Analysis of Ni-Zn Batteries Performance for Hybrid Light-Vehicles Applications

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Within the *electrochemical systems for the electrical energy storage*, recent improvements in the reliability of *Ni-Zn* batteries make this technology one of the most promising for hybrid-electric vehicles applications.
Introduction

Ni-Zn batteries characterization

Short-term characterization
- Dynamic discharge tests (ECE-15/UDC)
- Constant current discharge tests
  - Model for Ni-Zn Capacity estimation

Long-term characterization
- Dynamic discharge tests (ECE-15/UDC)
PC-controlled bench
Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Ni-Zn battery characteristics:

- Evercel; model: Ni-Zn 40-12;
  - 38.5 Ah at C/20;
  - 32.7 Ah at C/1;
  - 31.1 Ah at 3C;
  - 20°C;
- weight 7.88 kg.
Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Lead-acid battery characteristics:

- Hawker; model: Genesis G12V26Ah10EP;
  - 26 Ah at C/10, 22.5 at C/5;
  - 20°C;
- weight 10.1 kg.
Ni-Zn batteries short-term characterization and comparison with lead-acid ones 

Ni-Zn Charge

- phase 1: charge at constant current C/1.75, maximum voltage: 14.7 V;
- phase 2: stop for 5 minutes;
Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Lead-acid Charge

- phase 1: charge with constant current equal to $0.4 \times C/10$ for a charging voltage less than 14.7 V (the duration of the phase 1 is $T_1$);
- phase 2: charge with constant voltage equal to 14.7 V for time equal to $T_2 = 2h - T_1$. 

![Graph showing voltage, current, internal temperature, and external temperature over time]
Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Ni-Zn discharges with constant current

Ni-Zn battery performances as function of discharge rate and temperature.

The decrease of the capacity for temperatures above 30° is probably due to the Nickel electrodes that show a kind of unstable behavior above this temperature.
Dynamic discharges based on the urban part of the **ECE-15** cycle: **ECE-15/UDC**

This type of tests is suitable for the simulation of the batteries performance when used on electrical vehicles and, in particular, when urban paths are of interest.
Ni-Zn batteries short-term characterization and comparison with lead-acid ones Cont.

Ni-Zn dynamic discharges based on the ECE-15/UDC mini-cycle.

(Figure show recorded quantities for the Ni-Zn elements under test. The ambient temperature is of 25 °C)
Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Lead-acid dynamic discharges based on the ECE-15/UDC mini-cycle for the lead-acid elements.

(Figure show recorded quantities for the lead acid elements under test. The ambient temperature is of 25 °C)
Comparison between Ni-Zn and lead-acid performances.

<table>
<thead>
<tr>
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<th>Ni-Zn specific energy [Wh/kg]</th>
<th>Lead-acid specific energy [Wh/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/5 constant current discharge</td>
<td>49.6</td>
<td>40.7</td>
</tr>
<tr>
<td>ECE-15/UDC dynamic discharge</td>
<td>27.9</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Note: average values obtained from 6 elements for Ni-Zn batteries and 2 elements for lead-acid ones.
Ni-Zn batteries long-term characterization

A long-term characterization has been performed considering the *on-board vehicle use* of the Ni-Zn batteries. Hence the urban part of the ECE-15 cycle has been adopted in order to reproduce the power absorption conditions met on a light electrical vehicle.

**Long-term test sequences:**

- series of 20 charge – discharges macro cycles;
- C/5 control discharge to evaluate the effective battery capacity and, in turns, the battery end-of-life.
Capacity of the Ni-Zn battery delivered during the control discharges as a function of the total delivered capacity.
Ni-Zn batteries long-term characterization

Capacity of the Ni-Zn battery delivered during the control discharges as a function of the total delivered capacity

![Graph showing supplied capacity during C/5 control discharge vs total delivered capacity. The graph includes a line labeled 'Total delivered capacity' and a dotted line labeled 'Cycle number'. There are also points labeled 'Equalization charges'.]
The measured value of the battery capacity during C/5 control discharge, is compared with the rated battery capacity at C/5 discharge rate and, when a decrease of 20% the rated capacity is reached, the battery is considered at the end of its life.

Note the severity of such a criterion, since for hybrid vehicle applications the capacity needed for the vehicle to cover a standard one-day route is reasonably much lower than 80% the rated one.

The long term tests show a performances of the Ni-Zn batteries of 600 total cycles with an approximately total delivered capacity of 15000 Ah.
Ni-Zn model for capacity estimation

The proposed model for the Ni-Zn capacity estimation, is inspired by a previous one, presented in [1], which was conceived to predict the behavior of lead-acid batteries according to the following relation:

\[
C(I, \theta) = \frac{Kc \cdot C_0^* \cdot (1 + \frac{\theta}{\theta_f})^\epsilon}{1 + (Kc - 1) \cdot (I/I^*)^\delta}
\]

- \(\theta\) is the electrolyte temperature;
- \(I\) is the battery current during a constant discharge profile;
- \(\theta_f\) is the electrolyte solidification temperature;
- \(Kc, C_0^*, \epsilon, \delta, I^*\) are model parameters to be identified by means of tests described in [1].

Ni-Zn model for capacity estimation

Such a model however, if applied to Ni-Zn batteries has been found to provide only a moderate agreement between experimental results and predicted ones.

Possible reasons:

1. capacity variation due to temperature and due to the discharge current are ‘decoupled’. Assumption reasonable for lead-acid batteries (temperature coefficient);

2. Nickel electrodes show a kind of unstable behavior above 30°C
Proposed model:

\[ C(I, \theta) = \frac{C_n \cdot [I_n/I + (\theta - \theta_n)]^\varepsilon}{(I/I^*)^\delta} \]

- \( \theta \) is the electrolyte temperature;
- \( I \) is the battery current during a constant discharge profile;
- \( C_n \) is the rated capacity at current \( I_n \) and temperature \( \theta_n \);
- \( \varepsilon, \delta, I^* \) are model parameters to be identified by means of short-time tests.
Identification of the parameters $\varepsilon$, $\delta$, $I^*$

An estimation of the three above parameters can be achieved by carrying out more than 3 measurements and by using them, together with a non-linear least squares method, to infer $\varepsilon$, $\delta$ and $I^*$.

The values of parameters $\varepsilon$, $\delta$ and $I^*$ so determined are:

$\varepsilon = 0.0225$
$\delta = 0.0428$
$I^* = 21.8$ A

with a residual norm of 2.7%
Ni-Zn model for capacity estimation  

Comparison between measurements and model predicted capacities at different temperatures and discharge rates.
Conclusions

The comparison between the two battery technologies under test has shown that the Ni-Zn one represents a promising solution for the hybrid/electrical vehicles application.

In particular the short term performance analysis shows the superior behavior of the Ni-Zn technology, as compared with the lead-acid one, when dynamic discharge profiles are considered. In addition, more homogeneous values of the supplied capacity as a function of the type of discharge, discharge rate and temperature, has been found for the Ni-Zn batteries.
Concerning the long-term performances, interesting values of total supplied capacity and total number of cycles are obtained for the Ni-Zn batteries under test. This result is particularly interesting considering the type of selected discharges based on the ECE-15/UDC dynamic cycle.

An engineering model aimed at estimating the capacity supplied by the Ni-Zn batteries, as a function of the constant discharge current and temperature, has been proposed and compared, with sufficient agreement, with experimental results.