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RAPID, EFFICIENT CHARGING OF LEAD-ACID AND NICKEL-ZINC TRACTION CELLS

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Lead-acid and nickel-zinc traction cells were rapidly and efficiently charged using a high rate tapered direct current (HRTDC) charge method which could possibly be used for on-the-road service recharge of electric vehicles. The HRTDC method takes advantage of initial high cell charge acceptance and uses cell gassing rate and temperature as an indicator of charging efficiency. On the average, in these preliminary tests, 300 amp-hour nickel-zinc traction cells were given a HRTDC (initial current 500 amps, final current 100 amps) to 78 percent of rated amp-hour capacity within 53 minutes at an amp-hour efficiency of 92 percent and an energy efficiency of 92 percent. Three hundred amp-hour lead-acid traction cells were charged to 69 percent of rated amp-hour capacity within 46 minutes at an amp-hour efficiency of 91 percent with an energy efficiency of 94 percent. In order to find ways to further decrease the recharge times, the effect of periodically (0 to 400 Hz) pulse discharging cells during a constant current charging process (0-4% duty cycle) was investigated. Preliminary data indicate no significant effect of this type of pulse discharging during charge on charge acceptance of lead-acid or nickel-zinc cells.
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ABSTRACT

Lead-acid and nickel-zinc traction cells were rapidly and efficiently charged using a high rate tapered direct current (HRTDC) charge method which could possibly be used for on-the-road service recharge of electric vehicles. The HRTDC method takes advantage of initial high cell charge acceptance and uses cell gassing rate and temperature as an indicator of charging efficiency. On the average, in these preliminary tests, 300 amp-hour nickel-zinc traction cells were given a HRTDC (initial current 500 amps, final current 100 amps) to 78 percent of rated amp-hour capacity within 53 minutes at an amp-hour efficiency of 92 percent and an energy efficiency of 52 percent. Three hundred amp-hour lead-acid traction cells were charged to 69 percent of rated amp-hour capacity within 46 minutes at an amp-hour efficiency of 91 percent with an energy efficiency of 64 percent. In order to find ways to further decrease the recharge time, the effect of periodically (0 to 400 Hz) pulse discharging cells during a constant current charging process (94% duty cycle) was investigated. Preliminary data indicate no significant effect of this type of pulse discharging during charge on charge acceptance of lead-acid or nickel-zinc cells.

INTRODUCTION

Recently there has been a growing interest in electric vehicles as a viable mode of urban transportation. This interest has been precipitated by a shortage of domestic oil, and by a more pollution conscious society. For an electric vehicle to be successful it must, of course, be accepted by potential users. The range of typical electric vehicles of today with the present generation of lead-acid batteries is less than about 50 miles on a single charge. For most users it is desirable to extend this range. Also in some industrial fleet applications increased vehicle utilization is needed. One method of increasing an electric vehicle's range and utilization may be to rapidly recharge the battery at a suitably equipped on-the-road service station in a similar manner as IC vehicles now refuel with gasoline at a service station.

Various methods of rapidly charging batteries have been proposed and reviewed (1). In some of the more promising methods the cell gassing rate is used to control charge current (1). Other rapid methods employ pulse charging (2,3).

After reviewing this literature, a high rate tapered direct current (HRTDC) method was selected for preliminary tests on 300 amp-hour lead-acid and 300 amp-hour nickel-zinc traction cells. This method takes advantage of the initial high cell charge acceptance, and uses the cell gassing rate as an indicator of how efficiently charge is being accepted.

In addition, because of conflicting reports concerning the benefits of pulse charging to charge acceptance (2,3) on the one hand and lack of demonstrable benefit on the other (1,4), a few exploratory tests of pulse charging were also run.

In this paper the HRTDC method of rapid efficient charging is described, the results of HRTDC charging of 300 amp-hour lead-acid and 300 amp-hour nickel-zinc traction cells are presented and the preliminary results of a limited study of pulse charging on charge acceptance are discussed.

EXPERIMENTAL

CELL CHARGER - The cell charger used is versa-


**Numbers in parentheses designate References at end of paper.
tile and allows for operation in either the direct current or pulse current mode (5). A wide range of adjustments of charge current, discharge current and pulse timing in either direct current or pulse current mode is available.

The charger has the following characteristics:
1. A charge (positive) current from 0 to 1000 amperes.
2. A discharge (negative) current from 0 to 1000 amperes.
3. Charge and discharge current pulses from 0 to 1000 Hertz.
4. Continuously variable discharge time from 0.1 to 100 milliseconds.
5. Provides zero cell charge (zero charge and discharge current) controlled by an electronic signal.
6. Operates in either continuous charge or continuous discharge mode.

The current switching is done with a water cooled high current transistor switch. The transistor switch is capable of carrying 1000 amperes as well as switching 1000 amperes at a 100 Hz rate.

Water cooling is provided for all of the solid state power components in order to obtain the compact, low parasitic inductance configuration necessary for high rate, high current switching.

MEASUREMENTS AND PROCEDURES

During each high rate tapered direct current charge experiment the quantities measured and their accuracies were as follows: Cell temperature (±1°C or less); cell gassing rate (±0.5%) in some cases evolved gases were analyzed to obtain reliable gassing rates; amp-hours (±0.5%); cell voltage (±0.5%); and charge current (±0.3%).

Cell temperatures were measured using an iron-constantan thermocouple located in the cell electrolyte. The thermocouple was coated with epoxy to prevent attack by the electrolyte.

Cell gassing rates were measured during charge using a calibrated laminar flowmeter (0 to 300 cm³/min at 21°C, 760 mm of Hg). Since the flow rate depends on gas temperature, the cell gas was heated to a constant 65°C via a heat exchanger prior to entering the flowmeter. Flow rates were then reduced to standard conditions (21°C, 760 mm of Hg). Since the gas flow rate also depends on composition, gas samples were taken periodically and analyzed by gas chromatographic analysis. The gas evolved by the lead-acid cell was about 67% H₂ and 33% O₂ by volume. The gas evolved by the nickel-zinc cell was about 94% H₂ and 6% O₂ by volume.

Cell charge and discharge amp-hours were measured using a conventional amp-hour meter. Cell voltage as a function of time was recorded on a strip chart recorder, and cell current was calculated from voltage measured across a shunt.

Amp-hour efficiency (charge acceptance) was obtained by discharging the cell after charging was completed at various decreasing current levels to a 1.0 volt cutoff in the case of nickel-zinc and a 1.75 volt cutoff for lead-acid. The amp-hours delivered at each current were obtained from the amp-hour integrator and totaled. A typical discharge amp-hour determination and the currents used for these measurements are shown in Tables 1 and 2 for nickel-zinc and lead-acid, respectively.

The total amp-hours delivered to the cell during charge were obtained in a similar manner. Amp-hour efficiency was calculated as a ratio of total amp-hours out of a cell during discharge to the total amp-hours into the cell during charge. The energy efficiency was calculated as a ratio of total energy out of a cell during discharge to total energy into the cell during charge. Total energy out of, or into a cell was calculated by summing the product of measured amp-hours and average cell voltage at each current level. Average cell voltage was obtained from a strip chart recording of cell voltage as a function of time.

Experiments were conducted to define the best combination of charging rate, temperature rise and gassing rate to obtain a reasonable charge acceptance in the shortest time. An initial 500 amp charge was tapered in 50 amp increments to 100 amps while gassing rate and temperature were monitored and held within preset limits chosen as experimental parameters. Efficient charging required that the gassing rate be less than 10 to 20 percent of the rate equivalent to the charging current and a rate of temperature increase of about 1.2°C (2.2°F) per minute.

The pulse charge experiments were limited to a periodic pulse discharge during a constant current charge at 250 amps. The discharge pulse was also set at 250 amps but the frequency was varied from constant current (zero Hz) to 400 Hz with a constant 94 percent duty cycle. During the charge, cell pressure and temperature were monitored and the charge was terminated when the cell pressure reached 3.5×10⁴ newtons/meter² (5 psi). The charging current as a function of time with the discharge pulse are shown schematically in Figs. 4 and 5.

The 250 amp current was chosen to reduce the possibility of "aging effects" associated with the cycling excursion during the duration of the tests and to mask the influence of pulse frequency on charge acceptance at currents higher than the C rate. The 94 percent duty cycle was selected because it allowed a relatively large charge time and with the charger equipment used preserved a rectangular pulse shape over the 1 to 400 Hz frequency range. The 3.5×10⁴ newtons/meter² (5 psi) pressure cutoff was dictated by the cell case construction.

RESULTS AND DISCUSSION

HIGH RATE TAPERED DIRECT CURRENT CHARGING - In Fig. 1 the charge current, cell temperature, and gassing rate as a function of charge time, for a representative 300 amp-hour nickel-zinc cell is shown. The initial charge current was 500 amps and was tapered to a final value at a time equivalent to 350 amp increments. During the initial portion of the charge the gassing rate was low, however, the rate of cell temperature increase was rapid (-1.2°C/min (2.2°F/min)). Because charge acceptance of the nickel electrode is greatly affected by temperature (6), the charge current was gradually stepped down. After a charge current of about 350 amps the current was decreased further due to onset of gassing. Onset of gassing for efficient charging was defined as the point where the gassing rate rises steeply, to about 10 to 20 percent of the rate equivalent to the charging current. Some gas is evolved at low rates prior to this point. For instance, at the end of the 350 amp charge the gassing rate was about...
125 cm$^3$/min (STD conditions 21° C, 760 mm of Hg),
which corresponds to about 10 percent of the charging
current producing gas (90% calculated amp-hr
efficiency).

A typical charge input as a percentage of
rated capacity as a function of charge time is
shown in Figs. 2 and 3, and results for each experi-
ment are summarized in Tables 3 and 4 for nickel-
zinc and lead-acid cells, respectively. For nickel-
zinc on the average about 78 percent of rated
300 amp-hour capacity can be returned within
53 minutes at an amp-hour efficiency of about
92 percent and an energy efficiency of 52 percent.

For lead-acid on the average about 69 percent can
be returned within 46 minutes at an amp-hour effi-
ciency of about 91 percent and an energy efficiency
of 64 percent. The use of this charging method
does provide a way of charging nickel-zinc and
lead-acid traction cells in times short enough to
be of potential interest in an on-the-road service
station context.

The effect of the HRTDC method of charging on
cell charge/discharge cycle life is unknown at this
time. However, since during the charging process
the gassing rate and cell temperature are con-
trolled, it is reasonable to expect that this rapid
method of charging would not be as detrimental to
battery cycle life as other high rate methods,
which are believed to produce excessive gassing
rates and high cell temperatures.

PULSE DISCHARGE DURING CHARGE - Figure 4 shows
for a 300 amp-hour nickel-zinc traction cell the
percentage charge input as a function of a 94 per-
cent duty cycle charge/discharge current pulse for
frequencies ranging from zero to 400 Hertz. No sig-
nificant effect of pulse charging on cell charge
acceptance is evident for these conditions compared
with dc charging (zero frequency). In Fig. 5 sim-
ilar uninteresting results for the same pulse cur-
rent conditions for a 300 amp-hour lead-acid trac-
tion cell are illustrated.

The effect on charge acceptance of further
variations of charge/discharge current duty cycle
and frequency parameters have not yet been studied
but will be the subject of a continuing effort.

CONCLUDING REMARKS

A high rate tapered direct current method con-
trolled by gassing rate and cell temperature appears
feasible for charging lead-acid and nickel-zinc
traction cells. Preliminary data indicate that
periodically pulse discharging during a constant
current charging process did not improve the charge
acceptance of lead-acid or nickel-zinc traction
cells.

The nickel-zinc and lead-acid traction cells
used in this work were not specifically designed
for rapid charging. Any serious attempt to use and
depend upon rapid charging of cells should be re-
lected in the basic cell design (3). In this re-

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REFERENCES

1. S. Groen, "Rapid Charging of Lead-Acid
Batteries," Paper Presented at IEEE IAS Eighth

Presented at Second International Electric Vehicles
Symposium. Atlantic City, New Jersey, November
1971.

3. R. N. Sparkes, "Rapid Charging Batteries for
Electric Propulsion Systems." Paper 720109 Present-
ed at SAE Automotive Engineering Congress, Detroit,
Michigan, January 1972.

4. W. E. Ripple, "Charge Acceptance Character-
istics of the Lead-Acid Cells." Paper Presented at
Second International Electric Vehicle Symposium,
Atlantic City, New Jersey, November 1971.

5. R. L. Steigerwald, "Pulse Battery Charger
Employing 1000 Ampere Transistor Switches," Paper
Presented at IEEE IAS Twelfth Annual Meeting, Los
Angeles, California, October 1977.

Spacecraft Batteries - Charger Control Methods," NASA
CR-62029, April 1966.
Table 1 - Ampere Hour Determination of a Representative 300 Ampere-Hour Nickel-Zinc Traction Cell

<table>
<thead>
<tr>
<th>Discharge Current (Amps)</th>
<th>Amp-Hrs Out</th>
<th>Voltage* (Volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>191.5</td>
<td>1.00</td>
</tr>
<tr>
<td>150</td>
<td>9.2</td>
<td>1.00</td>
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<tr>
<td>100</td>
<td>5.6</td>
<td>1.00</td>
</tr>
<tr>
<td>50</td>
<td>7.6</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>213.9</strong></td>
<td></td>
</tr>
</tbody>
</table>
*Voltage at which discharge was terminated.

Table 2 - Ampere Hour Determination of a Representative 300 Ampere-Hour Lead-Acid Traction Cell

<table>
<thead>
<tr>
<th>Discharge Current (Amps)</th>
<th>Amp-Hrs Out</th>
<th>Voltage* (Volts)</th>
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<tr>
<td>100</td>
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<tr>
<td>75</td>
<td>17.6</td>
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<tr>
<td>50</td>
<td>22.8</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>204.2</strong></td>
<td></td>
</tr>
</tbody>
</table>
*Voltage at which discharge was terminated.

Table 3 - Results of Rapid Charging of 300 Ampere-Hour Nickel-Zinc Traction Cells

<table>
<thead>
<tr>
<th>Cell</th>
<th>Amp-Hrs in</th>
<th>Amp-Hrs out</th>
<th>Amp-Hr Efficiency</th>
<th>Energy Efficiency</th>
<th>Percentage* Charged</th>
<th>Charge Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>106</td>
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<td>226</td>
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<td>222</td>
<td>213</td>
<td>96</td>
<td>55</td>
<td>74</td>
<td>49</td>
</tr>
</tbody>
</table>
*Percentage of rated amp-hr capacity (300 amp-hr).

Table 4 - Results of Rapid Charging of 300 Ampere-Hour Lead-Acid Traction Cells

<table>
<thead>
<tr>
<th>Cell</th>
<th>Amp-Hrs in</th>
<th>Amp-Hrs out</th>
<th>Amp-Hr Efficiency</th>
<th>Energy Efficiency</th>
<th>Percentage* Charged</th>
<th>Charge Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>218</td>
<td>204</td>
<td>94</td>
<td>66</td>
<td>73</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>204</td>
<td>188</td>
<td>92</td>
<td>65</td>
<td>68</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>175</td>
<td>86</td>
<td>61</td>
<td>67</td>
<td>46</td>
</tr>
</tbody>
</table>
*Percentage of rated amp-hr capacity (300 amp-hr).
Figure 1. - Charge current, cell temperature, and cell gassing rate as a function of charge time; 300 Ah nickel-zinc cell.

Figure 2. - Percentage charged as a function of charge time for a representative 300 Ah nickel-zinc traction cell.
Figure 3. - Percentage charged as a function of charge time for a representative 300 Ah lead-acid traction cell.

Figure 4. - Pulse charging - percentage charged as a function of frequency for a representative 300 Ah nickel-zinc traction cell.
Figure 5. - Pulse charging - percentage charged as a function of frequency for a representative 300 Ah lead-acid traction cell.