temperature Excursions in Overcharge When Using an Automatic Reset Thermostat

This repeated bouncing into high rate overcharge shortens battery life because the cells are exposed to high temperature and high internal pressure for longer periods of time. One way in which this can be alleviated is by using a manually reset thermostat. The manually reset thermostat will not reclose until it is manually reset by an action, such as pushing a button or reinserting the battery into the charger. Another method that might be used to correct this condition is to use a heater with the automatic reset thermostat to keep the thermostat from reclosing. This keeps the battery at an elevated temperature until it is disconnected from the charger, tending to reduce battery life. A more commonly used method is to provide in the charger a latching function which keeps the fast charge switch "off" until a positive action, such as removing the battery from the charger, has taken place.

2.2.3.3 Thermistors

Thermistors are temperature sensitive resistors that can be used to sense the temperature of a cell in a battery pack. Thermistors are available with positive temperature coefficient (PTC) and negative temperature coefficient (NTC).

The PTC thermistor generally has a very large temperature coefficient, making its output signals easy to sense. NTC thermistors have a lower temperature coefficient but feature lower cost. To control the charging current, the voltage sensed by the thermistor circuit is continuously applied to the control circuit as shown in Figure 2-10. When the temperature rises to the set point, the control circuit acts to open the current switch. The charging current now flows only through the bypass resistor, lowering the charge rate to the 0.1C rate. The latching voltage function in the control circuit, which is not reset until the battery is removed from the charger circuit, holds the current switch open even when the temperature of the cell falls. Thus bouncing into high rate overcharge is avoided.

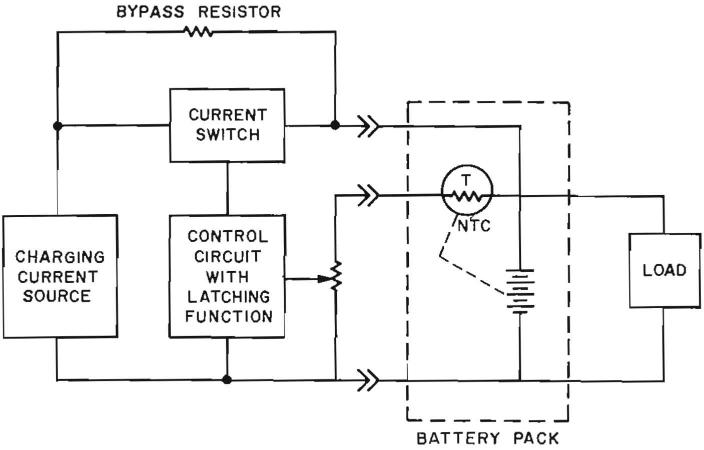


Figure 2-10. Thermistor Sensing Circuit

The advantages of the thermistor are:

- Small size
- No "dead" band

The thermistor is small enough to fit into almost any battery pack without increasing the physical size. The thermistor has no "dead" band which means that the battery can be charged whenever the cell temperature is below the cutoff setting.

The disadvantage of the thermistor is that it does not directly perform the switching action. A separate current switch triggered by the change in thermistor resistance must be provided in the charger to terminate the fast charge current. When using the thermistor, a latching function, as shown in Figure 2-10, is required in the charger to prevent the "bouncing" in overcharge at the fast charge rate.

2.2.3.4 Charging current source

The charger should be designed to furnish the proper charge current as the battery enters overcharge. The overcharge current, as described earlier, will depend upon the cell size, battery pack, and other thermal considerations. The maximum rate is 2C; the minimum rate is that amount that will always ensure cutoff at the specified minimum ambient temperature.

Once the ideal charge rate is selected, attention must be given to variations in this charge rate and their possible effect on performance and reliability of the system. A major cause of charge rate variation on any system is the inherent change of output current on (1) the normal line voltage variations, and (2) the ratio of source voltage (ac rms voltage in transformer secondary) to the battery voltage. A sound rule of thumb is that the charger design should be such that the lowest anticipated power line voltage will not cause more than a 25 percent drop in charge current for a given battery voltage. The source voltage should be substantially higher than the battery voltage so that the charger circuit will not excessively amplify the variation in line voltage. A transformer no load (unrectified) voltage of about 2.5 volts rms per cell should be satisfactory. Refer to the discussion of constant-current charger design starting on page 5-3 of the Nickel-Cadmium Battery Application Engineering Manual, GET-3148.

2.2.3.5 Need for 0.1C topping charge

At the time when a battery is switched from the fast-charge rate to the topping rate (0.1C) by the temperature sensing circuit, it is often not fully charged. The state of charge would be sufficient for most uses immediately after fast-charge cutoff, but the battery may not be at its top capacity. By switching to the 0.1C rate, the charger will continue to charge the battery until all cells in the pack reach their maximum capacity. A battery can be left on charge at the topping rate in this type of charger indefinitely and will be fully charged and ready for use at any time. This follow-up topping charge is beneficial for the battery pack as it will help to equalize the charge in the individual cells in the pack. Repetitive fast charge without the topping charge, because of the slight difference in cell charge acceptance at the fast rate, may build up over a number of cycles a significant unbalance in the state of charge of individual cells within the pack. Occasional periods of significant overcharge at the topping charge rate will help eliminate these undesirable differences.

2.3 FAST CHARGE VOLTAGE CUTOFF BATTERIES

2.3.1 Voltage Cutoff Concept

Nickel-cadmium sealed cells, when charged at constant current, generally exhibit a charge voltage versus state of charge characteristic which has the following features:

a. The cell voltage will rapidly rise from the rest voltage of about 1.20 to a "plateau" value which depends on charge rate and cell temperature.
b. As charge is continued the voltage will continue to rise very slowly (plateau value) until the cell approaches full charge.
c. As the cell goes into overcharge, the cell voltage will rise more rapidly, reach a peak and slowly fall to an equilibrium level based on stabilized cell temperature and charge rate.

This charge voltage profile for a representative cell charged in a 25°C ambient temperature at the 4C charge rate is shown in Figure 2-11. This rising voltage characteristic is the basis for the voltage cutoff method of terminating the fast charge current.

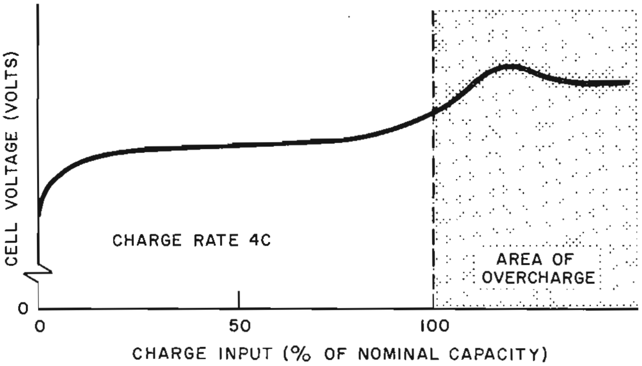


Figure 2-11. Representative Fast-Charge Voltage Characteristic of a Sealed Cell Design

NOTE

The subject of fast charge voltage as a means of charge control is also discussed in considerable detail in Section 5.1.6.2 of the Nickel-Cadmium Battery Application Engineering Handbook, GET-3148.

2.3.2 Considerations in Selecting the Cutoff Voltage

There are five major variables that affect the charge voltage characteristic of a battery designed for fast charge voltage cutoff. These variables which have impact on the proper voltage cutoff setting are:

- Charge rate
- Cell temperature
- Cell design
- Degree of cell matching
- Peak cell voltage and profile of the cell voltage characteristic

These and other considerations are discussed below.

2.3.2.1 Effect of charge rate

The charge voltage profile of a typical nickel-cadmium sealed cell is significantly influenced by charge rate. Figure 2-12 demonstrates the relative effect on the charge voltage profile at three different fast charge rates. One can observe from Figure 2-12 that:

- Cell voltage at all states of charge is higher for higher charge rates.
- The peak voltage reached is higher for higher rates.
- The difference between the plateau voltage and the peak voltage increases as rate is increased.

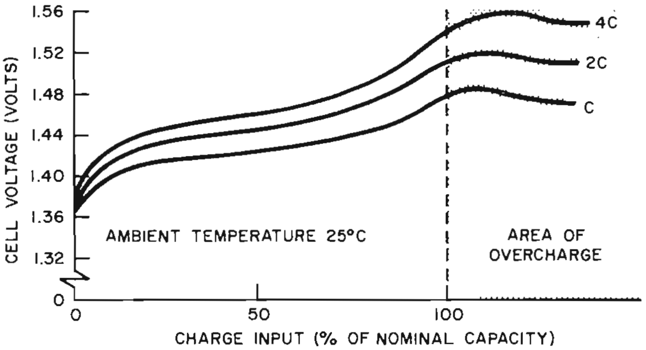


Figure 2-12. Effect of Charge Rate on Voltage of a Sealed Cell Designed for Voltage Cutoff

2.3.2.2 Effect of cell temperature

The charge voltage profile is also influenced by ambient temperature as is shown in Figure 2-13.

A cell charged at 25°C has a definite rise in voltage as the cell goes into overcharge. However, as the cell temperature is raised, the differential between the plateau voltage and the peak voltage is reduced. As cell temperature is increased the overall cell voltage at any charge rate is reduced and the differential between the plateau and peak voltage tends to diminish.

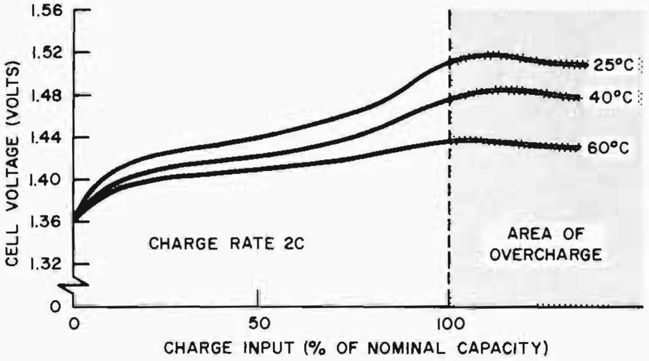


Figure 2-13. Effect of Ambient Temperature on Charge Voltage - Sealed Cell Designed for Voltage Cutoff

When utilizing charging voltage as the primary indicator for fast charge termination, the cutoff voltage must be varied to account for the effect of cell temperature on the charge voltage characteristic. This is illustrated in Figure 2-14.

Figure 2-14 shows the charge voltage profile of the same cell charged at three different temperatures. Note that as the cell temperature increases the Δv decreases. It is obvious that if the reference voltage of set point P_1 were used when charging the cell at 60°C, the cell voltage would never reach the set point and the fast charge would continue until the cell was destroyed. However, if the charger design provides for automatically adjusting the cutoff voltage in response to cell temperature, set points P_2 and P_3 can be made to fall essentially in the center of the Δv available on the cell at charge temperatures of 40°C and 60°C.

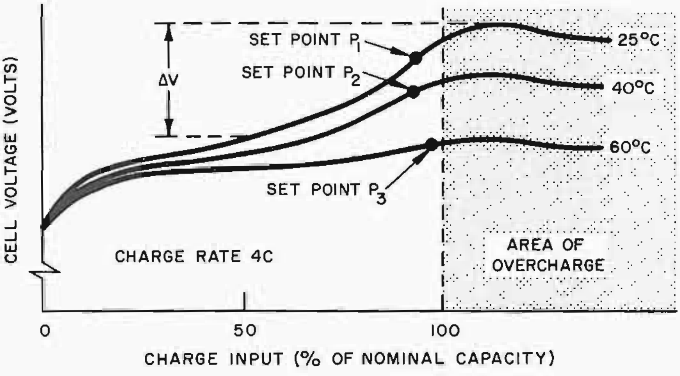


Figure 2-14. Charge Voltage at Various Cell Temperatures - Sealed Cell Designed for Voltage Cutoff

2.3.2.3 Effect of cell design

The third factor which affects the charge voltage characteristic of a battery pack and is the basis for a reliable charge control for voltage cutoff is the overall shape of the profile and the consistency of this characteristic from cell to cell. Nickel-cadmium sealed cells of various designs yield various charge voltage profiles. Figure 2-15 shows the voltage characteristics of three different cell designs when charged at the 4C rate.

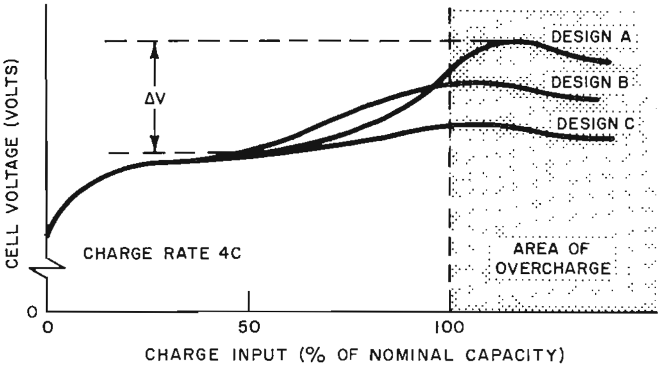


Figure 2-15. Fast Charge Voltage Characteristics of Various Sealed Cell Designs

The larger the Δv between the plateau voltage and the peak voltage, the more easily a control circuit can be designed for fast charge termination. Design A provides a significantly greater Δv than design B or C. It is apparent that for the highest reliability of charge termination based on charge voltage would be the use of design A type cells.

General Electric manufactures a line of sealed cylindrical cells designed specifically for fast charge voltage control applications. These cells are different from the cells designed for temperature cutoff fast charge batteries and are also different from the PowerUp-15 batteries. Cells for voltage cutoff are designed to accentuate voltage rise and to provide a more predictable charge voltage profile. These cells provide a significant Δv between plateau and peak when charged at selected high rates.

2.3.2.4 Degree of cell matching

Although cells can be provided that yield the more desirable charge voltage characteristic required for reliable voltage control of fast charge, there are still inherent variations in the charge voltage profile from cell to cell which require careful consideration. Figure 2-16 demonstrates one of the variables which is inherent in any lot of "voltage cutoff" type cells.

Although the variations from cell to cell within a lot of the peak voltage, Pv and the Δv may be quite small, the actual charge time to reach the reference voltage, Rv, will vary. See Figure 2-16. For a single cell application, this variation in capacity or charge acceptance from cell to cell is inconsequential since the only result will be varying times to cutoff and possible varying discharge capacities. However, multicell batteries require matching of

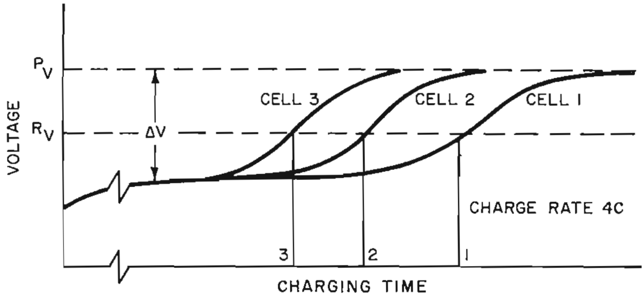


Figure 2-16. Variations in Time to Reach Peak Charge Voltage

the cells for the pack. It is apparent that if three cells with the individual characteristics shown in Figure 2-16 were assembled into a battery a new concern arises. Since each cell contributes to the total voltage required to meet the battery reference voltage (3 x Rv), in order to terminate the charge by the time the combined voltage of cells 1, 2 and 3 is high enough to reach (3 x Rv), cells 3 and 2 in this example will have been driven to a voltage higher than Rv. If the differential between cells in a multicell battery pack is "too wide" or if the cutoff voltage is raised "too high", it is possible to significantly overcharge one or more cells in the battery pack prior to reaching the battery cutoff voltage.

Another characteristic of importance when considering voltage cutoff as a fast charge control scheme is the inherent variation in peak voltage reached by various cells in a "voltage cutoff type" lot. Although the examples shown present each cell as having the same peak voltage, in fact the peak reached will vary from cell to cell. This peak voltage variation should be taken into account by the battery-charger designer in the determination of the cutoff value. In practice, the cutoff value is usually set at a low, "conservative" point which results in some sacrifice in the charge input at the fast charge rate.

2.3.2.5 Voltage cutoff summary

To summarize, the design of a reliable fast charge voltage termination control system must include recognition of the following factors:

- The cells used must have, by design, a predictable fast charge voltage characteristic.
- This voltage characteristic must have a significant Δv between the plateau voltage and the peak voltage reached in overcharge.
- The reference cutoff voltage must be set to fall above the plateau but below the peak. The amount below the peak will determine the reliability of the system.
- The reference cutoff voltage must be automatically adjusted in response to cell temperature to accommodate the effect of cell temperature on the charge voltage profile.
- The cells in multicell batteries must be matched in terms of charge voltage characteristics, charge acceptance and discharge capacity at the conditions expected in service.

Careful tradeoff studies must be made between cutoff voltage, degree of charge-discharge characteristics match, number of cells in the battery, maximum operating temperature expected, minimum charge rate expected, output capacity expected, and reliability objectives. The higher the cutoff voltage is set, the more closely the output capacity will approach maximum capacity of the cells. But the higher the cutoff is set, the more care must be taken in matching cells and tighter tolerances and controls must be designed into the charger. Lower cutoff voltages tend to increase reliability, but decrease the output capacity at cutoff.

2.3.2.6 Charger-battery compatibility

It is evident from the foregoing discussion that the interface between the charger and the battery is critical. To assure the reliability, it is essential that the charger be designed to be compatible with the specific battery design. When the charger is designed for a particular battery in a specific product, the charger designer can properly evaluate the tradeoffs in performance, cost and reliability, and make a judgement as to the degree of sophistication he needs to incorporate into the charger control circuit. Further, the charger manufacturer can optimize the system in terms of cost and performance by having control of both charger design and the degree of cell matching for the battery pack. It is for this reason that General Electric makes available the special fast charge voltage cutoff cells to manufacturers who design and make chargers. These cells are characterized by production lot for a good rising voltage characteristic. The charger manufacturer or battery user is called upon to grade and match the cells to the degree necessary for the particular application and to assemble them into the battery packs. With this approach the charger manufacturer or user has control over all elements of the system and can offer the most economical system consistent with the desired reliability for the application.

2.4 VOLTAGE AND TEMPERATURE CUTOFF: THE POWERUP-15 BATTERY

2.4.1 Voltage-Temperature Cutoff Concept

A new 15-minute fast charge system developed by the General Electric Company is designated the PowerUp-15 Battery System. The key to the PowerUp-15 charge system is the unique General Electric PowerUp-15 cell design. This special fast charge cell is capable of tolerating overcharge at the 4C rate well beyond the limits of previous cell designs. This additional overcharge capability permits greater freedom in designing the fast charge system and more reliable control at a reasonable cost.

Coupled with this new cell development is a new method of determining when to terminate fast charge. This system calls for use of both cell temperature and battery voltage for sensing when to cut off. This results in a reliable, modest-cost, 15-minute charge system.

Though the special PowerUp-15 cells can tolerate significant overcharge at the 4C rate, the system calls for a charger with a voltage-temperature cutoff

(VTCO) sensing and control circuit which will reliably terminate the fast charge before the cell pressure or temperature can build up to an excessive value. The charger for the PowerUp-15 fast charge battery continually monitors both cell temperature and battery voltage, which are applied to the charger control circuit through an "OR" type logic circuit. The variable which first reaches its cutoff setting causes the control circuit to switch the charger from high rate charging to a topping charge rate.

Voltage control alone can be quite reliable but requires costly fast charge cell characterization and matching and temperature compensation in the charger. (Refer to paragraph 2.3.2.) Temperature control alone for certain charge rates can also be reliable at room temperature, but special precautions must be taken at low temperatures. (See paragraph 2.2.)

When both cell temperature and battery voltage are used as indicators to control the charger, as in the PowerUp-15 system, the limitations of each individual system are avoided. The two signals are complimentary. In an environment or use pattern where one is weak, the other provides positive indication when the fast charge current requires termination. Also, as the battery ages with time or with charge/discharge cycling history, the characteristics of the cells change slightly. The redundant sensing of both voltage and temperature permits the cell characteristics to change yet still maintain reliable termination of the fast charge current. Both temperature and voltage cutoff points can be set to achieve a high state of charge before fast charge is terminated without compromising battery life or reliability.

2.4.2 Reliability of the PowerUp-15 Fast Charge Battery System

The new PowerUp-15 cell can tolerate overcharge at the 4C rate for some period of time without damage. As stated earlier, the two principal factors affecting life of any sealed nickel-cadmium battery are:

- Excessive internal cell pressure, and
- Excessive cell temperature

Any fast charge system must provide reliable means of terminating the fast charge current before either of these two life limiting factors occur. The following paragraphs will examine the two indicators, voltage and temperature of the battery, as they relate to the reliability of the PowerUp-15 fast charge battery system.

2.4.2.1 Charge voltage characteristic

A charge voltage profile for a typical cell designed for voltage cutoff only in a 25°C ambient temperature is shown in Figure 2-12. At the 4C rate the average voltage characteristic of a typical PowerUp-15 cell in a 25°C ambient temperature differs only slightly.

For lower cell temperatures the level of the entire voltage characteristic at the 4C rate will be higher and hence the peak voltage reached will be higher. Conversely, at higher cell temperatures, the charge voltage characteristic will be depressed and the peak will be lower. The range of maximum "trough" charge voltage of PowerUp-15 cells over a range of cell temperatures is illustrated in Figure 2-17. (See paragraph 2.4.3 for definition of "trough" voltage.)

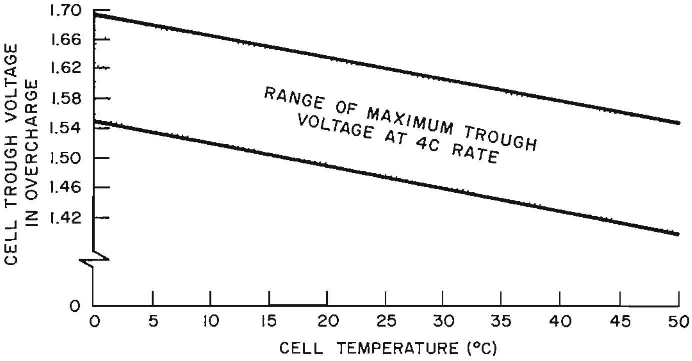


Figure 2-17. Maximum Voltage of a PowerUp-15 Cell Charged at 4C Rate

In addition to the relationship between maximum charge voltage and cell temperature at the 4C charge rate, careful analysis of PowerUp-15 cells subjected to high rate charging has demonstrated that there is a strong correlation between undesirable gas generation in overcharge and the maximum voltage the cell is allowed to reach. Undesirable gas generation in PowerUp-15 cells tends to be coincident with a charge voltage above 1.60 volts/cell at the 4C rate. If the trough charge voltage is limited to a value of 1.50 volts/cell, damaging gas generation is avoided. This line of protection is illustrated in Figure 2-18.

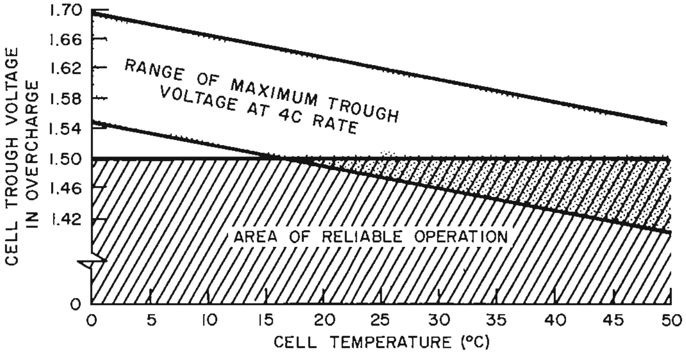


Figure 2-18. Area of Reliable Operation for a PowerUp-15 Battery Under Charge at 4C Rate

2.4.2.2 Area of reliable operation

The PowerUp-15 cell, because of its ability to tolerate significant overcharge at the 4C rate, can be repeatedly cycled at the 4C charge rate provided that the charge voltage or cell temperature does not go outside the bounds of the area of reliable operation shown in Figure 2-18. When the cutoff voltage is set at trough voltage of 1.50 volt/cell maximum and the cutoff temperature is set at 49°C maximum, reliable 4C rate charging is assured.

At low temperatures the battery voltage will usually be the controlling factor with the charging voltage reaching the voltage cutoff point before cell-damaging overcharge can take place. Low temperature charging is the primary limitation for fast charge systems using only temperature cutoff (see paragraph 2.2). For the PowerUp-15 system, low temperature charging is permissible, the only limitation being an early cutoff and hence a reduced input at the fast charge rate.

At high temperatures the battery temperature will usually be the controlling factor with the cell temperature rising to temperature cutoff before cell damaging overcharge can take place. If the battery temperature is so high that it exceeds the cutoff point prior to charge, the fast charge cannot be initiated.

2.4.2.3 Effects of repetitive cycling

Extensive life testing of PowerUp-15 batteries at the 4C charging rate has shown that the charging voltage characteristic, particularly the peak voltage, is not a constant and is influenced by such factors as rest periods and cycle regime. This shifting of charging voltage level with cycling tends to be directly related to charge rate and severity of discharge duty. The voltage temperature cutoff (VTCO) redundant method of terminating fast charge is well suited to duty cycles which require repetitive closely-coupled cycling. Rest periods also may cause a temporary change in the high rate charging voltage characteristic. Since the PowerUp-15 charger control circuit is monitoring both temperature and voltage, these minor shifts in charging voltage will not reduce the reliability of the system since they will be offset by the redundant cutoff control. As the charge voltage characteristics change, the leading indicator may change from voltage to temperature and back to voltage again. Figure 2-19 illustrates a typical situation showing how the shifts in characteristics might occur. (This figure plots the maximum trough charging voltage which would have been reached had the voltage cutoff not been applied.)

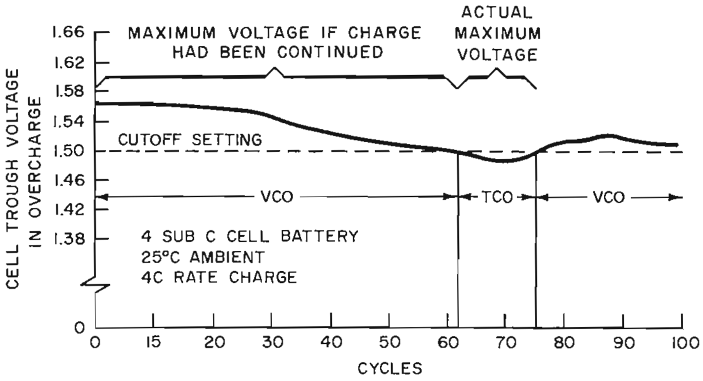


Figure 2-19. Effect of Cycling on Voltage Characteristic on a PowerUp-15 Charge System

2.4.3 Methods of Sensing Battery Voltage and Cell Temperatures

The two key indicators, battery voltage and cell temperature, must be accurately sensed so that the fast charge current can be properly terminated. The cell temperature sensors can be either a thermostat or a thermistor buried in the battery pack. A detailed discussion on temperature sensors is found in paragraph 2.2.3.

The method of sensing voltage is critical. Three methods are commonly used:

- Peak voltage
- Average voltage
- "Trough" or open circuit voltage

The peak voltage is the easiest and least costly method since most solid state voltage detectors inherently react to peak voltage. But peak voltage is the least desirable for fast charge control for two reasons. First, any unwanted voltage spike or noise would initiate a pre-mature cutoff switching action. Second, there is more variability in a cell's peak voltage than its average or trough voltage because of variability in the cell's effective internal resistance plus the variability in the resistance of the means of connecting battery to charger. These two sources of variability can be minimized by sensing average voltage or trough voltage.

To sense average voltage, a time integrating circuit such as an R-C circuit is used to filter out any ac voltage components of the battery voltage leaving only the average value. The average voltage method tends to minimize the problem of noise by filtering out the short-time spikes. It also reduces voltage effects of the variations from cell to cell permitting a more repeatable voltage characteristic.

The preferred method of sensing voltage is "trough" voltage. The source voltage in a typical full-wave battery charger system is shown in Figure 2-20(A). Also shown in the top waveform is a dc level representing the voltage of the battery under charge. Charging current shown in Figure 2-20(B), will flow to the battery only during the intervals when the open circuit source voltage exceeds the battery voltage. The voltage across the terminals of the battery being charged by the pulsating dc current is a ripple voltage superimposed upon its dc level as shown in Figure 2-20(C). This ripple voltage has sinusoidal peaks when the pulsating charge is applied and relatively straight, horizontal "trough" in the intervals between current pulses. Since the battery is not receiving charge current during the "trough" intervals, the "trough" voltage can be thought of as the open circuit voltage of the battery between charge current pulses. The peak voltage will vary considerably because of charge current variations and variations in connections and in the individual cells. However, the "trough" voltage is a repeatable and reliable indicator of state of charge. For this reason it is recommended that "trough" voltage be sensed rather than peak voltage for the VCO control circuit.

One way to obtain "trough" voltage for use as the VCO control is to connect a series resistor of small ohmic value in the battery return circuit. The pulsating positive voltage pulses (ripple) across this resistor are applied to the VCO voltage divider network in such a way that they are subtracted from the

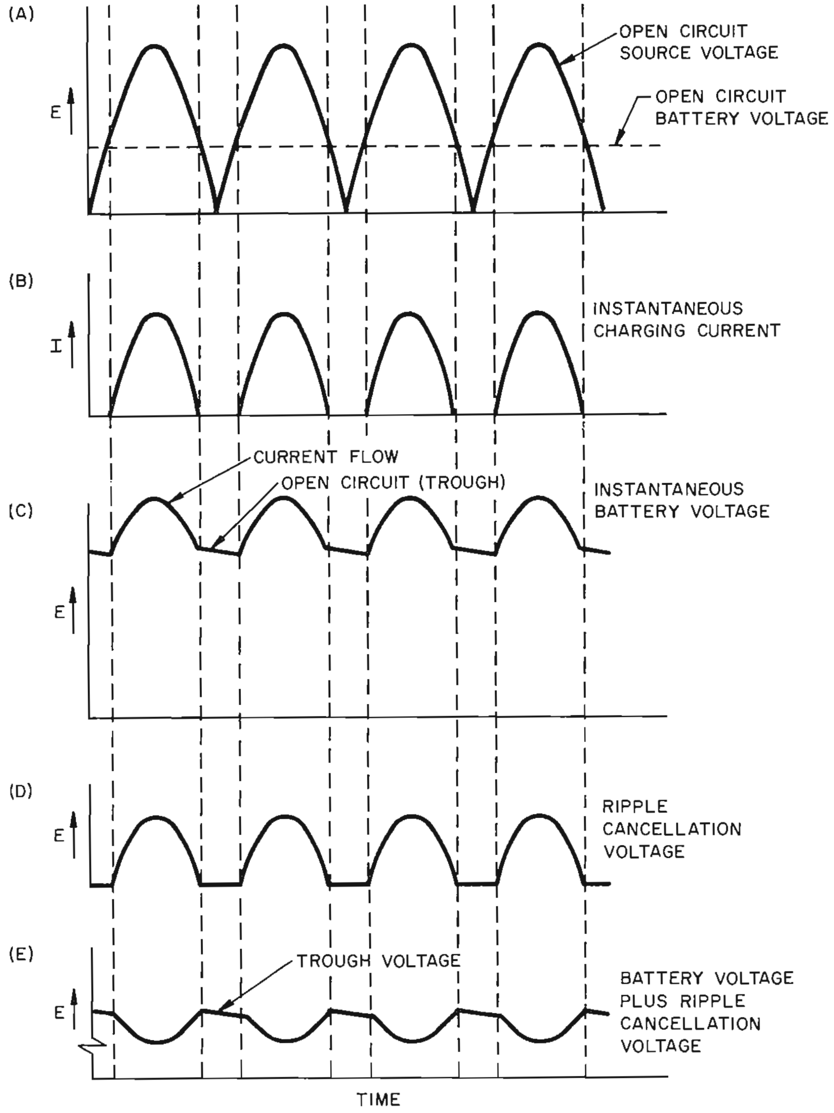


Figure 2-20. Voltage Cutoff Waveforms

battery voltage waveform. See Figure 2-20(D) and (E). The design is made such that the voltage across the ripple cancellation resistor more than cancels the battery ripple input to the VCO detector. The original "troughs" now become peaks and are readily sensed by the peak voltage detection characteristic of the detector in the control circuit.

2.4.4 Chargers for PowerUp-15 Batteries

Chargers for PowerUp-15 batteries are designed to charge at the 4C rate until one of the signals, either battery voltage or cell temperature, reaches its cutoff point. The chargers must have the capability of reliably sensing the battery voltage and cell temperature and must translate these indicators into switching action to properly terminate the fast charge current. These basic functions of the charger are illustrated as a block diagram in Figure 2-21.

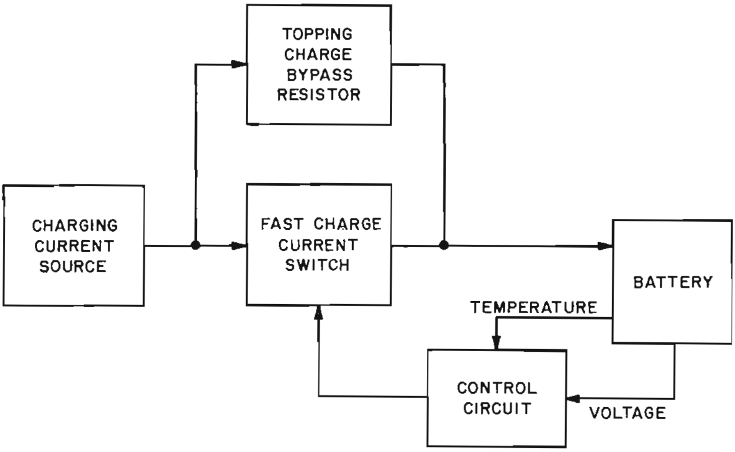


Figure 2-21. PowerUp-15 Battery Charger - Functional Block Diagram

2.4.4.1 Basic functions of charger circuit

CHARGING SOURCE. The charging source is usually a rectified ac (reasonably well regulated) but can also be a large battery or other dc current source. The charging source must be thermally capable of delivering the 4C rate on a repetitive cycling basis, since the application may call for a number of batteries to be charged, one right after another, from a single charger. If the charging source is a rectified ac supply, it can have either a full-wave rectifier or a half-wave rectifier circuit. Usually full-wave is used to reduce the cost of the transformation at higher rates. Half-wave can successfully be used and is frequently the choice for small cell sizes whose 4C current rate is not high. The degree of current regulation required for a reliable application is not critical. However, the charge current regulation for ac input voltage variations from 105 volts to 130 volts should not exceed 25 percent for a given battery voltage. For charge currents that will be less than 75 percent of the 4C rate in the worst case, refer to paragraph 2.4.5.

FAST CHARGE CURRENT SWITCH. The current switch should reliably interrupt the fast charge current when it receives the proper signal. It can be either a solid-state switch or a mechanical switch. Typically a thyristor (SCR) is selected, though a power transistor or relay can also be used. The switch should have a continuous current rating of at least the 4C rate. Some leakage current through the switch, when it is off, is acceptable provided it does not exceed the 0.02C rate of the battery.

TOPPING CHARGE CURRENT BYPASS RESISTOR. This bypass resistor allows the 0.1C rate to flow to the battery whenever the battery is connected to the charging source. When the 4C rate current is cut off, only the topping charge current can flow to the battery.

CONTROL CIRCUIT. The control circuit is the heart of the charger. The two signals, battery voltage and cell temperature, are monitored by the control circuit through OR-type logic and the leading indicator is translated into switching action at the proper moment to turn off the current switch. The control circuit not only has to convert the indicator signal into a switching signal at the proper moment, but it must also reject false signals such as "noise" and unwanted voltage spikes that may be present. Either signal, voltage or temperature, which first reaches the preset cutoff value, must cause the control circuit to turn off (open) the current switch so that the fast charge current is terminated, allowing only the 0.1C rate to flow through the bypass resistor. The OR logic in the circuit differs from temperature compensated voltage cutoff in that either voltage or temperature will initiate the switching action.

The paragraphs that follow describe two circuits that operate on the principles stated above. There is naturally a wide variety of circuits that can be used. The first one shown is a simple, economical 2-wire circuit and the second circuit is a more complex 3-wire circuit. Either circuit can be designed with a simple or a very sophisticated control circuit. The designer should be aware that the inexpensive circuits have some disadvantages or limitations that must be weighed in deciding which type of circuit to use.

2.4.4.2 Simple, 2-wire charge circuit

The charger circuit described functionally by the block diagram in Figure 2-22 is quite simple. Only two terminals are required to connect the battery to the charger. The temperature sensor is a thermostat which carries and terminates the fast charge current. The control circuit monitors only the battery voltage to turn off the current switch. When the fast charge current is turned off by the current switch (by means of the voltage signal), the topping charge current continues to flow to the battery through the thermostat which is still closed. When the fast charge current is terminated by the series thermostat due to battery temperature, the control circuit must sense this condition and turn the current switch off. The topping charge will flow after the thermostat resets as the battery cools down, but the current switch will remain open (non-conducting). Switch SW starts the fast charge current by

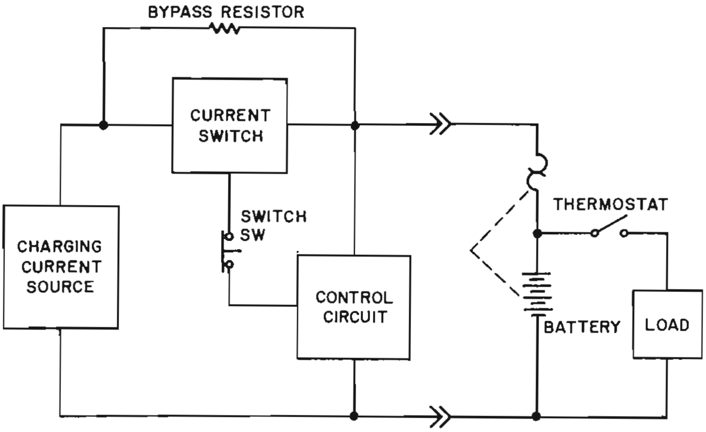


Figure 2-22. 2-Wire Simple Charger for PowerUp-15 Batteries

unlatching and closing the current switch. The simplified circuit of Figure 2-22, though it is economical, has a number of limitations.

- Space in the battery pack is required to mount the relatively large thermostat.
- There is no lamp or other indication of charging mode shown in this circuit.
- The temperature cutoff point is determined by the thermostat and cannot otherwise be adjusted.
- The thermostat has a "dead" band in which the fast charge current will not flow. (See paragraph 2.2.3.)

2.4.4.3 3-wire charger circuit

The 3-wire charger circuit shown functionally in Figure 2-23 contains several improvements over the 2-wire charger circuit previously described.

A thermistor is buried in the battery pack and is electrically connected to the charger through a third terminal. The thermistor carries no power current; the third terminal provides a signal path for cell temperature to reach the control circuit. Either the voltage or the temperature, whichever first reaches its cutoff point, will be seen by the control circuit as the signal to turn off the current switch. This switching action terminates the 4C rate and the current switch is held open (non-conducting) until the switch SW is again pushed.

The improvements in this system compared with Figure 2-22 are:

- Indicator lights L1 and L2 provide an indication of when the fast charge current is flowing (L1) and when it is not flowing (L2).
- The thermistor is small (compared to the thermostat) and can usually fit easily into the battery pack.
- The third terminal, though sometimes viewed as a disadvantage, provides a means for independent adjustment of the temperature cutoff point in the control circuit.

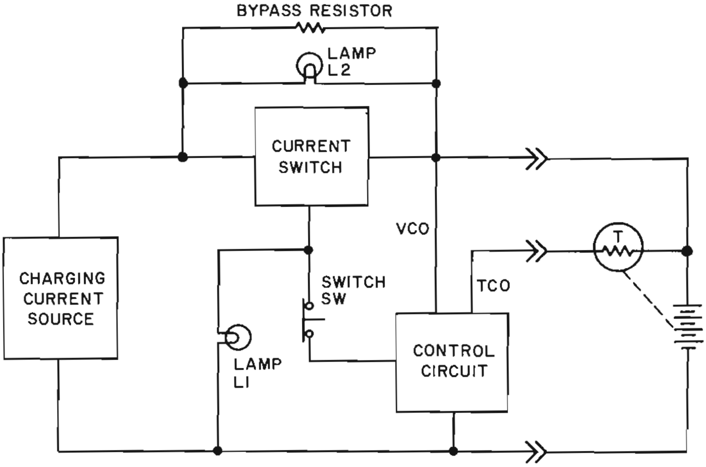


Figure 2-23. 3-Wire Charger for PowerUp-15 Battery

- The topping charge flows whenever the battery is connected to the charger; no wait is required for the battery to cool down.

Many variations of these two basic circuits can be conceived. There are methods of improving the reliability of the charger through:

- "Trough" voltage sensing (see paragraph 2.4.3)
- Temperature compensation of critical components
- Careful selection of critical components
- Decoupling and filtering circuits to eliminate effects of "noise" on the line.

If the application requires a maximum capability from the battery immediately following fast charge termination, the cutoff points are set as close to the maximum as possible. This allows no margin for error and this means that some or all of the above improvements should be incorporated into the charger design. However, if the application can tolerate a slightly lower battery capability immediately following fast charge cutoff, then the voltage setting can be lowered or tolerances expanded. This permits a lower cost control circuit, and most of the features above will not have to be incorporated into the charger design.

2.4.5 Considerations in the Selection of Temperature and Voltage Cutoff Points

As stated in paragraph 2.4.2, the most significant benefit of the PowerUp-15 cell design is that its high rate overcharge capability simplifies the control for properly terminating the fast charge current. The area of reliability places two limits on the system. The selection of these limits depends upon the application as discussed in the following paragraphs.

2.4.5.1 Normal duty cycles, charging at 4C rate

In normal applications calling for non-repetitive cycling or low rate discharge, the trough voltage cutoff point may be set as high as 1.50 volts per cell and the temperature cutoff point is set at a nominal 45°C (113°F), not to exceed 49°C. This will normally charge the battery to at least 90 percent of rated capacity. The cutoff voltage should be flat with no compensation for temperature.

In paragraph 2.2.2 covering temperature cutoff fast charge batteries, a variety of thermal considerations were presented. These precautions are not necessary in the PowerUp-15 fast charge battery system operated at the 4C rate. There are two reasons for this. One is that at low temperatures, charging in the PowerUp-15 system is not a concern. The battery voltage will rise to its cutoff setting at low temperature before cell pressure can build to an excessive level. The other reason is that at the 4C charge rate the cell temperature will always reach the temperature cutoff point in room temperature ambients regardless of cell size, number of cells, or packaging.

2.4.5.2 Effect of repetitive cycling, charging at 4C rate

Applications in which the duty is likely to include periods of heavy use with the battery subject to repetitive closely-coupled charge/discharge cycles, may make a lower cutoff voltage setting appropriate. Heavy duty repetitive cycling may lead to high battery temperature. If the battery becomes heated due to the heavy duty repetitive cycling and has a charge voltage which is below 1.50 volts per cell, the system will rely on the cell temperature each cycle for terminating the fast charge. As a consequence, at the end of each charge cycle, the battery temperature will be at the cutoff point of approximately 45°C. During a rapid high rate discharge the battery may heat up even further. After discharge, a cooling down period may be required before fast charge can be initiated again due to a “sensed” TCO condition. This condition is accentuated if a thermostat is used because of the “dead” band of a thermostat. See Figure 2-24.

However, if the voltage setting is reduced to about 1.45 volts per cell, the battery under this same heavy duty cycle will usually cut off due to voltage rather than temperature cutoff. This will eliminate the heating effect during the charge portion of the duty cycle. After the voltage cutoff and high rate discharge, the battery will be much cooler than if the battery had been charged to a temperature cutoff. The battery will most likely be cool enough, in this case, so that immediate recharge at the fast rate can be achieved. The tradeoff for obtaining immediate recharge after a high rate discharge, by lowering the voltage cutoff setting, is a slightly reduced capacity due to a lesser amount of fast charge input.

The duty cycle illustrated in Figure 2-24 is more severe in terms of heating during dicharge than most application duty cycles. A more common use pattern would call for longer periods of time for discharge which, in turn, would increase the cooling effect during discharge. Typically, the battery in cordless portable devices is discharged intermittently at high rates. Figure 2-25 pictures the temperature profile for one of these more typical duty cycles where the average discharge rate is less. In this case the temperature of the

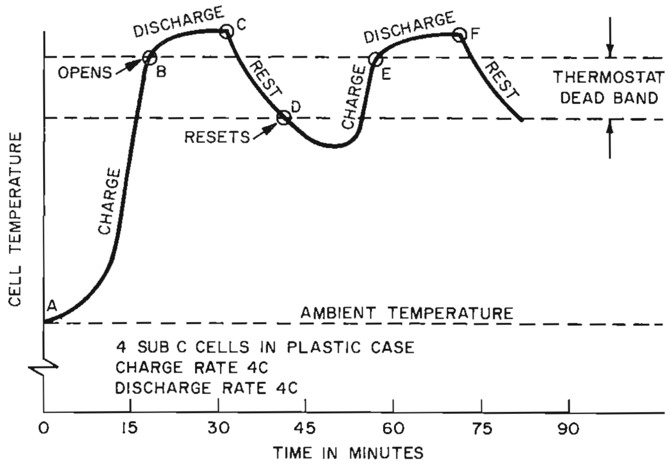


Figure 2-24. Typical Duty Cycle - Fast Charge, Continuous Discharge

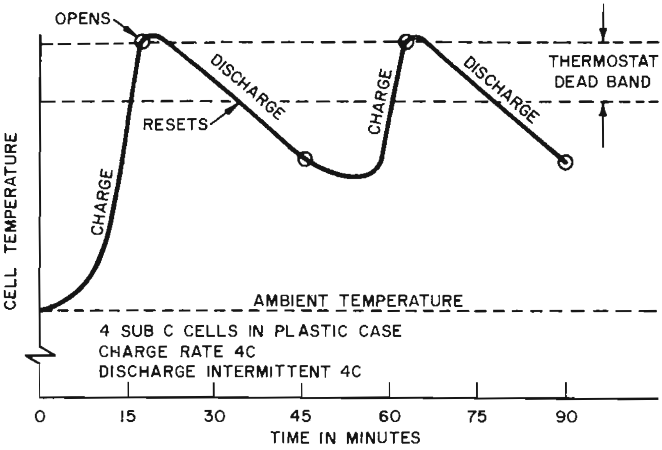


Figure 2-25. Typical Duty Cycle - Fast Charge, Intermittent Discharge

battery cools off during discharge and the thermostat resets prior to the time for recharge. Consequently, there is no need to reduce the VCO setting to reduce the overall battery heating.

If the ambient temperature is raised, cooling during discharge is reduced and the thermostat "dead" band may again be a limiting factor. If this occurs, reducing the VCO setting will help to ensure immediate recharge by reducing battery heating due to charging.

The capacity available for various voltage cutoff settings is illustrated in Figure 2-26. This performance data for different voltage cutoff points will help the designer determine what degree of sophistication needs to be designed into the elements and tolerances of the control circuit to assure desired performance.

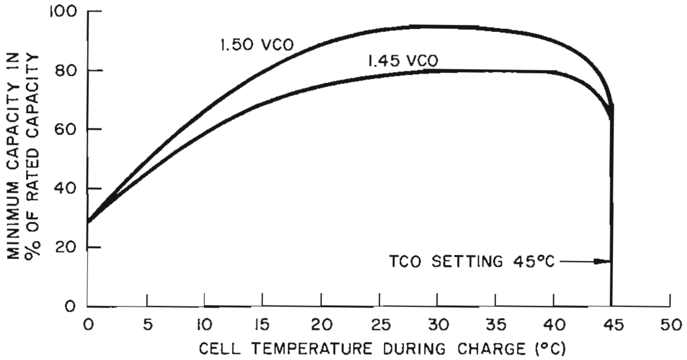


Figure 2-26. Capacity of a PowerUp-15 Battery Immediately Following 4C Rate Charge Termination (TCO Setting at 45° C)

2.4.5.3 Operation of PowerUp-15 batteries at charge rates other than the 4C rate

Although the PowerUp-15 fast charge system was designed to recharge in 15 minutes using the 4C rate, other charge rates can be considered.

The PowerUp-15 cell's high rate overcharge capability makes it adaptable for charging currents of less than the 4C rate. As stated in paragraph 2.4.2, the area of reliable operation at the 4C rate was bounded by a maximum "trough" voltage of 1.50 volts/cell and a maximum cell temperature of 49°C (120°F). At lower charge rates both the voltage cutoff point and the temperature cutoff point must be reduced. At charge rates of less than 4C, the thermal considerations outlined in paragraph 2.2.2 (temperature cutoff only) become important. At the 4C rate a sufficient amount of heat is generated in the cells in overcharge so they always reach the TCO setting of 49°C maximum (assuming the fast charge current had not been first terminated by the voltage signal). But at lower charge rates the amount of heat generated may not be sufficient to give the temperature rise necessary to ensure reliable cutoff in all circumstances before damaging overcharge can take place. As discussed in paragraph 2.2.2, there are large combinations of possible variables, namely, charge rate, battery pack configuration, type of battery enclosure, ambient temperatures and cell temperature at the outset of charge, that must be evaluated. Accordingly, broad statements about recommended charge rates and cutoff settings cannot be made with confidence until the specific case is carefully analyzed.

It is recommended that any specific application for PowerUp-15 batteries with overcharge rates of less than 4C rate be reviewed with General Electric application engineers and battery designers for specific charge rate and cutoff setting recommendations. The larger transformer and rectifiers required at higher charge rates increase the cost significantly. In addition, the battery charge acceptance is reduced for charging currents greater than the 4C, which means that the available capacity tends to be less for higher charging currents. These two factors favor a fast charge rate of 4C or lower.

2.4.6 Performance of PowerUp-15 Batteries

The capacity of the PowerUp-15 batteries depends primarily upon the temperature of the battery during charge and the cutoff settings. The length of topping charge will become important if the fast charge current is terminated early due to temperature extremes.

At low temperatures the battery voltage will rise quite quickly and the fast charge current will be terminated prior to a full charge. For battery temperatures above the TCO setting, no fast charge current will flow. The capacity following termination of the 4C rate charging current is illustrated in Figure 2-26. If the temperature cutoff setting is raised or lowered slightly from the nominal 45°C point illustrated, the curve in Figure 2-26 can be adjusted for that particular cutoff point.

After an early termination due to low temperature a full charge can be achieved from a 0.1C topping charge as shown in Table 2-1. By using Table 2-1 along with Figure 2-26, the total charge time to obtain a full charge can be easily estimated.

Table 2-1. Amount of Topping Charge Required for a Full Charge

Capacity at the Moment of 4C Charge Rate Termination	Hours of 0.1C Topping Charge to Obtain 100% Capacity
30%	10-12
40%	9-11
50%	8-10
60%	7-9
70%	6-8
80%	4-6
90%	2-3

2.4.7 Operation of PowerUp-15 Batteries with Only One Indicator for Terminating Fast Charge

2.4.7.1 Voltage cutoff only

Charging a PowerUp-15 battery pack with a voltage only cutoff fast charge system is not recommended as it is likely to prove unreliable.

2.4.7.2 Temperature cutoff only

In many applications a PowerUp-15 battery pack can successfully and reliably be charged at lower rates (1C to 2C) with a temperature only cutoff system. All the considerations in paragraph 2.2.2 and 2.2.3 must be observed.

SECTION 3

QUICK-CHARGE BATTERIES

3.1 INTRODUCTION

For many years the users of nickel-cadmium sealed cell batteries had to be content with a 16- to 24-hour recharge time to bring a discharged battery back to full capacity. The recommended charge rate for most nickel-cadmium sealed batteries was the 0.05C to 0.1C rate. At this rate, the battery could be charged for long periods of time without harm; however, any faster rate needed termination as the battery entered overcharge since the cell was not capable of handling the higher oxygen pressure developed at the higher rates in overcharge.

Today battery users have a choice and can obtain sealed cells that can handle higher overcharge rates. For many battery packs and in many applications, the temperature of the battery in overcharge at the 0.3C rate will rise to a rather high value. For these applications the battery must not only provide the capability to handle the higher overcharge current, but also provide long life when operated at these high temperatures. For these applications, Goldtop* quick-charge batteries are recommended. The remainder of this section is devoted to the Goldtop quick-charge battery. It should be noted, however, that in a few applications, the temperature rise may not be severe. For these applications, quick-charge batteries without Goldtop high temperature capability may be used. With the exception of long life at high temperatures, the performance of General Electric's non-Goldtop quick charge batteries will be the same as described below for Goldtop batteries.

* Trademark of General Electric Company

3.1.1 Quick-Charge Rates

The quick-charge rate as defined by General Electric is one that will recharge a discharged battery to full capacity in 3 to 5 hours. The special quick-charge cell is capable of handling the higher charge current efficiently in overcharge without excessive pressure rise in the cell. For most Goldtop cells the quick-charge rate is 0.3C.

At the 0.3C charge rate, a partially discharged battery can be returned to full capacity in an hour or two. A completely discharged battery can be fully recharged and used again within half a day. The amount of energy that can be returned to the battery in a few hours at the quick-charge rate is illustrated in Figure 3-1.

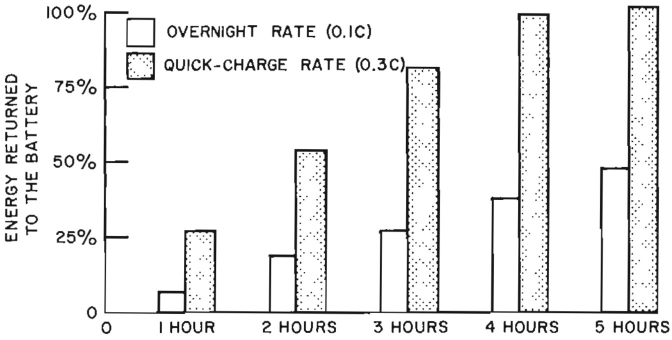


Figure 3-1. Energy Returned to Battery in 1, 2, 3, 4 and 5 Hours

3.1.2 Low Charger Cost

An additional benefit of the Goldtop quick-charge battery is that the 3- to 5-hour recharge time can be achieved with a low-cost charger. Since the battery is capable of sustaining an overcharge current of the 0.3C rate for long periods of time, the charger design is very simple. Figure 3-2 shows the simple elements involved, namely, a transformer, a single rectifier, and a series

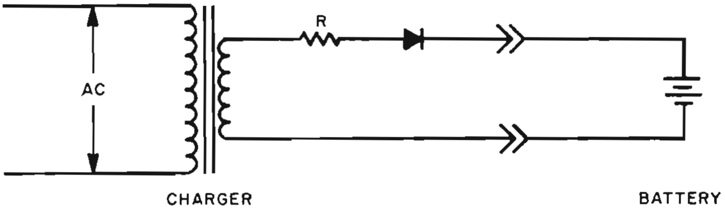


Figure 3-2. Simple Charger

voltage-dropping resistor. Most charger manufacturers design the resistance, R, into the windings of the transformer. For the larger cell types, the economics may favor a full-wave rectifier rather than the half-wave system illustrated.

The Goldtop quick-charge batteries are well suited for use in portable electronic devices, such as the portable desk calculator, where the average drain rate of the load is equal to, or less than, the quick-charge rate. In these applications the battery can be used in an ac/battery power supply as the filter for the charger/adapter, as shown in Figure 3-3.

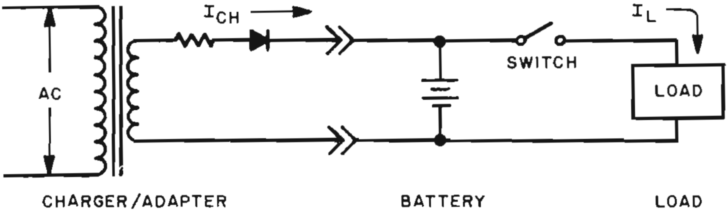


Figure 3-3. Charger/Adapter for AC/Battery Operation

When the charger/adapter is plugged into the battery and the load is drawing current, most of the load current is being supplied by the charger/adapter and the battery acts as a filter. The battery never becomes discharged in this mode of operation as long as $I_L \leq I_{ch} \leq 0.3C$.

3.2 CHARGING AT QUICK-CHARGE RATES

General Electric quick-charge Goldtop nickel-cadmium batteries are designed for overcharge rates up to the 0.3C rate compared with the normal 0.1C rate recommended for conventional sealed cells. These Goldtop cells are designed to recombine on the negative electrode the oxygen which is generated on the positive electrode at the higher overcharge rate, and to have these reactions take place at modest pressures. (See paragraph 5.2.)

Once the cell has become fully charged, the oxygen pressure in the cell will reach an equilibrium overcharge pressure determined by the cell design, the charge current, and the cell temperature. The overcharge current generates heat and the cell temperature will rise. The cell temperature will reach an equilibrium value determined by:

a. The magnitude of the overcharge current
b. The size and number of cells
c. The battery packaging
d. Battery ambient temperature

These four factors contributing to cell temperature in overcharge are discussed in more detail as they relate to the quick-charge rates.

3.2.1 Factors Affecting Cell Temperature in Overcharge

The overcharge current rate has the most significant impact on cell temperature. Figure 3-4 shows that the cell temperature remains relatively close to the ambient temperature until the cell approaches full charge. Then the cell temperature begins to rise as it goes into overcharge. The rate of rise is partly dependent upon the charge rate as shown. The amount of cell temperature rise of a quick-charge cell in overcharge at the 0.3C rate is roughly three times the rise of the same cell in the same package at the normal 0.1C rate.

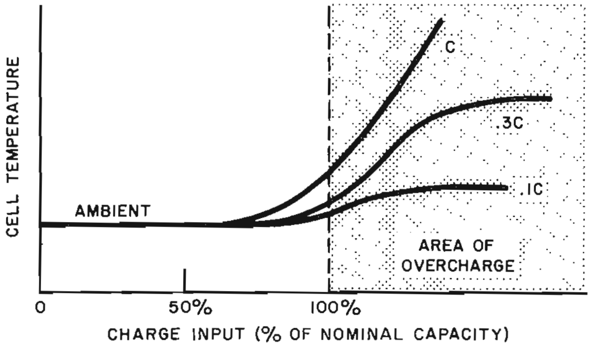


Figure 3-4. Cell Temperature During Charge and In Overcharge

The cell size and the number of cells in the battery pack have a marked effect on the cell temperature rise in overcharge. Batteries made up of large diameter cells tend to run hotter than batteries made up of smaller diameter cells. This is due to the amount of case surface area available to dissipate heat. The rate of heat dissipation is less in relation to the cell capacity for large diameter cells than for smaller diameter cells. One can expect a battery of 10 D cells, for example, to run hotter than a battery of 10 AA cells. The effects on cell temperature rise in overcharge of both charge rate and cell size in a battery pack are shown graphically in Figure 3-5.

The number of cells in the battery pack will also affect the temperature rise in overcharge. A 10-cell pack, for example, can have a temperature rise of up to twice the amount as can a 5-cell pack of the same cell size and with the same type of battery case construction. Accordingly, one can make a rough estimate of the temperature rise within a battery pack by multiplying the number of cells in the pack by an empirically-derived value for the temperature rise per cell. Figure 3-6 shows the temperature rise in degrees per cell per 100 mA of overcharge rate for nickel-cadmium sealed cells. The band shows the range one might expect to see for various types of battery packaging and enclosure.

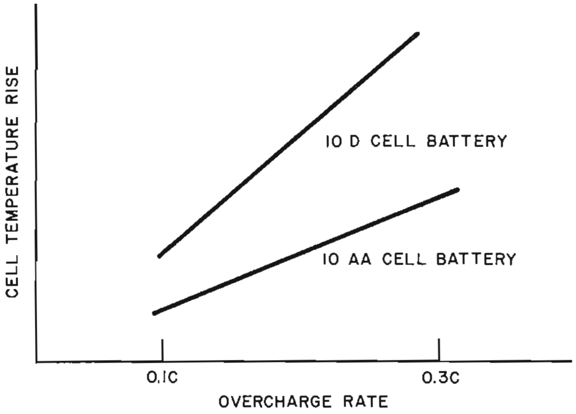


Figure 3-5. Cell Temperature Rise Versus Overcharge Rate for Two Plastic Enclosed Batteries: One with 10 AA Cells and One with 10 D Cells

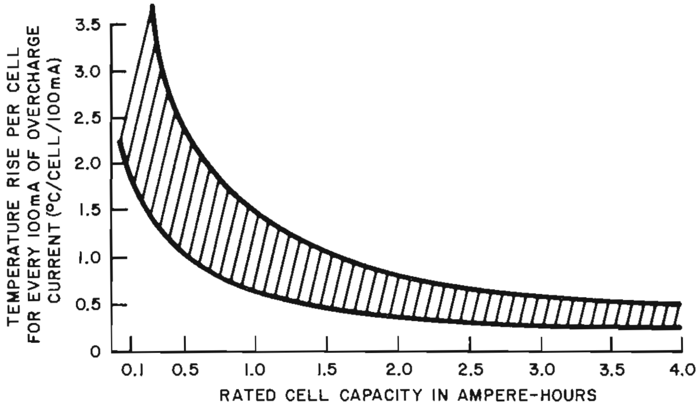


Figure 3-6. Approximation of Cell Temperature Rise in Overcharge by Cell Size

The battery packaging and the enclosure in which the encased battery pack is placed will have an impact on the amount of cell temperature rise in overcharge. If the battery pack has the cells arranged in a "stick" configuration (cells connected end-to-end) or in a grouping where the cells are physically separated, the battery pack is likely to be cooler than the same number of cells bunched up together in a very tight pack. The case material of the pack, if it is a thick plastic material which acts as a good thermal insulator, will cause the battery pack to run hotter than a case which will dissipate heat more readily. The enclosure in which the battery pack is placed, if it is also a thermal insulator, will cause the battery temperature to run higher than an enclosure that is well ventilated. The variation of temperature rise in overcharge due to the cell arrangement in the pack, the type and material of the battery encasement and the enclosure in which the battery is placed could make as much difference as 10°C rise for some large quick-charge batteries.

Finally, the other element which will determine the cell temperature in overcharge is the ambient temperature in which the battery is charged. In most applications the battery is charged at room temperature. However, in some devices the temperature in the equipment surrounding the battery may be higher than the ambient temperature outside the equipment due to heat generating components mounted near the battery pack. If this is the case, the cell temperature in overcharge can be very high.

Because of its chemical and physical properties, the special separator used in the General Electric Goldtop line of nickel-cadmium sealed cells is much more tolerant of high temperatures than the separator used in conventional cells. For example, GE Goldtop cells when subjected to a high temperature stress test survived for months in a temperature at which standard cells failed completely in weeks. The high temperature capability of the GE Goldtop cell allows the designer greater latitude in battery design, packaging, and proximity to other components, for it provides satisfactory separator life under any cell temperature within the recommended range.

Prior to the introduction of the Goldtop battery, many applications were limited to the 0.1C overcharge rate just to keep the cell temperature low enough to ensure reasonable life. The Goldtop battery, with its 65°C maximum cell temperature limit, provides more freedom to use the quick-charge capability of the cell. The designer can thus take advantage of the rapid recharge capability of the Goldtop quick-charge cells and still expect long life even in applications which develop the high cell temperatures that are caused by the combination effects of overcharge at the quick-charge rate, cell packaging, and/or high ambient.

3.2.2 Recommended Rates for Quick-Charge

The recommended overcharge quick-charge rates in Table 3-1 are applicable to batteries in ambient temperatures down to 15°C. If the ambient temperature is below 15°C, the cell temperature in overcharge may be cool enough to inhibit the recombination of oxygen at the negative electrode, and the cell pressure will rise to a pressure that may cause the cell to vent. (See Figure 3-7.) Also, as has been previously stated, the maximum recommended temperature for Goldtop batteries is 65°C. Hence, the qualifications for the recommended quick-charge rates listed in Table 3-1 are:

a. Cell minimum ambient temperature 15°C
b. Cell case maximum temperature 65°C

Table 3-1. Recommended Quick-Charge Rates

Cell Size	AH	Quick Charge Rate in mA
1/3 AA	0.100	30
1/3 A	0.130	45
1/2 AA	0.250	75
AA	0.450	150
A	0.600	180
2/3 C	0.900	270
Sub C	1.0	300
C	1.5	450
1/2 D	2.0	600
D	3.5	1000

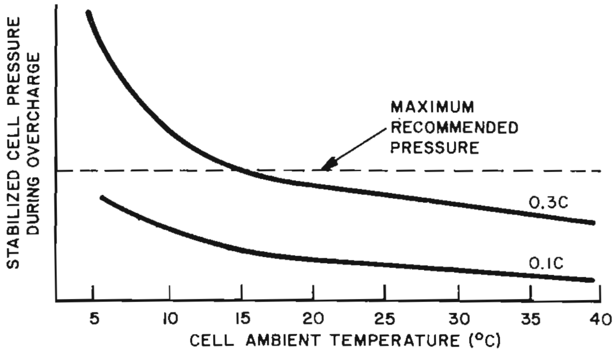


Figure 3-7. Internal Cell Pressure at Various Ambient Temperatures in Overcharge

3.3 PERFORMANCE OF QUICK-CHARGE BATTERIES

3.3.1 Discharge Voltage and Capacity

The quick-charge Goldtop cells can be charged at the 0.3C rate with no deteriorating effect on discharge voltage or capacity. One can expect these cells charged at the 0.3C rate to have voltage and capacity performance similar to the same cells charged at a 0.1C rate. For some sizes, the Goldtop cells may have a slightly lower capacity than the same physical size in the standard construction. Capacity ratings of Goldtop batteries are given in Section 6.

The discharge voltage characteristic for quick-charge cells is essentially the same as for standard cells. The reader may want to refer to Section 6 of the Nickel-cadmium Battery Application Engineering Handbook, GET 3148 for more detail. Also, typical discharge curves are illustrated in Section 6 of this book.

3.3.2 Life of Quick-Charge Batteries

The considerations governing the life expectancy of nickel-cadmium sealed cells used at a charge rate of 0.3C are the same as for high-temperature operation. Refer to paragraph 4.3.3. As in the case of cells charged at the 0.1C rate, high internal cell temperature coupled with internal oxygen atmosphere causes deterioration of the cell's insulation system. The cell experiences higher oxygen pressure in overcharge at the quick-charge rate. The life of a cell is reduced when it is subjected to long periods of high temperature at the higher pressure of 0.3C overcharge. The Goldtop cell has a greater tolerance to the combined effects of higher pressure and temperature in overcharge than a cell of standard construction. The life comparison is shown in Figure 3-8.

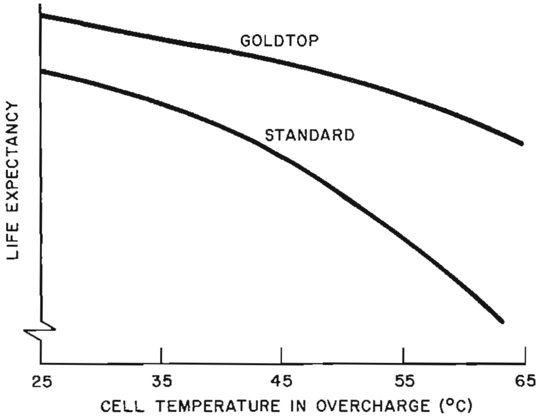


Figure 3-8. Life Expectancy Versus Cell Temperature in Overcharge at the 0.3C Rate

SECTION 4

HIGH TEMPERATURE BATTERIES

4.1 INTRODUCTION

Until very recently, most applications in which high temperatures were present could not practicably use commercial rechargeable batteries. At high temperatures, the useful life of aqueous electrolyte batteries was just too short for consideration.

The General Electric Goldtop battery opens up many new opportunities for use of this rechargeable nickel-cadmium sealed cell power source. All elements of the Goldtop battery, including the plates, the seal, and the separator, have been designed to better withstand higher cell temperatures.

4.1.1 Temperature Rating

Prior to the availability of the Goldtop battery, nickel-cadmium sealed cell batteries were limited to applications in which the maximum cell temperature would not exceed 50°C. Manufacturers typically rated the battery capable of storage in temperatures up to 50°C and operation in up to a 40°C ambient (figuring a battery temperature rise over ambient would not exceed 10°C).

The Goldtop battery is rated differently. The maximum allowable sustained temperature of the Goldtop battery in order to achieve reasonably long life is 65°C cell temperature. Hence, the Goldtop battery increases the maximum temperature limit by 15°C. And even at 65°C maximum cell temperature, it has an average life several times the life of a conventional nickel-cadmium battery at 50°C cell temperature.

4.1.2 High Temperature Application

This high temperature capability permits the Goldtop batteries to be used in many new applications. Emergency fluorescent lighting is one example. The batteries can be reliably applied inside the fluorescent fixture in the same channel where conventional ballasts are mounted. Though the temperature in some fixtures may run as high as 60°C, the Goldtop battery can survive for many years in this hot environment, and perform on a moment's notice to operate the lamp through a special inverter/ballast combination. See Figure 4-1.

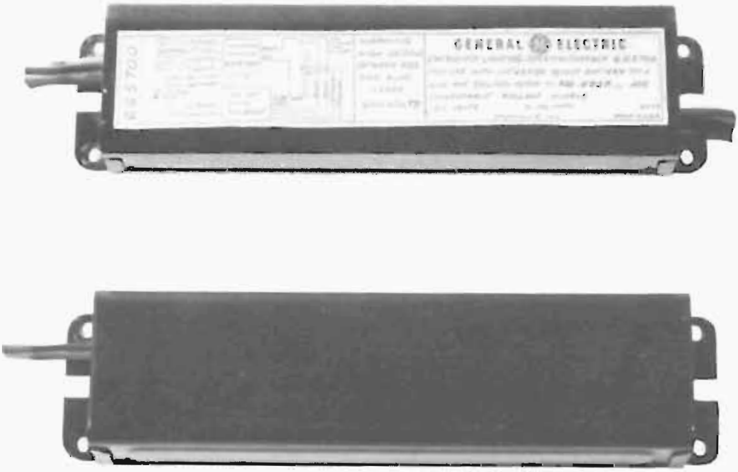


Figure 4-1. Battery and Inverter/Charger for Emergency Fluorescent Lighting

4.2 CHARGING AT HIGH TEMPERATURES

The nickel-cadmium sealed cell, whether it is used at normal room temperatures or in higher ambient temperatures, should be charged with a constant current. It is not crucial (except for some fast charge systems) whether or not the current is highly regulated for ac line voltage variations, but the maximum limits should be observed. The cell can accept a pulsating dc (rectified ac) or a smooth dc charge current, with equally good results.

The capability of the cell to accept charge at elevated temperatures is reduced. This charge acceptance phenomenon is described later in this section.

The minimum charge current, listed in Table 4-1, will provide just enough energy to convert all the available active material to the fullest capability of the cell. Any charge rate less than the recommended minimum will reduce cell performance. There is no need to reduce the charge rate of the Goldtop battery to the so-called "trickle" rate of 0.01C or 0.02C when the battery becomes fully charged.

Table 4-1. Recommended Overcharge Rates (in Milliamperes)

Cell Size	AH	Maximum	Minimum
1/3 AA	0.100	10	5
1/3 A	0.130	13	7
1/2 AA	0.250	25	13
AA	0.450	45	23
A	0.600	60	30
2/3 C	0.900	90	45
Sub C	1.0	100	50
C	1.5	150	75
1/2 D	2.0	200	100
D	3.5	350	175

The maximum recommended overcharge rate is subject to two limits, namely, cell temperature in overcharge and cell pressure. At high temperatures the most likely limit is cell temperature in overcharge. As discussed in paragraph 3.2, the cell temperature will rise in overcharge as a function of charge rate, the number of cells in the battery pack, the configuration of the pack, and its enclosure. If the cell temperature rise plus the ambient temperature takes the cell above 65°C, then the charge rate should be reduced to a point so that the 65°C cell case temperature limit is maintained. A thermocouple can be buried in a pack to make this test.

The other limit for maximum overcharge rate is cell pressure. This is generally not a problem at high temperatures even at charge rates slightly exceeding the maximum recommended rate. But if the cell will also be exposed to ambient temperatures down to +5°C in overcharge, then the maximum charge rate must be observed. The cell pressure in overcharge increases quite significantly as the cell temperature is reduced. See Figure 3-7. If the application will require charging in temperatures below 5°C, the charge rate must be reduced as recommended in paragraph 4.3 of the Nickel-cadmium Battery Application Engineering Handbook, GET-3148.

4.3 PERFORMANCE AT HIGH TEMPERATURES

The performance of a nickel-cadmium sealed cell is affected by high temperatures. The discharge voltage, as well as the capacity of a hot cell is less than a cell operated at normal room temperature.

4.3.1 Discharge Voltage

The discharge voltage of a cell at high temperatures can best be understood by analyzing the simplified equivalent circuit of the cell shown in Figure 4-2.

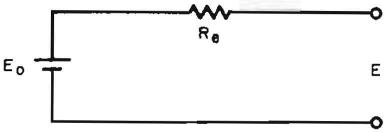


Figure 4-2. Cell Equivalent Circuit

The cell discharge voltage, E, is governed by the following equation:

$$E = E_o - IR_e$$

By analyzing the effects that high temperature has on E_o and R_e, the discharge voltage relationship with temperature can be understood.

The open circuit voltage of the cell, E_o, tends to be depressed as the cell temperature rises. E_o is also related to the state of charge of the cell. These two relationships are displayed in Figure 4-3.

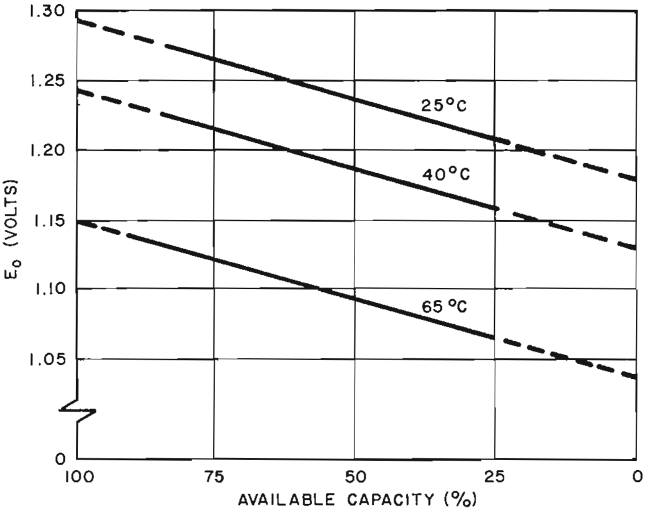


Figure 4-3. Effective Cell No-Load Voltage Versus Available Capacity - Goldtop Cell

The effective internal resistance, R_e, also changes with temperature. The resistance is a minimum at about 20°C to 60°C. Above 60°C and below 20°C the R_e begins to rise rapidly as shown in Figure 4-4.

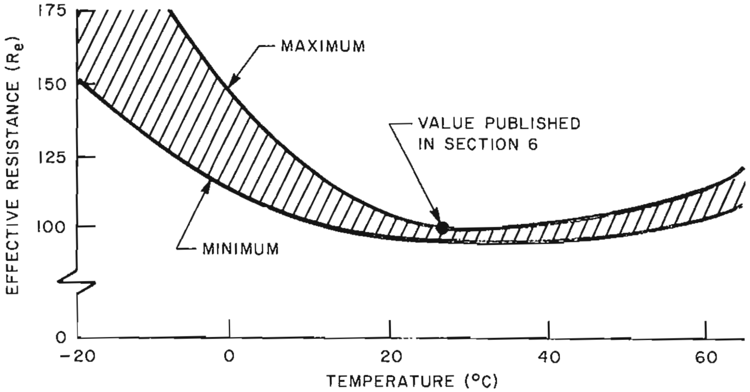


Figure 4-4. R_e Versus Cell Temperature

The combined effect of these two variables is rather complex and differs somewhat for each cell type. The midpoint voltage (described in Figure 5-5) is a convenient point from which comparisons can be made. Figure 4-5 illustrates the effect of high temperatures on the midpoint voltage of a Sub C cell.

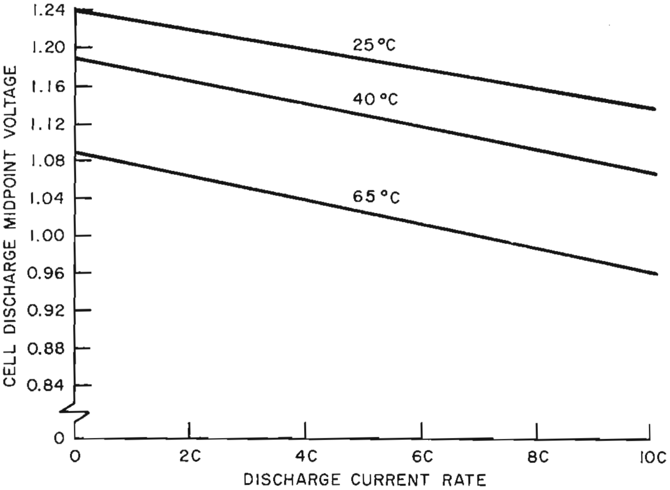


Figure 4-5. Typical Midpoint Discharge Voltage of a Sub C Cell Used in Repetitive Cycling Applications

4.3.2 Capacity

High temperatures can affect the capacity of a cell in a number of different ways. The discharge voltage, as described previously, is depressed due to high temperatures. If the acceptable end-of-discharge voltage is quite low, there may be no effect on the capacity of the cell. But if the end-of-discharge voltage is 1.0 volt per cell and the discharge rate is high, then the high temperatures will have an effect on apparent capacity, as can be seen from Figure 4-6. If a cell that has been charged to 100 percent capacity at a lower temperature is then soaked at an elevated temperature, the cell capacity will decrease over a period of time due to self-discharge. There will be no appreciable loss of available capacity or depressed voltage if the cell is discharged immediately at the high temperature.

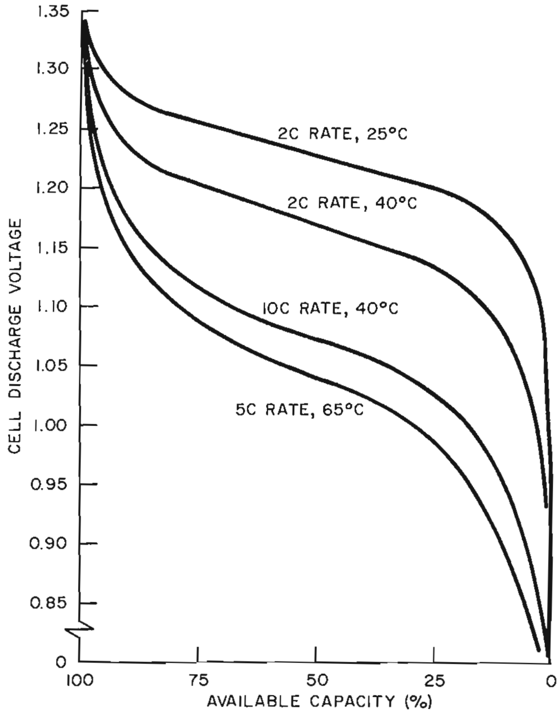


Figure 4-6. Representative Discharge Voltage Profiles at Elevated Temperatures

Also, if the cell is maintained on charge at the 0.1C rate at the high temperature, it will retain a high percentage of the charge it accepted at the lower temperature. However, the available capacity will drop significantly if the charged cell is stored at rest at high temperature for an extended time. (Typical values for this self-discharge characteristic are shown in Figure 4-10.)

4.3.2.1 Charge acceptance

The other effect that high temperature has upon capacity is the temperature during charge. The total amount of charge input that the cell is capable of accepting and making available for discharge is referred to as "charge acceptance". The charge acceptance of a hot cell is less than that of a cell at room temperature. Even though the charging input energy to a hot cell may be many times its rated capacity, the cell is not able to make available for discharge its full rated capacity.

It is characteristic of nickel-cadmium sealed cells that as the cell approaches maximum state of charge, the charging current beings to produce gaseous oxygen at the positive electrode instead of increasing its state of charge. At maximum state of charge the reaction is 100 percent oxygen gassing. As the temperature of the cell increases the cell goes to 100 percent gassing at lower states of charge, thus limiting the charge acceptance of the cell and causing reduced discharge capacity at the high temperatures. This phenomenon is illustrated in Figure 4-7.

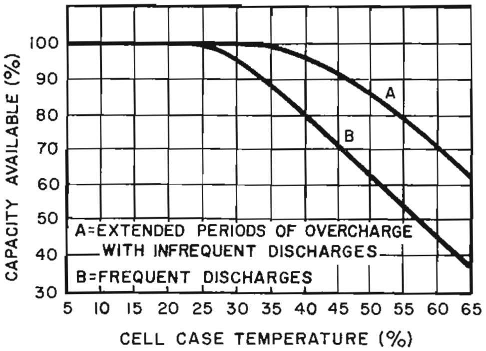


Figure 4-7. Effect of Battery Temperature During Charging Upon Available Capacity

4.3.3 Life at High Temperatures

4.3.3.1 Time-temperature effects

The effect of high temperatures on cell life is dependent on the magnitude of the temperature and the amount of time for which the high temperature is applied to the cell. Cell life is shortened when the cell is operated at elevated temperatures for a long period of time. It is the combined time-temperature effect, time being of the greater importance, that reduces the life of the cell. Moderately high temperatures applied to the cell for a long time, for example, can be more destructive than short, occasional, large over-temperature excursions.

Figure 4-8 shows the effect of cell temperature on cell life for Goldtop cells as compared to conventional nickel-cadmium sealed cells. It can be seen that in addition to being usable at temperatures up to 65°C, the Goldtop cells have a longer life than conventional cells at the lower average temperatures.

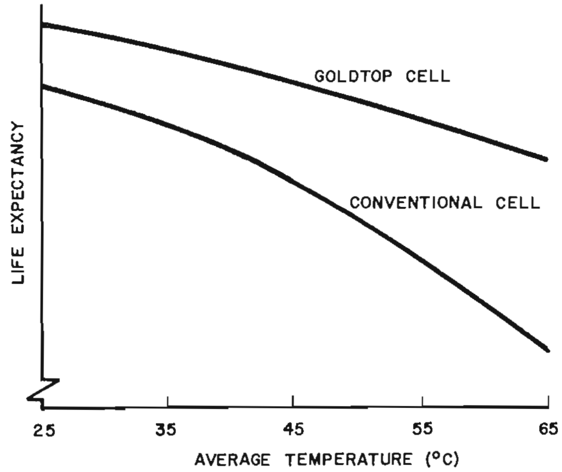


Figure 4-8. Life Expectancy Versus Cell Temperature

4.3.3.2 Failure modes

Two modes of failure account for essentially all of the permanent failures of nickel-cadmium sealed cells at high temperatures. The first cause of irreversible failure is the internal short circuit. Shorts are caused primarily by separator failure which is accelerated by high temperature stressing and oxidation. The tolerance of the new high temperature separators to high temperature stressing has minimized this cause of failure as a limiting factor in the life of Goldtop cells. When high cell temperatures are associated with overcharge, high oxygen pressure may also be present in the cell. The separators used in Goldtop cells have improved tolerance to separator failure caused by oxidation.

The second cause of irreversible failure of nickel-cadmium sealed cells results in an open circuit. The principal cause of open circuits is dry-outs (loss of water in the electrolyte) which are caused by deterioration of the seal, case, or vent. The high temperature degradation of these cell components is accompanied by deterioration resulting from oxidation when high oxygen pressure also exists in the cell. The materials and processes used in fabricating Goldtop cells provide increased tolerance to these high temperature and oxidation effects as compared to conventional nickel-cadmium cells. These improvements in the Goldtop separator and the seal give an order of magnitude of improvement to cell life over conventional units at temperatures greater than 50°C.

At this writing, the effects of high temperature on Goldtop cell life are not completely known because of the time element in testing. Although the Goldtop cell has not been available long enough to obtain long term life test data, data accumulated after 18 months plus accelerated life test data at elevated temperatures provide a basis for projecting an average life of about 7 years at 65°C.

4.3.3.3 Temporary effects

In addition to the irreversible cell failure described previously, there may be temporary reversible failures that are caused by high cell temperatures. High temperature operation reduces the charge acceptance of a cell as described earlier in this section. High temperatures associated with sustained overcharge may cause the discharge voltage to be depressed during the latter portion of the discharge period as shown in Figure 4-9. This phenomenon will be explored in greater depth in Section 5. Cells have a tendency to self-discharge when stored; this is accentuated at higher temperatures as shown in Figure 4-10. Lowering of the cell temperature will usually restore the cell to normal operating condition.

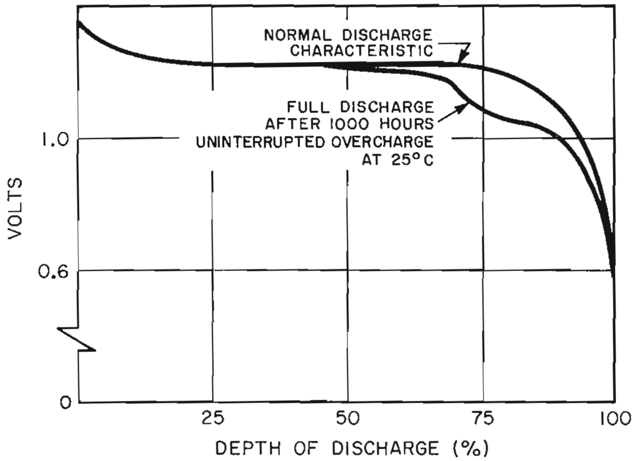


Figure 4-9. Temporary Effects of Sustained Overcharge

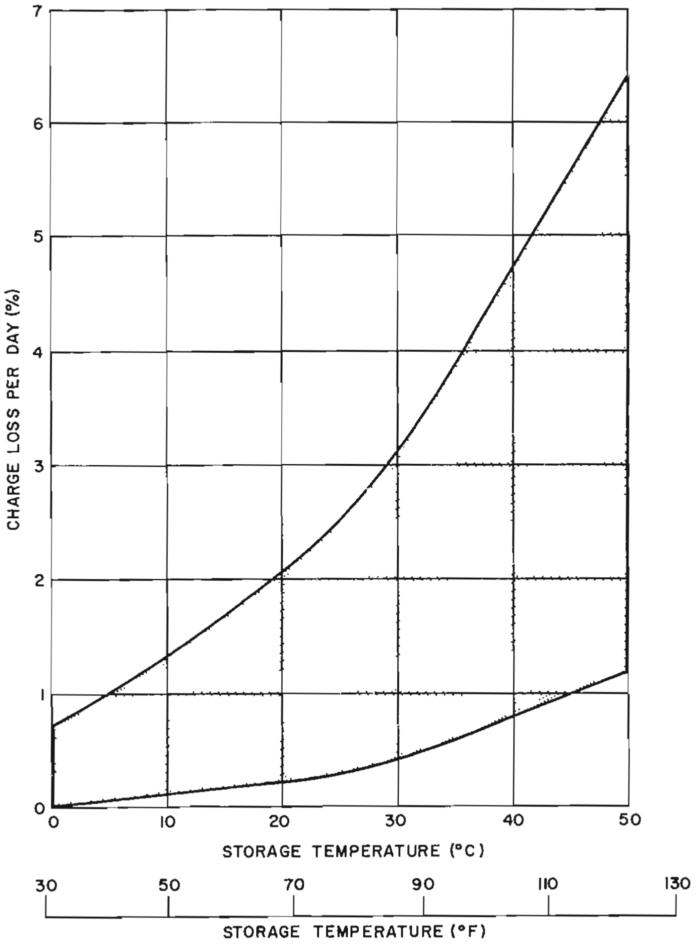


Figure 4-10. Typical Self-Discharging Rates

SECTION 5

BATTERIES FOR USE IN STANDBY POWER APPLICATIONS REQUIRING LONG-TERM OVERCHARGE

5.1 INTRODUCTION

Nickel-cadmium sealed cell batteries are now widely used in standby power applications to provide temporary service during power outages. The increased concern of many equipment buyers for continuity of service during "brown-outs", actual power outages, or momentary power interruptions has brought considerable attention to methods of furnishing uninterruptable power. This focus of interest on uninterruptable power systems coupled with new technology which requires standby power, such as "volatile" semiconductor memory, has created new markets and demand for maintenance-free nickel-cadmium sealed cell batteries in standby systems.

Cylindrical nickel-cadmium sealed cell batteries offer an attractive array of features for standby systems requiring modest levels of energy. Since they are completely sealed, the batteries can be mounted in any position and in remote locations. The sealed cell is small in size and can be assembled into a variety of different shapes of multi-cell battery packs. The new capability of General Electric Goldtop batteries allows constant use in high temperature applications which may be too hot for other battery systems. And they have long, reliable life up to 65°C continuous operating temperature.

In a standby power system the battery must be instantly ready to serve the moment the normal power fails, and it should provide the proper amount of energy during the outage. This means that the battery must be fully charged at all times and ready to serve.

The long-term overcharge capability of the sealed cell design allows the overcharge current to flow continuously into the cell without using up any materials. An additional benefit is that a simple charger like that illustrated in Figure 3-2 can be used. This overcharge capability plus the high temperature rating of the Goldtop battery makes it well-suited for standby power applications. When the overcharge current is properly selected the battery can operate for years in overcharge and then on demand will instantly deliver its energy to the load.

One example of standby power, which is described in Section 4 and illustrated in Figure 4-1, is emergency fluorescent lighting. Another example of how the Goldtop battery is being used for standby power is a small computer which uses MOS semiconductor memory. The memory must have the proper value of voltage to "hold" its memory; if voltage is reduced or lost, the entire contents of the memory would have to be retrieved and read back into the memory once normal power service was resumed. The block diagram in Figure 5-1 illustrates this application.

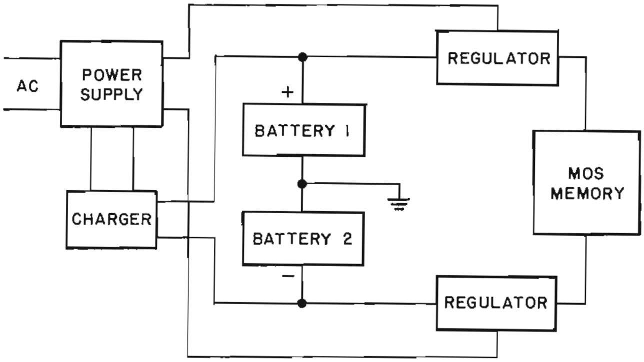


Figure 5-1. Uninterruptable Power Supply for MOS Memory

5.2 OVERCHARGING A BATTERY

5.2.1 Definition of Overcharge

Overcharging is the continued application of charging current to a battery after the battery has reached its maximum state of charge. Overcharging causes a rise in temperature and oxygen pressure within the cells, the magnitude of the increases depending primarily on the overcharge rate (see paragraph 3.2). Standard nickel-cadmium sealed cells are designed to be charged at a rate of 0.1C and will generally withstand long-term continuous overcharge at that rate. Fast-charge batteries that are normally charged at 1C to 4C rates must use charger systems that automatically switch to an acceptable topping charge rate when the battery approaches full charge.

Quick-charge batteries are normally charged at 0.3C rates. When used with simple chargers that do not have provisions for switching charge rates, overcharging also occurs at the 0.3C rate. This requires the use of special quick-charge cells to withstand these overcharge rates for an extended time. (See Section 3.)

5.2.2 Ability of Battery to Sustain Continuous Overcharge

The ability of a sealed cell to sustain continuous overcharge depends on (1) the efficiency with which the oxygen recombination reaction operates, and (2) the ability of the cell to withstand the heat and oxidizing action of the oxygen generated by overcharging. The Goldtop cells are desirable in this application because of their superior tolerance to high temperatures.

5.2.2.1 Oxygen recombination reaction

The nickel-cadmium sealed cell can be charged continuously by a simple constant current charger without using up any of the materials in the cell. It is designed so that the electrochemical reaction occurring at one electrode during overcharge is exactly opposite to that occurring at the other electrode. When the cell becomes fully charged, all of the electrical current going into the cell in overcharge generates oxygen at the positive plate at a rate proportional to the current.

$$4OH^- \rightarrow 2H_2O + 4e^- + O_2 \quad \text{(at positive plate)}$$

At the same time oxygen is electrochemically reacted (reduced) with water at the negative plate at the same rate to make hydroxyl ions.

$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^- \quad \text{(at negative plate)}$$

Hydroxyl ions travelling to the positive electrode carry the current inside the cell, while the electrons produced at the positive plate are moved externally by the charging source to the negative electrode completing the circuit.

The improved plate design in Goldtop cells tends to decrease the amount of oxygen pressure in the cell due to its ability to more efficiently recombine the oxygen at the negative plate.

5.2.3 Recommended Overcharge Rates

The maximum recommended rate is 0.1C and the minimum recommended rate to keep the battery fully charged is 0.05C as illustrated in Table 4-1. As pointed out in Section 4.2, for Goldtop cells the overcharge rate should be limited to a rate such that the maximum cell temperature in the battery pack does not exceed 65°C.

Most nickel-cadmium sealed cells, when used in an application in which they are subjected to long-term overcharge, will gradually take on a new discharge voltage profile. Allowances must be made for this phenomenon in system design in order to ensure long term satisfactory operation of the system.

5.3 PERFORMANCE

5.3.1 Discharge Voltage

The discharge voltage of a cell under continuous overcharge is subject to a "voltage depression" phenomenon, the range of which is shown in Figure 5-2.

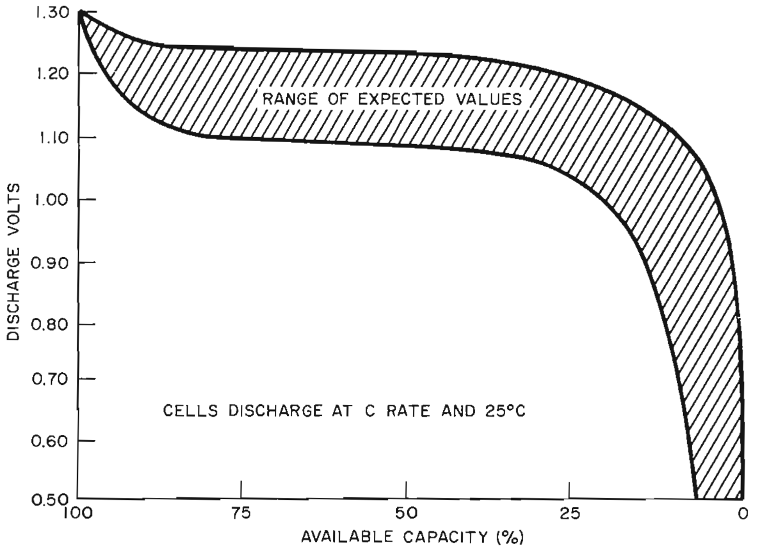


Figure 5-2. Effect of 0.1C Continuous Overcharge

The voltage depression effect is initially limited to the end of the discharge cycle. (See Figure 4-9.) As the length of time of continuous overcharge increases, this voltage depression moves, taking effect sooner in the discharge period. After very long periods of overcharge the shape of the discharge voltage is similar to the original "fresh" cell except that the entire level has been depressed.

The crystals of active material in plates of a cell with long overcharge and infrequent discharge begin to increase in size. As the crystals grow larger, access to all the active material in the cell is more difficult and this phenomenon manifests itself as a slight increase in the effective internal resistance, R_e, and a decrease in the open circuit voltage, E_O, of the cell. These changes do not display themselves uniformly throughout the discharge voltage profile. The first evidence of the effect of crystal growth appears near the end of discharge and evidences its presence by a step in the discharge voltage profile. One or more discharge/charge cycles will remove almost all of the effects of this voltage depression. It is for this reason that in most nickel-cadmium battery applications where the battery is frequently exercised by discharge, this voltage depression is not observed. In standby power applications, the battery is not exercised except under the infrequent conditions of a power outage or during a routine maintenance check. This lack of discharge activity permits the crystal growth to go unchecked until the discharge voltage finally becomes depressed for most of the discharge period.

Long-term overcharge as just mentioned has an effect on R_e. This, in turn, makes the magnitude of the voltage depression dependent upon discharge rate. The change in R_e is quite variable in magnitude. The time of sustained overcharge to effect the change in R_e as well as the change in E_o is also highly variable. Figure 5-3 shows the range of these variable effects on the midpoint discharge voltage for cells under continuous overcharge. The midpoint voltage is a convenient point on the discharge voltage curve to make comparisons of performance. The midpoint voltage of any discharge curve is the half-way point, as illustrated in Figure 5-4, between the full charge and the fully discharged state where the discharge voltage falls to 0 volts rapidly.

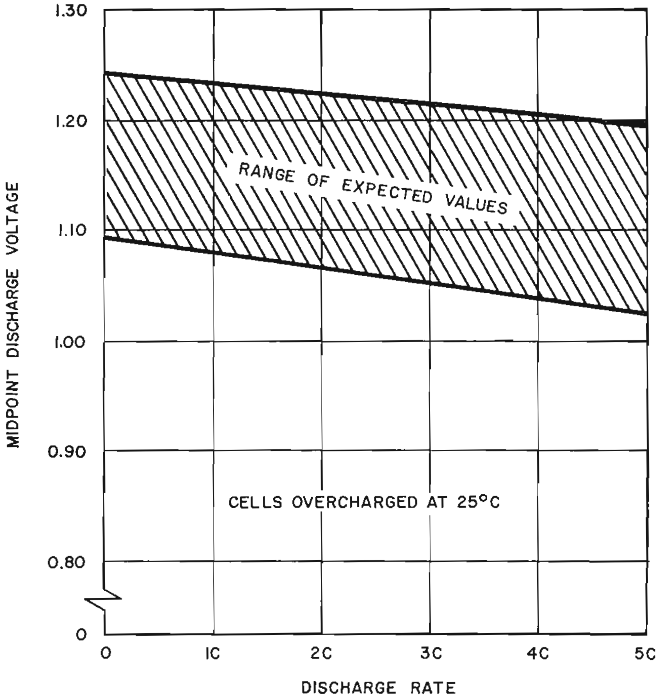


Figure 5-3. Midpoint Discharge Voltage Versus Discharge Rate After Sustained 0.1C Overcharge at 25°C

The voltage depression on cells overcharged at elevated temperatures tends to be greater than for cells overcharged at room temperature. Figure 5-5 illustrates the effect of temperature upon the cell's midpoint discharge voltage.

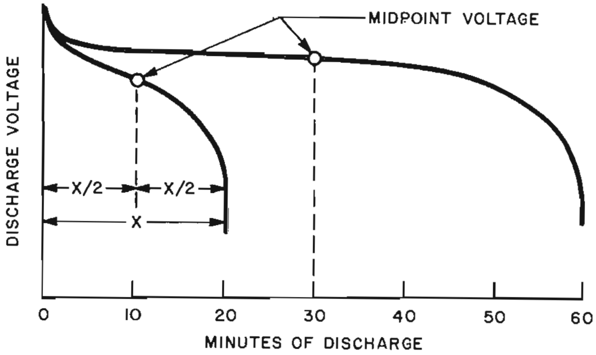


Figure 5-4. Illustration of Midpoint Voltage

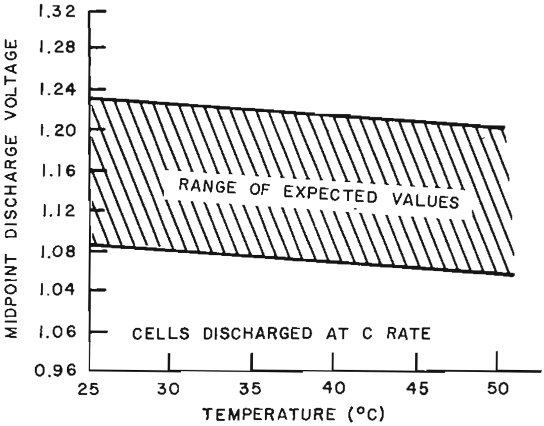


Figure 5-5. Midpoint Discharge Voltage Versus Temperature After Sustained 0.1C Overcharge

5.3.2 Cell Capacity

The capacity available in a cell under sustained overcharge depends on (1) the voltage selected by the designer as the minimum required for operation of the system, (2) the drain rate of the system at the selected voltage, (3) the actual cell temperature during overcharge, and (4) the length of time on continuous overcharge since the battery was installed or was last reconditioned.

Figure 5-2 shows the representative C rate discharge performance for typical cells. The minimum system design voltage should be set below the discharge voltage shown for these representative curves. Figures 5-3 and 5-5 can be used to estimate performance at discharge rates other than the C rate and at temperatures other than 25°C. These curves show a rather wide range of values which will illustrate the variances described above. The equipment designer should base calculations on the lowest practical voltage value if it is desired to obtain reasonable utilization of the available capacity from the battery. Since the application requires only infrequent discharges, a low end-of-discharge cutoff can be selected without the concern of the degrading effects of cell reversal due to overdischarge. For more information on cell reversal refer to Section 6.7 of the Nickel-cadmium Battery Application Engineering Handbook, GET-3148.

5.3.3 Life

The life of nickel-cadmium sealed cells when subjected to extended periods of overcharge at the 0.1C rate is similar to that described in paragraph 4.3.3, "Cell Life at High Temperatures".

5.4 SUMMARY

Sealed nickel-cadmium batteries can be continuously overcharged at rates sufficient to maintain the batteries in a state of full charge. However, due to active material crystal growth which occurs on continuous overcharge, the ability to discharge the active material in the battery decreases as overcharge time increases. This phenomenon exhibits itself by a depression in the discharge voltage profile. The discharge voltage depression is accelerated by overcharge temperature. The voltage depression becomes more significant as the discharge rate is increased.

The designer must recognize these inherent characteristics of nickel-cadmium sealed cells when applying them to long term overcharge applications such as emergency lighting, computer memory preservation and other uninterrupted power supply systems. As a general guide the designer can optimize the performance reliability of his system by:

a. Keeping cell temperature during overcharge near room temperature. Heat sinking and ventilation are key design elements.
b. Designing enough cells into the battery package to compensate for the expected voltage depression.
c. Providing access to the battery and instituting maintenance procedures which periodically recondition the battery. The battery can be reconditioned to erase nearly all the voltage depression by thoroughly discharging and recharging the individual cells in the battery pack. For further information contact:

General Electric Company
Battery Products Section
P.O. Box 114, Gainesville, Florida 32601
Attn: Manager - Application Engineering

SECTION 6.

GENERAL ELECTRIC NICKEL-CADMIUM BATTERY PRODUCTS

6.1 GENERAL ELECTRIC PRODUCT LINE – SUPPLEMENT

This section contains electrical characteristics and rating information for the new extended capability nickel-cadmium sealed cells that have been developed by the General Electric Company. For information on other General Electric nickel-cadmium battery products, refer to Section 8 of the Nickel-Cadmium Battery Application Engineering Handbook, GET-3148.

These extended capability cells are available in three types:

- Goldtop cells for normal charge rates are capable of operating at cell temperatures up to 65°C. These cells are suitable for applications requiring long cell life at high ambient temperatures and/or at high cell temperatures caused by continuous, long term overcharge.
- Goldtop cells for quick-charge rates are used where continuous overcharge rates of 0.3C are combined with high operating temperatures.
- PowerUp-15 cells are supplied for use in PowerUp-15 battery/charger systems that charge the battery at fast-charge rates of 1.0C to 4.0C. These cells have voltage and temperature versus state-of-charge characteristics that permit properly designed charger control circuits to sense both battery temperature and battery voltage. The fast-charge is terminated by either voltage or temperature, permitting reliable fast charging to a high capacity.

The General Electric extended capability cells are listed in order of rated ampere-hour capacity. The data include ratings, typical discharge curves, dimensions, and model numbers of each basic cell. The listings follow in paragraph 6.2.

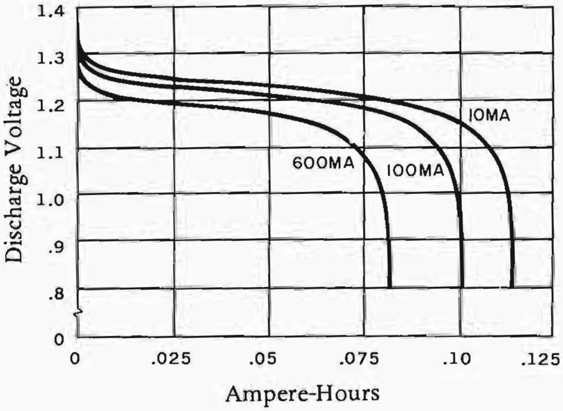
Figure 6-1. General Electric Extended Capability Cells.

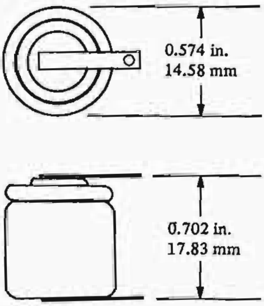
6.2 EXTENDED CAPABILITY CELLS

Extended Capability Cell: 1/3AA

Nominal Volts	1.20 Vdc
Rated Capacity:	
at 100 mA	100 mAh
at 10 mA	110 mAh
Internal Resistance, R_e	80 milliohms
Weight	0.35 ounce (9.9 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCF100ST	Goldtop Cell For Normal Charge Rates	10	5
XKCF100ST	Goldtop Cell For Quick Charge Rates	30	5
XFCF100ST	PowerUp-15 Cell	10*	5

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: 1/3A

Nominal Volts . . . . 1.20 Vdc

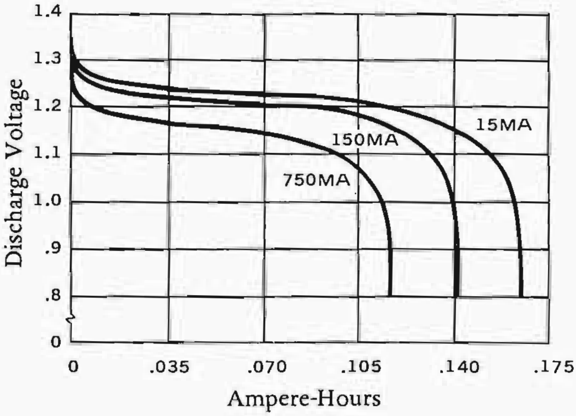
Rated Capacity:

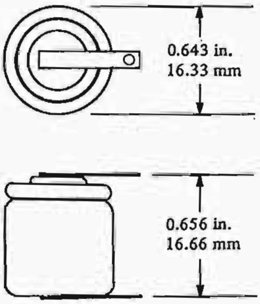
at 130 mA	**130 mAh**
at 13 mA	**150 mAh**

Internal Resistance, R_e . . 100 milliohms

Weight . . . . 0.40 ounce (11.3 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCK130ST	Goldtop Cell For Normal Charge Rates	13	7
XKCK130ST	Goldtop Cell For Quick Charge Rates	45	7
XFCK130ST	PowerUp-15 Cell	13*	7

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: 1/2AA

Nominal Volts . . . . 1.20 Vdc

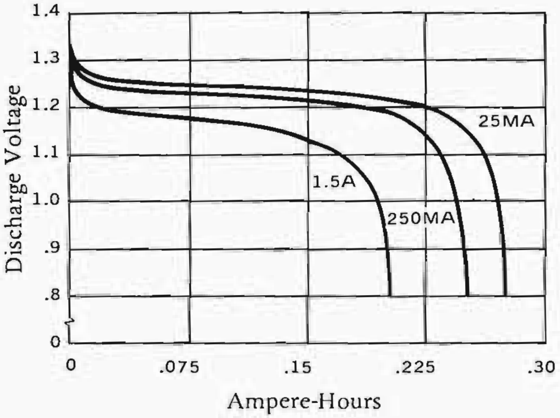
Rated Capacity:

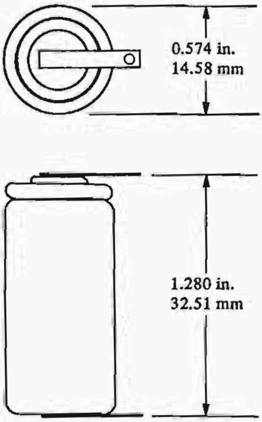
at 250 mA . . . . 250 mAh
at 25 mA . . . . 275 mAh

Internal Resistance, R_e . . 60 milliohms

Weight . . . . 0.60 ounce
(17.0 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCF250ST	Goldtop Cell For Normal Charge Rates	25	13
XKCF250ST	Goldtop Cell For Quick Charge Rates	75	13
XFCF250ST	PowerUp-15 Cell	25*	13

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: AA

Nominal Volts . . . . 1.20 Vdc

Rated Capacity:

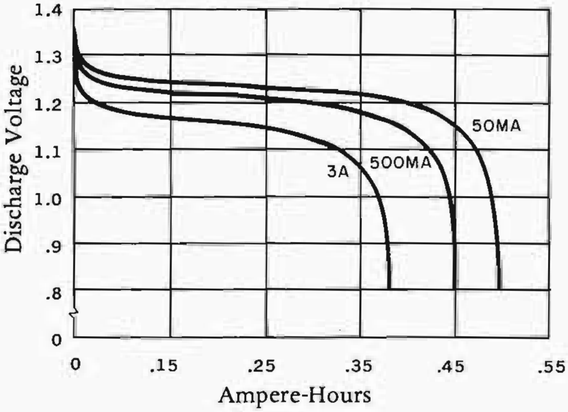
at 450 mA . . . . 450 mAh

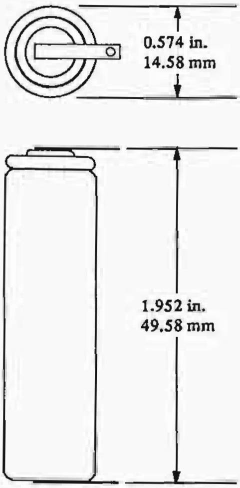
at 45 mA . . . . 500 mAh

Internal Resistance, R_e . . 28 milliohms

Weight . . . . 1.0 ounce (28.3 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCF450ST	Goldtop Cell For Normal Charge Rates	45	23
XKCF450ST	Goldtop Cell For Quick Charge Rates	150	23
XFCF450ST	PowerUp-15 Cell	45*	23

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: A

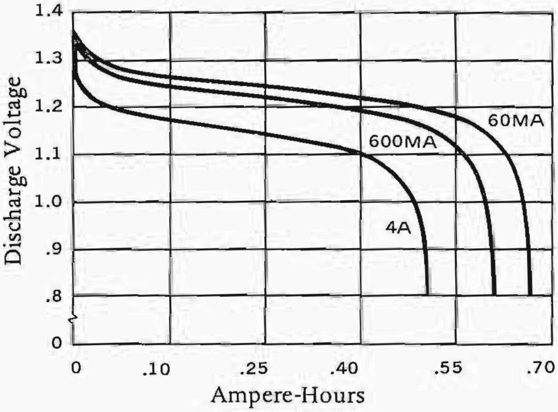
Nominal Volts . . . . 1.20 Vdc

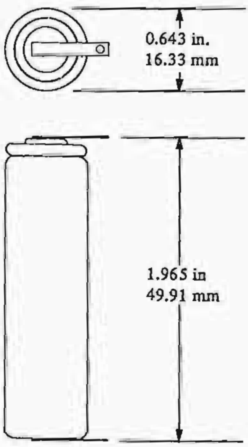
Rated Capacity:
at 600 mA . . . . 600 mAh
at 60 mA . . . . 660 mAh

Internal Resistance, R_e . . 26 milliohms

Weight . . . . 1.0 ounce
(28.3 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCK600ST	Goldtop Cell For Normal Charge Rates	60	30
XKCK600ST	Goldtop Cell For Quick Charge Rates	180	30
XFCK600ST	PowerUp-15 Cell	60*	30

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: 2/3C

Nominal Volts . . . . 1.20 Vdc

Rated Capacity:

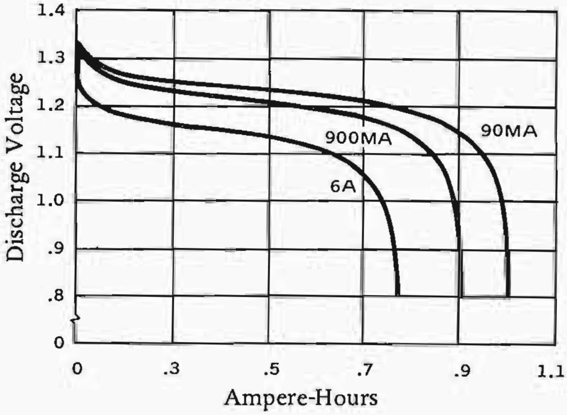
at 900 mA . . . . 900 mAh

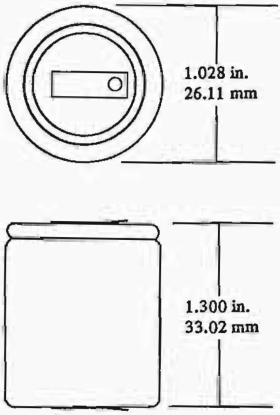
at 90 mA . . . . 1000 mAh

Internal Resistance, R_e . . 15 milliohms

Weight . . . . 1.6 ounces
(45.4 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCT900ST	Goldtop Cell For Normal Charge Rates	90	45
XKCT900ST	Goldtop Cell For Quick Charge Rates	270	45
XFCT900ST	PowerUp-15 Cell	90*	45

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

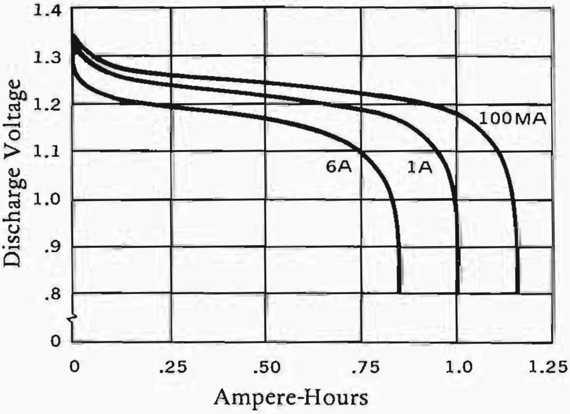
Extended Capability Cell: Cs

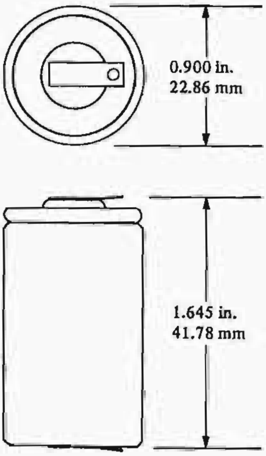
Nominal Volts . . . . 1.20 Vdc

Rated Capacity:
at 1000 mA . . . . 1.0 Ah
at 100 mA . . . . 1.2 Ah

Internal Resistance, R_e . . 12 milliohms

Weight . . . . 1.5 ounces
(42.5 grams)


Typical Discharge Curves



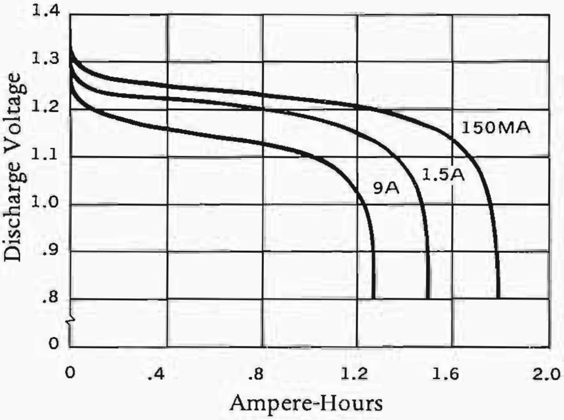
Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCR1.0ST	Goldtop Cell For Normal Charge Rates	100	50
XKCR1.0ST	Goldtop Cell For Quick Charge Rates	300	50
XFCR1.0ST	PowerUp-15 Cell	100*	50

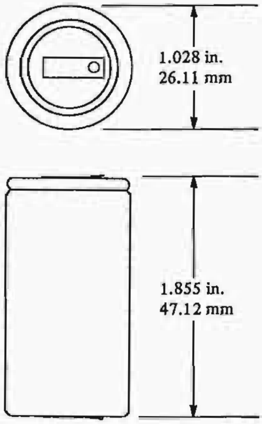
* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: C

Nominal Volts	1.20 Vdc
Rated Capacity:	
at 1.5 A	1.5 Ah
at 150 mA	1.8 Ah
Internal Resistance, R_e	10 milliohms
Weight	2.3 ounces (65.2 grams)

Typical Discharge Curves





Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCT1.5ST	Goldtop Cell For Normal Charge Rates	150	75
XKCT1.5ST	Goldtop Cell For Quick Charge Rates	450	75
XFCT1.5ST	PowerUp-15 Cell	150*	75

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

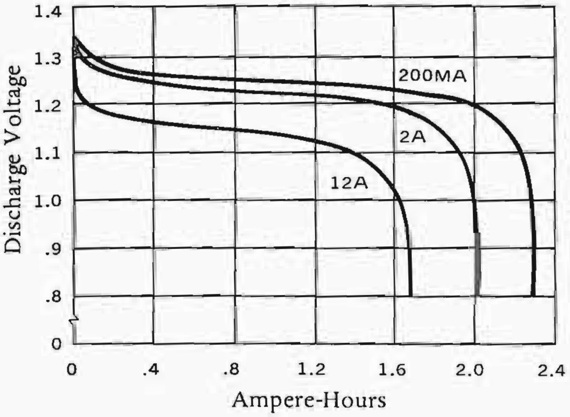
Extended Capability Cell: 1/2D

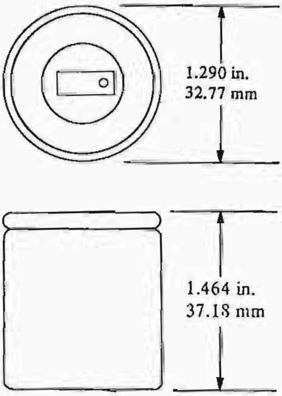
Nominal Volts . . . . 1.20 Vdc

Rated Capacity:
at 2.0 A . . . . 2.0 Ah
at 200 mA . . . . 2.3 Ah

Internal Resistance, R_e . . . 8 milliohms

Weight . . . . 3.2 ounces
(90.7 grams)


Typical Discharge Curves



Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCW2.0ST	Goldtop Cell For Normal Charge Rates	200	100
XKCW2.0ST	Goldtop Cell For Quick Charge Rates	600	100
XFCW2.0ST	PowerUp-15 Cell	200*	100

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

Extended Capability Cell: D

Nominal Volts . . . . 1.20 Vdc

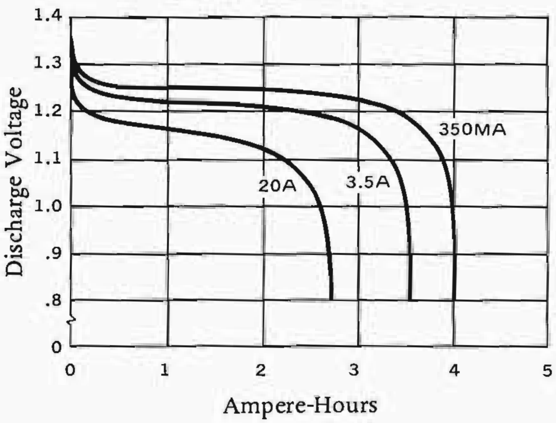
Rated Capacity:

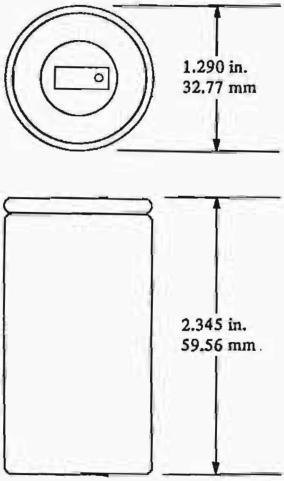
at 3.5 A . . . . 3.5 Ah

at 350 mA . . . . 4.0 Ah

Internal Resistance, R_e . . . 5 milliohms

Weight . . . . 5.2 ounces (147.4 grams)


Typical Discharge Curves



Model No.	Application	Continuous Overcharge Rate (mA)	
		Max.	Min.
XGCW3.5ST	Goldtop Cell For Normal Charge Rates	350	175
XKCW3.5ST	Goldtop Cell For Quick Charge Rates	1000	175
XFCW3.5ST	PowerUp-15 Cell	350*	175

* PowerUp-15 cells take the fast charge rate up to predetermined fast charge cutoff point.

GLOSSARY

(For more information on these terms and other battery terms, refer to the Nickel-Cadmium Battery Application Engineering Handbook, GET-3148).

B

BOUNCING – Repeated cycling of a battery/charger system in overcharge between fast-charge rate and topping charge rate. Caused by using an automatic reset thermostat or other switch that does not latch when terminating the fast charge current.

C

CAPACITY – Ampere-hours available from a fully-charged battery.

CHARGING – Return of electrical energy to a battery.

CONSTANT CURRENT CHARGING – Charging method in which current does not change appreciably regardless of battery voltage.

CUTOFF VOLTAGE – Voltage at which a discharge or charge is terminated.

D

DEAD BAND – The range of temperatures between the point at which the thermostat opens and the point where it recloses (resets). If the temperature first exceeds the point at which the switch opens and then drops below this point, the switch remains open within the "dead band" until the temperature falls below the reset point.

DISCHARGING – The withdrawing of energy from a battery.

F

FAST CHARGE BATTERY – A nickel-cadmium battery which can be charged at the fast charge rate and which gives a suitable signal which can be used to terminate the fast charge current without damage to the battery.

FAST CHARGING – Charging rate that equals or exceeds the one-hour rate, 1.0C.

G

GOLDTOP BATTERY – The General Electric trademark for high performance nickel-cadmium sealed cells that are capable of long life at temperatures up to 65°C.

M

MIDPOINT VOLTAGE – The battery voltage at the half-way point in the discharge between the fully charged state and the fully discharged state of a cell.

O

OVERCHARGE CURRENT – The charging current flowing to the battery after all the active material has been converted into a dischargeable state. Sealed nickel-cadmium batteries are capable of accepting continuous overcharge current at recommended rates.

P

PLATES – One of two cell electrodes in which chemical energy is stored and released.

POWERUP-15 BATTERY – The General Electric trademark for a nickel-cadmium battery which permits charging at rates up to the 4C rate to at least 90 percent of rated capacity in 15 minutes at room temperature. As the battery reaches full charge, the fast charge rate is switched by the charger to a lower, continuous overcharge rate by sensing either the battery voltage or temperature.

Q

QUICK CHARGE – Charging rate that ranges from 0.2C to 0.5C rate.

QUICK-CHARGE BATTERY – A nickel-cadmium battery that can be charged fully in 3 to 5 hours in a simple, constant current charger and is capable of continuous overcharge at this quick charge rate.

R

RATE – Amount of current, either charge or discharge current, frequently expressed as a fraction of the one-hour rate, 1.0C.

S

SEALED CELL – A cell that is free from routine maintenance and can be operated without regard to position. Many sealed-cell models are designed with a high-pressure resealable vent.

SEPARATOR – Material which provides separation and electrolyte storage between plates of opposite polarity.

T

TEMPERATURE

- AMBIENT TEMPERATURE – The average temperature of the battery's surroundings.
- CELL TEMPERATURE – The average temperature of the battery's components.

TEMPERATURE CUTOFF (TCO) – A method of switching the charge current flowing to a battery from fast charge to topping charge by means of a control circuit in the charger that is activated by battery temperature.

TOPPING CHARGE – A reduced rate charge that completes (tops) the charge on a cell and can be continued in overcharge without damaging the cell.

TROUGH VOLTAGE – The instantaneous open circuit voltage of a battery that is charged by a pulsating current. See Figure 2-20C.

V

VOLTAGE CUTOFF (VCO) – A method of switching the charge current flowing to a battery from fast charge to topping charge by means of a control circuit in that charger that is activated by battery voltage.

VOLTAGE-TEMPERATURE CUTOFF (VTCO) – A method of switching the charge current flowing to a battery from fast charge to topping charge rate by means of a control circuit in the charger that is activated by either battery voltage or temperature.

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nickel-cadmium battery

APPLICATION ENGINEERING HANDBOOK SUPPLEMENT

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