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Multiple cell common pressure vessel nickel–hydrogen battery

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Abstract

Johnson Controls Battery Group, Inc. has developed a multiple cell common pressure vessel (CPV) nickel–hydrogen battery that offers significant weight, volume, cost and interfacing advantages over the conventional individual pressure vessel (IPV) nickel–hydrogen configuration that is currently used for aerospace applications. The baseline CPV design was successfully demonstrated through the testing of a 26-cell prototype, which completed over 7000 44% depth-of-discharge LEO cycles at COMSAT Laboratories. Two-cell boilerplate batteries have now exceeded 12 500 LEO cycles in ongoing laboratory tests. CPV batteries using both nominal 12.7 and 25.4 cm diameter vessels are currently available. The flexibility of the design allows these diameters to provide a broad capability for a variety of space applications.

Key features of the Johnson Controls CPV design

Nickel–hydrogen batteries are well established as an energy storage subsystem for commercial communication satellites. The standard design has been the individual pressure vessel (IPV) which provides an independent vessel for each cell of the battery. The comparative advantages of a common pressure vessel (CPV) design configuration, in which many series connected cells are contained in a single vessel, are widely recognized. These include higher specific energy, higher system energy density, simplified interfacing and reduced cost as compared to the IPV [1]. However, historical concerns related to electrolyte and thermal management had previously prevented the introduction of a reliable CPV design.

Johnson Controls has successfully developed a patented [2] CPV battery design which overcomes the historical concerns. A radial heat fin provides a pathway for heat transfer from the center of each cell to the pressure vessel wall. Since the metal fins make direct contact with the vessel, they actually provide an improved thermal interface as compared to the IPV design where heat must be transferred either through the polymeric wall wick or through a hydrogen gap in order to pass from the cell to the vessel wall.

The heat transfer interface at the exterior of the vessel is simplified since only one vessel is used for a multicell battery. Since IPV design specific energies are often reported without including their thermal baseplate, there

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is an additional specific energy advantage for the CPV which might not be readily apparent from a direct comparison of reported specific energies.

The CPV's vessel is electrically neutral so no insulating layer is required on the outside of the vessel. This allows a direct metal to metal contact between the outer vessel wall and the mounting bracket, further enhancing heat transfer. In an IPV, the vessel wall is electrically live and must be insulated from the mounting bracket. Prior to launch condensation can occur on the outside of the IPV vessels creating a possible shorting path between the IPV cells.

Although thin-walled the polymeric cell container called an electrolyte containment system (ECS) addresses the issue of electrolyte management in the CPV configuration. The thermally sealed ECS isolates the electrolyte within each cell. An intercell connect between each of the series connected cells employs a specially designed compression seal to prevent electrolyte bridging between cells. Examination of the seals removed from the 26-cell prototype no. 1 battery after 7400 cycles showed no evidence of any leakage.

A hydrogen vent sealed onto the ECS face of each cell allows hydrogen to pass into the vessel plenum from the cells during charge and vice versa during discharge. The vent is designed to prevent wetting with electrolyte and to ensure recombination within a given cell of any oxygen that is generated within that cell during overcharge. This prevents the development of electrolyte imbalances between cells during extended cycling.

Initial prototype design

As an initial demonstration of the capabilities of the CPV design, a 26-cell 22 A h prototype was fabricated in a joint effort with COMSAT Laboratories in 1988 [3]. The CPV prototype is shown in relation to its IPV counterpart in Fig. 1. This battery was composed of two 13-cell half-stacks

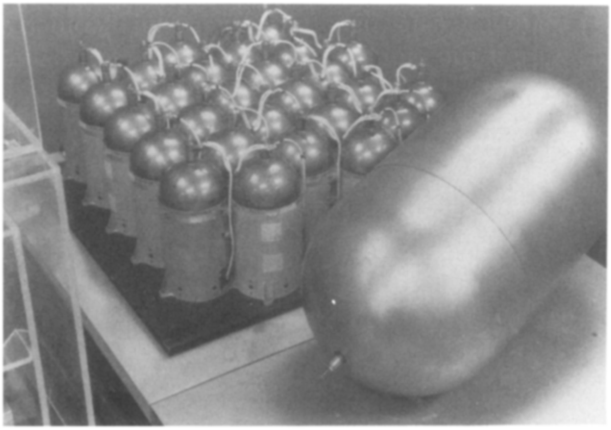

Fig. 1. 26-Cell CPV prototype battery and IPV counterpart.

which are connected in series within the single common vessel to provide a nominal 32 V. The 25.4 cm diameter cells have a semicircular geometry and employ a double tab design to enhance current distribution, as shown in Fig. 2.

The half-stacks were inserted into two fixed heat fin cavities (Fig. 3) which each contain 13 slots, one for each of the 26 cells. The cells are slipped into the fixed cavity prior to the addition of electrolyte. Upon addition of electrolyte, the asbestos separators in the cells swell providing the desired cell compression and an intimate thermal contact between the cell face and the heat fin. Heat generated in the cell passes axially through the cell face to the heat fin, then radially through the heat fin to the vessel wall. It is the direct thermal contact between the heat fin and the vessel wall that provides a thermal advantage over the IPV design which provides no direct

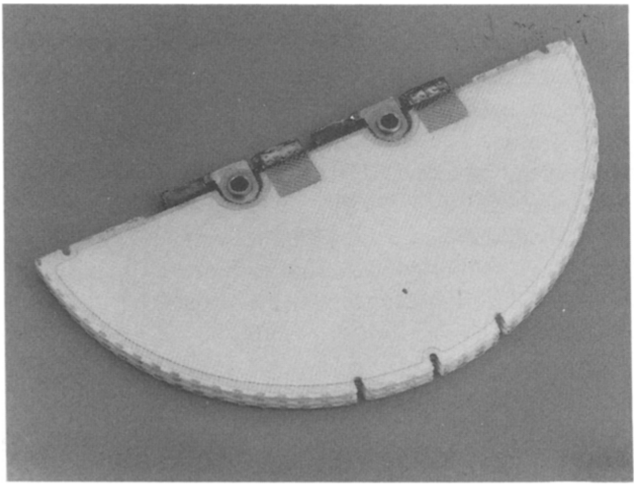

Fig. 2. 25.4 cm Diameter semicircular cell.

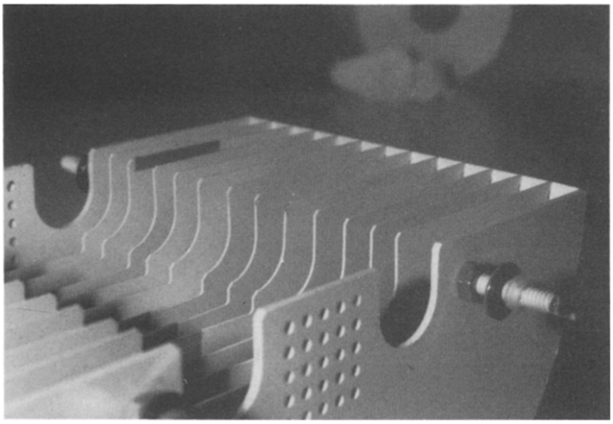

Fig. 3. 13-Cell half-stack fixed heat fin cavity.

radial pathway for heat conduction to the vessel. It is believed that this thermal advantage will translate to extended life in LEO applications. In GEO applications, where long life is not required, additional improvements in specific energy can be achieved due to the improved thermal pathway.

The two half-stacks for the prototype battery were inserted into a hydroformed Inconel 718 vessel cylinder/dome section. Springs pushed the half-stacks outward against the vessel wall, maintaining the intimate contact between the heat fin cavity and the vessel wall. After insertion of the half-stacks a second dome was welded in place using the same general weld ring design approach that is applied in the IPV vessels.

Initial prototype testing

The prototype battery was put on a real time a LEO life test at COMSAT Laboratories. Over 7000 44% depth-of-discharge (DOD) cycles were completed at 10 °C. Voltage performance was relatively stable over the first 6400 cycles, prior to the rapid voltage degradation which ultimately caused the battery to reach the 1.0 V/cell battery failure criteria (Fig. 4).

Subsequent destructive physical analyses (DPA) showed that some of the cell ECSs had been damaged at the time of insertion into the fixed heat fin cavity, leading to electrolyte leakage from the cells. The resulting drying out of the positives and separators is believed to have caused the voltage decline and failure of the battery. All cell components, including the negative electrodes were in excellent physical condition. No pinholes or other signs of popping were observed on the negative electrodes. No signs of blistering or other physical degradation were observed on the positives. In retrospect,

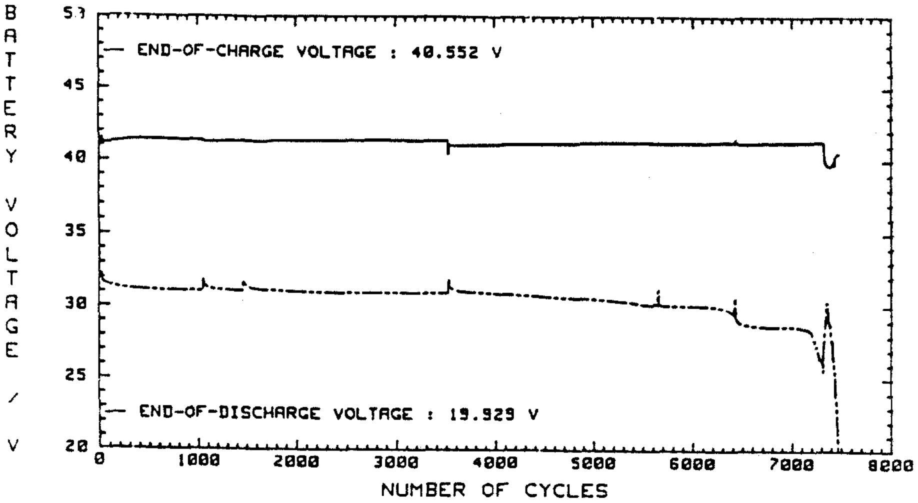

Fig. 4. CPV prototype no. 1 life cycle test.

the ability to complete over 7000 LEO cycles with a battery which was leaking electrolyte from the onset of testing provides testimony to the resilience of the CPV design.

Two 2-cell laboratory test batteries of the same baseline design [4] continue on a 44% DOD LEO life test, one each at Johnson Controls and COMSAT. They have now exceeded 9000 and 12 500 cycles, respectively, with no significant performance degradation.

Features of improved loose heat fin CPV design

A new loose heat fin design was developed to overcome the problems encountered with insertion of the cells into the fixed heat fin cavity. The cell design was also modified by providing a double ECS with a staggered vent pathway to further enhance the electrolyte management reliability. These approaches were introduced using a 12.7 cm diameter vessel, circular cell component design. The circular cell with its loose heat fin is shown in Fig. 5. The cells and heat fins are assembled into a stack using a special alignment fixture. The 10-cell stack, shown in Fig. 6, has a 9.6 A h capacity, is 24.6 cm long and weighs 3 kg. A 22-cell version offers a 13.4 A h capacity, is 52.3 long and weighs 7.9 kg. In general, the higher the capacity and/or voltage, the better the specific energy.

The 12.7 cm cell stack is also inserted into a cylinder, but in this case two separate end domes and weld rings are welded in place. This approach allows an unlimited vessel length for design flexibility. Although the cell stack for the 22-cell battery is only 24.6 cm long, the vessel length is 52.3 cm to provide the required void volume to maintain a 700 psi maximum operating pressure. Significant improvements in energy density can be achieved by using a thicker, up to 0.152 cm, Inconel 718 shell to allow higher operating pressures.

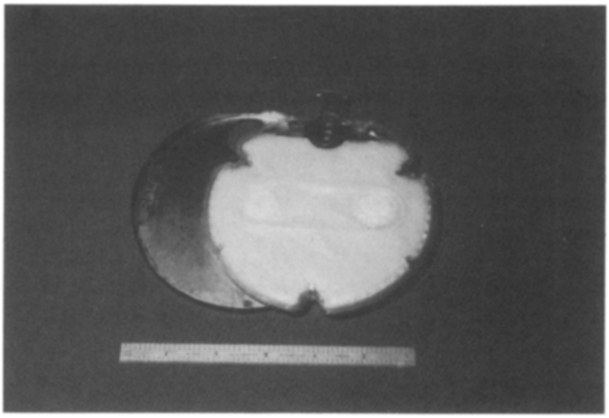

Fig. 5. 12.7 cm Diameter circular cell and loose heat fin.

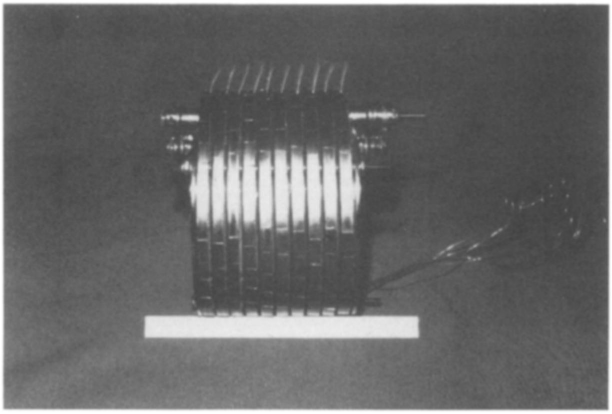

Fig. 6. 12.7 cm Diameter 10-cell stack.

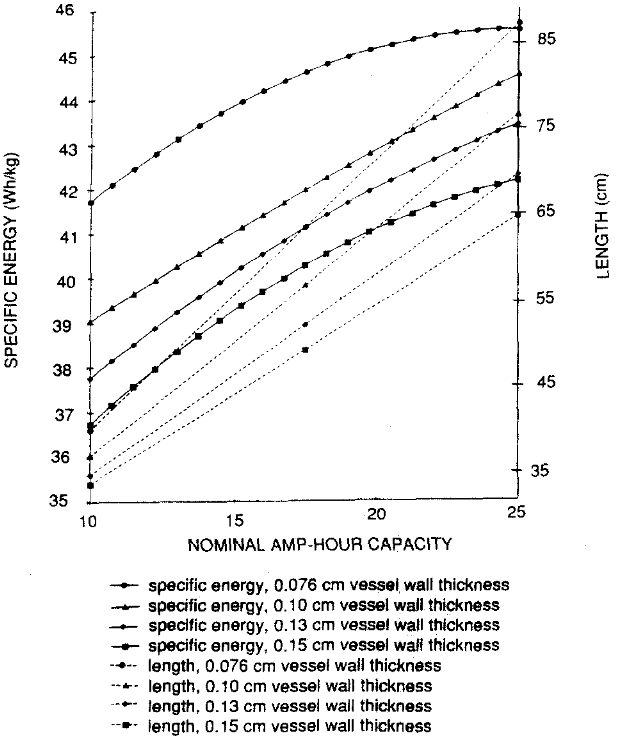

Fig. 7. Design curves for a 22-cell LEO CPV nickel–hydrogen battery in a 12.7 cm diameter vessel.

General design characterization

A computer model is used to help optimize battery design parameters in the initial design stages for a new battery. The model defines optimum

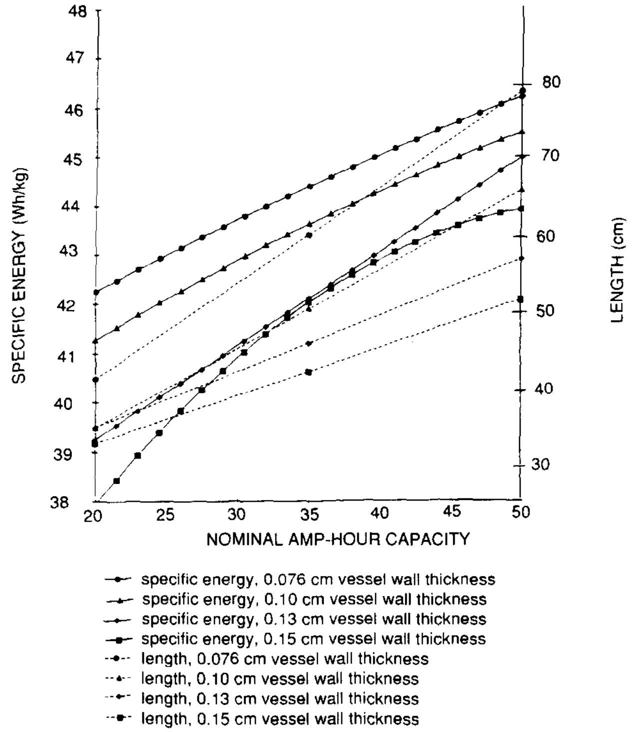

Fig. 8. Design curves for a 22-cell LEO CPV nickel–hydrogen battery in a 25.4 cm diameter vessel.

design parameters including vessel diameter, positive electrode thickness, number of modules per cell, battery length and weight, given input on the desired battery voltage and capacity. Several design curves for common aerospace design ranges have been developed using this model. Examples are provided in Figs. 7–9 for a 22-cell LEO battery in a 12.7 cm diameter vessel, a 22-cell LEO battery in a 25.4 cm diameter vessel and a 26-cell GEO battery in a 25.4 cm diameter vessel. These curves can be used to obtain an initial estimate of the available specific energy and length for a variety of designs. Such estimates serve as a convenient starting point for more detailed design analyses.

Other applications

The core CPV design concept has been expanded to provide a family of CPV batteries (Fig. 10) for a variety of uses including aerospace, aircraft starting and terrestrial applications. The combined volume offered by this array of markets provides the potential to eliminate product consistency problems related to intermittent production schedules, minimize the use of

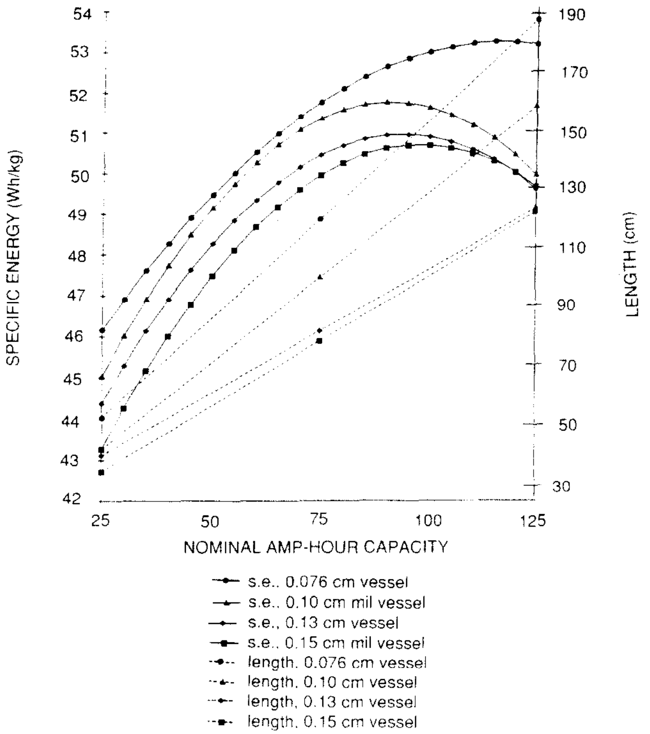

Fig. 9. Design curves for a 26-cell GEO CPV nickel–hydrogen battery in a 25.4 cm diameter vessel.

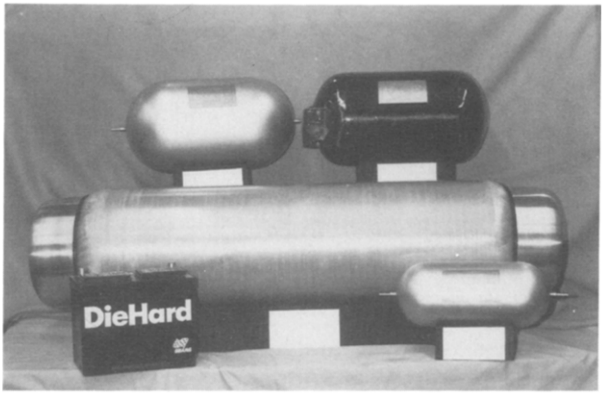

Fig. 10. Family of CPV batteries for multiple applications. Clockwise from upper left: 26-cell, 22 A h GEO battery; 20-cell, 50 A h aircraft starting battery; 10-cell, 160 A h terrestrial battery; 22-cell, 13 A h LEO battery; conventional lead/acid starting battery.

batch processing techniques, and allow the introduction of statistical process control (SPC) into the component fabrication processes. These factors will results in a higher level of quality, improved product consistency, and ultimately lower cost than is presently achieved in the IPV nickel–hydrogen battery industry.

The reduced cost provided by the CPV configuration coupled with other cost reducing design refinements developed under contract to Sandia National Laboratories [5] have made the system viable for a number of terrestrial applications. Among these is a 2 kW h battery designed for photovoltaic applications. This battery employs a composite fiber-wound vessel design. Four 2-kW h prototypes are presently undergoing photovoltaic tests, two each at facilities in New Mexico and Florida [4].

Aircraft starting battery designs also use the fiber-wound vessel approach, but employ a carbon filament to enhance heat transfer and minimize weight. Initial tests suggest that the CPV battery will provide performance equal to or better than nickel–cadmium in this application. The CPV battery will also provide a reliable measurement of state-of-charge and significantly reduced maintenance. In addition to life-cycle cost savings, the limited maintenance requirements would free aircraft designers to locate the batteries in a remote area since accessibility will no longer be a primary concern. A 20-cell aircraft starting battery prototype is presently being fabricated for test by the U.S. Air Force.

Conclusions

In summary, a family of CPV battery designs has been developed for a wide variety of applications. Aerospace designs are presently available in 12.7 and 25.4 cm diameter vessels. Although the database is still limited, tests to date indicate that the significant advantages of the CPV design can be realized in a reliable package.

Johnson Control's present aerospace CPV designs cover a wide range of voltages, 12–100 V, and capacities, 10–125 A h. Vessel diameters have been limited to 12.7 and 25.4 cm diameter versions to date, although a 8.9 cm diameter design is being advanced to optimize the configuration for battery capacities below 10 A h.

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