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RESPONSE OF LEAD-ACID BATTERIES TO CHOPPER-CONTROLLED DISCHARGE: PRELIMINARY RESULTS

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16. Abstract

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SUMMARY

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INTRODUCTION

One widely-used technique for motor speed control in electric vehicles is the chopper (pulse) control (ref. 1). Electric vehicle designers have comparatively little data available on battery respeonse to the pulse discharges presented by these choppers in contrast with alternative constant-current discharge. This investigation was conducted to obtain such data on a typical commercial lead-acid traction battery. This initial report presents the preliminary results of the work, to provide for timely dissemination.

The available energy and capacity of a lead acid battery are dependent on many factors, the most significant one being the magnitude of the discharge current, with higher currents resulting in less delivered capacity. It has been suggested (ref. 2) that discharging in a pulse mode will yield a greater delivered capacity from a battery than constant current. The basis for this increase in capacity is that after the discharge pulse, the off-time period in each cycle will allow additional discharge due to various recovery phenomena. It is possible, however, that the actual power and energy output from the battery will decrease in a pulse discharge mode.

In view of the current efforts to develop efficient, cost effective electric vehicles, it is of great practical interest to quantify these effects. Experiments were therefore undertaken to determine delivered battery energy and power at various peak to average current levels. The parameters being investigated are representative of values encountered in electric vehicle operation. They are peak discharge currents of 200, 300 and 400 amperes and average values of 100, 200 and 300 amperes at frequencies of 50, 100 and 500 Hz, as displayed in table I. In this report only Group 1 of table I is covered. Tests under Groups 2 and 3 at higher average currents of 200 and 300 amperes, are in progress and will be reported at a later time. Further work on the effects of pulse discharging on battery life will be the subject of future studies.

EXPERIMENTAL PROCEDURE

The batteries used in these tests were commercial 132.5-ampere-hour, 6-volt, lead acid traction batteries. These separate batteries were studied at each test condition to check reproducibility of the data.

The batteries were charged with an initial current of 23 amperes, tapering to 3 amperes overnight. Ambient and electrolyte temperatures and specific gravities were recorded before and after each discharge. A 75-ampere constant current discharge drain was carried out 1 hour after each discharge experiment to remove the remaining capacity of the battery. The pulse and constant-current discharges were terminated when the average battery voltage reached 5.10 volts. A constant-current discharge at 100 amperes equal to the average value of the pulse discharge rate was performed before and after each group of tests for the baseline comparison.

The apparatus used was a chopper simulator shown in block diagram form in figure 1. It consists of transistors in the Darlington configuration as the switching device driven at appropriate variable pulse width and frequency (pulses per second). The discharge energy was dissipated non-inductive in the transistor module itself, mounted on a water-cooled heat sink.

The battery voltage and current pulses (via a noninductive shunt) were monitored on a calibrated dual beam-oscilloscope and traces photographed at the beginning and end of each chopper discharge test on each of three replicate batteries. Each discharge took about 1 hour. V_s, the steady battery voltage during the pulse current draw was measured to ±3 percent. The pulse current magnitude, I_p, could be set within ±3 percent. $\overline{V}$, the average battery voltage, was monitored by an integrating digital voltmeter (IDVM) placed directly across the battery terminals with an accuracy of ±0.1 percent. The average current $\overline{I}$, was read across the shunt with an IDVM capable of averaging the signals faithfully over the range of frequencies involved with an accuracy of ±0.1 percent.

Figure 2 shows a typical oscilloscope trace of the chopper simulator discharge. The trace for each test condition was used to set I_p at the desired value and to measure V_s and T, the period between pulses. All the other quantities were taken from the IVDM's.

The initial power output, P_i, obtained at the fully charged state and the final power output P_f, obtained at the end of the discharge time t(hr) to the 5.10-volt cutoff, were calculated from equation (1) using the appropriate measured quantities.

$$P = \bar{I}\, V_s \tag{1}$$

The average power output during the discharge, $\bar{P}$, was obtained from equation (2).

$$\bar{P} = \frac{P_i + P_f}{2} \tag{2}$$

The average energy delivered, $\bar{E}$, from equation (3)

$$\bar{E} = \bar{P}\, t \tag{3}$$

and the average capacity $\bar{C}$ from equation (4)

$$\bar{C} = \bar{I}\, t \tag{4}$$

RESULTS

Table II summarizes the numerical results of the preliminary experiments for the Group 1 parameters and compares them to the direct current discharge (d.c.) at the same average current of 100 amperes. Significant differences in energy and power output can be seen with changing peak current to average current ratio as shown in figure 3(a) and (b). The energy output at a 400-ampere peak pulse is approximately 25 percent less than at constant current. The 300-ampere and 200-ampere peak pulse result in a 22 percent and 18 percent less energy output, respectively. Similar decreases in power output are observed. There was no discernible increase in available battery capacity to offset the loss in power occurring with high peak current values. Significantly a net loss in energy output is observed in pulse discharging over the range of parameters investigated.

The battery electrolyte temperature increases with increasing peak current shown in figure 4. The 400-ampere pulse discharge results in a 100 percent greater rise in temperature than the d..c.. case.

The precision of the data does not allow any significant conclusions to be drawn regarding the influence of pulse repetition frequency at this time and will be the subject of futher investigations.

CONCLUSIONS

The preliminary results of simulated electric vehicle chopper, speed controller pulse discharge of a battery show substantial energy output losses (up to 25 percent with a 400-ampere peak pulse) compared to constant current discharge when the comparison is made at the same average current of 100 amperes. The energy losses, as a result of pulse discharging, is manifest as a temperature rise in the battery, amounting to as much as a two-fold increase for 400-ampere peak current pulses compared to the constant current case.

These results indicate that suggestions made heretofore, that discharging a battery in a pulse mode will yield a greater delivered capacity, are not correct. Because of the potentially large energy inefficiency, the results also suggest that electric vehicle battery/speed controller interaction must be carefully considered in vehicle design.

REFERENCES

1. Morrison, John J.: Electronic Control of Battery Electric Vehicles. Radio Electron. Eng., vol. 42, no. 2, Feb. 1972, pp. 91-100.
2. Jayne, Marcel G.: The Behaviour of Lead-Acid Batteries Under Pulsed Discharge Conditions. Presented at the 10th Interational Power Sources Symposium, (Brighton, England), September 13-16, 1976, pp. 1-12.

TABLE I. - PULSE DISCHARGE TEST PARAMETERS

Group	Peak Current (amperes)			Average Current (amperes)	Frequency (Hz)
1	400	300	200	100	50
	400	300	200	100	100
	400	300	200	100	500
2	400	300		200	50
	400	300		200	100
	400	300		200	500
3	400			300	50
	400			300	100
	400			300	500

TABLE II. - RESULTS OF TESTS AT 100A AVERAGE CURRENT, GROUP 1, AVERAGES WITH AVERAGE DEVIATIONS FOR THREE REPLICATES

Frequency (Hz)	Peak Current (Amperes)	Average Energy (Watt Hrs)	Average Power (watts)	Average Capacity (Amp Hrs)	Temperature Rise (°C)
500	400	525 ± 8	470 ± 7	112 ± 8	20
500	300	555 ± 15	505 ± 7	119 ± 8	15
500	200	576 ± 36	540 ± 3	107 ± 7	10
100	400	513 ± 6	460 ± 13	111 ± 3	22
100	300	515 ± 22	490 ± 7	104 ± 6	16
100	200	546 ± 5	520 ± 7	104 ± 3	11
50	400	495 ± 3	450 ±26.7	110 ± 2	19
50	300	515 ± 6	490 ± 7	105 ± 3	15
50	200	565 ± 9	538 ± 10	105 ± 4	11
D.C.	100	712 ± 83	587 ± 3	129 ± 15	10

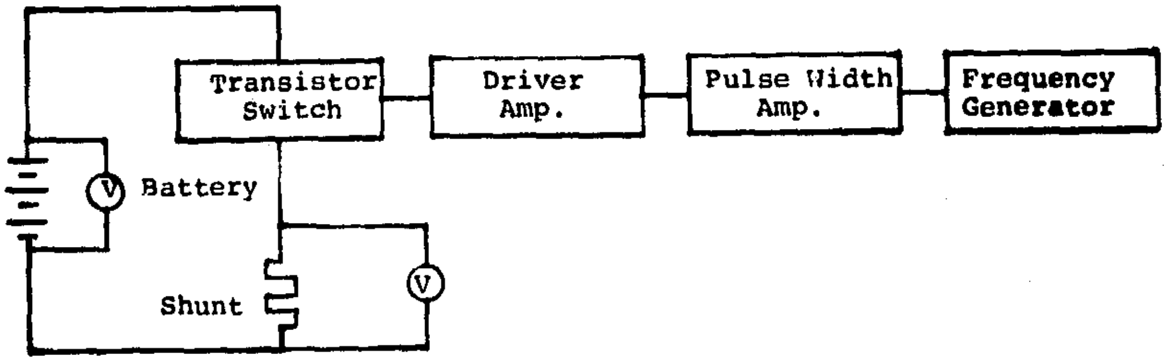

Fig. 1. - Block Diagram of Chopper Simulator

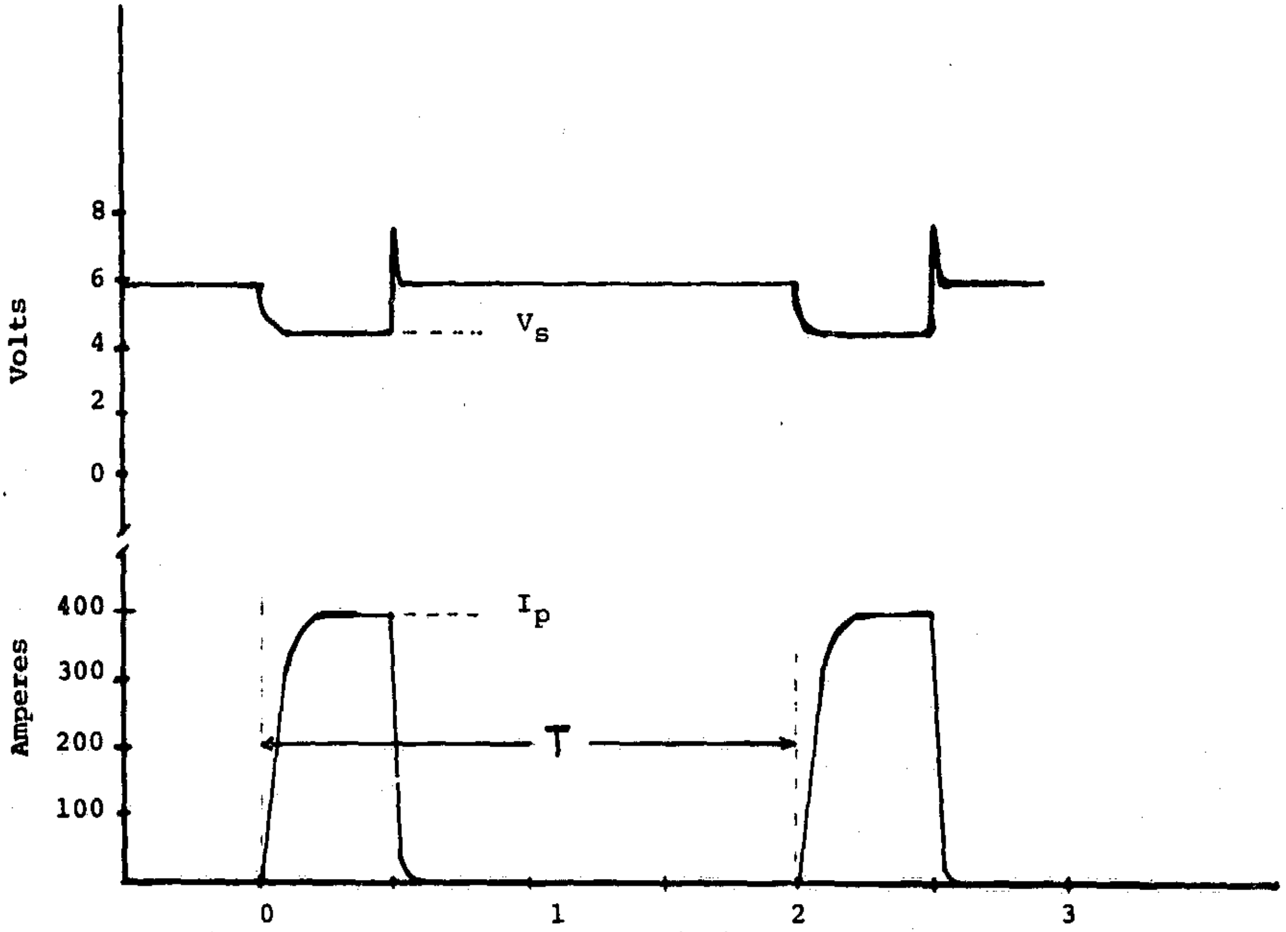

Fig. 2. - Typical Oscilloscope Trace of the Chopper Simulator Discharging a Lead Acid Battery at a 400A. Peak Current With a 100A. Average Current at 500 Hz

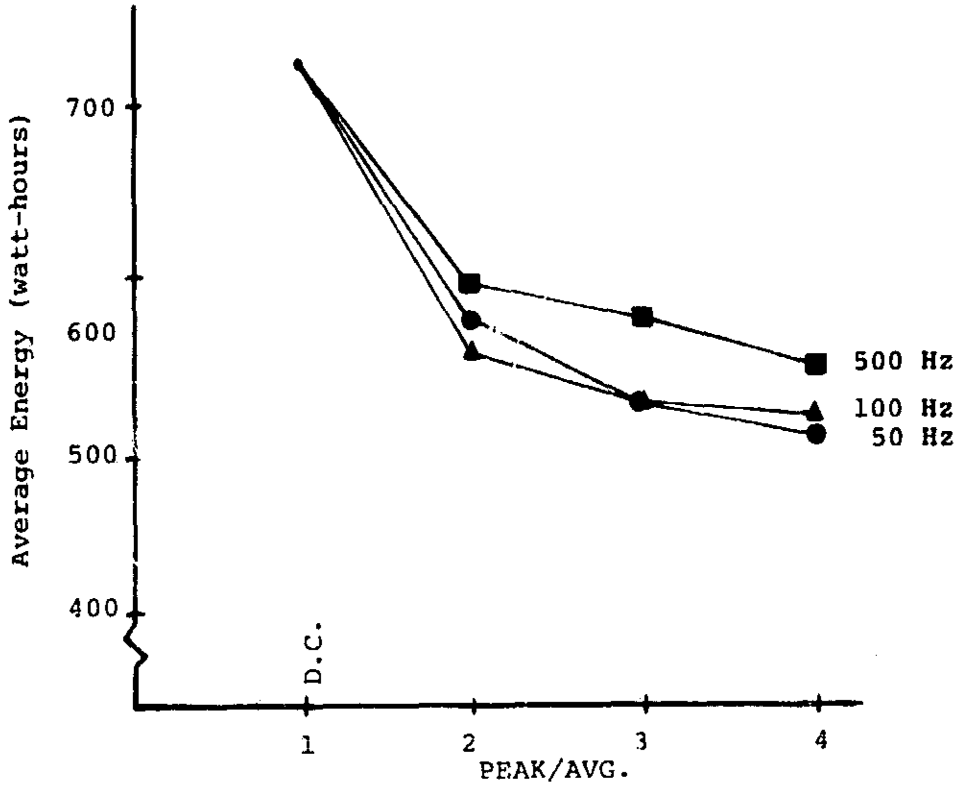

Fig. 3(a). - Energy Output vs. Peak to Average Current Ratio. $\bar{I}$ = 100A. in All Cases

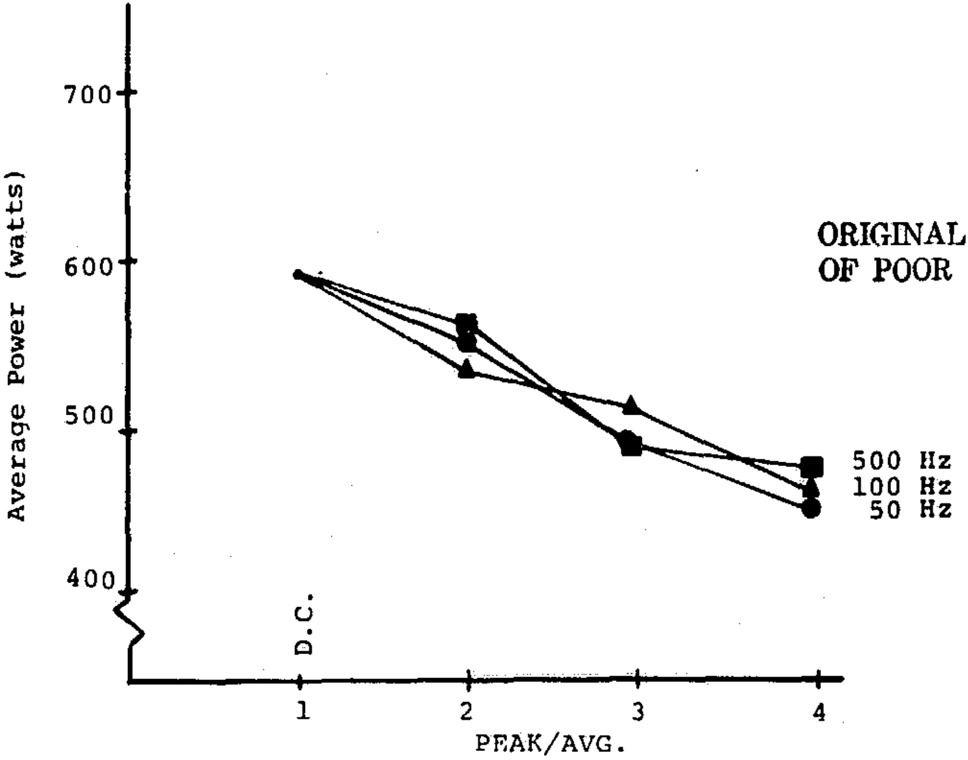

Fig. 3(b). - Average Power Delivered vs. Peak to Average Current Ratio. $\bar{I}$ = 100A. in All Cases