CoP Measurement Methodology

The methodology laid out below can be used for a variety of devices and setups and involves using either the energy (kJ) or the charge (Ah) supplied to the system, and that available from it.

Whereas at one time the discharge stage was conducted first, conceptually it made sense to reverse this on the basis that in practice one wants to use the energy that has been imparted to the battery by pulse charging, after it has been delivered.

Supply/PSU:

The use of a PSU makes sense here when testing a single receiving battery with the swapper turned off, and makes it easier to manage and adjust the voltages as part of the parameter adjustments as well avoiding having to keep charging up a supply battery.

In my case the feed from the PSU goes to the v4 PCB, via a recording digital multimeter, where it passes through the main relay which determines which of batteries 1 or 2 is supplying the input. With the swapper switched off and battery 1 (PSU) set as the supply, and the feed goes out through an output terminal where additional loads can be attached. This route bypasses the optional Buck and Boost converters that would otherwise allow adjustment of the coil voltage feed if the PCB was being fully used as normal. The v4 PCB output terminal connects directly to the power input of the BD1 PCB (SSG) device.

During the typical hour long charging run, the current is measured by the RDM but not necessarily recorded, depending on how much variation in the current occurs. Usually the current is very stable and is recorded to a precision of 10mA at some point during the run.

Charging battery:

The charging battery had, up until recently, been connected to the HV pulse output via a connection hub, where various other connections to the positive terminal are connected. However, tests showed that much better charging occurs when the output path is uninterrupted and without the presence of lumps of conducting material that might disrupt the flow.

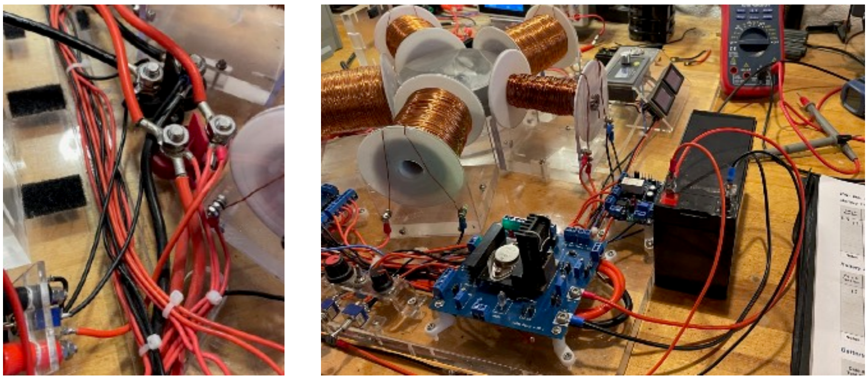

Fig 1: Charging battery and CBA connections

As can be seen in the pictures, the charging battery is now connected directly to the output, resulting in minimal disruption to the surface orientated energy flow. The CBA connection directly off the battery terminals and, although its presence might make a small difference to the energy flow, it is required for the graphical measurements.

Using larger capacity batteries will require custom made cables to suit the battery placement, but a larger than normal wire gauge will likely minimise unwanted losses. In this setup with a small 7Ah AGM battery, I am using 16awg silicone coated wire and with the larger batteries (18, 40 & 100Ah) I will be using the 12awg version.

Procedure:

The procedure steps are as follows:

1. With the PSU supply on, the CBA monitor is started and the rotor is spun quickly up to a speed of about 500rpm using a rubber arbor attached to a drill on its top surface. A timer is started as the PCB ‘on’ switch is turned on, lighting the power led on the PCB.

2. After exactly 1 hour (3,600s), the power to the PCB is turned off and the rotor slowly spins down. The CBA is left on for another hour and then switched off, resulting in a final charging trace such as shown in Fig 2. As is normal, the peak voltage reached during charging gradually drops to a stable value and this is the value used later in the CoP calculation.

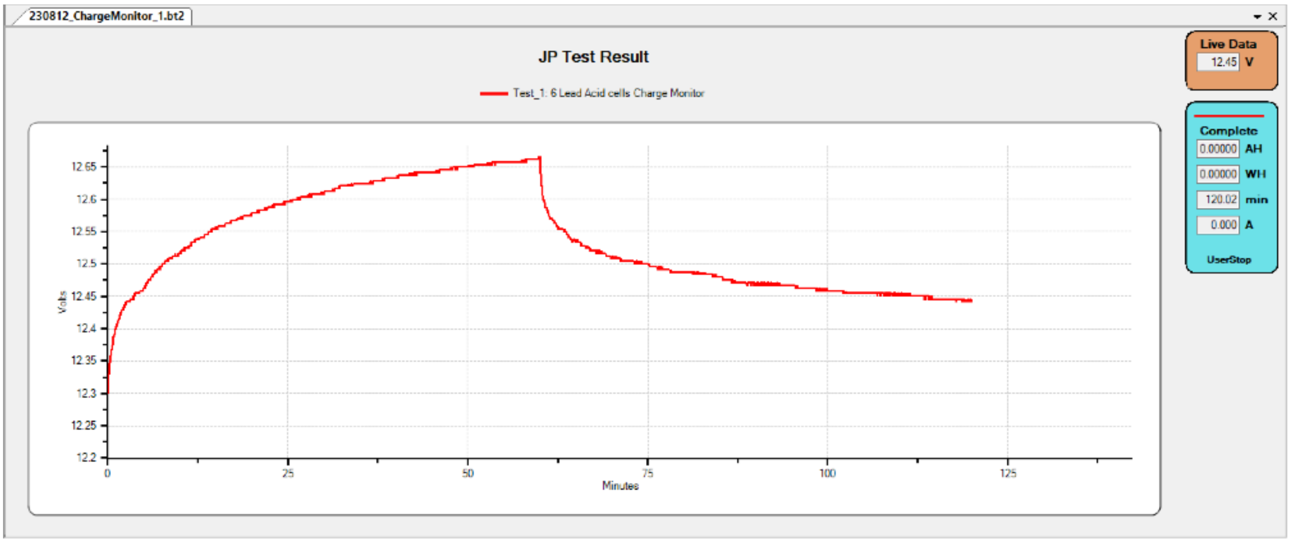

Fig 2: Typical 60 min charging curve with 60min rest period after

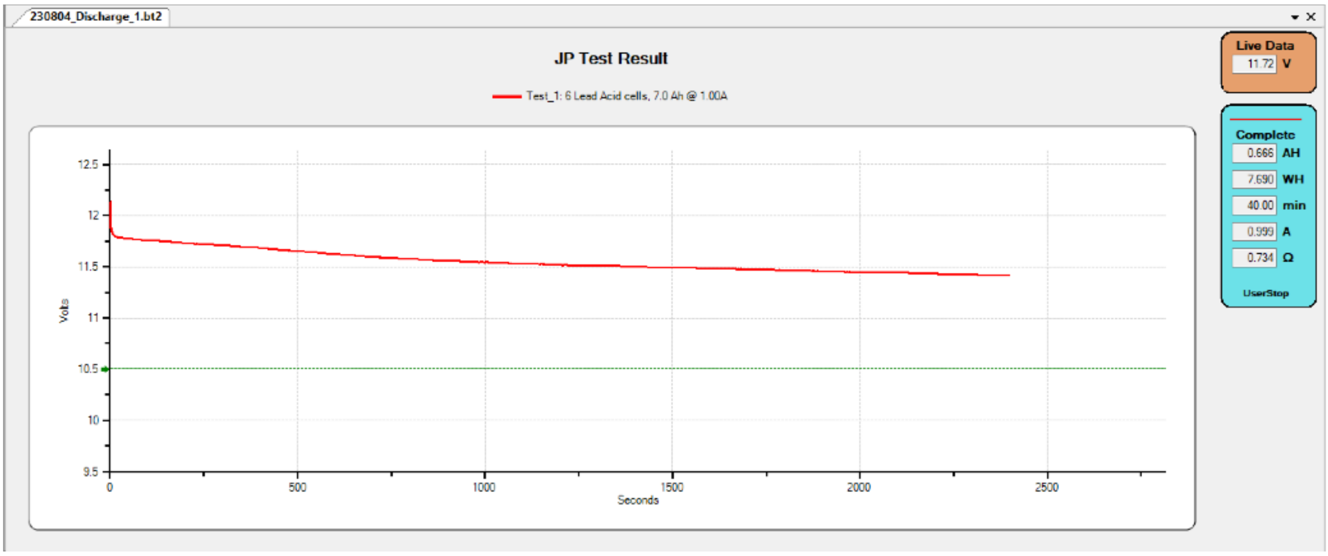

Fig 3: Typical discharging curve with 60min rest period after charging

3: The CBA is then set to run a 'Discharge' test for typically 20min @ 1A. An example of a discharge graph is shown in Fig 3 and where this one is not the actual one that followed the charging shown in Fig 2 (at the moment the discharge graphs are not always saved). The important figures that are recorded are the total Ah and Wh (charge and energy released values) and where the Wh is converted to kJ (1Wh = 3.6kJ) and added to the '$E_{(Disch.)}$' column in the spreadsheet shown in Table 3.

4: The battery is again rested for 60 mins to allow the chemistry to rebalance and this will cause the voltage to bounce back towards its starting value after the voltage drop, caused by being under load during the discharge. The settled value is taken as the battery voltage after discharge and used to derive a corrected energy discharge value for the CoP calculation, as explained later.

5: With the various figures now recorded, the CoP value can be calculated.

Test No.	Ah	B1 ID	Start %Ah B1 [1]	B2 ID	Start %Ah B2 [1]	%Ah drop [2]	Mode (S/D/R)[3]	Wiring (GS)[4]	PRF (Hz)	Duty (%)	kV	Trig	Core /Gap	Dev	Diode	Run Time (s)	Coil V (Load)	Ext. Load (W)
13	7	PSU	---	B6	---	---	R	G	54	50	0.15	Coil	R45/4	MJ	IN	3,600	12.01	0
14	7	PSU	---	B6	---	---	R	G	57	50	0.15	Coil	FR/4	MJ	IN	3,600	12.11	0
15	7	PSU	---	B6	---	---	R	G	53	50	0.15	Coil	R45/4	2N	IN	3,600	12.19	0
16	7	PSU	---	B6	---	---	R	G	53	50	0.15	Coil	R45/4	MJ	SC	3,600	12.18	0
17	7	PSU	---	B6	---	---	R	G	47	50	0.15	Coil	R45/4	MJ	IN	3,600	12.18	0
18	7	PSU	---	B6	---	---	R	G	45	50	0.15	Coil	R45/4	MJ	IN	3,600	12.20	0
19	7	PSU	---	B6	---	---	R	G	60	50	0.15	Coil	R45/4	MJ	IN	3,600	11.50	0

Total Current I (A) [6]	Start V1 [7]	End V1	dV1	Start V3 [8]	End V3	dV3	CoP	CBA Test ID	Screengrab File
0.26	12.30	12.45	0.15	PSU	PSU	---	**1.16**	*120823-Charge Monitor_1-1.bt2*	*120823-Charge Monitor End 1.png*
0.33	12.22	12.40	0.18	PSU	PSU	---	**0.96**	*130823-Charge Monitor_1-1.bt2*	*130823-Charge Monitor End 1.png*
0.30	12.17	12.33	0.16	PSU	PSU	---	**0.95**	*130823-Charge Monitor_1-2.bt2*	*130823-Charge Monitor End 2.png*
0.26	12.15	12.29	0.14	PSU	PSU	---	**0.95**	*140823-Charge Monitor_1-1.bt2*	*140823-Charge Monitor End 1.png*
0.24	12.13	12.27	0.14	PSU	PSU	---	**1.03**	*140823-Charge Monitor_1-2.bt2*	*140823-Charge Monitor End 2.png*
0.24	12.07	12.22	0.15	PSU	PSU	---	**1.03**	*150823-Charge Monitor_1-1.bt2*	*150823-Charge Monitor End 1.png*
0.23	12.03	12.16	0.13	PSU	PSU	---	**0.93**	*150823-Charge Monitor_1-2.bt2*	*150823-Charge Monitor End 2.png*

Table 1: Spreadsheet data input for CoP calculation

CoP Calculation:

Now we have all the relevant data, a spreadsheet is used to automate many of the calculations.

The calculation process is as follows:

Input energy:

If using the energy method (kJ) then the supply energy is:

$E_{(supply)} = V \cdot I \cdot t$ kJ

and where I = the total current provided by the supply and so includes a small component for the PCB (30-90mA) as well as that flowing through the actual coils.

The pat of the spreadsheet that calculates the energy input value is not shown here but ends up in the ‘$E_{(supply)}$‘ column of Table 3 below.

Discharge Energy:

The energy available resulting from pulse charging is derived from a controlled discharge using the CBA, but also involves a small degree of interpolation or extrapolation depending on where the resting voltage ends up after the discharge.

To give an example, if the battery is charged from voltage A to voltage B and then discharged from voltage B down to voltage C, the voltage drop on discharge (B - C) might end up greater or less than the voltage rise on charging, since it is difficult to match it exactly. In this case a factor for the discharge energy is derived and used to correct the value of the energy discharged before it is used in the CoP calculation.

For example, if the voltage rise was 0.15V but the voltage drop was then 0.17V, the discharge energy is corrected by a factor of 0.15/0.17 = 0.88. This process assumes that the change of voltage with energy is linear, which is a reasonable assumption for small voltages changes on the linear part of the overall charging profile.

Test No	Charging (V)	dV (V)	Energy Supply (kJ)	Discharge (V)	dV (V)	Energy Disch (kJ)	$V_{Correction}$	Corrected E Disch (kJ)
	12.30	- -	- -	12.45	- - -	- - -	- - -	
13	12.45	0.15	**11.29**	12.22	0.23	20.16	0.65	**13.15**

Table 2: Discharge - Interpolation/extrapolation

To obtain the correction factor, Table 2 is used that derives a corrected discharge energy to use in the CoP calculation. This corrected value is inserted into Table 3 in the ‘Corrected $E_{(Disch.)}$ kJ’ column (numbered footnotes are not shown).

Test No.	Capacity (Ah)	%Ah	HV (kV)	PRF (Hz)	Core	Coil V (Load)	Charge V1	Charge V2	Disch. V3	Disch. V4	$E_{(Supply)}$ kJ [1]	$E_{(Disch.)}$ kJ[1]	Corrected $E_{(Disch.)}$ kJ[2]	CoP
13	7	- - -	0.15	54	R45/4	12.01	12.30	12.45	12.45	12.22	11.29	20.16	13.15	**1.16**
14	7	- - -	0.15	57	FR/4	12.11	12.22	12.40	12.40	12.17	14.43	17.66	13.82	**0.96**
15	7	- - -	0.15	53	R45/4	12.19	12.17	12.33	12.33	12.15	13.20	14.06	12.50	**0.95**
16	7	- - -	0.15	53	R45/4	12.18	12.15	12.29	12.29	12.11	11.44	14.00	10.89	**0.95**
17	7	- - -	0.15	47	R45/4	12.18	12.13	12.27	12.27	12.09	10.56	13.92	10.83	**1.03**
18	7	- - -	0.15	45	R45/4	12.20	12.07	12.22	12.22	12.03	10.54	13.81	10.90	**1.03**
19	7	- - -	0.15	60	R45/4	11.50	12.03	12.16	12.16	12.01	9.60	10.34	8.96	**0.93**

Table 3: Calculating CoP (without uncertainties)

The final stage is to divide the ‘Corrected $E_{(Disch.)}$ kJ’ column value by the ‘$E_{(supplied)}$ kJ’ column to give the CoP value based on energy values. This is shown in Table 3 but without also deriving the uncertainty values at this stage. At the point where the values have reached a degree of stability and repeatability, then that will also be done as described in the ‘Replication & Guidance’ manual for the earlier CoP work.

Using charge (Ah) method:

While it has not been explicitly done in the spreadsheet shown, a similar process using the charge (Ah) values can be used and which should give similar results.

An example is shown using the values in Test 13:

$Ah_{(in)}$ = 0.26A x 1h = 0.26 Ah

$Ah_{(out)}$ = 1.0A x (30/60 x 0.65)h = 0.325Ah. (for a discharge of 30mins @1A)

CoP = 0.33/0.26 = 1.27

The difference in the larger Ah derived value is due to the precision of the measured input current (to 2d.p) and the overall uncertainties for the whole procedure. Without accurate uncertainty calculations being used at this point, the uncertainty is estimated to be ± 5 - 10%. This will bring these two values into line with each other as their values fall within each others range, i.e. CoP value ± their uncertainty.

It is approbate in the case where both the energy and charge based values are derived to then take an average. At the moment the lower energy based CoP value is being used.

Changing Parameters:

With a methodology established, it is now straightforward to change one variable at a time to see how it affects the CoP. Such changes include the use of a different core, transistor, output diode and coil supply voltage, but can include other variables such as the use of insulated and uninsulated output cable and additional coils.

The coil load voltage in particular has a significant effect on the CoP while leaving all other factors the same. It is for this reason that the v4 replication PCB was equipped with various options to incorporate a Buck/Boost converter to precisely adjust the coil load voltage, or instead to use that supplied by the battery directly. Any small efficiency loss from the converters is more than made up for in the improvement in CoP from fine tuning the energy supplied to the coils.

When all variables have been tested, the CoP results will be presented in tabular form helping to guide decisions on parameters for others using an SSG, and by inference an SG, type circuit. As such these results will also inform the design and measurements using my next planned SG type device utilising 5 coils, each with their own switched channel.

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16th Aug, 2023