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Design of a 1-kWh Bipolar Nickel Hydrogen Battery

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DESIGN OF A 1-kWh BIPOLAR NICKEL HYDROGEN BATTERY

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ABSTRACT

This paper discusses the design of a nickel-hydrogen battery utilizing bipolar construction in a common pressure vessel. Design features are as follows: 40 ampere-hour capacity, 1 kWh stored energy as a 24 cell battery, 1.8 kW delivered in a LEO Cycle and maximum pulse power of 18.0 kW.

INTRODUCTION

Space power systems of the future are projected to require power levels that extend far beyond those currently in the 1 kW range. High power systems will most likely utilize either higher battery voltages in the 200 V-300 V range or special power processing equipment to convert low battery voltage to high system voltage. This second option will demand batteries with high capacity (greater ampere-hours per cell or cells configured in parallel), and high discharge current capability. The energy storage for such large systems becomes a challenging battery engineering problem.

The two candidate battery systems for space power are nickel-cadmium and nickel-hydrogen. Presently, both these types are available in capacities ranging from 30 to 50 ampere-hours. The energy storage for a low-earth orbit mission requiring 35 kW of power would contain about 500 individual 50 ampere-hour cells, arranged in series and/or parallel. No battery of this magnitude has yet been constructed and tested, and there are serious concerns about the feasibility of such a system for the long lifetimes required in low earth orbit.

In light of this problem, a study was initiated in late spring of 1981 at the NASA Lewis Research Center to design and evaluate a new design concept for nickel-hydrogen cells. This concept involved constructing a battery in a bipolar stack with cells consisting of one plate for each nickel and hydrogen electrode. Preliminary designs at the system level of this concept promised improvements in both volumetric and gravimetric energy densities, thermal management, life extension, costs, and peak power capability over more conventional designs (1, 2).

To get an early confirmation of these encouraging design studies, a concept verification program was initiated. The first phase of the program was the design and assembly of a preprototype bipolar battery. The design incorporated hardware and components available from past programs along with some that were specially constructed. Stack hardware was loaned to the NASA by Life Systems Inc. of Beachwood, Ohio, for testing proposes. The size of the cell hardware (10.16 cm x 21.7 cm active area) allowed the use of a 6.5 ampere-hour capacity nickel electrode. Ten of these cells were assembled into a stack with the following dimensions length - 35.4 cm, height - 15.2 cm, width - 10 cm. The second phase included a series of characterization and cycle tests.

The results of these tests showed conclusively that a bipolar design could be incorporated into the nickel-hydrogen battery system. Highlights of the test results are as follows: discharge rate capability exceeded 25C, 80 percent of nominal capacity removed at the 10C rate, cyclic watt-hour efficiency of 76 to 80 percent of a one hour charge, half hour discharge to 80 percent depth (3). Over 2000 LEO cycles were run, when a stack tear-down analysis was performed. The analysis was made to determine if any early warning component degradation was occurring (4).

Based on these encouraging results a 10 cell version of a 1 kWh stack was designed. Battery design specifications are listed in table 1. The capacity will be approximately 40 ampere-hours. This would result in a 1 kWh unit being a conventional 28 volt, 24 cell module. The 1 kWh module would be of a reasonable size to construct energy storage systems in the 2 to 5 kWh range. This encompasses many near-term space power needs such as larger communication satellites and extended shuttle missions.

The 1 kWH battery design was a team effort. The team members and areas of responsibility are as follows: R. Cataldo, electrical and instrumentation design; O. Gonzalez-Sanabria, electrolyte management; J. Herzau, recombination/oxygen management; M. Hoberecht, thermal management; A. Lieberman, mechanical design; M. Manzo, electrode and separator design; and T. Miller, thermal/instrumentation design.

The following discussion of oxygen, electrolyte, and thermal management, convey the design philosophies incorporated into the bipolar concept as applied to nickel-hydrogen batteries. Use of these concepts offers a high probability of a successful design which theoretically would yield good performance and long life.

DESIGN FEATURES

Oxygen Management

In prior designs, oxygen generated on overcharge has been allowed to combine with hydrogen at the hydrogen electrode. A separate electrode for recombination would prevent damage to the hydrogen electrode from the heat generated. The approach taken in this design was to have recombination occur behind the Ni electrode (1). Figure 1 depicts the methodology used. A high bubble pressure asbestos separator forces the O_2 produced at the nickel electrode into a highly porous electrolyte reservoir plate. They are encapsulated in a vapor permeable tubing to allow passage of gases in, and water vapor out. The tubing also isolates the catalyst electrically, preventing parasitic reaction between the recombination sites and the nickel electrode. This method of oxygen management also benefits the overall electrolyte management scheme by keeping the recombined water from possibly flooding the hydrogen electrode.

Electrolyte Management

Electrolyte management can have a significant effect on the cycle life of a nickel-hydrogen battery and should be a prime consideration of the overall battery design. The objective of electrolyte management is to prevent flooding of the hydrogen electrodes and drying of the nickel electrodes and separators. The approach taken to achieve this objective is through pore size selection of components such that each component has the optimum amount of electrolyte (5).

The electrolyte reservoir plate has a pore size that freely accommodates the water formed during the charge portion of the cycle and returns electrolyte by wicking to the nickel electrode and separator as required. The wicking action is created by choosing a reservoir plate with larger pores than the electrode and separator and maintaining physical contact. Flooding of the hydrogen electrode is also prevented by proper pore size selection as well as use of hydrophobic materials in the electrode.

Thermal Management

Thermal management is of particular concern to a battery designer for numerous reasons. Temperature limits must be maintained to maximize the battery's cycle life.

Operational considerations are also factored into thermal management when charge schemes are selected. Charge acceptance of the nickel electrode is a function of temperature, thus to maintain a set of cells that constitute a battery in balance from an electrochemical standpoint, only small variations from cell to cell are allowable. In particular, in the case of a bipolar design, large single electrodes are encountered where it is necessary to also maintain small temperatures gradients across the electrode face to insure maximum utilization of each electrode. Transport of water vapor caused by temperature gradients between cells or between the cells and the vessel is a consideration with a cell stack located within a common gas space (as in the bipolar $Ni-H_2$ design). The driving force on the water vapor can cause an imbalance in electrolyte concentrations between cells and could cause possible cell dryout if extreme temperature gradients would occur.

Cell Components

The following paragraphs describe the composition, manufacture, and function of each cell component. Figure 2 depicts the relative positioning of the components within a typical repeated single cell.

Nickel Electrode

The electrodes used in this design are electrochemically impregnated dry sinters. The electrodes have a screen grid and an active material loading of 1.60 grams/cc of void volume. The overall dimensions are 8 x 24 x 0.043 in. (20.3 x 61 x .11 cm). Because of the manufacturing limitations, the nickel electrode will be in two sections, each 8 x 12 in. (20.3 x 30.5 cm). The capacity of this electrode will be 48 ampere-hours at the c/4 discharge rate based on tests performed on samples of this electrode.

Hydrogen Electrode

The hydrogen gas electrode is a fuel cell type catalyzed porous screen electrode. This electrode does not have a teflon coating on the back side. The thickness will be a nominal 0.025 cm. The total electrode area will be made of three sections, each 8 x

8 in. (20.3 x 20.3 cm). Other properties of the electrode are proprietary to the manufacturer.

Gas Flow Screen

The gas access screen, located behind the hydrogen electrode, is expanded nickel metal. The dimensions will be 8 x 24 in. (20.3 x 61.0 cm) in one section. The thickness is 0.042 in. (0.107 cm).

Separators

The separator to be used is a beater treated asbestos (BTA). BTA is a reconstituted blend of asbestos sheets with a 5 percent latex binder. The bubble pressure (pressure at which the first air bubble passes through the separator) of the separator is 2.0 atmospheres. The dimensions of the separator are 9 x 25 in. (22.9 x 63.5 cm), which is larger than the nickel electrode in order to provide a barrier against the passage of oxygen from the nickel electrode to the hydrogen electrode. The total separator thickness is comprised of 3 layers of 0.007 in. (0.02 cm) in its uncompressed state. The compressed thickness is 0.015 in. (0.04 cm) nominally. This provides the necessary compressive load to maintain sufficient contact between components to ensure low internal resistance.

Wick Ring

The asbestos wick ring, which surrounds the nickel electrode, has the function of drawing excess electrolyte from the electrolyte reservoir plate (ERP) back to the separator. The wick ring, together with the separator, prevents the oxygen gas from passing to the hydrogen electrode from the edge of the nickel electrode by forming a compressive seal between the cell housing and ERP (a total of 0.071 in. (0.18 cm) is compressed, to 0.058 in. (0.15 cm)). The wick ring is 0.050 in. (0.13 cm) thick, 0.375 in. (0.95 cm) wide and is placed between the outer perimeter of the nickel electrode and inner perimeter of the cell housing. The 0.050 in. thickness is achieved by using 5 layers of 0.010 in. asbestos.

Electrolyte Reservoir Plate

The electrolyte reservoir plate (ERP) is a foamed nickel structure with a density of 5.0 percent. The ERP has a average pore diameter of 0.015 in. (0.038 cm), which allows the passage of oxygen and hydrogen into the recombination sites and the wicking of electrolyte back to active cell areas. The ERP is 0.090 in. (0.23 cm) thick and is made up in six sections each 9 x 4.2 in. (22.9 x 10.67 cm). A series of grooves 0.056 mils (0.142 cm) deep and 0.312 mils (0.792 cm) wide are cut out of the ERP to house the recombination sites. The grooves are cut on the face of the ERP opposite to the nickel electrode so that the electrode material does not expand into the grooves (ref. 5). The function of the ERP is to store extra electrolyte for long cyclic operation and to aid in electrolyte management between the charge and discharge half-cycles. The formation of water vapor occurs in the recombination sites near end of charge and then condenses diluting nearby electrolyte. This more dilute electrolyte is returned to the separator and nickel electrode by wicking actions created by the proper pore size selection of the components.

Recombination Sites

The recombination of oxygen with hydrogen is accomplished via catalyzed sites located within the ERP slots behind the nickel electrode. The catalyzed sites are strips of hydrogen electrode placed in a gas permeable, insulating tube. Each strip is 0.010 in (0.025 cm) thick and 0.187 in. (0.47 cm) wide. The membrane tube has a wall thickness of 0.02 in. (0.05 cm) and an inside diameter of 0.16 in. (0.4 cm). The maximum pore size of the tube is 2.0 μm with a 50 percent porosity.

Bipolar Plates

The bipolar plates are made of nickel 200 and are 0.020 in. (0.05 cm) thick. The bipolar plate separates adjacent cells physically, but provides electrical conduction. The two end bipolar plates are terminal plates with a thickness of 0.109 in. (0.28 cm). These are made thicker because the load current passes through the edge cross section and tab areas where the terminal cables are connected.

Stack Compression RODS

The stack is compressed using 24 3/8 inch stainless steel rods. Each rod is enclosed in shrink insulating tubing to prevent possible shorting to bipolar plates or comtamination with electrolyte.

Cell Housings

Each housing is fabricated out of polysulfone and is 0.200 in. (0.50 cm) thick with an inner dimension of 8 x 24 in. (20.3 x 61 cm) and outer dimension of 11.7 x 28.5 in. (29.7 x 72.4 cm). Hydrogen gas access slots are provided for in the cell housing. Eight channels 0.125 x 0.031 in. (0.32 x 0.08 cm) supply the gas flow screen with enough volume to sustain 1000 amperes discharge current. The ERP side also has identical channels to supply hydrogen for recombination.

Stack End Plates

Two stainless steel plates are used, one on each end of the stack, to supply the necessary compression of cell components. Each plate is a solid, 1.0 in. (2.54 cm) thick slab 12 x 28.7 in. (30.5 x 72.9 cm). The end plate is of sufficient stiffness to allow only a 0.005 in. (0.01 cm) deflection under load.

Insulation Plates

Two insulation plates are used to electrically isolate the two end plates from the active stack. Each plate is made of polysulfone and is 0.250 in. (0.64 cm) thick.

Bipolar Cooling Plates

The cooling plates are made of nickel 200 and are 0.203 in. (0.51 cm) thick. A copper brazing technique under vacuum, is used to fabricate the plates with five 0.050 x 0.250 in. (0.13 x 0.63 cm) coolant flow channels. The cooling plate ports are manifolded through each cell housing, bipolar plate, terminal plate, insulation plate, and end plates using O-ring seals. An electrically nonconductive fluid is used, thereby eliminating the need to electrically insulate each cooling plate. In this design, five cooling plates are used and repeat every two cells. This design scheme will reject sufficient heat to maintain a 1° C temperature differential between inlet and outlet of each cooling plate while removing a total of 250 watts of waste heat. The cooling system is capable of maintaining stack operating temperature down to 0° C.

Pressure Vessel

The battery will be enclosed in a test facility pressure vessel capable of operating between 50 and 600 psi hydrogen. The vessel is of boiler plate construction and not a flight type vessel.

CONCLUSIONS

This design of a 1 kWh, 40 ampere-hour bipolar battery emerged from the encouraging test results of a 10 cell, 6.5 ampere-hour bipolar battery. The need for higher levels of space power for satellites, and in particular a space station is becoming more real. Batteries comprised of single cells, require integrating hundreds of individual units into a battery system. Packaging of an individual cell system results in severe weight and volume penalties, along with additional problems related to thermal management. Certain advantages accrue from the bipolar concept, one being packaging many cells in one pressure vessel and treating it at the system level rather than at the individual cell level. Weight and volume reductions occur when the entire energy storage subsystem is integrated with the total power system. The modularity of the battery can be used as a building block to accommodate any required power levels. Once a design is generated, variations in dimensions (capacity or voltages) can be made to tailor the design for a specific mission without significiantly affecting the technical aspects of the design or performance characteristics.

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TABLE 1. - BATTERY DESIGN SPECIFICATIONS

Watt-hour capacity	1 kW-hr
Ampere-hour capacity	
1.6 c rate	40 A-hr
(LEO orbit)	
Discharge current	64 A
Voltage =	28.8-36 V (24 cells)
Cell area	192 in.^{2}
Active cooling	0° to 30° C
Depth-of-discharge	80 percent
Cyclic watt-hour efficiency	78 percent
Maximum pulse power	18 kW
Cycle life	TBD
Electrolyte	31 KOH
Pulse current	1000 A

= only 10 cell stack will be fabricated and tested.

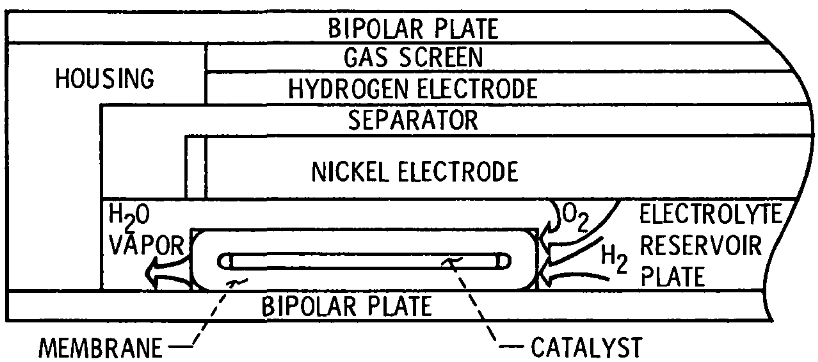

Figure 1. - Graphic representation of oxygen-hydrogen recombination.

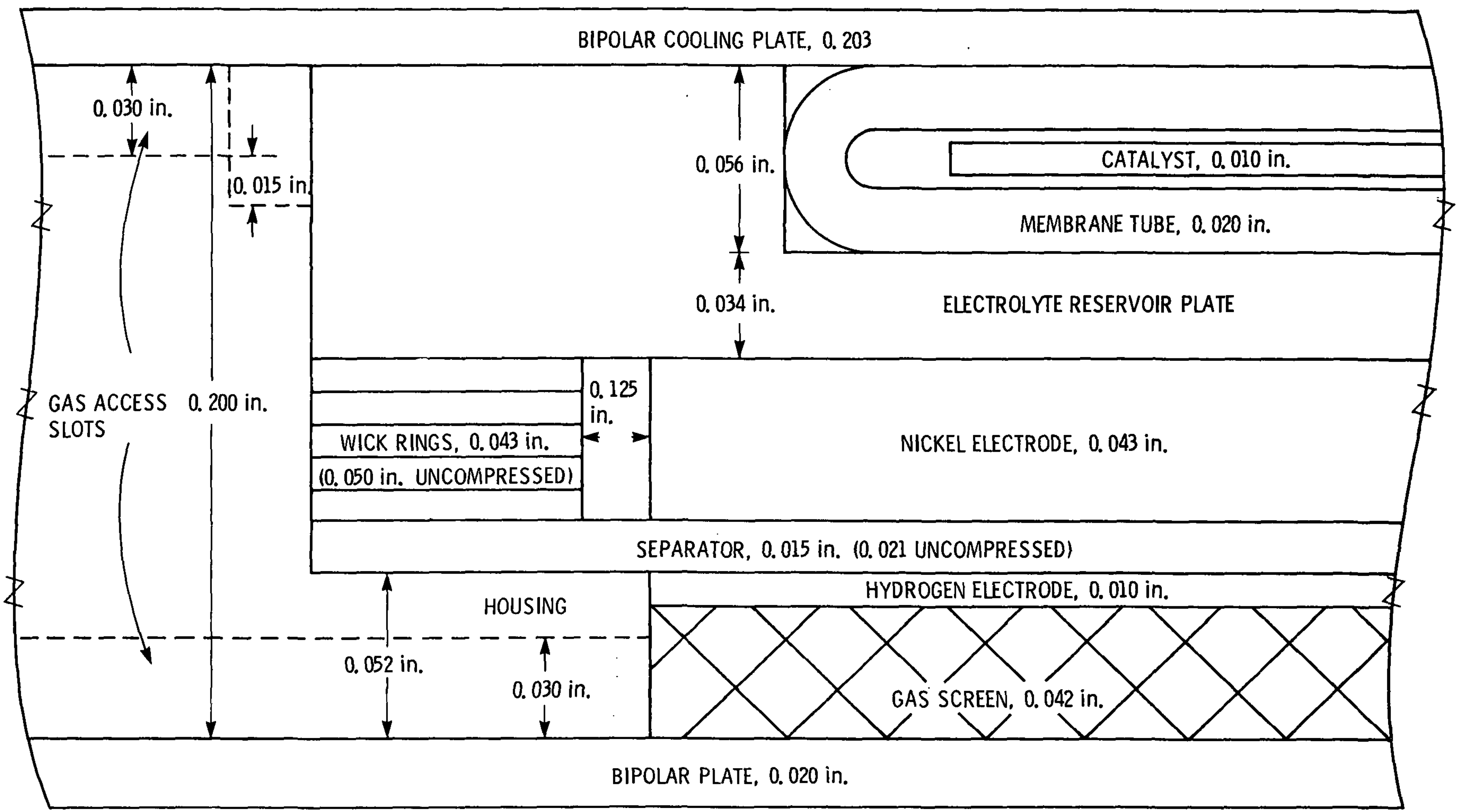

Figure 2. - Unit cell cross section.

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16. Abstract

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