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Lithium Battery Charging Circuit

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Abstract: With the rapid development of science and technology, lithium batteries have gradually gained broad market prospects and development space due to their advantages of long life and light weight. Lithium batteries have been widely used in wearable portable low-power electronic products, so this paper studies the lithium battery charging circuit. This paper is divided into three parts for the research on lithium electronic charging circuit. The first part is related to the description and introduction of the lithium electronic charging and discharging characteristics and the factors affecting the charging of lithium batteries. The second part is the design of the charging circuit, and the third part is the circuit analysis. In the charging experiment of different rates of the auxiliary charging circuit of lithium battery, when the charging rate is 1, the voltage reaches 3.6V in the 10th minute.

1. Introduction

Lithium batteries are widely used in various fields, and their electrical characteristics and charging control methods have received extensive attention and research [1]. Lithium batteries are widely used due to their various advantages. The charging speed and safety of various charging methods are the most concerned indicators, and the actual charging capacity and battery cycle life of lithium batteries obtained are also used to measure the advantages and disadvantages of charging methods [2]. Combined with the target battery, the design and selection of the charging strategy, and the combination of various charging methods to achieve better charging control are very beneficial for various portable electronic products [3].

At present, many researchers have carried out in-depth research on the lithium battery charging circuit, and have achieved good results. For example, researchers such as Mohamad A introduced active anode materials for lithium batteries, preparation methods, and secondary lithium batteries using anode materials. The fluorine-containing coatings in the active materials can improve battery performance and reduce the moisture content in the active ingredients. The adsorption of external moisture can be prevented, eliminating concerns about side reactions caused by moisture [4].

Scholars such as Muthamizhan T applied the unscented Kalman filter to lithium batteries, avoiding the linearization of the nonlinear state equation through unscented transformation, improving the filtering accuracy, realizing the accurate estimation of the SOC of lithium batteries under nonlinear conditions and increasing the system's SOC. The simulation results show that the UKF method controls the estimation error of the SOC of the lithium battery within 1% in the whole process [5]. As lithium batteries are widely used in various fields, further in-depth research on lithium battery charging circuits is of great significance to social development.

Lithium batteries are widely used in various industries and fields because of their unique advantages, especially in the field of electronic products. Electronic products have high requirements for charging speed. Therefore, this paper studies the charging circuit of lithium batteries. The structure of this paper can be divided into three parts: the first is the introduction of the relevant theory of lithium battery charging, and the second is the design of the lithium battery circuit. In the circuit design part, the main circuit module, the mixed-mode circuit and the circuit acquisition module are designed., and finally the circuit analysis. In the circuit analysis part, the main and auxiliary charging circuits are mainly analyzed.

2. Related Theories

2.1. Lithium Battery Charge and Discharge Characteristics

The capacity of a single lithium-ion button battery is generally small, and the full charge voltage has various specifications, generally 4.2V, 3.6V, 3.3V, etc. [6]. The charging voltage requires an accuracy of about 1%. When the voltage of the lithium battery is low, it will be charged at a lower charging rate to realize the safety protection of the battery [7]. During the charging process, along with the rise of the battery temperature, the internal resistance of the lithium battery will also increase, which has an impact on the actual rechargeable capacity of the battery [8]. At the same time, high temperature rise can easily damage the battery, so it is necessary to try to avoid the occurrence of high temperature rise, that is, reasonable charging temperature control is required. It is also necessary to avoid inefficient charging caused by low battery temperature.

2.2. Influencing Factors

There are three main factors that affect the performance of lithium batteries: overcharge, overdischarge, and overcurrent.

(1) Overcharge. If the battery is overcharged and the battery continues to charge in a fully charged state, the structure of the positive electrode material of the battery will change, resulting in permanent damage. From the molecular level analysis, it can be intuitively understood that too much Li^+ is hardened into the carbon layer structure of the negative electrode, so that Li^+ cannot be released. From a chemical perspective, if the battery has been in an overcharged state, heat will continue to be generated inside the battery, resulting in an increase in internal pressure, causing the battery to swell, and in severe cases, spontaneous combustion or explosion. The number of charging times of lithium batteries is inversely proportional to the battery voltage. The higher the overcharge voltage, the less the number of charging times [9].

(2) Overdischarge. Over-discharge is similar to over-charge. If the battery is always in over-discharge state, excessive current will cause internal heating of the battery, and at the same time, the reversibility of the positive and negative electrodes of the battery will be damaged. This phenomenon is an irreversible chemical reaction. If the battery is over-discharged for a long time, the battery will be scrapped.

(3) Overcurrent. Whether it is charging overcurrent or discharging overcurrent, excessive current will cause permanent damage to the battery. The higher the current, the higher the heat, and the easier it is for the battery to burn or even explode. In summary, during the use of lithium batteries, we must pay attention to the occurrence of overcharge, overdischarge, overcurrent, and overtemperature. In order to be suitable for wearable portable electronic products, the choice of the charging method for lithium batteries is particularly important [10].

2.3. System Architecture Design

The charge and discharge protection module mainly includes protection functions such as overcharge, overdischarge, overcurrent and overtemperature. The specific functions of the module are as follows:

(1) Overcurrent detection module (OC): used to detect whether the circuit has discharge overcurrent when the battery is connected to the load.

(2) Temperature detection module (TS): used to detect whether over-temperature protection occurs during linear charging.

(3) Internal clock timer (OSC): The internal clock is generated by charging and discharging the internal integrated capacitor, so as to time the protection functions such as overcharge, overdischarge, and discharge overcurrent.

(4) Drive module (DRV): used to generate the drive signal of the charging tube CO and the discharging tube DO, and further drive the external charging and discharging power tubes.

(5) Load detection module (VM): It is used to detect whether the load is removed. When the battery is over-discharged or over-discharged, it is one of the conditions for releasing a function.

3. Circuit Design

3.1. Hybrid Mode Charging Circuit Design

The whole charging process of the lithium battery is: after the front-stage step-down circuit normally establishes the output voltage VC, the signal is enabled, the latter-stage charging circuit enters the working state, and the relationship between the lithium battery voltage and multiple reference potentials is judged, and the charging mode is switched. control until the battery is fully charged.

The charging process is: when there is a voltage input at the beginning, the step-down circuit starts, the startup is completed and the normal output voltage VC is established, and then the judgment of the charging stage is started. First, judge whether the voltage of the lithium battery is lower than VJ. Trickle charge control with smaller current, otherwise judge whether it is higher than the full charge voltage VL, and stop charging when fully charged. When the lithium battery voltage VL is between VJ and VH, the lithium battery voltage VL is compared with VM1 and VM2 in turn, that is, the judgment and selection of the lithium battery in constant current charging, fast pulse charging and slow pulse charging are *completed*. Until the lithium battery voltage reaches the full charge level VH, stop charging. Combined with the charging logic flow, the charging mode that should be used is determined according to the range of the lithium battery voltage VL, and the corresponding relationship is shown in Table 1.

Table 1. Lithium battery charging mode selection table

Lithium battery	VL<VJ	VJ<VL<VM1	VM1<VL<VM2	VM2<VL<VH	VL>VH
Charging mode	trickle	Constant current	Fast pulse	Slow pulse	End of charging

3.2. Control Circuit Design of Main Charging Module

The switch of the charging MOS tube is determined by the high and low levels of the CHARGE signal given by the control circuit single-chip microcomputer, and the external resistance and the down resistance are added to the level input terminal to increase the stability of the signal. When the single-chip microcomputer outputs a high level, when CHARGE=1, the base of Q20 is turned on at a high level. At this time, the base of Q21 is at a high level, and the base of Q21 is turned on, and the battery is charged; when CHARGE=0, Q20 and Q21 are turned off. The MOS tube is turned off and charging stops.

The PWM output of the switch tube is adjusted according to the state of the series battery pack, and the PWM output is adjusted according to the total voltage, so that the battery can be fully charged, and the battery can be prevented from overcharging. The PWM output program flow chart is shown in Figure 1.

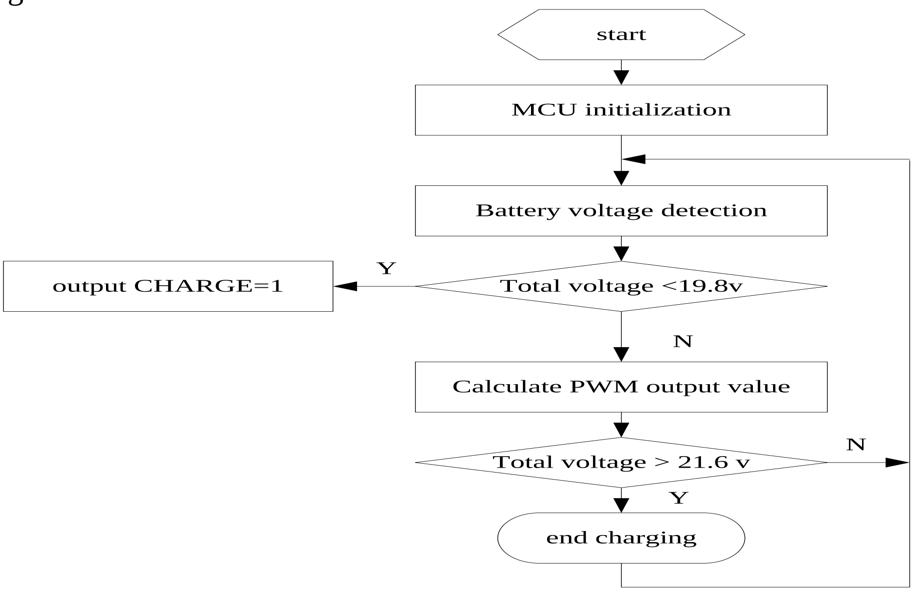

Figure 1. PWM output program flow chart

When the voltage of the detected battery pack is less than 19.8V, the conduction rate of the MOS tube is 100%. If the detected voltage is between 19.8V and 21.6V, PWM control charging is adopted, and the conduction ratio of the MOS tube varies with the voltage of the battery pack. With the increase of, the duty cycle is continuously reduced until the battery terminal voltage rises to 21.6V, the PWM output is 0, and the charging is stopped.

3.3. Design of Charging Current Acquisition Circuit

The acquisition mode of charging current is the same as that of voltage acquisition. Two parallel resistors are added at the end of the 6-series series battery pack, and the voltage on the resistor is collected to obtain the current value. High-power precision carbon film resistors, which are different in materials from ordinary resistors, have larger packages, can withstand power of 1-3W, and have high precision. They are often used as sampling resistors in circuits. The reason for using two in parallel is to increase the current capacity of the circuit. When a current flows in the circuit, according to Ohm's law, a voltage drop will be generated, and the voltage follower will also transmit the generated voltage value to the single-chip microcomputer. The obtained charging current value flowing through the circuit, the current acquisition circuit is shown in Figure 2.

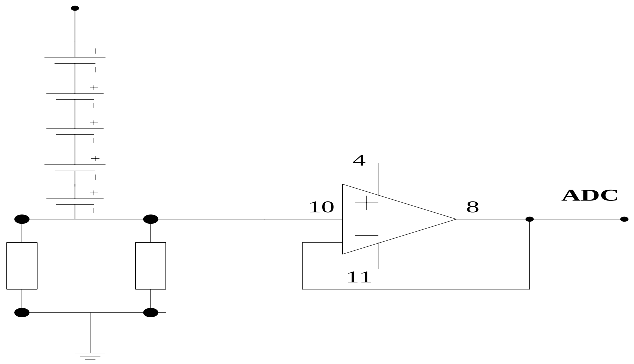

Figure 2. Current acquisition circuit diagram

4. Circuit Analysis

4.1. Auxiliary Charging Module Circuit

The maximum charging current of the constant current in the auxiliary charging circuit module is determined by the feedback resistor R1, Ich is the maximum charging current, and the calculation formula of R1 is:

$$R_1 = \frac{200mV}{I_{ch}} \tag{1}$$

The voltage value of the battery -side constant voltage output is determined by the voltage network composed of resistance R3 and R4. The constant voltage calculation formula is:

$$V_L = 2.146*(1+R3/R4)+I_B*R3 \tag{2}$$

The formula for calculating the power loss of the MOS tube is as follows:

$$P = \frac{V_L}{V_{CC}} \times R_d \times I_{ch}^2 \tag{3}$$

Among them, P is the power loss of the MOS tube, VL is the set saturation cut-off voltage,Vcc is the minimum input voltage, Rd is the on-resistance of the P-channel field effect transistor at an ambient temperature of 25 ℃, and Ich is the set maximum Constant current charging current, so it can be seen that the MOS tube with less conduction loss should be selected.

4.2. Main Charging Circuit Charging Analysis

The main charging method for the series battery pack is constant current mode, the current is relatively large in the early stage, the total voltage of the battery pack is detected in real time, the duty cycle of different outputs is controlled in different voltage ranges, and the size of the charging current is adjusted to ensure lithium batteries. Different PWMs are set according to different voltage intervals to adjust the size of the charging current. The main charging circuit can accurately collect the battery voltage and output different duty ratios according to the preset voltage interval to control the size of the charging current. When the total voltage of the battery pack gradually increases, reducing the charging current can weaken the electrochemical reaction inside the battery, making the battery charging process more sufficient, and the control method conforms to the characteristics of lithium battery charging.

4.3. Auxiliary Charging Circuit Charging Analysis

The auxiliary charging circuit module starts to start the auxiliary charging circuit when it is monitored that the cell voltage is lower than the average voltage of the cell. The charging cut-off voltage is 3.6V, and the maximum charging current is 5A. The actual output current is based on the data collected by the microcontroller. The single battery voltage is intelligently adjusted, and the collected data is drawn into a curve as shown in Figure 3.

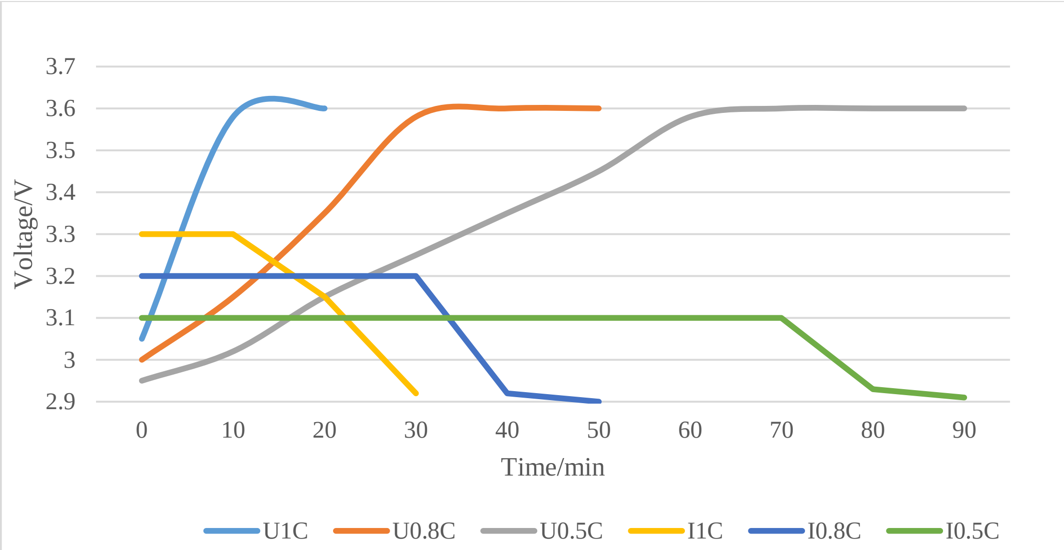

Figure 3. Different rate charging curves

We have done charging experiments with different rates on the auxiliary charging circuit of lithium batteries, and plotted them into curves. It can be seen from the curves that the voltage platform of lithium batteries is between 3.2V and 3.4V, which is also the part with the largest battery capacity, including 85%-95%; the charging method of the auxiliary charging circuit is to charge the lithium battery with constant current first, until the battery voltage reaches the charging limit voltage of the battery, and then switch to constant voltage charging, until the current is reduced to zero, the charging is over; 3 different It can be seen from the circuit experiment that the auxiliary charging circuit can accurately control the charging cut-off voltage to 3.6V, which can safely be used as an auxiliary charging circuit for lithium batteries.

5. Conclusion

With the development of science and technology, people have higher requirements for the charging speed and performance of lithium batteries, so this paper designs and analyzes the charging circuit of lithium batteries. The main charging circuit and the auxiliary charging circuit module are very important modules in the lithium battery charging circuit. When analyzing the main charging circuit, it is found that the main charging circuit design meets the characteristics of the lithium battery and can accurately collect the battery circuit. In the analysis of the charging circuit, it is found that the auxiliary charging circuit can accurately control the charging cut-off voltage and can safely be used as an auxiliary charging circuit for lithium batteries through charging experiments with different rates. There are still many deficiencies in the design of the lithium battery charging circuit in this paper, which need to be improved, but the research on the lithium battery charging circuit is a direction worthy of in-depth discussion.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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