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Discharge and safety characteristics of improved low magnetic signature lithium cells

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Abstract

A family of non-magnetic cells has been developed by Wilson Greatbatch Ltd. (WGL) for use in equipment that is sensitive to magnetic interference. These cells power devices for acoustic mapping of the ocean floor, recording current meters, and downhole tools used in directional drilling equipment. While their magnetic signature was reduced by a factor of 15 over the standard cells, it was too large for use in the stringent environments of a magnetic resonance imaging (MRI) suite. A new series of low magnetic signature (LMS) cells has been developed for more demanding environments. Their magnetic signature was reduced by a factor of 12 over the original non-magnetic design. BCX cells in low magnetic signature (BCX-LMS) configurations were evaluated under a series of performance and safety tests. BCX-LMS cells exhibit energy densities greater than 400 Wh kg^{-1} at room temperature. Safety tests show that these cells conform with the UN Recommendations for the Transport of Dangerous Goods, Manual of Tests and Criteria T-1 and T-2. Visual examination of the cells after the tests showed no evidence of leakage, venting or case distortion.

Keywords: Applications/medical; Lithium primary cells; Safety

1. Introduction

The design of the improved non-magnetic cell was predicated on the Li/BrCl in $SOCl_2$ (BCX) chemistry [1]. This system exhibits an OCV of 3.90 V at room temperature. Practical, hermetically sealed cells have an energy density of approximately 450 Wh kg^{-1}. The operational temperature range is −55 to 72°C. Standard cells are constructed with 304L stainless steel cases. Current collectors for both the anode and cathode consist of an expanded nickel screen which extends the entire length of the respective electrodes. Spirally wound electrodes are designed with moderate surface area to provide a balance between performance and safety considerations. In addition, each cell is internally fused (fuses are located under the terminal cap) to preclude possible hazards associated with an inadvertent short-circuit.

2. Materials of construction

In the design of a non-magnetic cell, the choice of construction materials, in conjunction with the cell chemistry, will define the magnetic signature and influence the performance of the cell. In choosing a material to replace the magnetic nickel utilized in the standard cell, the following parameters had to be met: low magnetic permeability, low electrical resistivity, chemical compatibility with oxyhalide systems, product cost and the availability of materials.

The material chosen in the initial design iteration was one of the austenitic stainless steels. This class of stainless steel is inherently non-magnetic due to the presence of the face-centered cubic austenite phase at room temperature. The material had to be specified in the annealed condition because austenitic stainless steels undergo a phase change to magnetic martensite when cold worked. The particular alloy chosen was 304L. The only disadvantage of this material is that the resistivity is much higher than nickel. The resistivity of nickel is 9.5 μohm cm compared to 72 μohm cm for 304L stainless steel. This can affect the performance of cells if discharged at high rates [2,3]. However, under nominal loads the effects on voltage are negligible.

Further improvements were made to the original non-magnetic design. Other austenitic stainless steels, such as 316L, were evaluated for use as header and case material in the BCX-LMS cells. As mentioned above, each cell is finished with an electrical fuse under the terminal cap. The materials used in the finishing operation were also evaluated.

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3. Magnetic field measurements

The measurement of the magnetic signature of each cell was performed using a portable MEDA fluxgate magnetometer. The location of the test site and the orientation of the magnetometer had to be carefully selected to avoid external sources of magnetic interference. Magnetic field interference and varying electrical currents may jeopardize test results.

The magnetometer could resolve magnetic fields down to 0.01 milligauss (1 milligauss = 100 gamma, 1 gamma = 10^{-5} Oersteds). A probe is used to measure the cell magnetic field and is positioned to cancel out the magnetic field of the earth. Test samples are placed in a plastic fixture to control the distance between the probe and the sample. Measurements were taken in both the near-field (6 mm) and far-field (115 mm) orientations.

Table 1 shows a comparison of the magnetic signatures of standard BCX 'C'- and 'D'-size cells compared to the original non-magnetic and BCX-LMS cells.

In comparison with the standard cell, the initial non-magnetic (BCX D-N and C-N) cells exhibited approximately a 15-fold reduction in their magnetic signature when measured at a distance of 6 mm. Additional improvements were made to the LMS series of cells. Measurements show that the BCX-LMS C- and D-size cells have a near-field magnetic signature of 3.2 and 4.5 milligauss, respectively. This is an additional 12-fold reduction in the magnetic signature over the original non-magnetic versions.

To provide a comparison of the BCX-LMS magnetic characteristics with other chemistries, commercially available alkaline manganese and nickel/cadmium cells were also measured. The magnetic measurements for these systems are summarized in Table 2. These data confirm that through the careful selection of materials the magnetic signature of oxyhalide cells can be reduced to levels suitable for use in applications where a low magnetic signature is critical.

Table 1
Magnetic signatures (in milligauss) of BCX C- and D-size cells

Battery type	Near-field (6 mm)	Far-field (115 mm)
BCX D	850	20
BCX D-N	56	0.6
BCX-LMS D	4.5	0.06
BCX C	550	10
BCX C-N	50	0.3
BCX-LMS C	3.2	0.04

Table 2
Magnetic signatures (in milligauss) of various commercially available D-size cells

Battery type (D-size)	Near-field (6 mm)
Lithium (standard)	850
Commercial alkaline	510
Industrial alkaline	380
Nickel cadmium	320
Lithium (BCX-LMS)	4.5

4. Performance data

The BCX-LMS C- and D-size cells have an OCV of 3.90 at room temperature. They have a rated capacity of 7.0 and 14.0 Ah for the C- and D-size cell, respectively. The maximum rated discharge current for the C- and D-size cells is 0.5 and 1.0 A, respectively. Fig. 1 shows a typical discharge curve for BCX-LMS D-size cells at room temperature, under a 10 ohm load. A unique discharge characteristic of lithium BCX cells is their flat voltage profile relative to the discharge time. The voltage stays above 3.0 for over 90% of the entire life of the cell.

Even though the BCX-LMS cells were designed as a moderate rate system, the cells deliver excellent capacity at high rates of discharge. For example, BCX-LMS D-size cells deliver approximately 90% of their rated capacity when discharged at a current of 1.0 A.

Table 3 shows a comparison of the energy density versus rate capability for the BCX-LMS D-size cells. The cells deliver a maximum capacity of 15 Ah at 300 mA. The average load voltage is approximately 3.25. At the maximum rated discharge current of 1.0 A, the cells deliver approximately 13 Ah.

The BCX-LMS cells can be discharged over a wide range of temperature. Their low temperature performance is exceptional. For example, cells discharged at −55°C deliver 45% of their room temperature capacity. Cells were also tested at

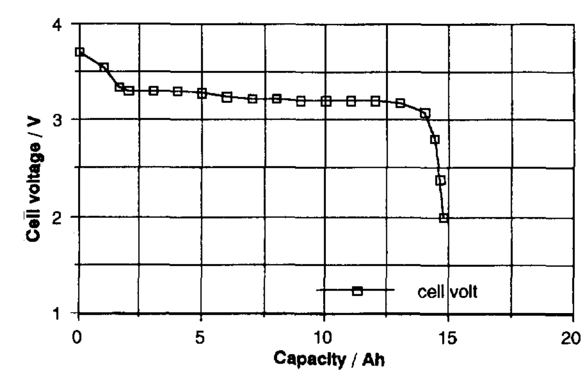

Fig. 1. Typical curve for a BCX-LMS D-size cell discharging into a 10 ohm load at room temperature.

Table 3
Energy densities for BCX-LMS D-size cells discharged under various loads at room temperature

Load (ohm)	Current (A)	Capacity (Ah)	Wh cm^{-3}	Wh kg^{-1}
3	1	13.3	0.79	352
6	0.5	14.2	0.86	390
10	0.3	15.0	0.92	420

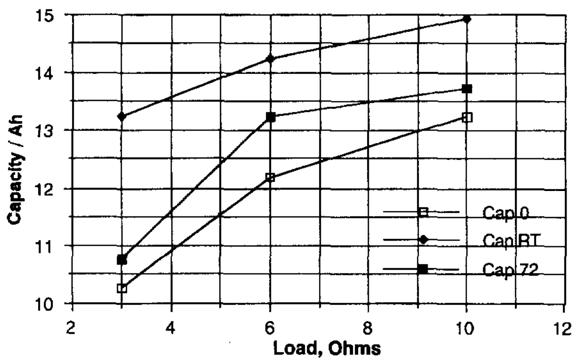

Fig. 2. Discharge characteristics of BCX-LMS cells.

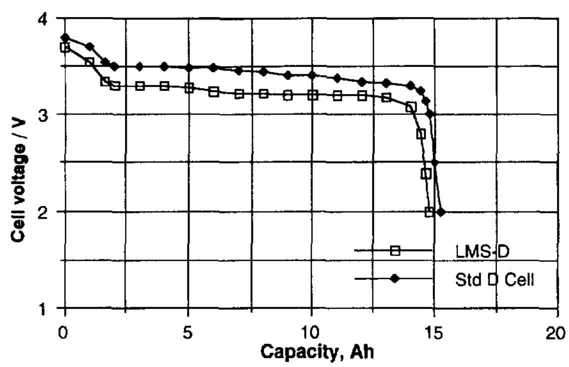

Fig. 3. Performance of standard BCX D-size cells compared to BCX-LMS D-size cells.

0, 22 and 72°C under various loads. Cells tested at the temperature extremes were equilibrated at their respective temperatures for a period of 16 h prior to discharge. The load voltage was measured with a times sequential electrometer coupled with a Hewlett-Packard computer. Capacities were calculated to a 2.0 V cutoff.

Fig. 2 shows the comparison of cell capacity versus discharge rate for various temperatures. These data show that cells discharged at 0°C deliver approximately 83% of their room temperature capacity. Cells discharged at 72°C deliver approximately 90% of their room temperature capacity. It is reasonable to assume that the load voltage of the LMS cells would be affected, especially at high discharge rates, due to the reduced conductivity of stainless steel, as compared to nickel. Fig. 3 shows a comparison of the performance of standard BCX D-size cell to BCX-LMS D-size cells under a 10 ohm load.

These data show that the use of non-magnetic materials has a slight effect on the performance of the cells. At a discharge current of approximately 300 mA, both cells deliver 15 Ah. However, the LMS D-size cell has an average load voltage of 3.25 compared to 3.45 for the standard D-size cell. In most applications this slight difference in load voltage should be transparent to the user since a typical voltage cutoff is 2.0.

5. Safety data

Mechanical and electrical safety tests were performed on the BCX-LMS C- and D-size cells in accordance with the UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria. They were subjected to the series of tests specified in T-1: altitude simulation, extreme temperature, and short-circuit; and T-2: vibration, shock, and short-circuit. These cells showed no signs of leaking, venting or case distortion. On the basis of these tests, cells are assigned as items of class 9 for shipping purposes.

In addition to the shock test required in the UN document, cells were tested to more stringent shock specifications. Cells were subjected to 10 repetitions in each of two mutually perpendicular axes at a level of 1000 g for a duration of 0.5 milliseconds. Post-test evaluation of the cells showed no degradation in performance.

BCX-LMS C- and D-size cells were also subjected to two electrical abuse tests. Cells were force-discharged at their maximum rate for 1.5 times their rated capacity. Charge tests were performed under the same conditions. Voltage, current and skin temperature were monitored during these tests. Each cell was visually examined after the electrical abuse tests. No physical changes were noted in the cells. Also, no hazardous conditions were observed during the tests; the cells did not leak or vent as a result of charge or forced over-discharge tests.

6. Summary

The BCX-LMS cells possess an exceptionally low magnetic signature. This characteristic will allow them to be used in applications that are extremely sensitive to magnetic interference.

The performance of these cells was not significantly degraded from their magnetic counterparts. For example, both standard and non-magnetic D-size cells deliver 15 Ah capacity to a 2 V cutoff. However, the load voltage of the non-magnetic cells was slightly depressed, running approximately 200 mV lower than the standard D-size cells.

Safety and abusive tests show that these cells represent no danger to personnel during use under normal operating conditions. In addition, the cells are tolerant to levels of charging and force that are within their operating envelopes.

References

[1] C.C. Liang, P.W. Krehl and D.A. Danner, *J. Appl. Electrochem.*, *11* (1981) 563.

[2] M.F. Pyszczek et al., Factors influencing lithium cell development for nonmagnetic applications, *Proc. 35th Int. Power Sources Symp., Red Bank, NJ, June 1992*, p. 115.

[3] P.W. Krehl and H.A. Hornung II, *IEEE J. Oceanic Eng.*, (1987) 271.