# MULTI-MISSION NICKEL–HYDROGEN BATTERY CELLS FOR THE 1990s

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## Summary

A sufficient production, test, and operational database is now available to permit design technology optimization for the next decade. The evolved battery cell design features standardized technology intended to support multiple type missions (*e.g.*, both GEO and LEO). Design analysis and validation test cells demonstrate that improved performance plus attractive specific-energy characteristics will be achieved.

## Introduction

In the year 1988 Eagle-Picher Industries (EPI) surpassed the production point of 10 000 space-type $Ni-H_2$ battery cells. Approximately 25 000 000 battery cell hours of space flight operation have now been accumulated. Multiple test cell groups continue to undergo real-time and accelerated life testing. Real-time GEO testing has now exceeded 13 years and LEO testing over 6 years. Accelerated LEO testing has exceeded 40 000 cycles.

Several design technologies evolved in the accumulation of this extensive database. Performance comparisons and post-test destructive physical analysis (DPA) have proved useful in the evaluation of the advantages and disadvantages of the various design technologies. Sufficient data are therefore available to propose a more standard, optimized battery cell design capable of supporting multiple types of missions for the next decade.

## Battery cell design

The following design summary proposes a baseline cell design. If optional technology is available which has been tested and proved, then it is noted in parentheses.

*Pressure vessel (PV).* A single girth weld design is proposed with opposing, axial compression, terminal seals. (For volume critical or other

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0378-7753/90/$3.50 

special applications, the terminals may be located at 45° off-set positions on either the same PV end or at opposing ends.)

EPI has established and qualified an "in-house", fracture-critical, vessel inspection capability which permits customizing the cell design, maximum-expected-operating-pressure (MEOP), and vessel wall thickness for the specific mission application.

*Electron beam welding.* All PV joining will be accomplished by the electron beam (EB) process. EPI has procured a FERRANTI Sciaky 60 kV, 250 mA EB welder for "in-house" capability and control. A large vacuum chamber was selected to permit equipment modifications for high precision, multiple cell self-indexing, fully automated welding.

*Electrode stack.* The electrode stack will feature "pineapple slice" geometry for optimum thermal, mechanical, and electrical characteristics. The positive electrodes will be configured in a "back-to-back" arrangement. Depending upon capacity, the design will feature a single or dual stack arrangement. For capacities of 50 A h or less, a single stack is generally used.

*PV wall coating.* The PV will feature a porous zirconium oxide wall coating to serve as an electrolyte return (wick) and reservoir. (A combination electrolyte transport and catalyzed wall coating design for enhanced gas management is also offered.)

*Positive electrode.* A high mechanical strength (1500 psi min.), slurry sinter positive electrode is utilized for long term dimensional stability. An electrode thickness of 0.03 in. (0.076 cm) is incorporated to maximize the quantity of electrodes and thus minimize operational current densities. A moderate active material loading level of 1.65 g $cm^{-3}$ of void volume is specified.

*Negative electrode.* A standard Teflonated catalyzed electrode with a platinum loading of 8 mg $cm^{-2}$ is featured. (Platinum loading reductions of up to an order of magnitude are also available.)

*Separator.* In consideration of long term availability, electrolyte reserve provision, and low impedance (particularly at lower temperatures), a two layer zirconium oxide (Zircar) material design is featured. (A combination asbestos/Zircar design is also available. In addition, for mass critical missions a single layer asbestos or Zircar design is offered.)

*Electrolyte.* A 31% potassium hydroxide solution will be incorporated in the standard cell. (For missions with a large number of cycles or high depths of discharge, a 26% solution is offered for positive electrode stress reduction.)

*Gas management.* The more open structural characteristics of the Zircar separator material pose additional problems with regard to oxygen gas management (Fig. 1). The proposed cell design will incorporate provisions which are intended to redirect the oxygen gas flow away from the positive electrode–separator interface during overcharge.

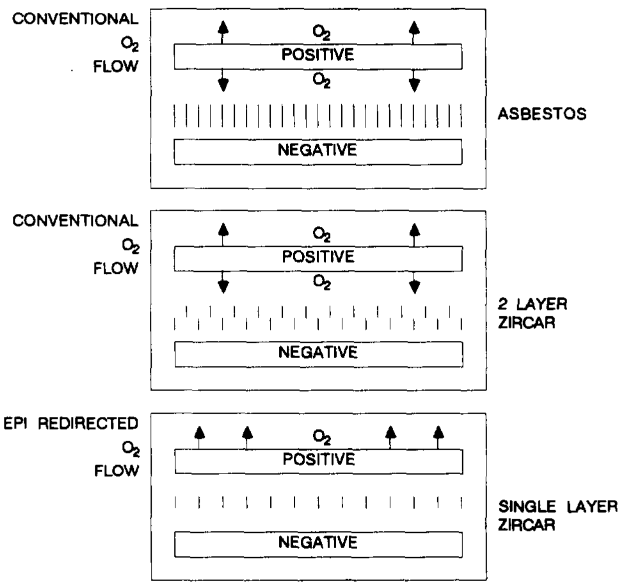


Fig. 1. Ni–$H_2$ separator design technology.

*Stack growth accommodations.* To accommodate potential electrode stack dimensional growth, and to maintain appropriate stack load under dynamic stress, a spring-type device is employed. The device incorporated in the proposed cell design offers significant advantages over the Belleville washer design employed in several cell types. The spring constant for the proposed device can be reproducibly controlled and maintained in the manufacturing process. In addition, load uniformity is maintained over a much greater length of travel at approximately one fourth the mass of equivalent Belleville washers.

## 80 A h cell designs

Battery cells rated at 80 A h are being produced, and validation cells have been placed on test. This program may serve as an example for projecting mass and volume characteristics for the proposed cell design. Tables 1 - 4 represent summaries of computer projections for the most influential technology option, separator type, and design.

TABLE 1

Baseline 80 A h rated (2 layer Zircar separator) cell design

| Battery cell design parameters | Value |
|---|---|
| Input | |
| 1. Rated cell capacity (A h) | 80.000 |
| 2. Cell capacity margin (%) | 10.000 |
| 3. Cell residual capacity (%) | 25.000 |
| Output features | |
| 1. Nominal cell mass (g) | 1991.280 |
| 2. Nominal cell capacity (A h) | 88.476 |
| 3. Cell specific energy (W h $kg^{-1}$) | 54.207 |
| 4. Pressure vessel length (in.) | 10.123 |
| 5. Total cell length (in.) | 13.373 |
| 6. Total cell length (cm) | 33.968 |
| 7. Cell diameter (in.) | 3.506 |
| 8. Cell diameter (cm) | 8.905 |

TABLE 2

Option #1 80 A h rated (asbestos/Zircar separator) cell design

| Battery cell design parameters | Value |
|---|---|
| Input | |
| 1. Rated cell capacity (A h) | 80.000 |
| 2. Cell capacity margin (%) | 10.000 |
| 3. Cell residual capacity (%) | 25.000 |
| Output features | |
| 1. Nominal cell mass (g) | 1947.790 |
| 2. Nominal cell capacity (A h) | 88.476 |
| 3. Cell specific energy (W h $kg^{-1}$) | 55.417 |
| 4. Pressure vessel length (in.) | 10.021 |
| 5. Total cell length (in.) | 13.271 |
| 6. Total cell length (cm) | 33.707 |
| 7. Cell diameter (in.) | 3.506 |
| 8. Cell diameter (cm) | 8.905 |

The design analysis of the proposed $Ni-H_2$ battery cell was performed on a TRS-80, Model 100 portable computer. The specific application software was coded in an extended version of BASIC. The program constructs a detailed model of the cell design via established electrochemical, physical, and material performance formulae.

The 80 A h cells for a program have now progressed sufficiently to permit model accuracy verification.

TABLE 3

Option #2 80 A h rated (1 layer asbestos separator) cell design

| Battery cell design parameters | Value |
|---|---|
| Input | |
| 1. Rated cell capacity (A h) | 80.000 |
| 2. Cell capacity margin (%) | 10.000 |
| 3. Cell residual capacity (%) | 25.000 |
| Output features | |
| 1. Nominal cell mass (g) | 1858.410 |
| 2. Nominal cell capacity (A h) | 89.271 |
| 3. Cell specific energy (W h $kg^{-1}$) | 58.604 |
| 4. Pressure vessel length (in.) | 9.643 |
| 5. Total cell length (in.) | 12.893 |
| 6. Total cell length (cm) | 32.749 |
| 7. Cell diameter (in.) | 3.506 |
| 8. Cell diameter (cm) | 8.905 |

TABLE 4

Option #3 80 A h rated (1 layer Zircar separator) cell design

| Battery cell design parameters | Value |
|---|---|
| Input | |
| 1. Rated cell capacity (A h) | 80.000 |
| 2. Cell capacity margin (%) | 10.000 |
| 3. Cell residual capacity (%) | 25.000 |
| Output features | |
| 1. Nominal cell mass (g) | 1803.090 |
| 2. Nominal cell capacity (A h) | 88.476 |
| 3. Cell specific energy (W h $kg^{-1}$) | 59.865 |
| 4. Pressure vessel length (in.) | 9.505 |
| 5. Total cell length (in.) | 12.755 |
| 6. Total cell length (cm) | 32.397 |
| 7. Cell diameter (in.) | 3.506 |
| 8. Cell diameter (cm) | 8.905 |

| Attribute | Model accuracy |
|---|---|
| Mass | 0.2% |
| Capacity | 0.2% |
| Length | 0.1% |

## Cell test data

Typical battery cell conditioning, and Acceptance Test data, are presented in Tables 5 and 6, respectively. To permit a level of performance

TABLE 5

Performance comparison of 80 A h cells during sealed conditioning cycles[a]

| Cycle | EOC (V) | | 1 h D (V) | | Capacity (A h) | |
|---|---|---|---|---|---|---|
| | #1[b] | #2[c] | #1 | #2 | #1 | #2 |
| 1 | 1.535 | 1.534 | 1.220 | 1.233 | 88 | 86 |
| 2 | 1.527 | 1.525 | 1.218 | 1.233 | 85 | 85 |
| 3 | 1.537 | 1.533 | 1.215 | 1.234 | 84 | 85 |

[a]Charged $C/10$ for 16 h, discharged $C/2$, 10 °C.
[b]Design #1 = Asbestos separator, 8 cells on test.
[c]Design #2 = Zircar (1) separator, 3 cells on test.
All data values are group averages.

TABLE 6

Performance comparison of 80 A h cells during acceptance test cycles[a]

| Test (°C) | EOC (V) | | 1 h D (V) | | Capacity (A h) | |
|---|---|---|---|---|---|---|
| | #1[c] | #2[d] | #1 | #2 | #1 | #2 |
| 25 | 1.491 | 1.486 | 1.204 | 1.211 | 73 | 71 |
| −5 | 1.595 | 1.585 | 1.140 | 1.188 | 82 | 84 |
| 10 | 1.530 | 1.515 | 1.185 | 1.205 | 87 (77)[b] | 86 (84)[b] |

[a]Charged $C/10$ for 16 h, discharged $C/1.6$.
[b]Discharge to 1.1 V.
[c]Design #1 = Asbestos separator, 8 cells on test.
[d]Design #2 = Zircar (1) separator, 3 cells on test.
All data values are group averages.
Cells were subjected to 30 "burn-in" cycles between conditioning and acceptance testing.
Cycle = 12 h, 75% DOD in 1.2 h, 1.25 C/D return in 10.8 h, 10 °C.

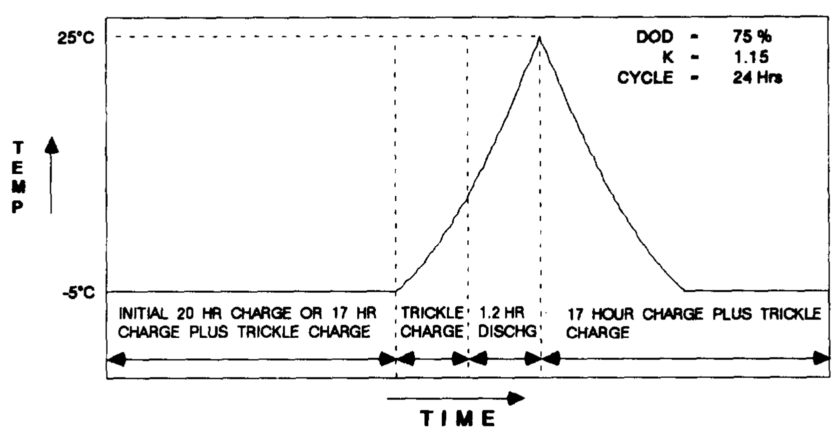


Fig. 2. Cycle test, cell temperature *vs.* time.

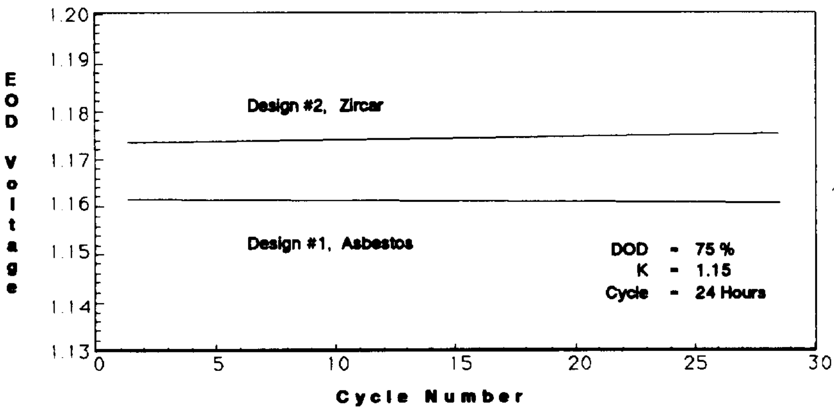


Fig. 3. Real-time GEO life cycle test end-of-discharge voltage.

comparison, data were selected for a single layer asbestos and a single layer Zircar separator cell design.

These same two test cell groups are part of a larger test cell group now undergoing real-time GEO life cycle testing in accordance with the test profile presented in Fig. 2. Typical end-of-discharge voltage (EODV) performance is compared graphically in Fig. 3.

## Conclusions

A multi-mission $Ni-H_2$ battery cell has been produced and is successfully undergoing validation testing. The cell design has assimilated the optimal, space flight proven technology which has evolved from a 15 year, 10 000 production unit, 25 000 000 flight-cell-hour database. Its standardized features should now support missions through the 1990s with minimal need for design requalification and dedicated cycle life testing.