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(Revision of
IEEE Std 1106-1987)

IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications

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IEEE Standards Board

Abstract: Installation design, installation, maintenance and testing procedures, and test schedules that can be used to optimize the life and performance of vented nickel-cadmium batteries used for continuous-float operations are provided. Guidance for determining when these batteries should be replaced is also provided. This recommended practice is applicable to all stationary applications. However, specific applications, such as alternative energy, emergency lighting units, and semiportable equipment, may have other appropriate practices and are beyond the scope of this recommended practice. Sizing, qualification, other battery types, and battery application are beyond the scope of this recommended practice.
Keywords: continuous-float operation, flooded cell, state of charge determination, stationary battery, vented nickel-cadmium battery

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Introduction

(This introduction is not a part of IEEE Std 1106-1995. IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.)

Today, stationary storage batteries play an ever-increasing role in industry by providing normal control and instrumentation power and backup energy for emergencies. This recommended practice fulfills the need within the industry to provide common or standard practices of installation, maintenance, testing, and replacement of vented nickel-cadmium batteries. The methods described are applicable to all installations and battery sizes for stationary applications.

The installations considered herein are designed for continuous-float operation with a battery charger serving to maintain the battery in a charged condition and to supply the normal dc load (see A.4). Applications wherein the battery is not fully recharged after every discharge (e.g., alternative energy applications) are beyond the scope of this recommended practice.

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IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications

1. Scope

This recommended practice provides installation design, installation, maintenance and testing procedures, and test schedules that can be used to optimize the life and performance of vented nickel-cadmium batteries used for continuous-float applications. It also provides guidance for determining when these batteries should be replaced. This recommended practice is applicable to all stationary applications. However, specific applications, such as alternative energy, emergency lighting units, and semiportable equipment, may have other appropriate practices and are beyond the scope of this recommended practice.

Sizing, qualification, other battery types, and battery application are beyond the scope of this recommended practice.

The portions of this recommended practice that specifically relate to personnel safety are mandatory instructions and are designated by the word *shall;* all other portions are recommended practices and are designated by the word *should.*

This recommended practice does not include any other component of the dc system, nor does it include inspection and testing of the overall dc system. Preoperational and periodic dc system tests of chargers and other dc components may require that the battery be connected to the system. Details for these tests will depend on the requirements of the dc system and are beyond the scope of this recommended practice.

2. References

This recommended practice shall be used in conjunction with the following standards:

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[1]

IEEE Std 1115-1992, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications (ANSI).

[1]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3. Definitions

The following definitions apply specifically to the subject matter of this recommended practice. For other definitions, refer to IEEE Std 100-1992[2].

3.1 acceptance test: A constant-current or constant-power capacity test made on a new battery to determine that it meets specifications or manufacturer's ratings.

3.2 capacity test: A discharge of a battery at a constant current or constant power to a specified terminal voltage.

3.3 float charge: A constant potential normally applied to a battery to maintain it in a charged condition.

3.4 high-rate charge: The application of a constant potential charge, at a higher level than the float charge, to a partially or fully discharged battery to recharge it.

3.5 performance test: A constant-current or constant-power capacity test, made on a battery after being in service, to detect any change in the capacity.

3.6 service test: A special test of a battery's capability, in an "as found" condition, to satisfy the battery duty cycle.

3.7 vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. *Syn:* flooded cell.

4. Safety

The safety precautions listed herein shall be followed in battery installation and maintenance. Work on batteries shall be performed only by knowledgeable personnel with proper, safe tools and protective equipment.

4.1 Methods

Work performed on a battery in service shall use methods to preclude arcing in the vicinity of the battery.

4.2 Protective equipment

The following protective equipment for safe handling of the battery and protection of personnel shall be available:

a) Goggles and face shields

b) Chemical-resistant gloves

c) Protective aprons and overshoes

d) Portable or stationary water facilities for rinsing eyes and skin in case of contact with alkaline electrolyte

[2]Information on references can be found in clause 2.

e) Boric acid solution, 50 g/l of water (7 oz/gal), or other suitable neutralizing agent recommended by the manufacturer for alkaline electrolyte spillage[3]

f) Class C fire extinguisher[4]

g) Adequately insulated tools

h) Lifting devices of adequate capacity, when required

4.3 Precautions

The following protective procedures shall be observed during installation and maintenance:

a) Ensure that metal racks are connected to ground in accordance with applicable codes.

b) Inspect all lifting equipment for functional adequacy.

c) Restrict all unauthorized personnel from the battery area.

d) Prohibit the use of acid-contaminated tools and equipment such as hydrometers and thermometers in or on the battery.

e) Provide signs prohibiting smoking and open flames, and avoiding arcing in the immediate vicinity of the battery.

f) Keep the top of the battery clear of all tools and other foreign objects.

g) Ensure that illumination requirements are met.

h) Ensure unobstructed egress from the battery area.

i) Ensure that the battery area is adequately ventilated.

j) Avoid wearing metallic objects, such as jewelry, while working on the battery.

k) Avoid excessive tilting of the cells so as to prevent spillage.

l) Neutralize static buildup just before working on the battery by contacting the nearest effectively grounded surface.

m) Ensure that load test leads are connected with a length of cable sufficient to prevent accidental arcing in the vicinity of the battery.

n) Ensure that all connections to load test equipment include short-circuit protection.

5. Installation design criteria

Considerations that should be included in the design of the battery installation depend upon the requirements or function of the system of which the battery is a part. The general installation design criteria for all nickel-cadmium batteries are given in the following subclauses. Other applicable codes should also be observed as appropriate to the installation.

[3]The removal and/or neutralization of an alkali spill may result in production of a hazardous waste. The user should comply with appropriate governmental regulations.

[4]Some battery manufacturers do not recommend the use of CO_2-type fire extinguishers due to the potential for thermal shock on the battery cases.

5.1 Location

The following criteria should be observed regarding location:

a) Space and floor supports allocated for the battery and associated equipment should allow for present and future needs. Calculations should be performed to ensure that floor loading capabilities are not exceeded.

b) The general battery area selected should be clean, dry, and ventilated, and should provide adequate space and illumination for inspection, maintenance, testing, and cell replacement. Space should also be provided above the cells to allow for operation of lifting equipment, addition of water, and taking of measurements (e.g., voltages, temperature, etc.).

c) The battery should be protected against natural phenomena such as earthquakes, winds, and flooding, as well as induced phenomena such as fire, explosion, missiles, pipe whips, discharging fluids, CO_2 discharge, and other hazards.

d) The optimum cell electrolyte temperature is 20–25 °C (68–77 °F), and is the basis for rated performance. A location where this temperature can be maintained will contribute to optimum battery life, performance, and cost of operation. Although nickel-cadmium batteries are tolerant of extreme temperatures, low temperatures will decrease battery capacity while prolonged high temperatures will shorten battery life.

   Installation in a location with an ambient temperature below the optimum operating temperature will affect sizing. Refer to IEEE Std 1115-1992.

e) The location and arrangement of cells should result in no greater than a 5 °C (9 °F) temperature differential between cells at a given time. Avoid conditions that result in spot heating or cooling, as temperature variation will cause the battery to become electrically unbalanced.

f) The battery location should be such that direct sunlight on the cells is avoided, as this may damage plastic cell cases and create localized heating.

g) For personnel safety in the event of electrolyte spillage, portable or stationary water facilities shall be provided. Provisions for neutralizing, containing, and/or safely disposing of electrolyte should be included. The floor surface should be alkali-resistant.

h) The charger and main power distribution center should be as close as practical to the battery, consistent with criterion 5.1 j).

i) Illumination in the battery area should equal or exceed the interior lighting recommendations in figure 11-1 of [B1][5].

j) Nearby equipment with arcing contacts shall be located in such a manner as to avoid those areas where hydrogen pockets could form.

5.2 Mounting

The most common practice is to mount cells on a steel rack with chemical-resistant insulation between the cells and the steel of the rack. Metal racks should be connected solidly to the grounding system in accordance with applicable codes. The cells may also be mounted on adequately insulated supports secured to a floor or base.

The number of tiers or steps selected should result in a minimum temperature differential between cells [see criterion 5.1 e)] and allow for adequate maintenance.

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[5]The numbers in brackets correspond to those in the bibliography in clause 13.

5.3 Seismic

Where applicable building codes require seismic protection, the racks, cabinets, anchors, and installation thereof shall be able to withstand the calculated seismic forces. To minimize the effect of seismic forces, the battery should be located at as low an elevation as practical. The following criteria should be observed regarding mounting:

a) All cells should be restrained. Using side and end rails is one method that can be used to prevent loss of function due to a seismic event.

b) Where more than one rack section is used, the rack sections should be rigidly joined, or the adjacent end cells in each rack should be connected with flexible connectors as provided by or recommended by the manufacturer. Connections between cells at different levels of the same rack should also be flexible.

c) Racks shall be firmly connected to the building structure in accordance with applicable codes by using approved fastening techniques such as embedded anchor bolts or racks welded to structural steel faceplates (sized to accommodate a range of battery rack sizes).

CAUTION

Anchoring a rack to both the floor and the wall may cause stress due to conflicting modes of vibration.

5.4 Ventilation

The battery area shall be ventilated, either by a natural or mechanical ventilation system, to prevent accumulation of hydrogen. The ventilation system should limit hydrogen accumulation to less than 2% of the total volume of the battery area, and should be sufficient to prevent the formation of local pockets of hydrogen external to the battery that exceed this limit. The maximum hydrogen evolution rate is 1.27×10^{-7} m^3/s (0.000269 ft^3/min) per charging ampere per cell at 25 °C (77 °F), at standard pressure. The worst-case condition exists when maximum current is forced into a fully charged battery.

A battery area that meets the above ventilation requirements should not be considered a classified (hazardous) location; thus special electrical equipment enclosures to prevent fire or explosion should not be necessary.

5.5 Instrumentation and alarms

The following general recommendations for instrumentation and alarms apply to the battery installation only. Requirements for the charger, dc system design, etc., are beyond the scope of this recommended practice.

Each battery installation should include the following instrumentation and alarms:

a) Voltmeter

b) High- and low-battery-voltage alarm

c) Ground detector (for ungrounded systems)

d) Ammeter

6. Installation procedures

See clause 4 for safety precautions.

6.1 Receiving and storage

6.1.1 Receiving inspection

Upon receipt, and at the time of actual unloading, each package should be inspected visually for apparent damage and electrolyte leakage. If either is evident, a more detailed inspection of the entire shipment should be conducted, and results should be noted on the bill of lading. Cell repair or replacement should be instituted as required. Record receipt date and inspection data.

6.1.2 Unpacking

a) When lifting cells, a strap and strap spreader should be used, as applicable.

b) If the cells are supplied filled, check electrolyte levels for evidence of leakage and to ensure that the plates are covered. Electrolyte should be added to any cell in which the electrolyte level is below the top of the plates.

c) If the cells are supplied unfilled, do not remove the plastic transportation seals until the cells are to be filled.

d) All cells with visible defects such as cracked jars, loose terminal posts, or improperly aligned plates should be repaired or replaced.

6.1.3 Storage

Cells should be stored indoors in a clean, level, dry, and cool location; localized sources of heat should be avoided. In most cases, a period of at least twelve months storage is allowable. Contact the battery manufacturer for specific instructions for longer storage periods.

6.2 Assembly

6.2.1 Rack assembly

The assembly of the rack should be in accordance with the manufacturer's recommended procedure.

6.2.2 Cell mounting and connections

The following sequence should be used.

a) If cells are supplied unfilled, they should be filled in accordance with the manufacturer's recommendations before mounting on the rack.

b) Lift the individual cells onto the rack following the procedures outlined in 6.1.2 step a). Mount the cells in accordance with the manufacturer's recommendations. Do not apply lubricant on rack rails unless approved by the manufacturer.

c) Where necessary, remove transport seals and ensure that flame-arrester vents are properly installed.

d) Check the cell polarity for positive-to-negative connections throughout the battery.

e) If potassium carbonate crystals (gray-white deposits) have formed on the top of a cell, remove the deposits with a soft brush and rinse the cell with water.

f) Ensure that the terminal post and intercell connector contact surfaces are clean, and then apply a thin film of corrosion-inhibiting compound to all contact surfaces.

g) Make intercell connections using manufacturer-approved connectors (normally furnished with the battery).

h) Tighten connections to battery manufacturer's recommended torque value.

i) Clean all cell covers and containers. Use a water-moistened clean wiper to remove dust and dirt. Avoid the use of hydrocarbon-type cleaning agents (oil distillates), which may cause plastic containers and covers to crack or craze.

j) Read the voltage of the battery to ensure that individual cells are connected correctly; i.e., the total voltage should be approximately equal to the number of cells times the measured voltage of one cell. If the measurement is less, recheck the individual cell polarities.

k) For future identification, apply individual cell numbers in sequence beginning with number 1 at the positive end of the battery; also add any required operating identification.

l) When 6.2.2 steps a) through k) have been satisfactorily completed, make final connections from the battery to the charger and dc system.

6.3 Initial charge

An initial charge should be applied after installation. Filled and charged nickel-cadmium cells require recharging to compensate for self-discharge losses during shipment and storage. Cells shipped in a discharged condition have to be given a complete charge.

Typically, the initial charge consists of the following procedures:

a) Inspect all cells to ensure that the electrolyte level is between the high-level and low-level lines.

b) Follow the manufacturer's recommendations for applying an initial charge. If the charge voltage exceeds the system voltage limit, perform the initial charge off-line from the dc system.

c) Upon completion of the initial charge, return the charger to float voltage.

d) At the end of 72 h, read and record all individual cell voltages, and the electrolyte temperatures of every tenth cell (see clause 11).

e) Add distilled or other approved-quality water to bring the electrolyte level of all cells up to the high-level line.

7. Maintenance

7.1 General

Proper maintenance will prolong the life of a battery and will aid in ensuring that it is capable of satisfying its design requirements. A good battery maintenance program will also serve as a valuable aid in determining the need for battery replacement. Battery maintenance should be performed by personnel knowledgeable about nickel-cadmium batteries and the safety precautions involved.

7.2 Inspections

All inspections should be made under normal float conditions. Refer to the annexes for more information.

7.2.1 General

Inspection of the battery should be performed on a regularly scheduled basis (at least once per quarter). The interval should be selected depending upon site conditions, charging equipment, and monitoring devices providing remote indications of abnormal operations. This inspection should include checking and recording the following:

a) Float voltage measured at the battery terminals
b) General appearance and cleanliness of the battery, the battery rack, and the battery rack area
c) Charger output current and voltage
d) Electrolyte levels
e) Cracks in cells or leakage of electrolyte
f) Any evidence of corrosion at terminals, connectors, or rack
g) Adequacy of ventilation
h) Pilot-cell electrolyte temperature

7.2.2 Semiannually

At least once every six months a general inspection should be augmented by checking and recording the voltage of each cell.

7.2.3 Yearly

At least once each year a semiannual inspection should be augmented by checking and recording the following:

a) Intercell connection torque
b) Integrity of the battery rack

7.2.4 Special inspections

If the battery has experienced an abnormal condition (e.g., a severe discharge or severe overcharge), an inspection should be made to ensure that the battery has not been damaged. Include the requirements of 7.2.1 and 7.2.2.

7.3 Corrective actions

7.3.1 Conditions requiring correction

The following items indicate conditions that should be corrected prior to the next general inspection. Major deviations in any of these items may necessitate immediate action.

a) When any cell electrolyte reaches the low-level line, distilled or other approved-quality water should be added to bring all cells to the high-level line. Water quality should be in accordance with the manufacturer's instructions.
b) When the float voltage, measured at the battery terminals, is outside of its recommended operating range, the charger voltage should be adjusted.
c) When corrosion, excessive dirt, or potassium carbonate (gray-white deposits) are noted on cells or connectors, wipe the cells with a wet cloth, wipe dry, and then coat metal parts with corrosion

inhibitor as recommended by the manufacturer. Avoid the use of hydrocarbon-type cleaning agents (oil distillates), which may cause containers and covers to crack or craze.

d) When a bolted connection is found loose, disassemble, clean, reassemble, and retorque the connection. The reassembly should be made using corrosion inhibitor, following the instructions of the manufacturer.

See the annexes for a more detailed discussion of these abnormalities and the urgency of corrective actions.

7.3.2 Other abnormalities

Correct and document any other abnormal conditions noted.

8. Test schedule

The following schedule of tests is used to:

a) Determine whether the battery meets its specification or the manufacturer's rating, or both.

b) Periodically determine whether the performance of the battery, as found, is within acceptable limits.

c) Determine, if required, whether the battery, as found, meets the design requirements of the system to which it is connected (see A.4).

8.1 Acceptance

An acceptance test of the battery capacity (see 9.4) should be made, as determined by the user, either at the factory or upon initial installation. The test should be made at a specific discharge rate and for a duration relating to the manufacturer's rating or to the purchase specification's requirements.

8.2 Performance

Performance testing should be carried out as follows:

a) A performance test of battery capacity (see 9.4) should be made within the first two years of service. It is desirable for comparison purposes that the performance test be similar in duration to the battery duty cycle.

b) Additional performance tests should be made at five-year intervals until the battery shows signs of excessive capacity loss. Excessive capacity loss is indicated when the battery capacity drops more than an average of 1.5% per year of rated capacity from its capacity on the previous performance test.

c) Annual performance tests of battery capacity should be made on any battery that shows signs of excessive capacity loss.

d) If performance testing is to be used to reflect baseline capacity or benchmark (the most accurate form of battery trending) capacity of the battery, then perform procedures a) through g) of 9.1. If performance testing is to be used to reflect maintenance practices as well as trending, then omit procedures a) and b), and perform procedures c) through g) of 9.1. If on a performance test that is used to reflect maintenance practices, the battery does not deliver its expected capacity, then the test should be repeated after the procedures of a) and b) of 9.1 have been completed.

8.3 Service

A service test of battery capability (see 9.6) may be required by the user to meet a specific application requirement upon completion of the installation, and periodically thereafter. This is a test of the battery's ability, as found, to satisfy the battery duty cycle. When a service test is being used on a regular basis it will reflect maintenance practices. If the system design changes, sizing will have to be reviewed, and the service test may have to be repeated.

8.4 Modified performance

A modified performance test may be performed if the test's discharge rate envelopes the duty cycle of the service test. The system designer and the battery manufacturer should review the design load requirements to determine if the modified performance test is applicable and to determine the test procedure. The acceptance criteria for this test should be determined by the system design. Typically this test is a simulated duty cycle consisting of just two rates: a short-duration, high rate as published for the battery, or the largest current load of the duty cycle, followed by the test rate employed for the performance test. If the ampere hours removed by the high-rate discharge represent a very small portion of the battery's capacity, the test rate can be changed to that for the performance test without compromising the results of the performance test.

A modified performance test is a test of the battery capacity and its ability to provide a high-rate, short-duration load (usually the highest rate of the duty cycle). This will often confirm the battery's ability to meet the critical period of the load duty cycle, in addition to determining its percentage of rated capacity. Initial conditions for the modified performance test should be identical to those specified for the service test. A modified performance test can be used in lieu of a service test and/or a performance test at any time.

9. Procedure for battery tests

This procedure describes the recommended practice for testing by discharging the battery. All testing should follow the safety requirements listed in clause 4. Refer to A.4.

9.1 Initial conditions

The initial procedures for all battery tests, except as otherwise noted, are as follows:

a) Verify that the battery has had a high-rate charge completed more than 1 day and less than 30 days prior to the start of the test.

b) Check all battery connections to make sure that they are clean and correctly torqued.

c) Read and record the float voltage of each cell just prior to the test.

d) Read and record the temperature of the battery electrolyte to determine an average temperature (every tenth cell is suggested).

e) Read and record the battery terminal float voltage.

f) Disconnect the charger from the battery.

g) Take adequate precautions (such as isolating the battery to be tested from other batteries and critical loads) to ensure that a failure will not jeopardize other systems or equipment.

9.2 Test length

The recommended procedure is to make a capacity test for approximately the same length of time as the duty cycle for which the battery is sized. When the battery is required to supply varying loads for specified time periods (a load duty cycle), the performance test may not substantiate the battery's capability to meet all design loads, particularly if very high-rate, short-duration loads determine the battery size. See 9.6 for test length of the service test.

9.3 Test discharge rate

The discharge rate depends upon the type of test selected. For the acceptance test or performance test, the discharge rate should be at a constant current or constant power load equal to the manufacturer's rating of the battery for the selected test. The charging method used as a basis for published data is an important factor. For a stationary float application, data based on prolonged constant potential charging should be used. If constant current charging has been used to establish the published data, appropriate float charging correction factors should be obtained from the manufacturer.

Note that the test discharge current is equal to the rated discharge current divided by the temperature correction factor for the initial electrolyte temperature. Above 25 °C (77 °F) there is no meaningful increase in capacity. Consult the manufacturer for the correct data for the battery to be tested. Also refer to A.5.

9.4 Acceptance, modified performance, and performance tests

a) Set up a load and the necessary instrumentation to maintain the test discharge rate determined in 9.3.

b) Disconnect the charging source, connect the load to the battery, start the timing, and continue to maintain the selected discharge rate. If the charging source cannot be disconnected, the current being drawn by the load has to be increased to compensate for the current being supplied by the charging source to the battery.

c) Read and record the individual cell voltages and the battery terminal voltage. The readings should be taken while the load is applied at the beginning and at the completion of the test, and at specified intervals. There should be a minimum of three sets of readings. Individual cell voltage readings should be taken between respective posts of like polarity of adjacent cells, so as to include the voltage drop of the intercell connectors.

d) Maintain the discharge rate and record the elapsed time at the point when the battery terminal voltage decreases to a value equal to the minimum average voltage per cell as specified by the design of the installation (e.g., 1.10 V) times the number of cells. If the battery does not pass the normal criteria for capacity testing, additional data may be beneficial for evaluation or for determining corrective action. If installation conditions permit, the testing should be continued to the original test time or a lower final voltage (e.g., 95% of the specified minimum) to acquire this information. Nickel-cadmium cells are generally not damaged as a result of cell reversal, so no provisions are required for bypassing weak cells.

e) If one or more cells are approaching reversal of their polarity, and the test is at 90–95% of the expected completion time, continue the test until the specified terminal voltage is reached.

f) If earlier in the test one or more cells are approaching reversal of their polarity, the test may be continued so as to determine the capacity of the remainder of the battery. Bypassing of cells is not recommended. Since the reversed cell(s) will be making a negative contribution to the overall battery voltage, adjust the minimum terminal voltage to compensate. The new minimum terminal voltage will be the minimum cell voltage multiplied by the number of non-reversed cells, plus the negative voltage of the reversed cell(s). If a modified performance test is being performed in lieu of a service test, the minimum terminal voltage should not be recalculated.

For example, a 95-cell battery is being tested to a minimum terminal voltage of 105 V (1.10 V per cell). During the discharge, two weak cells go into reversal and stabilize at –0.30 V. The new minimum terminal voltage is 93 × 1.10 + (2 × –0.3) – 101.7 V.

g) Observe the battery for abnormal intercell connector heating.

h) At the conclusion of the test, determine the battery capacity according to the procedure outlined in 9.5.

9.5 Determining battery capacity

For an acceptance or performance test, use the following equation to determine the battery capacity at the test rate:

Percent capacity at the test rate at 25 °C (77 °F) = $[T_a/T_s] \times 100$

where

T_a is the actual time of test to specified terminal voltage [see 9.4, step d)]

T_s is the rated time to specified terminal voltage

9.6 Service test

A service test is a special battery test that may be required to determine if the battery will meet the battery duty cycle (see 8.3). The system designer should establish the test procedure and acceptance criteria prior to the test. The battery should be tested in its "as found" condition and the test discharge rate should not be corrected for temperature or age. If the battery was sized in accordance with IEEE Std 1115 1992, the margins added for temperature, load growth, and aging will provide adequate battery capacity to meet the battery duty cycle throughout its service life. Trending battery voltage during the critical periods of the load cycle will provide the user with a means of predicting when the battery will no longer meet the duty cycle. If the system design changes, sizing (IEEE Std 1115-1992) will have to be reviewed, and the service test will have to be modified accordingly. Successful test results can be used to evaluate battery performance and degradation.

The recommended procedure for the test is as follows:

a) The initial conditions should be as identified in 9.1, except that procedures a) and b) should be omitted.

b) The discharge rates and test length should correspond as closely as is practical to the battery duty cycle.

c) If the battery does not meet the duty cycle, review its rating to see if it is properly sized. High-rate charge the battery, inspect it as discussed in 7.2, take necessary corrective action, and repeat the service test. A battery performance test (see 8.2) may also be required to determine whether the problem is with the battery or the application.

9.7 Restoration

Disconnect all test apparatus. High-rate charge the battery and return it to normal service.

10. Replacement criteria

The timing of battery replacement is a function of the sizing criteria utilized and the capacity margin available, compared to the load requirements. Whenever replacement is required, the recommended maximum time for replacement is one year. Other factors, such as unsatisfactory battery service test results (see 8.3), require battery replacement, unless a satisfactory service test can be obtained following corrective actions.

Replacement cells, if used, should be compatible with existing cells and should be tested prior to installation. Replacement cells are not usually recommended as the battery nears the end of its life.

Failure to hold a charge, as shown by cell voltage, is a good indicator for further investigation into the need for replacement.

11. Records

The analysis of data obtained from inspections and corrective actions is important to the operation and life of the batteries. Data such as indicated in 7.2 should be recorded at the time of installation and as specified during each inspection. Records should also contain reports on corrective actions (see 7.3), and on tests indicating discharge rates, their duration, and results.

It is recommended that forms be prepared to record all data in an orderly fashion and in such a way that comparison with past data is convenient. A meaningful comparison will require that all data be converted to a standard base in accordance with the manufacturer's recommendations.

12. Reapplication, recycling, and disposal

All batteries have a useful life and eventually have to be either repaired or scrapped. The constituents of the nickel-cadmium cell, such as the corrosive potassium hydroxide electrolyte and the toxic cadmium metal, are hazardous. Therefore, a nickel-cadmium battery that is not of any use or value should be disposed of in a proper fashion.

12.1 Reapplication

Nickel-cadmium batteries retain their ability for service, albeit at a lower capacity level, for many years. Therefore, when they reach the end-of-service life in a particular application, they may be used in another application whose requirements are met by the lower capacity. Pocket-plate batteries may require replacement of the electrolyte at this time.

12.2 Recycling

Nickel-cadmium batteries can be fully recycled. Seek advice from the battery manufacturer on how to proceed with battery recycling.

12.3 Disposal

When a battery is to be disposed of, the governmental regulations for such disposal should be followed.

13. Bibliography

[B1] *Illuminating Engineering Society of North America Lighting Handbook, Reference and Application,* 1993.

Annex A

(informative)

Nickel-cadmium battery

A.1 Construction

The nickel positive active materials and the cadmium negative active materials are firmly contained in plates of alternate polarity, insulated by separators, and formed into plate groups. Plate groups are assembled into cells with either plastic or steel containers. One or more cells connected together constitute a battery.

A.2 Electrolyte

Nickel-cadmium battery electrolyte is an aqueous solution of potassium hydroxide (KOH). Lithium hydroxide is sometimes added. The alkaline electrolyte does not enter into the electrochemical charge/ discharge reactions; it merely acts as an ionic conductor. Consequently, the specific gravity does not change with the state of charge of the cell.

Specific gravity readings are not required as part of the normal maintenance routine for nickel-cadmium batteries.

The specific gravity of electrolyte furnished by the manufacturers may vary slightly (1.180–1.200). The specific gravity also varies with temperature and electrolyte level. Each manufacturer publishes specific gravity correction factors for temperature.

In most stationary battery applications, the electrolyte will retain its effectiveness for the life of the battery. However, under special battery service conditions, such as high temperature or frequent cycling, potassium carbonate buildup in the electrolyte may reach a level that will influence battery performance. If the electrolyte is found to be carbonated (using the manufacturer's test kit), battery performance can be improved by replacing the electrolyte.

A.3 Charging voltage

The nominal voltage for the nickel-cadmium cell is 1.2 V per cell. The manufacturers of nickel-cadmium batteries provide charging recommendations for each battery type. These recommendations typically fall within the following ranges:

1.37–1.47 V per cell. Float voltage per cell. Charged batteries will be maintained in a charged condition with low water consumption.

1.45–1.55 V per cell. High-rate charge voltage per cell. This is a practical voltage to be used in recharging a partially or fully discharged battery without exceeding system limitations.

1.56–1.74 V per cell. Maximum high-rate charge voltage per cell for most rapid recharge of a partially or fully discharged battery. This voltage should be used for all installations where the connected equipment is not affected by the resultant high overall voltage or where voltage-sensitive equipment can be either disconnected during recharge, or isolated by a voltage-regulating device. Do not exceed system voltage limits.

NOTE—Continuous high-rate charging is not recommended because of high water consumption.

A.4 Capacity and float charging

The nickel-cadmium industry uses the term "fully charged" to identify the condition that exists following a short-term, constant-current charge. Prolonged float charging of a nickel-cadmium battery causes a lowering of the average voltage on discharge. Constant potential float conditions may therefore reduce available capacity to some degree, dependent upon the test discharge rate, end-of-discharge voltage, and battery type. Some manufacturers publish capacities based upon constant potential float charge conditions; others are able to provide appropriate correction factors to adjust ratings based on constant current charging.

A.5 Temperature

Nickel-cadmium batteries will operate satisfactorily over a wide temperature range, typically –55 to +45 °C (–67 to +113 °F). At temperatures lower than +20 to +25 °C (+68 to +77 °F), the battery's capacity is reduced. Table A.1 shows typical ranges for derating factors; contact the manufacturer for specific values. Electrolyte with normal density (specific gravity of 1.180–1.200) will crystallize at temperatures below –20 °C (–4 °F). Higher density electrolytes are required for operation at lower temperatures. Consult the manufacturer.

Table A.1—Temperature correction factor

Initial temperature		Factor range
(°C)	(°F)	
–17.8	0	1.1–2.0
–12.2	10	1.1–1.6
– 6.7	20	1.1–1.5
–1.1	30	1.1–1.3
4.4	40	1.0–1.2
10.0	50	1.0–1.1
15.6	60	1.0–1.1
21.1	70	1.0–1.1
25–45	77–113	1.0

These factor ranges are typical for various plate designs and discharge rates. They are not to be used for a specific application.

At temperatures higher than +25 °C (+77 °F), there is no meaningful increase in capacity. Battery life is adversely affected by extremely high temperatures. The recommended high temperature operating limit is +45 °C (+113 °F). The battery will operate if subjected to intermittent higher temperatures of up to +70 °C (+158 °F), but its life span will be shortened.

Annex B

(informative)

State of charge determination and charging

A nickel-cadmium battery maintained at the recommended float voltage will remain in a charged condition subject to the limitations described in A.4. When the battery's state of charge is in question because of a recent discharge, the following procedure may be used to ensure that the battery is in a high state of charge. This procedure presupposes that the battery charger is a two-rate (float and high-rate), constant potential type, with sufficient current capacity to carry both the connected loads and the charging current required by the battery.

With the battery on float charge:

a) Read and record the current output of the charger in amperes. (This may include the connected dc load plus battery charging current.)

b) Read and record the voltage at the battery terminals.

c) Note the time when readings a) and b) were taken.

Place the charger in the high-rate charge mode.

d) Read and record the current output of the charger [at least momentarily this will be significantly higher than noted in a)].

e) Read and record the voltage at the battery terminals. Continue the high-rate charge until the voltage reaches the high-rate maximum voltage previously established for the system. The state of charge may then be determined as follows:

   1) If the high-rate charge voltage is reached in less than 1 min and the current output from the charger drops to approximately the float current found in a), the battery is charged; or

   2) If the high-rate charge voltage is not reached rapidly, it indicates that the charger is in current limit and that the battery is in need of a charge; or

   3) If the charge current is unaccountably greater than the charge current output found in a), the battery is in need of a charge.

NOTE—It is recommended that the high-rate charge, if required, be continued until such time as the charge current is essentially the same as the current recorded in a); normally no longer than 72 h is required. At completion of high-rate charging, return the charger to float voltage.

Annex C

(informative)

Corrective actions

C.1 Low-voltage cell

If the voltage of an individual cell in a floating battery is found to be 1.35 V or less, apply a high-rate charge. It may be more effective to apply the high-rate charge to the individual cell concerned.

C.2 Water consumption

Unusual water consumption is an indication of excessive charge voltage. When it becomes necessary to add water, fill all cells to the maximum level with distilled or other approved-quality water. Check the charger voltage setting at the battery terminals.

If the level of electrolyte has dropped so low as to expose plates, add water immediately. If visual inspection shows no evidence of leakage, then high-rate charge the battery and test it in accordance with the manufacturer's recommendations.

C.3 Low-voltage battery

If the total battery float voltage is found to be less than the manufacturer's recommended minimum value, the battery is not being charged properly. At 1.30 V per cell, the battery is in a discharging state. Follow the instructions in annex B to determine the state of charge and take corrective action.

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