Journal of Power Sources 80 (1999) 107–111

Development of a hybrid battery system for an implantable biomedical device, especially a defibrillator/cardioverter (ICD)

Jürgen Drews *, R. Wolf, G. Fehrmann, R. Staub

LITRONIK Batterietechnologie, Birkwitzer Straβe 79, D-01796 Pirna, Germany

Abstract

An implantable defibrillator battery has to provide pulse power capabilities as well as high energy density. Low self-discharge rates are mandatory and a way to check the remaining available capacity is necessary. These requirements are accomplished by a system consisting of a lithium/manganese dioxide 6 V battery, plus a lithium/iodine-cell. The use of a high rate 6 V double-cell design in combination with a high energy density cell reduces the total volume required by the power source within an implantable defibrillator. The design features and performance data of the hybrid system are described.

Keywords: Applications/medical; Lithium/manganese dioxide batteries; Lithium/iodine batteries

1. Requirements for defibrillator batteries

Implantable power sources have to be as small as possible, lightweight and able to provide safe and reliable performance over their whole lifetime. For a power source within a defibrillator/cardioverter, high rate discharges on demand, low rate discharge for monitoring and pacing are required. In fact, the pulse power performance is the main requirement for batteries suitable for that application [1]. Usable lifetime of the power source has to be 4–5 years, depending on the total energy removed for shocks. Within the single device, different electrochemical systems can be used. Therefore, a hybrid battery system can increase the energy density and thus prolong the lifetime of the system. The specific capabilities of both systems can be optimized in respect to power and energy density.

The integration of two smaller, single, batteries within the defibrillator/cardioverter provides a higher degree of freedom in placing the power sources within the defibrillator and therefore contributes to the volume reduction of the newly designed device.

2. The defibrillator battery LiS 32125/K6

The defibrillator battery LiS 32125/K6 is a 6 V lithium/manganese dioxide primary battery with rectangular shaped electrodes within a prismatic stainless steel laser-welded case. The cells are cathode limited with photoetched stainless steel grids being used for cathode and anode. The organic electrolyte is a mixture of three components and contains lithium perchlorate as the conducting salt. The battery case is divided into two compartments.

Within one cell the positive electrode and within the other the negative electrode is connected to the case, thus both cells are connected in series. Full battery voltage of 6 V is available between the two terminals. One hermetically sealed feed-through is used per cell. The single cell voltage can be obtained between case and each cell terminal. The 6 V design of implantable defibrillator batteries is described in detail in Refs. [2,3].

Mechanical and electrical data are given in Table 1. Pulse power performance has been tested using a pulse

Table 1
Technical data for the LiS 32125/K6 battery

Parameter	Units	Value	Comments
OCV	V	6.4 ± 0.15	beginning of life (BOL)
Impedance	Ω	0.4–2.0	at 1 kHz, BOL
Nominal capacity	A h	0.45	into 600 Ω to 4.8 V (EOL)
Pulse capacity	A h	0.30	1 A pulse train, see text
Self-discharge		< 2%/year	mean value over whole lifetime
Capacitor charging	s	< 9 s	185 μF, 30 J, BOL
Length	mm	18	
Width	mm	12.5	BOL
Height	mm	32	excluding terminals
Mass	g	< 21	

* Corresponding author. Fax: +49-3501-530-599

0378-7753/99/$ - see front matter
PII: S0378-7753(98)00254-7

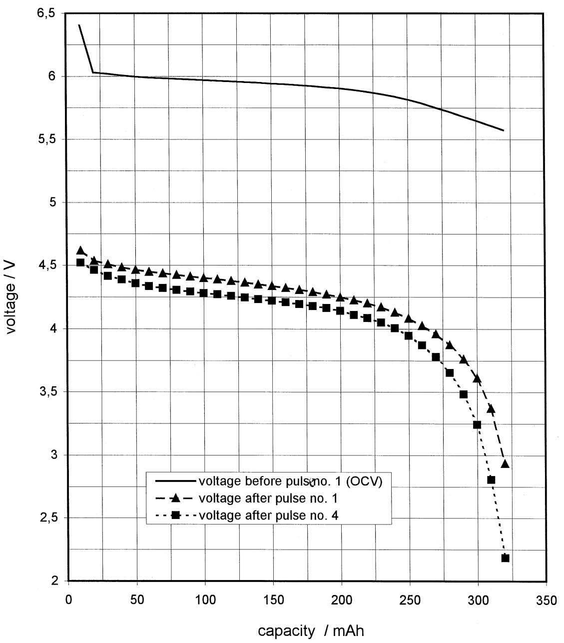

Fig. 1. Pulse discharge of LiS 32125/K6. Four pulses of 1 A for 9 s at 15 s intervals form one train. 30 min on OC between trains. One train discharges the battery by 10 mA h.

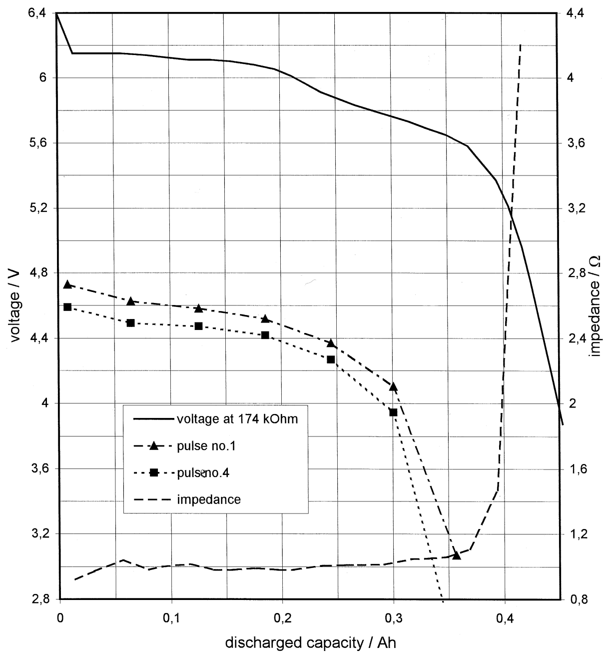

Fig. 2. One year accelerated discharge of LiS 32125/K6. Six pulse trains per year, four pulses of 1 A for 9 s at 15 s intervals form one train, 30 min on OC between trains. The voltages shown were taken at the end-of-pulse. Background load was 600 kΩ. Impedance is shown as function of discharged capacity.

train regime which includes four sequential 1 A pulses each lasting 9 s, with 15 s at OCV between each pulse. After each pulse train, the battery remained on open circuit for 30 min. The end of discharge voltage was set to 3.0 V. All tests were performed at 37°C. Fig. 1 gives the results of an accelerated discharge test under this regime.

By reaching 3.0 V during pulse no. 4, more than 0.31 A h were removed, which is about 67% of the total capacity. The remaining capacity is not usable within the pulse discharge regime, but can be used by a low rate discharge. Pulse power density of the battery within this regime is about 590 W dm^{-3} from BOL to MOL (middle of life).

3. One-year accelerated lifetests

The batteries have been discharged with a continuous background load of 174 kΩ and six pulse-trains per year, each train consisting of four, 9 s, 1.0 A pulses. A typical result is presented in Fig. 2.

The capacity removed by pulse discharges is about 355 mA h down to 3.0 V. Impedance is about 1.0 Ω slowly increasing until 370 mA h has been removed and rapidly increasing to 5 Ω after passing that value. Fig. 2 shows also the polarisation of the battery during pulse discharge.

The knowledge of the battery performance at various pulse loads is important for the development and design of the defibrillator/cardioverter circuits. In relation to a 3 V cell the 6 V battery provides a higher starting level for the DC/DC converting necessary for capacitor charging, so the polarisation during pulse discharge of the battery can

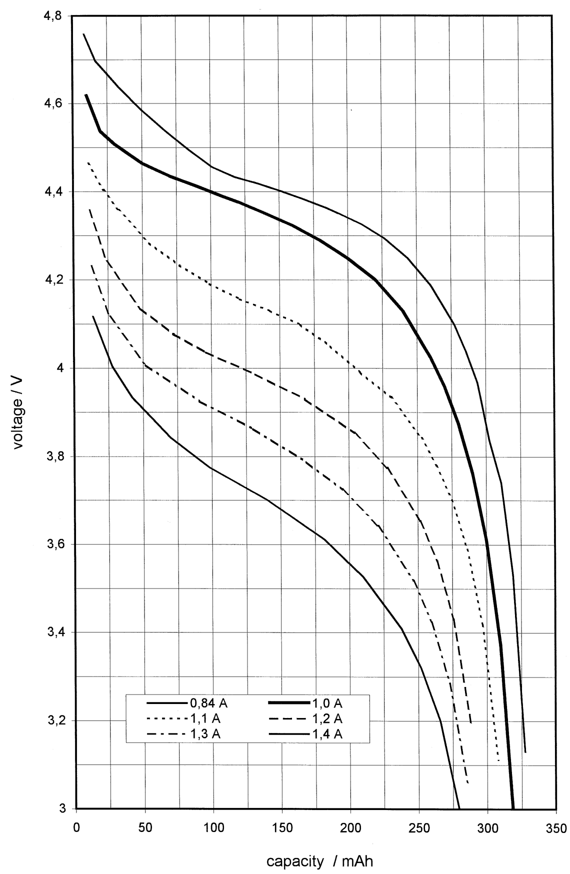

Fig. 3. LiS 32125/K6. Available-high rate capacity vs. end voltage of first pulse. Various pulse currents between 0.84 and 1.4 A.

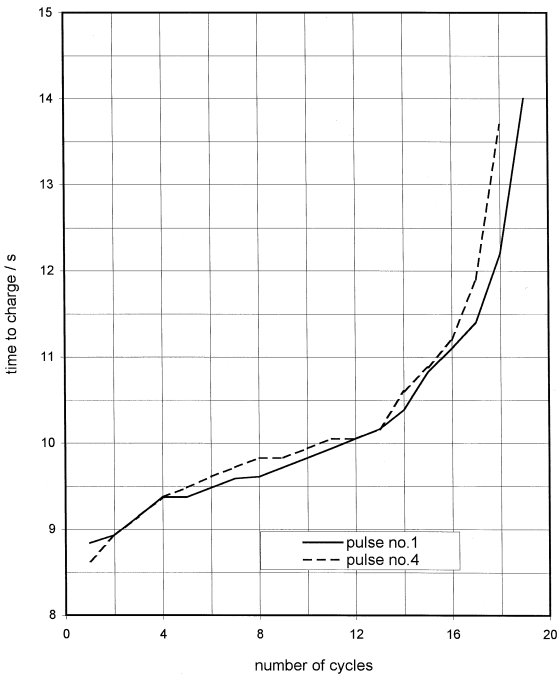

Fig. 4. Capacitor loading times as a function of number of cycles. Breadboard circuit with 185 μF capacitance, charged to 775 V. Each cycle consisted of four charges, each requiring 30 J from the LiS 32125/K6 battery.

be larger. A voltage drop of 2.5 V or more can be accepted with the DC/DC converting still working at good efficiency. In Fig. 3, discharge results of the battery under various pulse loads are given. These data reflect the pulse power characteristics of the battery. The maximum power output of the battery is well above 5 W at the end of the 1st pulse in the train, from BOL to MOL.

These characteristics are also important in respect to the amount of energy available for low rate discharge after removing capacity for shocks. The remaining capacity of the lithium/manganese dioxide battery is used for monitoring and pacing. The ERI (election of replacement indicator) point is detected by monitoring the voltage of the lithium/iodine battery. After depletion of the low-rate cell, the whole power is supplied by the 6 V battery [4].

4. Breadboard discharges

Breadboard discharges have been performed to demonstrate the capacitor-charging capabilities of the batteries.

Table 2
Heat dissipation from LiS 32125/K6 batteries

Storage condition	Heat dissipated [μW]	Comments
On open-circuit:		
After 1 month	15.4–18.0	
After 6 months	6.4–8.6	
Pulse life test:		background load: 600 kΩ
After 1 month	14.7–19.8	2 pulsetrains per year
After 6 months	6.8–10.6	four, 1 A, 9 s pulses, 15 s intervals

Table 3
Technical data for the LiS 1270 battery

Parameter	Units	Value	Comments
OCV	V	2.79–2.80	beginning of life (BOL)
Voltage under load	V	2.785–2.795	175 kΩ at BOL
Nominal capacity	A h	0.680	into 175 kΩ to 2.5 V (EOD)
Impedance	kΩ	0.2–1.2	BOL to MOL
Self-discharge		< 7% in 5 years	at 37°C
Length	mm	32	
Width	mm	7	
Height	mm	12	excluding terminal pin
Mass	g	10.9–11.5	

This test is a simulation of the actual power requirement of the battery within the implanted device.

A 185 μF, high-voltage capacitors have been charged to an end-voltage of 775 V. This calculates to an available shock energy of 30 J. Loading times have been 8.7 s at BOL and 9.7 s at MOL to charge up to 775 V. Fig. 4 shows loading times as a function of state of discharge. Taking into account a background load of 7 mA, which is drawn by the breadboard circuitry, the battery is able to deliver up to 90 shocks. The mean current during capacitor charging is 1.15 A. The battery supplies 48.3 W s during charging, and this equates to 57% effectiveness in loading the capacitors using this specific breadboard design.

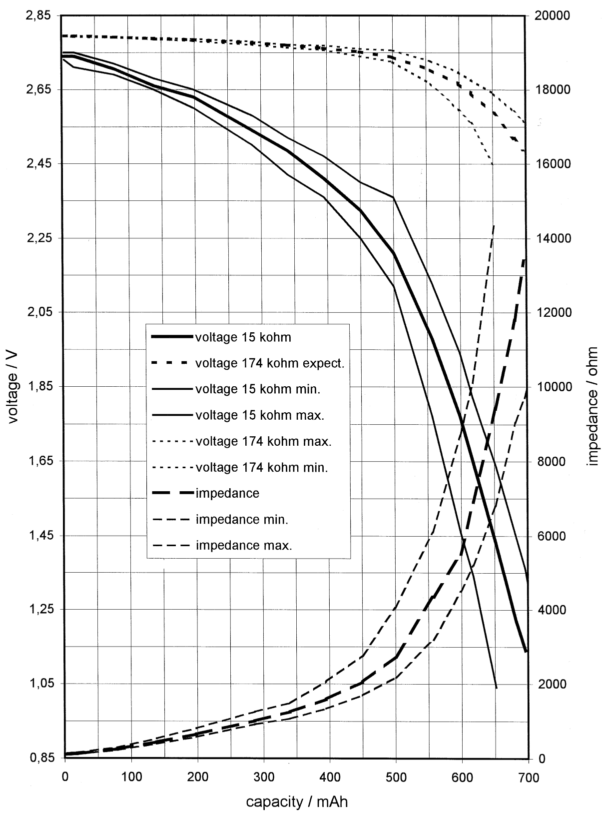

Fig. 5. LiS 1270. Capacity removed vs. voltage and impedance. 15 kΩ data is experimental, 174 kΩ calculated.

5. Self-discharge

The self-discharge of the batteries has been determined with microcalorimetry. Due to parasitic chemical processes on the anode surfaces as well as on the cathode mass, which reduce the amount of water and other impurities in the electrolyte, the rate of self-discharge decreases during lifetime. Table 2 shows the values after storage at OCV and during life pulse testing.

The amount of dissipated heat decreased during the first three months to a basic value of about 6 μW. No significant difference between storage at OCV and storage under load has been observed.

6. The lithium / iodine battery LiS 1270

To provide sufficient lifetime for the defibrillator, a small lithium/iodine cell has been developed. This prismatic battery has the performance data given in Table 3.

The battery case is made from stainless steel, the case-to-lid joint being laser welded. Electrical performance has been tested by discharging into a constant resistance of 15 kΩ. The results are recalculated for a 174 kΩ discharge. EOD voltage is set to 2.5 V.

Capacity for a 174 kΩ discharge is 0.680 A h. Fig. 5 summarizes the electrical characteristics of the cell.

7. Conclusions

The development of a hybrid-battery system for an implantable defibrillator/cardioverter resulted in an increase in specific energy densities in respect to weight and volume without significant reduction in pulse-power rating. The low-rate capacity provided by the hybrid system is larger and lifetime is enhanced. A direct comparison of the hybrid system, which is shown in Fig. 6, and another 6 V battery used in a defibrillator is given in Table 4.

As a result of this work, weight and volume of the power sources have been reduced, while the capacity has been increased. Capacitor charging times can be rated only by comparing performances of the user devices. To increase the high rate performance of small 6 V lithium/manganese dioxide batteries will be the next step in further improvement efforts.

Acknowledgements

This development work has been supported by the German Ministry of Technology and Science (BMBF).

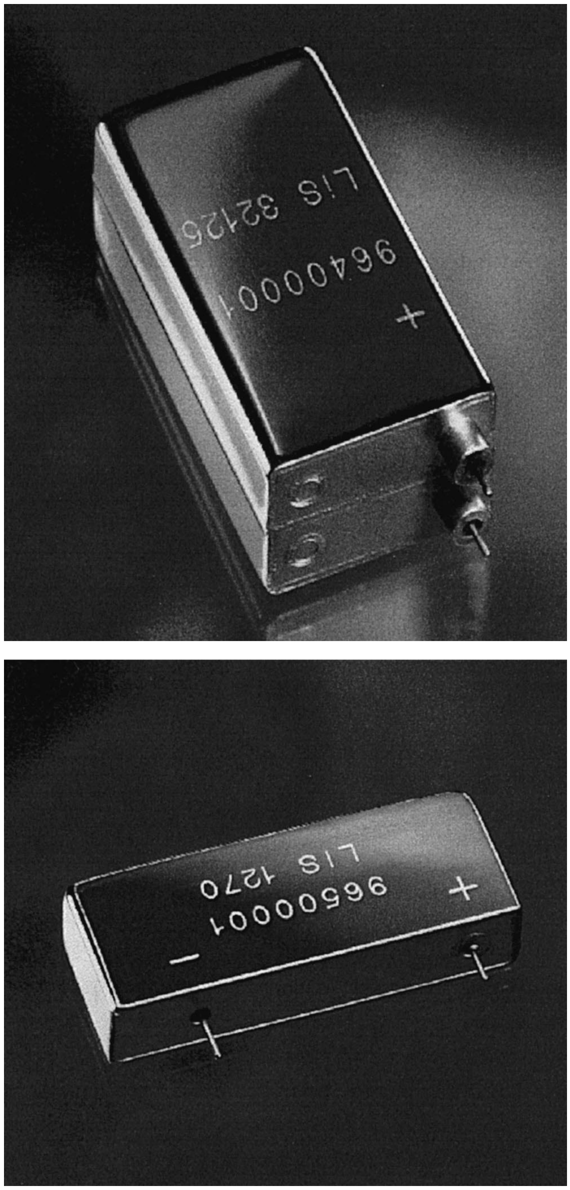

Fig. 6. The hybrid system: A LiS 3215/K6, 6 V lithium/manganese dioxide battery (upper) plus LiS 1270, 3 V lithium/iodine battery (lower).

Table 4
A comparison of capacity, volume and weight for a 6 V battery and a hybrid-system

	6 V battery LiS 43100	Hybrid-system LiS 32125/ K6 + LiS 1270	Comment
Capacity [A h]	0.8	1.1	low rate
Volume [ml]	11.6	9.9	without terminals
Weight [g]	34	32	

References

[1] E.S. Takeuchi, Proc. 10th Int. Seminar on Prim. and Second. Battery Technology, Deerfield Beach FL, 1993.
[2] J. Drews et al., Journal of Power Sources 65 (1997) 129–132.
[3] R. Staub, G. Fehrmann, R. Wolf, Th. Fischer, H. Heimer, US patent, 5.713.936, 1998.
[4] J. Pilz, J. Müller, R. Staub, G. Fehrmann, European patent, 0 872 261 A2, 1998.