

Document history:

Rev. 1	22.08.2016	First version
Rev. 1.1	17.11.2017	Error regarding position of END label corrected UbatCh and UbatDch included

This application note shall help users to cycle batteries with the BaSyTec Battery Test System. It shall not replace the BaSyTec manual but give additional information, hints and advices.

Most procedures are given for Li batteries but the main principles may be used for other types of batteries as well.

The procedures given are tested with BaSyTec software version 6.1.10 and a BaSyTec CTS battery tester. It is no longer recommended to use version 5 today, and most procedures will not work with version 5 that way.

1. Introduction

There are three main tasks when testing batteries:

1.1. Parameter tests

To check the parameters of the battery for a given application, for example the actual capacity for a given discharge current (power, or current or power profile) at a certain (or different) temperatures (all that called operation conditions)

1.2. Lifetime tests

To check the lifetime of a battery for given operation conditions.

Unfortunately, that's not that easy.

Usually, the life of a battery is defined to end if the remaining capacity of the battery is less than 80% of the rated capacity (not the initial one!).

In general, there are 2 different lifetimes:

1.2.1. Calendar life

This is the time from production in months or years until the life of the battery ends, without regarding cycling. For some types of batteries (e.g. some Ni types do) the lifetime is in fact quite independent from cycling. Other batteries (like standby batteries) are usually not cycled during operation, so for them calendar life is the most important life time.

Calendar life may depend on:

- Temperature
- State of charge
- Charge conditions (when in float charge)
- Self discharge (when not in float charge) → will change state of charge
- Other environment conditions (humidity, vibrations, ...)

1.2.2. Cycle life

The cycle life is the number of cycles a battery may perform at given operating conditions.

There are:

- Full cycles

cycles between full and at least 80% depth of discharge (DOD)

- Partial cycles
cycles between any other state of charge (SOC)

As partial cycles may reach from less than 1% to 79% charge it's important to have a close look when comparing data. The absolute state of charge is also very important.

2. Implementation with the BaSyTec system

2.1. Basic cycling

The basic cycling of a Li cell is given in Procedure 1:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		U>1UBatMax&t>1s U<1UBatMin&t>1s			Basic cycling of a Li cell Rene Groiss - 17.11.2017
2		pause		t>5s		t=1s	
3		Cycle-start					
4		discharge	I=0.1CA	U<1UBatDch		U=20mV t=12min	
5		charge	I=0.1CA U=1UBatCh	I<0.01CA&t>1s t>15h	Next Goto END	U=20mV t=12min	
6		Cycle-end	count=500				
7	END	Pause		t>5s		t=1s	
8		Stop					

Procedure 1: Basic cycling

2.1.1. Global limits

We do strongly recommend to **always** use the voltage limits of the battery as a global termination (that is, the termination of the first line which will be valid for the complete test procedure).

The current limits are not that important because it's the voltage which will kill a battery.

It's not possible to insert both limits with the wizzard, the second one must be inserted manually (use CTRL-ENTER to get the second line) – or simply keep the given ones after creating a new procedure.

It is recommended to use the delay time for the global voltage limits. A short exceedance will not be critical for the battery, and the delay time will avoid the tests to stop if there is a short overshoot in charge voltage control or a short delay in switching off after end of discharge voltage detection.

2.1.2. Using the battery database?

Procedure 1 (and all others) are using the battery database for most parameters. This is recommended if different cells with different parameters shall be cycled with that procedure. If a parameter will be the same for all batteries that procedure will be used for it is more save to write fixed numbers in the procedure. For example, the voltage limits will be more fix than the rated

capacity.

In Procedure 1, both the parameters (like the charge voltage) and the limits (safety voltage limits) are used from the battery database:

The screenshot shows a 'View/edit battery' dialog box with the following fields and values:

Field	Value
Identifier	18650
Internal name (option)	
Manufacturer	***NoName***
Name	18650
Type	Li-Ion
Date of Manuf.	10.08.2014
Rated capacity	3 Ah
Nominal Voltage	3 V
No. of cells	1
Weight	0.66 g
Volumina	0.05 l
Maximum Voltage	4.3 V
Minimum voltage	2.1 V
Max. charge current	0.5 A
Max discharge current	0.6 A
Charge voltage	4.2 V
End of disch. volt.	2.5 V
Charge current	0.3 A
Discharge current	0.4 A

Figure 1: Battery Database

2.1.3. Pause as a first step?

It is recommended to always begin with a pause of few seconds for several reasons:

- Usually the open circuit voltage before the test should be registered
- If the polarity of the battery is reversed, the test will be stopped because of the global voltage limits before the output relays are closed. This will protect hardware with output relays from potential damage because of reversed batteries.

Of course, the initial pause may be prolonged if required.

2.1.4. Sample rate

With the sample rate, you'll have to keep the balance between:

- Sample as less data as possible in order to save space and speed up analyzing
- Sample enough data to get all required information

Usually you start with "better more than less". But you'd rethink it after some time (and experience) and check whether it is really required to create that amount of data.

It is recommended to use "dynamic sampling" (that is, do not sample with a fixed time interval but occasionally, for example on a certain voltage change – see Procedure 1.

That change should be

- Not less than the given precision of the tester
- Far enough away from noise (mainly important for delta-I sampling in constant voltage (CC) mode – therefore it is recommended to avoid that if possible)
- Small enough to plot smooth graphs

Example:

The voltage change for the battery VL1220 in all examples is 900mV (3.4V Charge voltage, 2.5V end of discharge voltage). For a smooth plot 50 points should be sufficient, so $900\text{mV}/50=18\text{mV}$. To get a “good” value 20mV are used. The precision of the BaSyTec CTS tester is 1mV, so that’s ok.

Regarding the time interval (especially for the CC phase:

0.1CA means 10h current, so it should take about 10h (=600min) to charge/discharge the battery. $600\text{min}/50 = 12\text{min}$.

2.1.5. CC/CV charge

It is recommended to program constant current / constant voltage (CC/CV) charging as shown in Procedure 1. If not necessary (as shown later), write both parameters in one single line. **Do never have only U in a line**, always combine with an I or P limitation!!!

Here, the charging is terminated after the charge current falls below a certain limit. If that limit is not reached within 15h the whole procedure will stop (programmed in the action column).

For the charge current termination, a delay time is recommended.

If the action column is used it is strongly recommended to fill in all lines to avoid errors– although “next” is not really necessary here. (Termination and action belong to each other line-by-line: so first termination line belongs to first action line, second termination line belongs to second action line, ...)

2.1.6. Registration format

The recommended registration format for that procedure is:

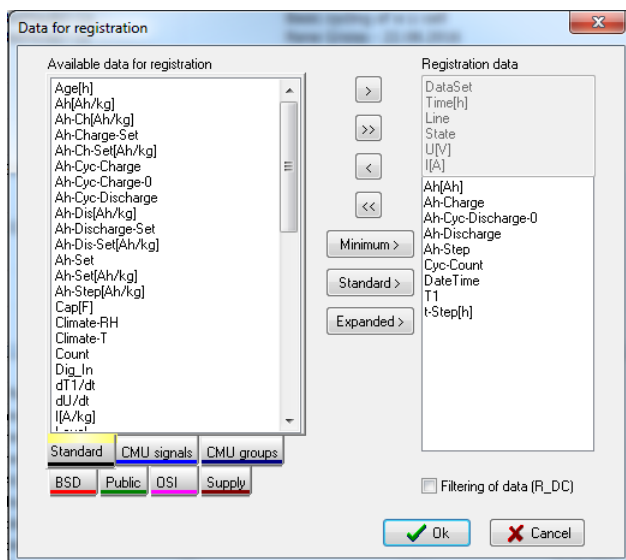


Figure 2: registration format – Cycle_Std.pln

- Greyed parameters – must be sampled
- Ah[Ah]: global ampere hour counter
- Ah-Charge: if the total charged ampere hours are of interest
- Ah-Discharge: if the total discharged ampere hours are of interest
- Ah-Step: will give the charged and discharged ampere hours per cycle
- Ah-Cyc-Discharge-0: will give the discharged ampere hours per cycle (same as before but

with positive sign – more convenient to plot graphs therefore)

- Cyc-Count: Cycle counter
- DateTime: to see the date and time when the measurement was made (careful: it's UTC, so usually different from local time)
- T1: temperature – a very important parameter for electrochemical reactions
- T-Step[h]: the step time – important to see the charge and discharge durations and to plot charge and discharge curves vs time

Of course additional parameters can be registered if required.

2.2. Charge efficiency

The charge efficiency is the relation between charged and discharged charge. It may be easily calculated with the calculate command:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		U>1UBatMax&t>1s U<1UBatMin&t>1s			Basic cycling of a Li cell Rene Groiss - 17.11.2017
2		pause		t>5s		t=1s	
3		Cycle-start					
4	DCH	discharge	I=0.1CA	U<1UBatDch		U=20mV t=12min	
5	f1	CalcOnce	eff=100*As_D[DCH]/As_C[CH]				
6		pause		t>5min		U=20mV t=1min	
7	CH	charge	I=0.1CA U=1UBatCh	I<0.01CA&t>1s t>15h	Next Goto END	U=20mV t=12min	
8	f1	CalcOnce	eff=100*As_D[DCH]/As_C[CH]				
9		pause		t>5min		U=20mV t=1min	
10		Cycle-end	count=500				
11	END	Pause		t>5s		t=1s	
12		Stop					

Procedure 2: Charge efficiency

In that case the CalcOnce command is used as that is the easiest way.

2.2.1. Calculate or CalcOnce?

It's very important to realize that there is a big difference between the Calculate and the CalcOnce command:

	Calculate	CalcOnce
Functionality	Will be performed all the time the test is in the same cycle as the Calculate statement	Only performed once if the test steps over the command
Computing power	"Costs" computing power during the whole cycle	"Costs" a short delay during execution but no computing power during the rest of the test
Variables	Only 1 statement per variable	The same variable can be modified at different positions in the test procedure
Operators	Not every operator may be used for both commands. Please refer to the software manual!	
Recursion	No	Statements like "x=x+1" are possible

2.2.2. Efficiency calculation

Important: these statements will not work with Rev. 5 software because of it's integer limitation! The trick here is that the As_D[] and AS_C[] operators will keep their last value after the line (or sequence) is left. As AS_D is a positive value it's not necessary to correct the sign of eff. Of course, eff must be added to the registration format.

In Procedure 2, the efficiency is calculated both after charge and discharge. For the first calculation, the charged capacity is still zero resulting in a division by zero. The BaSyTec system has no problem with that but will use a large number as result (for different procedures may be different ones as the internal scaling may differ).

If that is a problem during data analysis, there are several ways to overcome:

- Skip line 5 and use line 8 only
- Filter by "eff < 1000" (as shown in Figure 3)
- Filter by "Cyc-Count >= 2"

If eff via cyclecount shall be plotted it is recommenden to use additional filters:



Figure 3: filter efficiency data

"Line = 9" (which is the pause after the second calculation) is used to get only data from the second calculation, "state = 0" (which will be the first point) to get only one point per cycle.

2.2.3. Charge efficiency – some thoughts on precision

The charge efficiency must always be $\leq 100\%$ (as it is not possible to discharge more than what has been charged), for a Li battery very close to 100% (as any difference from 100% is regarded as irreversible capacity loss). So if a battery will lose 20% in 2000 cycles the efficiency is expected to be 99.99% ($20\%/2000 = 0.01\%$ away from 100%).

Let's calculate the precision of the eff value for the given example (and a BaSyTec CTS(-LAB) Battery Tester):

Step	Duration	current	precision	Ah error
Charge	12h	7mA	2.5 μ A	30 μ Ah
Pause	0.083h	0mA	200nA	0.0167 μ Ah
Discharge	10h	7mA	2.5 μ A	25 μ Ah
Pause	0.083h	0mA	200nA	0.0167 μ Ah
Total	22.167h			55.03μAh

Table 1: efficiency error calculation

As the nominal capacity of the battery is 7mAh, the efficiency error may be $55.03\mu\text{Ah}/7\text{mAh} = 0.0786\%$. Guess that the real efficiency is 99.99%, the measured efficiency may be between 99.911% and 100.069% - so even more than 100% is possible!!!

Vice versa: the expected capacity loss is only 1/8 (0.0786% by 0.01%) of the capacity loss measuring precision – so the measuring error is 786%.

The capacity loss should be at least 0.786% (in order to be able to measure with a precision of 10%) – which would relate to only 23 cycles until a capacity loss of 20% (which is end of life!) – for a Li battery.

The time measurement should be no problem here (compared to the precision of the current) as the stability of the time base of a BaSyTec Battery Tester is better than 10ppm. The absolute time precision is no problem here (as the same for charge and discharge), and the switching delay of a BaSyTec (< 5ms between low voltage detection and charge/discharge stop – compared to 10h) is also negligible here.

Conclusion: Efficiency measurements make no sense for Li batteries as the required precision for that is about a factor of 100 away from what is possible. Although [1] say that they are able to (using a Keithley high precision current source with 50ppm precision – factor 4 better than a BaSyTec CTS), but their batteries do have an efficiency of only about 99.8% - their capacity loss is factor 20-50 away from a "state-of-the-art" Li battery. Consequently, their data is only for 20-25 cycles.

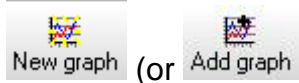
Only for aqueous systems (where efficiencies are usually less than 98%) such efficiency measurements are recommended.

2.3. Data Analysis –capacity vs. cycle-count

The main goal in battery cycling is the capacity vs. cycle-count plot. It's very easy to do with the BaSyTec software. There are 2 possibilities:

2.3.1. capacity vs. cycle-count from the database-of-Tests window

- Select the test(s) you want to have



- Click **New graph** (or **Add graph**)
- Select “Cyc-Count” as X-value
- Select the discharge line (Lines 4 to 4 for the charge efficiency plan)
- Mark “only step change” (to get only the final value of the step)
- Select “Ah-Cyc-Discharge-0” as Y-value
- Press “Ok”

Your selection should look like that:

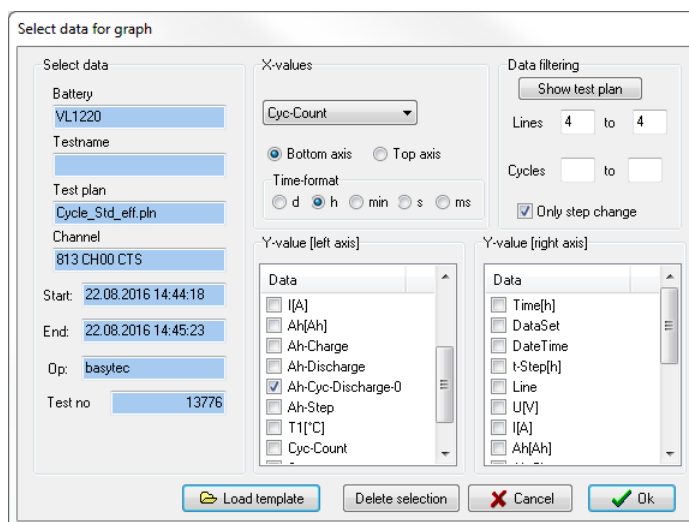


Figure 4: selection for capacity vs. cycle-count – database of tests

The resulting graph can be exported to Excel then – including the data.

2.3.2. capacity vs. cycle-count from the data table window

- Right mouse click on the Cycle-Count column header (to select Cycle-Count as X-axis, or simply select the X Field name)
- Left mouse click on the Ah-Cyc-Discharge-0 column header (to select Ah-Cyc-Discharge-0 as Y-axis, or simply select the Y Field name)
- Mark “Only stepch.”
- Select the discharge line (Line = 4 for the charge efficiency plan)

Should look like that now:

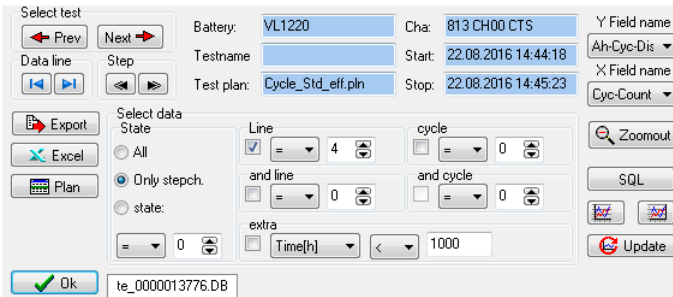








Figure 5: selection for capacity vs. cycle-count – data table

- Now press  to copy to the graph window
- Press  to change to the graph window

For the efficiency values it's the same except that you have to select "eff" instead of "Ah-Cyc-Discharge-0". If you want to see both you may use the right Y axes for eff (or  instead of ). And for any other value as well.

2.3.3. Charge/discharge curves from the database-of-Tests window

- Select the test(s) you want to have
- Click  (or )
- Select "t-Step[h]" as X-value
- Select the charge or discharge line (Lines 4 to 4 / 7 to 7 for the charge efficiency plan)
- Select "U[V]" (or whatever else you want) as Y-value
- Press "Ok"
- Your selection should look like that:

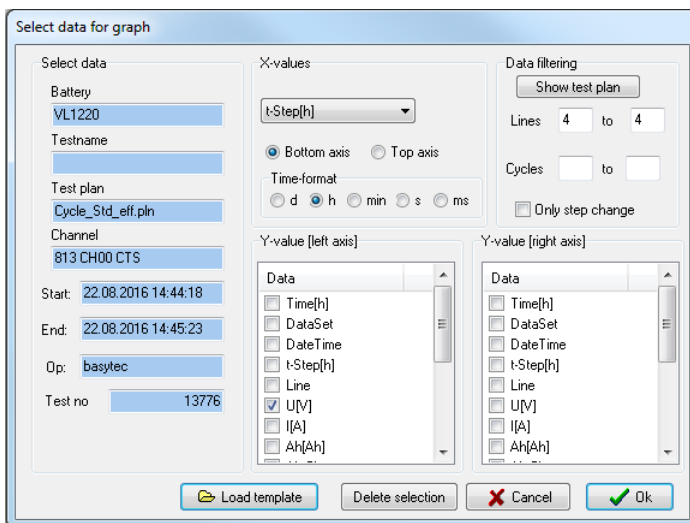


Figure 6: selection for charge/discharge curves – database of tests

The resulting graph can be exported to Excel then – including the data.

2.3.4. Charge/discharge curves from the data table window

- Right mouse click on the t-step[h] column header (to select t-step as X-axis, or simply select the X Field name)
- Left mouse click on the U[V] column header (to select U as Y-axis, or simply select the Y Field name) – or any other value you want to see
- Select the charge or discharge line (Line = 4 or 7 for the charge efficiency plan)
- Select the cycle you want to have

Should look like that now:

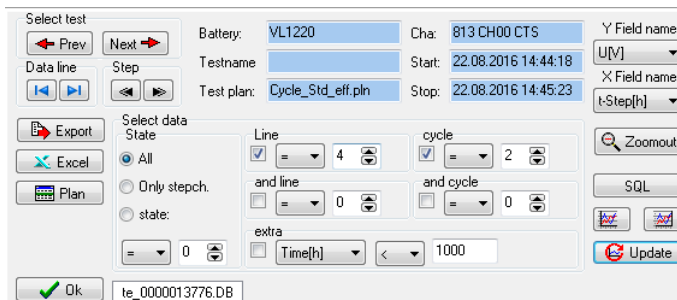




Figure 7: selection for charge/discharge curves – data table

- Now press  to copy to the graph window
- Press  to change to the graph window

3. Pulse discharge and measuring internal resistance

There are some special items if the charge/discharge is more than one line in the test procedure – therefore let’s have a closer look on the procedure:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		U>1UBatMax&t>1s U<1UBatMin&t>1s			Pulse discharge Rene Groiss - 17.11.2017
2	f1	CalcOnce	cyc=0				
3	→	pause		t>5s		t=1s	
4	↶	Cycle-start					
5	f1	CalcOnce	cyc=cyc+1				
6	↶	DCH Cycle-start		U<1UBatDch			
7	↷	discharge	I=0.5CA	t>1s		U=20mV t=12min	1s R_DC value
8	↷	discharge	I=0.5CA	t>2s		U=20mV t=12min	3s R_DC value
9	↷	discharge	I=0.5CA	t>3s		U=20mV t=12min	5s R_DC value
10	↷	discharge	I=0.5CA	t>5s		U=20mV t=12min	10s R_DC value
11	↷	discharge	I=0.5CA	t>50s		U=20mV t=12min	
12	↷	discharge	I=0mA	t>60s		U=20mV t=12min	
13	↶	Cycle-end	count=0				
14	f1	CalcOnce	eff=100*As_D[DCH]/As_C[CH]				
15	→	pause		t>5min		U=20mV t=1min	
16	↶	CH Cycle-start					
17	↷	charge	I=0.5CA	U>1UBatCh		U=20mV t=12min	
18	↷	charge	I=0.5CA U=1UBatCh	I<0.01CA&t>1s t>5h	Next Goto END	U=20mV t=12min	
19	↶	Cycle-end	count=1				
20	f1	CalcOnce	eff=100*As_D[DCH]/As_C[CH]				
21	→	pause		t>5min		U=20mV t=1min	
22	↶	Cycle-end	count=500				
23	→	END Pause		t>5s		t=1s	
24	📄	Stop					

Procedure 3: Pulse discharge

If the R_AC and R_DC values of the BaSyTec system shall be used a change in current must be programmed in order that these resistances can be measured. The BaSyTec system will not perform a current change on it’s own; that must always be done by the user.

For the R_AC (giving the Ohm’s resistance) it’s easy, any short interruption of the current will work.

For R_DC it’s more complicated as also the history of the battery will influence the result. Therefore, the R_DC measurement is usually defined exactly in the appropriate standards. Usually, before the R_DC measurement there must be a pause of a minimum length after which

the battery must be stressed by a certain current while R_DC is determined. For other standards, there is a low-current-period between the pause and the measuring step. So, carefully read the standard in order to see what must be done.

In our example, the R_DC at 1s, 3s, 5s and 10s is measured after a pause of 1min. Total discharge time is 60s between the measurements – see lines 6-13.

The recommended registration format for that test is:

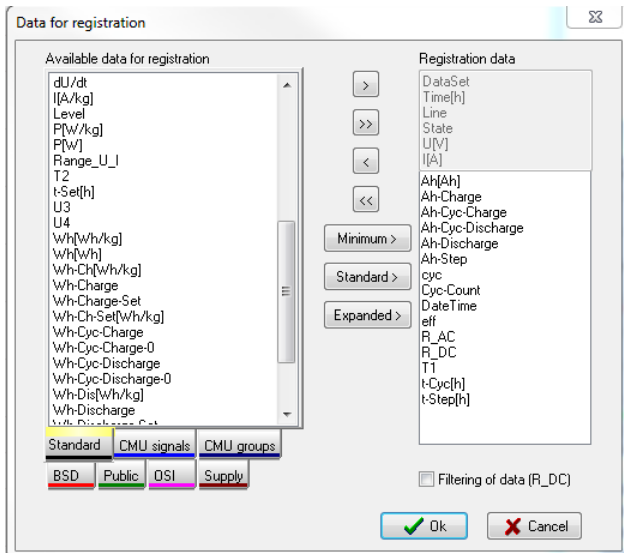


Figure 8: recommended registration format for pulse discharge

3.1. Cycle counter

As the discharge itself is a cycle now (lines 6-13) we have nested cycles: the main cycle (lines 4-22) containing the pulse discharge cycle (lines 6-13) and also a charge cycle (lines 16-19).

As there is only one Cyc-Count column in the registration format but 2 cycles (the main cycle and the discharge/charge cycle) active at the same time there is a problem: if the nested cycles are active Cyc-Count shows the cycle counter of the nested cycles, so the cycle counter of the main cycle is not available for analysis at that time.

Therefore, a new variable containing the main cycle cycle counter must be created (and added to the registration format): cyc. It is not important how that variable is called but must be different from any predefined values.

The easiest way is to use CalcOnce for that purpose as shown in Procedure 3.

3.2. R_DC at different times

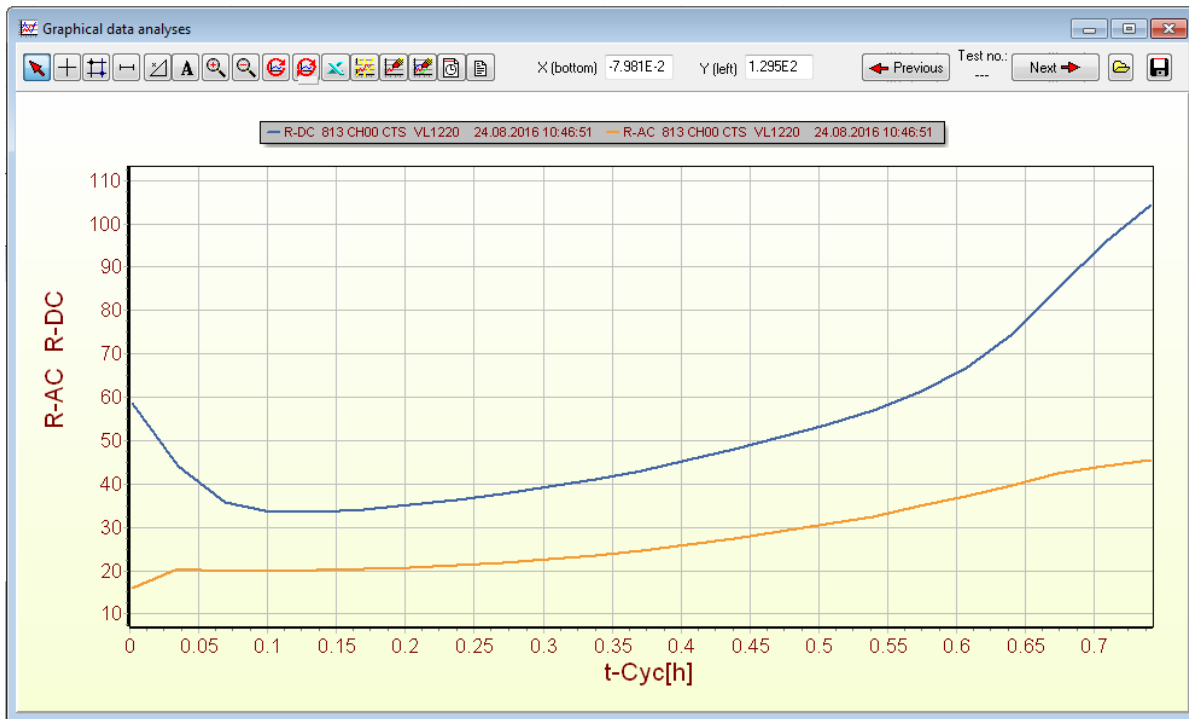


Figure 9: R_AC and R_DC vs. discharge time

Sometimes, the R_DC value shall be determined not only for one delay time (e.g. 5s) but for different times. Typical values are 1s, 3s, 5s and 10s.

Procedure 3 shows how to do: simply put different steps with the same parameter (lines 7-10) in series. So:

- At the end of line 7 we have the 1s value (1s)
- At the end of line 8 we have the 1s value (1s+2s)
- At the end of line 9 we have the 1s value (1s+2s+2s)
- At the end of line 10 we have the 1s value (1s+2s+2s+5s)

Remember: the value at the end of a step (line) can be selected by selecting "Only stepch." So, the selection for Figure 9 looks like that:

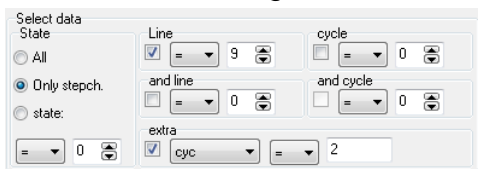


Figure 10: selection for Figure 9

As line=9 is chosen the 5s R_DC value is shown.

As x value, t-Cyc is used as t-Cyc (of the cycle lines 6-13) is the discharge time here.

3.3. Discharge I=0mA

For short pauses (every pause which is less than 1-3min) it is recommended to use the Charge/Discharge command with I=0mA as parameter instead of the Pause command. As the Pause command will always require relay switching the pause will always be a bit longer (about 100ms to 1s, depending on the testers family and the actual required computing power) than programmed. The disadvantage of I=0mA instead of a pause is that still some current of maximum the current precision will flow in either direction.

3.4. Capacity vs. cycle-count

Getting the final discharge capacity of each cycle is as easy as for the standard cycling here. The discharge capacity will be accumulated in the variable Ah-Cyc-Discharge, so Ah-Cyc-Discharge vs. cyc must be plotted.

Now, how to get the end of discharge? Checking the data you see that there is a State = 120 after the voltage falls below the end of discharge voltage ($U < 1.03U_{batMin}$ in Line 6). So, you may simply select "state=120" (without knowing in which line the voltage will fall below):

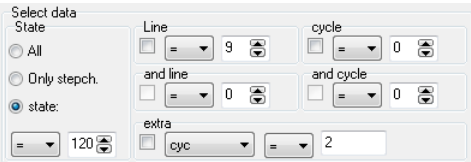


Figure 11: selection for discharge capacity in pulse discharge

Then plot Ah-Cyc-Discharge vs cyc.

Please keep in mind that the exact state may differ from procedure to procedure but will always be the same for the same procedure, so simply check the data.

Same for the charge capacity (it's also a cycle here in order to get both the CC time (t-step[h] of line 17) and the CV time time (t-step[h] of line 18), select "state=130" and plot Ah-Cyc-Charge vs. cyc.

If both charge and discharge show the same state at their end you'll have to separate both by the Line selection.

Another possibility would be to generate new variables before line 21 with the CalcOnce command:

```
CalcOnce      Ah_C = As_C[CH]/3600
CalcOnce      Ah_D = As_D[DCH]/3600
```

And plot them at the end of line 21 (which will be line 23 then).

3.5. Efficiency

Efficiency calculation is the same as for the standard procedure except that the Ch and DCH labels must belong to the Cycle-start of the charge and discharge cycle now.

4. Partial cycles

The problem with partial cycles is that the battery will never be full and never be empty, so there is no defined SOC during the cycle.

But there are many applications like HEV where the battery will be used in partial cycles, so they have to be tested.

As there is no defined SOC during the cycles, the battery will always drift away during the cycles, at least if the cycles are determined by charge (Ah's) (which is equal to current and time) or energy (Wh's), not by voltage.

Even worse, it's just random how fast and to which direction the battery will drift, whether to full or empty SOC. Nevertheless, this is dependent on the test equipment rather than on the battery. By checking the test equipments precision a forecast for the maximum drift speed can be given. But that's all, not more.

So, some additional mechanism is necessary to keep the battery in it's designated SOC window. Usually, partial cycling starts at a designed SOC which must be adjusted first:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		$U > 1U_{BatMax} \& t > 1s$ $U < 1U_{BatMin} \& t > 1s$			Setting SOC in partial cycles Rene Groiss - 17.11.2016
2		pause		$t > 5s$		$t = 1s$	
3		charge	$I = 0.1CA$ $U = 1U_{BatCh}$	$I < 0.01CA \& t > 2s$		$U = 20mV$ $t = 12min$	Full charge ==> SOC=100%
4		discharge	$I = 0.1CA$	$Ah < -0.2CN$			Discharge -20% of nominal capacity ==> SOC=80% now
5		Cycle-start					
6		discharge	$I = 0.1CA$	$Ah < -0.1CN$		$U = 5mV$ $t = 1min$	Discharge -10% of nominal capacity ==> SOC from 80% to 70%
7		charge	$I = 0.1CA$	$Ah > 0.1CN$		$U = 5mV$ $t = 1min$	Charge 10% of nominal capacity ==> SOC from 70% to 80%
8		Cycle-end	count=1000				
9		Stop					

Procedure 4: Partial cycles

Therefore, the battery must be fully charged (or discharged) first, then set to the start SOC.

4.1. Voltage limit – between charge and end of discharge voltage

The easiest way is to limit the maximum and minimum voltage between the cycles:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		$U > 1U_{BatMax} \& t > 1s$ $U < 1U_{BatMin} \& t > 1s$			Setting SOC in partial cycles Rene Groiss - 17.11.2017
2		pause		$t > 5s$		$t = 1s$	
3		charge	$I = 0.1CA$ $U = 1U_{BatCh}$	$I < 0.01CA \& t > 2s$		$U = 20mV$ $t = 12min$	Full charge ==> SOC=100%
4		discharge	$I = 0.1CA$	$Ah < -0.2CN$			Discharge -20% of nominal capacity ==> SOC=80% now
5		Cycle-start	$U_{max} = 1U_{BatCh}$ $U_{min} = 1U_{BatDCh}$				
6		discharge	$I = 0.1CA$	$Ah < -0.1CN$		$U = 5mV$ $t = 1min$	Discharge -10% of nominal capacity ==> SOC from 80% to 70%
7		charge	$I = 0.1CA$	$Ah > 0.1CN$		$U = 5mV$ $t = 1min$	Charge 10% of nominal capacity ==> SOC from 70% to 80%
8		Cycle-end	count=1000				
9		Stop					

Procedure 5: Partial cycles between Charge and discharge voltage – with parameters

In Procedure 5, the voltage is limited to the maximum and minimum voltage during the partial cycles, meaning that the voltage will be controlled if the limit's are hit. The other possibility is to stop charge or discharge if the limit is hit:

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		$U > 1U_{BatMax} \& t > 1s$ $U < 1U_{BatMin} \& t > 1s$			Setting SOC in partial cycles Rene Groiß - 17.11.2016
2		pause		$t > 5s$		$t = 1s$	
3		charge	$I = 0.1CA$ $U = 1U_{BatCh}$	$I < 0.01CA \& t > 2s$		$U = 20mV$ $t = 12min$	Full charge ==> SOC=100%
4		discharge	$I = 0.1CA$	$Ah < -0.2CN$			Discharge -20% of nominal capacity ==> SOC=80% now
5		Cycle-start	$U_{max} = 1U_{BatCh}$ $U_{min} = 1U_{BatDCh}$				
6		discharge	$I = 0.1CA$	$Ah < -0.1CN$		$U = 5mV$ $t = 1min$	Discharge -10% of nominal capacity ==> SOC from 80% to 70%
7		charge	$I = 0.1CA$	$Ah > 0.1CN$		$U = 5mV$ $t = 1min$	Charge 10% of nominal capacity ==> SOC from 70% to 80%
8		Cycle-end	count=1000				
9		Stop					

Procedure 6: Partial cycles between Charge and discharge voltage – with limits

Practically, there is not a big difference between both.

The big disadvantage of that method is that the battery will soon hit the upper or lower voltage – so it will be cycled between 0% and 10% SOC or between about 95% and 85% SOC – whether it's the first or the latter is random. And for the battery that will be a very big difference.

Therefore it's much better to remember the voltage of the first cycle:

4.2. Partial cycles with stored voltage

Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1		Start		$U > 1U_{BatMax} \& t > 1s$ $U < 1U_{BatMin} \& t > 1s$			Partial cycles with stored voltage limit Rene Groiß - 17.11.2017
2		Calculate	$u_{top} = last([TOP]; U)$				
3		pause		$t > 5s$		$t = 1s$	
4		charge	$I = 0.1CA$ $U = 1U_{BatCh}$	$I < 0.01CA \& t > 2s$		$U = 20mV$ $t = 12min$	Full charge ==> SOC=100%
5		discharge	$I = 0.1CA$	$Ah < -0.2CN$			Discharge -20% of nominal capacity ==> SOC=80% now
6		discharge	$I = 0.1CA$	$Ah < -0.1CN$		$U = 5mV$ $t = 1min$	Discharge -10% of nominal capacity ==> SOC from 80% to 70%
7	TOP	charge	$I = 0.1CA$	$Ah > 0.1CN$		$U = 5mV$ $t = 1min$	Charge 10% of nominal capacity ==> SOC from 70% to 80%
8		Cycle-start					
9		discharge	$I = 0.1CA$	$Ah < -0.1CN$		$U = 5mV$ $t = 1min$	Discharge -10% of nominal capacity ==> SOC from 80% to 70%
10		charge	$I = 0.1CA$	$U > U_{Top}$		$U = 5mV$ $t = 1min$	Charge 10% of nominal capacity ==> SOC from 70% to 80%
11		Cycle-end	count=1000				
12		Stop					

Procedure 7: Partial cycles with stored voltage

In that case, it's important to remember the voltage at the end of the first charge cycle (line 7). If

the voltage at the end of line 5 would be used (and lines 6 and 7 skipped) the SOC would be correct but would be a discharge instead of a charge current – so the stored voltage U_{top} would be too small because of the voltage drop.

Same with the CalcOnce command: One may think that it must be possible to store the voltage after line 7 with a calconce command like that:

CalcOnce $u_{top} = U$

But in that case the voltage without a current will be used as line 7 has already been finished when executing the CalcOnce command. So, the stored voltage would be too small again.

[1] Smith, Bourns, Trussler, Dahn: Precision Measurements of the Coulombic Efficiency of Lithium-Ion Batteries and of Electrode Materials for Lithium-Ion Batteries, Journal of The Electrochemical Society, 157 2 A196-A202 2010