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Lithium-ion testing for spacecraft applications

J.P. Fellner[a,*], G.J. Loeber[a], S.P. Vukson[a], C.A. Riepenhoff[b]

[a]Air Force Research Laboratory, Propulsion Directorate, 1950 Fifth Street, Wright-Patterson AFB, OH 45433-7251, USA
[b]Wyle Laboratories, Technical Support Services, 4200 Colonel Glenn, Suite 900, Dayton, OH 45431, USA

Abstract

The Air Force Research Laboratory is developing lithium-ion batteries for low earth orbit (LEO) and geosynchronous earth orbit (GEO) spacecraft applications. As a part of this lithium-ion battery development effort, a testing program is underway to determine the viability of lithium-ion batteries for LEO/GEO applications. For LEO, lithium-ion battery cycle lifetimes of >60,000 cycles at 25% depth-of-discharge (DOD) are projected. For GEO, lifetimes of >14 years at 80% depth-of-discharge are projected.

Keywords: Lithium-ion battery; Spacecraft; LEO; GEO; Rechargeable

1. Introduction

The Air Force Research Laboratory is developing lithium-ion and lithium/polymer batteries for aircraft, spacecraft, and for various high-rate applications. Lithium-ion based batteries have several characteristics that make it attractive for aerospace applications. These include higher energy density and per cell voltage than its competing, more mature technologies such as lead–acid, nickel–cadmium, nickel–hydrogen, or nickel–metal hydride. While perfectly adequate for typical commercial applications, the lithium-ion based technology has not yet advanced sufficiently for widespread use in aerospace applications. For use in aerospace applications, lithium-ion and lithium/polymer batteries need further development to perform at the required temperature extremes and to exhibit the desired cycle and calendar life. Satellite applications require a cycle life of >30,000 cycles for low earth orbit (LEO) and a calendar life of >10 years for geosynchronous earth orbit (GEO).

In the aerospace arena, the shape of the curve for the expected cycle life of recharge-able batteries versus depth of discharge, (semi-log plot of cycle life versus depth of discharge), has been theoretically and experimentally described by Thaller [1–4]. These correlations are only expected to hold for lithium-ion batteries where the battery's temperature is tightly controlled to a given temperature.

2. Experimental

Prismatic 25 Ah rated lithium-ion cells were developed under contract and were tested in simulated LEO and GEO regimes. The active cathode material was $LiNi_{1-x}Co_xO_2$, the electrolyte was $LiPF_6$ in an organic solution, and the active material in the anode was a graphitic-based carbon.

For LEO, the cells were cycled at 40, 50, and 60% depth-of-discharge (DOD) in Tenney Environmental temperature chambers maintained at 10 °C. For each simulated cycle, the discharge times were 30 min and the charge times were 1 h. The charge currents were 12.5, 15.625, and 18.75 A for the 40, 50, and 60% DOD tests, respectively. The discharge currents were 20, 25, and 30 A for the 40, 50, and 60% DOD tests, respectively. The cells where charged at the respective currents to a cell voltage limit of 4.1 V and then the voltage was held constant until a total charge time of 1 h was reached. End of cell life was considered to be if the end-of-discharge (EOD) cell voltage was below 3.0 V.

For GEO, there are two 45-day eclipse periods per year or 90 battery cycles per year. The 45-day GEO eclipse period was simulated by having the cells cycled in Tenney Environmental temperature chambers maintained at 10 °C with discharge rates at 2/3*C* or 16.7 A and the cycle length varying from 12 to 72 min and back to 12 min for a maximum DOD of 80%. The charge rate was *C*/25 or 1 A to a cell voltage limit of 4.1 V. After the cell reached 4.1 V, the cell voltage was held constant at 4.1 V until a total charge time of 24 h minus the previous discharge time was reached.

* Corresponding author. Tel.: +1-937-255-7770; fax: +1-937-656-7529.
E-mail address: joseph.fellner@wpafb.af.mil (J.P. Fellner).

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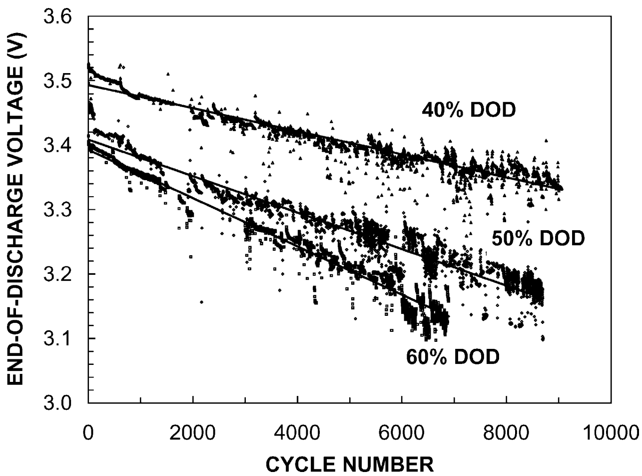

Fig. 1. End-of-discharge voltage for 25 Ah lithium-ion batteries from a given manufacturer.

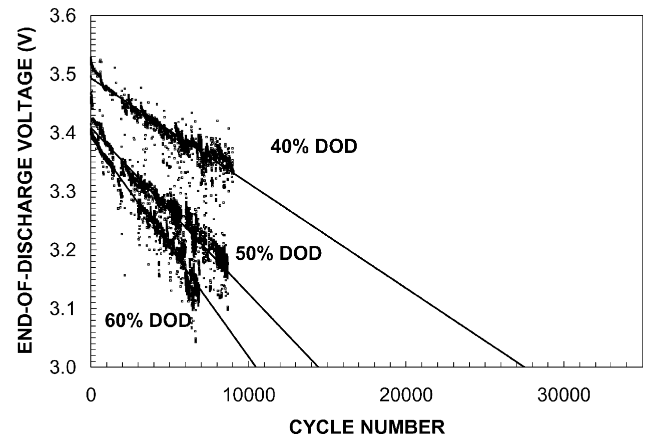

Fig. 2. Life predictions for 25 Ah lithium-ion batteries from a given manufacturer.

End of cell life was considered to be if the end-of-discharge voltage was below 3.0 V.

3. Results and discussion

3.1. Simulated LEO results

Figs. 1 and 2 show the cell EOD voltage as a function of cycle number for the 40, 50, and 60% DOD cases, respectively. The EOD voltage decreases faster with cycle number as the percentage DOD increases. At high cycle numbers, the EOD voltage appears to decrease linearly with cycle number for the three DOD cases examined.

Using the idea of EOD voltage linearity with cycle number, Fig. 3 was generated from the 12 cells under test. It appears from Fig. 3 that 4 of the 12 cells are poor performers and could have been removed from testing after

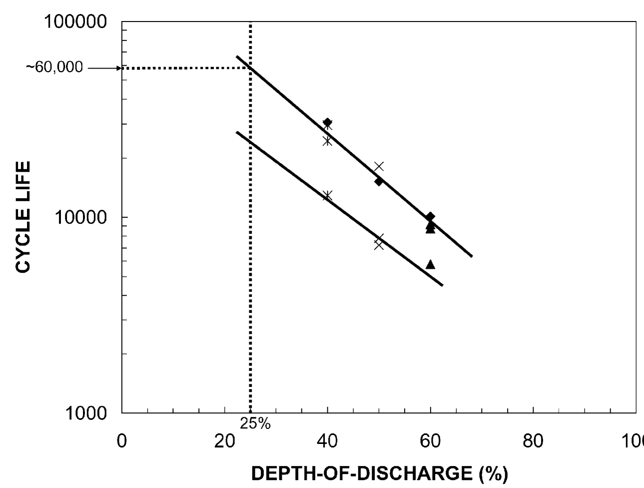

Fig. 3. Effect of depth-of-discharge on cycle life for 25 Ah lithium-ion batteries from a given manufacturer.

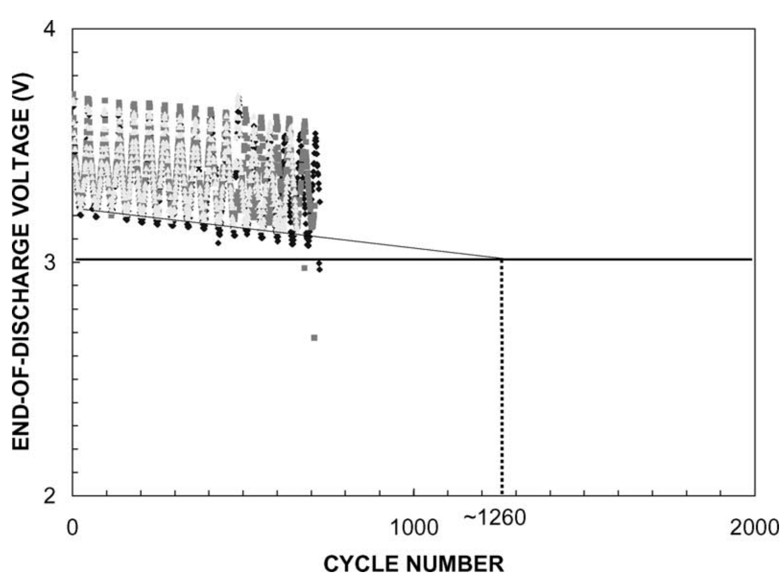

Fig. 4. Cycle-life prediction for lithium-ion batteries under simulated GEO testing.

examination of their performance after several tens of ''shakedown'' cycles.

Projection of the top line of Fig. 3 for the 25% DOD yields an estimated cycle life of >60,000 cycles or >10 years in orbit. The effect of capacity loss due to the calendar effect at these temperatures, although from different cell chemistries, is predicted to be negligible for the 10-year life [5,6]. The effect of increased capacity loss due to the higher discharge rates at higher depths of discharge is given in Thaller's model [1]. Note that the shape of the cycle life versus depth of discharge curve is still semi-logarithmic when an additional penalty for deeper depths of discharge is taken into account.

3.2. Simulated GEO results

Fig. 4 shows the results of our simulated GEO testing. The trend shows a life of about 1300 cycles or >14 years in orbit. While the simulate LEO testing is real time, the GEO testing did not have a break of 275 days between eclipse periods. This accelerated GEO testing may overpredict the cycle life of the lithium-ion batteries. The conditions under which the lithium-ion batteries should be maintained at between eclipse periods are presently being examined.

4. Conclusions

From simulated LEO/GEO testing of 25 Ah prismatic lithium-ion batteries from a given manufacturer, projected lifetimes for LEO and GEO are >60,000 cycles at 25% depth-of-discharge and >14 years at 80% depth-of-discharge, respectively. Further studies and tests are warranted to further verify the accuracy and validity of these projections.

References

[1] L.H. Thaller, J. Electrochem. Soc. 130 (1983) 986.
[2] L.H. Thaller, in: Proceedings of the NASA Aerospace Battery Workshop, Huntsville, AL, 1990, p. 677.
[3] L.H. Thaller, in: Proceedings of the NASA Aerospace Battery Workshop, Huntsville, AL, 1993, p. 377.
[4] L.H. Thaller, in: Proceedings of the NASA Aerospace Battery Workshop, Huntsville, AL, 1997, p. 411.
[5] T. Inoue, T. Sasaki, N. Imamura, H. Yoshida, M. Mizutani, M. Goto, in: Proceedings of the NASA Aerospace Battery Workshop, Huntsville, AL, 2000.
[6] H. Croft, B. Staniewicz, in: Proceedings of the NASA Aerospace Battery Workshop, Huntsville, AL, 2001.