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Technical Report

The Design of an Voltage Type Online Automatic Maintenance Device Based-on Pulse Theory For Lead-acid Batteries

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In this paper, the sulfation failure mechanism on negative plates of lead-acid batteries and the pulse-repairing technology are analyzed, and an online auto maintenance equipment of Voltage type based-on the Boost topology circuit is designed. The test results show that via adjusting hardware devices and programs, the high-frequency and high-amplitude of recharge-and-discharge pulses can be achieved. And online maintenance function for lead-acid battery is came ture and the device meets the design requirements.

Keywords: Sulfation failure; Pulse-repairing technology; Automatic maintenance design

1. INTRODUCTION

The starter-type lead-acid battery is an essential and important part of our military vehicles and equipments, every year its reserves and use consumption are huge, it ranks only second to tires in the vehicle consumes equipment and occupies a significant proportion[1]. With intermittent use characteristics, battery lacks timely and necessary maintenance in the disabled period, so lead to battery sulfation failure. The average life span of battery is only two years, or even less. So as a vivid metaphor “the starter-type lead-acid battery is not being used badly, but is bad for a long period of place". Due This situation, the productions of lead-acid battery negative plates, $PbSO_4$ crystal, grow gradually from tiny particles a thick hard mass, whose electric conductivity is very poor. Finally batteries can’t be charged again and are damaged[2]. Based on this theory, we develop an online maintenance device of voltage type for the starter-type lead-acid batteries.

2. THE ANALYSIS OF THE SULFATION FAILURE MECHANISM ON NEGATIVE PLATES OF LEAD-ACID BATTERIES AND THE PULSE-REPAIRING PRINCIPLE

2.1. Analysis of the negative plate sulfation mechanism

The following reactions occur in the charging and discharging process of lead-acid battery[3]:

Negative plates: $Pb + HSO_4^- \underset{charge}{\overset{discharge}{\rightleftarrows}} PbSO_4 + H^+ + 2e$ (1)

Potive plates: $PbO_2 + 3H^+ + HSO_4^- + 2e \underset{charge}{\overset{discharge}{\rightleftarrows}} PbSO_4 + 2H_2O$ (2)

Reaction of batteries: $Pb + PbO_2 + 2H^+ + 2HSO_4^- \underset{charge}{\overset{discharge}{\rightleftarrows}} 2PbSO_4 + 2H_2O$ (3)

We can find that the active substance in the positive and negative plates of the lead-acid battery is turned into $PbSO_4$ from chemical equations above on. Right now the $PbSO_4$ microscopic structure is spongy and tenuous and the plate is in the state of high potential energy. If the battery in discharge state is not be recharged in time and kept for a long time, $PbSO_4$ crystal will change from the unstable situation of high potential energy into stable situation of low potential energy[4]. And in microscopic structure, polycrystal tends to develop in the direction of reducing its surface free energy. Because of the double factors, the $PbSO_4$ crystal grows from spongy and tenuous mass into thick and dense mass[5]. The crystallization mechanism shows us that the solubility of tenuous crystal is higher than the dense crystal. So the $PbSO_4$ crystal in the negative plate is inactivated and can't be recharged again. But the $PbSO_4$ crystal in the positive plate can be oxidizes to original substance because the oxygen atom produced from the recharge reaction has potent antioxidation capacity. As a result, sulfation only occurs in the negative plate[6].

2.2. Theory of the pulse-repairing technology

When the inactive negative plate is being repaired, the plate receives a certain frequency excitation pulse from the external device. According to the principle of atomic physics, the excitation signal activate the S atom from the lowest energy state (the covalent bond state) into high energy and unstable state. In this way, the S atom in the covalent bond state is broken down into the ion state and the thick and dense $PbSO_4$ crystal gradually dissolves, then the activity of negative plate is restored[7]. This excitation signal not only transfers the old, thick and dense sulfates into the original active substance, but also destroys the static conditions of producing $PbSO_4$ crystal and makes the $PbSO_4$ crystal in the active state [8].

3. HARDWARE SYSTEM DESIGN OF LEAD-ACID BATTERIES VOLATAGE TYPE MAINTENANCE DEVICE

3.1. System components and operating principle of the Maintenance devices

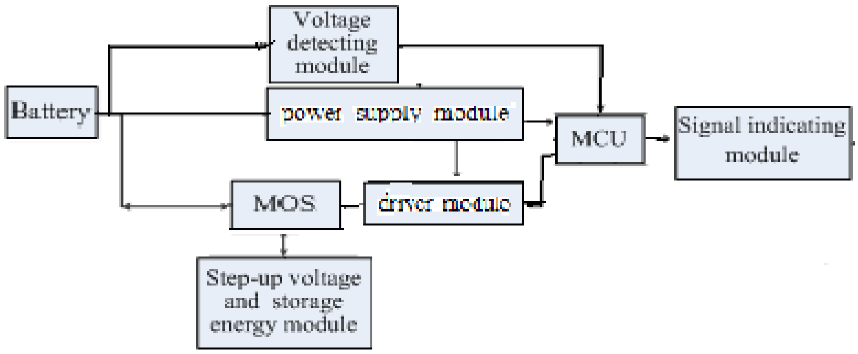


Figure 1. Schematic drawing of the online automatic maintenance device

As shown in Fig.1, the device's hardware system consists of the control module, the voltage detecting module, power supply module, driver module, the signal indicating module, voltage step-up, energy storage module, electronic switches and other modules[9].

This device takes battery as energy. The control module controls the MOS transistor drive circuit by the microcontroller and program, and then controls the power MOSFET to change the turn-on and turn-off time, so as to adjust the charge-discharge frequency. Between MOSFET turn-on/turn-off conversion period, capacitor completes the process of recharge energy storage and charge the battery process, in order to achieve the recharge-and-discharge pulses impact for the battery. When the battery voltage is too low (lower than a value) the device will make the buzzer and LED indicator to give an alarm.

3.2. Design of maintenance device working circuit

The device adopts Boost topology circuit based on the ATtiny24 microcontroller chips. MOS tube achieves turned on or off alternately by the duty cycle D pulse controlling, in order to control the oscillation circuit with the inductance and capacitance, and complete the battery (12V) voltage raised and lowered. And the formation of the charge and discharge pulses is formed, while the battery charging and discharging process via the voltage pulses are completed. The main circuit of the device is shown in Figure 2. Figure 3 is MOS transistor driver circuit diagram. Fuse GP60 plays a protective effect when circuit is short circuit and over-current; D2 is fast recovery diode, mainly prevents maintenance device reversing; D3 also is fast recovery diode, its main function is blocking inductor L3 pathway during charging the capacitors[10].

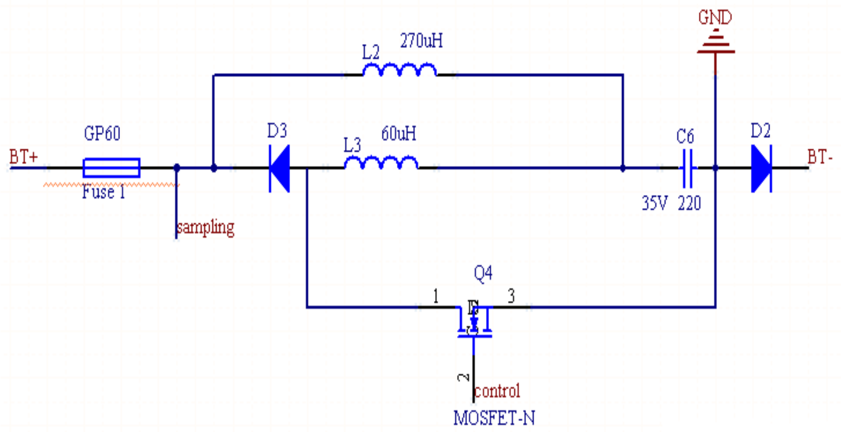


Figure 2. The circuit schematic diagram of the Maintenance device main circuit

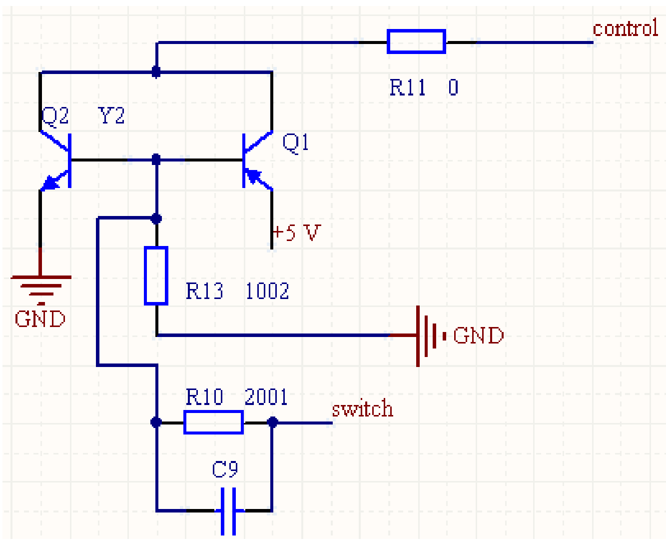


Figure 3. The MOS tube drive circuit schematics of maintenance device

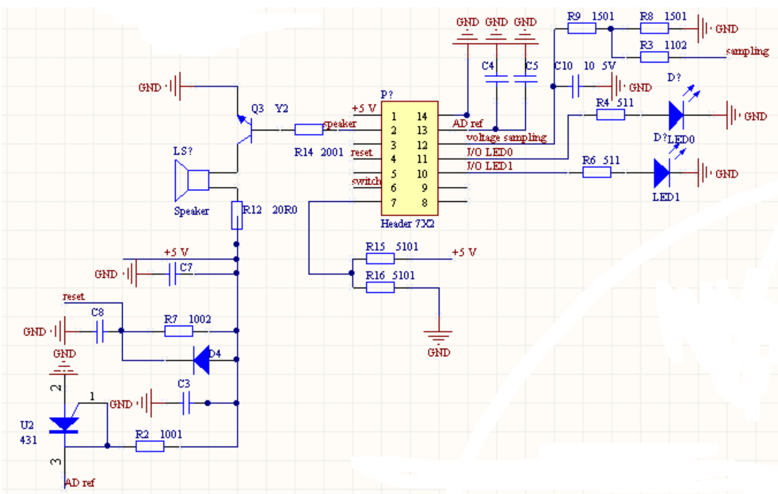


Figure 4. ATtiny24 microcontroller basic external circuit

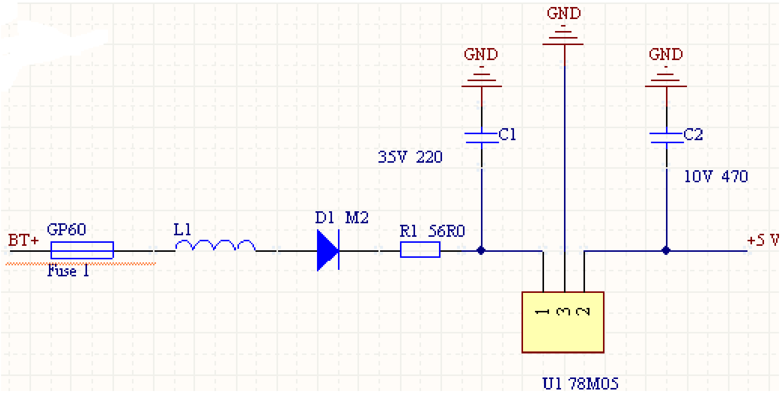


Figure 5. The supply voltage change circuit schematic of maintenance device

As shown in Figure 4, the ATtiny24 microcontroller pin 1 supplies MCU operating voltage. Because battery voltage is 12V, but the microcontroller working voltage is 5V, so we need a regulator to adjust the voltage conversion, and voltage conversion circuit is shown in Figure 5. The pin 4 has a reset function, to generate a reset if the minimum pulse width time continued to a lower value. Pin 6 sends a certain frequency square wave to the MOS transistor drive circuit, in order to control MOS transistor turn-on and turn-off time and frequency. Pin 12 is the voltage sampling pin, its one end connects the battery to sample voltage after the main circuit fuse GP60, then the value is provided to the Attiny24 microcontroller chip. Through program analysis, control light-emitting diode by pin 10 and pin 11 and control buzzer by pin 2. If the battery voltage is lower than 11.8V, the protector buzzer alarms, and the light-emitting diode of pin 10 and pin 11 flashes alternately. Pin 13 obtaines a certain voltage through a precise regulator chip 431, while the C4 and C5 in parallel filters clutter, as the reference voltage of the A/D converter. Pin 14 is connected the ground, and the pin5, 8 and 9 is empty.

3.3. Key component selection of the main circuit

1) The inductor and capacitor selection

The maintenance module achieves voltage boost function through the inductor of Boost topology circuit, and then backs the high-voltage to the battery. The main circuit of the input voltage V_{IN} is 12V, the boosted voltage V_O is 22V, the duty cycle is 1/12, the average charging current flowing through L2 is approximate 0.7A, i.e. I_{O2} = 0.7A; the average charging current flowing through L3 is approximate 3.2A, i.e. I_{O3} = 3.2A.

The inductor is calculated as follow:

$$I_{L2} = \frac{I_O}{1-D} = \frac{0.7}{1-1/12} = 0.76\text{A} \qquad (4)$$

In the equation: V_O—The output voltage of Boost topology circuit;

V_{IN}—The input voltage of Boost topology circuit;

D —The duty cycle;

I_{L2}—The current flowing through L2.

The ripple rate of the current across the inductor is taken as 0.6, Oscillator frequency is taken as 8.3 kHz, so we can know:

$$L_2 = \frac{V_{ON} \times D}{r \times I_L \times f} = \frac{V_{IN} \times D}{r \times I_L \times f} = \frac{12 \times 1/12}{0.6 \times 0.76 \times 8300} = 264\mu H \quad (5)$$

In the equation (3-12), V_{ON} is the inductor voltage during MOSFET conduction. V_{ON} is equal to V_{IN} for the Boost topology circuit. So we choose the inductor whose rated current and inductance is 2A and 270μH when we take into account the loss.

Similarly, the inductance L3 can be calculated as follows:

$$I_{L3} = \frac{I_O}{1-D} = \frac{3.2}{1-1/12} = 3.5A \quad (6)$$

In the equation: V_O—The output voltage of Boost topology circuit;

V_{IN}—The input voltage of Boost topology circuit;

D —The duty cycle;

I_{L3}—The current flowing through L3.

The ripple rate of the current across the inductor is taken as 0.6, Oscillator frequency is taken as 8.3 kHz, so we can know:

$$L_3 = \frac{V_{ON} \times D}{r \times I_L \times f} = \frac{V_{IN} \times D}{r \times I_L \times f} = \frac{12 \times 1/12}{0.6 \times 3.5 \times 8300} = 57\mu H \quad (7)$$

In the equation (3-14), V_{ON} is the inductor voltage during MOSFET conduction. V_{ON} is equal to V_{IN} for the Boost topology circuit. So we choose the inductor whose rated current and inductance is 2A and 270μH when we take into account the loss[11].

The capacitor C1 acts as a filter capacitor. Since the main circuit boosts the voltage reached 22V, and we avoid instantaneous flyback electromotive breakdown capacitor, we design the parameters of the capacitor C1 is the voltage level of 35V, the electric capacity of the standard 220μF.

2) Power MOS switch selection calculation

Due to the pulse frequency of the maintenance device is mainly influenced by the switching frequency of the MOS transistor, so we choose the switching frequency of the MOS tube around in 8KHZ, for the realization of high-frequency, high-amplitude pulses. Since the turn-on voltage of the MOS transistor is about 4.3V, we select the highest gate voltage should be less than 4.3V. And because the main circuit enhances the voltage up to 22V, we select power switch tube pressure level is higher than 117V, when we take into account the flyback electromotive force of the inductor is 90V. And taking into account that the current flowing through the inductor L2 can reach 3.5A instantaneously, we select the peak current of the power switches is 4.6A. Based on the above conditions and combined MOS tube junction and case temperature, we choose the main circuit power switch Model IRF630, the turn-on voltage is 4.1V, the withstand voltage is 200V, the drain and source-resistance is 400mΩ, and it can withstand the current pulse reached 9A under the conditions of 25 °C, so it has a very low power consumption.

4. PROGRAM DESIGN OF MAINTENANCE DEVICE

According to the hardware system and working principle, the workflow is shown in Fig. 6.

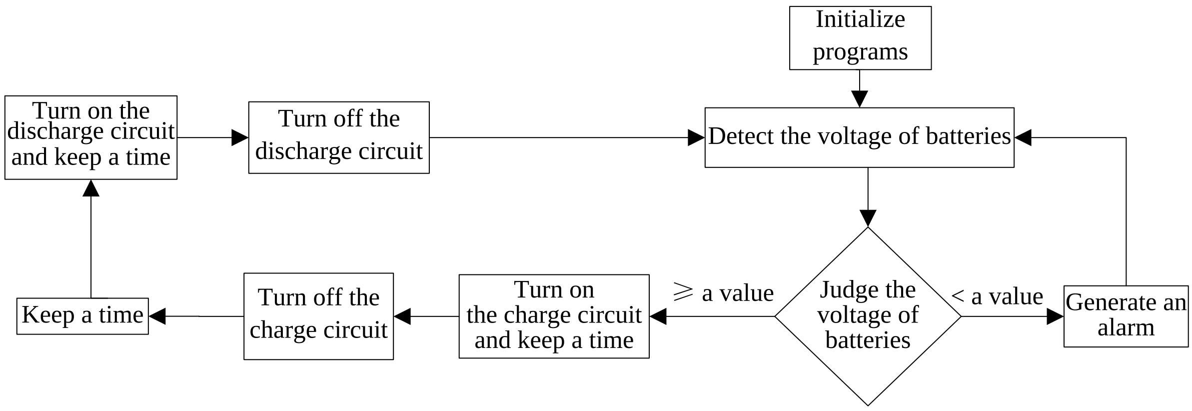


Figure 6. Working flow chart drawing

Firstly, the program of the microcontroller is initialized, including the initial value of the register, timer/counter and AD acquisition register assigned zero and the selection of interrupt control and interrupt functions open. When the initialization is completed, the overall program enters While (1) loop. The first step in the cycle is to collect the terminal voltage of the battery, and compare this value with the parameters set by the system. When the voltage is less than the programmed value 11.5V, the program considers that the battery voltage is too low, in the power loss or half loss of electricity, and then the maintenance device opens the buzzer and flashing diodes, the alarm sounds appears and traffic lights flash alternately suggesting that the battery should be charged. If this value is greater than or equal to the set value of parameters, we consider the battery voltage is normal, and the maintenance module opens the online maintenance function. Since the device connects the battery in parallel all the time, if the battery discharges in high current, the battery voltage will decrease to a certain degree. As a result, MCU produces a misjudgment and gives a wrong signal. In order to eliminate these influence factors, we use capacitor filters in hardware systems and average filter algorithm in programs[12].

5. MAINTENANCE DEVICE EXPERRIMENTAL STUDY

The battery online automatic maintenance device in the work is shown in Figure 7, and it has the anti-reverse function in its work.

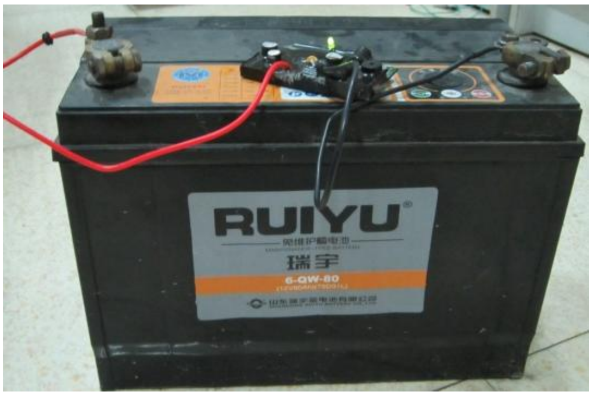
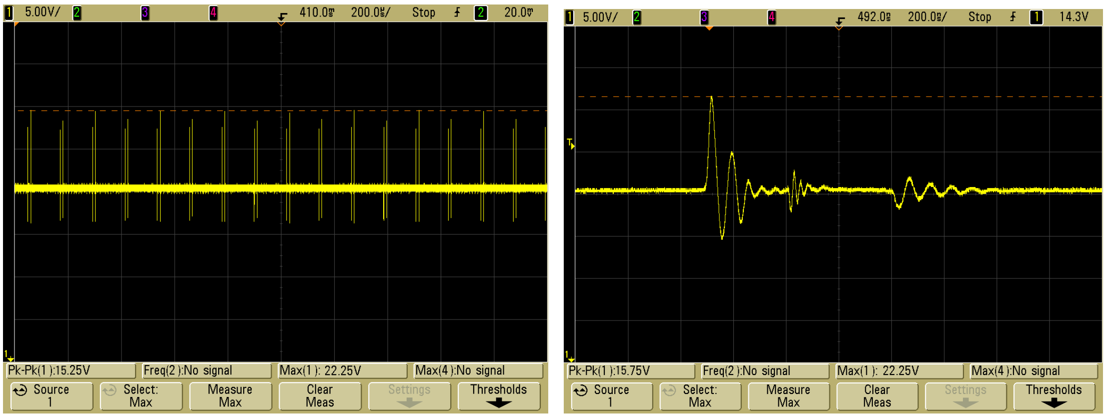


Figure 7. The battery online automatic maintenance device in the work

In the experiments, we use the oscilloscope voltage probe collecting the voltage waveform of the lead-acid battery voltage-type maintenance device, as shown in Figure 8. In Figure8, we can see that the battery may be formed on the rise in voltage of 10V, the drop voltage of 5V voltage pulses, and pulse amplification can be clearly seen that the waveform is the sinusoidal oscillation pulse, so this means that the voltage waveform amplitude and frequency of the voltage-type maintenance device has reached the high-frequency, high-amplitude range, and automatic maintenance function to lead-acid batteries is achieved.



(a) Overall voltage waveform (b) Single voltage waveform

Figure 8. The voltage waveform diagram of the lead-acid battery voltage-type maintenance device

Via Oscilloscope current probe, we acquire the current waveform of the lead-acid battery voltage-type maintenance device, as shown in Figure 9. From Figure 9, we can see the current waveforms of the voltage-type maintenance module Undulating smaller loop, and the maximum current is 156mA, so it means that the power consumption of the voltage-type maintenance device is very small, but the parameters of the voltage pulse are closer to the high-frequency, high amplitude requirements, so the maintenance function would be better.

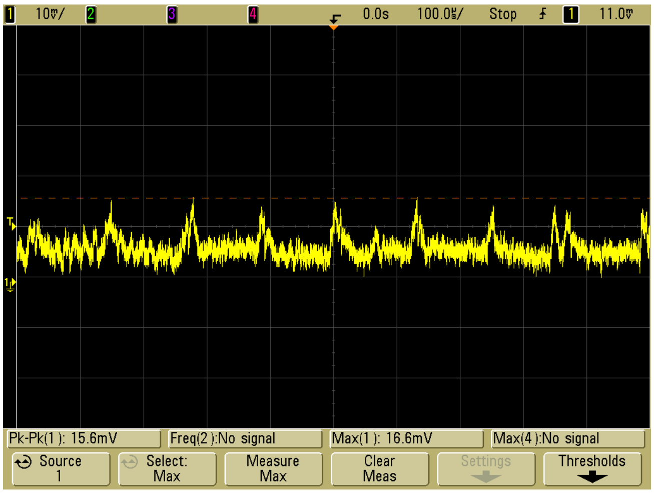


Figure 9. The current waveform diagram of the lead-acid battery voltage-type maintenance device

6. SUMMARIES

We design a Voltage-type online auto maintenance device to the lead-acid batteries by studying the sulfation failure mechanism on negative plates and the pulse-repairing technology.

1) The Voltage-type online auto maintenance device of the lead-acid batteries can produce the voltage pulse, frequency of 8KHz, the increase amplitude value of 10V and decreased the amplitude of 5V. The device can effectively prevent sulfide crystals of lead-acid batteries at the static condition, so it can achieve the automatic maintenance function to lead-acid batteries.

2) The boost voltage part of the maintenance device is the Boost topology circuit, and the amplitude and frequency of the boost voltage is affected by the switching frequency of the MOS tube.

3) The maintenance device adopts digital circuit controlling. In addition to capacitor filter in sampling circuit, the device also uses the average filtering algorithm in the program to prevent CPU misjudgment and to eliminate voltage fluctuations.

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