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ZEBRA battery meets USABC goals

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Abstract

In 1990, the California Air Resources Board has established a mandate to introduce electric vehicles in order to improve air quality in Los Angeles and other capitals. The United States Advanced Battery Consortium has been formed by the big car companies, Electric Power Research Institute (EPRI) and the Department of Energy in order to establish the requirements on EV-batteries and to support battery development. The ZEBRA battery system is a candidate to power future electric vehicles. Not only because its energy density is three-fold that of lead acid batteries (50% more than NiMH) but also because of all the other EV requirements such as power density, no maintenance, summer and winter operation, safety, failure tolerance and low cost potential are fulfilled. The electrode material is plain salt and nickel in combination with a ceramic electrolyte. The cell voltage is 2.58 V and the capacity of a standard cell is 32 Ah. Some hundred cells are connected in series and parallel to form a battery with about 300 V OCV. The battery system including battery controller, main circuit-breaker and cooling system is engineered for vehicle integration and ready to be mounted in a vehicle [J. Gaub, A. van Zyl, Mercedes-Benz Electric Vehicles with ZEBRA Batteries, EVS-14, Orlando, FL, Dec. 1997]. The background of these features are described.

Keywords: ZEBRA; Battery; Electric vehicle

1. Introduction

Driven by the unacceptable bad air quality in Los Angeles, the California Air Resources Board (CARB) has generated regulations to reduce emissions from traffic. This is justified because about 70% of the local emissions in the Los Angeles basin are generated by traffic. As a part of this Clean Air Act, zero emission vehicles (ZEV) are to be launched to the market. This is not an easy task, because new technologies for batteries and drive systems have to be developed and brought to production in competition to conventional internal combustion engines. In order to support and focus the necessary battery development, the United States Advanced Battery Consortium (USABC) has set goals that have to be met at least mid-term in order to develop electric vehicles acceptable for the market. This situation has triggered battery development world-wide in order to participate in this large emerging market for electric energy storage devices.

Fifteen years ago, the development of the ZEBRA battery was started [1]. The guiding idea from the very beginning was to achieve high energy density and performance as demonstrated in sodium sulfur batteries but avoiding the safety concerns which are caused by the sulfur content. This lead to the invention of the new electrochemical couple sodium and nickelchloride. The charming background of the system is that neither during production nor during recycling has the metallic sodium have to be handled. The raw materials used for the production of the ZEBRA cells is nickel and salt in combination with a ceramic electrolyte and a molten salt electrolyte. This battery system meets the USABC goals and is being produced in a pilot line (Table 1).

The specific energy density of 85 Wh/kg is without the additional 10 Wh/kg thermal energy available for cab heating. The liquid cooling system allows the withdrawal of up to 8 kW heat available instantaneously for wind screen defrosting. The ragone diagram (Fig. 1) also shows that the unavoidable losses inside the battery are available for heating as well. Thus the ZEBRA battery allows a range of 150 to 200 km independent of climate conditions. The double-walled vacuum insulated battery box in combination with the thermal management is designed for operation at −40°C to +70°C.

The specific power of 150 W/kg at 80% depth of discharge for a two third open circuit voltage at the end of a 30 s pulse is the requirement for a proper acceleration in

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Table 1
ZEBRA meets USABC criteria

Parameter	Mid-term criteria	ZEBRA Z11
Price	< US$150/kWh	US$300/kWh production start
Cycle life	600 @ 80% DOD	1000 @ 100% DOD
Range @ life (urban miles)	100,000	70,000 demonstrated
Calendar life	5 years	5 years demonstrated, 10 years potential
Power density	250 W/l	256 W/l
Energy density	135 Wh/l	149 Wh/l
Specific power	150 W/kg (200 desired)	150 W/kg[a]
Specific energy	80 Wh/kg (100 desired)	86 Wh/kg[a]
Regenerative specific power	75 W/kg	200 W/kg[a]
End of life (EOL)	20% of rated power and capacity specification	20% of rated power and capacity specification
Operating performance	−30°C to +65°C	−40°C to +70°C
Normal charge	6 h, 20–100% SOC	6 h, 20–100% SOC
High rate charge	< 15 min, 40–80% SOC	36 min, 20%–70% SOC
Efficiency at EOL	75%	> 80%
Off-tether pack energy loss	Thermal loss < 3.2 W/kWh (< 15% in 48 h); Self discharge < 15%/48 h	Thermal loss 5.5 W/kWh compensated by operation; Self discharge zero

[a] System weight including BMS, IFB, cooling.

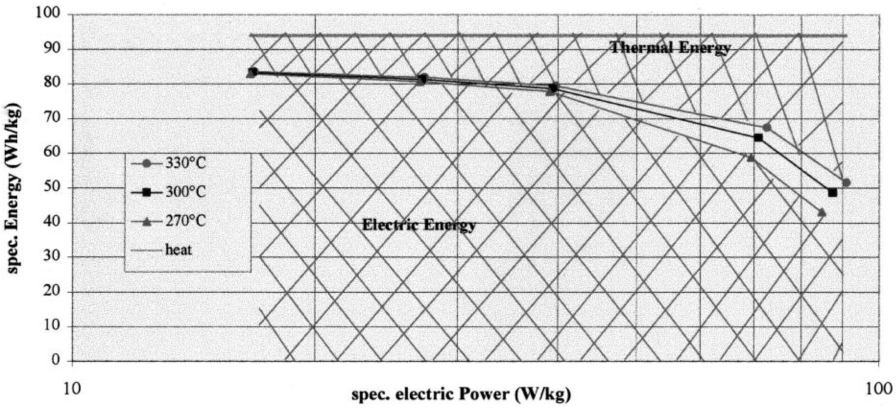

Fig. 1. Ragone diagram for ZEBRA batteries Z5, Z11, with ML3 cells thermally available energy.

normal traffic. By the redesign of the ceramic electrolyte shape and some other detailed work, this power is available nearly over all the battery capacity (Fig. 2) [2,3].

The cycle life of batteries is most important for the vehicle economy because the replacement of single modules or complete battery packs is always an expensive exercise. The ZEBRA battery has the important advantage in it's being maintenance-free for life because in the case of single cell failures no maintenance or anything else is necessary. The reason for this is the low resistant cell failure mode which means that in case of a cell failure the internal resistance of the failed cells is very low. In case of a crack in the ceramic, the liquid electrolyte reacts with the sodium to form aluminum and salt. This aluminum shortens the cell so that the ZEBRA cell has a looping element by its chemistry (Fig. 3). Therefore, up to 5% of failed cells can remain in the battery untouched before the battery would have to be taken out of service.

The performance of the ZEBRA battery is independent of the ambient temperature. All materials and the electronic parts of the battery system are designed for a temperature range of −40°C to +70°C. Besides the thermal energy storage capability, this is one of the main advantages of the hot battery because of its thermal management.

The ZEBRA battery has a very high level of safety incorporated in its features.

1.1. Chemical system

The chemical system has a built-in feature to reduce the heat burden in case of damage. The reaction of the liquid

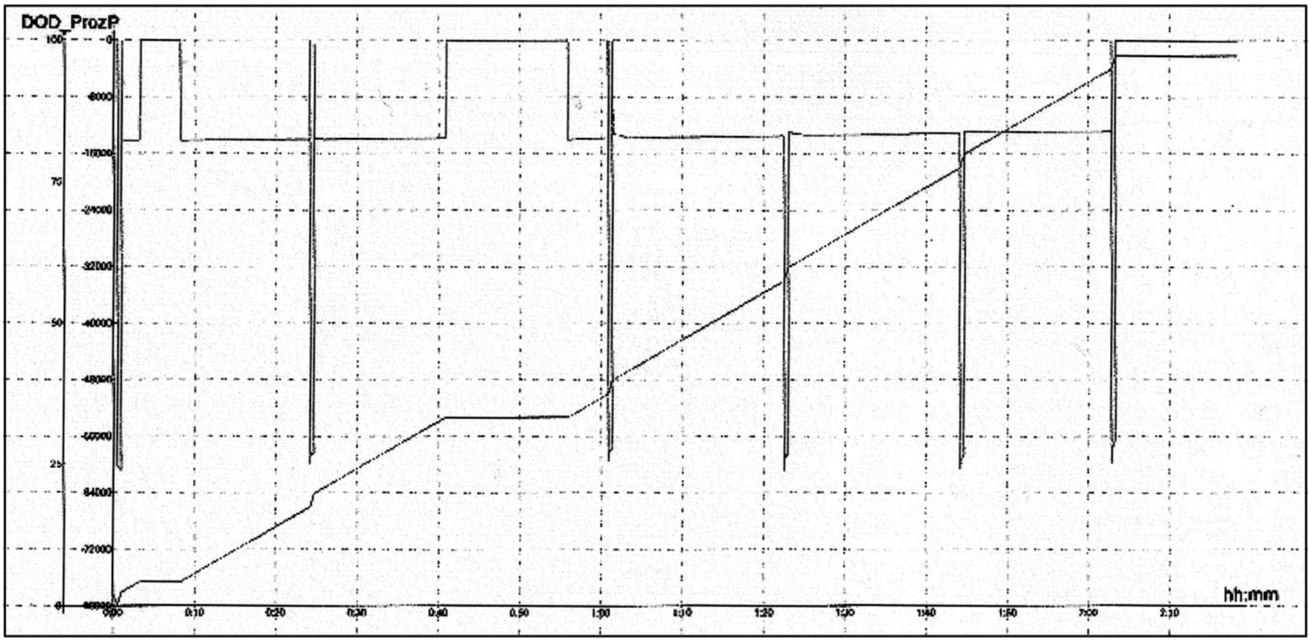

Fig. 2. Peak power independent of DOD.

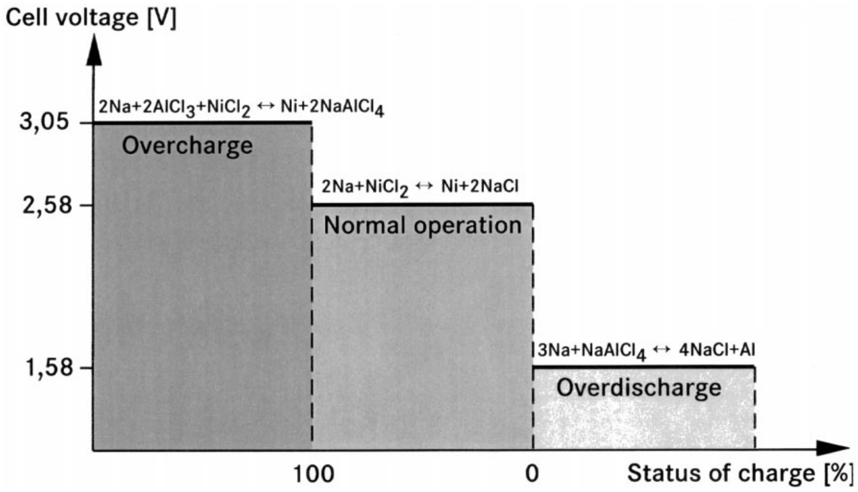

Fig. 3. ZEBRA cell reactions at 300°C.

electrolyte with the liquid sodium produces only two thirds of the energy of the main storage reaction, and the reaction products (salt, aluminum) passivate the cathode to suppress further normal discharge reactions (Fig. 4).

1.2. Three-fold steel enclosure

All reactants are encapsulated in the steel-made cell cans with welded tetrachlorobiphenyl (TCB) seals. The

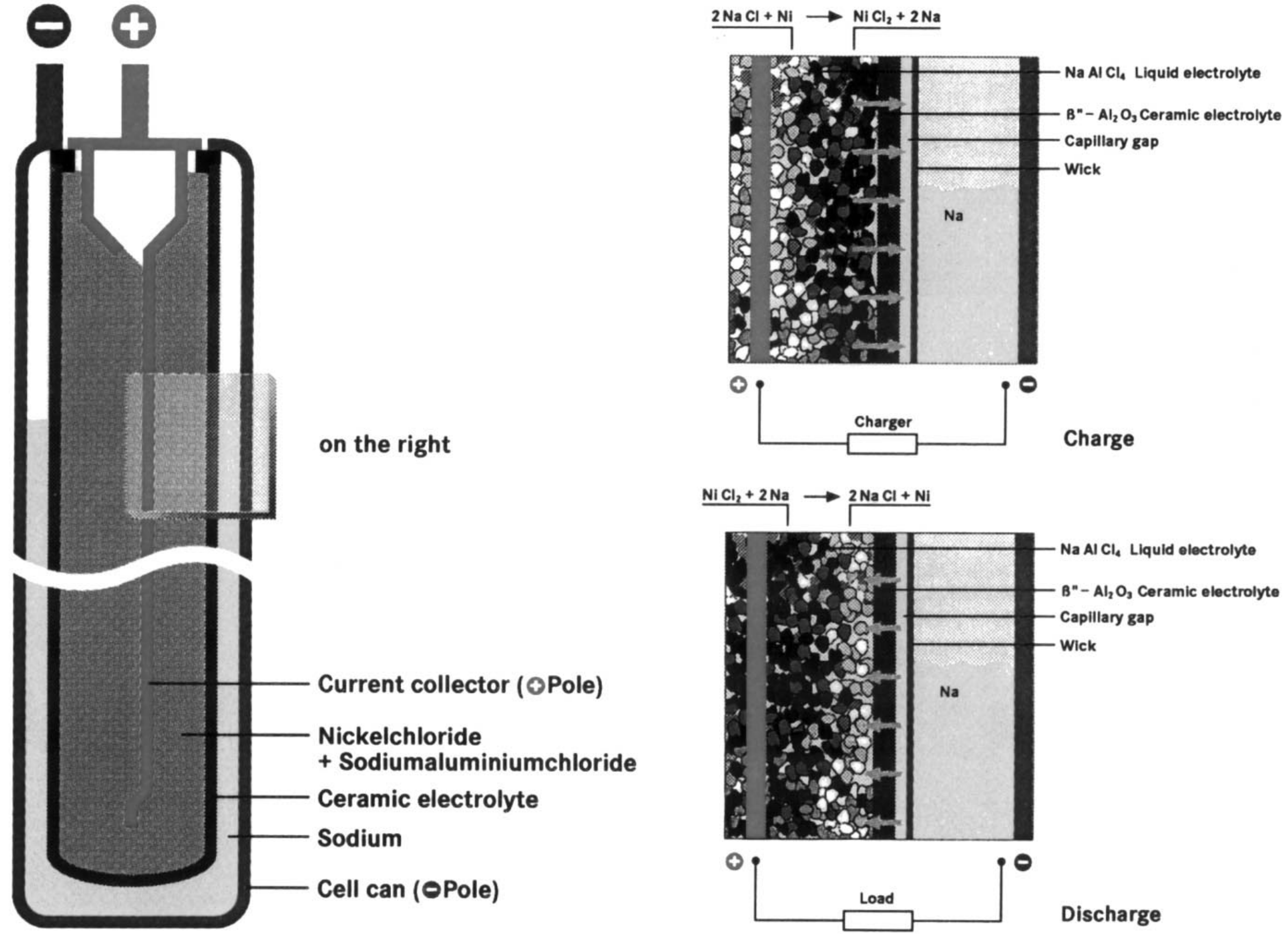

Fig. 4. ZEBRA cell design.

cells are ceramic coated for melt resistant electric insulation and are encapsulated in the double walled stainless steel battery box with inside high temperature resistant thermal insulation. This box encloses the reactants even at extreme conditions of 1000°C inside.

1.3. Internal short protection

In case of an internal short, a thermal runaway is prevented by the coated ceramic cell insulation, the partitions constraining any effects to battery segments and the built-in sump which absorbs melt in case of cell opening. The insulation resistance is permanently monitored by the BMS.

1.4. External short protection

The main circuit breaker is an integral part of the battery system and protects it from damage from an external short. It is operated by the BMS. In case of a vehicle crash, the crash sensor signal is used to disconnect the battery.

1.5. Crash and abuse tested

The qualification of each ZEBRA battery type includes on pole drop testing with 50 km/h vibration test for 24 h according to USABC specification, freeze/thaw cycling, overheating, overcharging and short circuit testing. In all tests the pass criteria is that the battery box remain closed except when it is mechanically opened from outside and no toxic components are emitted.

The ZEBRA battery passed all tests.

1.6. Thermal shut off

In contrast to ambient temperature battery systems, the ZEBRA battery can be passivated totally by cool down.

2. System design

The ZEBRA battery was developed and designed from the very beginning as a ‘ready to mount’ battery system with well defined interfaces to the car. The system includes the battery box with internal heating and cooling devices, the two pole main circuit breaker which is integrated in the interface box, the battery controller and the cooling box which contains the oil/water heat exchanger, the circulation pump and an expansion vessel for the cooling liquid. A logistic system was developed in order to supply the ‘ready to mount’ battery system to the production line of the cars.

3. Recycling

The ZEBRA battery is also being prepared for the recycling of worn out batteries. First investigations indicated that the recycling cost can be covered by the sale of the nickel inventory. The cost situation seems to be neutral.

4. Conclusion

The ZEBRA battery system is an advanced battery being tested very extensively with more than 1.5 million km on public roads.

The next important step now is to start series production which is solely dependent on the market.

References

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