COMMON - PRESSURE-VESSEL NICKEL-HYDROGEN BATTERY DEVELOPMENT

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Abstract

The dual-cell, common-pressure-vessel, nickel-hydrogen configuration has recently emerged as an option for small satellite nickel-hydrogen battery application. An important incentive is that the dual-cell, CPV configured battery presents a 30 percent reduction in volume and nearly 50 percent reduction in mounting footprint, when compared with an equivalent battery of individual-pressure-vessel (IPV) cells. In addition energy density and cost benefits are significant. Eagle-Picher Industries and Rockwell International have collaborated on the development and test evaluation of a 40 Ampere-hour, nickel-hydrogen, dual-cell, CPV battery module. The module was committed to a cycle life test in Rockwell's advanced battery test facility. Performance and cycle life data for this first proof-of-concept module, collected over more than 6 years and 15,000 cycles of testing is presented.

Introduction

A two-cell, series-connected, common-pressure-vessel (CPV) battery has been successfully designed, produced, and tested in a joint effort by Rockwell and Eagle-Picher. The prototype unit is of 40 Ampere-hour size. In comparison with two 40 Ampere-hour individual pressure vessel (IPV) cells to which it is equivalent in power, it offers a 19-percent improvement in energy density. Perhaps more significantly, the CPV module offers a 30-percent reduction in volume and a nearly 50-percent reduction in the battery mounting footprint on the thermal radiator of a communications satellite. This smaller footprint may be of particular advantage for those applications requiring smaller capacity batteries (5 to 25 Ampere-hour) with a limited thermal radiator area.

A physical description of the prototype module is provided in Table 1. Note that the energy density is particularly good at 61.8 Watt-hours per kilogram.

Development History

A common-pressure-vessel configuration in nickel-hydrogen batteries consists of two or more series-connected cells in a single-pressure vessel, where the available hydrogen gas is common to all the cells. The electrolyte of each cell must, however, remain isolated from the other cells to prevent shorting or open-circuit dry out due to vapor transfer and/or electrolyte redistribution.

Early appreciation for the problems and advantages of the CPV configuration was acquired by building and testing a four-cell CPV boilerplate unit in 1978. Rockwell reported the apparent feasibility of the technology and problems needing resolution to the Goddard Space Flight Center battery workshop that year.

Feasibility of the CPV concept was further confirmed by EIC Laboratories between July 1979 and February 1982 under a contract with Air Force Wright Aeronautical Laboratory (AFWAL). Work on a CPV development program by Hughes under an AFWAL contract was redirected in Late 1982 to larger IPV cell development because "larger IPV cells represented a nearer-term technology with fewer development risks and costs involved."

In FY 1983 Rockwell concluded that a series-connected, two-cell CPV could be constructed in a tandem arrangement on either side of a nearly solid weld ring (with one bus-bar aperture) to form a module with all of the multicell advantages and virtually none of the problems.

A summary of Rockwell's efforts in the development of the CPV concept is given in Table 2.

Prototype Development

By using proven production technology from IPV programs, Eagle-Picher constructed a 40 Ampere-hour, proof-of-concept dual-cell module and delivered it to Rockwell in June 1984 as part of a joint proprietary development effort. This battery module was then committed to a modified low-earth-orbit (LEO) life cycle test, at approximately 45% depth-of-discharge. The battery module is still performing well as of August 1, 1991 with over 15,280 cycles completed. There has been no evidence of electrolyte problems nor any significant voltage degradation noted.

Prototype Test Details

The performance of the prototype module during its initial acceptance tests is tabulated in Table 3. These tests included a capacity retention cycle during which the capacity was measured after the module was left fully charged on open circuit for 72 hours. The results of this test were equivalent to those for flight-quality IPV's.

The module has continued to perform well during life-cycle testing. Capacity retention results have ranged from 80 to 88 percent, (Table 4). The capacity has been measured occasionally during the life test and has increased and then decreased somewhat. However, the latest capacity to 2.0 volt cut-off is still excellent at 48.7 Ampere-hours, somewhat greater than the initial acceptance test value.

The capacity trend data are displayed in Table 5.

The life-cycle testing is, at this writing, in excess of 15,280 cycles. A typical capacity verification cycle (i.e., temperature, voltage, etc.) is shown in Figures 1 and 2 (charge and discharge, respectively). These data are for cycle No. 15,200.

Conclusions

The difficulties in developing the nickel-hydrogen, dual cell, common-pressure-vessel concept are less severe than had at first been feared. Excellent results have been obtained with no apparent problems in internal shorting or electrolyte imbalance.

The concept provides definite, measurable benefits in energy density. When used in a larger battery, the two-cell CPV will result in lower voltage drop because the internal connection between the two cells of each module are shorter than if the pressure vessels were separate, and because only half the number of external connections are required. But more importantly, only half the number of thermal mounting sleeves are required.

The dual-cell CPV concept embodied here entails minimum risk because almost all the technology is flight proven. The same concepts that appear to offer improvement to the standard IPV design can be equally applied to the CPV module. These include fiber-mat nickel plates, reduced platinum catalyst electrodes, and alternative separator designs. One area that does need more study is the effect of variations in the thermal environment in the CPV vis-a-vis the IPV design.

As a follow-on to the proof-of concept module, Eagle-Picher delivered four flight-quality modules to Rockwell. These embody zirconium-oxide separators and high-porosity nickel electrodes. The specification sheet for this design is provided in Table 6. The initial test results appear to confirm those from the prototype.

TABLE 1. 40 Ahr PROTOTYPE CPV MODULE PHYSICAL DESCRIPTION

DESIGN	TWO 40 Ahr STACKS IN SERIES
PLATE SEQUENCE	BACK TO BACK
SEPARATOR	ASBESTOS
PV LENGTH	9.00 IN
WEIGHT	1,849.6 g
ENERGY DENSITY	61.8 W-hr/kg (28.0 W-hr/lb)
OPERATING PRESSURE	950 psig

TABLE 2. ROCKWELL CPF NICKEL-HYDROGEN TECHNOLOGY EFFORT

1975	Nickel-hydrogen technology search	Report SD75-SA-0171
1976-77	Two IPV cells and a dual cell CPV module evaluated	Reported in IR&D
1978	Four-cell CPV boilerplate tested to synchronous eclipse season parameters	Paper presented at GSFC battery workshop
1979-1980	Two AFWAL-furnished 50 Ahr cells characterized	Paper presented at IECEC 1980
1981-1982	AFWAL cells evaluated; CPV battery sized for SC-90 study	Reported in IR&D brochure-results in 1982. Project 394
1983	Advantages of dual cell, CPV, configuration for GPS noted in battery options study	Reported in IR&D brochure-results in Project 285
1984-1991	Accelerated cycle life evaluation test continuing on a dual cell, CPV module	Reported in IR&D brochure-results in 1984. 1991 more than 15,000 charge/discharge cycles completed

TABLE 3. 40 Ahr PROTOTYPE CPV MODULE ACCEPTANCE DATA SUMMARY

	Capacity			Overcharge	Charge Retention*
CHARGE TIME (HR)	20°C	10°C	0°C	10°C	10°C
CHARGE RATE (AMPS)	16	16	16	72	16
EOC VOLTS	4.0	4.0	4.0	2.0	4.0
EOC PRESSURE (PSIG)	2,982	3,027	3,118	3,013	3,032
DISCHARGE RATE (AMPS)	1,020	1,050	1,110	1,160	1,090
CAPACITY TO 2.0 VOLTS (Ahr)	20.0	17.92	17.92	17.92	17.92
	41.7	45.4	47.2	53.8	36.6

*CELL ALLOWED TO STAND OPEN CIRCUIT FOR 72 HOURS BEFORE DISCHARGING

TABLE 4. CAPACITY RETENTION RESULTS FOR 40 Ahr PROTOTYPE CPV MODULE

DATE MONTH/YEAR	CYCLE NO.	INITIAL CAPACITY	AFTER 72-HR STAND RETAINED	CAPACITY RETAINED (%)	TEMPERATURE (°C)
6-84	EPI ACCEPTANCE TEST	45.4	36.6	80.4	10.0
8-87	8,201	54.7	46.3	84.7	10.0
10-87	8,303	54.5	48.2	88.4	5.0
4-89	9,592	46.1	39.7	86.1	12.5
6-89	10,003	47.3	40.4	85.4	10.0
12-89	11,546	45.6	39.2	86.0	8.6
7-91	13,425	41.7	35.5	85.1	9.7

TABLE 5. CAPACITY TREND DATA FOR 40 Ahr PROTOTYPE CPV MODULE

DATE MONTH/YEAR	CYCLE NO.	DISCHARGE CAPACITY (Ahr)	TEMPERATURE (°C)
8-84	EPI ACCEPTANCE TEST	45.4	10.0
8-85	4	44.8	11.4
11-85	1,215	44.5	11.3
3-86	2,414	47.5	9.6
6-86	3,244	48.4	10.6
9-86	4.038	50.5	11.4
11-86	4,811	50.7	10.4
12-86	5,004	51.6	14.6
4-87	6,016	48.7	9.3
8-87	6,208	55.6	7.6
4-88	6,459	48.3	20.3
4-89	9,591	46.1	12.5
6-89	10,003	47.3	10.0
7-90	13,428	46.2	11.9
6-91	15,266	48.7	7.9

TABLE 6. 40 Ahr FLIGHT QUALITY CPV MODULE SPECIFICATION SHEET

PART NO.	EAGLE-PICHER IND. RNH-40.3
CONFIGURATION	TWO TANDEM, SERIES-CONNECTED CELLS IN A COMMON 3.5 IN. DIAMETER INCONEL PRESSURE VESSEL WITH HEMISPHERICAL ENDS; PLATE STACKING IS BACK-TO-BACK
SEPARATOR	ZIRCONIUM-OXIDE CLOTH, DOUBLE LAYER
POSITIVE PLATES	82% POROUS SLURRY NICKEL
DESIGN PRESSURE	900 PSIG (MAXIMUM: 1,000 PSIG)
ELECTROLYTE ISOLATION	CLOSED-WEB WELD RING, TEFLON-COATED INTERNALS
CAPACITY	40 Ahr AT 10°C TO 2.0 VOLTS AT THE C/2 (20 AMP) RATE
NOMINAL MIDVOLTAGE	2.5 VOLTS
PRESSURE SENSOR	STRAIN GAGE
WALL GAP	0.80 in.
NEGATIVE PLATES	PLATINUM/TEFLON CATALYST OVER PATENTED NICKEL GRID GEOMETRY
ELECTROLYTE	26% KOH IN $H_2 0$
SIZE	• MAXIMUM LENGTH: 13.0 in. • DIAMETER: 3.520 in. • MASS: 1,980 g

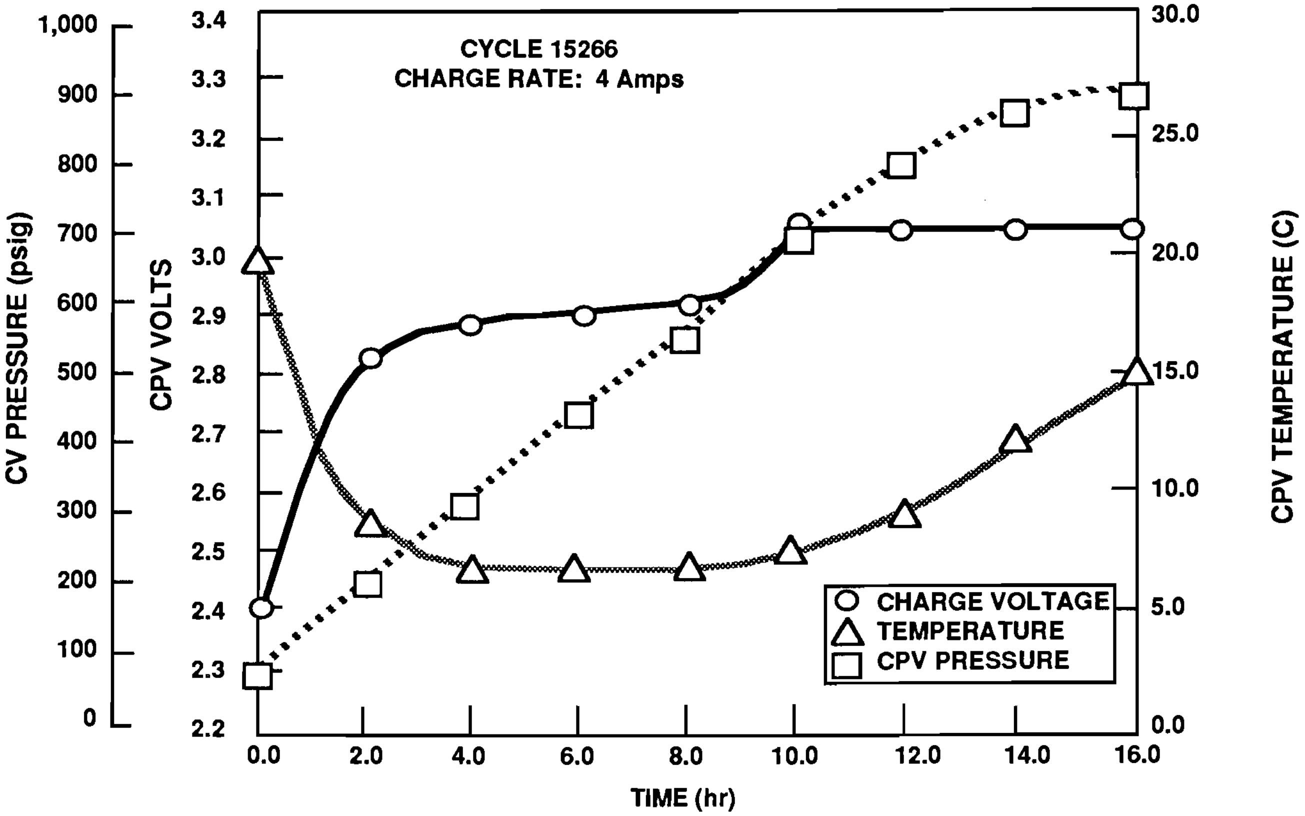

FIGURE 1. Ni H2 CPV CHARGE

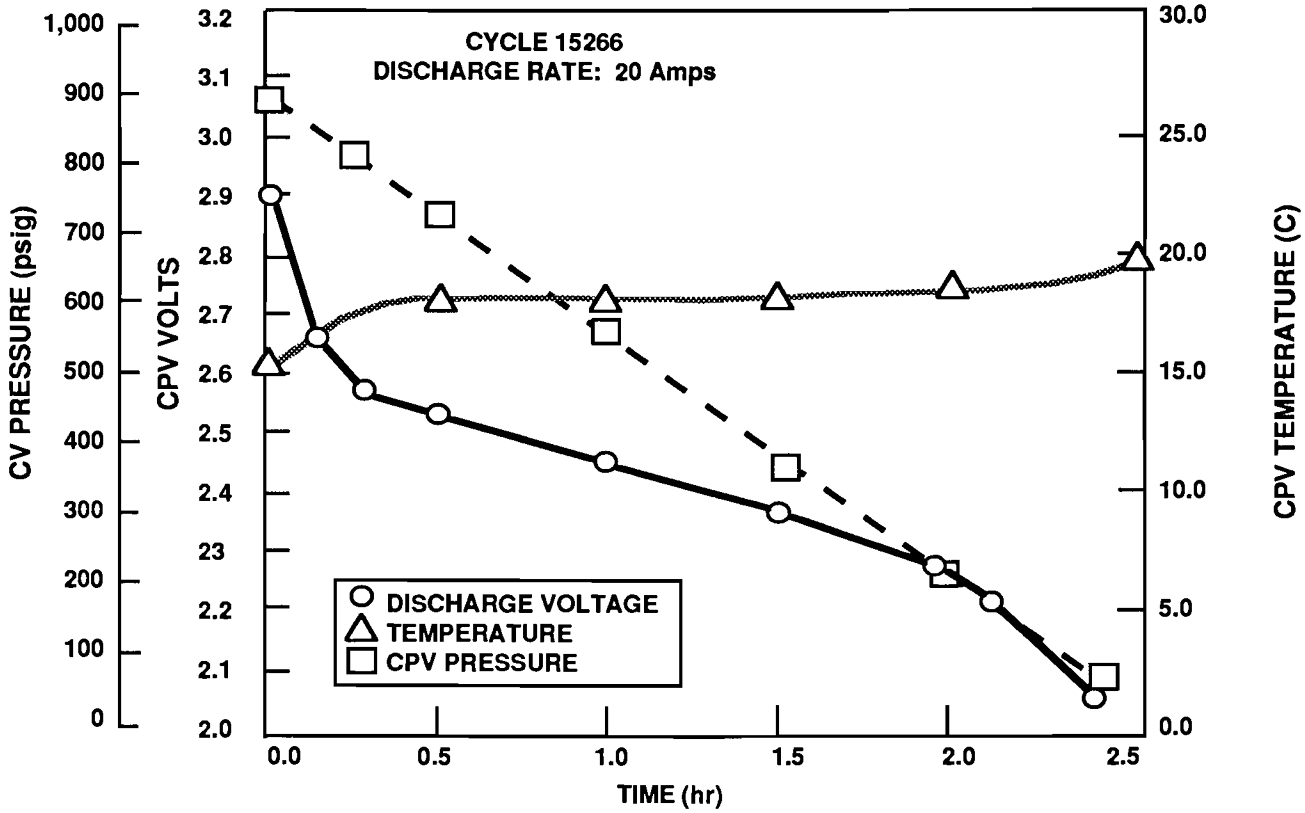

FIGURE 2. Ni H2 CPV DISCHARGE