

Design of a 10.8 kWh, 28V Ni-MH Battery Using Commercial Ni-MH Cells

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Abstract

This paper describes the design of a 10.8 kWh, 28V, Ni-MH battery using commercial off-the-shelf (COTS) 4/3A Ni-MH cells for the X-38 vehicle, an experimental version of the Crew Return Vehicle (CRV). This will be an autonomous vehicle that will enable International Space Station crews to return to earth in the event of a medical, or other, emergency. The X-38 will be powered by 3 batteries: a 32 V primary battery, which will power the vehicle avionics for up to 7 hours for a loiter and de-orbit phase of the descent; a 28 V Ni-MH battery which will take over for the primary battery after de-orbit until landing, and a 270V Ni-Cd battery, which will be used to power electromechanical actuators and the winches controlling a parachute for landing.

Introduction

The 28V, Ni-MH battery is an assembly consisting of eight modules connected in parallel and enclosed in one battery crate. Each module contains a Battery Charge and Gauge Panel (BC&GP) and sixteen strings of Ni-MH cells connected in parallel.

The BC&GP allows the battery to be charged prior to launch and while docked to the space station. It also provides state of charge information. Each string of Ni-MH cells contains 24 commercial 4/3A Ni-MH cells connected in series, one by-pass diode per cell, two thermistors and four electrical/thermal switches.

The battery crate contains the modules and is attached to the X-38 structure at five locations. The crate dimensions are 34.31" by 25.37" by 12.13". Excluding external electrical connectors, the battery weight is less than 335 kg.

During the design phase, commercial cells were purchased and tested; battery thermal and stress analyses were performed and prototype hardware was fabricated. Cell acceptance and lot certification processes were established to screen a lot at 100% of a

lot of over 4900 cells and verify that the lot will meet all performance and safety requirements.

Using commercial off-the-shelf (COTS) cells to fabricate a battery is in keeping with NASA's goal to build hardware faster, cheaper and better by eliminating the effort associated with designing and qualifying a unique cell. Recognizing the possible cost and time savings, one of the authors (Eric Darcy) had COTS cells from several manufacturers tested to determine if they could meet the scaled requirements summarized in Table 1. The results of these tests, which have been reported elsewhere,⁽¹⁾ indicated that at least two manufacturers were producing cells that could be used to build a battery that will meet the requirements.

Table 1: Requirements

Description	Requirement
Power, average	3.6 kW, average over 3 hrs
Power, peak	10.8 kW for <0.1 s over 3 hrs
Energy	10.8 kWh, minimum
Open Circuit Voltage	28 to 34 V
Closed Circuit Voltage	>24V during entire discharge
Capacity, minimum	387 Ah
Charge, duration	8 h
Charge, maximum cell temperature	50°C
Charge, maximum crate temperature	45°C
Mass, Battery	≤ 335 kg
Temperature, non-operating	-7 to + 49°C
Temperature, operating	10 to 30 °C
Life	2 years and 2 weeks

In 1999, Yardney Technical Products was awarded a contract to design and build a 10 kWh, 28V Ni-MH battery using cells from one of the manufacturers. As part of the contract, Yardney also procured and tested a lot of cells, which would be used for the qualification/flight battery. A sketch of the final design is shown in Figure 1.

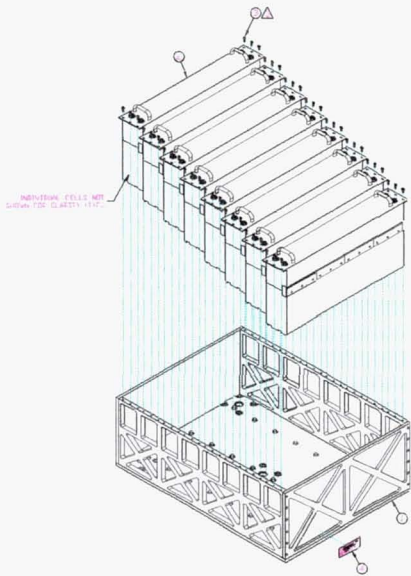


Figure 1: Top Assembly of 28V, 10.8 kWh Battery

One of the key design issues was to assure that the cells did not exceed 50°C during charge. Rather than assembling the strings in a densely packed bundle, a tray concept was developed which allowed air from a plenum attached to the side of the battery crate to flow through the modules. The cell string design is depicted in Figure 2.

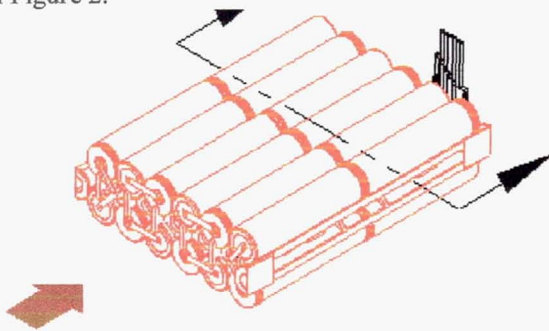


Figure 2: String Assembly

In order to assure that any string in a module could be isolated from all of the other strings and the load in the event of a localized high temperature and/or short circuit, a design utilizing four thermal switches was selected.

Because of voltage and physical limitations, many commercial devices were not suitable for this particular application. A bi-metallic device with an integral PTC feature was selected and verified by test to demonstrate that it would perform as expected.

Experimental

Cells

One lot of 5000 4/3A Ni-MH cells was procured and tested. All of the cells were stripped of their insulating sleeves, serialized and tested in accordance with NASA's requirements

Lot Acceptance Tests

One hundred and fifty cells were randomly selected from the lot and subjected to the tests below:

- High Temperature Exposure/Heat to Vent
- Cell Short Circuit, @ 0.02 and 0.125 ohm
- Shock & Vibration
- Overcharge
- Capacity, @ C, C/4, & C/8 rates
- Capacity, @ 10 and 32 °C
- Prolonged Charged Stand, @30, 60, & 90 days

Ten samples were archived, 3 samples were subjected to destructive physical analysis and 17 samples were kept as replacements for any no-test event. Except for the shock, vibration and overcharge tests, where one group of ten cells was used for all three tests, each test was conducted using 10 cells.

All charge cycles were performed at room temperature at 0.4 A for 16 hours. The high temperature exposure test consisted of placing the cells in a chamber at 70 °C for two hours, inspecting them and then raising the temperature until they vented. The short circuit test was performed at room temperature after the cells were fully charged. Shock tests were performed by subjecting each test cell to a 60g, 11 msec sawtooth shock in 3 mutually perpendicular axes while monitoring the voltage.

Random vibration tests were performed in accordance with the vibration levels in Table 2.

Table 2: Vibration Levels

Frequency	G ² /Hz
20	0.234
50	1.44
800	1.44
2000	0.234
Vibration Level	42 grms

The overcharge test was performed at 32°C by charging the cells at a 0.5A rate for 48 hours. Room temperature capacity tests were performed at 0.5A, 1A and 3.5A discharge rates to a 1.0V cutoff. Upon completion of

five cycles, the cells were subjected to the reversal test at the rates above for 8, 4, and 1 hour respectively.

Capacity tests at 10°C and 32°C were performed at 1A discharge to 1.0V until 36 cycles were reached.

Individual cell tests

Each cell was fully charged and subsequently placed in a chamber at $45 \pm 5^\circ\text{C}$ and a pressure of < 1 Torr for 2 ± 0.1 hours. Subsequently, the cells were allowed to cool to room temperature and then discharged. Finally, the cells were subjected to another charge/discharge cycle. Thirty minutes after the start of the discharge cycle, the current was reduced to a C/4 rate for ten seconds.

After the last discharge, the cells were tested for leakage by spraying a 0.5% phenolphthalein solution around the crimp seal and vent areas. Cells that had any indication of leakage were rejected.

The average capacity and the average internal resistance were calculated. Any cell which exceeded the \pm two sigma confidence limit for either attribute was rejected.

Thermal tests

To determine the minimum flow rate needed to maintain the cell skin temperature below 50°C , we built a test fixture which was 1/16 the volume of a module and conducted tests at selected flow rates while measuring the cell skin temperature at 8 locations.

Results and Discussion

Cell lot tests

With the exception of the overcharge test, which showed some indication of leakage using phenolphthalein, all of the test criteria were met.

Individual cell tests

The average cell capacity was 3.61 Ah with a standard deviation of 0.09 Ah while the average cell resistance was 19.7 mOhm with a standard deviation of 0.5 mOhm.

In all, 261 cells were rejected for leakage; 349 cells were rejected because they exceeded the capacity criteria and 250 cells were rejected because they exceeded the resistance criteria.

Thermal characterization.

After attaching eight thermocouples to various locations in the cell string, it was placed in the fixture and cycled at selected flow rates. The data, at the end of an 8 hour, 0.4A charge, is depicted in Figure 3. As can be seen from Figure 3, a minimum flow-rate of 5 liters per minute was required in order to assure that the temperature increase was less than 15 degrees Centigrade. This equates to a flow rate of 0.75 cubic feet per minute on a module basis or 6 CF/minute on a battery basis.

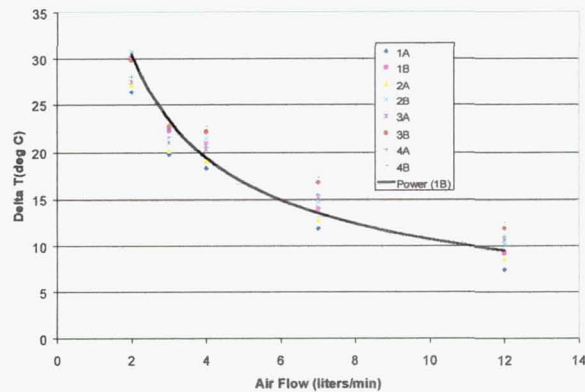


Figure 3: Temperature Rise vs. Air Flow During 8 hours 0.4A

Thermal/Electrical fuse

The test regime and results are summarized in the Table 3 below:

Table 3: Test Regime and Results

Step	Description	Results
1	Measure the resistance of the device at room temperature	20 mOhm
2	Apply a 0.5 A current at 38V & 60°C for 1h	Device did not trip
3	Measure the resistance of the device 30 minutes after it equilibrates at room temperature	20 mOhm
4	Apply a 1A current at 28V and 60°C for 3 h. Apply a 3A, 100 ms pulse every 6 minutes	Device did not trip
5	Repeat step 3	23 mOhm
6	With the voltage at 30V and the device at room temperature, increase the current until the device trips	Tripped at 6.5A
7	Repeat step 3	15 mOhm
8	Repeat steps 6 & 3 eleven times	Last step: trip current = 7A, resistance=23 Ohm
9	With the voltage at 30V and the device at 60°C, increase the current until the device trips	4.2A
10	Repeat step 3	22 Ohm
11	Repeat step 9	4.6A
12	Repeat step 3	22 Ohm