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Response of Nickel Zinc Cells to Electric Vehicle Chopper Discharge Waveforms

Robert L. Cataldo
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Work performed for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Energy
Office of Transportation Programs
Washington, D.C. 20545
Under Interagency Agreement DE-AI01-77CS51044

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ABSTRACT
The preliminary results of simulated electric vehicle chopper
controlled discharge of a nickel/zinc (NiZn) battery shows delivered energy
increases of 5 to 25 percent compared to constant current discharges of the
same average current. The percentage-increase was a function of chopper
frequency, the ratio of peak-to-average current, and the magnitude of the
discharge current.
Because the chopper effects are of a complex nature, electric vehicle
battery/speed controller interaction must be carefully considered in vehicle
design to optimize battery performance.

INTRODUCTION
One widely used technique for motor
speed control is the chopper (pulse) control
(ref. 1). The motor speed is varied by in-
creasing or decreasing the average current
supplied to the motor. Electric vehicle de-
signers have comparatively little data avail-
able on battery response to pulse discharges
associated with these choppers in contrast
with the more traditional alternative of di-
rect current (d.c.) discharge.
The available energy and capacity of a
battery are dependent on many factors, the
most significant being the magnitude of the
discharge current, with higher currents re-
sulting in less delivered capacity. Tests
completed on lead-acid batteries (ref. 2)
demonstrated that when high levels of power
are needed, pulse discharging can yield
greater capacity and energy when compared to
equivalent direct constant current discharg-
ing. However, when low levels of power are
needed, the constant current method yields
greater capacity and energy than the equiva-
 lent pulse current method. This crossover
occurs when the discharge rates are greater
than the "C" rate.

In view of the current efforts to devel-
op efficient, cost effective battery systems
for electric vehicles, it is of great practi-
cal interest to quantify the effects on capac-
ity associated with pulse discharging tech-
niques when applied to NiZn cells. As part
of the Department of Energy's program in
electric vehicles, experiments were therefore
undertaken to determine delivered battery
capacity, energy, and power at various ratios
of peak-to-average current. The parameters
investigated were peak currents of 100, 200,
300, and 400 amperes and average values of
50, 100, 200, and 300 amperes at frequencies
of 50, 100, and 500 Hz. Table I summarizes
the test matrix used.

EXPERIMENTAL CELLS
The experimental cells used for the
tests were manufactured by Yardney Electric
Corporation for NASA under contract NAS3-
20904. Two groups of four cells with consec-
tutive serial numbers were chosen at random
from a lot of 75 cells. The cells were de-
signed so that when four are placed face to
to face they fit into a space having the dimen-
sions of 10-3/8 in. long x 7-3/16 in. wide x
11-7/32 in. high (top of terminal). The Zn
electrode separators used were NASA K-19.
The negative (Zn) electrodes were pressed
powder type construction and the positive
(Ni) electrodes were of the electrochemically
impregnated sintered type. The potassium
hydroxide (KOH) electrolyte used was 34 per-
cent by weight. The cells have a nominal
capacity of 250 ampere-hours.
The formation of all cells consisted of
three charge and discharge cycles after an
initial "reverse charge" of the electro-
formed Ni electrode to an end cell voltage of
-0.8 volt. This reverse charge was done to
remove the residual charge in the Ni elec-
trode, thus both the Ni and Zn electrodes are
at the same level of charge. The cells were
charged at constant current to 250 ampere-
hours and discharged at 50 amperes to 1.0
volt with an actual capacity of about 210
ampere-hours.

EXPERIMENT PROCEDURE
The cells were tested as a 6.0-volt bat-
tery of four cells closely representing a
mono-block 132 ampere-hour lead-acid battery
in size, weight, and voltage. Each cell was
instrumented with an iron-constantan thermocouple located in the electrolyte near the top of the plates. The cells were tightly bound together with an additional thermocouple sandwiched between the faces of the middle cells near the center of the face.

The test equipment used to pulse discharge the cells was a chopper simulator shown in block diagram form in figure 1. A Darlington configured power transistor driven at appropriate variable pulse width and frequency (pulses per second) acted as the switching device. The power transistor was mounted on a water-cooled heat sink to dissipate the discharge energy. A non-inductive shunt was used to maintain the current signal in phase with the voltage signal as required to obtain accurate power measurements.

The battery voltage and current pulses were monitored on a calibrated dual-beam oscilloscope and photographed as required. In addition, a calibrated digital time and frequency domain waveform analyzer was used to calculate the delivered energy per pulse obtained by multiplying and integrating the instantaneous values of voltage and current with an accuracy of better than ±0.5 percent. Capacity and energy was measured with a digital integrating amper-hour meter to an accuracy of ±1 percent. The average current (I) (shunt millivolt signal) and voltage (V) were read with an integrating digital volt meter capable of averaging the signals accurately over the range of test frequencies involved with ±0.1 percent. The voltage and current waveforms were in phase at all frequencies thus assuring proper energy measurement.

Figure 2 represents an oscilloscope waveform of a chopper pulse of 400 amperes peak current, 25 percent duty cycle at 100 Hz. The average battery voltage was 6.50 volts.

The following equations represent the measured quantities:

\[ c = \int_{t_1}^{t_2} i \, dt \]  
\[ e = \int_{t_1}^{t_{off}} i v \, dt \]  
\[ E = \int_{t_1}^{t_2} p \, dt \]  
\[ p = \frac{\int_{t_1}^{t_2} p \, dt}{t_2 - t_1} \]

where

- \[ t_1 \] time at start of test
- \[ t_2 \] time at end of test

Equation (4) was calculated by dividing equation (3) by the quantity \( (t_2 - t_1) \).

The discharge tests were concluded at a battery terminal voltage of 4.0 volts. The cut-off for the pulse tests was the average of the load and no load (off-time) voltages, and the load voltage for the constant current case. For a baseline comparison, a direct current discharge equal in magnitude to the average current level was performed before and after each group of 50, 100, 200, and 300 ampere tests. Ambient and cell temperatures were recorded prior, during, and after each discharge. A 50 ampere constant current discharge was performed to remove the remaining cell capacity after all test conditions of 100 amperes or greater average current.

The cells were recharged to 225 Ampere-hours after every discharge at the C/8 rate (28A) after cell temperatures stabilized within 3°F of ambient.

RESULTS

Figure 3 is a plot of the capacity checks performed at the 50 ampere rate. The curves clearly indicate a loss in capacity. The original group 1 cells were removed from testing after 30 cycles when several cells in the pack were experiencing reversal near the end of a discharge. A new set of cells, group 11, were formed to complete the test matrix at the 200 and 300 ampere level.

Figure 3 also shows an effect of average current rate on rate of capacity loss. A precipitous increase in capacity degradation is noted at the 300 ampere average current level.

The degradation of cell capacity with cycling makes the results biased according to the sequence in which the cells were run. In an attempt to eliminate the biased results, a linearized amount of capacity, determined from the slope of the curves in figure 1, was "added" to each successive cycle. In this manner, the capacity and energy results were normalized to the baseline results of the last formation cycle.

The biased raw data and normalized data, tabulated in tables II, III, I*, and V, summarize the numerical results of tests conducted at the various parameters and compares them to the constant current discharge at the same average current. In the case of 50 amperes average current, normalized pulses conditions yielded equal or greater energy outputs of 10 to 15 percent at 500 Hz for all levels, than constant current. The trends of the data are an increase in energy with increasing frequency and a decrease in energy with an increase in the current pulse magnitude. The results of 100 amperes average
current, also show an increase in energy output with increasing frequencies with a maximum of 22 percent at 500 Hz, 300 and 400 amperes peak. However, the relationship of energy output to pulse magnitude is not straight-forward. Also all pulse tests at 50 Hz delivered energy below that of the direct current discharge energy. The 200 ampere average current data does not indicate any first-order relationships between energy output and frequency or pulse magnitude. The greatest energy output is seen at 500 Hz and 400 amperes pulse magnitude which is a 5 percent increase over the comparable direct current test. The results of tests of the 300 ampere average current at 400 amperes peak, show the energy delivered from the cells to increase with increasing frequency. A 9 percent energy output increase is noted at 500 Hz compared to the comparable direct current test.

Generally, pulse discharging NiZn cells at the lower current levels of 50 and 100 amperes yielded greater increases than at the higher discharge rates. These results are the inverse of the findings with lead-acid batteries where significant increase in energy and capacity were noted at the higher discharge rates (ref. 2).

The relationship between temperature and peak/average current is shown in figure 4. The rate of temperature rise, as expected, increased as the peak/average ratio increased. These thermal effects are consistent with the losses associated with higher peak currents. The quantitative effects of temperature on NiZn cell discharge capacity is not known. The higher generated temperatures associated with pulsing as compared to direct currents could contribute in part to the increased energy outputs obtained using pulse discharging.

Figure 5. average current versus capacity, shows the groupings of the pulsed and nonpulsed data. Except for a few cases, pulse discharging yielded more capacity. A plot of power versus energy is shown in figure 6. This curve also shows a greater energy output by pulsing at lower discharge rates.

CONCLUSION

The effects on delivered energy and capacity resulting from pulse discharge techniques or NiZn cells are complex. Pulse discharging generally yielded greater energy and capacity than the comparable constant current nonpulsed discharge test. These increases in energy amounted to 15, 22, 9, and 5 percent at 50, 100, 200, and 300 amperes average current, respectively. The greater increases were seen at discharge of low power levels that is, 50 and 100 amperes. This indicates that extended electric vehicle range could be achieved using pulse discharging (chopper) with a NiZn battery.

Temperature effects on NiZn battery performance are not known to the extent of making quantified corrections to the data.

Higher temperatures were observed with increasing peak currents which could have contributed, in part, to the increases in energy and capacity associated with pulse discharging.

REFERENCES


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### Table III. - Test Results at 50 Amperes Average Current

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*D.C. (direct current).*

### Table III. - Test Results at 100 Amperes Average Current

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<th>Frequency, Hz</th>
<th>Mean power, W</th>
<th>Energy, W-hr</th>
<th>Capacity, amp-hr</th>
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*D.C. (direct current).*

### Table IV. - Test Results at 200 Amperes Average Current

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<th>Frequency, Hz</th>
<th>Mean power, W</th>
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*D.C. (direct current).*
### TABLE V. - TESTS RESULTS AT 300 AMPERES AVERAGE CURRENT

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*D.C. (direct current).*
Figure 1. - Block diagram of chopper simulator

Figure 2. - Typical oscilloscope trace of the chopper simulator discharging a nickel zinc battery at 400 A peak current and 100 ampere average current at 100 Hz.

Figure 3. - 50 ampere capacity checks versus cycle number.
Figure 4. - Rate of temperature rise versus peak/average current ratio.

Figure 5. - Time average discharge current versus discharge capacity.

Figure 6. - Time average power versus energy.