Testing to find the cyclic Life of Lithium Polymer Batteries.

Although this is the first time I have written an article for RCMW, some readers may well be aware that I write a regular Technology column in Q&EFI. I have been recently producing cyclic life test results for lithium polymer packs and the publication of these in Q&EFI (where they are of obvious interest to electric flight modellers) led to Editor Tony’s request for a one-off (quickly extended to two-off) article on this topic.

The use of LiPo batteries has grown enormously since they were introduced a couple of years back, and although the main application has been as supply packs for electric powered flight (including specialist applications such as helicopters and electric ducted fan), they are starting to appear in much more generalised applications such as Tx and Rx batteries. The safety implications of these cells is now widely understood and we are gradually coming to terms with the rather restrictive limitations of charging and discharging procedures, but I will start by giving a quick run down of the way these batteries are designated and classified, especially in terms of performance.

a) Firstly there is the cell format. Each cell provides a nominal 3.7 volts (4.2 volts maximum) and they are assembled in packs to provide a total voltage. When LiPo batteries first became available in the modelling world, the size of the cells and their capacity (see later) meant that many packs were assembled in a combination of series S and parallel P groups. The series grouping provided the voltage required and the parallel grouping provided the maximum discharge rate in amps. A 4S3P pack made up of individual 1200 mAh cells with a max discharge of 10 amps could therefore provide 30 amps (3P x 10) at 14.8 volts (4S x 3.7). This pattern has changed over the last year or so as the cell sizes and discharge currents has increased. The same performance would now be obtained from a 4S pack of 2000 mAh cells with a max discharge of 30 amps.

b) Secondly there is the pack voltage. This is simply the number of series cells multiplied by 3.7 volts (see above).

c) Thirdly there is the pack capacity. This is expressed in mAh (it would be better in Wh but the manufacturers have so far stuck with the mAh units). Remember that this figure relates to a slow discharge rate (usually a full discharge over one hour). At higher rates the capacity will be lower.

d) Fourthly there is the maximum discharge rate. This is normally expressed in multiples of C where C is numerically equal to the capacity in amps. A 15C rated pack of 2200 mAh cells could be discharged at 15 x 2.2 = 33 amps.

The label on a LiPo battery should therefore include all four of the above e.g. a 3S – 11.1volt – 2200 mAh – 20C pack.

LiPo Performance.

All types of commercial batteries are produced in very large numbers, usually for equipment which is used worldwide in equally large numbers. Mobile phones, laptop computers, and power tools, are typical applications needing the best possible battery, and our model flying hobby hangs on to the coat-tails of these industries. Our ideal requirements are usually very different to those of, for example, the laptop computer manufacturer, and we need to bear this in mind when we talk about performance. Even so, the basic properties are easy to confirm. The voltage of a cell/pack can be measured by use of a digital voltmeter, either unloaded or loaded. It will invariably fall between the upper limit of 4.2 volts and a lower one of 3 volts (for a single cell, with multiples for a pack), with the position reflecting the level of charge of the cell/pack. The unloaded value is a function of the electrochemistry of the cells and is independent of normal usage.

The capacity of a cell/pack is more difficult to assess since it requires a controlled discharge (preferable at constant current) from the fully charged condition (4.2 v per cell) down to the fully discharged condition (3 v per cell). The capacity is then the product of the current (in mA) and the time (in hours) to give a capacity in mAh. As I said earlier however, the capacity decreases as the rate of discharge increases so the measured value should be quoted with the discharge rate as a multiple of C. A test might then give a capacity of a rated 2200 mAh pack as 2190 mAh discharged at 1C or 1950 mAh discharged at 20C.

Assessment of the maximum discharge rate is even more complex. As the discharge rate is increased we get several side effects. These are common to all batteries and are the result of the internal resistance of the pack. The current being produced by the pack during discharge has to overcome this resistance in addition to the external load and the higher the current the more energy is wasted here. This reduction in the energy available to the external portion of the circuit causes the reduction of capacity already mentioned, and also depresses the voltage available. The energy wasted internally is converted into heat so that the temperature of the pack rises during high current discharges. This can be helpful initially, as the rise in temperature reduces the internal resistance of the pack and increases the efficiency of the system. Eventually, however, the temperature of the pack rises to a value where the pack begins to degrade, initially by swelling, but eventually by total breakdown and possible ignition. The maximum discharge rate is therefore set by the manufacturer so that the pack can be continuously discharged from full to empty at this current without damage occurring. The conundrum here is that checking this is, by definition, going to take the pack very close to its limits and the possibility of damage during the process will be high.

The final aspect of performance is the one on which my testing has concentrated, and that is the usable life of the pack. The performance of a pack when it is brand new is normally very close to the manufacturers' specification. Since the cells/batteries are re-chargeable their use is cyclic, i.e. they are cycled through charging and discharging repeatedly. The charging process normally leaves the pack fully charged but we do not always fully discharge the pack in use and this can complicate this process. In an ideal world the cycling through charge, discharge etc. would be a perfect process which did not involve any deterioration of the pack and the pack would have the same performance after several hundred cycles as it had when new. Unfortunately this is not the case, and there is always a small loss in performance with each cycle, even if the charge/discharge parameters are perfectly controlled and kept within specification.

My testing is therefore aimed at assessing the extent of this progressive loss in performance of a LiPo pack over the first 100 cycles of its life in a controlled and repeatable sequence. This will not indicate how the pack will perform over the whole of its life but it will give a reasonable indication of the rate of loss of capacity and if a nominal limit is adopted (say a 20% loss being equivalent to the end of the usable life) then the number of cycles to this point can be extrapolated.

There are two other aspects of LiPo performance which are good indicators of the quality of a pack and both originate from the analysis above. The first is capacity loss at maximum load. What is the reduction from the specified capacity (as stated on the pack label and usually based on a 1C discharge) when the pack is discharged at the specified maximum rate of discharge? As an example, a 2000 mAh pack might be labelled for 20C discharge but when tested at 20C it only produces 1900 mAh, a capacity reduction of 13.6%. The second is the voltage suppression at the specified maximum rate of discharge. This has to be based on the extent of discharge and the pack temperature so I personally set this as the initial voltage about 10 seconds after the start of discharge (before the pack begins to heat). An example of this for a 3S pack might give a voltage of 3.9 volts 10 seconds after the start of a 1C discharge, but only 3.2 volts 10 seconds after the start of a 20C discharge giving an 18% voltage suppression. Both of these figures can be obtained from the initial test of a 100-cycle run

Test Equipment.

Although my testing background has given me a sound footing for the kind of work I now spend a lot of time on, it was to a somewhat larger scale (engineering materials, concrete and steel structures). The gap in my knowledge has been largely electronic/instrumentation, and I have been very fortunate in teaming up with Wayne Giles who is a retired instrumentation engineer. We have co-operated on several test projects over recent years (with all of the circuit design and production being done by Wayne), and this project is the latest and most ambitious of these.

The cyclic testing equipment was built from 4 separate components. The obvious elements are the charger to deliver a 1C charge to the pack, a discharge load to discharge the pack at a constant and pre-set amperage, a safety chamber to contain and control the pack environment during testing, and a control unit to set up the sequencing of the stages and to record the test data.

Two aspects of this basic design needed special consideration. The first was temperature control, both from a safety point of view, but also from a repeatability one, since, as previously mentioned, the temperature of the pack has significant effect upon its performance. Wayne designed an aluminium pack container fitted with a heater plate and with cooling fans, and with thermostatic switching to maintain the pack temperature between 30 and 40 degrees Celsius. This may seem quite high at first sight, but we estimated that this was a typical temperature for a pack in use during flying. Warm enough to get the advantage of reduced internal resistance, but cool enough to prevent any accumulative damage. We also incorporated a thermal probe data-logger into the system to record the temperature variation and to act as a back-up timer/capacity recorder.

The second area of particular consideration was the balancing/cut-off arrangement. We realised from the start that we would have to limit our testing to one size of pack (we chose 3S as being the commonest size in use) but even with this limitation the need to balance the cells on every charge and to organise the charge and discharge cut-off voltages would complicate the equipment greatly. Wayne managed to include the active balancing facility within the control unit using individual balancers on each cell, and he also extended the LED indicator lights so that they would show imbalance during both charge and discharge. We started using an MGM Compro balancing charger, but quickly discovered that there was too much interaction between the charger and controller cut-offs. The charger you see in the photographs is a simple unit produced by Wayne to provide the correct CC/CV charge pattern but without cut-off or balancing.

We did try to make the controller as adaptable as possible with a view to alternative testing scenarios, and built in a tuneable charge cut-off (based on pack voltage) and a multi-stage discharge cut-off which can use a range of voltage limits either for the whole pack or for the individual cells. Wayne included voltage-tapping points and I built a triple range digital voltmeter to give us a visual check on the individual cell voltages throughout the process. The final, and most critical, component of the controller was the data-logger. Here we utilised a Lomcovak HiBox, a unit having an adjustable interval which facilitates recordings of voltage, current, capacity etc. over long periods. I am currently using a 15-second interval which gives me about 22 hours continuous recording. I then need to download the data in 7 blocks of 15 charge/discharge cycles over a six-day period to cover the 100-cycle total.

The load unit is one built for me a couple of years ago (by Wayne again) and is based upon driving a series of powerfets in three groups, each group being mounted on a heat sink which is force-cooled by a temperature sensitive (thermistor controlled speed) fan. Each of these units can handle up to 20 amps giving a total of 60 amps load adjustable in 1 amp steps. The unit also has a pulse loading facility although this is not used in the cyclic life testing. Since the unit provides a stable repeatable load, it has enabled us to use the timing function of the temperature logger as a capacity recording back-up. The switching function of the controller between phases (charge, rest, discharge, rest) also drives the mechanics of a cannibalised computer mouse which in turn drives the time recorder of the temperature logger (separate to the HiBox logger) so that the product of the constant current and the discharge period (recorded to 0.1 secs) gives an additional discharge capacity in Ah for each discharge phase.

The final aspect of the rig was all mine own work. Even though I was running the rig in my garage, I was having nightmares about burning down the garage and its contents if a malfunction let to pack ignition. The opportunity for such a malfunction is always present with continuous long-term testing (it is just not feasible to watch the system throughout such time periods) and I therefore built a secondary outer container for the pack box using bricks and concrete slabs which I am sure is capable of containing any pack fire, even though I would much prefer that this was not put to the test.

I hope the photographs will help to illustrate what is a fairly complex piece of equipment, but the proof of the pudding is etc., and the second instalment of this article in next month's mag will hopefully justify all of this theory.

Contacts.

MGM compro, Ing. G. Dvorsky, Sv. Cecha 593, 76001 Zlin, Czech Republic Tel: +420 577001350, +420 577001349, Fax: +420 577001348 emailmgm@mgm-compro.cz Website http://www.mgm-compro.com/

Lomcovak, Dipl.Ing Roman Vojtech , U Studanky 31, 170 00 Praha 7, Czech Repulic. website http://www.lomcovak.cz/eindex.html Email info@lomcovak.cz

Modelec, Wayne Giles, Biggin Hall Lane, Thurlaston, Warwickshire CV23 9LD Tel +44(0) 1788 817 413 email waynegiles@modelec.co.uk website www.modlec.co.uk

Photographs.

RCMW1-1 The custom-made charger without cut-off or balancing.

RCMW1-2 The load unit capable of up to 60 amps.

RCMW1-3 The control unit showing the HiBox data-logger in position.

RCMW1-4 The pack container showing cooling fans and heater plate for temperature control.

RCMW1-5 The Tenma data-logger with temperature probe.

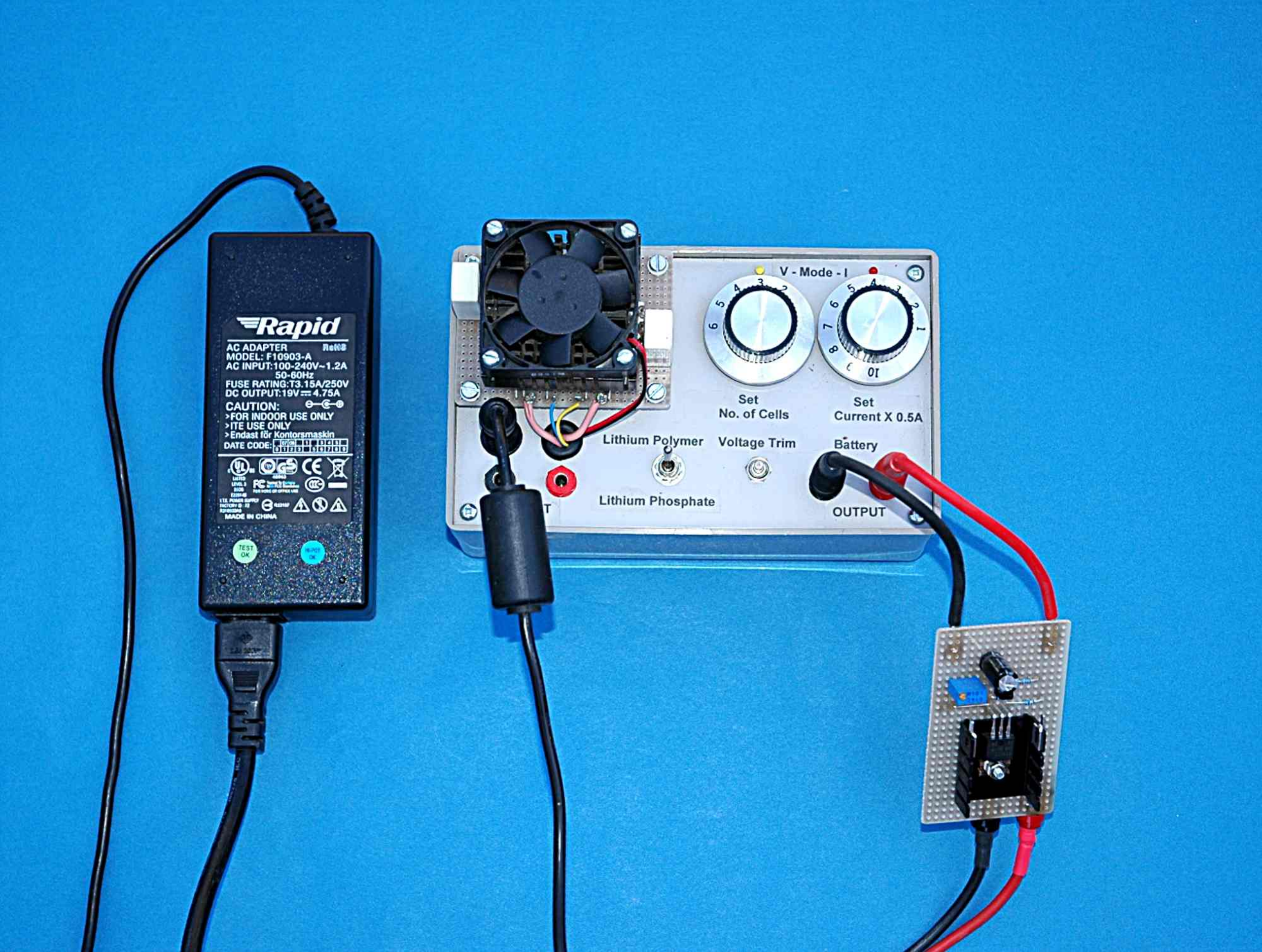
RCMW1-6 The triple digital voltmeter to give individual cell readings.

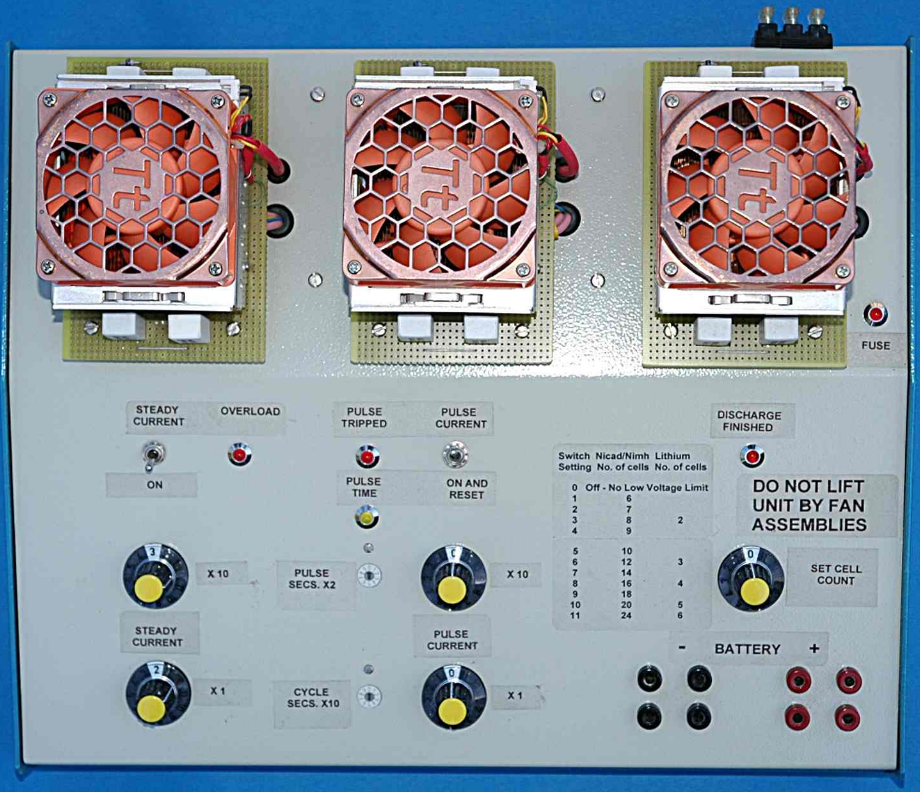
RCMW1-7 The brick and concrete safety chamber with the pack container inside.

RCMW1-8 The safety chamber closed by the top concrete slab.

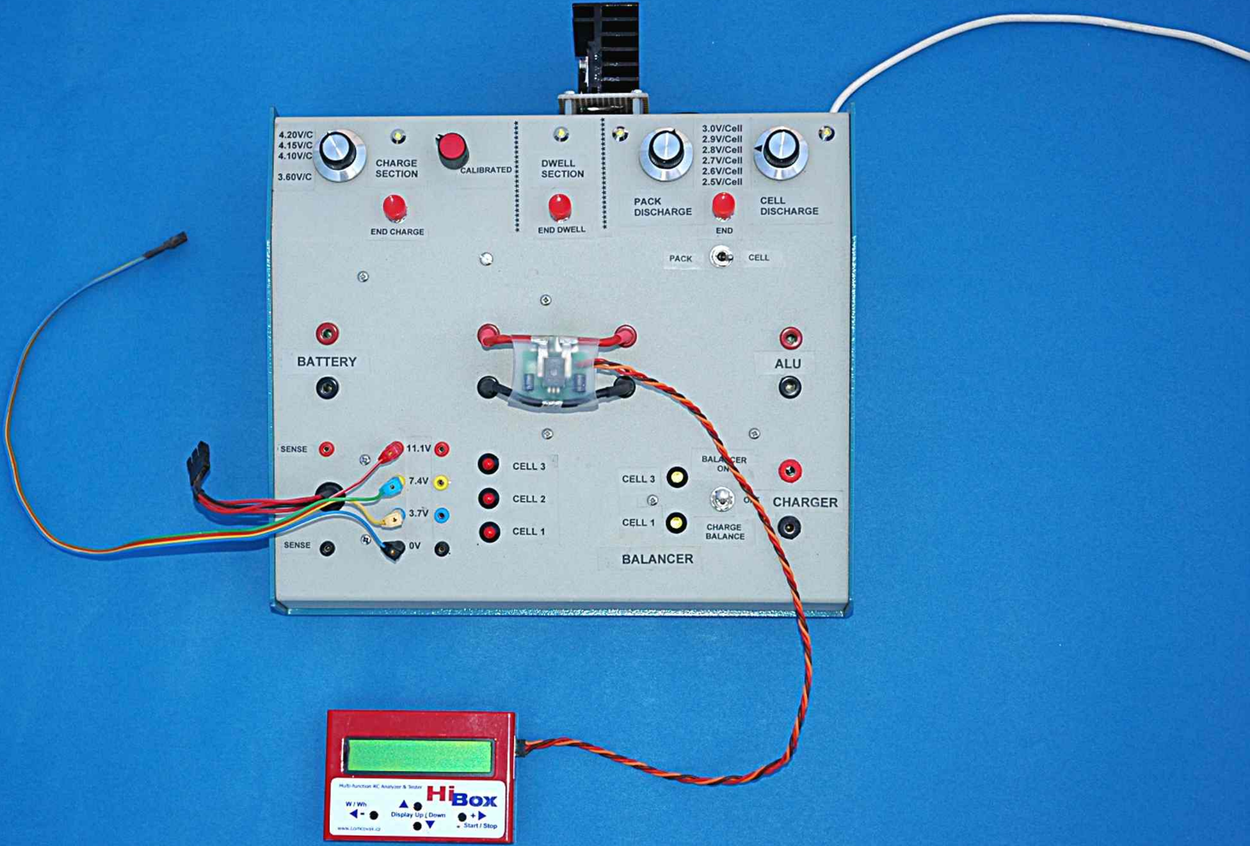
RCMW1-9 The equipment assembled on the garage bench – left half with most of the instrumentation.

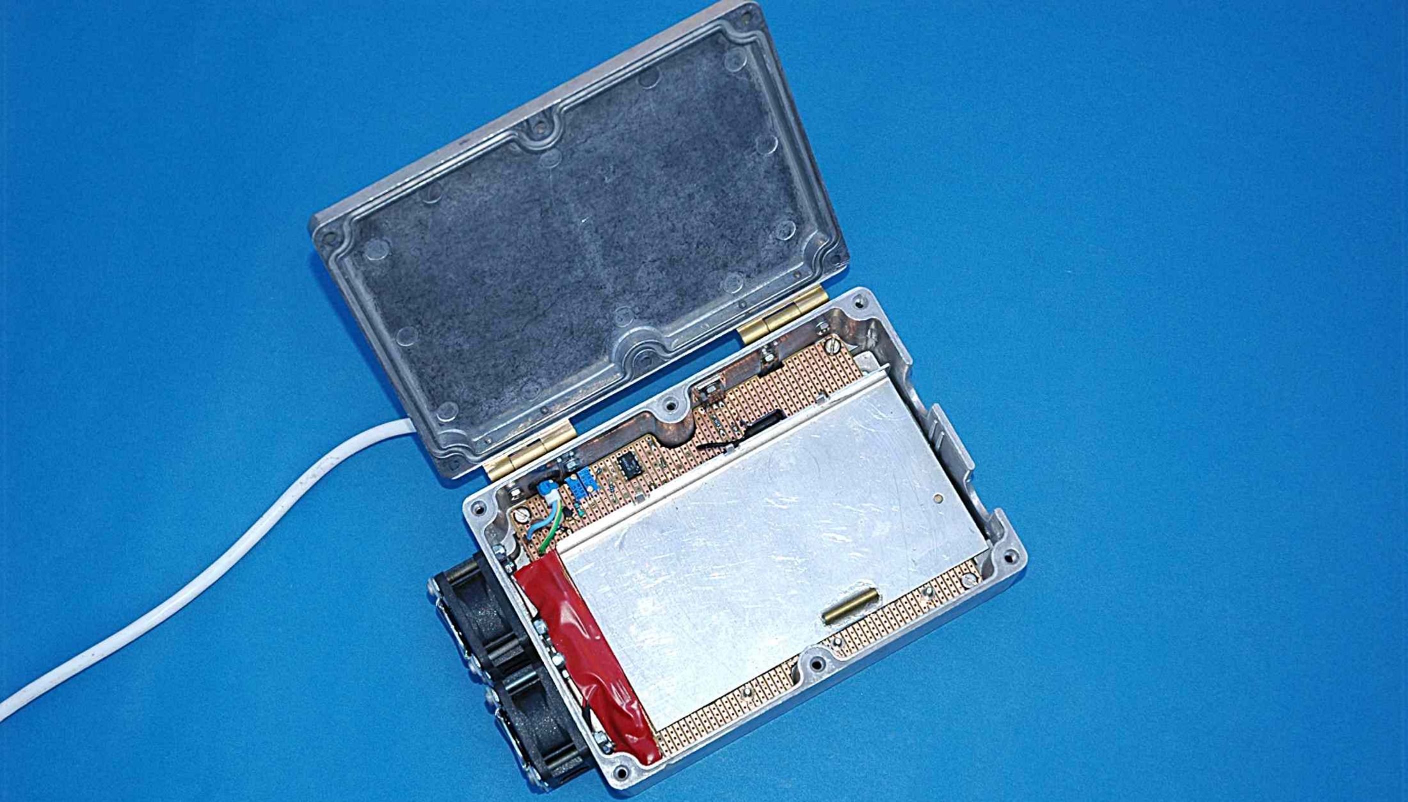
RCMW1-10 The right half with temperature logger/timer and computer.


Rapid
AC ADAPTER
RoHS
MODEL: F10903-A
AC INPUT:100-240V~1.2A
50-60Hz
FUSE RATING:T3.15A/250V
DC OUTPUT:19V ⎓ 4.75A
CAUTION:
>FOR INDOOR USE ONLY
>ITE USE ONLY
>Endast för Kontorsmaskin
DATE CODE:
MADE IN CHINA
TEST OK
HI-POT OK
V - Mode - I
Set
No. of Cells
Set
Current X 0.5A
Lithium Polymer
Voltage Trim
Battery
Lithium Phosphate
OUTPUT

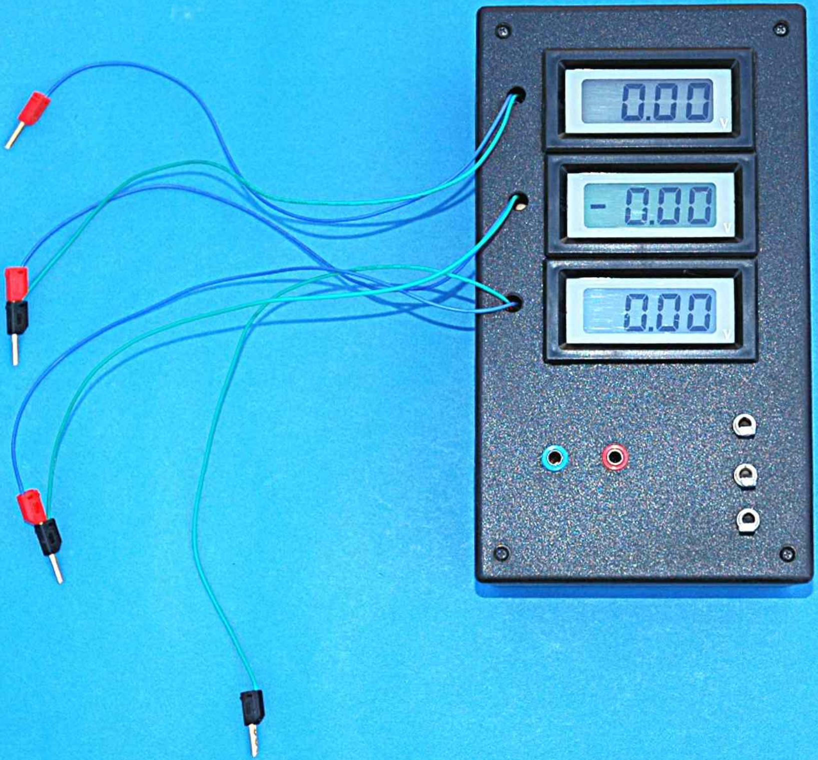


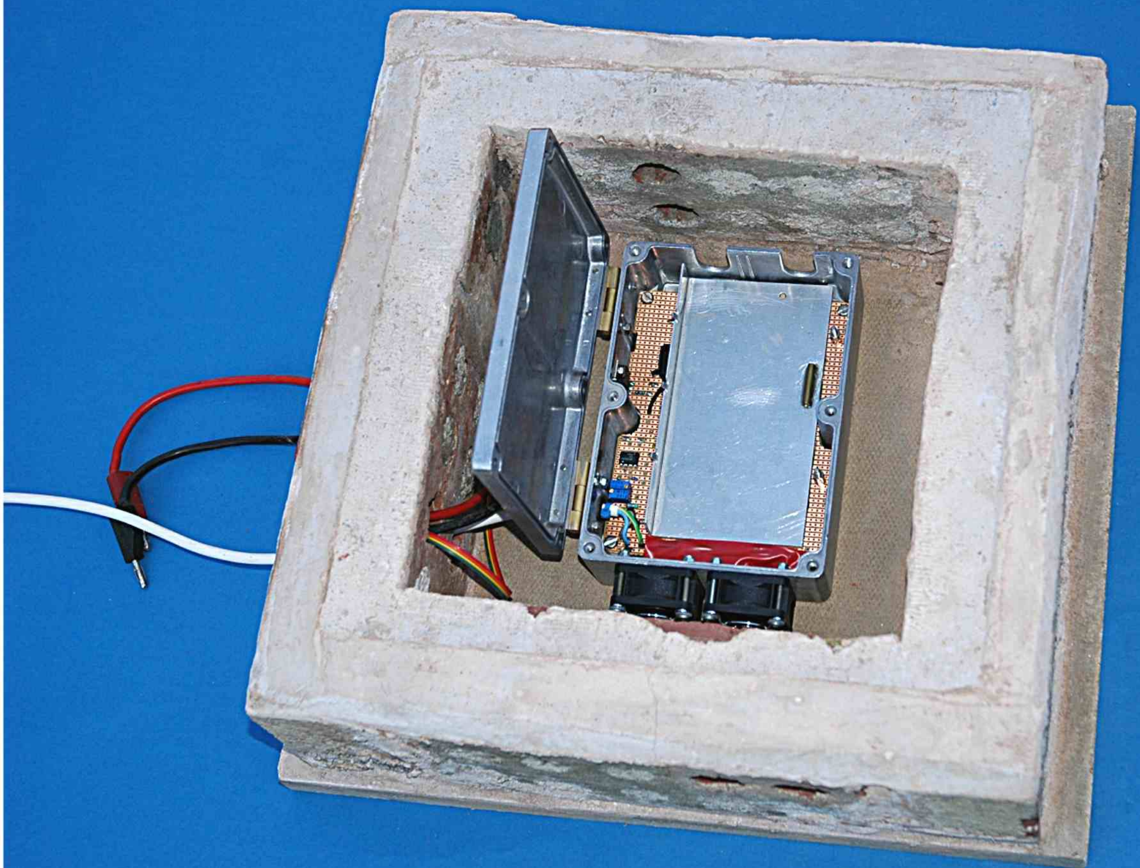
Switch Setting	Nicad/Nimh No. of cells	Lithium No. of cells
0	Off - No Low Voltage Limit	
1	6	
2	7	
3	8	2
4	9	
5	10	
6	12	3
7	14	
8	16	4
9	18	
10	20	5
11	24	6

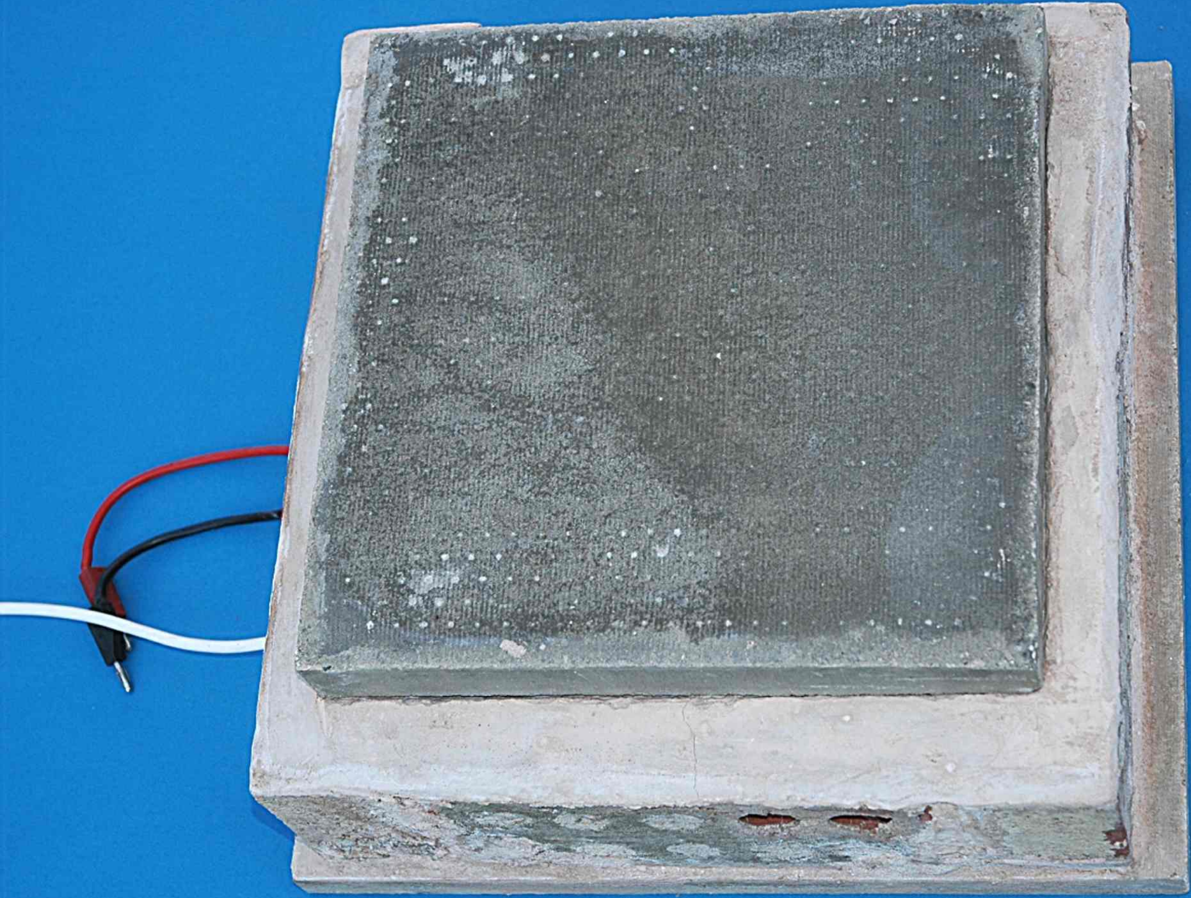

4.20V/C
4.15V/C
4.10V/C
3.60V/C
CHARGE SECTION
CALIBRATED
END CHARGE
DWELL SECTION
END DWELL
3.0V/Cell
2.9V/Cell
2.8V/Cell
2.7V/Cell
2.6V/Cell
2.5V/Cell
PACK DISCHARGE
CELL DISCHARGE
END
PACK
CELL
BATTERY
ALU
SENSE
11.1V
7.4V
3.7V
0V
SENSE
CELL 3
CELL 2
CELL 1
CELL 3
CELL 1
BALANCER ON
OFF
CHARGE BALANCE
BALANCER
CHARGER
Multi-function RC Analyzer & Tester
HiBox
W / Wh
Display Up / Down
Start / Stop




AUTO RANGE & POWER OFF
Auto RS232
022.3 °C
SEL
RAN/Hz
REL
Ω / ⇥ / •))) CAP
°C
Hz
ON
OFF
RS232
V
mA
A
OFF
TENMA®
72-6870
CE CAT II
10A 15S MAX COM
FUSED
V/Ω /mA
/°C/Hz


0.00
V
-0.00
V
0.00
V






ULTI TEX
DO NOT LIFT UNIT BY FAN ASSEMBLIES
HiBox
BATTERY
BALANCER
CHARGER
SANYO
SC-780(S)
VACUUM CLEANER
Vacuum Cleaner
Staubsauger
Aspirateur
Stofzuiger
FARNELL


AOC
Tevion
TENMA
LG
PowerG
COMPRESSOR ACCESSORIES