FOURTH-GENERATION ZINC-AIR BATTERIES

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ABSTRACT

Fourth-generation zinc-air batteries are being developed for Army and Marine Corps missions requiring both high specific energy and power, in compact volume. The first application was UAV's, Dragon Eye in particular, and subsequently dismounted soldier/marine systems.

INTRODUCTION

First-generation zinc-air batteries (GEN 1), introduced in the 1950's, resemble automotive SLI batteries in construction and are used in remote signal applications such as buoys and railroad crossings (Figure 1). They are designed for low-rate (< 1 A), multi-year service and have moderate specific energy. [1]

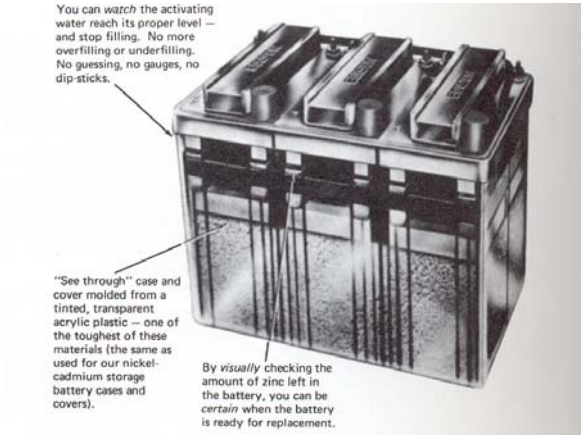

Figure 1: Zinc-Air Signal Battery

Second-generation zinc-air (GEN 2) is the button-cell, commercialized in the 1970's for hearing aids (Figure 2). With specific energies of more than 400 Wh/kg, the button cell is typically limited to about 10 mW in power and has a service life of one month. [1]

Figure 2: Zinc-Air Button Cell

Third-generation zinc-air cells (GEN 3), employ molded plastic cell housings sealed and joined with epoxy adhesives (Figure 3). [2,3]

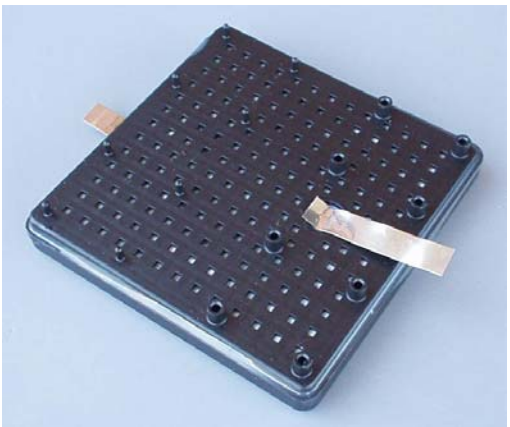

Figure 3: BA-8180 Zinc-Air Cell

Batteries using 30 Ah GEN 3 zinc-air cells were first fielded in 2003 as the BA-8180 (Figure 4). The BA-8180, a 12/24 V, 750 Wh battery used for battlefield power by dismounted units,

Figure 4: BA-8180 Battery

is designed for moderate power (up to 50 W) and a service life of several months. It powers tactical radios for up to a week or more for typical duty cycles. [4]

Fourth-generation (GEN 4a and GEN 4b), whose development began in 2002, uses the air cathode as the cell housing, folded in half around the zinc electrode and its edges sealed for leaktight integrity (Figure 5).

Figure 5: 4th Generation Zinc-Air Cell

DISCUSSION

The advancement of the zinc-air electrochemical cell can be seen in Figure 6. The figure presents the performance characteristics of each generation in the form of specific energy vs. specific power.

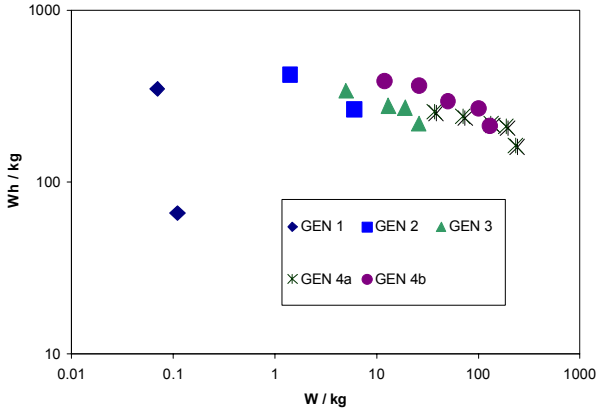

Figure 6: Specific Energy – Specific Power Data for All Generations of Zinc-Air Cells

At more than 400 Wh/kg, the button cell (GEN 2) has the highest specific energy, while the power optimized GEN 4a cell has the highest specific power, exceeding 200 W/kg. Button cell technology limits power capability to 10-20 mW. The signal battery (GEN 1) is, to a lesser degree, power limited as well, with much lower specific energy. It is designed for minimal cost per Wh and multi-year service.

Focusing on GEN 3 and GEN 4 (Figure 7), we see the clear specific energy and specific power advantage of the GEN 4 design. The GEN 4 cells are divided into two categories; the first is a power optimized cell GEN 4a and the second is an energy optimized cell GEN 4b.

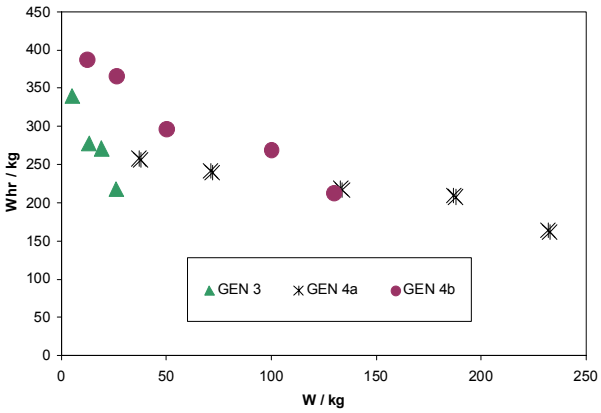

Figure 7: Performance Data of
GEN 3 vs. GEN 4 on Linear Scales

The figure shows that, at low rates (< C/60), the specific energy of GEN 3 approaches that of GEN 4b, but falls off rapidly as the rate increases. This is because the anode is very thick (more than 5 mm, at least twice those of GEN 4 cells), the cell being designed for delivering 30 Ah, in BA-8180's, to power radiotelephones over a period of several days to a week, at minimal cost.

4th Generation Zinc-Air Battery Technology: Dragon Eye

The fourth generation zinc-air electrochemical cell was first developed for the Dragon Eye UAV used extensively by the Marine Corps (Figure 8).

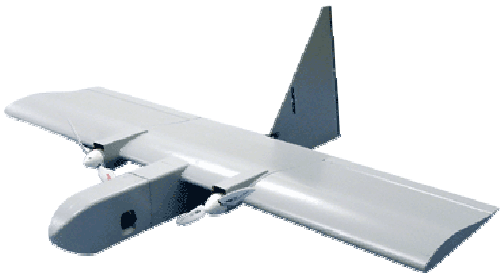

Figure 8: Dragon Eye UAV

With a 48 inch wingspan, a battery of 8 lithium sulfur dioxide D cells located in the fuselage powers it. Peak power exceeds 200 W, and cruise power in level flight ranges between 110 and 130 W. This was perhaps the most demanding application for which to develop GEN 4 zinc-air, considering power, energy, weight, volume, and cost. The lithium battery, at just over 700 g, is capable of delivering 200 W climb-out power, and provides up to an hour of total flight time.

Figure 9 shows the GEN 4 prototype flight battery developed for Dragon Eye. It comprised three stacks of seven cells in series (Figures 10 and 11).

Figure 9: Gen 4 Zinc-Air Dragon Eye Battery

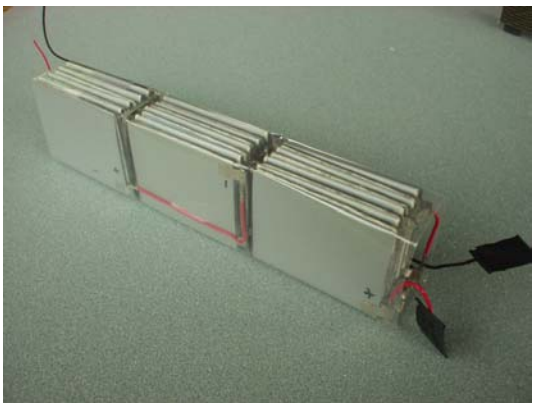

Figure 10: Dragon Eye Battery, Cell Stack Arrangement

Figure 11: Dragon Eye Cell Stack

The connector for mating to the plane was located at the aft end, and a fan located at the front of the battery provided reaction and cooling air flow prior to takeoff (the plane provides ram air in flight, for cooling the lithium battery). The same ram air is used in the zinc-air design for both reactant and cooling air.

After initial ground and flight testing over a period of several months, which evolved the GEN 4 design to the power-optimized GEN 4a, 45 minutes of flight capability was demonstrated. Figure 12 shows polarization data for a GEN 4a cell, which weighs 30 g.

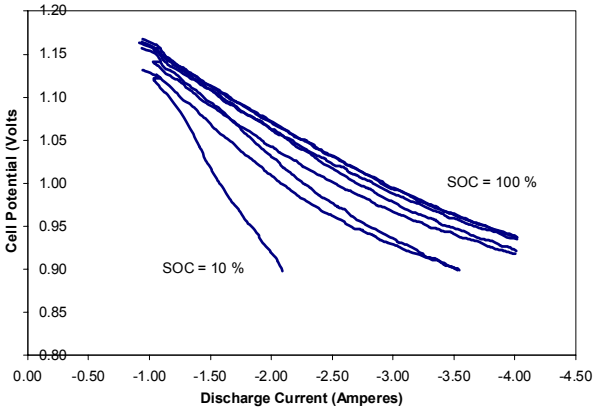

Figure 12: Polarization for GEN 4a zinc-air Cell.

Ground Power Opportunities for Gen 4b

Easing the specific power and power density requirements imposed by Dragon Eye allows dramatic improvements in specific energy. Doubling the anode thickness, from 1.5 to 3 mm, increases cell specific energy from about 260 Wh/kg to more than 360 Wh/kg. Even with weight allowances for packaging, GEN 4b battery specific energies of well over 300 Wh/kg have been demonstrated. Optimum performance is achieved in the range C/10 – C/40.

A particularly attractive feature of the GEN 4 technology is the absence of extensive hard tooling for cell development and manufacturing. This provides the capability of (1) building a new cell of arbitrary dimensions, rated power, and energy content in a matter of days in the product development cycle, and (2) production flexibility among several cell sizes in manufacturing.

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