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Testing of a sodium/nickel chloride (ZEBRA) battery for electric propulsion of ships and vehicles

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Abstract

One of the promising future batteries for electric propulsion of vehicles and ships is the sodium/nickel chloride or ZEBRA (Zero Emission Battery Research Activities) battery. Despite some disadvantages with respect to the high temperature, the advantages with respect to specific energy and energy density are such that, especially in applications where the battery is used on a more or less continuous basis (e.g., in delivery vans and taxies) it is an interesting candidate battery. Another interesting application is on board of ships, like submarines or future electrical surface ships with electric propulsion. In 1995 a 2 year feasibility study, including experimental testing of a 10 kW h battery, was completed. This investigated the naval applicability of the sodium/sulphur battery, which is also a high temperature battery. Here the limited, experimentally proven, life-time of the batteries of about 1.5 years and this made naval application almost impossible. A paper about this study was presented at the 19th International Power Sources Symposium held at Brighton, England, in April 1995 [R.A.A. Schillemans, C.E. Kluiters, Sodium/sulphur batteries for naval applications, in: A. Attewell, T. Keily (Eds.), Power Sources 15, International Power Sources Symposium Committee, Crowborough UK, 1995. p. 421.]. Because of the more or less comparable specifications on specific energy and the more promising results of the life-time and field tests with sodium/nickel chloride batteries, a ZEBRA battery from AEG Anglo Batteries has been tested for naval applications. This was done by simulating the charge and discharge as it occurs in practice for the applications investigated. With respect to the electrical ship application (investigated for the Royal Netherlands Navy) the power versus time taken from the battery was simulated as well as the charge procedures. The same can be done for the vehicle application: in this case typical drive cycles for a van or taxi are translated to power versus time taken from the battery. The results of the tests for application of the battery in naval ships are very promising.

Keywords: Applications/submarines; Applications/electric vehicles; Sodium/metal chloride batteries

1. Introduction

In the past, and even more today, many batteries and fuel cells have been available which could replace lead–acid batteries. As part of the research programme for the Royal Netherlands Navy (RNLN) the Chemical Engineering Department of TNO continuously monitored the research and development activities in this area to validate these developments.

Four years ago, a thorough evaluation showed that a promising candidate was being introduced: the sodium/sulphur battery. The specifications as claimed and the development stage at that time, indicated that the replacement of lead–acid batteries with sodium/sulphur could become feasible in the near future. To investigate the application to a further extend, a feasibility study was carried out by TNO [1]. The application concentrated upon was submarine propulsion. Another application that was dealt with was emergency power supplies on-board surface ships.

To investigate the feasibility of the sodium/sulphur battery for naval application,calculations had been made on the expected performance within the two envisaged applications. The calculation on the submarine application had been validated with experimental testing. Experiments have proved that the performance of the sodium/sulphur battery, is in accordance with the claims. A submarine equipped with sodium/sulphur batteries outperforms a submarine using traditional lead–acid batteries. The most important disadvantage of the sodium/sulphur battery for

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naval application at that time was the short, experimentally proven, lifetime of about 1.5 years, For application in submarines and as emergency power supply for frigates this is far too short. Both manufacturers of sodium/sulphur batteries, ABB and Silent Power, have now stopped their activities with sodium/sulphur batteries. AABG (AEG Anglo Batteries) is now involved in the ZEBRA battery (Zero Emission Battery Research Activities). The ZEBRA or sodium/nickel chloride battery is like the sodium/sulphur battery, being also a high temperature battery and is, with respect to the specifications, more or less comparable with the sodium/sulphur battery. The same test work (operational profile) that was performed in 1994/1995 with the sodium/sulphur battery, has been executed on the sodium/nickel chloride battery in 1998.

The results of calculations and of experimental testing of the battery are described in the following sections.

2. The submarine application

The submarines currently in use with the RNLN are equipped with two parallel strings of lead–acid cells. Diesel-driven alternators completes the energy system. The alternators drive the submarine during surface operation and are used to charge the two strings of cells. The following compares the operational characteristics of an existing submarine equipped with lead–acid batteries with the characteristics of one equipped with sodium/nickel chloride batteries.

2.1. A sodium / nickel chloride submarine battery

A sodium/nickel chloride battery is built up of many individual cells. The functioning and construction of the individual cell is not discussed here, being given in paper 28 of this Symposium.

We will concentrate on the consequences of the introduction of sodium/nickel chloride batteries within the navy.

To predict the performance of a submarine equipped with sodium/nickel chloride batteries, a number of parameters has to be defined. One of the most important parameters is the energy content of the battery, For our predictions,we have chosen to fill the volume currently occupied with lead–acid cells with standard Z5 (second generation) modules from AABG. This is a conservative scenario for two reasons:

(a) The volume to be occupied with sodium/nickel chloride battery modules can be larger because of the lack of need for maintenance. At present, battery room space is reserved above the cells for maintenance of the lead–acid batteries.

(b) The chosen module is not optimised for submarine application. Individual modules can be larger; with them it is likely that more energy could be provided in the same volume.

Table 1
Specification for the AABG ZEBRA sodium/nickel chloride battery type Z5/171

Description	Data
Battery type	sodium/nickel chloride
Manufacturer's code	Z5/171
Cell type	ML1C (monolith)
Cell configuration	2×110 cells in series/parallel
Size (incl. controller) $L \times B \times H$	810 mm×541 mm×315 mm
Size (excl. controller) $L \times B \times H$	730 mm×541 mm×315 mm
Weight	200 kg
Open-circuit voltage (OCV)	110×2.58 V = 183.5 V
Minimum voltage (2/3 OCV)	189.2 V
Maximum discharge current (< 60 s)	2×80 A = 160 A
Maximum continuous discharge current	80 A
Maximum voltage (during recuperation)	110×2.85 V = 313.5 V
Charging voltage	110×2.67 V = 293.7 V
Maximum charge current	no practical limit
Capacity	64 A h
Energy	18 kW h
Specific energy	90 W h kg^{-1}
Energy density	132 W h dm^{-3}
Working temperature	270–350°C
Cooling	Air
Cell resistance (0% DOD to 80% DOD)	17 mohm
Battery resistance (0% DODto 80% DOD)	9 mohm

The prediction resulted in a main battery consisting of 210 parallel strings each of two modules in series. The nominal voltage of one string is 567 V (see specifications in Table 1).

Another important issue to be looked at is the peripheral instrumentation and the associated energy consumption. For the currently used lead–acid batteries, cooling, acid circulation and ventilation are the most important energy consumers needed for the operation of this type of battery.

Regarding sodium/nickel chloride batteries, heating and cooling are the most important energy consumers to keep the battery at the operating temperature. The energy consumption necessary for cooling the battery during use has to be investigated more closely.

2.2. Discharge profile

To compare the performance of a submarine equipped with two different types of batteries the RNLN defined a certain operational profile. It consisted of a combination of three different patterns of operational use:

(a) Snorting cycle: normal operation, in which the battery is charged over a defined period of time during low sub-surface operation. The same amount of energy is then discharged when operating deeper underwater.

(b) Speed burst: a short period of time during which the submarine operates at maximum speed.

(c) Silent-watch: the submarine stays underwater,at minimum speed and with the lowest possible use of energy.

The operational profile used for comparison started with a standard discharge from a snorting cycle, as an introduc-

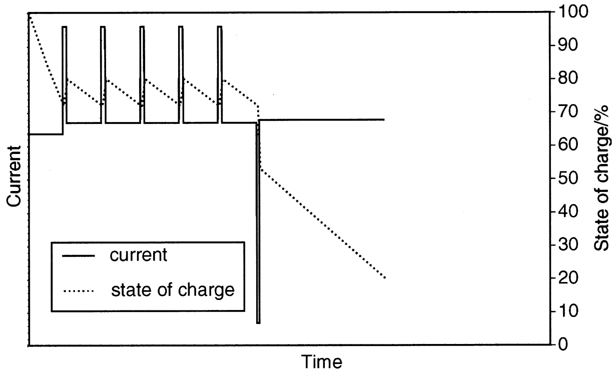

Fig. 1. Current/time characteristic and state-of-charge for lead–acid batteries during the operational profile defined in Section 2.2.

tion to five consecutive snorting cycles. The last snorting discharge was followed by a speed burst, which was followed by a period of silent-watch until 80% of the battery capacity had been discharged.

2.3. Predicted performance

Comparison of the submarine equipped with different battery types is illustrated in Figs. 1 and 2. These show the current and the state-of-charge (SOC) as a function of time. Several differences can be seen:

(a) The lead–acid battery never returns to a 100% SOC during the snorting cycles. To avoid gassing and low charge efficiencies, the battery is charged only to about 80% SOC.

(b) The higher, and constant, voltage of the sodium/nickel chloride batteries at a high SOC results in a lower current when discharging at a set power. This results in a longer period of discharge in the snorting cycles.

(c) The submarine equipped with sodium/nickel chloride batteries is able to maintain a silent watch period about twice as long as submarines fitted with lead–acid batteries. This period is rather longer than if sodium/sulphur batteries are used.

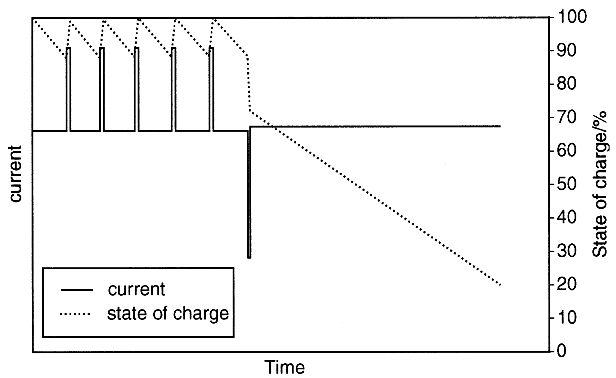

Fig. 2. Current/time characteristic and state-of-charge for sodium/nickel chloride batteries during the operational profile defined in Section 2.2.

3. Experimental testing of the sodium/nickel chloride battery

3.1. Description of the battery

A sodium/nickel chloride battery produced by AABG has been tested. It was an 18 kW h battery type Z5 (second generation), with a nominal voltage of 283.5 V, and consisting of 220 cells connected in a 110×2 matrix, with air cooling. Its specification is presented in Table 1. The tests started in March 1998 and the last test took place in September 1998. Constant current charge and discharge cycles were carried out to check the specification.

4. Test installation

The battery module was tested at the TNO Road Vehicles Research Institute test facilities using Digatron test bench equipment having a power output of up to 300 kW (750 V, 400 A), both in the charge and discharge modes. These facilities are not only used in testing of batteries and other electrical components (e.g., engine/generator sets, electrical motors), but also for testing these components in complete drive trains and vehicles (in combination with mechanical testing on engine test benches and roller test benches). The electrical test equipment of Digatron also has the possibility to simulate components like batteries. A schematic drawing of the Digatron test facility is given in Fig. 3.

5. Results

The nominal capacity of the battery could not always be fully removed during a discharge because of a deliberate offset by AABG of the output from the shunt which

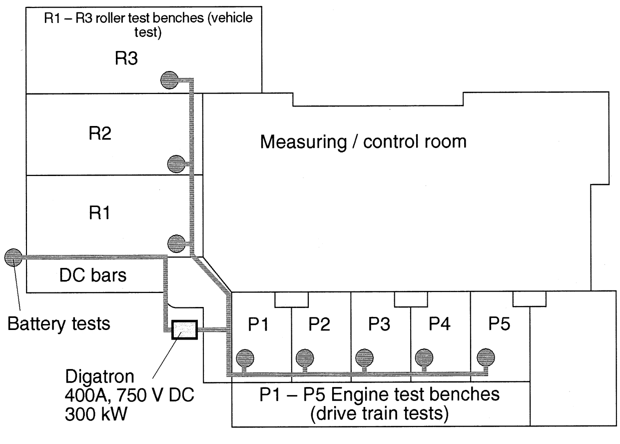

Fig. 3. Schematic drawing of the Digatron test facility.

measures the battery current. This current measurement is used to calculate the battery SOC. This offset gives a ‘loss’ of capacity of 0.25 A h per hour. In naval application this problem will be overcome. Also, in the next generation of sodium/nickel chloride batteries, this problem has been solved.

Figs. 1 and 2 show the measured SOC of a lead–acid battery and of the sodium/nickel chloride battery tested at TNO, and presented on the same time scale. It can be seen that the last silent-watch period for the sodium/nickel chloride battery is twice as long as that for the lead–acid battery (which has the same volume). For the sodium/sulphur battery this time was nearly twice that of that for lead–acid battery.

Experimental simulation of submarine operation proved that, during the discharge phase of the snorting cycle, the voltage was constant. During charge, the battery reached almost a 100% SOC. Decreasing voltage only occurred during and after the speed burst. The duration of the period of silent-watch was in line with the expectations for this battery.

6. Conclusions

The AABG module Z5 (second generation) meets the manufacturer’s specification. The results with the sodium/nickel chloride battery are somewhat better than the results with the sodium/sulphur battery. In combination with the long life-time found in other applications, it can be an interesting alternative to the lead–acid battery in submarines.

A submarine equipped with sodium/nickel chloride batteries outperforms a submarine equipped with the traditional lead–acid batteries. Especially in that the low speed endurance period in the defined profile is twice as long.

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