Battery Situation on *s/v Beatrix* – May 2010

History

The existing main battery bank on *Beatrix* consists of 4 pairs of Lifeline GPL-4CT 6-volt batteries with a capacity of 220AH per pair. These were installed new in Sept. 2007 (see Fig. 1) and were acquired directly from Lifeline in Azusa, CA. At that time I the charging source was nearly always shore power at the dock plus attempting to work with a Panda AGT 265A DC genset. This generator was according to its specifications a perfect solution, but in practice was nothing but trouble and it was finally sold in March 2009 in Australia. That is another story, but it did change our ability to properly charge the batteries during our offshore passage.

We had to use the main engine plus solar for much of our Pacific Crossing until we reached American Samoa in Oct 2008 where we bought a small 2KW Honda EU2000i. This is an inexpensive, a brilliant and reliable machine which can deliver up to 90 amps DC through the Outback FX2012 inverter/charger. Once we had the Honda we were able to properly charge batteries on a daily basis.

Daily records are available kept of the amp-hours used as reported by the Link-10 battery monitor. We also monitor charging amps, house voltage, and ending amp-hours. The records show a steadily deteriorating battery capacity over the last 2.5 years since the batteries were installed.

The batteries were originally installed as 4 pairs of parallel strings of 6-volt pairs. In 2008 I learned that parallel strings seriously reduce the lifetime of batteries due to inequalities in the internal resistance (impedance) of each parallel string. The estimate is a 30% reduction in battery life for each additional parallel string. Because the battery strings are in a "star" patternwith a common bus it was easy to switch to using 3 pairs of parallel strings and rotating one pair every month. (see Figure 1 below)

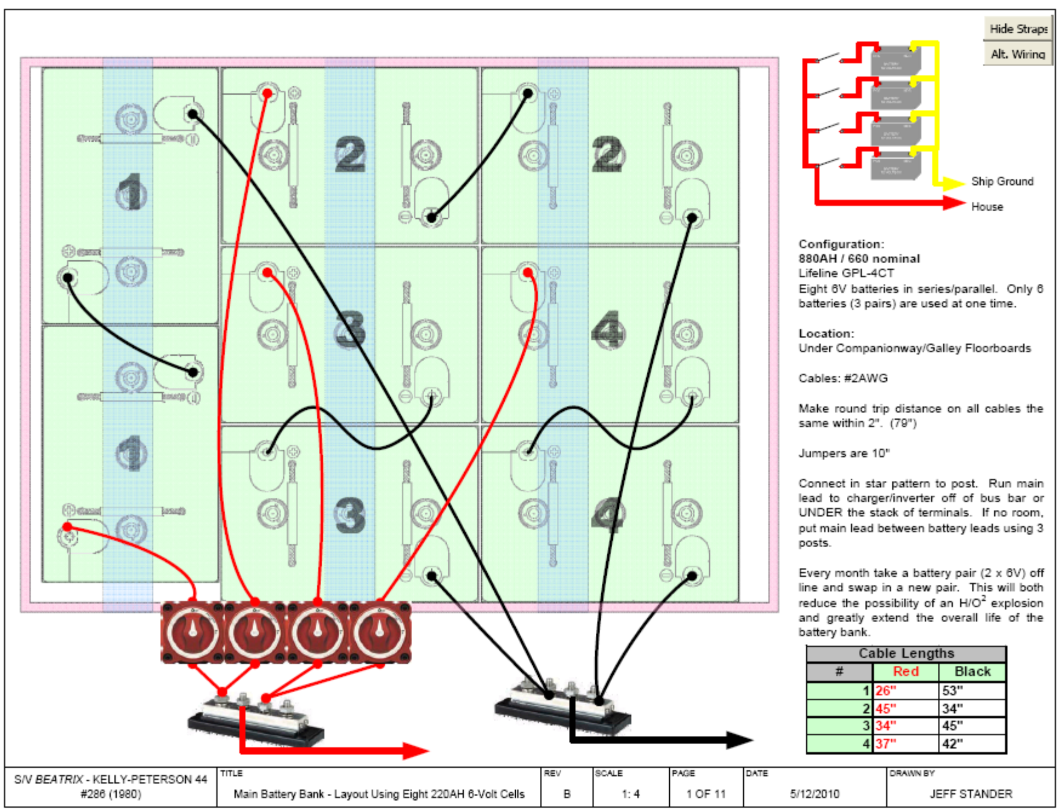

Figure 1. Existing Main Battery Bank

Daily Energy Budget

We have at times consumed up to 260 AH/day while at anchor. This is partly due to lack of paying attention to the daily power consumption, which can vary considerably depending on what we are doing.

Although one daily charge in the morning allows us to run 1 refrigeration cycle (24AH) plus inductive loads from the coffee maker and toaster while the Honda 2KW generator is running, it doesn't necessarily always work. To keep loads down we are now running the genset at night to use up another refrigeration cycle (about 25 AH per cycle).

In trying to understand where the power is going I have updated the DC load chart (see Appendix). This updated chart and estimated power consumption has led me to believe a battery bank of 900 AH will fit the requirements for 3 "days of autonomy", i.e. there is enough capacity in the bank to run the boat for 3 days without exceeding 50% of the AH capacity of the bank.

We have 270 watts of solar power in two panels and are in the process of installing another 160 watts for a total of 430 watts. The maximum real output we should then see from all panels is 24 amps. This means we could realistically expect 80 to 100AH per day from solar panels. For the Energy Budget Analysis I have assumed that we can get 50AH per day.

Charging

My notes from 31 May 2007 quote Andrew at Lifeline as recommending the following:

- The batteries must be FULLY CHARGED every day.[1]
- If partially discharged, don't let them sit at that lower level.
- They need to be run up at the 14.2 volt charge until they are accepting about 2 amps or less
- The solar panels will only work to "top up" the charge IF the bulk/float setting is high enough. Trace C40 manual recommends 14.4v/13.4v. Lifeline recommends 14.2 volts.

Note that the Trace has been replaced with a BlueSky 2510 MPPT unit.

On a sailboat off-the-grid, which we are for months at a time, getting a complete charge every day is difficult. I strive to put back all the amps used every day, but that last 10 amp-hours is difficult. We would have to turn off everything in the boat and let the solar cells top up the batteries. I'm hoping the new solar panels will give us enough extra power to allow a daily full top-up of the batteries to a float of 2-3 amps while replacing every AH used.

We usually charge in the morning. If the AH deficit is deep we have been using the main engine which can generate up to 200 amps of DC with it's two high-capacity alternators (100A + 210A). Once the charging load drops to about 100 amps we switch to the Honda, which can put up to 90A of DC power into the batteries via the Outback inverter/charger. As the charging load drops off, the Honda slows down, and when the input is around 12-15 amps we stop charging. This is when the solar should come into play. However, there are days when we need to keep using power which negates the positive solar input; and sometimes the sun doesn't shine. More panels will help.

[1] This is clearly impossible on a cruising sailboat

Equilization

The recommendations of the battery manufacturer and others are widely disparate. Most experts agree that a bi-annual maintenance equalization is required even of AGM batteries. However, the times and voltages vary widely. On July 6, 2007, Dave at Lifeline recommended 15.5V for 3 hours. Tom at thesolar.biz strongly disagreed and instead recommended 15.0 volts for 1 hour. I have been equalizing the batteries, one pair at a time, using 15.1V for one hour every six months. Standard procedure is followed where the batteries are all fully charged first.

Andrew at Lifeline was sent a copy of our recent load test by John Redmon. He replied:

> *The attachment that show a "load test" is simply a battery usage graph. If you look closely you see that the batteries are 50% discharged before he starts using them. Would seem to me that they are not charging the batteries properly. Fully charged my batteries should read 12.85 to 12.9v. If he is unable to get the batteries above 50% state of charge than they have sulfated as a result of under charging. He may be able to reverse the damage if it has not been happening for a long period of time by equalizing the batteries. He will need to charge the batteries at 15.5v for 10 hours non-stop. He will need to insure that he has charged them up as much as possible prior to equalizing.*

I think Andrew did not understand that the batteries **can not be charged above 12.7** (see voltage test below). Dave made it very clear in 2007 that it was important to fully charge the batteries and have striven to do so. Many cruisers only charge to 80% of capacity. Unlike those sailors, we spend lots of liters of petrol or diesel charging the batteries back to (or very close to) the "full" state every day, attempting to return every amp-hour removed. These batteries simply do not have the capacity for a complete charge anymore.

What I am most concerned about is his recommendation that we give them a 15.5v equalization for 10 hours non-stop. I've never heard of subjecting AGMs to such a high voltage for so long. Would that actually give us more life out of these batteries or is it a "Hail Mary" play that can do even more damage if it doesn't work?

Voltage Test

A resting voltage test was recently performed in May 2010 on each pair of 6-volt batteries. This involved fully charging the batteries and then measuring the voltage after at least 8 hours. The results indicate that the batteries are definitely not dead, but certainly diminished[2].

RESTING VOLTAGE TEST - 12 HOURS				
Battery	1	2	3	4
Volts	12.70	12.70	12.71	12.73

Load Tests

Load tests as specified by Dave of Lifeline Batteries were performed in Aug 2009 and May 2010. After full charging the battery is subjected to a constant load and the voltage monitored every hour. All batteries had similar results. Below are the results for Battery pair #1. It appears to show that the batteries can only supply 50 amp-hours at best, well below the rated 50% capacity of 110AH.

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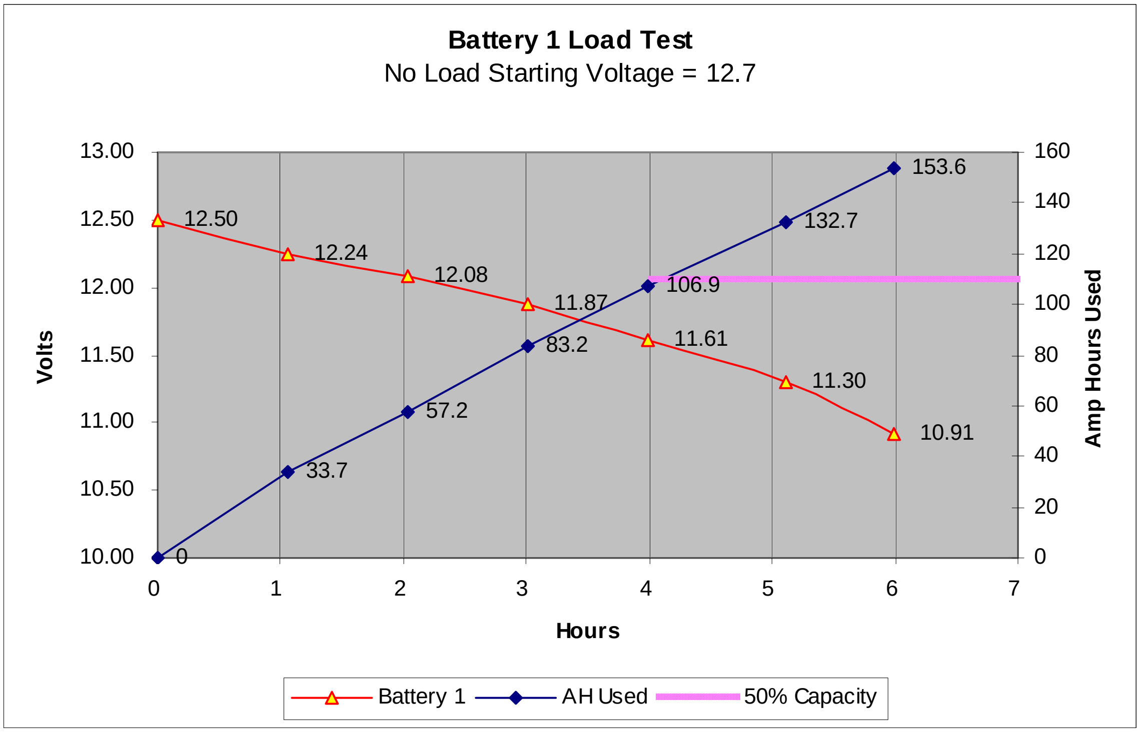
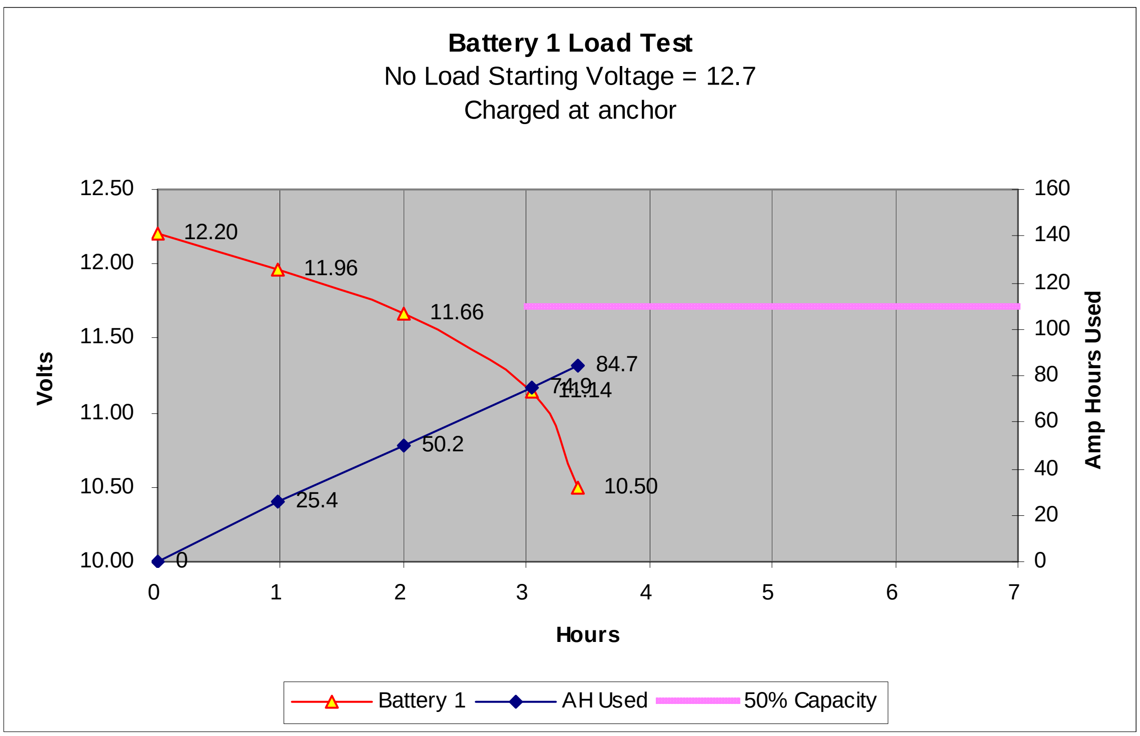
[2] Patty at thesolar.biz states that a resting voltage test of at least 8 hours (preferably 24 hours) on a fully charged six volt battery should show 6.6V when new and 6.2V or below if dead. The battery is not subjected to any charge or load during the rest time.


Battery 1 Load Test
No Load Starting Voltage = 12.7
Volts
Amp Hours Used
Hours
12.50
12.24
12.08
11.87
11.61
11.30
10.91
0
33.7
57.2
83.2
106.9
132.7
153.6
Battery 1
AH Used
50% Capacity


Battery 1 Load Test
No Load Starting Voltage = 12.7
Charged at anchor
Volts
Amp Hours Used
Hours
12.20
11.96
11.66
11.14
10.50
0
25.4
50.2
74.9
84.7
Battery 1
AH Used
50% Capacity

Questions

1. Equalization? Should I continue with the bi-annual equalization or go for the “Hail Mary” equalization that Andrew recommends?
2. If I charge the batteries fully in the morning with the generator and solar sources, and then run the generator in the evening for an hour to cover a refrigeration cycle, how will this affect battery life? It reduces the daily load on the batteries, but it also puts 50-70 AH into the batteries as well while they are about 100-120AH in deficit.
3. Sometimes, due to weather or other situations I cannot do a full charge, especially that last 10Ah at 2-4 volts. The ideal is a full charge every day but if that is not achievable, what is a rule of thumb for charging? I.e. what is the impact of only doing a full charge every other day, every third day, every week? There are lots of conflicting opinions about this.
4. Another way of putting question 3. If you were able to charge all but the last 10AH every day, what impact would that have on battery life?
5. Does “co-consumption” make any sense? E.g. using the small generator more than once a day to power a refrigeration cycle, or using solar panels to offset consumption.
6. Since the batteries are already at 50% capacity, should I combine all 4 parallel strings for the next six months, or continue to only use 3 strings at a time?

Conclusion

We will be trying to make our battery bank last until November, when we will have finished our cruising for the year.

A re-assessment of our daily loads (see Appendix) has resulted in a Nominal Daily Load of 140AH. In practice this load could exceed 200AH at times.

I am convinced that the optimum 12V sailboat cruising battery bank is a single string of 2V cells. Even better would be two equal banks made of 2V cells, but unfortunately that is too heavy, too expensive, and too space consuming.

Although the death of a 2V cell is very unlikely, there is room for a single 220AH GPL-4D 12V battery as a backup and emergency battery. (Note: the engine start battery is an Optima AGM which is charged with a Balmar Digital Duo Charge combiner).

Although a 1200AH bank made of six GPL-L16-2V cells would be best, it requires a rebuilding of the aluminum battery tray under the floorboards.

The simplest replacement single-string battery bank would be a 900AH bank of six Lifeline GPL-6CT-2V batteries. Even though it is comparable in capacity (900AH vs 880AH) to the old bank of 4-strings of 6-volt series pairs, it should last a lot longer because there will be no parallel string degradation. Also 2V cells are much more robust and rarely, if ever, fail. If we can use power management and co-consumption to reduce the daily load and keep the 3 days of autonomy, then these batteries will not be cycled as deeply, which seems to be the other reason our existing bank has degraded.

s/v *Beatrix*
Hawkesbury River, NSW, Australia

Appendix I. DC LOAD ANALYSIS FOR s/v Beatrix

USE	POWER TYPE	LOAD IN DC AMPS	\@ Sea 15%		@ Anchor 85%	
			Average Daily Use (hrs)	Amp-hours	Average Daily Use (hrs)	Amp-hours
Laptop PC	DC	1.0	2.00	**2.0**	8.00	**8.0**
Computer Monitor	AC	5.0	2.00	**10.0**	8.00	**40.0**
HF Radio, Xmit	DC	15.0	0.10	**1.5**	-	**-**
HF Radio, Rcv	DC	1.0	1.00	**1.0**	-	**-**
Radar, Standby	DC	1.5	2.00	**3.0**	-	**-**
Radar ON	DC	3.5	1.00	**3.5**	-	**-**
Inverter, Stdby	DC	1.0	-	**-**	-	**-**
VHF Radio ON	DC	4.0	0.10	**0.4**	0.20	**0.8**
VHF Radio, Stdby	DC	0.5	24.00	**12.0**	-	**-**
GPS	DC	0.1	24.00	**2.4**	-	**-**
Stereo System	DC	1.0	2.00	**2.0**	4.00	**4.0**
Windlass	DC	80.0		**-**	-	**-**
Propane Solenoid	DC	0.7	2.00	**1.4**	2.00	**1.4**
Autopilot	DC	4.0	20.00	**80.0**	-	**-**
Nav Instruments	DC	1.2	24.00	**28.8**	-	**-**
Tricolor	DC	1.2	12.00	**14.4**	-	**-**
Anchor Light	DC	1.2	-	**-**	12.00	**14.4**
Compass	DC	0.1	12.00	**1.2**	-	**-**
Chart Lt	DC	0.5	1.00	**0.5**	-	**-**
Bunk Lts	DC	1.2	1.00	**1.2**	1.00	**1.2**
Red Night Light	DC	0.5	10.00	**5.0**	-	**-**
Cabin Lights	DC	3.2	4.00	**12.8**	4.00	**12.8**
Spreader Light	DC	1.0	-	**-**	-	**-**
Watermaker	DC	12.0	1.00	**12.0**	-	**-**
Refrigeration	DC	23.5	4.00	**94.0**	4.00	**94.0**
Bilge Pump	DC	3.5	-	**-**	-	**-**
Shower Pump	DC	7.0	0.10	**0.7**	0.10	**0.7**
Water Pump	DC	7.0	0.50	**3.5**	0.50	**3.5**
Washdown Pump	DC	50.0		**-**	-	**-**
Vacuflush	DC	20.0	0.40	**8.0**	0.40	**8.0**
Cabin Fan	DC	0.5		**-**	12.00	**6.0**
Blowers	DC	1.0	-	**-**	-	**-**
Vampire Loads	DC	1.4	24.00	**33.6**	24.00	**33.6**
				-		**-**
Espresso Machine	AC	90.0		**-**		**-**
Toaster	AC	80.0	0.05	**4.0**	0.05	**4.0**
TOTAL				**338.9**		**232.4**

CO-CONSUMPTION

Power management and solar input offsets amp-hours drawn from the batteries.

USE	POWER TYPE	LOAD IN DC AMPS	@ Sea 15%		@ Anchor 85%	
Power Mangement	DC			**59.5**		**57.0**
Wind Generator	DC			**-**		**-**
Solar Panels	DC	17.0	6.0	**102.0**	6.0	**102.0**
TOTAL				**177.4**		**73.4**

DAILY LOAD IN AH	12 hrs	24 hrs	48 hrs
Sail	169	339	678
Anchor	116	232	465
Weighted Average	124	248	497

DAILY LOAD IN AH	12 hrs	24 hrs	48 hrs
Sail	89	177	355
Anchor	37	73	147
Weighted Average	45	89	178

Lights	
Sea	**Port**
14.4	-
-	14.4
1.2	-
0.5	-
1.2	1.2
5.0	-
12.8	12.8
-	-
35.1	**28.4**

NOMINAL DAILY LOAD 140.0 **AH**

The above is a weighted average of land and sea loads less 50% of expected solar input

Batteries die faster if drawn down consistently every single day.
Cycled with one day of autonomy (50% discharge every day)

Batt Size (AH)	Optimum AH for 3 DOA	Days of Autonomy
1200	200	4.29
900	150	3.21
880	147	3.14
660	110	2.36
330	55	1.18