Managing A123 Cells with FMA Cell Balancing Technologies

By
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Executive summary

FMA Incorporated has independently tested A123 Lithium Ion nanotechnology cells and found them to be very good high energy density cells. A123 discharge rates that approach and exceed 17C continuous rival contemporary LiPo cells.

FMA charge and control technology improves A123 pack service life.

A123 cell characteristics

A123 cells have an abrupt drop in voltage at the end of discharge that can lead to pack unbalance. That characteristic can be countered effectively using FMA's Discharge Protection Module (DPM). A123 cells are not damaged by under voltage at 2.5V, but do suffer shortened life if voltage is allowed to drop to 0V (as would happen if left with the receiver/servos connected for a period long enough to drain the pack).

A123 cells can withstand short bursts at discharge rates up to 33C (33 times capacity). Despite outlandish marketing claims of 20C-30C capability, LiPo cells struggle to deliver much greater than 15C, and that is accompanied by very short life in the range of 50 cycles. Capacity for A123 cells at this time is limited to a nominal 2AH.

While A123 energy density is superior to LiPos, cell weight is 56% heavier than LiPo for a given WH delivery. Applications in RC for the A123 will be limited to those aircraft that are not sensitive to the weight disadvantage (e.g., helicopters) or that demand a very high discharge rate (e.g., hotliners).

FMA, Inc. has developed and has available optimized charge and control equipment that matches the charge and discharge regime unique to A123 cells. FMA has performed the research and development needed to create products that allow for totally safe charging of Lithium Ion and Lithium Polymer packs in any voltage and capacity range. Our balanced discharge control products, when combined with balanced charging, maximize the life and safety of these cells.

A123 cells are not as sensitive to under voltage as LiPos, but still do suffer damage if subjected to low undervoltage. An A123 cell has almost zero capacity left at a 2.5V cut-off. FMA's CellPro Discharge Protection Module (DPM) has an adjustable low voltage cut off that protects A123 cells overdischarge.

The charge characteristics of A123 cells tested by FMA, Inc. show a definite need for balance charging of the cells, particularly in higher voltage packs. Failure to balance charge may not result in fire, but will certainly lead to damaged cells in a pack.

Cell testing equipment and conditions

FMA operates intelligent Li Ion / LiPo testing equipment that provides 1% measurement accuracy, and can discharge at up to 500A. This equipment was programmed for A123 charge and discharge cutoff voltages.

This equipment can subject cells or packs to a variety of scenarios, including:

- A constant current load.
- A stepped constant current load.
- A duty cycle simulating operation in some application.
- Repetitive charge/discharge to determine cycle life in some application.

Sample cells were non-destructively tested to produce the data cited in this report. End of life was defined as a decline to 80% of original capacity.

Test data and analysis

The voltage curves below were obtained by discharging A123 cells at constant current at room temperature. Cycle life and cell operating temperatures are noted in the legend.

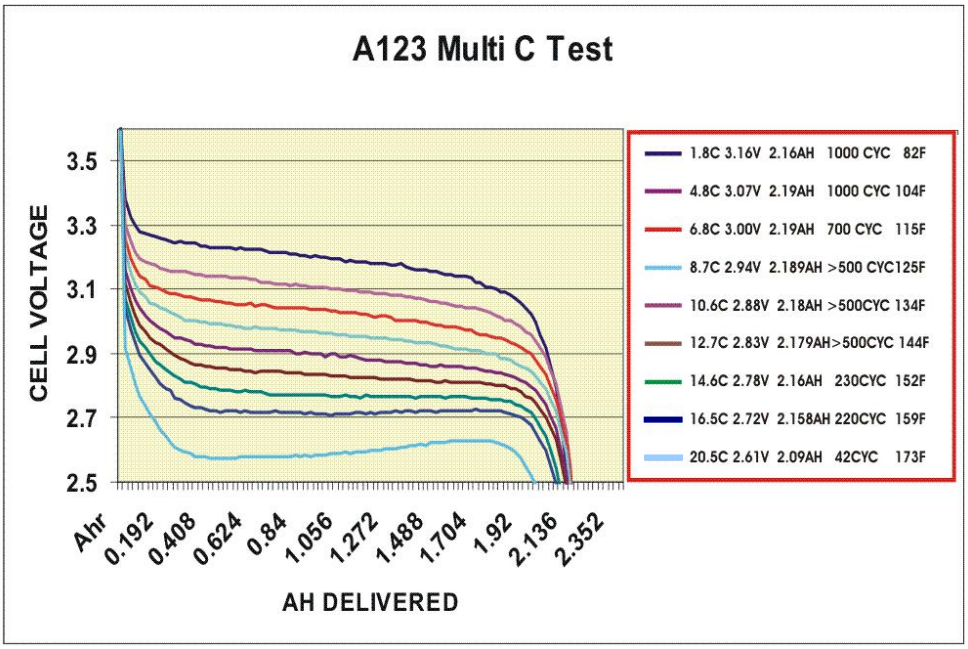
One shortcoming of A123 cells is that maintaining acceptable voltage under high discharge rates may require adding cells in series.

FMA previously determined that LiPo cycle life is directly related to cell operating temperature. We recommend 140° F as the maximum LiPo operating temperature. Operating temperature is such a key factor that we define the nominal LiPo discharge as the rate at which cell temperature reaches 140° F.

FMA introduced and promoted cell temperature as a cell rating factor. A 2s LiPo pack tested at 140° F exceeded 450 cycles. Operating cells above 140° F has a devastating effect. An identical 2s pack reached end of life at 38 cycles when operated at 175° F.

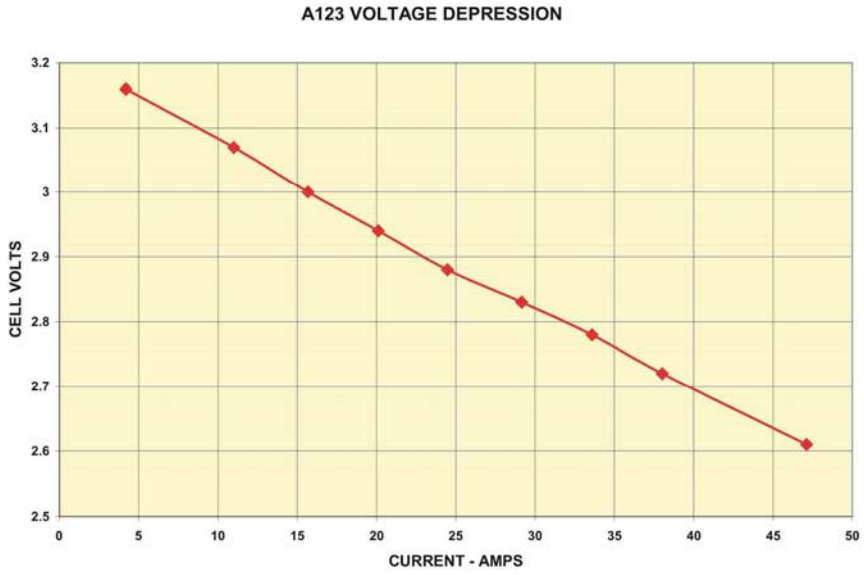
In general, cycle life is about flat up to an operating temperature of 140° F. Above that life deteriorates at about 12 cycles per degree F.

The discharge curves below indicate that the 140° F guideline also applies to A123 cells. For the cells tested, a cycle life of greater than 500 is possible if constant current discharge is kept below 12.7C (which keeps operating temperature below 140-145° F.



In most cyclic load applications, including power tools and RC aircraft, average load is never as high as the constant current load, but load peaks are often well above the average load. This is significant, because at high discharge rates, temperature rises as the square of the current.

As the voltage depression graph below shows, a 10s application would require at least one extra A123 cell to accommodate the 0.6V/cell drop under a 45A load.



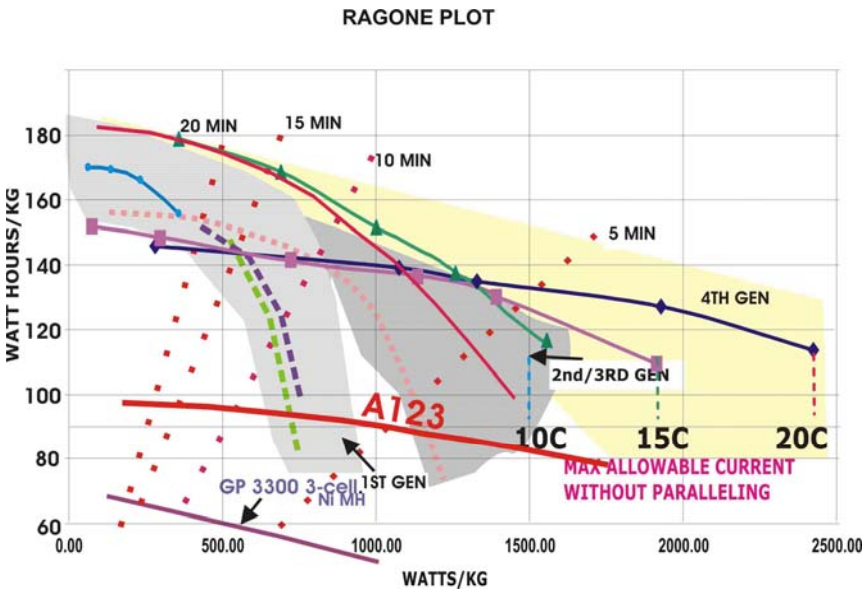
When rated like a LiPo, an A123 cell would be conservatively rated at 17C, and would tolerate 33C in bursts. Keep in mind that peak and continuous ratings depend on acceptable cycle life. At 16.5C, A123 cells deliver 230 cycles.

Here is a comparison of an Enerland 3300 LiPo cell with an A123 cell:

	Enerland	A123
Energy at 2C	12.25 Wh	6.83 Wh
Energy at 8C	11.48 Wh	6.41 Wh (8.7C)
Efficiency	93.7%	93.8%
Energy density	142.8 Wh/kg	91.6 Wh/kg
	1Wh/7g	1Wh/10.9g

Here is a further analysis with cost factored in:

	Enerland 3s pack	A123 3s pack
Power	152.46 W	103.4 W
Energy	10.56 Wh	5.87 Wh
Retail price	$125	$75
Power density	1955 W/g	1477 W/kg
Energy density	135.4 Wh/kg	84 Wh/kg
Cost	$3.95/Wh	$4.25/Wh



Although the A123 technology has a slightly higher cost per watt-hour, it is attractive for its lower initial cost, safety and longevity. The A123 also offers good cycle life if the temperature is kept below 140° F.

Here are some other comparison factors:

	Enerland 3s pack	A123 3s pack
Voltage	9.9V	6.47V
Power	9.9V x 54.45 A = 539 W	6.47V x 54.45A = 352 W
Capacity at 16.5C	98%	99%
Energy	32.Ah x 3.3V = 10.56 Wh	2.158 Ah x 2.72V = 5.87 Wh

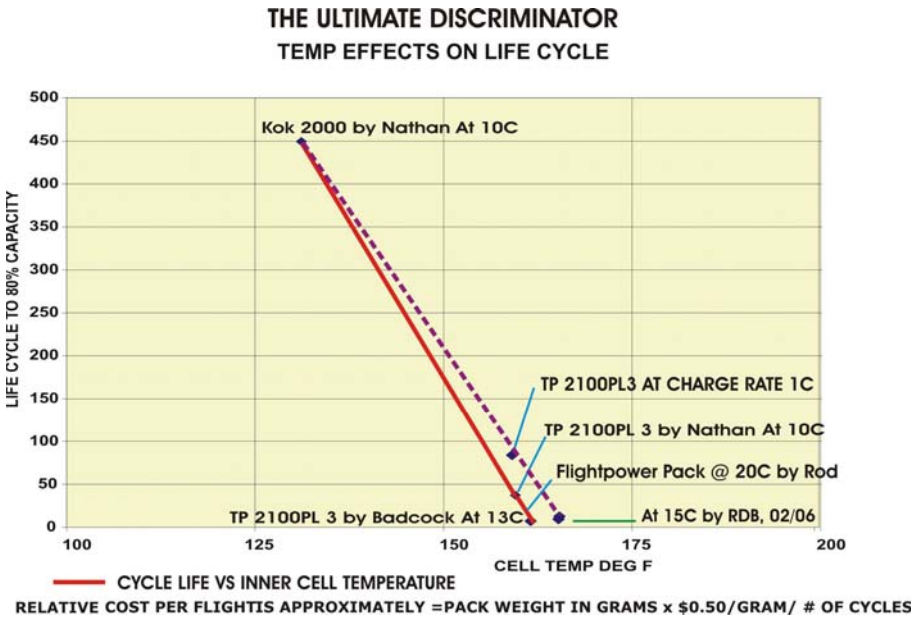
The Enerland 9.9V versus the A123 5.87V is key. Adding a cell brings the A123 pack up to 8.59V and produces similar power and energy. However, the A123's cost per watt-hour will further exceed that of the LiPo, plus the (now) 4s pack gains another 70 grams.

FMA uses a method for accelerated life cycle testing that has proven reasonably accurate in hundreds of runs over the past four years. Cells are run through multiple constant current discharge sequences consisting of a 4.2A baseline followed by a high current (for example, 16A). Capacity measured during the second step subtracted from capacity measured during the first step is a measure of damage incurred from the high current run. The discharge rate is increased by small increments after each set, so that testing is accelerated without destroying cells.

The following observations were made:

- A123 cells do not display a steep decline in cycle life as long as cell temperature remains below 140° F. Life is greater than 500 cycles at moderate discharge rates.

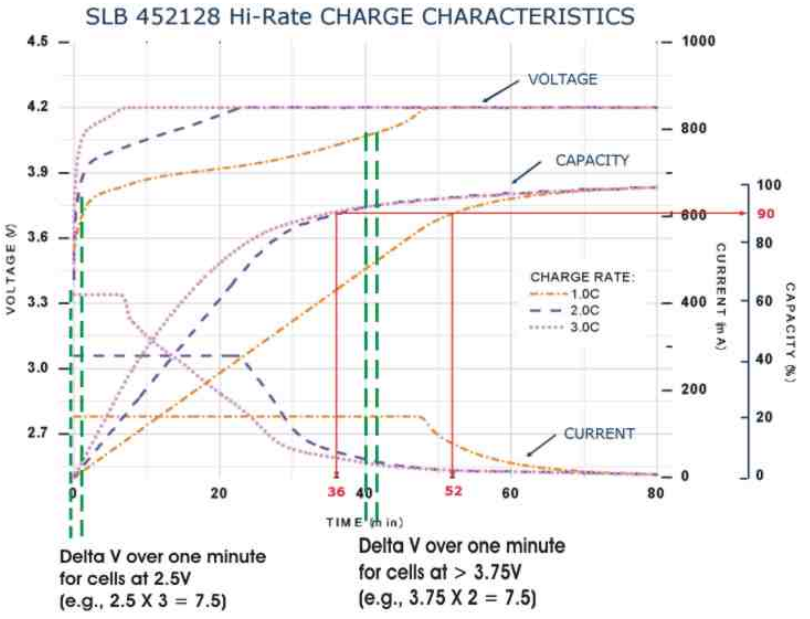
- When cell temperature exceeds 140° F, deterioration increases markedly. When temperature exceeds 170° F, A123 cells suffer the same short cycle life as LiPos.



A123 charge algorithm

The optimum A123 charge algorithm is unique among Lithium cells. Response to charge is different than LiPo and lead acid cells. Response to overcharge is more like NiCd. Note that A123 cells are damaged if charge voltage exceeds 3.7V.

The charge algorithm for LiPo is shown below as constant current / constant voltage, with constant voltage set at 4.2V. Cell voltage responds nearly asymptotically, that is, as the cell approaches the maximum 4.2V, current slowly drops. It may take an hour to reach full charge as defined by 0.1C current.



NOTE: SLOPE OF THE CURVE IS ABOUT 20:1 DELTA BETWEEN THE TWO CHARGE CURVE SEGMENTS. THAT'S EASY FOR THE MICROPROCESSOR TO DETECT. VERY SIMPLE AND VERY SMART. A REAL NO BRAINER.

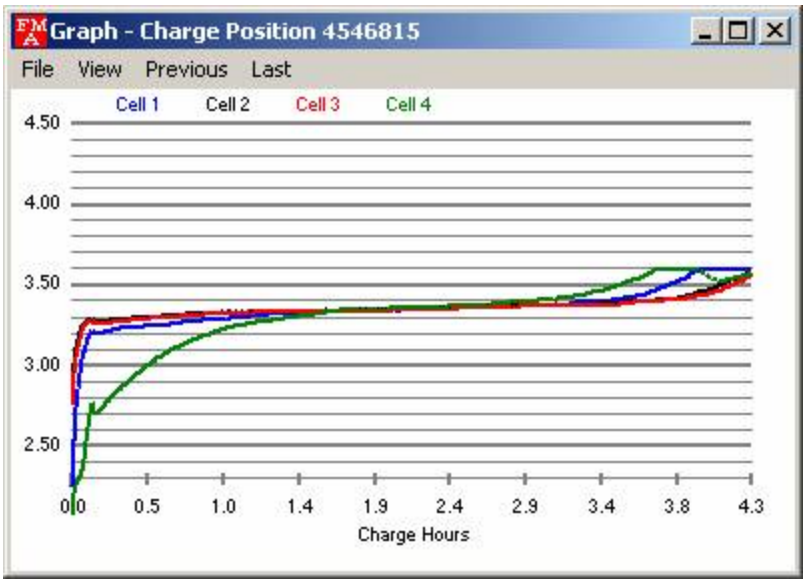
The A123 charge curve (below), as measured and recorded from an FMA Balance Pro 6s Charger programmed for A123 cells, provides several insights.

- Cell #4 would have exceeded 3.7V if the charger had not charged each cell independently. This graph shows capacity imbalance caused by over discharge.

- As each cell approaches full charge, voltage rises abruptly (somewhat like NiCd cells). If a non-balancing charger had been used, the #4 cell would have been ruined. The manufacturer said the cell would vent, but would not ignite.

- Examine cell #1 at the end of charge. It drops down, then finishes. It would not be possible to charge this pack above 75% without balancing.

- After 15 minutes, the charger entered its Safety Mode and lowered current to 0.5A. This pack was clearly damaged, but the charger successfully charges it to 100%.



In conclusion, FMA charge and control technology can be used to maintain A123 cells and packs.

Notes

1. The A123 testing worked out very well as demonstrated on 4 packs tested that had slowly been damaged over a period of 7 deliberate over discharges. If a power tool pack has been on the shelf for some time, the internal pack circuit apparently slowly discharges the cells such that some cells may not recover unless charged using CellPro. The charger handled 35 cycles on the A123 (1s thru 4s) from brand new condition to 50% damaged condition. The charger is smart enough to handle how A123 cells rejuvenate in Low Voltage Restore and A123 Fast Charge. In particular, the charger can automatically figure out the proper cell count as the cells spring to life.

2. To err on the side of safety, the charger always starts with low cell count. A set of simple rules help the charger establish the proper cell count. If a pack charges more then 30% in 5 min, the charger knows it has the wrong cell count. Or, if a pack is in low voltage restore and one cell reaches 90%, the cell count is wrong and the charger will re-count.

3. All the cells in the pack have to add up to within 300 mV of the pack total. It is not possible to read ½ a node. However, it is possible that two 1V cells might be mistaken for a single 2V cell. That double cell will fill up to 2x50% very quickly and the charger will determine that it has the wrong cell count.

The A123 code was modified to deal with this situation being reported by A123 users who purchased power tool packs for conversion.

4. This type of testing was not possible with LiPos because they can only take one over discharge cycle before they are damaged beyond repair. LiPo charging will benefit from A123 modifications.

Suggested reading

http://www.rcgroups.com/forums/showthread.php?t=597662

http://www.rcgroups.com/forums/showthread.php?t=501252

http://www.rcgroups.com/forums/showthread.php?t=598394
The answer to this post is: CellPro, hands down!

http://www.rcgroups.com/forums/showthread.php?t=599316

http://www.rcgroups.com/forums/showthread.php?t=597093
We would never buy them off e-bay!

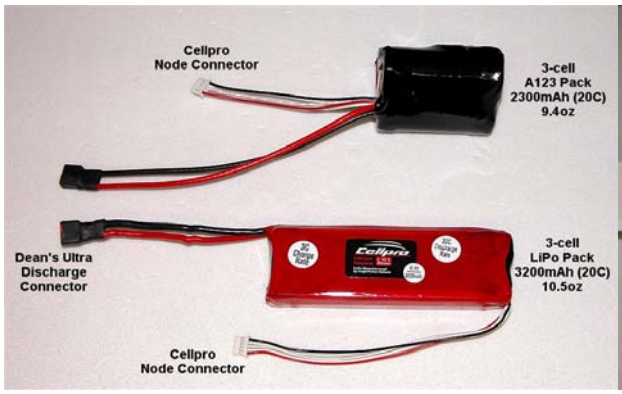
http://www.rcgroups.com/forums/showthread.php?t=599431

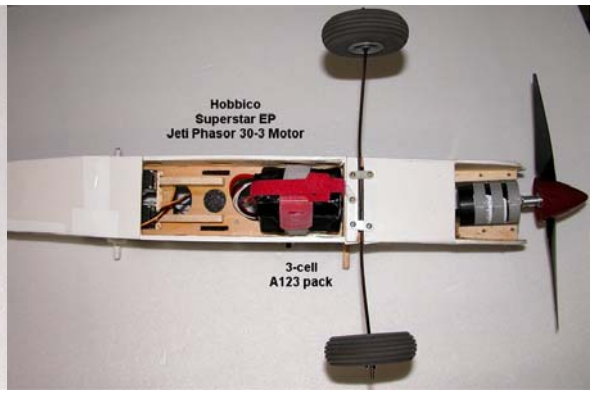
http://www.rcgroups.com/forums/showthread.php?t=525664

http://www.wattflyer.com/forums/showthread.php?t=11945

http://www.rcuniverse.com/forum/forumid_450/tt.htm

From the e-mail blast





<u>CellPro/Balance Pro is the best thing that has happened to A123 cells!</u>

NOTE: CellPro 4S charges either normal Li Pos or the A123 packs without need to change anything.

A123 packs benefit greatly from use of FMA charge and control technology in that the service life and customer satisfaction for the packs are enhanced. The higher the cell count in the pack, the greater the need for using FMA cell balancing technology. The A123 cells specifically have a very abrupt drop in voltage at the end of discharge that can lead to pack unbalance. That characteristic can be countered effectively using the Discharge Protection Module (DPM). The A123 cells are not damaged by undervoltage at 2.5V but do suffer shortened life if voltage is allowed to drop below about 0.5V such as happens when left with the receiver/servos attached for a period long enough to drain the pack. CellPro still recovers the pack from over discharge but its cycle life is shortened somewhat. CellPro still lets you get the best you can out of the damaged pack. If you use the DPM and CellPro/BalancePro from the start, the cells will last for more than 500 cycles if not severely overloaded or overheated.

Everything is automatic; just plug and play.