NICKEL-HYDROGEN BATTERY TESTING FOR HUBBLE SPACE TELESCOPE

Randy M. Baggett and Thomas H. Whitt

National Aeronautics and Space Administration
Information and Electronics Systems Laboratory
Marshall Space Flight Center, Alabama

ABSTRACT

Nickel Hydrogen batteries are being tested at Marshall Space Flight Center (MSFC) to provide data to support the Hubble Space Telescope (HST) program. Life cycling on an Eagle-Picher RNH-30-1, 14-cell battery and an Eagle-Picher RNH-35-3, 12-cell battery began in November 1986 and May 1988, respectively. A four-cell pack from HST test module 1 (TM-1) cells began life cycling in November 1988, followed by a second four-cell pack using test module 2 (TM-2) cells which began cycling in February 1989. A similar four-cell "flight spare" pack went on-line in March 1989. Immediately following a thermal-vacuum test on TM-1 at MSFC in April 1989, the complete HST six-battery simulation breadboard was put on-line. All of these tests have the batteries/packs cycling under an HST flight profile. These and other proposed Ni-H₂ battery tests will help NASA/MSFC and Lockheed Missiles and Space Company (LMSC) evaluate the possibility of launching Ni-H₂ batteries on HST. This paper will identify objectives and provide data from each of these tests described above.

BACKGROUND

The batteries "baseline" for HST are six type 44 nickel cadmium (NiCd) batteries manufactured by Eagle-Picher Industries, Joplin, MO. Six of these 55 ampere-hour (Ah) NiCd batteries have recently completed 30 months of life testing on the HST NiCd Six-Battery breadboard at MSFC [1].

In 1987 HST program management contracted with LMSC (HST prime contractor) and Eagle-Picher Industries, Joplin, to design, develop, and manufacture a Ni-H₂ battery that would fit in the same footprint as the "baseline" NiCd battery. Three of these batteries would be housed in an Orbital Replacement Unit (ORU) module which is approximately the same volume as three NiCd batteries. A diagram of the ORU module assembly is shown in Figure 1. These Ni-H₂ batteries are planned for the HST Maintenance and Refurbishment (M&R) mission scheduled to occur within the first three years following launch. However, since the HST launch date is now projected to be late March 1990, launching HST with the longer life Ni-H₂ batteries is feasible.

Cell Description

The HST cells are manufactured using Air Force technology. These cells consist of a stack of nickel electrodes, separators,

hydrogen electrodes, and gas screens assembled in a back-to-back configuration. In this configuration, two opposing nickel electrodes are assembled between two hydrogen electrodes forming an electrode pair assembly. The electrode pair assemblies are connected in parallel and packaged into a cylindrical pressure vessel with hemispherical ends. The pressure vessel is made of Inconel 718 and lined with a coating of zirconium dioxide. The positive and negative terminals exit through a single end dome at a 45 degree angle to the stack center line, a "rabbit ear configuration." The separators are made up of two layers of zircar. The zircar separators extend beyond the electrodes making contact with pressure vessel walls forming a wick to recover the electrolyte expelled from the stack during cycling. The gas screens are made of polypropylene. The electrolyte is a 27-percent aqueous solution of potassium hydroxide (KOH). The nickel electrode is manufactured from a dry sinter plaque containing a nickel screen substrate and is electrochemically impregnated with Ni-(OH)₂. The cells have a 14.5 psia precharge of hydrogen.

HST Ni-H₂ Battery Development

The HST Ni-H₂ battery is made up of 23 individual pressure vessel cells with a nameplate capacity of 88 Ah. The battery was designed to be either 22 or 23 cells. Each battery has 23 cells in its footprint with one cell not electrically connected. The use of 22 cell batteries in the HST power system allows for more complete charge of the batteries (i.e. charge to a higher

Figure 1. Module Assembly.

voltage). Use of the 23-cell configuration would allow more effective utilization of the increased Back Surface Field Reflector (BSFR) solar array power.

Each battery has an external sense connector that serves as the interface for all battery sense circuits that monitor individual battery performance. These sense circuits include the following [2]:

- Battery temperature (5 thermistors)
- Battery heater status, both primary and secondary
- Battery strain gauge electronics output, two per battery
- Battery voltage
- Battery current

These battery sense circuits are monitored from the ground during flight.

Ni-H₂ BATTERY/PACK TESTING AT MSFC

Individual Ni-H₂ battery/ pack tests for HST are described below. A single battery/ pack test is set up as one of the six-battery channels in the HST EPS. Each test has a data acquisition system that scans the data every half minute and provides automated control of the test conditions.

RNH-30-1, 14-Cell Battery

In October 1986, cycling began on fourteen 30 Ah, Eagle-Picher RNH-30-1, COMSAT design cells. The purpose of this test was to become familiar with the characteristics of the IPV nickel hydrogen cells and to increase the Ni-H₂ low-earth orbit (LEO) real-time data base for the HST application. To date, this battery has 14,000 LEO cycles with no failures and no sign of degradation. Every thousand orbits a capacity test is run to record the capacity degradation over the life of the battery. Operating at an end-of-charge voltage of 1.533 volts/cell, these capacity checks continue to exceed the nameplate capacity to 1.0 volt/cell at 0 degrees celcius. The data in Figure 2 shows capacity results to 1.15 volts/cell and 1.0 volts/cell for the last ten months of cycling.

RNH-35-3, 12-Cell Battery

This battery is made up of 12 Eagle-Picher RNH-35-3, 33 Ah Air Force type Ni-H₂ cells. The cells were manufactured in 1976 and stored at MSFC open circuit and at room temperature until November 1987. These cells were taken out of storage, sent to Eagle-Picher for checkout, and returned to MSFC for testing. The purpose of this battery test is to get a better understanding of Ni-H₂ battery characteristics under HST flight conditions.

Figure 2. Capacity Test Summary.

Test Operation

From May 1988 until January 1989 the battery underwent parametric testing to determine the optimum charge voltage and charge scheme for this Ni-H₂ battery operating under HST conditions. During this parametric testing the solar array charge currents, the load, and the sun/eclipse times were held constant for the sake of comparing the different charge voltages and charge schemes.

In February 1989, life cycling began on this 12-cell battery. The solar array currents are varying seasonally and degrading with time and the load is also varying seasonally. The battery will continue to life cycle with a capacity test and reconditioning planned every three months to check battery capacity degradation.

Results

During the parametric testing described above, the sun period and the eclipse period were held constant at 60 and 36 minutes, respectively. These times were representative of a 0-degree beta angle at a 320-nmi orbit. The battery recharge ratio, as a function of the charge voltage during this parametric testing, is shown in Figure 3. The top curve in Figure 3 shows the battery operating with a step-taper charge scheme. The lower curve is when the battery was operating with the step to 0.5 ampere trickle charge scheme. The battery capacity as a function of the charge voltage is shown in Figure 4. This capacity curve is independent of the charge scheme. These capacity test results show that the capacity of the pack did not increase with the extra lower rate charge put into the battery after a certain voltage trip back limit was reached. Since the recharge ratio did increase this indicates that the low rate charge was going into heat. The step-to-trickle charge scheme was chosen for life cycling because the battery efficiency is higher than the step-taper charge scheme without sacrificing any capacity.

Figure 3. RR versus Charge Voltage.

Figure 4. Capacity versus Charge Voltage.

The charge level chosen to begin life cycling was 1.513 volt/cell at 0 °C. This is one of the eight possible charge level settings available on the HST EPS. This charge level was chosen based on the plot of the recharge ratio as a function of the charge voltage in Figure 3. At 1.513 volt/cell the battery was cycling with a recharge ratio of 1.045 and a capacity of 27 Ah. A recharge ratio of 1.043 in the test yields a battery efficiency of about 90 percent.

To date the 12-cell pack has completed approximately 1800 orbits. The pack has been cycling at 1.513 volt/cell at 0 °C, with a step-to-0.5 ampere trickle charge. The recharge ratio during this cycling has varied between 1.04 and 1.14. The higher recharge ratios occur during the high beta angles with the long sun periods and short eclipses. This is when there are long periods of trickle charge, which is the low rate, inefficient charge. The cell divergence so far has stayed below 20 mv at the end of charge and below 30 mv at the end of discharge. The capacity of the battery after the first three months of cycling was 27.6 Ah, which is 102 percent of the capacity predicted from the parametric tests.

The only problem that has occurred in the test so far happened during the parametric testing when the battery was being cycled with the step-taper charge scheme at 1.545 volt/cell. The

recharge ratio at the time was about 1.20. One of the cell voltages in the pack started to go high during charge and low during discharge. About 60 cycles after this started to occur the cell voltage exceeded 1.6 volts, which shut the test down. When the test was started again approximately six hours later, the cell was no longer out of the normal range of voltages. At a recharge ratio of 1.20 the battery was operating with an efficiency of under 80 percent. The cell that went out of range must have started heating up and increasing its internal resistance. When the test shutdown, the cell had time to cool off. The battery resumed cycling at the same charge level for approximately 50 more cycles and then a capacity test was run. The heating of the cell did not recur. After the capacity test the battery resumed cycling at a lower charge level.

HST Ni-H₂ 4-Cell Packs

The HST four-cell packs are three separate packs from the HST Ni-H₂ cells manufactured by Eagle-Picher. Pack 1 is four cells from the TM-1 Lot, Pack 2 is four cells from the TM-2 Lot, and Pack 3 is four cells from the "flight spare" Lot. The first of these cells arrived at MSFC for testing about six months prior to the TM-1 and TM-2 battery modules that went into the Ni-H₂ six battery system simulation breadboard. The purpose of testing these packs was to get as much parametric testing and data collected on the HST cells as possible before the TM-1 and TM-2 battery modules arrived.

Test Set-Up

The three four-cell packs are located in the same thermal chamber and are controlled by the same data acquisition and control computer, but the packs are independent of each other and are not electrically connected in any way. The only parameter that is common to each pack is the sun/eclipse periods.

Test Operation

The initial charge of packs 1 and 2 was at C/10 for 10 hours and then 4 amperes for 14 hours at 10 °C. The packs would then sit for one hour while the temperature stabilized, then a baseline (initial) capacity test was run. The results of these capacity tests compared favorably with the cell capacity data from Eagle-Picher.

After the initial capacity tests, the packs began parametric testing to determine battery performance at several charge levels with different charge schemes. Following the parametric testing the four-cell packs will begin life cycling to supplement the HST Ni-H₂ six battery system simulation breadboard.

Results

In the baseline capacity test, TM-1 cells had an average capacity of 91.8 Ah and TM-2 cells had an average capacity of 93.1 Ah. A baseline capacity test was not run on the "flight spare" pack.

In the parametric testing thus far, the packs have been cycling for one-week periods at various charge levels and charge schemes. The one-week period gives the packs adequate time to stabilize under the charge scheme before a capacity test and reconditioning is run. The recharge ratio and capacity of the cells, as a function of the charge voltage, is very similar to the plots of the RNH-35-3, 12-cell battery. The one major difference is that the four-cell packs are getting between three and four percent more capacity with the step-taper charge scheme. With the step-taper charge scheme, the packs are cycling five to ten percent less efficiently than with the step to trickle charge scheme.

At this point in the testing it is hard to say what is the optimum charge level and scheme for the Ni-H₂ batteries on the HST. There are many power system considerations that need to be taken into account. As testing proceeds on these four-cell packs and on the HST six-battery system simulation test, the direction to take will become more clear.

Thermal Vacuum Test

A thermal vacuum (TV) test was performed on TM-1 in April 1989. The TV testing was required to verify the Ni-H₂ battery module/bay heat rejection capability, the heater control operation, and the ability of the thermal design to maintain acceptable cell-to-cell temperature differences. Also, an improved mathematical model of the HST bay/Ni-H₂ battery thermal characteristics was developed.

The module was mounted inside an HST bay mock-up which included simulation for all the components normally inside that bay, and incorporated a "flight type" door and a set of flight spare thermal louvers on the outside. Both the cold and the hot design orbit environments were simulated. As the batteries

were cycled in real time, a myriad of thermal measurements, electrical parameters, and heater data were recorded. Preliminary review of the test data indicates that the heat rejection capability of the module/bay is acceptable. The heater control operation was acceptable, but the control thermostats operated near tolerance extremes, which resulted in a larger "deadband" of temperature control than was expected. The cell-to-cell temperature differences were slightly outside the required limits (0.3 °C in at least one case) and has resulted in deactivating a different cell within a battery.

Immediately following the TV test, TM-1 was delivered to the MSFC battery test facility to begin the HST six-battery system simulation.

Ni-H₂ Six-Battery System Simulation Breadboard

A complete electrical power system (EPS) breadboard with six nickel hydrogen batteries began operation May 1989. This breadboard includes every pertinent element of the actual HST EPS. Battery test modules 1 and 2 (TM-1 and TM-2) contain the six test batteries used in the breadboard. These batteries are made up of closely matched cells that are equivalent to the flight batteries.

Breadboard Description

The HST six-battery breadboard is made up of five major elements: simulated solar panel assemblies (SPA), the batteries, the power distribution circuits, the load banks, and the control computer (CC). A simplified block diagram of the EPS breadboard is shown in Figure 5. Each battery channel is equivalent to the B1 and B2 circuits shown. All six battery channels are connected in parallel and the diode busses (DB) are switched together during normal operation.

Figure 5. Simplified HST Breadboard Block Diagram.

The batteries are located in environmental chambers to simulate orbital temperature conditions. Each chamber is purged with nitrogen to create an inert atmosphere. The nitrogen gas, and the hydrogen gas if any, would be removed from the chamber through an exhaust vent system to outside air.

The battery power circuits are fused to protect the batteries should a fault occur, and battery isolation circuits provide automatic shut-down capability. Front panel meters provide continuous visual monitoring of all battery voltages and currents. Front panel switches allow SPA switching, battery reconditioning, and battery isolation, all of which can be controlled from the ground during the HST mission. The major elements of the breadboard, with the exception of the batteries, can be seen in Figure 6. Three strip-chart recorders provide continuous recording of each battery voltage, current, heater status, and one cell pressure. An uninterruptable power supply (UPS) can maintain power to necessary equipment during facility power outages of up to one hour.

Figure 6. Ni-H₂ System Simulation Breadboard Test Panels.

A data acquisition system (DAS) monitors critical test parameters and provides continuous data acquisition and control with minimal human interface. The test can be stopped by the DAS if out of limit conditions on cell voltage or battery temperature exist, or for a failure of a solar array simulator (SAS) power supply. The loss of redundant facility power sources or loss of the control computer will also stop the test and open circuit the batteries. An automatic telephone dialer will notify key personnel at work or home if the test is stopped.

Test Objectives and Results

The primary objective of this simulation is to obtain real time life cycle (aging) data on HST Ni-H₂ batteries under the HST charge scheme and a shallow depth of discharge (DOD < 10 percent). This data will show the effects of prolonged (>3 years) cycle life in LEO. This test will also provide data on cell voltage divergence and the effects of simulated vehicle maneuvers on battery performance.

Following the baseline (initial) capacity test on all six batteries, a series of tests are planned to cycle at several charge voltage cutoff levels and at 0 and 10 °C. After a week of cycling at each charge voltage cutoff level, a capacity test is run on all six batteries. These tests are necessary to obtain battery capacity data at several operating levels. Average capacity results from the first three of these tests are shown in Figure 7. Following completion of these tests, the life test will continue tracking the HST mission profile with a late March 1990 launch date.

Figure 7. Battery Capacity Averages.

Future Testing

In June 1989 a complete 22 cell "flight spare" battery will be delivered to MSFC for testing. This battery is made up of closely matched cells remaining from the "flight spare" cell lot which are identical to all flight cells. The proposed testing of this single battery will begin with a baseline capacity test (equivalent to the baseline capacity test described for the four-cell packs) followed by life cycling.

REFERENCES

- [1] Jackson, L.G., Bush, J.R., and Lanier, J.R., "Hubble Space Telescope Six-Battery Nickel-Cadmium Mission Simulation Test". IECEC Proceedings, 1989.
- [2] Nawrocki, D., March 1988: "Detail Specification, Battery Module (Nickel-Hydrogen)," LMSC-4177751A, Lockheed Missiles and Space Co., p. 3-8.