Failure Causes and Effective Repair Methods of Lead-acid Battery

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Abstract. Lead-acid batteries are widely used due to their many advantages and have a high market share. However, the failure of lead-acid batteries is also a hot issue that attracts attention. This article starts with the introduction of the internal structure of the battery and the principle of charge and discharge, analyzes the reasons for the repairable and unrepairable failures of lead-acid batteries, and proposes conventional repair methods and desulfurization repair methods for repairable failure types.

Lead-acid batteries have the advantages of working under high-current discharge conditions, abundant and easily available raw materials, low price, high reliability, and wide working range. Therefore, since its inception, they have been widely used in transportation, communications, electricity, high-tech weapons and other fields. The survey data shows that the scale of lead-acid batteries in the global is showing a rising trend year by year, but in the process of use, the problems of lead-acid batteries were inevitably exposed. Usually, the charging time becomes shorter and the battery fails within a year or even less. Based on the principle of charge and discharge of lead-acid battery, this article mainly analyzes the failure reasons and effective repair methods of the battery, so as to avoid the waste of resources and polluting the environment due to premature failure of repairable batteries.

1. Lead-acid batteries

1.1. The Internal Structure of Lead-acid Batteries

The internal structure of a lead-acid battery is mainly composed of positive and negative plates, electrolyte, separators, etc., as shown in Figure 1.

Figure 1. Internal structure of the battery
(1) Positive and negative plates. It consists of grid plate and surface active material. The surface active material of the positive plate is mainly lead dioxide, and that of the negative plate is lead. In the process of battery charging and discharging, the mutual conversion of electric energy and chemical energy is realized by the active material of the two plates and electrolyte.

(2) Electrolyte. The ingredient is sulfuric acid, which is made up of pure sulfuric acid and distilled water in a specific proportion.

(3) Single lattice. It consists of a group of positive and negative plates, separators and electrolyte. There are multiple groups of single cell inside the battery, and each cell completes the charging and discharging process independently.

(4) Partition. In order to reduce the volume and resistance of the battery, the distance between the plates is very close. In order to prevent the adjacent positive and negative plates from being short-circuited due to contact, insulating separators are added between the plates. There are many small holes on the separator to ensure the normal progress of the reaction and prevent the electrolyte from corroding plates.

1.2. Charge and discharge principle of lead-acid battery

In the process of discharge, because $H_2SO_4$ is a strong electrolyte, it exists in the form of $H^+$ and $SO_4^{2-}$ in the solution, and the reaction of the positive electrode is

$$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- = PbSO_4 + 2H_2O$$

(1)

The reaction of the negative electrode is

$$Pb + SO_4^{2-} - 2e^- = PbSO_4$$

(2)

In this process, sulfuric acid is gradually consumed, the concentration of the electrolyte gradually decreases, and the final product of the positive and negative plates are both lead sulfate, so it is called the "bipolar sulfation theory". In the process of charge, under the action of the charging current, $H_2O$ is electrolyzed into $H^+$ and $OH^-$, $PbSO_4$ is electrolyzed into $Pb^{2+}$ and $SO_4^{2-}$, so the reaction product of the positive electrode is $PbSO_4$, and that of the negative electrode is $Pb$.

The total reaction of the charge and discharge process is:

$$2PbSO_4 + 2H_2O \underset{charge}{\overset{discharge}{\rightleftharpoons}} PbO_2 + Pb + 2H_2SO_4$$

(3)

Side reactions will also occur during the actual charging process, the main being the electrolysis of water, also known as gassing reaction, that is

$$2H_2O = 2H_2 \uparrow + O_2 \uparrow$$

(4)

2. Failure analysis of lead-acid batteries

2.1. Reasons for repairable failure

(1) Improper maintenance during use. After running for a period of time, the individual battery will be breakdown or failure. If not maintained properly, a single failed battery will affect the normal use of other cells.

(2) Overcharge and float charge. If the charging time is too long, the electrolytic water will be carried out after the lead sulfate reaction is complete. A large amount of water is consumed, not only make the concentration of sulfuric acid increases, resulting in plate corrosion, water as a reactant in the charging process, but also will affect the battery recharging process. At the same time, the bubbles generated by water electrolysis will wash the electrode plates, causing the active material of the electrode plates to fall off, reducing the capacity and life of the battery.
(3) The influence of electrolyte temperature. The best operating temperature of the battery is 25°C. Generally, the battery can play the best performance in the moderate temperature of the electrolyte. If the temperature is too low, the viscosity of the electrolyte will increase, the ion diffusion speed will slow down, and the reaction process will slow down. The battery charging process is an exothermic reaction, and the internal resistance will also generate heat. If the heat is not released in time, the temperature of the electrolyte will rise, which will affect the normal operation of the battery.

(4) Over discharge and sulfation. Over-discharge of the battery will continue to produce lead sulfate, which is a very easy to crystallize substance. When the concentration of lead sulfate in the electrolyte is too high or if it is left for a long time, it will form small crystals. The small crystals continue to attract the surrounding lead sulfate to form large crystals. The crystallized lead sulfate not only does not participate in the reaction, but also adsorbs on the surface of the electrode plate, which increases the internal resistance of the battery and affects the charge and discharge performance of the battery and the battery capacity. The characteristic of the battery at this time is that the charging and discharging time becomes shorter and the internal resistance increases.

2.2. Reasons for irreparable failure

(1) The manufacturing level of the battery is different. The conductance is different because that battery manufacturers produce batteries of the same capacity with different technical levels. The larger the conductance value, the smaller the internal resistance, the higher the technological level and the higher the technical content. Therefore, if the technology level is low, the battery life is short, and the battery technology cannot be changed after leaving the factory.

(2) Battery short circuit or open circuit. If the internal fault of the battery leads to the existence of a conductor between the positive and negative plates, the battery will be short-circuited and the overall voltage will drop. Open circuit means that the circuit connection is interrupted and the overall battery has no voltage.

(3) Repairable failures without timely intervention will cause irreparable failures of the battery. For example, in the case of overcharging, high-concentration sulfuric acid will severely corrode the electrode plate, and even causing it to deform and permanently fail. When a large amount of lead sulfate is not handled, it will cause a short circuit in the battery, and even crystalline materials will accumulate in the gaps of the sealed plastic shell, generating expansion force and causing the shell to rupture. When the battery is affected by temperature, the temperature of the electrolyte gradually rises, the internal resistance decreases, the current becomes larger, and more heat is released. Such reciprocation will eventually lead to thermal runaway of the battery.

3. Failure repair method

3.1. Conventional repair methods

For failures caused by improper maintenance, basic maintenance techniques should be mastered, and single-cell failed batteries should be comprehensively and carefully checked and cleaned up in time.

For the water loss of battery caused by overcharge, distilled water can be supplemented in time to restore the concentration of electrolyte.

Failures caused by changes in electrolyte temperature are usually caused by excessively high temperature. When the temperature continues to rise, the battery should be stopped working and air-cooled or water-cooled should be used to cool down.

3.2. Devulcanization repair method

Traditional desulfurization methods include hydrotherapy, chemical repair, etc., but these repair methods are complicated to operate and the repair effect is not ideal. Physical repair methods are usually used, including positive and negative pulse repair technology, high-frequency resonance repair and scanning resonance frequency technology. This kind of repair method has the advantages of low cost, easy to operate, and does not change the internal structure of the battery.
(1) Positive and negative pulse repair methods

The principle of pulse repair: for any material with poor conductivity, there is a maximum voltage value that it can withstand, called the minimum breakdown voltage. When the externally applied voltage value is greater than the critical value, the insulating material will be broken down and become a conductor. Using this principle, during a positive pulse, a larger voltage value is applied to the battery, which can break the lead sulfate crystal attached to the electrode plate and turn it into lead sulfate that can participate in the charging reaction. Under the continuous action of the positive pulse, the concentration of lead sulfate near the electrode plate becomes larger and larger, and the high concentration of lead sulfate will crystallize again, which will hinder the further dissolution of the crystal. At the same time, facing the high voltage value, the heat generated by the internal resistance increases the temperature of the battery, even cause the battery to fail in severe cases. Therefore, in order to solve this side effect of the positive pulse, a negative pulse is added to the waveform, which is essentially to discharge the battery for a short time. The negative pulse can absorb the heat released by the charging reaction and reduce the concentration of lead sulfate. The positive and negative pulse diagram is shown in Figure 2.

![Figure 2. Positive and negative pulse](image)

(2) High-frequency resonance repair and scanning resonance frequency technology repair

These two repair methods use the resonance principle of crystal. Lead sulfate crystals have an inherent resonance frequency. When the externally applied frequency is just equal to the resonance frequency of the crystal, the lead sulfate crystal will resonate and be transformed into lead sulfate molecules that can participate in the charging reaction.

The waveform generation methods of the two are different. High-frequency resonance repair is to generate clutter of various frequencies through the hardware circuit, and resonate with lead sulfate crystals of different sizes. During the resonance process, the crystals are broken into small particles of lead sulfate, which are converted into lead and lead dioxide during charging. The high-frequency resonance waveform is shown in Figure 3. Scanning resonance frequency technology uses a program to control the pulse frequency sweep, using scan pulses with variable frequency, width and amplitude to scan the battery in a continuously variable manner, and to determine the resonance state of the crystal by detecting and analyzing the changes in the internal resistance of the battery. Once the resonance point is found and determined, the resonance pulse with fixed frequency, width and amplitude in this state will be output, so as to achieve the purpose of eliminating sulfide on the plate.
(3) Composite superposition repair method

In practical applications, it is found that a single repair method cannot effectively eliminate all lead sulfate crystals. The repair principle of each repair waveform is different, and the vulcanization degree and vulcanization reason of different batteries are different, so the effect of partial lead sulfate crystals repaired by one of the repair methods is not ideal. In view of this, any two methods can be combined to form a composite superposition repair method. For example, a positive pulse can be superimposed on a high-frequency resonance waveform to generate a composite waveform for repair. The composite repair can produce richer repair waveforms, the repair effect on the battery is more obvious, and the applicability is stronger.

4. Conclusion

This article begins with an introduction to the internal structure and charging and discharging principles of lead-acid batteries. On this basis, the causes of failure of lead-acid battery are analyzed, and targeted repair methods are proposed for the reasons of repairable failure. Effective repair of the battery can maximize the utilization of the battery and reduce the waste of resources. At the same time, when using lead-acid batteries, we should master the correct use methods and skills to avoid failure caused by misoperation.

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