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Hubble Space Telescope Nickel-Hydrogen Battery Testing An Update

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The Marshall Space Flight Center (MSFC) began testing the HST Ni-H2 Six Battery Test and the Flight Spare Battery Test approximately one year before the launch of the HST. These tests are operated and reported on by MSFC, but are managed and funded by Goddard Space Flight Center in direct support of the HST program.

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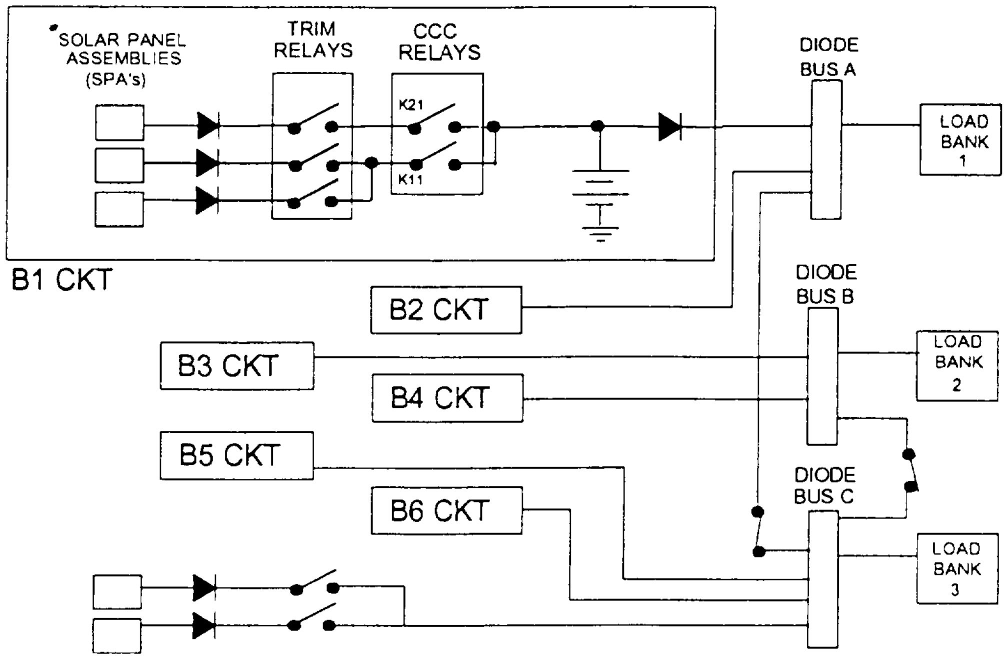
The HST Batteries
Eagle Picher RNH-90-3

- High rate charge => 10 - 13 amps (C/8)
- Charge scheme => V/T limit
- Discharge => 9 - 11 amps (C/9)
- Depth of discharge (DOD) => 6 to 9%
- Operating temp => 0 to 3 degrees C
- Sun/eclipse periods => 60/36 to 70/26

The HST Ni-H2 Batteries are built from Eagle Picher RNH-90-3 cells. The bullet chart above describes the typical operating conditions of the batteries in the HST EPS.

SIMPLIFIED BLOCK DIAGRAM OF THE HST EPS



The figure above is simplified block diagram of the HST electrical power system (EPS). The HST EPS is direct energy transfer power system. The solar array is divided into 20 solar panel assemblies (SPAs) with 3 SPA sections going to each battery channel and 2 going directly to the load bus. The trim and charge current control (CCC) relays are the battery charge control relays that are located in the power control unit (PCU). The 3 load busses are normally tied together to act as a common load bus.

HST Battery Tests at MSFC

- HST Six Battery Test
  - Breadboard of the HST EPS
  - 6 batteries of test module cells
  - Packaged in flight type modules
- "Flight Spare Battery"
  - Simulation - 1 of 6 battery channels
  - Cells from flight spare lot

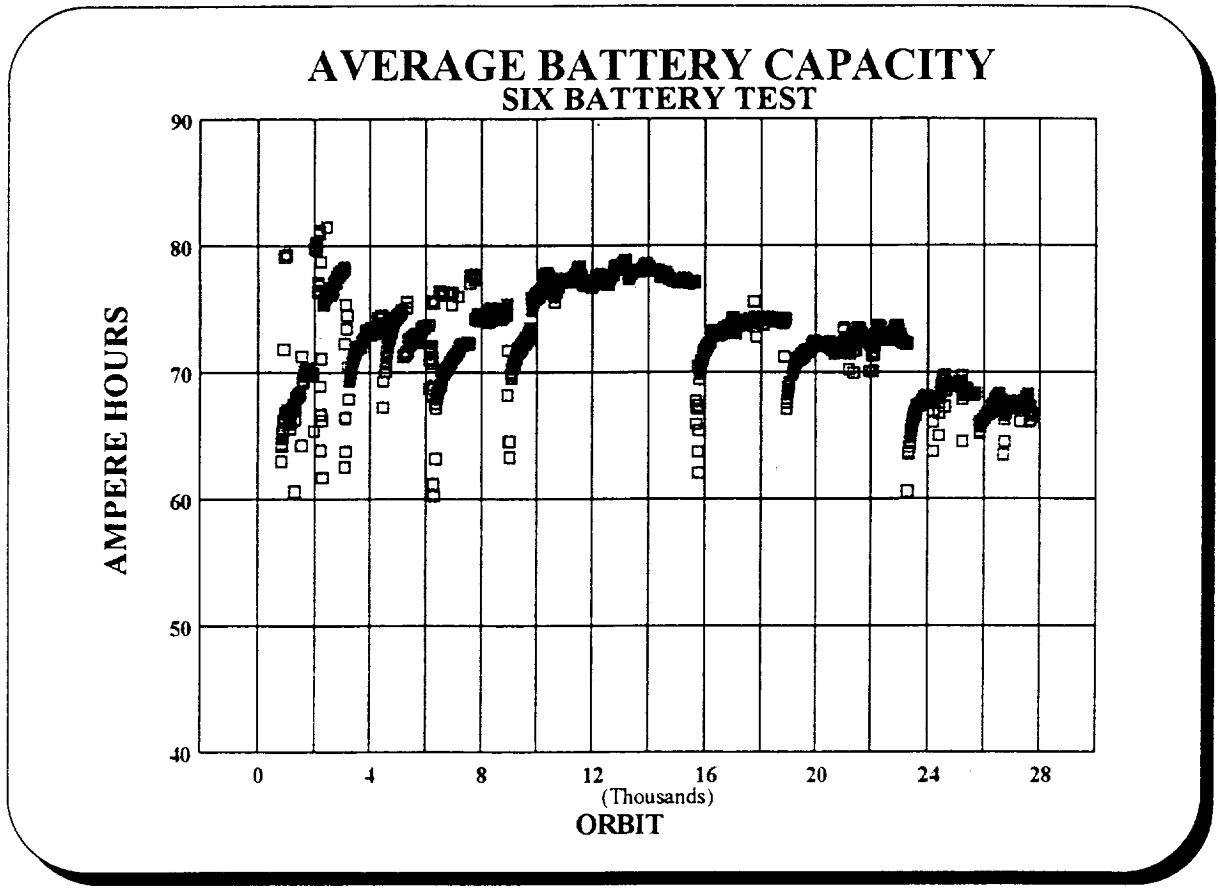
The HST Ni-H2 Six Battery Test is a breadboard of the HST EPS. The batteries in the test are composed of test module cells and packaged into 3 battery modules identical to the flight modules. This test is the HST EPS Testbed.

The "Flight Spare Battery" Test is a simulation of 1 of the 6 battery channels on the HST. The cells in the test are from the flight spare lot of cells, which are the same lot of cells that 3 of the 6 HST flight batteries are made from. This test is the battery life test for the HST program.

Test Objectives

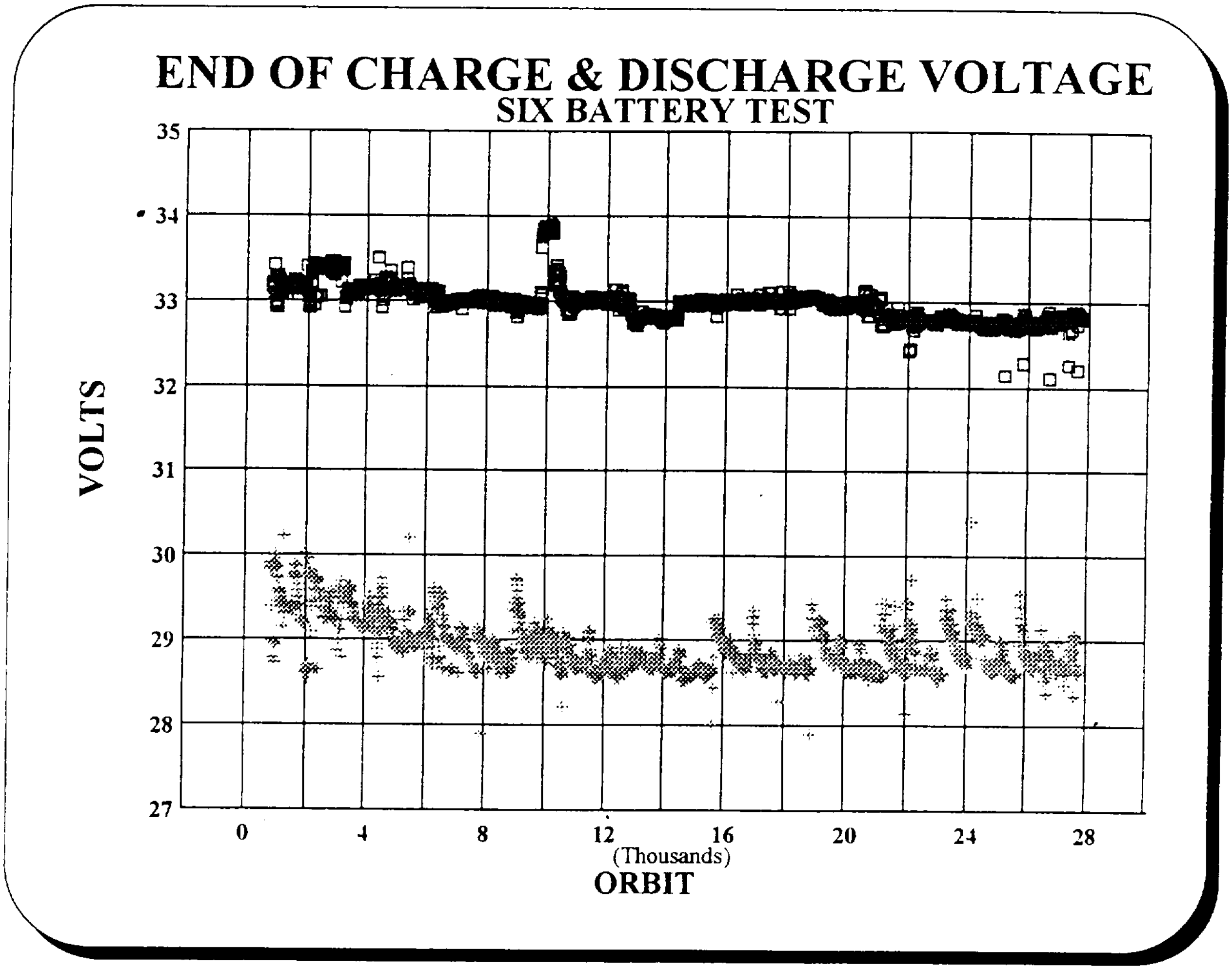
- **Determine operating characteristics of the batteries**
- Investigate on-orbit anomalies
- Test proposed variations prior to implementation on orbit

The first of the test objectives is to determine the operating characteristics of the batteries. The test batteries began cycling one year before the launch of HST and have now been cycling under the HST Flight conditions for over 5.5 years. The graphs on the following 3 pages show the average battery capacity, the end of charge & discharge voltages, and the battery watt-hour efficiency over the life of the test.

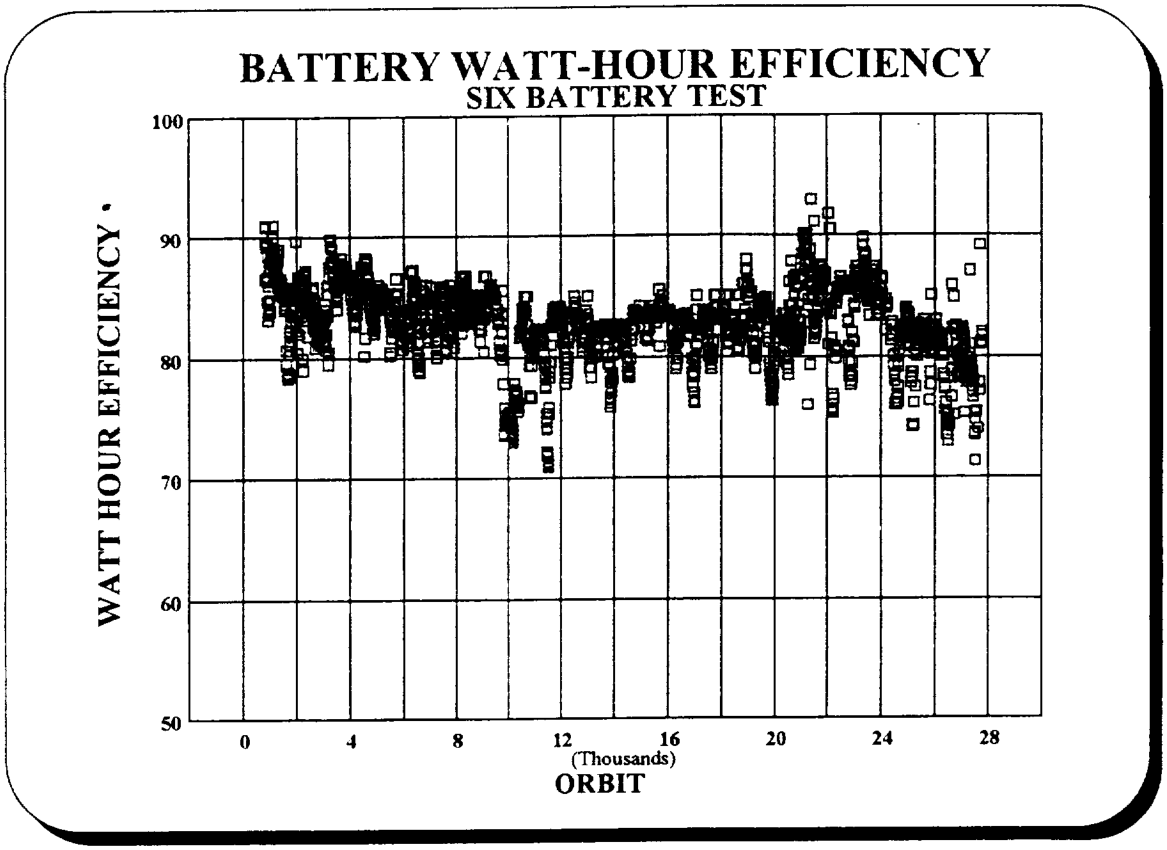


This plot is of the average battery capacity of the HST Ni-H2 Six Battery Test over the life of the test. The fluctuations in the capacity are a result of the numerous capacity tests run on the batteries (approximately 9). Over the first 4 years of the test the average battery capacity was between 70 and 77 ampere-hours (AH). During this time the batteries were being charged to 1.5 v/cell with a step to trickle charge scheme. At orbit 20,000, the charge voltage was dropped to 1.49 v/cell as a result of some charge control relays failing and the thermal situation of the batteries. The thermal situation of the HST batteries is the reason the batteries have not been charged to higher charge voltages from the beginning.

Since launch the flight batteries have always had 10 to 15 AH more than the test batteries. The flight batteries underwent an almost ideal launch scenario and within a couple of months on flight were cycling with 90 to 95 AH. To date the HST flight batteries have cycled for almost 4.5 years and have underwent or will soon have underwent 2 capacity checks per battery. The present average capacity of the flight batteries is 78 to 80 AH. It is felt that most of the operating capacity lost is a result of the low charge level (1.49 v/cell) that the batteries are being charged to. Thermal changes to the HST battery bays are being considered for the next servicing mission to allow for charging the batteries to a higher voltage.



This plot shows the end of charge and end of discharge voltages over the life of the Six Battery Test. The end of charge voltage tracks the different charge levels that have been used and the end of discharge voltages track the general state of health of the batteries. Even though the end of discharge voltages have essentially stabilized, a gradual decline over the life of the batteries is to be expected.



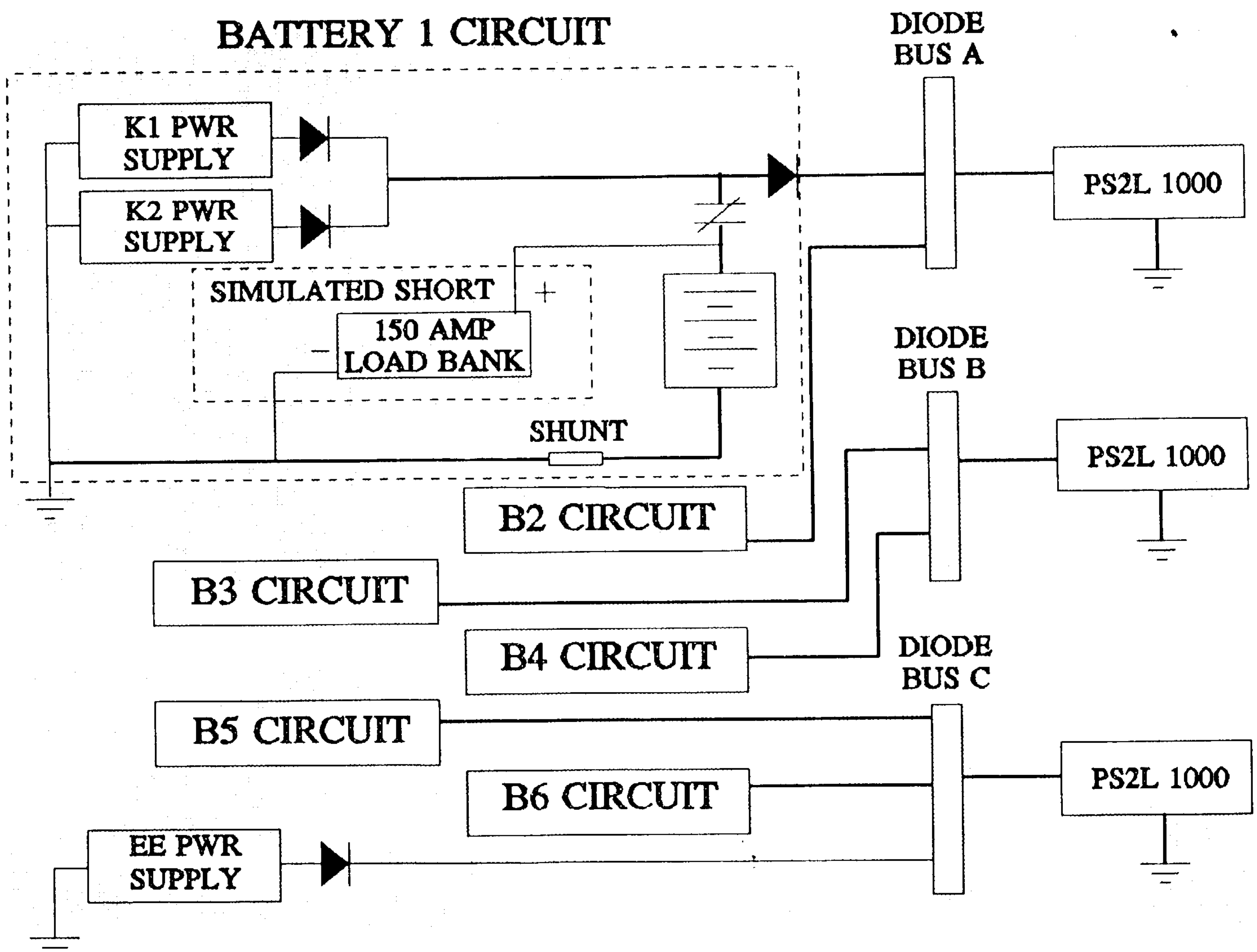
This plot shows the average battery watt-hour efficiency over the life of the HST Ni-H2 Six Battery test. The batteries cycled with a step to trickle charge scheme and charged to 1.5 v/cell for the first 20k orbits. After orbit 20k the charge scheme was changed to hardware control (essentially a taper charge) and the charge voltage was lowered to 1.49 v/cell. The watt-hout efficiency of the HST Ni-H2 cells has varied from about 77 to 85%.

Test Objectives

- Determine operating characteristics of the batteries
- <u>Investigate on-orbit anomalies</u>
- Test proposed variations prior to implementation on orbit

As a result of an electrical fault that occurred on the Hubble Space Telescope (HST) in September, 1991, the HST Electrical Power System (EPS) Operations group at GSFC requested a series of tests on the HST batteries on test at MSFC. In October '91 tests were run on the HST Six Battery Test with 3 second discharges as high as 70 amperes. From 12/23/91 to 1/3/92 additional tests were run on a 4 cell pack of HST Flight Spare Module cells on test at MSFC where the cells were discharged at rates up to 250 amps. The Six Battery Test results revealed that a fault as low as 70 amperes could have caused the EPS anomalies observed during the fault. Further test to 250 amperes indicated that: (1) no damage should have occurred to the HST batteries as a result of the fault and (2) that the HST test batteries impedances were constant over the entire tested range at 1.2 to 1.3 milliohms per cell. On the following page is a block diagram showing how the fault was simulated on the Six Battery Test.

Block Diagram of Battery Anomaly Simulation



Test Objectives

- Determine operating characteristics of the batteries
- Investigate on-orbit anomalies
- Test proposed variations prior to implementation on orbit

The Six Battery Test has been used extensively for testing proposed variations in operating mode. The test was used for launch scenario testing, investigating possible methods to boost up operating capacity, and investigating possible EPS configurations during the first servicing mission. Prior to the servicing mission, the HST Six Battery Test underwent numerous test in support of the servicing mission. In the simulations the test batteries were put through conditions the flight batteries would experience during the servicing mission. The simulations determined the battery capacity and the optimum configuration for the battery circuits for the mission.

Power Control Unit (PCU)

Relay Minimization Test

- Background
  - 2 PCU relays have failed
  - Failures have potential to damage DIU
  - PCU is not an orbital replacement unit
- Purpose - minimize cycling on the PCU relays
- Plan - develop a battery charge control algorithm that will minimize PCU relay cycling w/out sacrificing battery capacity

The most recent use of this test as a means for testing proposed variations in operating mode is the investigation of a proposed "PCU Relay Minimization Scheme". Since launch, the HST electrical power system (EPS) has had two solar array trim relays fail. The relays were being used as battery charge control relays when the failures occurred. The relays are located on the power contol unit (PCU), which was not designed as an orbital replacememnt unit (ORU). To reduce the cycling on the PCU relays, GSFC is investigating operating the EPS with a reduced solar array by opening a number of solar array trim relays. A set of conditions, based on the batteries state of charge (SOC) and the number or orbits since the batteries were fully charged, will determine the number of trim relays to open or close. A reduced solar array will reduce battery charge current, and require less charge control relays to cycle. The algorithm that determines the number of trim relays to open or close is being referred to as the "PCU Relay Minimization Charge Scheme". Phase I of this sheme was tested on the HST NiH2 Six Battery Test from 6/28/94 to 8/24/94.

PCU Relay Minimization Phase I

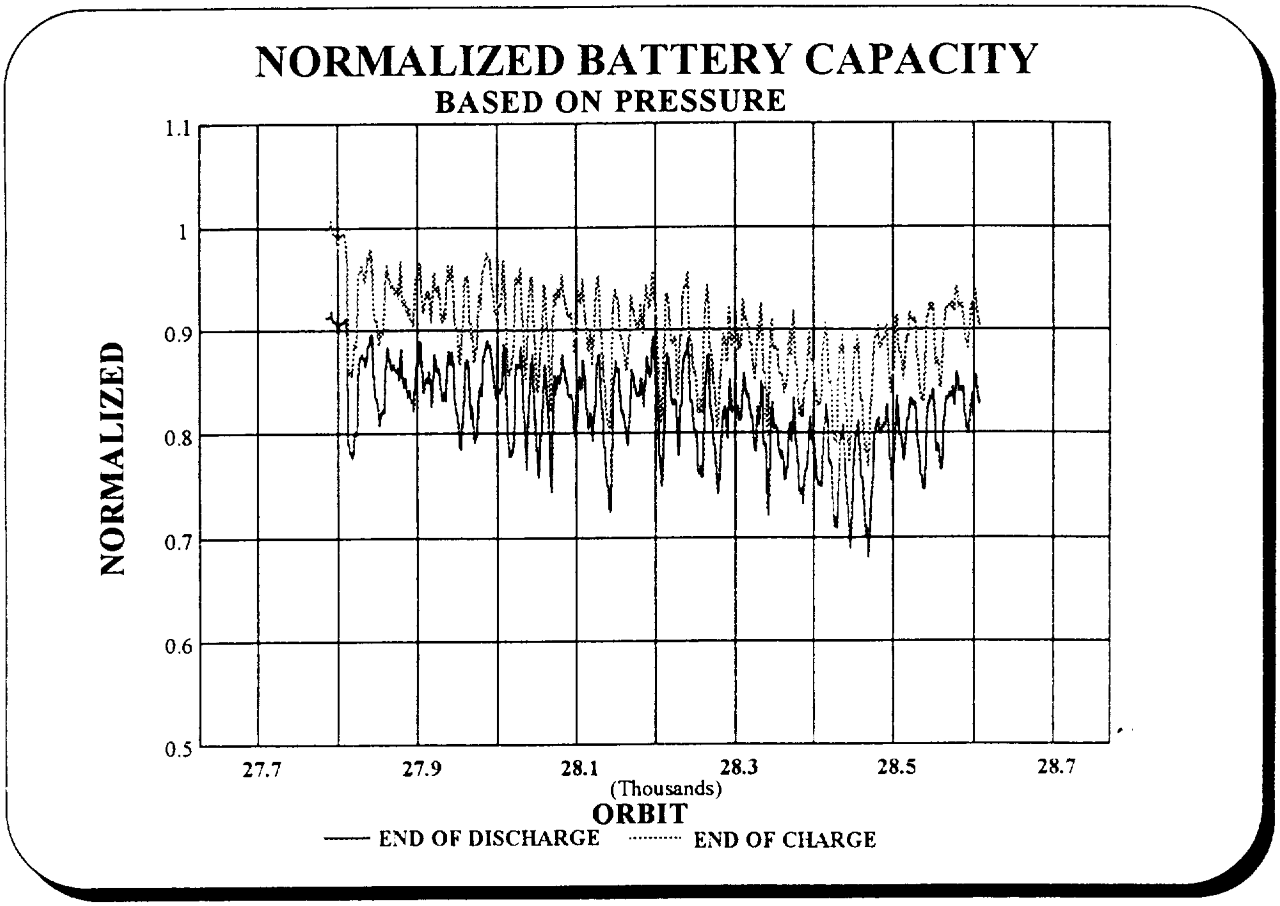
- Remove SPAs until batteries are unable to charge to V-T charge level (STARVATION MODE)
- When SOC gets below 85% or 15 orbits since last full charge, put 1 SPA back on line (this is the transition to FULL CHARGE MODE)
- When 2 batteries reach V-T limit for 2 consecutive orbits, remove 1 SPA (transition back to starvation mode)

The above chart describes the basic conditions of the Phase I of the PCU relay minimization charge scheme. The charge scheme consisted of two modes of operation:

1) STARVATION MODE - remove enough SPAs so the batteries do **not** reach the V-T limit. Stay in this configuration for 15 orbits or until the batteries SOC at the end of discharge goes below 80 or 85%. Then put one SPA back on line and transition to:

2) FULL CHARGE MODE - in this mode the batteries capacity will be increasing. The system will stay in this configuration until 2 or 3 of the batteries have charged up and reached their V-T limit. Then one spa will be removed and the system will return to the starvation mode.

Phase I was implemented on the Six Battery Test for 60 days and reduced PCU relay switching by 90%.



This graph shows the normalized battery capacity during Phase I of the PCU relay minimization test. Even though 2 of the batteries were reaching the V-T limit during the full charge mode, the capacity was gradually going down. At orbit 28450, when it was decided to require 3 batteries to reach the V-T limit before returning to the starvation mode, the capacity began to slowly increase. But, during this testing GSFC ran a capacity check on one of the HST flight batteries, and the battery had less capacity than was being predicted. With the flight batteries having less capacity than predicted and this charge mode showing another possible reduction in capacity, GSFC began considering changes to the algorithm to optimize the trade off between relay cycling and battery capacity. The changes to the algorithm are Phase II of the PCU Relay Minimization Charge Scheme.

PCU Relay Minimization
Phase II

- Instead of putting 1 SPA on line to transition to full charge mode, return entire solar array.
- Return to starvation mode after 4 or 5 batteries reach the V-T level.
- Phase II should reduce PCU relay cycling by 75%

In Phase II of the PCU Relay Minimization test, during the FULL CHARGE mode the entire solar array will be put back on line instead of just one additional SPA. This will give the batteries a higher rate full charge and and this charge mode will continue until 4 or 5 of the batteries reach the V-T limit. This phase of the test has just begun and it is too early to predict exactly how this change will effect the capacity. A HST EPS model predicts this charge scheme will reduce PCU relay cycling by 75%. This test will be completed by February '95.

SUMMARY

- Batteries have cycled for over 5 years and performance continues to be nominal
- Testbed continues to be a very beneficial tool for testing proposed operating configurations and investigating flight anomalies