INVESTIGATION REPORT ET/IR366R

Evaluation of Megapulse Technology

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EXECUTIVE SUMMARY

The objective of this investigation is to determine whether Megapulse technology can enhance the service life of automotive batteries through suppressing over-sulfation of the plates.

Megapulse technology is presented in the form of an electronic device which is connected to the positive and negative terminals of the battery. The device operates by using power from the battery and transmits pulses back to the battery. Since there is a minor energy loss between the power received from the battery and the power supplied back to the battery, the device does in fact draw a very small net current from the battery. In order to protect the battery from overdischarge, the device is designed in such a way that it ceases to operate when the battery voltage falls below a set threshold level (i.e., the 'activated voltage').

Two versions of the Megapulse device have been examined in this study: one with an activated voltage of 12.8 V and the other with an activated voltage of 10.5 V. The SAE J537 cycling test of the American Society of Automotive Engineers has been adopted and has been modified slightly to evaluate the effect of employing Megapulse technology on battery life under conditions, which simulate taxi-driving duty. **Data from the simulated duty, together with evidence obtained from teardown analyses, have suggested that the use of Megapulse devices can extend the service life of batteries through restricting the size of lead sulfate crystals produced during discharge.** To confirm this preliminary finding, a larger number of trials should be performed.

It has been found that the Megapulse device draws a current of ~60 mA when connected to the battery. This value is higher than the typical key-off load current (i.e., < 25 mA) of the car. Accordingly, it is recommended that:

- A Megapulse unit with a high activated voltage (i.e., 12.8 V) should be used for taxi and passenger cars
- A Megapulse unit with a low activated voltage (i.e., 10.5 V) should be used for folk-lift trucks
- A Megapulse unit with either a high or a low activated voltage can be used for road trucks and buses.

The incorporation of Megapulse technology in vehicles does not damage the on-board electronic equipment. This is because such equipment can withstand voltage spikes of 45 to 80 V and these are greater than the peak voltage of the Megapulse device.

1. BACKGROUND

An automotive battery is designed to accomplish the following three functions:

- to supply power for fuel injection, the ignition system, and the starter
- to provide/accept the deficit/surplus energy between the charging system and the electrical loads of the vehicle
- To act as voltage stabilizer in the electrical system.

The failure of batteries to meet the above requirements is due to either separately or in some combination: positive-material shedding, heavy grid corrosion, negative-material shrinkage, internal short-circuits, over-sulfation of positive and negative plates. In most cases, over-sulfation has been found to be the key problem because it can also be the primary cause of grid corrosion and material shedding (due to non-uniform current distribution during charging) as well as internal short-circuits (due to decrease in acid concentration).

In general, 'sulfation' means the formation of lead sulfate on the surface and in the pores of the active material in the plates. Lead sulfate develops as a reaction product on both the positive and the negative plates during discharge of the battery. The overall electrode reactions are as follows.

At the positive plate:

$$PbO_2 + 2H^+ + H_2SO_4 + 2e^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} PbSO_4 + 2H_2O \qquad (1)$$

At the negative plate:

$$Pb + H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} PbSO_4 + 2H^+ + 2e^- \qquad (2)$$

The overall discharge reaction of the battery is thus expressed by:

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2PbSO_4 + 2H_2O \qquad (3)$$

The lead sulfate formed in this way is composed of fine crystals and is readily reconverted by the charging current. Hence, it does not present any undue problems.

Large crystals or crusts of lead sulfate can, however, develop as the result of prolonged overdischarge, undercharge and/or extended open-circuit stand (re-crystallization through dissolution and precipitation). This kind of 'hard' sulfate is difficult to convert and, therefore, has a deleterious effect on each of the above three functions of the battery. It should be noted that if the battery can no longer act as a voltage stabilizer, the alternator may deliver high voltage spikes directly to the on-board electronic equipment and thus cause damage.

The search for an effective means to overcome over-sulfation problems has resulted in the development of Megapulse technology. It is claimed that the technology can:

- maintain a lead–acid battery in a healthy state, i.e., free from accumulation of 'hard' sulfate
- Recover a battery that has already been over-sulfated.

Megapulse technology is presented in the form of an electronic device which is connected to the positive and the negative terminals of the battery. The device functions by drawing power from the battery and transmits pulses back to the battery. There is a minor energy loss between the power received from the battery and that supplied back to the battery. Thus, the device draws a very small net current from the battery. In order to protect the battery from overdischarge, the device is designed in such a way that it ceases to operate when the battery voltage falls below a set threshold level (i.e., the 'activated' voltage). An LED on the device signals the activated state. It is further claimed that the Megapulse unit does not interfere with, nor require any modifications to, commercial chargers used with batteries.

Power Distribution Enterprises Pty Ltd. is the Manufacturer of the Pulse devices. This company requested the CSIRO Novel Battery Technologies Group to assess the efficacy of Megapulse technology in preventing irreversible sulfation of lead–acid batteries under certain automotive duties. In general, automotive batteries can experience the development of hard sulfate in the following situations.

(i) *'Key-off' load.* During standing of automotive batteries in dealerships, a very low 'key-off' current (< 50 mA) is drawn continuously from the battery for back-up of the computer, alarm system, and clock. This so-called 'squeeze discharge' can give rise to heavy sulfation and possibly failure of the battery.

(ii) *Headlights.* Neglecting to switch off the headlights on parking the vehicle can also result in overdischarge of the battery.

(iii) *Insufficient charge.* Some automotive applications place heavy demands on batteries. For example, the operation of taxis and urban buses involves frequent stop–start duty and also requires substantial battery energy to run the heater/air-conditioner and electronic devices. Under such conditions, there may be insufficient time and energy to charge fully the batteries. Consequently, the batteries will be taken to progressively greater depths-of-discharge during service and will eventually fail through overdischarge.

A test which simulates condition (iii) is adopted in this study to evaluate the efficacy of the Megapulse technology. The experimental strategy is to compare the cycle-life and crystal size/morphology of lead sulfate for batteries fitted with or without Megapulse units

2. EXPERIMENTAL

CSIRO was provided with three Megapulse units. Two units have an activated voltage of 12.8 V while the remaining unit has 10.5 V. The Megapulse unit only operates when the battery voltage exceeds its activated value. Power distribution enterprises pty Ltd agreed to a preliminary study on four 12-V Exide flooded batteries (E470H, cold-cranking current = 470 A, reserve capacity = 96 min).

2.1. Full Charge

The batteries were charged using a constant voltage of 14.8 V with a maximum current of 10 A for 24 h at room temperature (about 22 °C). Megapulse devices were not fitted to the batteries during charging. The batteries were then allowed to stand at open-circuit for 30 min and both the relative density and the level of the electrolyte in each cell were checked. The relative density was found to be within the range specified by the manufacturers, namely, 1.260 to 1.270.

2.2. SAE J537 Life Test

After full charge, the batteries were fitted with/without Megapulse units and were labelled as follows:

- battery MP1: without Megapulse device
- battery MP2: with 12.8-V Megapulse device
- battery MP3: with 12.8-V Megapulse device
- battery MP4: with 10.5-V Megapulse device

The batteries were subjected to SAE J537 cycling; this is a standard test developed by the American Society of Automotive Engineers. The test procedure involved placing the batteries in a water bath which was maintained at 72 °C. The water level was kept at a height equal to or greater than 75% of the overall height of the battery container. The batteries were allowed to stand at open-circuit until they reached the bath temperature. Discharge was carried out at 50 A for 4 min, whilst charging was achieved with a constant voltage of 13.93 V and maximum current of 50 A for 10 min. (Note, in order to accommodate a temperature compensation of 10 mV / ^{o}C above 25 ^{o}C, a top-of-charge voltage of 13.93 V was used instead of 14.4 V as quoted in the standard.) The discharge–charge sequence was taken as ‘1 cycle’. After repeating the sequence for 96 h (411 cycles), the batteries were allowed to stand at open-circuit for 70 h in the same water bath. The batteries were then charged for 10 min at a maximum current of 50 A to a maximum voltage of 13.93 V.

With the batteries in the water bath, discharge was conducted at the rated ‘cold-cranking’ current of 470 A to 7.2 V or 30 s, whichever occurred first. The final voltage was recorded. The test procedure was repeated for each battery until a voltage of 7.2 V could not be sustained over the 30-s discharge at the cranking rate. Between each test, the batteries were returned to a fully-charged state by conducting a charge at 50 A for 10 min.

2.1. Teardown Analysis

After completion of SAE J537 cycling, the cycled batteries (in discharged state) were dissembled. All the plates were washed and then dried at 60°C. The dried plates were submitted to both visual inspection and scanning electron microscopy (SEM) examination. For the latter analysis, samples of positive materials, removed from the central plate of cell #3 of each battery, were mounted on a carbon block and a carbon film of 250 nm was deposited over the entire block to provide satisfactory imaging of the material. (Note, the cells in each battery are numbered 1 to 6 from the positive to negative terminal.)

3. RESULTS AND DISCUSSION

3.1. Charging Ability of Batteries during SAE J537 Cycling

The SAE J537 test has been devised to evaluate the performance of automotive batteries under conditions which simulate the major requirements of their applications. For evaluation of the Megapulse device, the test was slightly modified and conducted under conditions which simulated taxi-driving duty. The revised procedure involved subjecting each battery to both shallow-discharge and a slight undercharge at high temperature. The occurrence of battery undercharge in taxi-driving duty is considered to result from:

- the frequent stop–start service
- the significant power requirements to run auxiliary devices (e.g., heater, air-conditioning and electronic devices)
- A low top-of-charge voltage (ToCV = 13.93 V) due to temperature compensation (10 mV / °C above 25°C).

In general, the charging efficiency of lead–acid batteries is less than 100% because of the side reactions of oxygen evolution and hydrogen evolution. Therefore, in order to maintain a full state-of-charge, the charge input to the battery during charging should be higher than that removed during the previous discharge. The ratio of these two quantities (i.e., charge: discharge) is known as the charge-to-discharge ratio or 'overcharge factor'.

It is important to check the charge-to-discharge ratio of each battery during SAE J537 cycling and to determine whether the battery can be maintained in a fully-charged state. The SAE J537 procedure is a partial state-of-discharge and charge test, i.e., the battery is discharged to about 90% state-of-charge during each 4-min period and is recharged to over 100% during each 10-min period. The charge-to-discharge ratios for the batteries under test are given in Fig. 1. The charge input to the battery is always greater than the charge removed from the battery during discharging. **Generally, the charge-to-discharge ratio of the test batteries (except for during very early stages of each block of 411 cycles) varies between 102.2 and 103.6 % and is higher for batteries fitted with Megapulse devices. This indicates Megapulse units enable batteries to accept slightly more charge.** Nevertheless, the question remains: 'Can batteries be maintained at a fully-charged state with these charge-to-discharge ratios?' This can be determined by examining the change in discharge voltage during cycling.

The change in voltage at the end of each 4min discharge during SAE J537 cycling of batteries MP1 to MP4 is shown in Fig. 2. A decrease in the end-of-discharge voltage (EoDV) during cycling is observed for all batteries under test. This behaviour is more pronounced for batteries MP1 and, particularly, MP2. The change in EoDV is related to the efficacy of the observed charge-to-discharge ratio for a given battery. Namely, a decrease in EoDV during cycling is indicative of undercharging of the battery, whilst an increase in EoDV suggests overcharging. The optimum charge-to-discharge ratio will yield a constant EoDV. From the data shown in Fig. 2, it is concluded that all the batteries are being undercharged. This is to be expected, as the tests have been performed under conditions which simulate taxi-driving duty.

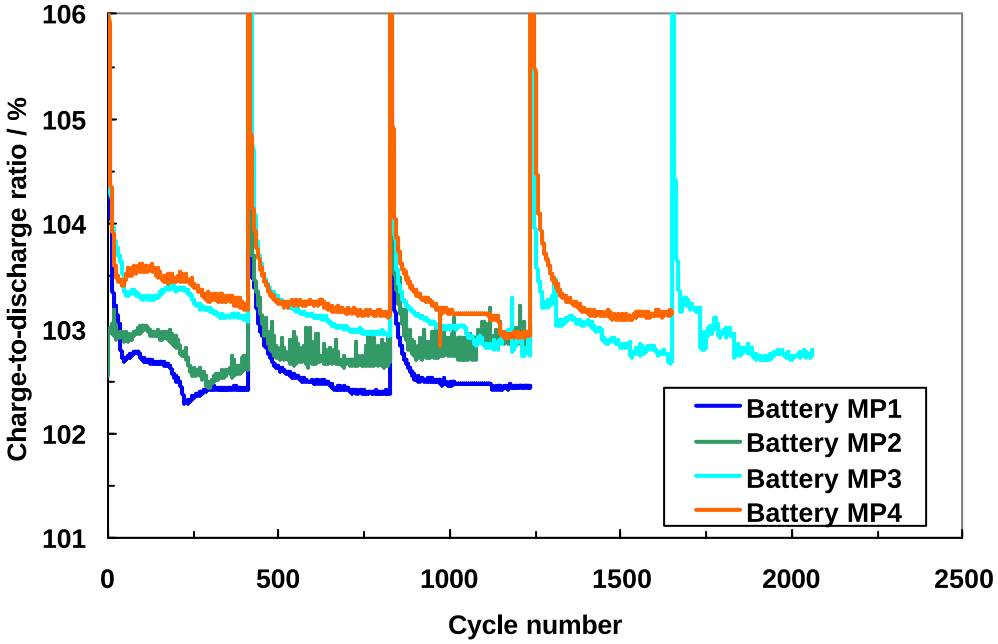

Fig. 1. Charge-to-discharge ratio of batteries under SAE J537 test.

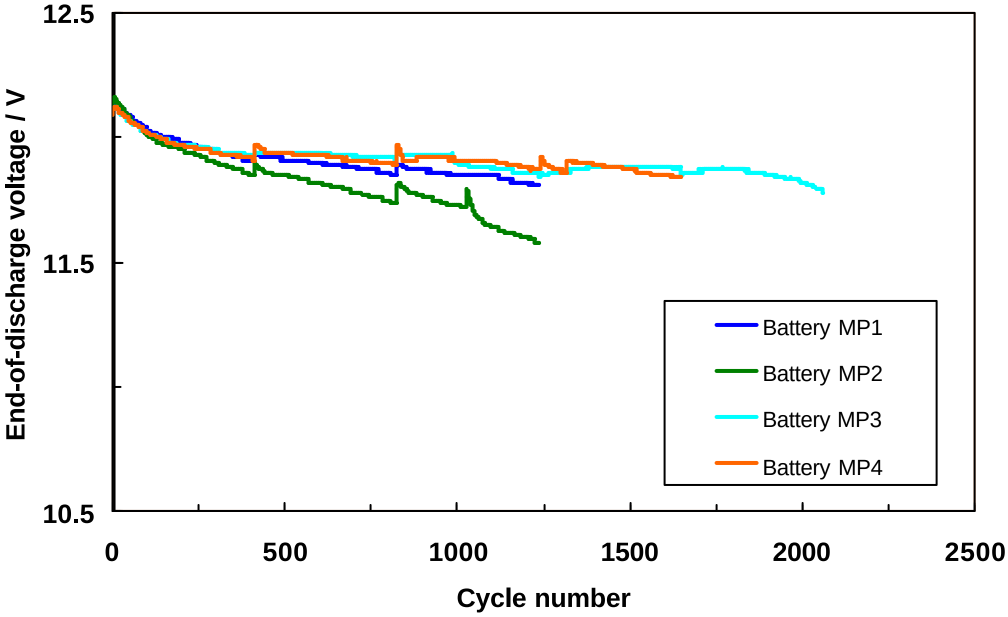

Fig. 2. Change in end-of-discharge voltage of batteries under SAE J537 test.

3.2. SAE J537 Cycling Performance of Batteries

The change in the 30-s voltage of each battery is presented in Fig. 3. As noted above, this voltage is that recorded at the end of each 30-s discharge at the cold-cranking current (470 A). Batteries MP1 and MP2 display a continuous decrease in the 30-s voltage throughout cycling. On the other hand, the voltage remains virtually constant up to 1600 cycles for battery MP3 and 800 cycles for battery MP4. Battery life is reported as number of cycles to the point where the battery fails to maintain 7.2 V for 30 s. **A summary of the cycling performance of the batteries is given in Table 1. Battery MP1 without a Megapulse device failed after 1233 cycles. Batteries MP2 and MP3 fitted with 12.8-V Megapulse, and MP4 with 10.5-V counterpart failed after 1233, 2055 and 1644 cycles, respectively. The battery MP3 gives the best cycling performance. Although batteries MP2 and MP3 were fitted with similar Megapulse units, the former battery gave a much inferior cycle-life. Indeed, the performance of battery MP2 is equivalent to that of battery MP1 which was not fitted with a Megapulse unit. Since the Megapulse units consistently generate similar pulse patterns and amplitudes (see Section 4), the discrepancy in the performance of batteries MP2 and MP3 may be due to the variation in battery manufacturing.** To address this problem, it is recommended that more experimental trials be performed.

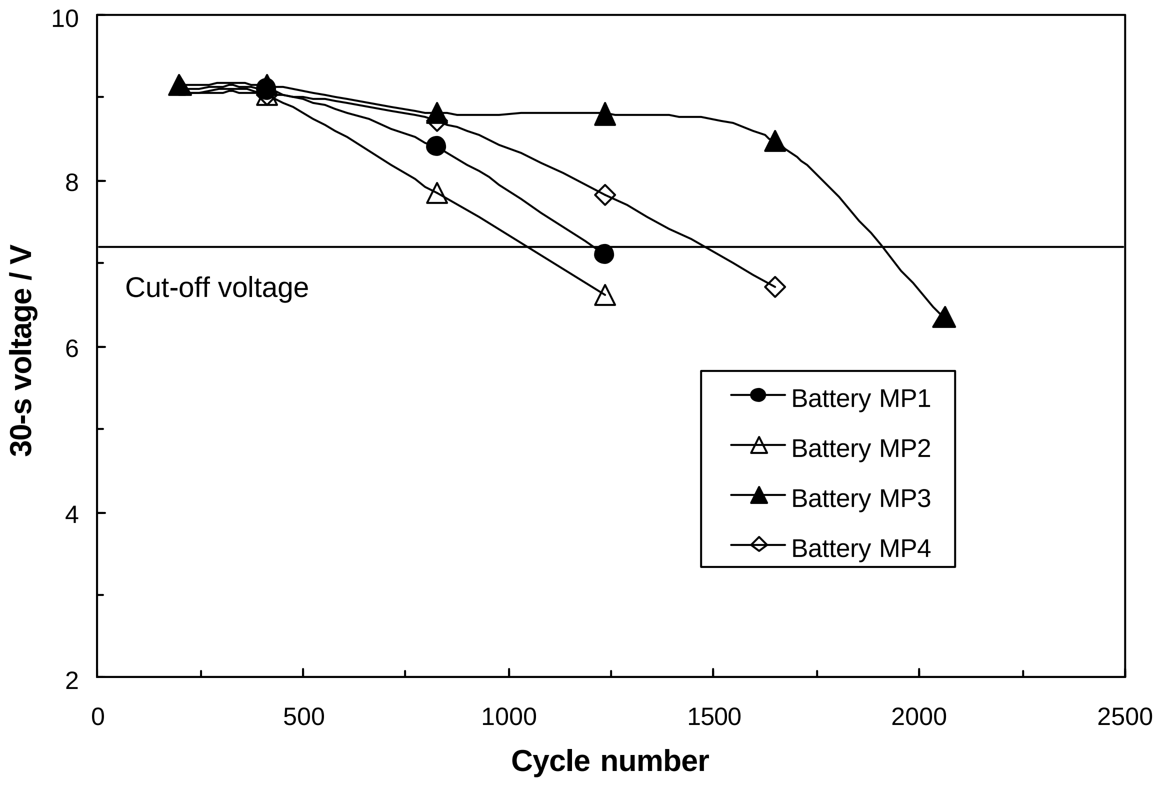

Fig. 3. SAE J537 performance of batteries MP1 to MP4.

Table 1. Cycle-life of batteries under SAE J537 test.

Battery	Megapulse device	Activated voltage	Cycle-life
MP1	No	Not applicable	1233
MP2	Yes	12.8 V	1233
MP3	Yes	12.8 V	2055
MP4	Yes	10.6 V	1644

3.3. Condition of Cycled Plates

3.3.1. Visual inspection

All negative plates from disassembled, cycled batteries displayed numerous cracks or gaps. This indicates that significant shrinkage of the material had taken place. Furthermore, the material was dense and hard, and little shedding was noticed. Yellow-coloured patches, believed to be β-PbO, were also present in different regions of the plates.

The positive plates in all test batteries were in a very poor condition. They had suffered from different degrees of sulfation, loss of mechanical strength, severe corrosion, material softening, and extensive shedding. As a consequence, a significant amount of the positive material (at least one-third) fell off the plates during removal of the plate-groups from the cells. This phenomenon was most prominent in battery MP3, in which the plates lost almost the whole amount of active material. It is noted that this battery gave the longest cycle-life of all test batteries.

3.3.2. Scanning electron microscopy examination

The morphology of positive plates removed from batteries MP1, MP3 and MP4, which suffered from overdischarging, is shown in Fig. 4. As expected, in all cases, the material is comprised of a mixture of lead dioxide and well-defined lead sulfate crystals. The latter crystals have sizes between 10 and 40 µm (note, the 'normal' size is ~5 µm). Some of the lead sulfate crystals are partially oxidised to lead dioxide. **Individual sulfate crystals have sharp, angular shapes and appear to be smaller in battery MP3 (with 12.8-V Megapulse) than in batteries MP1 (without Megapulse) and MP4 (with 10.5 V Megapulse). The sulfate crystals in the positive material of battery MP4 are comparable in size with those in battery MP1 even though the former battery enjoyed a longer cycle life (1644 vs. 1233 cycles). The observed difference in crystal size of the lead sulfate is most probably the result of the Megapulse action.**

In summary, the cycling performance data and studies of plate morphology suggest that the use of Megapulse technology can increase the service life of batteries through suppressing the size of lead sulfate crystals. Obviously, more experimental trials are required to establish this preliminary finding at an acceptable level of confidence. It worth noting here that we estimate that an improvement of 411 cycles obtained under the SAE J537 test is roughly equivalent to one extra year of battery life when used in typical passenger car. This corresponds to two extra months of battery life under the more arduous conditions of taxi driving.

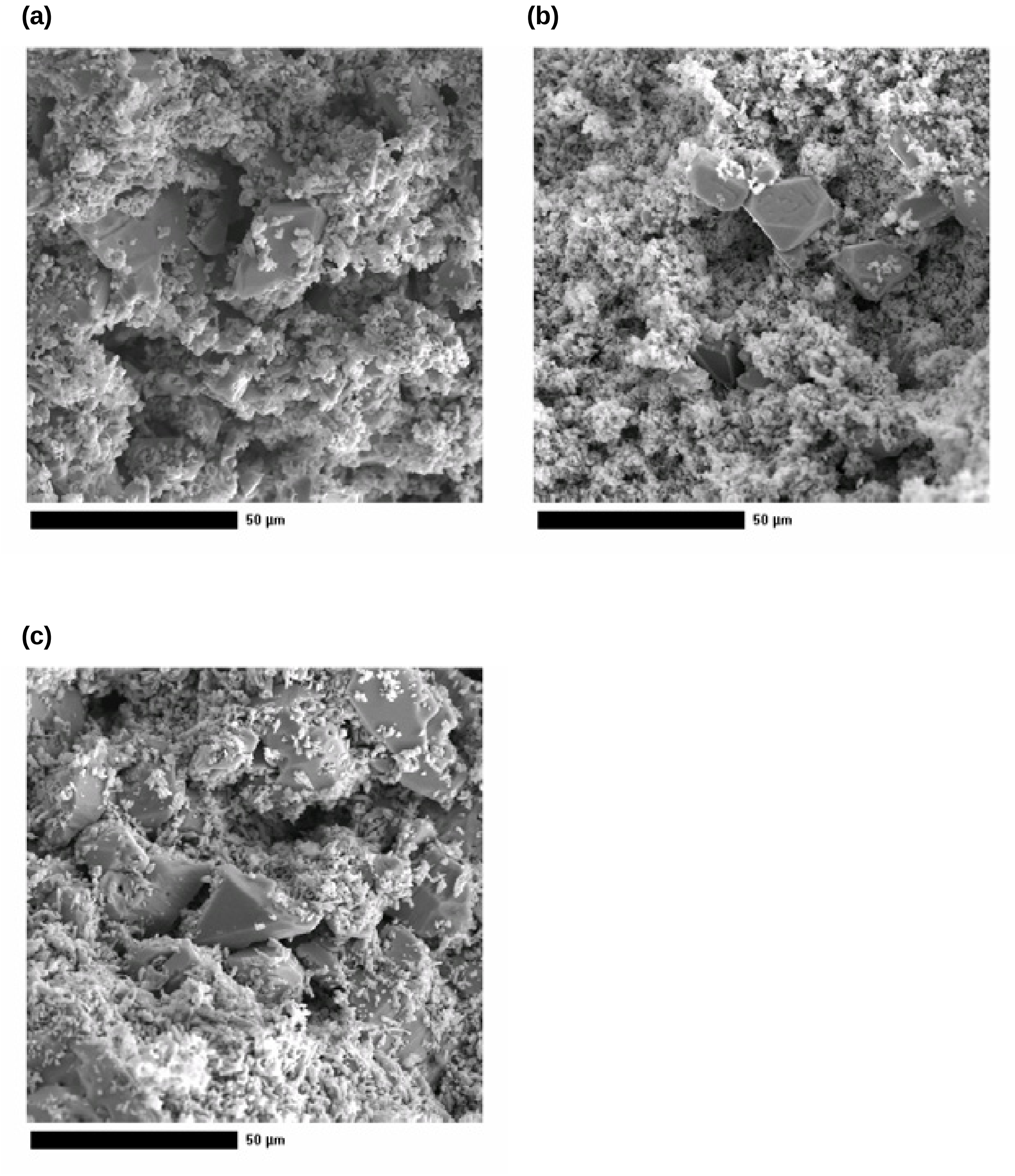

Fig. 4. **Morphology of positive-plate material removed from: (a) battery MP1; (b) battery MP3 and (c) battery MP4.**

4. OPERATIONAL CHARACTERISTICS OF PULSE TECHNOLOGY

Two types of Megapulse device have been evaluated in this study. One type is activated at 12.8 V (two units) and other at 10.5 V (one unit). When these units are connected to the positive and negative terminals of batteries which have voltages greater than their corresponding activated values, the devices will provide sets of current pulses to the batteries. The pattern and amplitude of the pulse should be similar for all units, even though units have different activated voltages. The pattern of the pulsed current given by a 12.8-V Megapulse is presented in Fig. 5. The on-time of the pulse is about 1 µs and the period is about 133 µs. Thus, the duty cycle is 0.75% [duty cycle = (on-time / period) x 100%]. The voltage amplitude of the pulse changes during the on-time and the peak value is found to be about 37 V (Fig. 6). Accordingly, the current amplitude is not constant and the average value is about 3 A. **Similar pulse patterns and amplitudes were also observed for the other units with the same, or even different, activated voltage. This suggests that there is good consistency in the product quality of the Megapulse devices.**

When current is averaged over the period of the pulse, a value of about –60 mA is obtained. As mentioned in Section 1, this is the overall current drawn by the Megapulse unit from the battery because of energy loss. With this current, a battery with a low reserve-capacity of 20.8 Ah (i.e., NS40 type) and fitted with a 10.5-V Megapulse will be discharged fully in 14.4 days [i.e., 20.8 Ah/(0.06 A x 24 h/day)]. In practice, this time will be shorter in automobiles because of the extra key-off load currents. If it is assumed that the key-off load current is 25 mA, then the time taken to discharge fully a battery with a low reserve-capacity and for example, fitted with a 10.5-V Megapulse unit will be 10.2 days, i.e., less than two weeks!

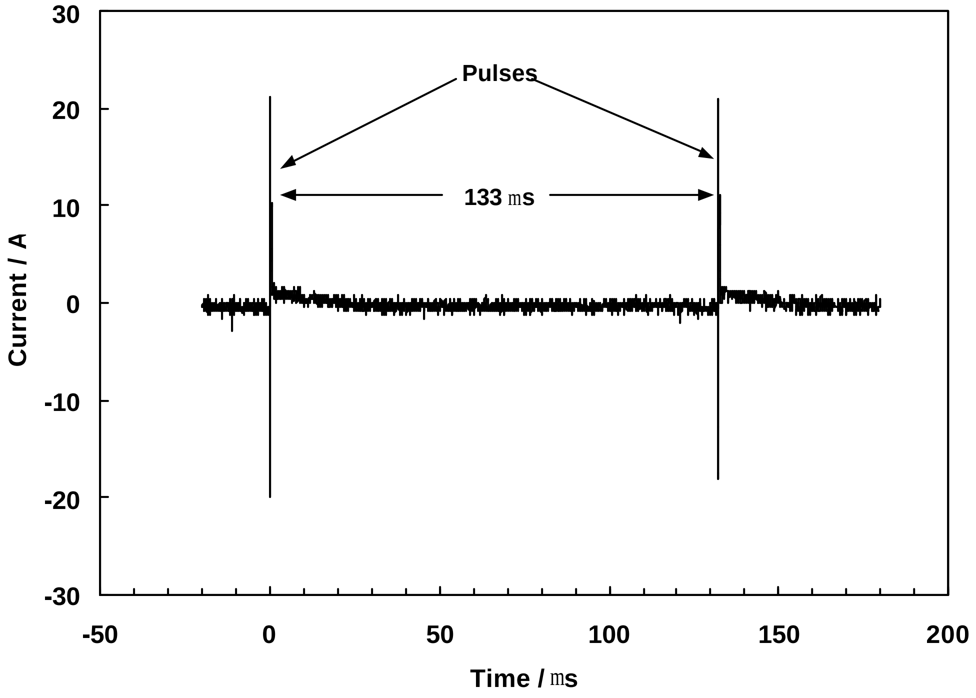

Fig. 5. Waveform of pulsed-current supplied by Pulse.

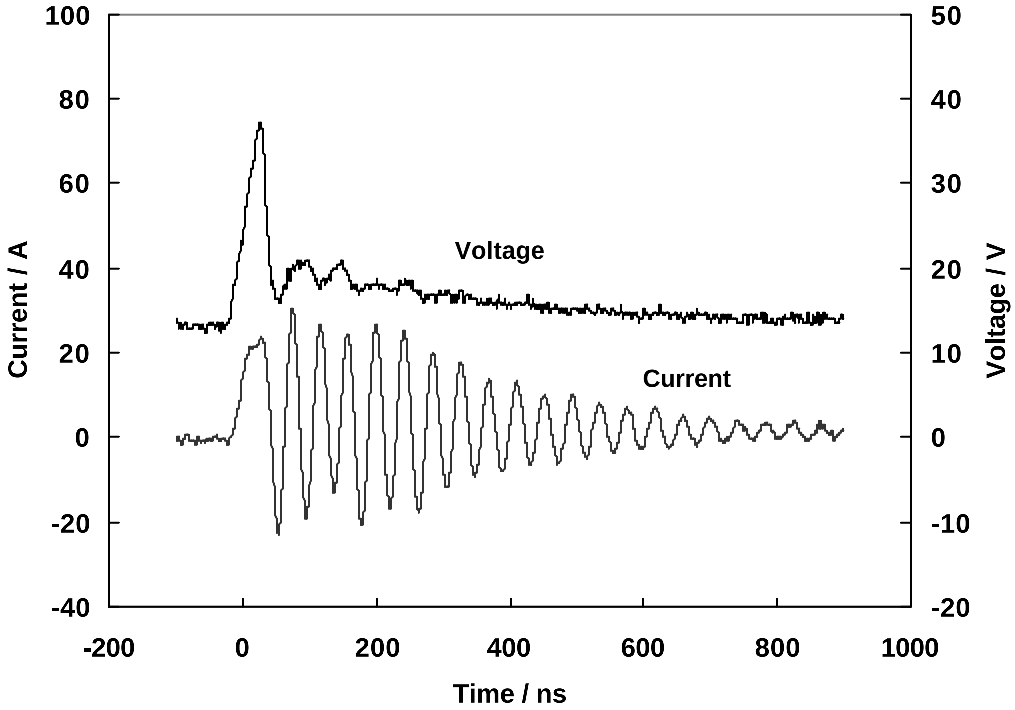

Fig. 6. Voltage and current amplitude given by the Pulse during the on-time.

From the above analysis, it is clear that a Megapulse unit with high activated voltage (i.e., 12.8 V) should be used for automobiles which use batteries with low reserve-capacity, for example, taxis and passenger cars. On the other hand, a Megapulse with low activated voltage (i.e., 10.5 V) is recommended for vehicles, which employ batteries of greater capacity, such as folk-lift trucks. High or low activated-voltage Megapulse units can be used in road trucks and buses. **Obviously, there may be some concern over the possibility of damage to the electronic components of the vehicle when fitting a Megapulse. Such concern is unfounded, however, because most of the electronic components of the vehicle can tolerate voltage spikes of 45 to 80 V and this range is greater than the peak value (i.e., 37 V) given by the Megapulse units examined in this study.**

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