Discharge Test for Bluefin Battery #0182/B6

MBARI took delivery of three Bluefin pressure tolerant batteries in June of 2005, serial numbers #0179, #0180, and #0182. These units have been used in both the MBARI CTD vehicle and mapping vehicle over the last year. The first runs with these batteries occurred on August 18th of 2005. To date, the batteries have seen 16 discharge cycles to ~85% depth of discharge, and ~20 discharge cycles to <50% depth of discharge. The batteries have seen >2000 pressure cycles to depths of 100m or more, as well as two pressure cycles to a depth of 500m. The typical configuration of the MBARI vehicles contains three batteries.

Early in the use of #0182, after approximately 5 discharge cycles and 1100 pressure cycles to 100m, one of the temperature sensors began exhibiting intermittent full scale readings. Further analysis of the data showed these readings to be cyclic with depth; as the vehicle descended, the temperature sensors would read properly, and as the vehicle ascended shallower than ~10m, it would read full scale. Further in-lab checking showed the sensor leads to be open circuit in the lab, indicating that the internal connections had broken. The most likely cause of this, based on past experience, was fatigue stress on the lead caused by the battery compressing and expanding with pressure.

A second anomaly occurred during the fall of 2005, when it was noticed that Cell5 of battery #0179 was 30mV lower than the other cells in the battery after a charge. Although this imbalance can be removed by balancing the battery, the balance history of the battery up to that point had been excellent. The ongoing concern is that a one of the cells of the quanta has become internally detached, again due to fatigue stress building up when the battery is pressure cycled. A similar problem has been noted in one of the Scripps Institute of Oceanography batteries (again on cell 5).

Beginning in 2006, MBARI began operating its CTD AUV without ship escort. The nominal flight profile is a 19 to 20 hour survey during which the vehicle undulates between 2m and 100m or 250m, depending on the survey. After 7 of these surveys, a noticeable loss in capacity occurred between these three batteries. To quantify this, we are performing constant current discharge tests on the batteries. We're still in the process of performing these tests, but the testing for #0182 is complete and will be presented here.

Battery #0182 Test 5/26/2006 to 5/27/2006

Battery #0182 was discharged at a rate of 4.0A using a programmable DC load. The battery had been fully charged prior to the test using a 4A/3A/2A charge profile, to a cell voltage between 4.14V and 4.16V. The discharge test was interrupted at ~3 hours elapsed time, for ~25 minutes, due to a computer glitch; the discharge current was set to 0A during this period. The discharge test ended after an elapsed time of 15:10, when the battery turned off due to low voltage on Cell 5. A graph of the discharge is shown in Figure 1.

Battery #0179 Test 5/27/2006 to 5/28/2006

Battery #0179 was discharged at a rate of 4.0A using a programmable DC load. The battery had been fully charged prior to the test using a 4A/3A/2A charge profile, to a cell voltage between 4.14V and 4.16V. The discharge logging was interrupted for 30 minutes at 3.5 hours elapsed time due to a problem with the logging program. During the glitch, discharge was maintained at 4.0A. Discharge ended after an elapsed time of 14:57, when the battery turned off due to low voltage on Cell 5. A graph of the discharge is shown in Figure 2.

Battery #0180 Test 5/28/2006 to 5/29/2006

Battery #0180 was discharged using the same procedure as the other two batteries. Initial cells voltages were between 4.13V and 4.14V. There were no interruptions in the discharge. Data is plotted in Figure 3.

Conclusions

Battery S/N	As-Delivered Capacity		Measured Capacity		Cell Voltage @ End of Discharge							
	Ah	Wh	Ah	Wh	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
#0179	80.71	2434.1	60.01	1834.8	3.42	3.65	3.62	3.43	3.15	3.64	3.64	3.28
#0180	77.21	2345.4	64.63	1977.7	3.64	3.64	3.64	3.48	3.14	3.56	3.63	3.33
#0182	76.80	2332.4	62.02	1907.3	3.61	3.66	3.65	3.62	3.16	3.65	3.66	3.50

Table 1 Discharge Test Results

Based on the data collected during this discharge, battery #0182 retains a capacity of 62Ah/1900Whr. The original test data for the battery showed a capacity of 76.8Ah/2332Whr. A capacity loss of almost 20% has occurred. Similar overall capacity changes have occurred in the other two batteries. This is well outside of what would be expected from the limited number of discharge cycles the unit has undergone. A review of operational discharges shows that this change has accelerated with unattended operations. These runs incur substantially more undulations. It should also be kept in mind that our discharge test was done at a substantially lower current than the data reported in the acceptance test. Had we conducted our test at higher current, the measured capacity would have been slightly lower due to cell impedance.

The discharge tests show that cell 5 and cell 8 of batteries #0179, #0180, and #0182 are the most affected. Other cells (highlighted in Table 1) show a lesser degree of capacity decrease. To date, MBARI has now seen problems with low voltage/capacity cells 5 and 8 in four batteries (MBARI #0179, #0180, #0182, and SIO #0162/Cell 5) that underwent cyclic pressure service. It is my conclusion that there exists a flaw in design, assembly or construction of the batteries which is aggravated by a large number of pressure cycles.

Past testing has shown that the individual Li Polymer cells making up these batteries can compress and change volume by 1% to 2%, translating to almost 1 inch of dimensional change in the battery. Although we haven't repeated that test with these particular

batteries or cells, its not unreasonable to expect that some compression still occurs. This cyclic dimensional change can exert substantial fatigue stress on the internal components of the batteries (which are all bonded together by the urethane potting), in particular the tabs joining the cells together. Fracture of these tabs would lead to exactly the problem we have documented here. If this is the failure mode, then we may likely see an accelerating trend of damage (and capacity loss), since the cell tabs at this point have been exposed to a large number of fatigue cycles and fracture may be imminent.

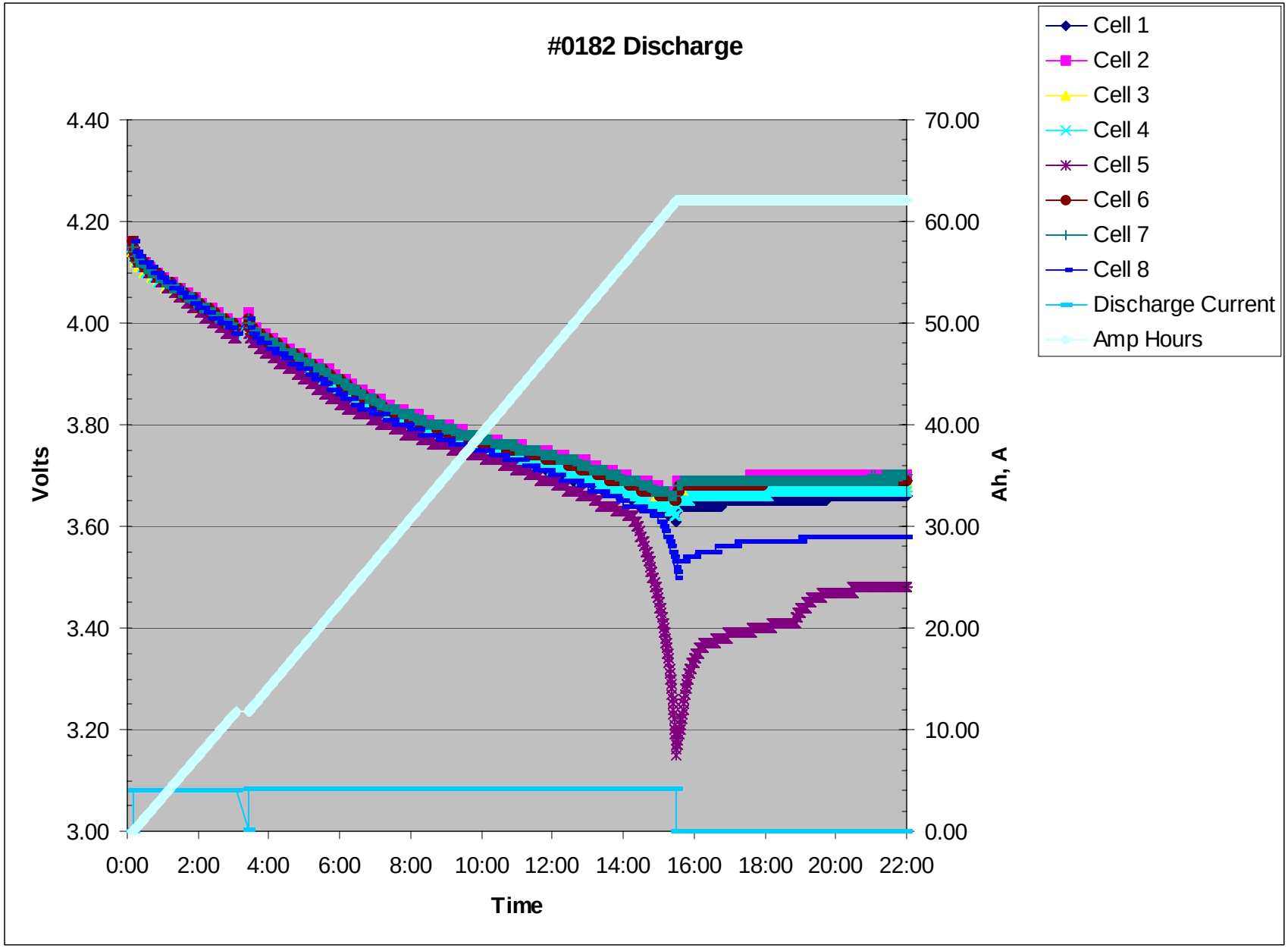

Figure 1 #0182 Discharge

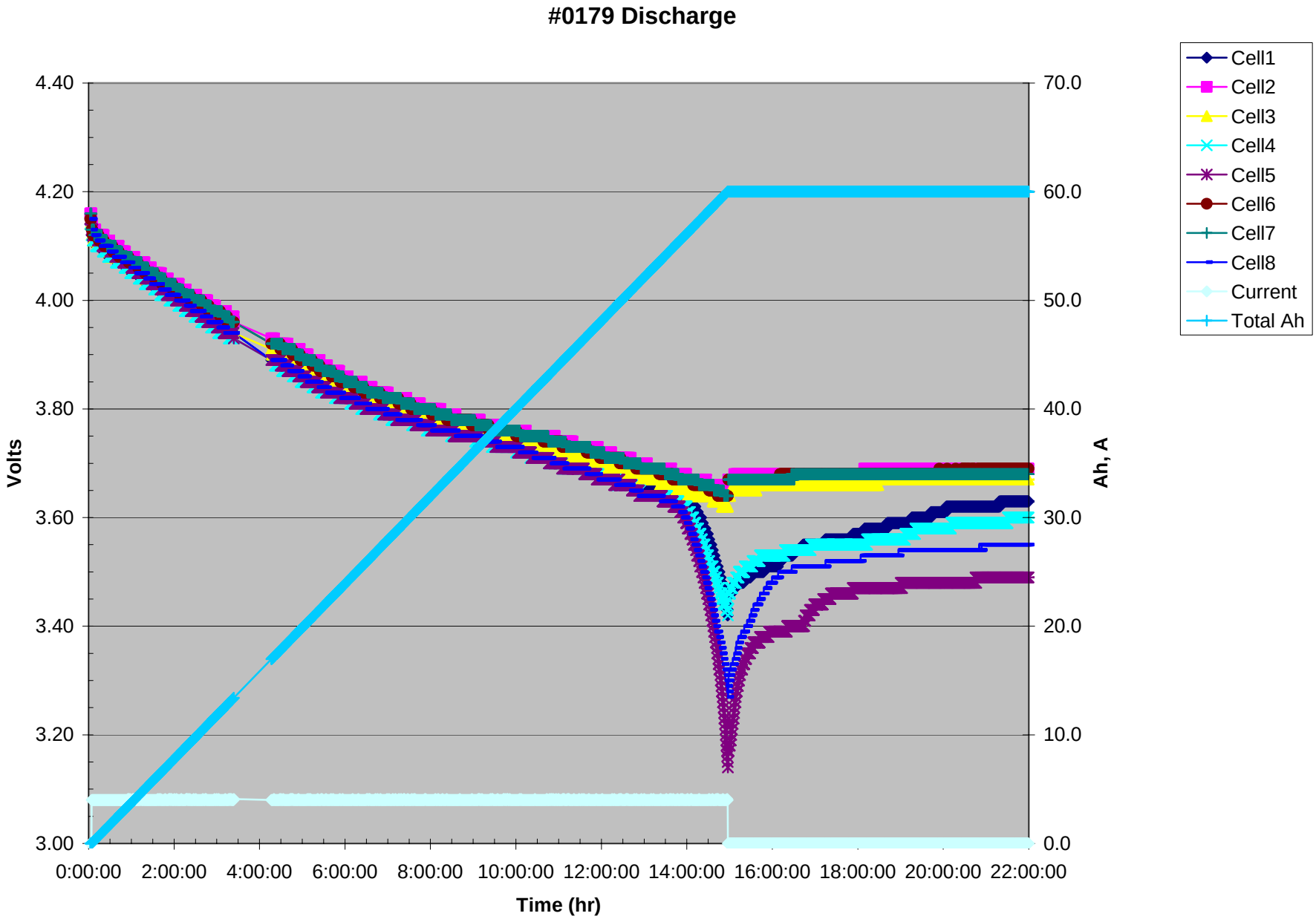

Figure 2 #0179 Discharge

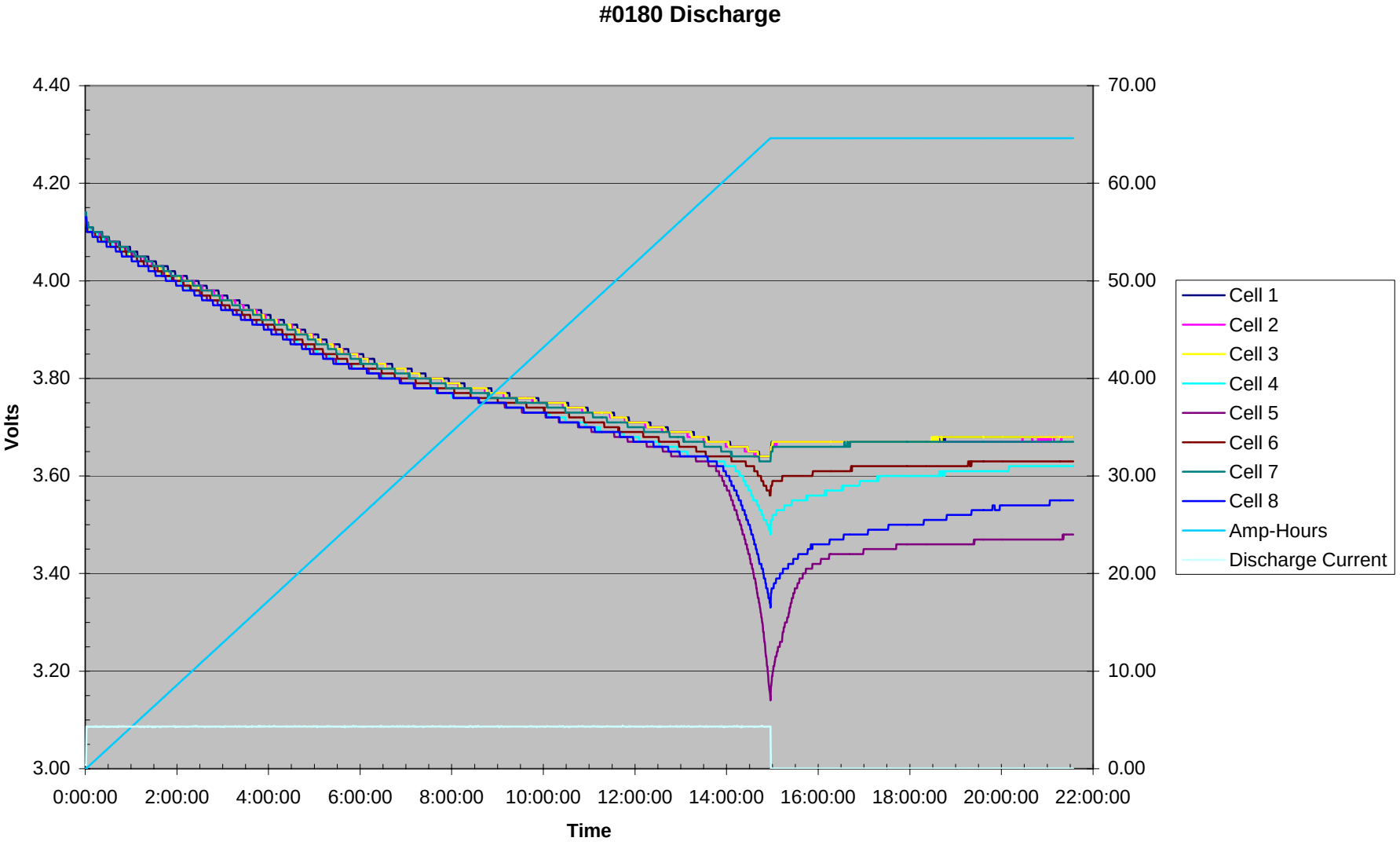

Figure 3 #0180 Discharge