Bes. Nr. 250190

Specification for

VH Cs 3000

Product Manager	Engineering Manager	Project Manager	Quality Manager
F. AURIOL	JP. SCHULTZE	O. AMIEL	J.SEGANTI

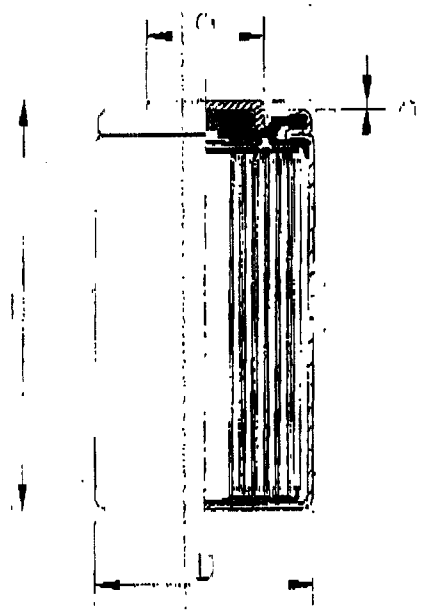
1 Scope

This specification applies to a Nickel-Metal Hydride cylindrical rechargeable single cell which SAFT designation is VH Cs 3000. This cell has been especially designed for power OEM application, such as cordless tooling, radio control market, hobby, home appliances (vacuum cleaner,...), ...

2 General electrical specification

Item	Specification	Units	Notes
SAFT cell designation	VH Cs 3000		
IEC cell designation	HR 23/43		
Nominal voltage	1.2	Volt	
Typical IEC capacity	2820	mAh	see § 4.1
Minimim IEC capacity	2630	mAh	see § 4.1
Typical Power capacity	2770	mAh	see § 4.2 (12 Amp)
Minimim Power capacity	2600	mAh	see § 4.2 (12 Amp)
Typical impedance	5	mOhms	at 1000 Hz (AC)
Charge current			
Standard	300	mA	see § 10
Quick	1000 to 2000	mA	see § 10
Fast	Multi-steps current		see § 10
Charge duration			
Standard	15	hours	see § 10
Quick	1.75 h ~3.5 h	hours	see § 10
Fast	0.75 h ~ 1.75 h	hours	see § 10
Peak voltage in charge			at 20° ± 5°C
Standard	1.40 / 1.45	Volt	
Fast	1.50 / 1.55	Volt	
Maximum continuous discharge current	40	A	13 C
Temperature range			
In Slow charge	-5 / +40	°C	
In Fast charge	-5 / +35	°C	
in discharge	+0 / +40	°C	
Recommended storage	+5 / +25	°C	
Extended storage	-20 / +40	°C	less than 1 month

3 General mechanical specification

Bare Cell drawing	Bare Cell dimensions (mm)
	Diameter : D = 22.00 +- 0.15 Height : H = 42.1 +- 0.3 Positive Contact Flat area Diameter : d = 12.0 +- 0.1 (mini 10) Overstep : h = 0,8 +- 0.2 Typical weight (g) : 59

4 Capacity

4.1 IEC capacity

IEC Capacity is defined as follows :

- ➔ Temperature : +20° ± 2°C
- ➔ Charge current : 300 mA constant current (C/10)
- ➔ Charge duration : 16 hours
- ➔ Period of rest : 1 hour
- ➔ Discharge current : 600 mA constant current (C/5)

Typical capacity : 2820 mAh
Minimum capacity : 2630 mAh

The operating time until the voltage drops to 1.0 volt/cell must not be less than 300 minutes (5 cycles permitted).

4.2 Capacity in power application

Capacity in power application is defined as follows :

➔	Temperature	:	+20° ± 2°C
➔	Charge current	:	1500 mA constant current (C/2)
➔	Charge duration	:	2 h 24 min
➔	Period of rest	:	No rest
➔	Discharge current	:	12 A constant current (4C)
➔	End of discharge	:	0.8Volt

Typical capacity : 2770 mAh
Minimum capacity : 2600 mAh

4.3 Capacity for various discharge rate

The following table gives **minimum** available capacities and **typical** half-discharge voltage of fully charged VH Cs 3000 cell under various discharge currents at +20°C ± 5°C. Deviation depending on test conditions may be observed.

Discharge Rate	Current (A)	End of discharge voltage (V/cell)	Capacity (mAh)	Half discharge voltage (V/cell)
C/5	0.6	1.0	2630	1.22
C	3	1.0	2600	1.20
3 C	9	0.8	2600	1.15
5 C	15	0.8	2600	1.13
7 C	22	0.8	2450	1.04
10 C	30	0.8	2400	1.00
13 C	39	0.8	2400	0.90

5 Overcharge

The VH Cs cell is not designed to be permanently overcharged, netherlesss it can withstand an overcharge at 0.1C rate for one week at +20°C without damage.

6 Charge retention (self-discharge)

After a 28 days storage at +20° ± 5°C, the VH Cs 3000 cell shall retain typically 80% (minimum 70%) of its initial capacity, the cell being initially fully charged.

After 7 days storage at +40° ± 5°, the VH Cs 3000 cell shall retain typically 80% (minimum 70%) of its initial capacity, the cell being initially fully charged.

In both cases, the VH Cs 3000 cell shall recover full capacity after a complete cycle.

7 Storage

SAFT recommends to store the battery within the temperature range +5° to +25°C in a 65 + 5% relative humidity atmosphere.
• After 1 month storage, the VH Cs shall recover 100% of its minimum capacity (after a complete cycle).
• After a long period of storage, in order to reach the optimal performance, it is recommended to cycle the cell/battery at least 5 cycles. The VH Cs shall recover 90% of its minimum capacity after 12 months.

An extended storage within -20°/+40°C temperature range and 65 ± 20% relative humidity is permitted no more than one month.
• After 1 month storage at 40°C, the VH Cs shall recover 95% of its minimum capacity (after a complete cycle).

8 Cycle life

The cycle life of a rechargeable battery depends on various parameters such as charge rate, discharge rate, depth of discharge, overcharge, temperature, period of rest between charge and discharge and so on.

The rechargeable battery reaches its end of life when its capacity is 70% of the average capacity obtained in the first 10 cycles.

Typical values for a VH Cs 3000 cell are listed below :

Temperature : +20°±5°C Capacity measured at 1,0 volt/cell	Expected Cycle Life (Number of cycles)

Negative Delta V Quick charge / Fast discharge	300
(Delta T / Delta t) Fast charge / Fast discharge	300

9 Battery assembly

In case of battery assembly, please note following rules and recommendations before proceeding to production :

9.1 Rules

- Use components adapted to high temperature : cell sleeve, battery case, insulations, glue, etc.
- Mount thermal breaker or/and a fuse in the battery.
- Adopt appropriate charging system for Ni-MH batteries.

9.2 Recommendations

- Educate your personal about handling and production procedure when mounting Ni-MH batteries.
- In case of high discharge drain , use pure nickel as tags between cells.

10 Battery management

10.1 Charge recommendation

10.1.1 General considerations

Ni-MH cells are normally assembled in series as Ni-Cd ones.
Ni-MH charge shows many analogies with Ni-Cd charge. The main difference is that charge is exothermic since the beginning.
With Ni-MH cells, heat release is "(U-1.28) x I x t" during charge and "U x I x t" during overcharge (with U in V ; I in Amp ; t in s).
In the Ni-Cd technology, the first heat release is (U-1.43) x I x t.
Charge coefficient (Ah charged / Ah discharged) gives full capacity when it is higher than 1.15 for normal or fast charge (nickel electrode needs some overcharge). An end of charge cut-off is requested.

Larger charge coefficient overheats the battery. **Temperature increase is detrimental to life duration (due to MH alloy corrosion).**

10.1.2 Charge control methods

Charge control method	Type of charge	Max charge duration	Charge rate	Temperature range
Time controlled charge	Standard	16 h	C/10	-5 ~ 40 °C
Negative delta V (ΔV) controlled charge (1) max ΔV= -5 ~ -10 mV / cell	Quick *(2)* Fast *(2)*	3 h 30 min 1 h 45 min	C/3 2C/3	-5 ~ 40 °C -5 ~ 35 °C
Temperature variation (Δθ/Δt) controlled charge max Δθ/Δt = 1 ~ 2 °C / min	Fast *(2)* Ultra-fast *(2)*	1 h 45 min See § 10.1.3	2C/3 See §10.1.3	-5 ~ 35 °C -5 ~ 35 °C

(1) : The negative delta V detection system must be inhibited during the first 2 min of the charge in order to avoid early signal detection (false –ΔV).

(2) : ▪ A topping charge (also called trickle charge) corresponding to 10% of the rated capacity (between 1 hour at C/10 and 2 hours at C/20) must be added at the end of the main charge in order to equilibrate in a full state of charge the different cells of the battery. This additional charge is not mandatory for each cycle but it improves charging especially after long rest periods (weeks) and reduces risk of leakage by ensuring balance of the battery. The minimal frequency for applying this topping charge is 1 every 10 cycles.

• A single or a combination of different cut-off criteria must be used in parallel in case of failure of the main cut-off method. These criteria are : -ΔV, Δθ/Δt, absolute temperature (60°C) and timer (to be adjusted depending on the current).

10.1.3 Ultra-fast charge

The purpose of this section is to point out where difficulties come from with charge of Ni-MH cells and to suggest some principles for designing the ultra-fast charge profile.

The two main problems are internal pressure and temperature increase. This is a general behavior of Ni-MH as far as we observe the same behavior with competitor cells.

When rate of charge is larger than 2.2 Amp, VH Cs cells cannot undergo overcharge. As the charging system must cut-off necessarily before overcharging, it is mandatory to use the $\Delta\theta/\Delta t$ criteria as the main one <u>but</u> 1 or 2 back up criteria (among those listed above) are also mandatory for a multi Ni-MH cells battery.

Taking into account the above remarks, it appears mandatory for designing an ultra-fast charge to apply a multi-steps charge current composed of a high current and a medium current. In the case of VH Cs, we could define :

<u>10.1.3.1 High charge current : 2 C (6 Amp)</u>

Voltage, internal pressure and temperature evolutions versus time for a 6 Amp charge rate at room temperature for a fully discharged VH Cs cell are plotted in appendix. We consider that overcharge starts after the point "A" : intercept of linear regressions of temperature increase during charge and overcharge. After this point, 10 % overcharge (in % of total capacity) at a rate higher than 2.2 Amp provides high leakage risks. Concern is that for a "n" cells battery, we must consider $A_i(t_i,\theta_i)$ for each cell "i" of the battery and take into account the smallest "t_i" for "i = 1 to n".

The difficulty is to detect "A_i" accurately. Therefore, it is possible to have several thermal sensors (1 thermal sensor for 10 cells is recommended). The location of the thermal sensor is also very important. To determine the distribution of temperatures inside the battery, the most convenient and accurate way is to use an infrared video camera.

Note that, A_i changes with the equilibrium of state of charge which depends on initial capacity spread and also storage time, self-discharge, local temperature in the battery, aging ...

<u>10.1.3.2 Medium charge current : 0.75 C (2.2 Amp)</u>

The charge current is then reduced from 6 Amp to 2.2 Amp when different signals coming from voltage and temperature show that the end of charge approaches:

- *Voltage threshold*

It must be measured during short interruption of charge (a few milliseconds).

- *Value of temperature slope*

This value depends on the battery casing and direct heating from the charger to the battery plugged on it (this latter must be minimized).

- *Absolute temperature*

The charge current is then reduced from 6 Amp to 2.2 Amp when the battery temperature is higher than 35°C.

The values of these parameters must be determined on the final system, it means battery + charger. A single criterion is not sufficient and a combined response of them is certainly necessary (the list is neither exhaustive nor inclusive).

10.1.3.3 **As an example,** we could define for VH Cs :

- A charger with 3 predetermined rates : 6 ; 2.2 and 0.15 Amp but with an interrupt during 3 ms every approximately 1 s.

- *Voltage threshold*

6 Amp charge is maintained until the voltage measured during current interruptions is less than $T_{u\theta}$, 1.48 V at 20°C (to be adjusted), with a correction of –1.4 m V/°C.

When voltage is over $T_{u\theta}$, 2.2 Amp rate is applied.

- *Value of temperature slope*

Charge at 6 or 2.2 Amp is stopped when $\Delta\theta/\Delta t \geq 1.5$°C/mn (to be adjusted between 1 to 2) or when $\Delta\theta$ from the beginning of the charge is ≥ 15°C. When $\Delta\theta/\Delta t$ cut-off occurs, charge can be considered as full.

Then rate is lowered to 0.15 Amp for 2 h.

- *Absolute temperature*

Current (Amp)	Temperature range (°C)		
0.15	From –10 to -5	and	from +45 to +60
2.2	From –5 to +5	and	from +35 to +45
6.0	Between +5 and +35		

☞ 6 Amp charge can occur if battery voltage is ≥ n 1.10 V / cell.

10.1.4 Conclusions

3 criteria must be kept in mind for the optimization of the charge profile :

❶ A good compromise between available capacity and life duration is reached when the end of charge temperature is around 45°C (50°C max). Apart from the charge profile, an additional way of limiting temperature increase is to cool the battery during charge by the means of a fan or similar device.

● According to criterion 1, the temperature charge control (near peak voltage cut-off) is more recommended than - ΔV charge control (especially for shorter time).

● According to criterion 1, the fastest charge can be reached with a multi-steps current charger with an initial current at 2 C and a decrease according to temperature evolution.

A full charge duration below 40 min while maintaining battery temperature around 45°C (with a charge current adjusted accordingly) is certainly possible (but not so easy) with Ni-MH cells. However, it needs accurate adjustment on the system.

10.2 Discharge recommendation

10.2.1 Battery reversal

Battery reversal occurs when one cell is <u>or</u> becomes shorter in capacity. When the end of the discharge approaches, this unbalanced cell is deep discharged until 0 V and then reverses its polarity in 2 steps :

☞ The first electrode (usually positive) reversal occurs around – 0.4 V.
☞ The second electrode (usually negative) reversal occurs around –1.4 V.

During both electrodes reversals, gas evolve from the electrode. The higher the discharge rate, the higher the gas flow is and the lower the gas recombination process is. When the total pressure of these gas overtakes the venting pressure of the cover, the valve opens and gas / electrolyte is released causing irreversible loss of performances (capacity, life duration, etc…).
When both electrodes reverse, the temperature increases steeply and can lead to an internal short-circuit if the insulating components melt (separator, insulator ring,…).

10.2.2 Influence of repeated reversals

The high energy Ni-MH cells are made of a <u>positive foam electrode</u> whereas low energy Ni-MH cells (like 2.2 Ah in Cs size) and Ni-Cd cells are made of a <u>sintered positive electrode</u>. These 2 types of positive electrode behave differently during reversal :
The sintered positive electrode doesn't seem to be affected by moderate repeated reversals (without gas / electrolyte release through the safety valve) whereas the positive foam electrode performances are debased (irreversible loss of capacity).

Therefore, it is mandatory to monitor the cut-off voltage in order to avoid battery reversal.

10.2.3 Cut-off voltage determination

Suppose that the numbers of cells connected in series in the battery is N and that there is one low capacity cell in the battery. During discharge, this weakest cell will be completely discharged and will reverse its polarity down to - 1.4 V while the other cells are still at an average voltage (AV) measured approximately at 80% of the full discharge. Therefore, the weakest cell will be protected against reversal if its voltage stays above 0 V.

The cut-off voltage (CV) avoiding battery reversal is obtained by the relation :

$$CV = (N-1) \times AV$$

(CV and AV are expressed in volt)

From the above relation, we can calculate the following examples :

Number of cells (N)	CV V / battery	CV V / cell	CV V / battery	CV V / cell
	If AV = 1.17 V (*)		If AV = 1.07 V (*)	
3	2.3	0.78	2.1	0.71
6	5.9	0.98	5.4	0.89
10	10.5	1.05	9.6	0.96
20	22.2	1.11	20.3	1.02

(*) The AV values of 1.17 and 1.07 V are typically obtained at 5 Amp and 15 Amp discharge current for VH Cs, respectively.

From the above table, we can draw the following conclusions :

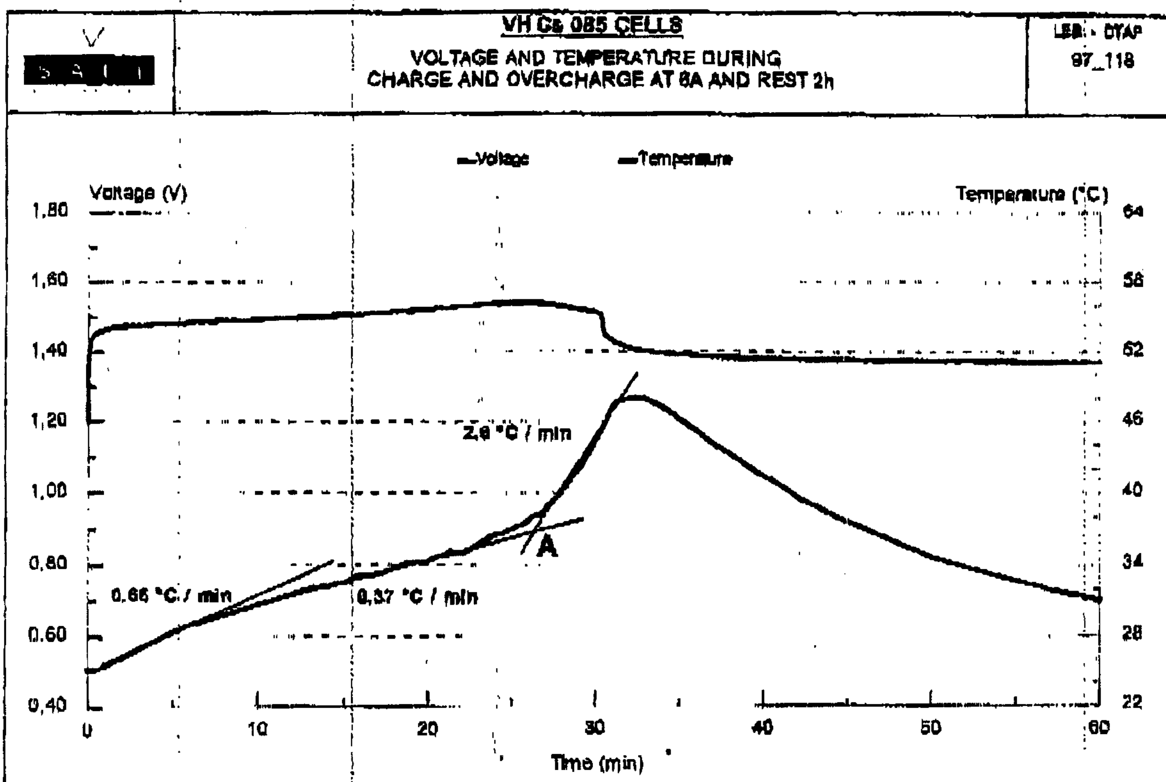
❶ The higher the number of cells in the battery, the higher the cut-off voltage per cell is and the higher the risk of overdischarging one cell is.

❷ The higher the discharge current, the lower the AV and CV are.

❸ For big batteries (higher than 10 cells), it appears necessary to monitor the voltage by sub-pack control.

For a 20 cells battery operating at 15 Amp discharge rate, the CV per cell is 1.02 V which is close to the AV. Therefore, the battery may cut in voltage before delivering full capacity. In such a case, we recommend to monitor the voltage of 10 cells sub-pack because the sub-pack cutting voltage (SPCV) per cell becomes 0.96 V.
The battery discharge cutting criteria can be when the first sub-pack is reaching the SPCV.

APPENDIX


SAFT
VH Cs 085 CELLS
VOLTAGE AND TEMPERATURE DURING
CHARGE AND OVERCHARGE AT 6A AND REST 2h
LEB - DTAP
97_118
Voltage
Temperature
Voltage (V)
Temperature (°C)
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1,60
1,40
1,20
1,00
0,80
0,60
0,40
64
58
52
46
40
34
28
22
2,8 °C / min
0,66 °C / min
0,37 °C / min
A
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10
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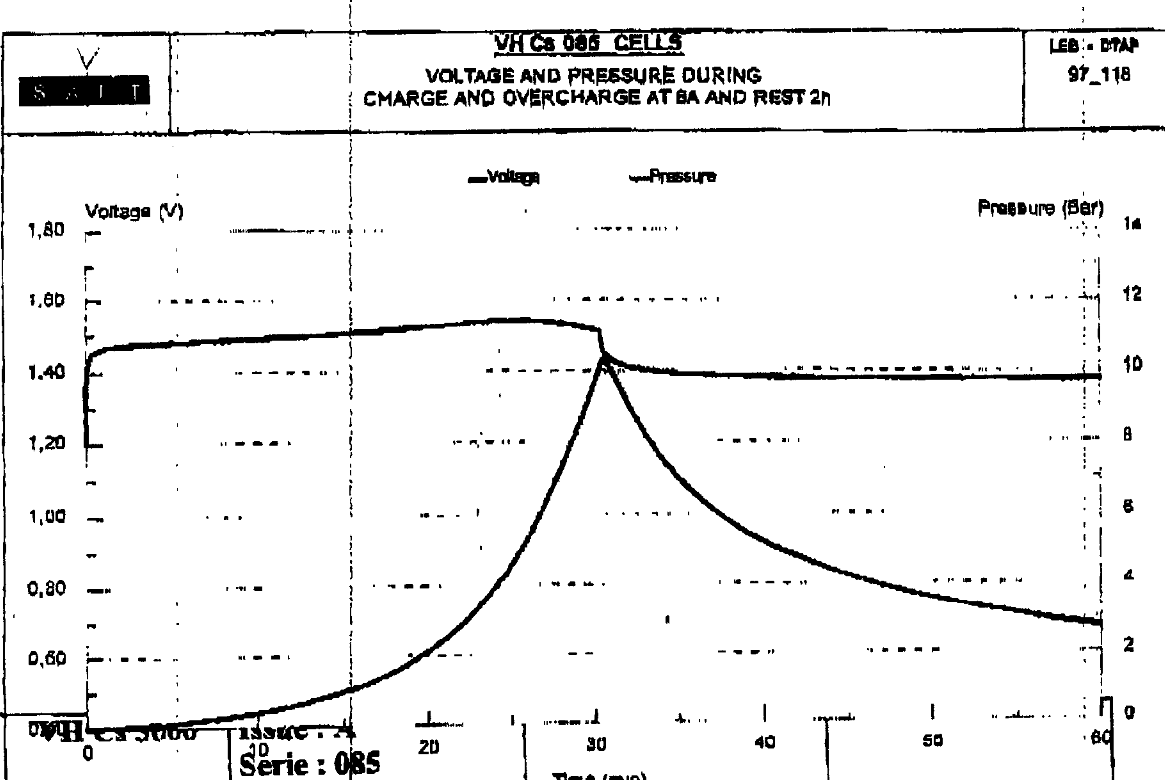
30
40
50
60
Time (min)


SAFT
VH Cs 085 CELLS
VOLTAGE AND PRESSURE DURING
CHARGE AND OVERCHARGE AT 6A AND REST 2h
LEB - DTAP
97_118
Voltage
Pressure
Voltage (V)
Pressure (Bar)
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Time (min)