ADVANCES IN NICKEL–HYDROGEN TECHNOLOGY

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Summary

This paper outlines the current major activities in nickel–hydrogen technology at Yardney, which consist of:

an update on life cycle testing of ManTech 50 Ah $Ni-H_2$ cells in the LEO regime;

an overview of the Air Force/Industry briefing on the Yardney ManTech program;

nickel electrode process upgrading;

4.5 in. cell development;

bipolar $Ni-H_2$ battery development.

1. Update on life-cycle testing of ManTech 50 A h $Ni-H_2$ cells in the LEO regime

At the 1985 Goddard Workshop, Yardney reported, in a short informal briefing, the effort at that time in the LEO regime life cycle testing of Yardney cells which were the prototypes of Phase II of the ManTech Program. This depicted the testing of two cells to 5000 cycles at 80% depth of discharge including, in the first 1000 cycles, efforts to optimize charge/discharge ratios and fine tune the computerized test and data aquisition systems. The consensus opinion of those in the $Ni-H_2$ technological community at that time was that the 80% DOD was overly rigorous and unrealistic. Therefore, we restarted cycle testing at 60% depth of discharge. Also, by this time we were delivering Phase III cells to customers which represented the final configuration for the ManTech Program. These cells differ from the prototype Phase II cells only in mechanical design. The number, type and arrangement of electrochemical elements remained unchanged. One of these Phase III cells was added to the test group as testing restarted.

Reconditioning or recharacterization of the cells was not performed at 6000 cycles but at 7000 and 8000 cycles. As can be seen in Fig. 1, cell 008 was the poorest performer of the group. This is attributed to test system problems encountered during the first 5000 cycles. In addition to power

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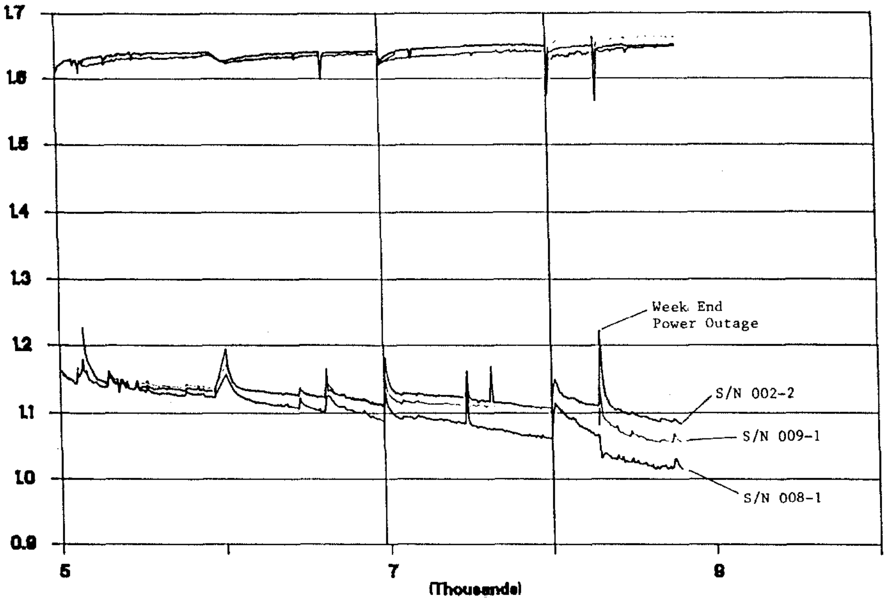

Fig. 1. LEO cycled cells at 60% DOD.

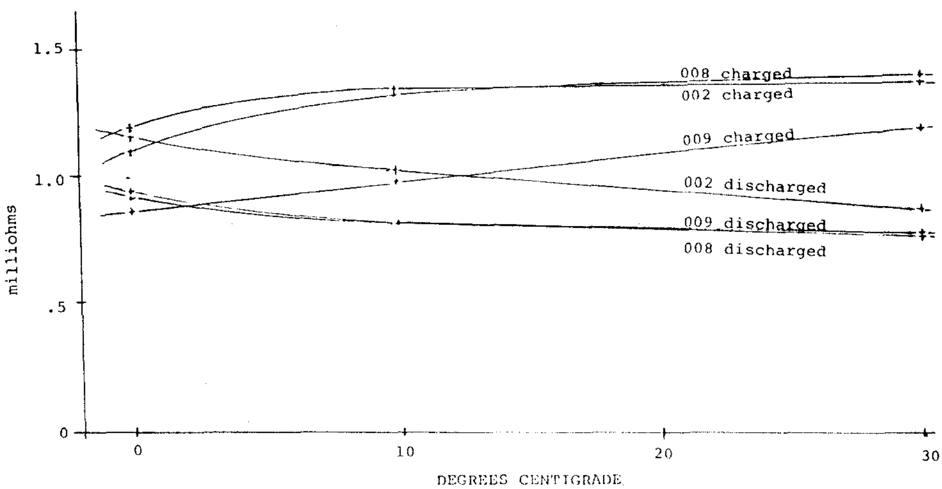

Fig. 2. Impedance of Ni–H_2 cells at various temperatures when fully charged and fully discharged. Cells 008 and 009 after 9000 LEO cycles, 5000 at 80% DOD plus 4000 at 60% DOD. Cell 002 after 4000 LEO cycles at 60% DOD.

failures, the cells were, at least once, driven into reversal as a result of test system malfunctions. Testing has proceeded to about 8900 cycles of which approximately 8800 cycles are represented in Fig. 1. During the current recharacterization it was decided to determine some additional characteristics of these cells. One of these characteristics was cell impedance at various temperatures and states of charge (Fig. 2) using a Keithley Model

503 milliohmmeter. It is of interest that at 0 °C, impedance values are similar for charged or discharged cells but as temperature is increased, charged cells have a greater impedance while discharged cells exhibit less impedance. It should be noted that these values were taken at 40 Hz.

A second characteristic was for what is sometimes referred to as the "double knee phenomenon" during discharge. The three ManTech test cells, which had been maintained for an extended time (10 - 14 days) at less than 10 mV, were charged at a $C/10$ rate for 20 h and then discharged. The first discharge was at $C/25$ and exhibited no "double knee" phenomenon (Fig. 3). Repeating the same cycle 3 days later exhibited the start of the phenomenon (Fig. 4). Another cycle at a $C/10$ discharge rate shows a slightly more pronounced effect (Fig. 5) and another cycle at a $C/2$ discharge rate shows a more substantive but less pronounced characteristic (Fig. 6). Finally, at a C rate discharge the differentiation of the two "knees" has almost disappeared (Fig. 7). These measurements illustrate an inherent dependence of the positive electrode active nickel structure on prior cycle history and rate of discharge. We are continuing to evaluate this phenomenon relative to cell performance.

Additionally, radiographic examinations were made to determine positive plate growth. Less than 0.002 in. growth per plate was noted on cells S/N 008 and 009 in the first 5000 cycles. No measurable growth occurred in the subsequent 3800 cycles.

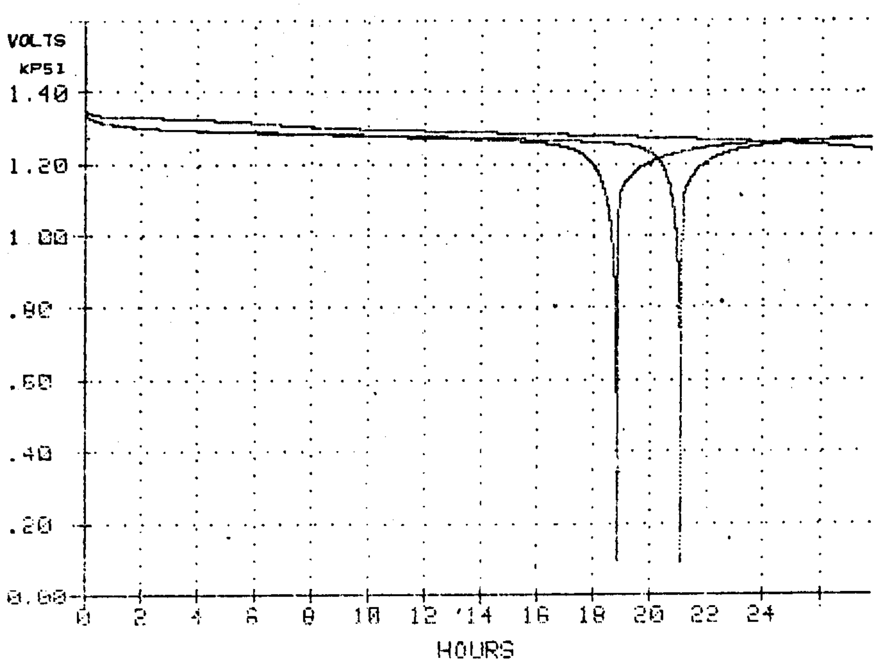

Fig. 3. Discharge at 2.1 A, 10 °C.

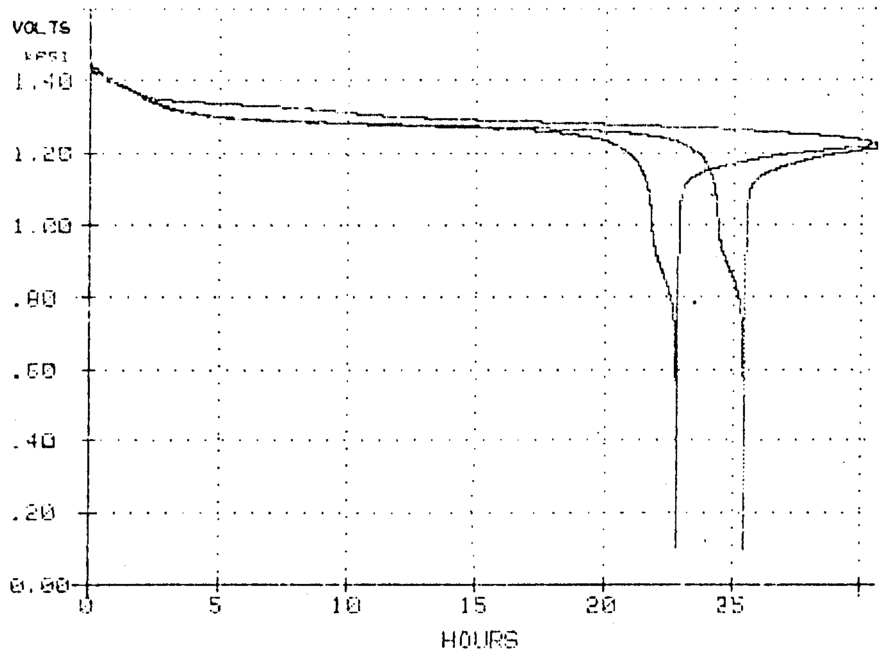

Fig. 4. Figure 3 cell discharged after 3 days at 2.0 A, 10 °C.

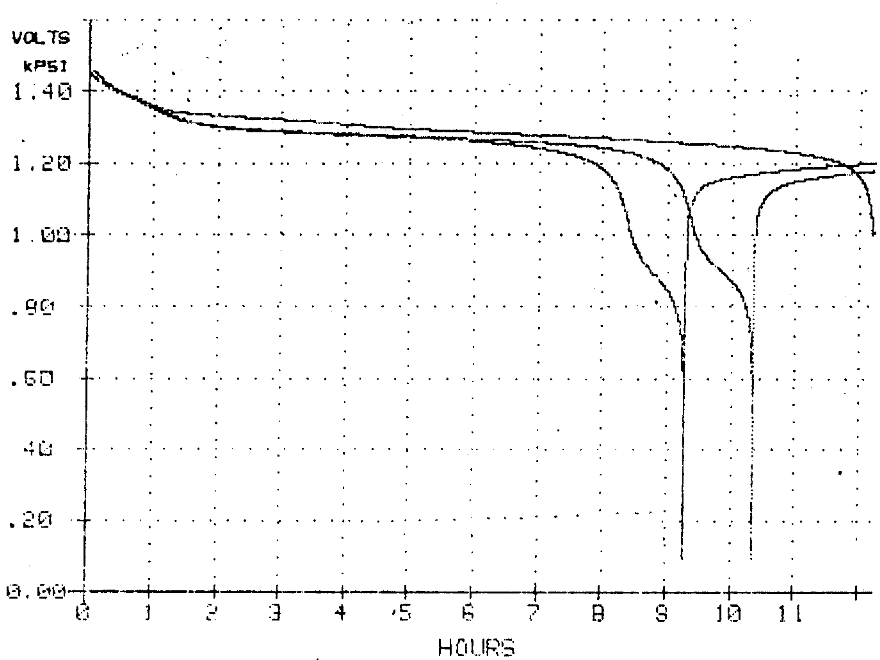

Fig. 5. Discharge at 5 A, 10 °C.

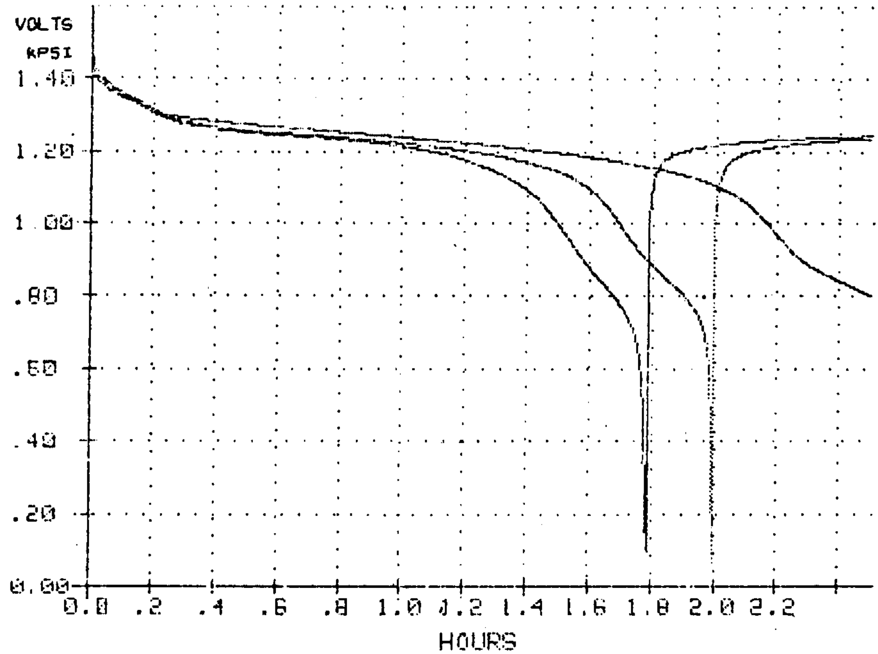

Fig. 6. Discharge at 25 A, 10 °C.

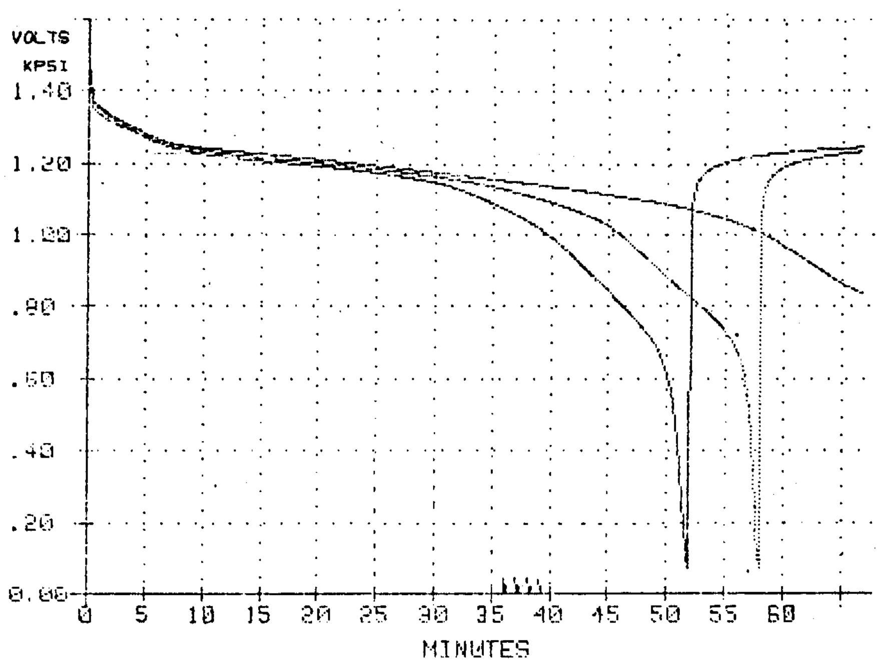

Fig. 7. Discharge at 50 A, 10 °C.

2. Overview of the Air Force/industry briefing on the Yardney/ManTech program

This program, initiated in 1981, has resulted in a number of technical break-throughs including the reduction in platinum loading of the negative electrode without loss of performance, the improvement in structural accommodation to plate growth and, most importantly, a reduction in price from the baseline cell of 30% to 50% or more depending on the production lot size.

In addition to the prototype cells being tested in house, Yardney has delivered two lots of cells to the Wright Patterson Air Force Base both of which are now on test at the Naval Weapons Support Center, Crane, Indiana. Additional cell lots in the Phase III configuration have been produced for other customers.

3. Upgrading of the nickel-electrode process

Within Yardney's new dedicated $Ni-H_2$ manufacturing facility a substantial effort has been directed at nickel electrode manufacturing techniques. The Yardney process includes a wet, slurry-type plaque which is sintered in a reducing atmosphere followed by electrochemical impregnation (EI) by the Pell–Blossom process. New plaque pulling, sintering, and EI equipment are providing superior control of these phases of the operation.

These efforts are now providing positive plates which meet the stringent requirements of thickness growth and blistering when subjected to a 200 cycle high-rate stress test. This test consists of a 10 *C* charge for 12 min and a 10 *C* discharge for 8 min at room temperature. Criteria for acceptance for the standard 31 and 35 mil-thick electrodes are a maximum of 3 mil thickness growth and less than 3% of the plate area blistered.

4. 4.5 inch cell development

In May of 1985 Yardney embarked on a cooperative effort with Ford Aerospace Corporation to develop a 4.5 in. dia. nickel–hydrogen cell with a nominal rating of at least 220 A h in a LEO regime. The design is a tandem stack, floating core type, typical of Yardney's 3.5 in. Air Force design, but incorporating wall wick recombination and back-to-back electrodes. Mechanically the structure is a 35% scale-up of 3.5 in. components employed in the ManTech and Air Force design cells. The program was somewhat accelerated in order to produce light-weight cells for performance evaluation in less than six months. Table 1 identifies some of the improved design features employed in this cell.

A series of characterization tests was carried out on five of these cells to determine the effect of temperature between 0 °C and 36 °C. The temper-

TABLE 1

Cell design features, Yardney 4.5 in. model YNH-HRWRTS220

- 4.5 in. dia. cyl. × 18 3/8 LOA
- ManTech/Milstar growth variant (1.35 scale-up)
- Back-to-back electrodes (0.031 in. ManTech thickness)
- Zircar and asbestos separator
- Weld ring w/minimal "width"
- Simplified center support plate
- Belleville spring stroke maximized
- Recombination & major heat source on walls
- Anti-twist terminal

ature was controlled by fluid transfer in manifolded sleeves clamped to the cylindrical section of each pressure vessel. These temperature trials, which were conducted as the first cycles, demonstrated that the best capacity is at 10 °C for an average value of 243 A h. After 150 LEO cycles this early capacity to 1.0 V increased to an average value of 259 A h.

Figure 8 illustrates the end of charge and discharge voltage trends for this initial cycle series. Continued life testing is planned for several of these cells.

There was consistency of discharge performance between cells from the 5th to the 150th cycle.

Early in 1986 Yardney responded to customer interest to produce 100 A h, 4.5 in. dia. cells for the LEO regime. This design also employed a tandem stack, floating core, but the stack elements were arranged in a conventional recirculating sequence. The pressure vessel wall was coated with zirconium oxide according to normal Air Force design practice and no platinum catalyst was incorporated for wall recombination. Assembly of the first 100 A h units is currently underway and characterization tests are scheduled for December 1986.

5. Bipolar activities

Yardney is in the third year of development of an experimental 75 A h bipolar battery for space applications. This NASA program was organized to evaluate a baseline design and its variants. Ford Aerospace Corporation is the prime contractor and Yardney has responsibility for the stack development. The design is inherently modular in nature, lending itself to high capacities and voltages depending on cell stack arrangement within a common pressure vessel. The program objectives include development of thick electrodes and evaluation of designs for heat removal within a context of simplicity and consequent ease of manufacture.

The basic electrode is 4 in. × 16 in. and 0.080 in. thick. Three such electrodes are joined together in individual frames on a common "bi-polar" heat conducting plate at each cell level. A model was built early in the pro-

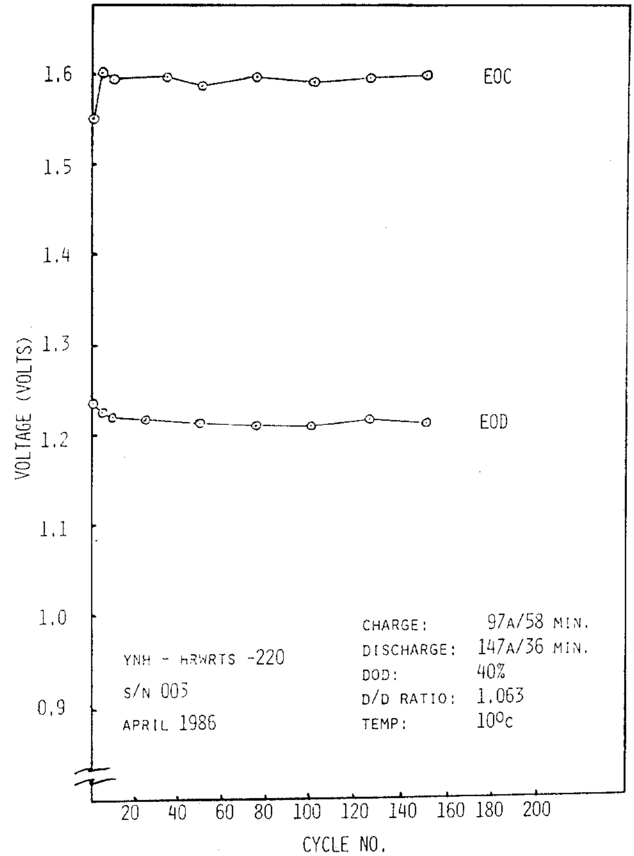

Fig. 8. LEO life cycle data summary of 4.5 in. dia. cells (S/N 003) at 10 °C, 40% DOD, C:D ratio 1.063:1.

gram to represent a full-scale section only one-sixth in. in length, with electrodes 4 × 8 in. Thermal path lengths and mechanical details remained the same for the model as for the prototype. The 10-cell model was characterized for capacity at approximately 10 °C by charging and discharging at various rates. A three-dimensional plot with capacity – charge rate – discharge rate axes showed that the capacity to 1.0 V varies in a continuous manner with the highest values at charge rates between *C*/2 and *C* and for discharges between *C*/4 and 2 *C*. After the characterization series, LEO cycles were run at 80% and 60% DOD for a total of approximately 380 cycles. The model was then disassembled and inspected. In general, the cells appeared to be in good condition with the exception of one shorted cell which was attributed to the mechanical design.