Development of Intelligent Rapid Batteries Charger

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Abstract - This paper presents a project entitled "Development of a Battery Charger for Racing Car". The purpose of this study is to build up a automatic detection of Ni-Cd and Ni-MH battery and provide a safe procedure to charge them in relative short period such as 0.5-1hr. This paper will give simple introduction to these two kinds of battery, with discharge scheme and high current charging scheme followed. Safety precautions and will also be discussed.

Figure 1: Different kinds of battery, with different capacity, in different size and shape, for different purposes.

I. INTRODUCTION

Batteries have been used for energy storage for more than a century. With rapid growth of customer electronics which hunger for lighter and more portable design pushing hard on batteries technology development. It is no doubt that someone will make great money with some kind of battery with higher energy-weight density. On the other hand, charging these batteries can become huge challenge as customers always want to shorten the charging time with the ultimate goal: plug and play. Improvement of technology now allow batteries full-charged within an hour, with 15-30 minutes charger are now commercially available that claim they are safe and intelligent.

II. NI-CD BATTERY

Ni-Cd batteries become popular since 1980s. The sealed designs with single cell voltage of 1.2V which near the traditional 1.5V zinc-carbon battery make it become rechargeable replacement solutions.

They key characteristics as follows:

1) maintenance free other than recharging
2) lower internal resistance allow higher current discharge
3) able to achieve 500-1000 charge and discharge cycle with proper control
4) "Fast charging" possible within 1hr
5) wide range of operating temperature of -40^{o}C-50 ^{o}C, with high temperature type able to work in 70 ^{o}C

Chemical equations as follow, with left to right show discharge and right to left as charge.

Anode:

$$(2\beta - NiOOH) + 2H_2O + 2e \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} 2Ni(OH)_2 + 2OH^-$$

Cathode:

$$Cd + 2OH^- \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} Cd(OH)_2 + 2e$$

With overall:

$$(2\beta - NiOOH) + 2H_2O + Cd \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} 2Ni(OH)_2 + Cd(OH)_2$$

Above equation showed a sealed design is possible as no gas will be emitted during the charge and discharge process. Energy is stored and released in such oxidation and Reduction process.

III. Ni-MH Battery

Ni-MH batteries become popular since late 1990s. It have advantages over Ni-Cd by its higher capacity with no toxic cadmium.

Chemical equations as follow, with left to right show discharge and right to left as charge.

Anode:

$$NiOOH + H_2O + e \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} Ni(OH)_2 + OH^-$$

Cathode:

$$MH + OH^- \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} M + H_2O + e$$

With overall:

$$NiOOH + MH \underset{DISCHARGE}{\overset{CHARGE}{\Leftrightarrow}} Ni(OH)_2 + M$$

Additionally, some "interesting" characteristic provide some means of protection on over-charge or deep discharge (reversely charged):

While overcharge:

Anode:

$$4OH^- \rightarrow 2H_2O + O_2 + 4e$$

Cathode:

$$2H_2O + O_2 + 4e \rightarrow 4OH^-$$

While deep discharged (reversely charged):

Anode:

$$2H_2O + 2e \rightarrow H_2 + 4OH^-$$

Cathode:

$$H_2 + 2OH^- \rightarrow 2H_2O + 2e$$

IV. Circuits

Buck converter by current control employed as a constant current source, this enhance energy efficiency with compared with traditional linear regulators. Current measurement is averaged by R-C filter network.

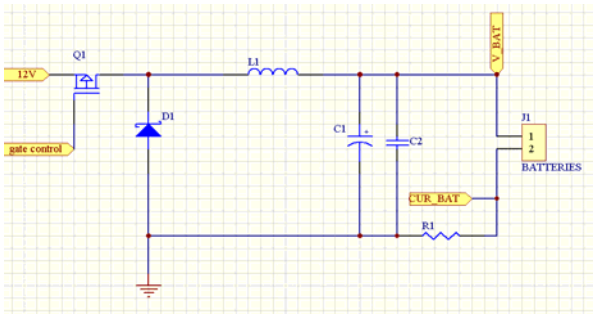

Figure 2: Constant current source by buck converter

Discharge circuit also been build as well by using a MOSFET as switch to drive a resistive load.

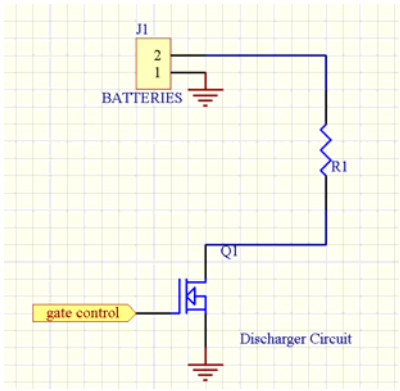

Figure 3: Discharge circuit

Sampling Circuit:

Data sampling made every second on both charge or discharge process.

V. DISCHARGE

Ni-Cd and Ni-MH cells have relative flat discharge profile. Discharge should be cut off while cell voltage drop around 0.9V per cell.

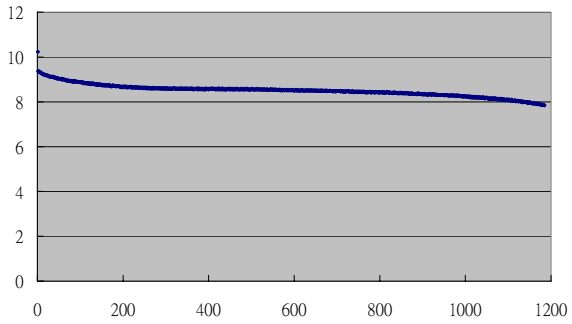

Figure 4: discharge voltage curve verse time in second of 8 1900mAH Ni-Cd cells with 2ohm resistor

Problems on Ni-Cd batteries:

Over discharging of serially connected batteries pack should be avoided as it may permanently damage the cells. As cells have different capacity, lower capacity cells will be reversely charged by other batteries. If no protection designed this can lead to reduction occurs in anode, which electrolysis water generating heat and release hydrogen gas (similar in cathode, with oxygen formed). To avoid aforementioned situation occur, small amount of $Cd(OH)_2$ added at anode as:

$$Cd(OH)_2 + 2e \rightarrow Cd + 2OH^-$$

That replaced the reform of hydrogen ions, and the cadmium formed also help to absorb the oxygen generated at cathode during such reverse charging progress. This help battery from explosion with slightly reversely charged in deep discharge stage of battery pack.

To avoid aforementioned troubles, it is wise to terminate discharge before every cell goes flat.

Methods of detection for the discharge cut-off:

If the load current is generally continuos, the following techniques can be used to terminate discharge:

1. detection of number of cells

   If the cells still contain certain amount of energy, a merely constant battery discharge voltage region can be expected. With is voltage divided by per cell voltage of 1.2V, number of cells can be detected. With getting the number of cells, discharge can be terminated by 0.9V time number of cells.

2. detection of falling slope

   If the cells nearly come flat, the discharge voltage will fall with a very deep slope. Thus detection of rate of change can also be a method of termination.

VI. CHARGING

The method of charging of Ni-Cd battery as follow:

1) Timer method

   With battery fully discharged, limit the charging current to C/10. For example, charge with 190mA for 1900mAh cell. Leave the battery for 15-20hr. Ni-Cd battery can withstand overcharge with this rate.

2) $-\Delta V$ method

   The cell voltage will drop about 10mV per cell after fully charged. Thus the detection of fulling voltage can also be used to terminate charge. Charge rate over 1C can also use this method to terminate charge. However, overcharge problem may exist as the slightly different if cells capacity in a single battery pack.

3) ΔT method

   Battery temperature will rise up quickly while fully charged. Thus the detection of voltage rise can also be a method of termination. For example, a rising rate of 1 degree Celsius per minute can be used to terminate charge. Addition protection can also apply to protect battery from charging in high temperature.

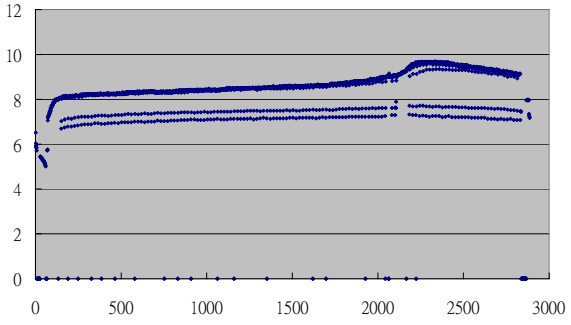

Figure 5: Charging profile of 7 1900mAh Ni-Cd batteries with 3A. Charging by scheme of 17second charge, 1 second discharge and 2 second recover method.

Pulse Charging

As the charging voltage does not actually represent the battery voltage, it is also include a sum of the potential different on the battery internal resistance by the charging current. As a result, issuing a short burst of discharge pulse may help getting the actual battery voltage. Commercial chargers have different pulse technology and some of them are patented.

An intelligent charge should employ aforementioned termination scheme to better protect the battery. A timer should be set to avoid charging twice the capacity of the battery. $-\Delta V$ method should be applied with the knowing the number of cells. For fail-safe, ΔT method should also be used as a backup protection measures

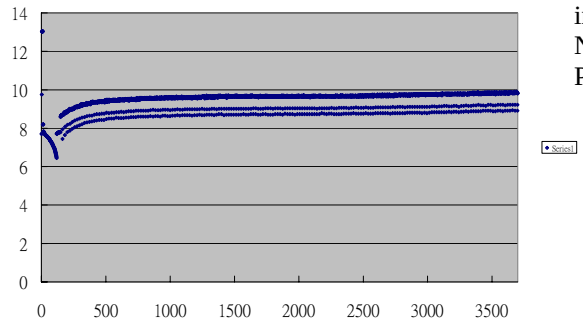

Figure 6: Charge of 6 3000mAh Ni-MH battery with 4A current shortly after the discharge

The methods of charging Ni-MH battery are similar with Ni-Cd with the follow different:

1) $0\Delta V$ method

The voltage drop of the Ni-MH cell during charge is small as 2-3mV per cell, it is safer to terminate the charge when the battery voltage no longer rise up. This can charge up to 85% to the battery capacity, and tickle charge current may apply in order to charge up the full capacity.

2) ΔT method

Ni-MH batteries generate more heat while charging, thus the ΔT method used in Ni-Cd may not suit. A relative temperature measurement may be used. Such as termination the charge whiles the temperature rise up 20 degree Celsius above the room temperature. Given that battery temperature do not higher than 50 degree Celsius.

VII. CONCLUSION

The battery technology updated rapidly due to the huge demand of needs of energy storage. By the improvements on the batteries, faster charging techniques on Ni-Cd and Ni-MH batteries have been discussed, and preclusions also suggested.

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