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Alkaline batteries for hybrid and electric vehicles

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Abstract

Forced by the USABC PNGV Program and the EZEV regulation in California, the development of hybrid vehicles become more strong. Hybrids offer flexible and unrestricted mobility, as well as pollution-free driving mode in the city. To achieve these requirements, high-power storage systems are demanded fulfilled by alkaline batteries (e.g., nickel/cadmium, nickel/metal hydride). DAUG has developed nickel/cadmium- and nickel/metal hydride cells in Fibre Technology of different performance types (up to 700 W/kg peak power) and proved in electric vehicles of different projects. A special bipolar cell design will meet even extreme high power requirements with more than 1000 W/kg peak power. The cells make use of the Recom design ensuring high power charge ability at low internal gas pressure. The paper presents laboratory test results of cells and batteries. © 1998 Elsevier Science S.A. All rights reserved.

Keywords: Alkaline batteries; Hybrid vehicles; Electric vehicles

1. Introduction

The compulsion to reduce noise and air pollution in the cities produced by combustion engine-driven cars, and to preserve individual and business mobility and flexibility, will force the development of hybrid cars. The hybrid system offers the advantage that the combustion engine can work with high efficiency in an optimal environmentally beneficial driving mode, and that the surplus of energy can be used for charging an energy storage system.

As energy storage systems, super capacitors, fly wheels and electrochemical storage systems are in competition. The advantage of the electrochemical storage systems are that the batteries are available today, while fly wheels and super capacitors are under development at the moment, and will be available in the mid-term or long-term future. Especially, the alkaline battery systems fulfil, besides the economic and environmental criteria, the technical requirements of high power input and output during charge and discharge, which are necessary for hybrid applications.

2. Recom cells in fibre technology

DAUG is involved in the development of all major alkaline storage systems especially nickel/cadmium-, nickel/metal hydride- and nickel/zinc- cells of different size and performance types. The cell electrodes are made from plaques of nickel-covered plastic fibres (Fig. 1) filled by a special process with active material. The fibre plaque electrodes provide mechanical strength and a certain degree of flexibility to compensate volume change of the active material during cycling. The fibre plate is a highly porous material of good electric conductivity.

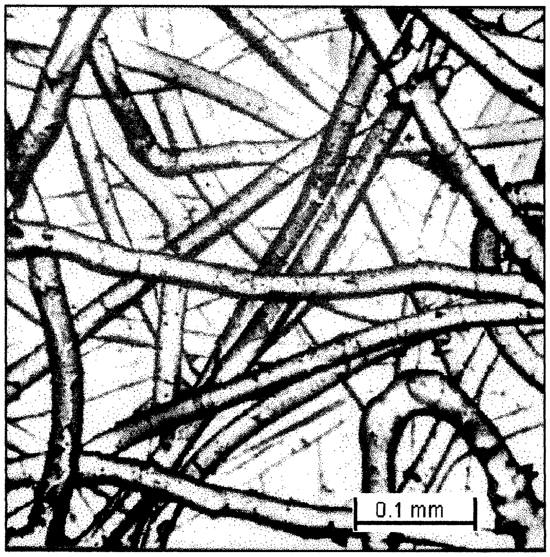

Fig. 1. Fibre plaque.

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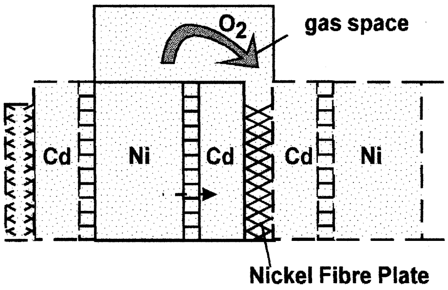

Fig. 2. Recom principle.

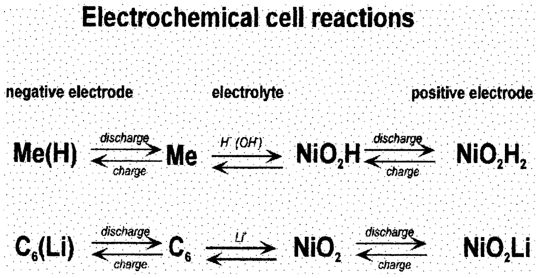

Fig. 4. Comparison of electrochemical cell reactions of lithium- and hydrogen-ion shuttle system.

The manufactured cells are sealed, maintenance-free and of rectangular (prismatic) shape. The cells make use of the RECOM principle. The new and unique design is characterised by the use of a porous nickel fibre plaque ‘sandwiched’ between negative fibre electrodes (Fig. 2).

This composite negative electrode arrangement enhances the consumption of oxygen during recharge, so that there is a low pressure (vacuum) inside the cell even at the end of charge when heavy gassing would otherwise take place.

3. Nickel / cadmium system

The nickel/cadmium cells, manufactured in a pilot plant, are the most advanced system, and are now installed in about 100 EVs and hybrid EVs.

There are even buses powered by FNC-Recom batteries running in a normal time schedule for public transportation. These buses have been on the road for more than 18 months. Their batteries were recharged twice or three times in less than 50 min daily.

At Rügen island, the fast recharge ability of FNC-batteries has been demonstrated, which enables a daily cruising range of about 350 km. In fact, the fast charge ability is one of the most important properties of alkaline batteries to make them the battery of choice in hybrid cars.

For all the cars, DAUG is delivering the complete battery system including thermal and electrical battery management (Fig. 3). Battery data—voltage, current, temperature, accumulated charged and discharged capacity and energy, as well as the state of charge—are monitored on a display, and abuse conditions for the battery will be made visible.

The nickel/cadmium cells can be substituted easily by the nickel/metal hydride system, because the cell voltage is rather the same. In addition, the change from the cadmium electrode to the nickel metal hydride storage system will reduce the environmental problems.

4. Nickel / metal hydride system

Nickel/metal hydride cells have some advantages in comparison to nickel/cadmium cells. The energy density (W h/kg; W h/l) is considerably larger (30–40%). The electrochemical reaction during charge and discharge do not consume or produce water; therefore, the electrolyte concentration and composition do not change during the whole cycle. The cell reactions may be discussed as an ‘ion shuttle’ system with similarities to the advanced lithium ion cells (Fig. 4).

The electrode processes are expected to proceed without hindrance, polarisation of the electrodes remain small, and a low internal resistance of the cells is assumed.

4.1. Characteristics of nickel / metal hydride cells

The cycle life of the nickel/metal hydride system is comparable to that of nickel/cadmium (Fig. 5).

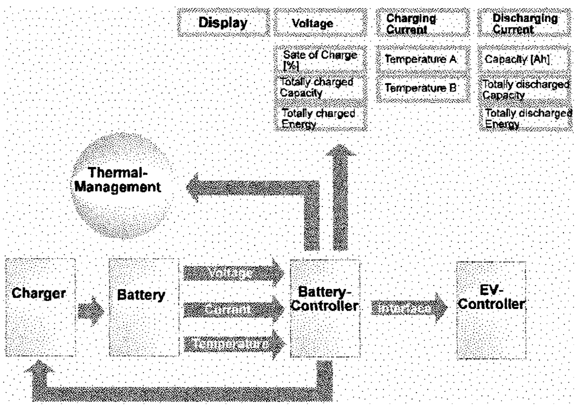

Fig. 3. Electrical and thermal battery management system.

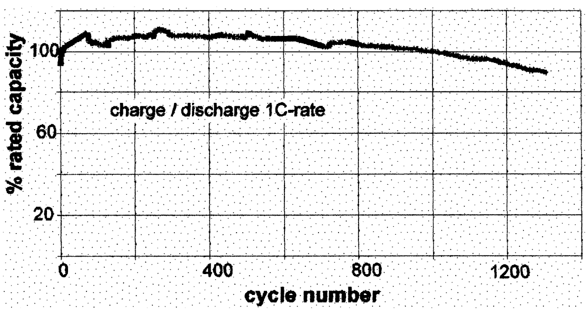

Fig. 5. Capacity of nickel/metal hydride cells during cycling.

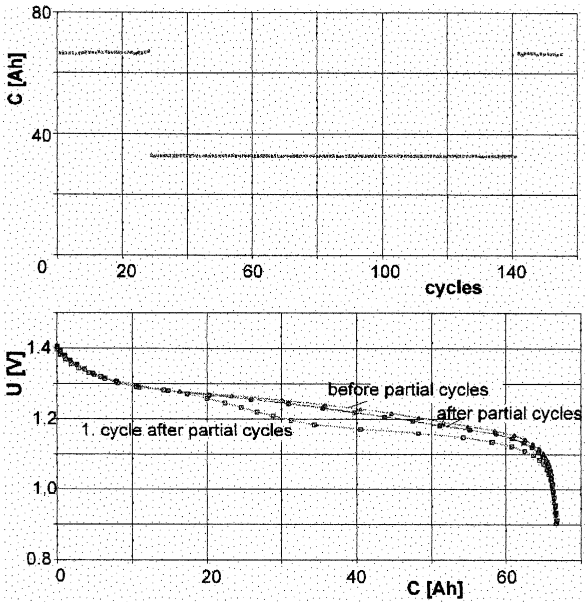

Fig. 6. Partially discharged nickel/metal hydride cells.

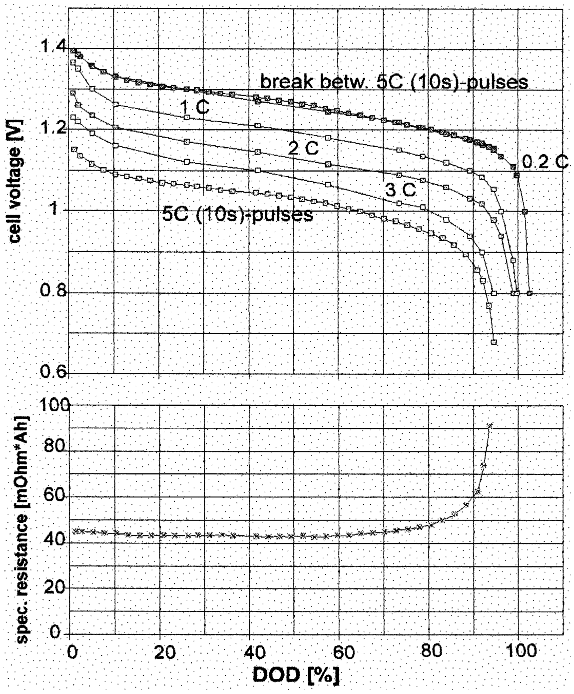

Fig. 7. Discharge curves and resistance of X-type nickel/metal hydride cells.

Experiments have shown that nickel/metal hydride cells do not have a capacity loss (memory effect) when they were partially discharged for several cycles (Fig. 6).

Typical discharge curves of a nickel/metal hydride X-type cell is shown in Fig. 7. The internal resistance determined by a pulse measurement remains approximately constant during the discharge, and is raised only at the end of discharge.

All alkaline systems will be produced at DAUG in the same cell case sizes, giving the advantage that the same thermal management can be used for all couples. There are three series of cell types, the H-type designed for pure EVs, the X-type for hybrid EVs (HEV) and additional the XX-type cells.

The XX-type cells will meet even extreme high power requirements for special HEV applications, e.g., demanded in the USABC/PNGV program.

In Table 1, the available cell sizes ($H \times W = 170 \times 115$ mm) and their characteristics have been compiled. Except the XX 11 A h ($H \times W \times T = 110 \times 59 \times 26.5$ mm) and the XX 22 A h ($H \times W \times T = 170 \times 59 \times 26.5$ mm) couples the cells differ only in their thickness (22 mm to 64 mm), which determines the cell capacity.

The cells can be used in a series of single cells or couples of two parallel cells allowing to build any required A h-capacity form 11 A h up to 280 A h.

The power available from a cell depends on the performance type (H-, X- or XX-type) and the state of discharge (% DOD) (Fig. 8).

Table 1
Cell dimensions and characteristics

	Dimensions									
Thickness (mm)	26.5	26.5	22	28	34	40	46	52	58	64
Width (mm)	59	59	115	115	115	115	115	115	115	115
Height (mm)	110	170	170	170	170	170	170	170	170	170
Volume (!)	0.17	0.27	0.43	0.55	0.68	0.78	0.9	1.02	1.13	1.25
	H-type cells for EVs									
Capacity (A h)	45	55	70	85	100	115	125	140		
Weight (kg)	1	1.15	1.4	1.7	2	2.3	2.6	3		
	X-type cells for HEVs									
Capacity (A h)	40	52	65	75	85	100	115	126		
Weight (kg)	1.06	1.25	1.55	1.8	2	2.4	2.75	3		
	XX-type cells for special HEVs									
Capacity (A h)	11	22	36							
Weight (kg)	0.38	0.72	1.15							

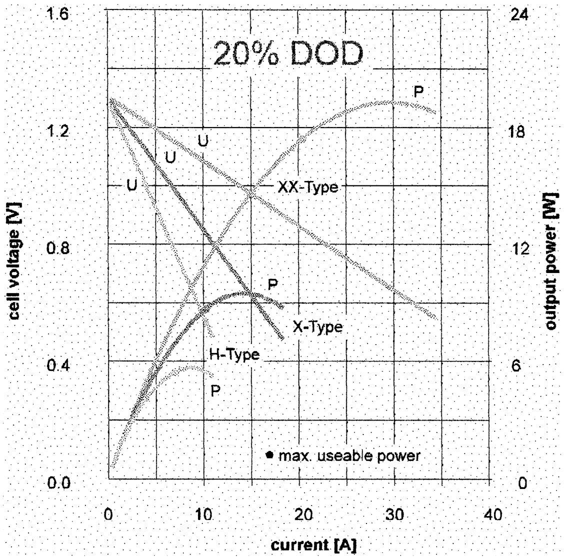

Fig. 8. Power output of nickel/metal hydride cells standardised to 1 Ah.

At a given current, the cell or battery voltage becomes reduced. The power output is a function of current, voltage and internal resistance. For practical applications, the discharge voltage should not drop down to lower values than 2/3 of the nominal voltage resulting in about 0.85 V for nickel/metal hydride cells, because the ratio of power output and heat generation becomes more and more unfavourable. The power output under this conditions for various cell-types as a function of depth of discharge is shown in Fig. 9.

4.2. Characteristics of nickel/metal hydride batteries

An example of results obtained from a complete X-type battery system is given in Fig. 10. It illustrates that large numbers of cells show the same behaviour as an individual cell, and prove that the battery and thermal management is well adapted to the needs of traction batteries.

Fig. 11 shows a sequence of current and voltage profile for a 4 kW h/11 A h XX-type battery (Fig. 12) during

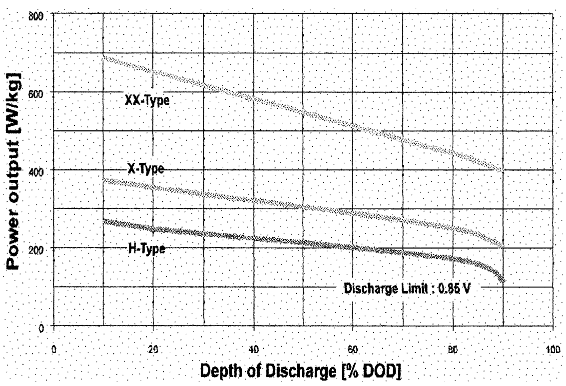

Fig. 9. Maximum power output of nickel/metal hydride cells at different state of charge.

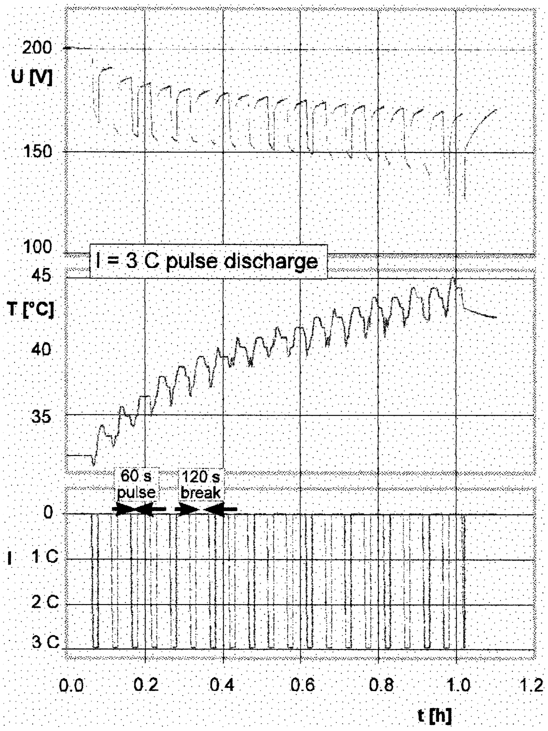

Fig. 10. Pulse discharge of a complete battery.

cycling. The battery consisting of 280 single cells was discharged with 40 kW from 90% state of charge (SOC) to 40% SOC and recharged with 20 kW.

During a 45-kW pulse-discharge the current rises up to 200 A at the end when the battery is fully discharged (Fig. 13).

5. Further developments

There are several ways to optimise a battery system. The choice of active electrode materials, cell design, thermal and electric management units influences the system performance. In addition, the improvement of the principal design of cells can help adapt the battery to the needs of car manufacturers.

DAUG is developing a new concept for bipolar nickel/metal hydride batteries (Fig. 14). The research

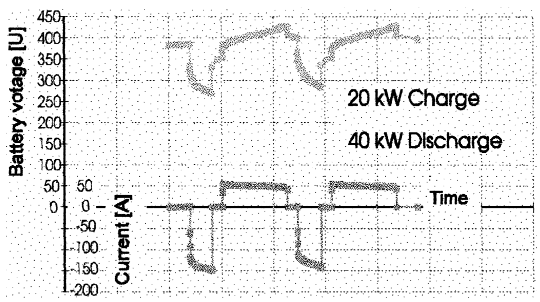

Fig. 11. Current and voltage profile during cycling.

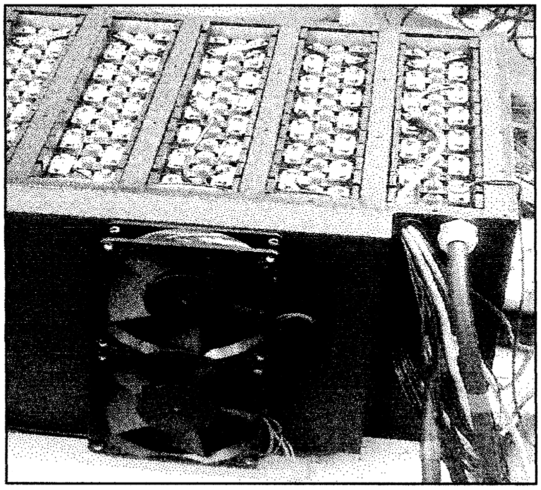

Fig. 12. Four kW h XX-type high power battery.

activities are based on the current achievements in the monopolar cell design, and take full advantage of the features of the nickel/metal hydride system. In addition to the electro-chemical H-shuttle concept realised in such cells, there are additional measures for heat and hydrogen transfer that will enable an easier control of the battery devices.

The main advantages are expected in terms of energy density, lower costs, easier handling and better balance between individual sub-cells. It is expected that the resulting cells will have a considerably increased power density —even much higher than conventional XX-type cells—at larger energy density (Fig. 15).

Laboratory tests of bipolar nickel/metal hydride cells are very encouraging. The results confirm that the power output of more than 1000 W/kg and the energy density of app. Forty-five Wh/kg (Fig. 15) will be achieved.

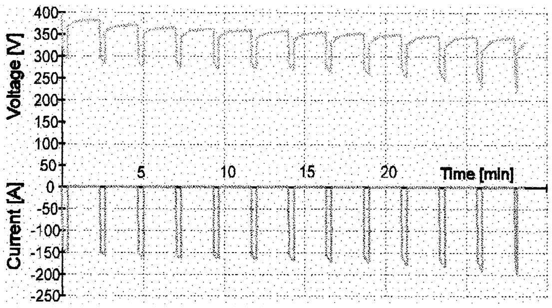

Fig. 13. Forty-five kW pulse discharge (20 s).

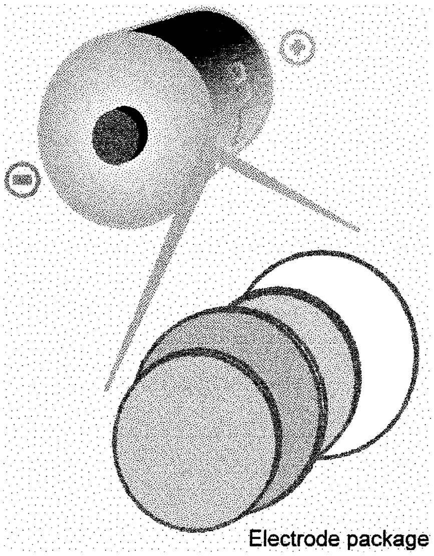

Fig. 14. Tubular bipolar battery design.

The power output of the bipolar battery system is similar, or higher than that of a super capacitor. The high energy density gives the battery system more advantage for hybrid applications than a super capacitor.

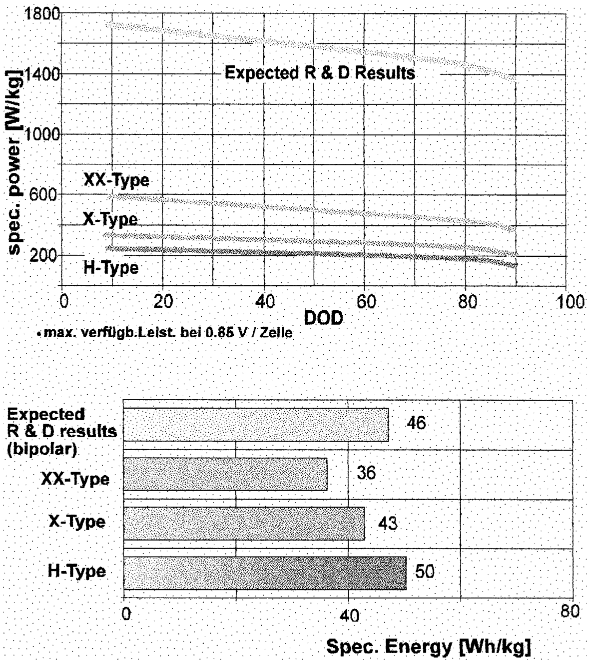

Fig. 15. Power output and energy density of new bipolar cell design.