Test instruction	Life test on lithium polymere battery packs	N°: PA06002e-v4
29.07.2006	for internal use only	Page 1 of 7

Preliminary Remarks

In general, tests are performed on packs (3S – 5S) only. Single cell testing is less relevant. The battery packs are randomised from stock. Specially prepared cells or material whose origin is unknown won't be tested.
The useful capacity/energy, the discharge voltage, the temperature rise and the internal resistance over the number of discharge cycles as well as the voltage and temperature characteristics within a discharge cycle are evaluated.
Typically the life test is done under the conditions as detailed in section 3. However, for certain applications a specific test might be performed.

When comparing results, test conditions have to be observed!

1. Preparation of the test samples

a) Solder of appropriate connectors, typically 4mm sockets.
b) Mounting of the temperature sensor (Pt100 element) preferably in the centre of the pack if necessary, the heat shrink tube has to be cut open (Appendix B).
c) 1 charge/discharge cycle under following conditions:

Charge current	1C
Charge voltage / cell	4.2V
Discharge current	4C
Min. discharge voltage / cell, Vcutoff	3.1V

Tab. 1

2. Initial dc test

Previous to the life test, the capacity, the developing of the individual cell voltages and the temperature rise is evaluated under dc load condition. The discharge current depends on the type of the cells (Tab. 2).

Charge current	1C ± 2%
Charge voltage / cell	4.2V, +0 -20mV
DC discharge current: „10C - cells“ „12C - cells“ „15C - cells“ „20C - cells“ „>20C - cells“	 7C 8C 10C 12C 15C tolerance ± 1%
Vcutoff / cell (depends on cell type)	2.9V…3.1V, +0 -50mV

Tab. 2

3. Life cycle test

The following sequence is used:

Charge – discharge – break – charge – discharge – break - etc.

Life cycle test is done with a pulse current pattern that should match the different applications as good as possible. On the other side, tests results can only be compared if a similar load was used but there are numerous applications and it is not feasible to test for each application separate.
Therefore, 3 different pulse patterns are used which stand for most of the applications (refer to appendix D for details):

3.1 Short peaks-> short full-load (Ip) and no-load cycles, focus on average current Iav.
3.2 Intensive -> longer full-load (Ip) cycles, short no-load times.
3.3 Stop & go -> long full-load (Ip) times followed by idling periods.

Ip and Iav are selected per table 3 dependent on the type of cells. I_{RMS} is given by Iav, Ip and the selected type of load pattern.

Charge current	1C ± 2%		
Charge voltage / cell	4.2V, +0 -30mV		
Discharge current (tolerance ± 1%)	average current $\mathbf{I_{av}}$	peak value $\mathbf{I_P}$	rms-value $\mathbf{I_{RMS}}$
„10C - cells“	4C	10C	4.7 .. 5.5C
„12C - cells“	5C	12C	5.7 .. 6.5C
„15C - cells“	5C	15C	6.0 .. 7.5C
„20C - cells“	6C	20C	7.5 .. 9C
> ”20C - cells“	6C	25C	8.5 .. 10C
Vcutoff / cell (depends on cell type)	2.9V…3.1V, +0 -50mV		
Break	20 - 30 minutes		

Tab. 3

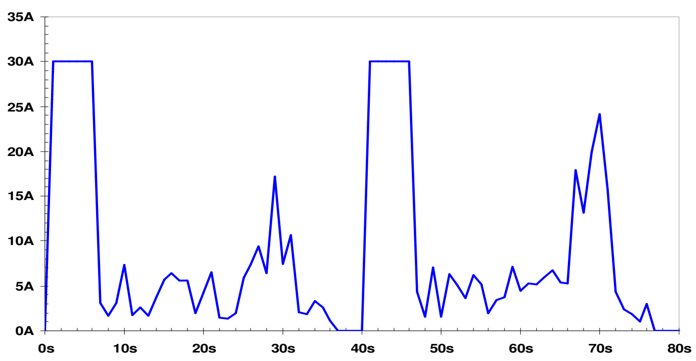


Fig. 1. Example of a part of a 1500mAh / 20C discharge cycle, load pattern “intensive”

3.4 data recording & processing

Temperature, current and voltage values (all cells individual) are recorded over the full cycle. From these values the discharged capacity & energy, the temperature rise ΔT, the mean average discharge voltage Vm and the internal resistance Ri are calculated.
The typical sample rate is 1 Hz during discharge and 1/30 Hz during charge and break.
Raw data and calculated values are stored in Excel spreadsheets. So, it is possible to perform some more analysis later on e.g. to track the behaviour of a specific cell or whatsoever.

4. Intermediate measurements

Life testing is interrupted each 25 to 40 cycles to perform an intermediate test with dc current as detailed in section 2 Tab.2.
This facilitates a better comparison also to data published by manufacturers or other published test results.

5. End of test

The live test is kept running until the cell deterioration can be estimated. Typically the test is stopped if one of the following criteria is met.

- Capacity ≤ 85% initial capacity
- Useful energy ≤ 85% of initial value
- Temperature rise ≥ 60K
- Visible damage, e.g. bloated cells.

Closing work:
a) Final measurement, i.e. dc-discharge as per section 2 Tab. 2.
b) Disassembly of the pack and visual inspection of the cells.
c) Data evaluation, test report.

Appendix A

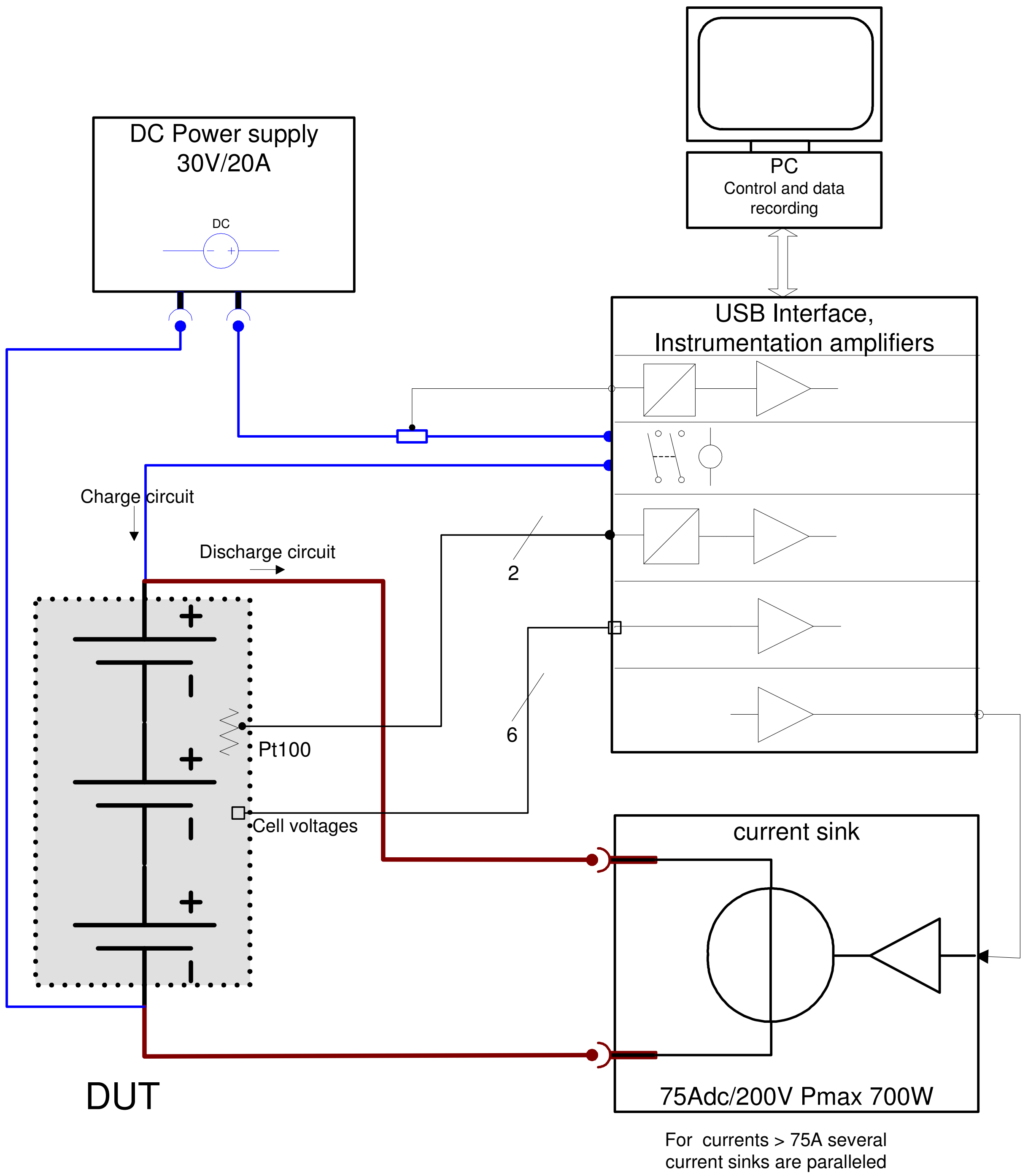


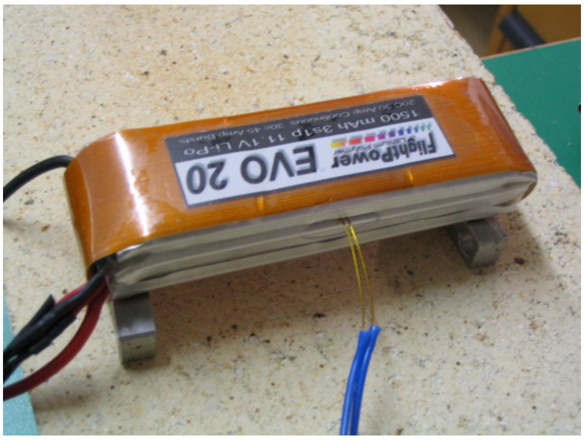
Fig. 2 Block diagram of the test setup

Appendix B

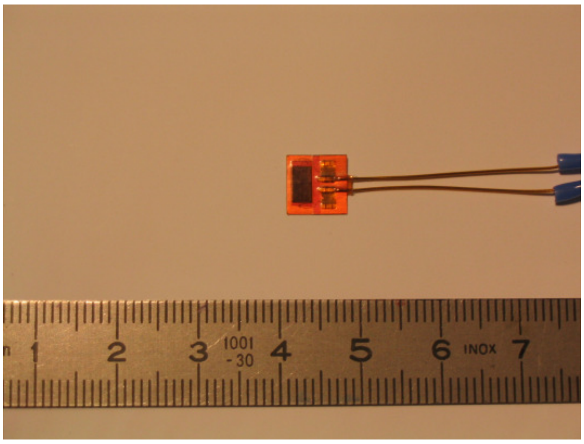
Temperature measurement

The operation temperature of the cells is important and it substantially influences the useful life. Depending of the dimension of the battery pack and the type of cladding the surface temperature differs more or less from the core temperature even for stationary conditions.

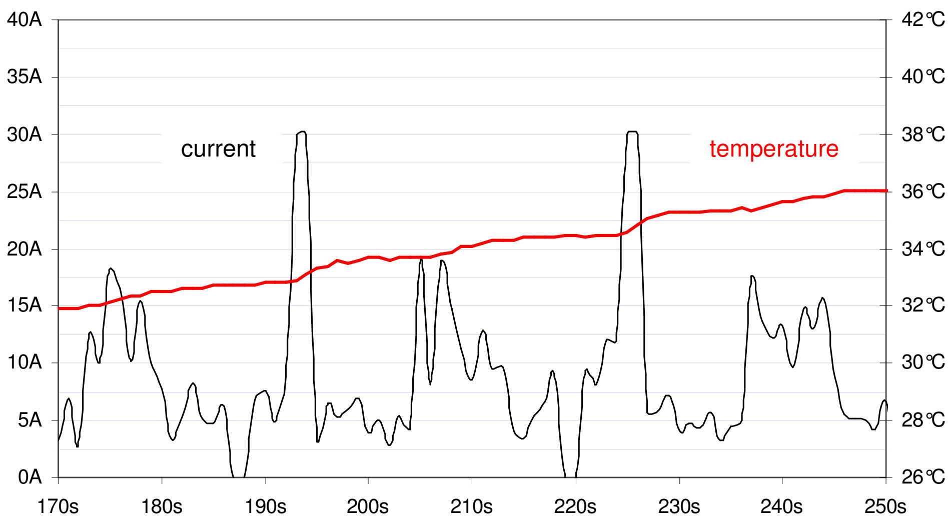
The Pt100 sensor that I use is less than 0.5mm thick and has small thermal time constant. It is mounted between the cells as close as possible to the centre of the pack. This method gives a good estimation of the core temperature at least for relatively slow temperature changes (refer to diagram below).



Mounting of the temperature sensor



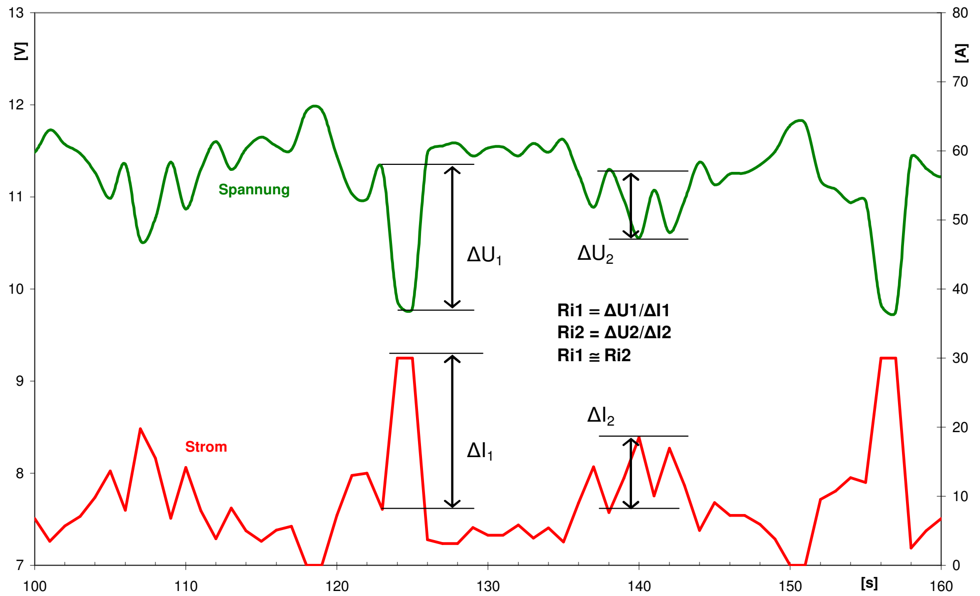
PT100 sensor



Appendix C

Internal resistance Ri

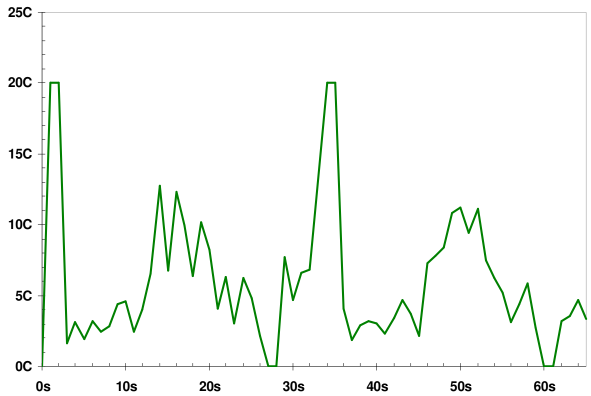
For a given cell, Ri depends on temperature, age of the cell (history), state of charge, test frequency etc. Strictly speaking there exists not a specific internal resistance, it is an impedance which depends on different factors and on the test method itself. Therefore, Ri values should only be compared if the test method and test conditions are known and more or less similar.



During life testing Ri is determined in the middle of each discharge cycle. For that purpose Ri is evaluated as the mean value of several recorded values within a time window of typical 20-30s. Only significant current steps (Δi >> 1C) are included.

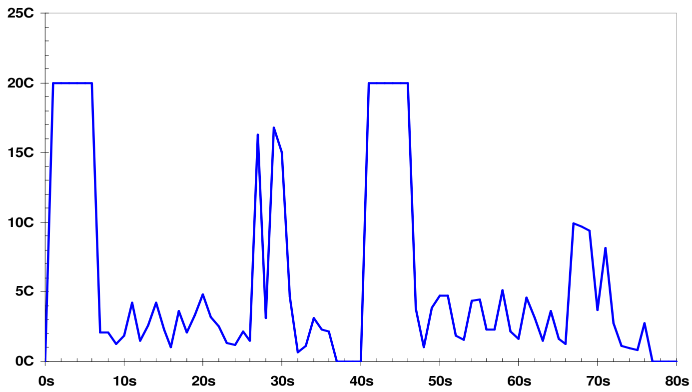
Appendix D

Sections of the 3 different load current patterns (diagrammed for 20C – cells)
For cells other than 20C, the current curve will be scaled accordingly.



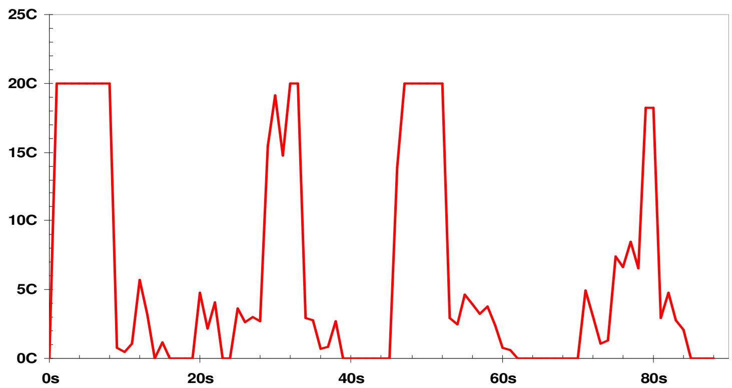
1) "Short peaks"
Ip = 20C, Iav = 6C, Irms = 7.5C

A typical load pattern where the max power is applied for short periods only



2) "Intensive"
Ip = 20C, Iav = 6C, Irms = 9C

A profile with a fairly intensive load due to relatively long peak power periods



3) "Stop & Go"
Ip = 20C, Iav = 6C, Irms = 10C

The load profile with the highest strain on the battery

Remark: the battery temperature rise is fairly proportional to Irms