Sealed Nickel-Metal Hydride Batteries for Small Satellite Applications

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Abstract

Sealed, nickel-metal hydride cells are being developed for aerospace applications by Eagle-Picher Industries, Inc. Sizes ranging from 3.5 ampere-hours to 20 ampere-hours are targeted for the small satellite program. The nickel-metal hydride system offers nearly twice the energy density of aerospace nickel-cadmium cells with no memory effect. The cells contain no cadmium, mercury or other toxic materials. The system operates at low pressure and offers significant cost advantages over the nickel-hydrogen system. The cells exhibit excellent overcharge and overdischarge capability with cycle life similar to that of nickel-cadmium. Cells are also being assembled and tested in a number of sizes and designs for use in terrestrial applications.

Introduction

The nickel-metal hydride battery chemistry has been under investigation for several years by a number of different groups. However, recent advances in metal hydride development have made the system practical for commercial battery production. Commercial size cylindrical cells are currently being manufactured which exhibit excellent performance characteristics. Further development is currently underway to adapt this technology to an aerospace cell for the small satellite market. The system offers an energy density comparable to the nickel-hydrogen battery at a cost competitive to a nickel-cadmium battery. In addition, the low operating pressure allows prismatic cell construction which results in greater battery packaging efficiency than nickel-hydrogen. Cell design can be sized to fit any application from 0.5 ampere-hours to 200 ampere-hours or larger with existing technology.

System Description

The key technology allowing the commercial development of the nickel-metal hydride system has been the development of a new family of alloys by the Ovonic Battery Company (OBC) of Troy, Michigan. Considerable work had been done in the past on LaNi5, Ni-Ti and other materials but due to inherent technical difficulties have never become commercially viable. The new materials developed and patented by OBC have overcome these basic problems and perform well in the alkaline battery environment. To date, the only commercially available Ni-MH batteries are offered by OBC and its licensees. The alloys are based on a V-Ti-Zr-Ni-Cr family of materials and are relatively inexpensive and easily produced. The materials have been fully described and evaluated in previous publications by OBC (1, 2, 3). The alloys are presently being produced in 60 Kg ingots and then processed into a fine powder. Electrode material is then produced in a continuous roll using a standard sintering process on a nickel wire substrate with no additives or binders required. OBC has also successfully developed the commerical nickel-metal hydride cell system including the positive electrode, separator, electrolyte and seals to fully take advantage of the superior performance of the hydride electrode.

Eagle-Picher Industries, Inc. (EPI) and OBC are currently working under a joint proprietary agreement to adapt OBC's existing commercial hydride technology to an EPI aerospace quality cell, the primary driver being to provide a high energy density, long cycle life cell at a competitive cost. The hydride system offers twice the weight energy density of nickel-cadmium and twice the volumetric energy density of nickel-hydrogen at a cost comparable to an aerospace Ni-Cd cell. The cells exhibit no memory effect, contain no toxic materials, and have overcharge and overdischarge capabilities similar to Ni-H_2. Nickel-hydride chemistry is similar to the nickel-hydrogen system with the exception of the hydrogen being stored as a solid hydride compound rather than as a gas. This results in a steady state overcharge pressure of about 50 psi. The negative electrode alloy provides a catalytic surface for the recombination of oxygen produced at the positive during overcharge. Several low cost commercial separators are compatible with the system. All cells utilize aqueous potassium hydroxide electrolyte and are in the electrolyte-starved state.

Cell Design

OBC has been producing commercial size cylindrical cells and providing samples since 1987. These cells are being tested at OBC, EPI and other facilities. The cells are standard "jelly roll" construction using commercial materials and techniques. The cells are sealed with a 400 psi safety vent. Series-parallel combinations of these cells could feasibly be used in aerospace applications compatible with their cycle life expectancy. Flat-plate prismatic cell designs are being developed for higher capacity, longer cycle life applications. These designs incorporate the hydride alloy negative electrode with aerospace quality positive electrodes, materials and construction techniques. The resultant cell retains the fully proven heritage of the Ni-Cd and Ni-H_2 systems which have millions of operating hours in space.

Prototype flat cells were built using existing parts and hardware from a 2.5 ampere-hour sealed aerospace Ni-Cd cell. This cell is from a fully qualified flight program and has flown several missions in space. Hydride alloy negative electrodes were substituted for the cadmium negatives with all other parts and processes held to the flight configuration with the exception of the positive electrodes. Two basic cell types were built. One contained OBC commercial grade nickel electrodes and the other type retained the normal aerospace positives as used in the flight batteries. The commercial positive electrodes are the sintered nickel powder type produced by OBC for use in "C" size cells and are designed to offer excellent discharge rate capability and cycle life. Cell specifications are contained in Table 1. Commercial nickel electrodes are more heavily loaded with active material and thus yield a higher capacity cell. There are also other differences including the type of impregnation process used in loading the electrode with active material. Several cells of this type were built and are currently under test. Additional cells are under construction for further testing.

Prototype flat cells of an 8 ampere-hour design have been built in ABS plastic cell cases. These cells incorporate a safety vent but operate normally sealed. Additional cells are being built in an aerospace flight-proven design which will yield 160 ampere-hours. These cells will be heremetically sealed and contained in a 0.012 inch thick stainless steel cell case. A 200 ampere-hour cell is also being developed for electric vehicle applications.

Test Results

Performance data on the OBC "C" cells has been previously reported (1, 4). A normal 2.0 ampere-hour Ni-Cd "C" cell yields 3.5 ampere-hours when the cadmium is replaced with the Ovonic hydride alloy. A group of 18 "C" cells were provided by OBC and tested at EPI. Capacity was very uniform yielding 3.25 ampere-hours (standard deviation was 0.045 ampere-hours) when discharged at a 2.0 ampere rate at room temperature (22°C). The cells were cycled and tested under a variety of conditions. Figure 1 shows the rate dependency of cell capacity. The cells were charged 15 hours at 350 milliamps and then discharged at from 0.70 to 5.0 amperes to a 1.0V cut-off. All were done at 22°C. Capacity ranged from 3.1 to 3.4 ampere-hours.

Several cells based on the 2.5 ampere-hour Ni-Cd flight cell design were constructed and are being tested at OBC and EPI. The cells were tested under a variety of rate and temperature conditions. Figure 2 shows a 1.0 ampere discharge curve at 22° C for a standard Ni-Cd flight-type cell (Ni-Cd), a hydride cell containing EPI aerospace quality positive electrodes (AERO) and a hydride cell containing OBC commercial grade positives (COMM). The cells ran 2.7, 4.2 and 5.3 ampere-hours respectively with each cell operating at approximately 6% above theoretical. The cells were charged 16 hours at 450 milliamps. Figure 3 shows a pressure response curve for a complete charge-discharge cycle. Figure 4 shows the effect of temperature on capacity. Standard 1.0 ampere discharges were performed at 10 degrees C and 30 degrees C as compared to 22°C above. Discharge capacity is relatively temperature independent with only slightly higher values at the warmer temperature. Discharge voltage is also slightly depressed at cooler temperatures. Figure 5 shows the rate dependence of capacity for hydride cells. The cells were discharged at up to 20.0 amperes (nearly a 5C rate) and still delivered 3.0 ampere-hours.

Future Testing

A comprehensive development and test plan is being implemented. New cell designs are being developed incorporating a number of different cell design variables. A new, lower cost hermetic seal is being developed similar to the nylon seal currently being used in flight Ni-H_2 cells. New separators are being evaluated which will reduce cost and extend cycle life. Developments in lightweight nickel electrode technology can be incorporated to increase energy density while also reducing cost by using non-woven nickel fiber material rather than sintered carbonyl nickel powder (5). New hydride alloys are also being developed which will increase performance and cycle life.

Eagle-Picher has an extensive background and data base in the life testing of aerospace cell designs (6). Cycle life testing is planned for sample cells representative of all the designs being built. This testing will provide information on failure modes which will be used to further improve cell design. In addition, cycle life testing is being conducted on commercial grade "C" size nickel-hydride cells under an aerospace regime to determine their suitability for that application. Initial results are promising and more extensive testing is planned.

Summary

Commercial viability of the nickel-metal hydride system has been successfully demonstrated. OBC's commerical Ni-MH cell has already shown excellent overall performance and further improvements have been demonstrated in the laboratory. Substantial progress has been made towards adapting this success to serve the aerospace industry. Projected growth in the small, lightweight satellite market has created a demand for higher energy density rechargeable power sources that can be delivered at a reasonable cost. Advances in metal hydride alloys and lightweight nickel electrode technology now make this goal achievable.

References

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Nickel-Metal Hydride Cell Specifications

	Aerospace Ni-Cd	Aerospace Ni-MH	Commercial Ni-MH	OBC Commercial "C" Cell
Rated Capacity (AHR)	2.5	4.0	5.0	3.5
Nominal Voltage (V)	1.25	1.25	1.25	1.25
Cell Mass (grams)	140	140	140	80
Thickness (cm)	1.4	1.4	1.4	--
Height (cm)	5.5	5.5	5.5	--
Width (cm)	5.2	5.2	5.2	--
Capacity (AHR)*	2.7	4.2	5.3	3.6
Specific Energy (WH/Kg)	24	38	47	56
Energy Density (WH/L)	84	130	165	180
Max Operating Pressure (PSI)	100	100	100	100
Burst Safety Factor	4:1	4:1	4:1	--

* (C/2 to 1.00V at 22°C)

TABLE 1

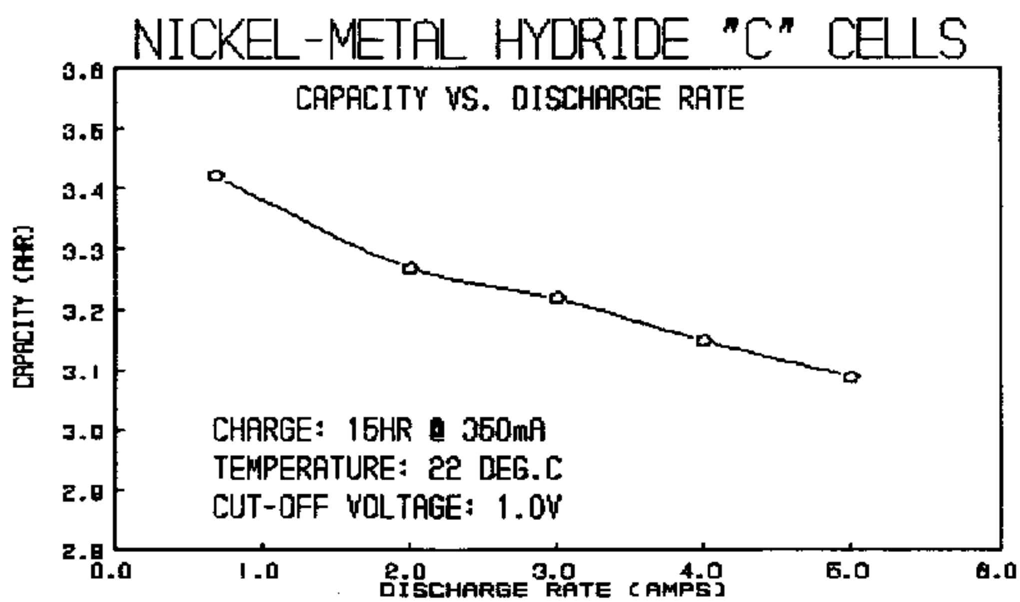

Figure 1

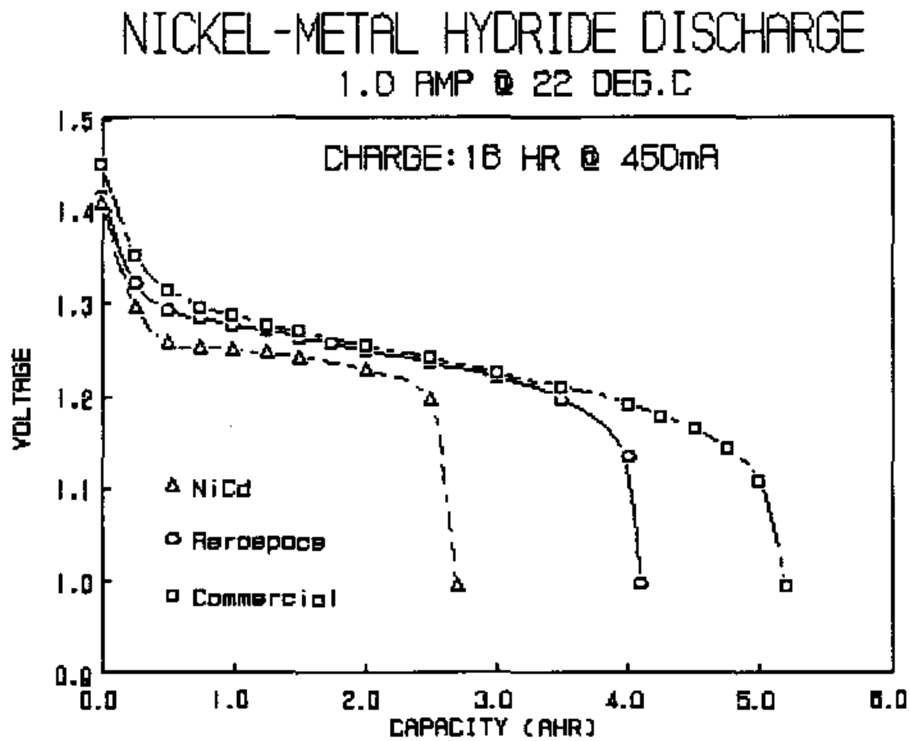

Figure 2

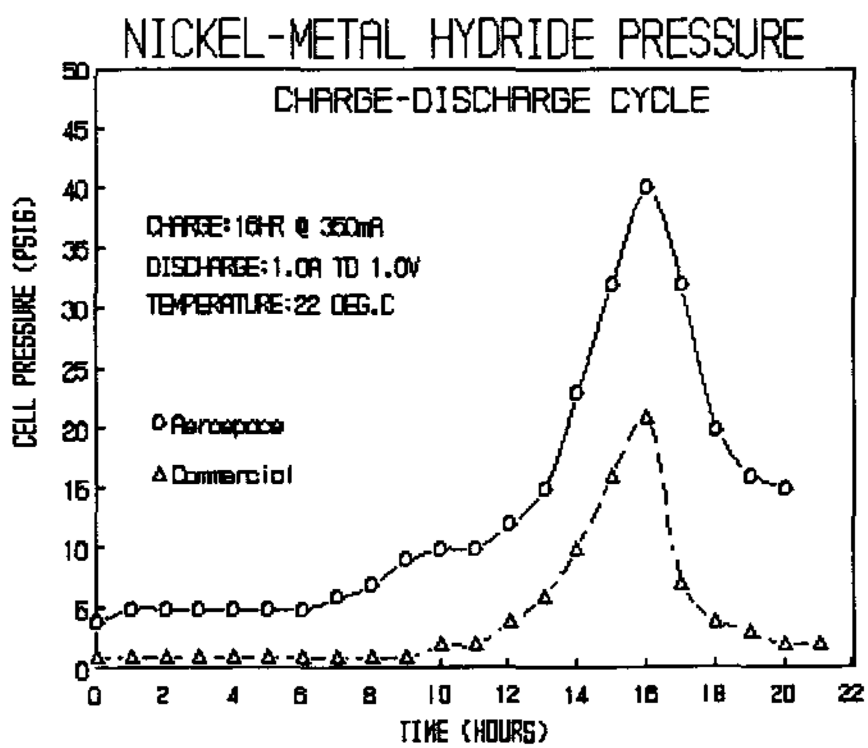

Figure 3

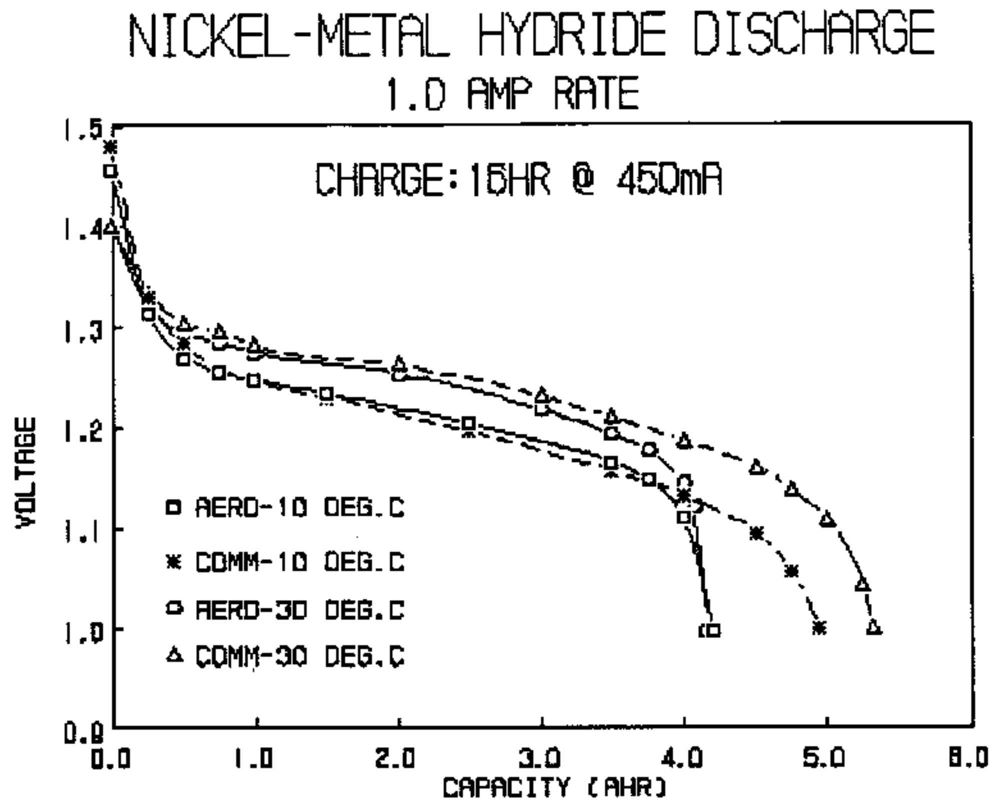

Figure 4

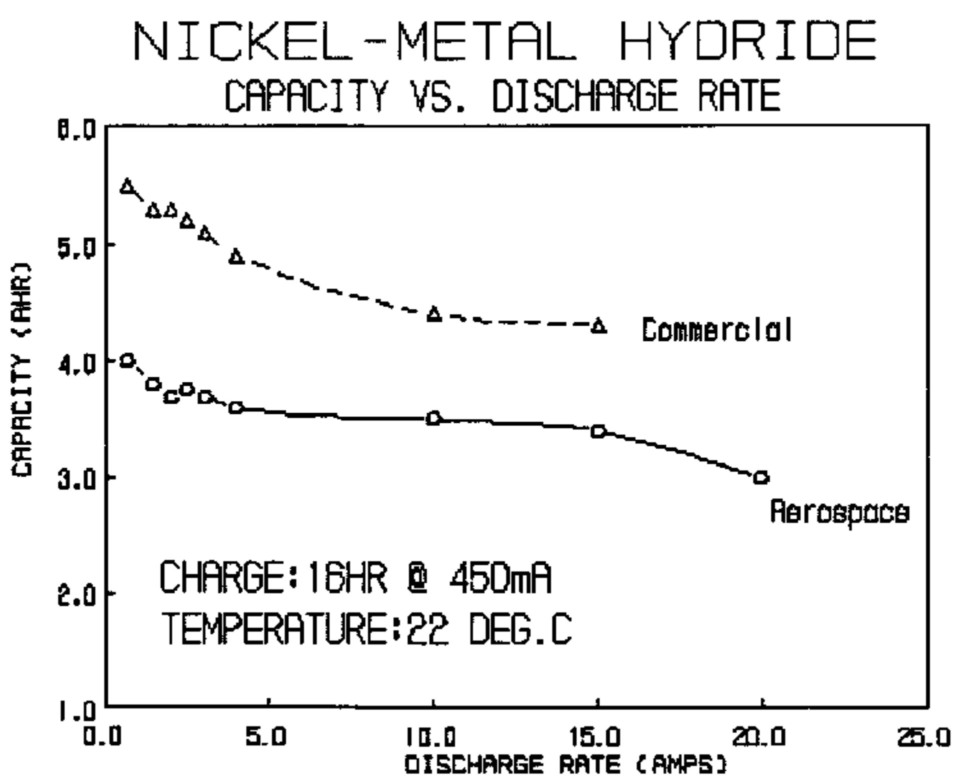

Figure 5