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NICKEL–HYDROGEN LOW-EARTH-ORBIT TEST PROGRAM

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Summary

The incorporation of nickel–hydrogen technology in low-earth-orbit (LEO) spacecraft requires the establishment of a data base. An extensive test program has been established to provide this. The paper outlines the test program and presents preliminary test results.

Introduction

The vast majority of spacecraft secondary energy storage systems flown in the last two decades were nickel–cadmium batteries. Such applications took advantage of the inherently long cycle-life, a good specific energy, and high reliability The hermetically-sealed nickel–cadmium system required a sophisticated charge control system and, as a result of temperature sensitivity, required operation under close environmental control. Increasing spacecraft power requirements dictated a higher performance battery system capable of a 10 year mission life with deeper depths-of-discharge (DOD) and variable load profiles. In the past, the extensive data base for nickel–cadmium systems had restrained aerospace contractors from investigating alternative energy storage systems. The limitations of nickel–cadmium batteries, however, particularly usable energy density, have provided strong economic incentives to look for a new system, and have led to the recent development of nickel–hydrogen technology

Nickel–hydrogen cell and battery technology has matured so that a viable choice now exists for current and future aerospace energy-storage applications. The nickel–hydrogen system offers a true, hermetically sealed design capable of thousands of maintenance-free cycles without need for complex charge control circuitry or close environmental control. The real potential of nickel–hydrogen systems has caused aerospace contractors to conduct in-house studies and investigate the feasibility of nickel–hydrogen implementation. Nickel–hydrogen cell technology represents the best engineering choice for numerous power-storage systems, and with the establishment and expansion in its data base, which is presently insufficient [1], the nickel–hydrogen system will become the practical choice.

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Nickel–hydrogen battery cell technology has been successfully demonstrated for geosynchronous (GEO) orbit applications, both in ground testing and in-flight performance. The GEO data base cannot, however, be extrapolated to provide relevant LEO data Applications of nickel–hydrogen technology in LEO require the development of a cycle life data base with DODs in the 40 - 60% range. A nickel–hydrogen test program was thus established to provide this LEO data base

Test plan

Table 1 identifies the suppliers and numbers of cells procured for nickel–hydrogen LEO testing. Eagle-Picher and General Electric were selected for the procurement of 36 Air Force designed nickel–hydrogen cells Six Yardney cells were also procured. Four cells from Eagle-Picher are identified in Table 1 as COMSAT designed cells. Eagle-Picher provided these cells to Martin Marietta for LEO testing The general concensus by the aerospace industry is that the COMSAT cell is not adequately designed for LEO application The addition of the four COMSAT cells to the test program will provide needed evidence

TABLE 1

Suppliers and number of cells procured for LEO test programme

Cell supplier	Cell type	Number of cells procured	Status
Eagle-Picher	Air Force	36	12 cells received 07/85 24 cells received 10/85
Eagle-Picher	COMSAT	04	04 cells received 08/85
General Electric	Air Force	36	20 cells scheduled for delivery 01/86 16 cells scheduled for delivery 02/86
Yardney	Man-Tech	06	06 cells received 10/85

The matrix for the nickel–hydrogen testing is shown in Fig 1 The primary area of interest is 40% DOD. This would translate into appreciable weight savings compared with nickel–cadmium systems [2] It is also assumed that 40% DOD is a conservative test parameter. The test temperature of 10 °C is based on the present thermal design capabilities of typical spacecraft [3] Vendors predict that 20 000 cycles at 40% DOD and 10 °C is attainable with their nickel–hydrogen cells The 60% DOD test will serve two main purposes first, accelerate the testing and provide early failure rate data, second, characterize cell performance at a higher DOD The added temperature of 20 °C is of interest because further weight and cost savings could be possible if the requirement for maintaining battery temperature

DEPTH-OF-DISCHARGE / TEST TEMPERATURE	40%	60%
10°C	16 EP CELLS 16 GE CELLS 6 YARDNEY CELLS 4 EP COMSAT CELLS	8 EP CELLS 8 GE CELLS
20°C	8 EP CELLS 8 GE CELLS	4 EP CELLS 4 GE CELLS

Fig 1 Nickel–hydrogen LEO test matrix

was less stringent. All testing conducted in this matrix will be a 90 min LEO regime consisting of a 55 min charge and a 35 min discharge. The 90 min LEO is generic, and also accelerates testing to an extent. The charge-control parameter was considered to be a significant factor with regard to LEO testing. Analysis of test equipment capabilities and the results of preliminary testing support charge control utilizing a current integrator. Charge control is therefore maintained by ending the charge and discharge phase after a predetermined capacity is achieved. A recharge fraction roughly between 1 05 and 1 10 (dependent upon test temperature and cell life) will be maintained for all testing.

Test procedure

All the nickel–hydrogen cells subjected to life cycle tests have aluminum collars The collars provide cell support to the test fixture and aid in thermal management. All cells are tested in the horizontal position. Possible problems have been identified with testing in the vertical position, therefore the horizontal testing requirement was imposed. It is also the general concensus that testing the cells in the horizontal position will aid electrolyte distribution within the cell. The test fixture for mounting and thermal management consists of copper tubing pressure-fitted between two aluminum plates Each test fixture has mounting provisions for four cells. The test fixtures are then mounted in an environmental test chamber. The test fixture temperature is controlled by a circulator bath. The chamber temperature is set to match the test fixture. Preliminary test data shown in Fig 2 indicate that the difference in temperature between cell case and test fixture is less than 5 °C during LEO testing.

Nearly all the nickel–hydrogen cells tested have strain gages. The strain gages allow the cell pressure to be monitored during LEO testing Possible

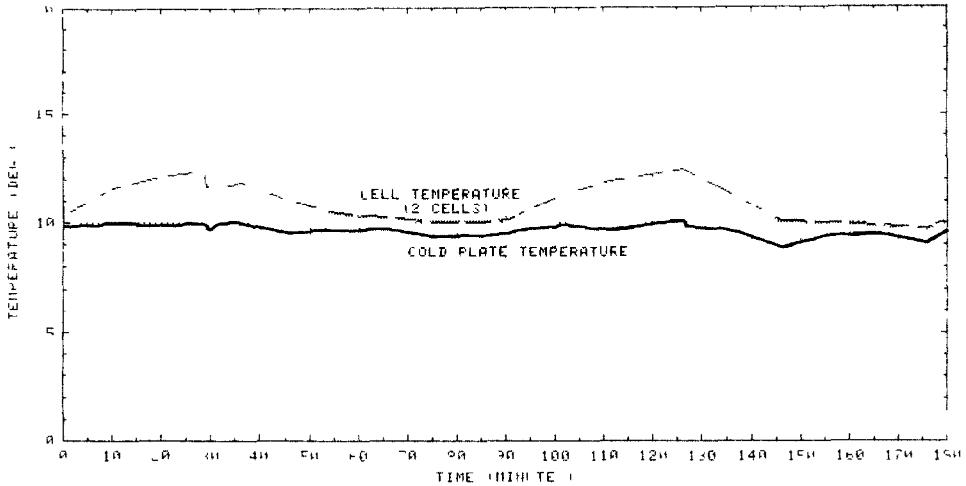

Fig 2 Cold plate temperature and cell temperature during LEO cycle testing

charge control utilizing cell pressure data has been proposed for nickel–hydrogen cells, but for our test program the pressure data are for characterization purposes only. It has been shown that a direct relationship exists between the state-of-charge and the pressure of a nickel–hydrogen cell [4, 5]

Table 2 outlines the actual test parameters for nickel–hydrogen LEO testing The discharge capacity for the 40% DOD testing is set at 20 0 A h This translates into a discharge current of 34.4 A. The charge current for the 40% DOD testing is set between 22 9 A and 24 A Depending upon cell test temperature and life, the recharge fraction is set between 1 05 and 1 10 by adjusting the charge current The end of a discharge phase is when 20 0 A h has been removed The end of a charge phase is when 20 - 22 A h (dependent upon test temperature and life) has been returned The 60% DOD testing follows the same recharge fraction control scenario as the 40% DOD testing The discharge current for 60% DOD testing is set at 51.5 A while the charge current is set between 34 3 A and 36.0 A

For each test group, a representative cell will be temperature monitored to thermally characterize the cell and test fixture (equipment) The coolant

TABLE 2

Actual test parameters for nickel–hydrogen LEO testing

Test temperature (°C)	DOD (%)	Discharge rate (A)	Charge rate (A)	Recharge fraction
10	40	34 3	22 9	1 05
	60	51 5	34 3	1 05
20	40	34 3	22 9 - 24 0	1 05 - 1 10
	60	51 5	34 3 - 36 0	1 05 - 1 10

plate will also contain thermocouple(s) to ensure that the test temperature is held as close to 10 °C or 20 °C as possible. Cell pressure will be monitored by strain gages. These data will be utilized for characterization purposes only and will be reported in the future. Due to safety concerns, all testing was conducted in an enclosed environmental chamber equipped with a nitrogen purge system.

The definition of a cell failure during life cycle tests is the inability of a cell to support an end-of-discharge voltage of 1.0 V. At the discretion of the test engineer, an attempt may be made to recondition the cell. Cells which cannot support a 1.0 V end-of-discharge voltage will be removed from the test group. Life cycling will then continue on the remaining cells. Analysis of the data from a failed cell will determine final cell disposition.

A capacity test will be conducted every 1000 cycles. The capacity test will consist of a cell discharge to 1 0 V, followed by a 16 h charge at 5 0 A, followed by a 25.0 A discharge to 1.0 V per cell The objective of the capacity test is to characterize cell degradation in relationship to LEO cycling. The capacity check may also be, in effect, a reconditioning cycle, due to the fact the cell is fully recharged. The data from the capacity test may also indicate possible electrochemical changes within the cell associated with LEO cycling.

Test results

Test results to date are for the first delivery of 12 Air Force designed nickel–hydrogen cells and the four COMSAT cells. The Acceptance Test Procedure (ATP) conducted by the vendor on the twelve Air Force designed nickel–hydrogen cells during late May, 1985, revealed a capacity range of 59.8 - 63.2 A h (10 °C test, 34.4 A discharge to 1.0 V per cell) Final ATP testing by the vendor was completed in June, 1985. The cells were first tested in the Power Sources Laboratory in late July, 1985. Initial capacity checks (five continuous cycles) consisting of a 5.0 A charge for 16 h followed by a 25.0 A discharge to 1.0 V per cell revealed a fourth cycle capacity range of 45.0 - 48 2 A h. Table 3 lists the capacities for both the vendor ATP data and the fourth cycle capacity check conducted in-house. The in-house capacity discharge was continued to an end-of-discharge voltage of 0.5 V. Significant residual capacity was noted in the cells as shown in Table 3. A typical capacity discharge cycle is depicted in Fig. 3. A second, distinct voltage plateau can be seen at 0 7 V. All twelve nickel–hydrogen cells shared this second plateau characteristic.

The first twelve vendor cells were divided into two groups. The first test group consisted of eight series-connected cells tested at 10 °C and 60% DOD The initial capacity (25.0 A to 1.0 V/cell) of this cell/battery test group was 55.1 A h. Figure 4 depicts the end-of-discharge voltage and recharge fraction plots for this test to date. The remaining four cells were series-connected and placed on test at 20 °C and 60% DOD. The initial

TABLE 3

Eagle-Picher Acceptance Test Procedure (ATP) *vs* in-house capacity tests

S/N	Eagle-Picher ATP capacity (05/29/85), 34 3 A D/C to 1 0 V (A h)	Martin Marietta capacity test (07/31/85) 25 0 A D/C to	
		1 0 V	0 5 V
1	62 8	46 9	55 6
2	63 2	46 5	57 1
3	61 1	48 2	57 7
4	64 5	47 1	57 7
5	60 6	46 9	55 8
6	62 9	45 0	55 2
7	60 7	47 3	57 1
8	59 9	46 3	56 0
9	63 4	48 0	57 3
10	60 3	46 1	57 3
11	60 4	46 3	57 1
12	59 8	45 9	55 2

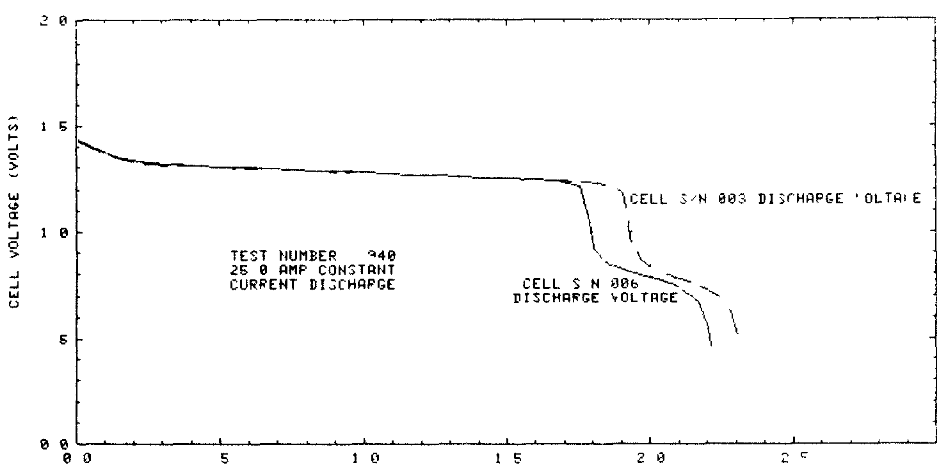

Fig 3 Initial cell capacity discharge cycle

capacity of this cell/battery test group was 44.0 A h. Figure 5 depicts the end-of-discharge voltage and recharge fraction plots for this four-cell test group to date

The four COMSAT cells were series-connected and placed on test at 10 °C and 40% DOD. The initial capacity of this four-cell test group was 62.5 A h. Figure 6 depicts the end-of-discharge voltage and recharge fraction plots for this four-cell group to date

Testing has not been initiated to date on the 24 recently received vendor cells nor the 6 Yardney cells LEO testing on these cells will be

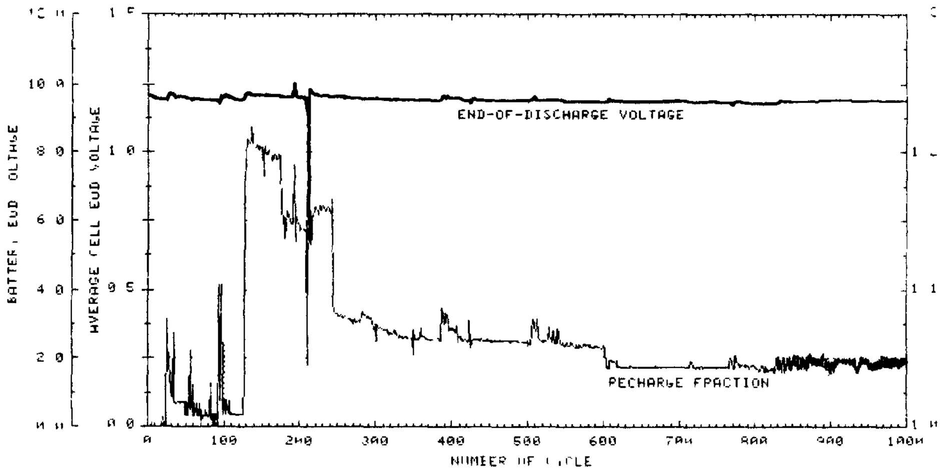

Fig 4 End of discharge voltage and recharge fraction plots Eagle-Picher first test group (8 cells) Temperature 10 °C, DOD 60%

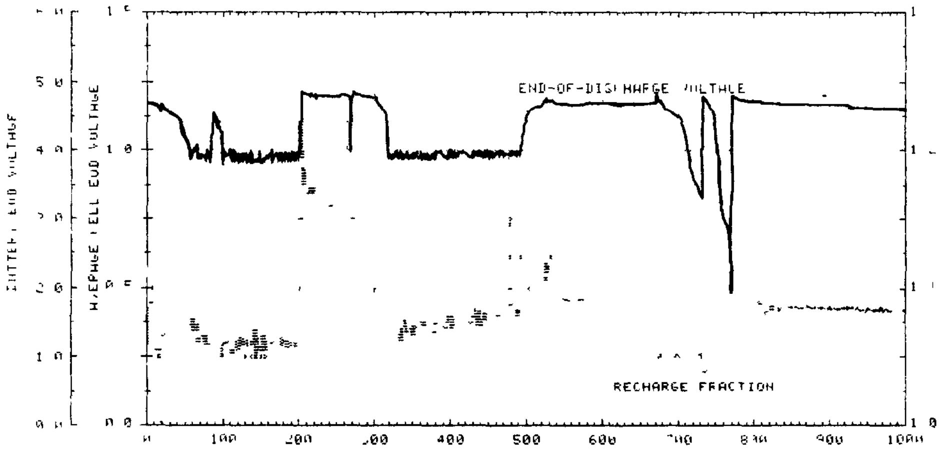

Fig 5 End of discharge voltage and recharge fraction plots Eagle-Picher second test group (4 cells) Temperature 20 °C, DOD 60%

underway by December, 1985 The addition of 36 more cells to the test program in 1986 will be the final group of cells procured for this test plan.

Conclusions

The significant loss of capacity observed in the first group of nickel–hydrogen cells from ATP testing to our initial capacity testing has several possible causes The activation procedure for these cells includes a hydrogen

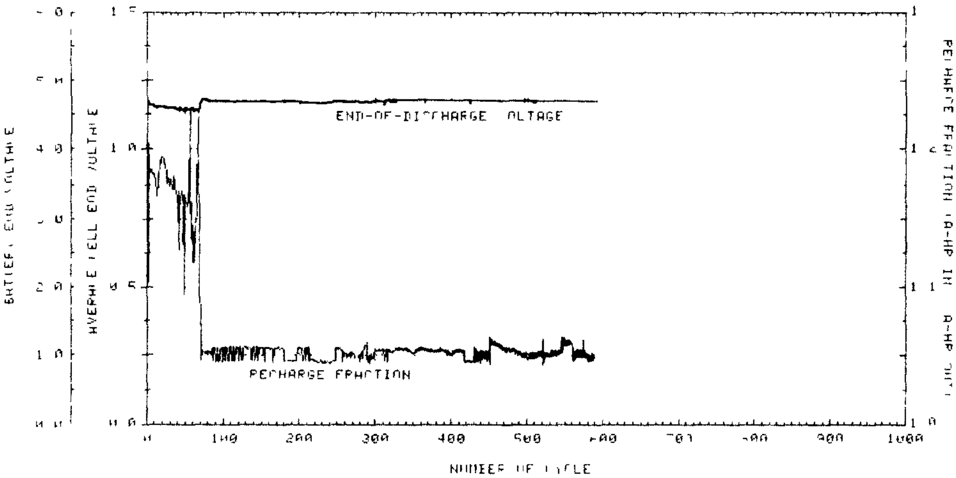

Fig 6 End of discharge voltage and recharge fraction plots Eagle-Picher COMSAT test group (4 cells) Temperature 10 °C, DOD 40%

precharge of 40 psig which is completed immediately prior to the conditioning cycles and ATP testing. The hydrogen precharge has recently been deleted from the specification, and nickel–hydrogen manufacturers have suggested that the hydrogen precharge of 40 psig may have caused the capacity degradation and resultant double-knee, or second plateau, discharge The twelve cells were in a stored, shorted condition for approximately six weeks, and it has been postulated that during this period the hydrogen precharge reacted with and changed the positive plate. At the present time, extensive studies are underway to characterize this positive plate change It was decided that for the second-cell-build of 24 cells a revised cell activation procedure would be utilized The 40 psig precharge was reduced to a one atmosphere precharge, or approximately 16 psig Hopefully, this change will minimize the capacity loss observed on the first twelve cells. The twenty-four cells recently received will undergo the same receiving, inspection, and initial capacity tests as the first twelve to ensure an accurate evaluation of the revised activation procedure. Tests are scheduled for November, 1985 on the second build of twenty-four cells.

Cells under LEO cycling have nearly 1000 cycles to date, therefore it is too early yet to draw any conclusions regarding nickel–hydrogen performance. Test control parameters were initially identified as major items for an accurate and reliable test program Early tests have shown the most reliable method for charge control is ampere hour integration The coolant fixtures have been shown to provide excellent thermal conductivity for the removal of heat from the cells Test control parameters have been optimized, and, hopefully, cells under the LEO test program will meet the goal of 20 000 cycles

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