Research on Lithium Battery Management System for Electric Trackless Rubber Tyred Vehicle in Coal Mine

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Abstract. This paper designs a kind of lithium battery management system for coal mine electric trackless rubber tyred vehicle based on chip STM32F105VCT7 as CPU. It focuses on the battery grouping mode, battery balancing strategy and the hardware and software design of the battery management system. The lithium battery management system uses LTC6811-1 chip to collect battery information, designs passive balance to maintain the battery, and uses RT thread real-time operating system to schedule the tasks in the lithium battery management system. Through the actual test application, the lithium battery management system designed in this paper can effectively monitor the battery voltage, temperature, current and other information, and complete the battery balance, charge and discharge control.

1. Introduction
With the popularization and development of civil electric vehicles, electric trackless rubber tyred vehicles are gradually promoted and applied in coal mines. Lithium battery has become the first choice of energy sources for electric vehicles because of its great advantages in volume, weight, energy density and so on. The lithium battery management system can accurately estimate the state of charge of the battery pack, dynamically monitor the working state of the power battery pack, realize the balance between individual batteries, ensure the power safety of the lithium battery, improve the endurance capacity of the lithium battery, and extend the service life of the lithium battery.

At present, the lithium battery management system in coal mine is mostly used in the back-up power supply of chamber, refuge chamber and communication monitoring equipment. The number of battery strings monitored by this lithium battery management system is mostly 8 or 16, which is far less than the number of hundreds of lithium batteries on electric trackless rubber tyred vehicle, and the monitoring objects are mostly small and medium-sized batteries. The lithium battery management system applied to civil electric vehicles, in circuit design, is not suitable for coal mine environment; in performance parameters, it does not meet the requirements of relevant industry standards and safety standards issued by the national mining product safety mark center. Therefore, it is necessary to develop a lithium battery management system for electric trackless rubber tyred vehicle in coal mine.

Aiming at the special application environment of coal mine, according to the relevant standards and technical requirements, this paper designs a lithium battery management system for electric trackless
rubber tyred vehicle in coal mine, focusing on the battery grouping mode, battery balancing strategy and the hardware and software design of lithium battery management system.

2. Composition of lithium ion battery management system

![Image of lithium ion battery management system diagram]

The management system of explosion-proof electric vehicle lithium-ion battery is mainly composed of seven parts: main control unit, single lithium battery information acquisition unit, battery pack current acquisition, charging pile and vehicle controller communication circuit, insulation resistance acquisition module, input and output relay control, liquid crystal display, etc. the system composition block diagram is shown in figure 1.

The overall workflow of the system is coordinated by the main control unit. The single lithium battery information acquisition unit collects the battery voltage and temperature data and transmits them to the main controller through SPI bus. The main controller makes corresponding instructions and alarm actions according to these data, such as battery over-voltage alarm, under-voltage alarm, high temperature alarm, low temperature alarm, etc. The discharging or charging current of the battery pack is converted into voltage signal by the Hall current sensor in proportion and sent to the main controller for collection. Combined with the voltage and temperature data of the battery, the SOC is estimated, and the battery equalization, the start and stop of the charging pile, and the on-off of the input and output relays are controlled. The main control unit should display the collected single battery data, battery voltage, current and alarm information, insulation resistance and other information on the LCD screen, and send them to the vehicle controller through CAN bus.

3. Battery group mode

Typical battery grouping modes include series connection and parallel connection and parallel connection and series connection, as shown in Figure 2. In connection reliability, the group mode of series connection and parallel connection is better than that of parallel connection and series connection. However, according to relevant regulations, for mine flameproof equipment, it is forbidden to place lithium-ion batteries in the flameproof chamber in the form of parallel connection,
because it can not guarantee that the internal resistance of parallel batteries is completely consistent. If the internal resistance is inconsistent, the current distribution of parallel batteries will be uneven during charging and discharging, and the uneven current distribution will aggravate the inconsistency of internal resistance, it is an unsafe factor that makes it possible for parallel batteries to charge each other, so in this design, all batteries can only be connected in series.

4. Battery balancing strategy
In the manufacturing process of lithium batteries, due to the manufacturing process and materials, there are inconsistencies in the voltage, capacity and internal resistance of batteries of the same model manufactured in the same batch, resulting in that the performance of group batteries in terms of utilization, service life and safety is far less than that of single batteries [4-5]. But after using the battery management system with balanced management function, it can greatly improve the overall performance of the battery pack, effectively extend the service life of the battery pack, and greatly reduce the use and maintenance costs of the vehicle.

The main battery equalization strategies are divided into active equalization and passive equalization. Active equalization is to balance the capacity or voltage differences between battery cells in the process of charging, discharging or placing, so as to eliminate various inconsistencies inside the battery. In this process, energy transfer is involved. There are generally two methods of energy transfer. One is to balance the energy of high-energy single battery to low-energy battery, the other is to transfer the energy of high-voltage (capacity) single battery to a standby battery, and then from the standby battery to other low-voltage (capacity) batteries.

The working principle of passive equalization is to find the difference between single batteries in series through the collection of voltage. Based on the "upper limit threshold voltage" of the set charging voltage, any single battery should reach the "upper limit threshold voltage" first during charging and detect the difference with the adjacent batteries, that is, the battery with the highest single voltage in the battery pack should be charged by In parallel with the energy consumption resistor of the single cell, discharge is carried out, and so on, until the single cell with the lowest voltage reaches the "upper limit threshold voltage" is a balance cycle.

Compared with passive equalization, active equalization has the advantages of large balancing current, fast balancing speed, high efficiency and small energy loss. However, due to the complexity of active equalization technology, high cost and high failure rate after complex structure, passive equalization strategy is adopted in this design.

5. Hardware design of lithium battery management system

5.1. Main control unit
The lithium battery management system has many communication interfaces, and it is used for mine explosion-proof vehicles. The working environment is relatively bad, and the requirements for the
main controller in terms of working temperature and number of interfaces are the same. Through comprehensive comparison, in this design, STM32F105VCT7 is used as the main control micro controller, which is an interconnected micro controller produced by Italian semiconductor. The working frequency can reach 72mhz, with built-in arm Cortex™-M3 core, with 2 can bus interfaces supporting CAN2.0B protocol, 1 full speed USB OTG interface, 3 SPI bus interfaces, its output rate can reach up to 18mhz, and 5 USART interfaces, and 2 12 bit ADC converters, which can ensure high precision sampling of analog voltage. STM32F105VCT7 can work normally in the temperature range of -40°C ~ 105°C, which improves the reliability and stability of lithium battery management system to a certain extent.

5.2. Hardware design of battery information collection

The lithium battery management system not only detects the total voltage, total current and battery capacity of the battery pack, but also detects the voltage and temperature of all the single cells. According to the measurement error requirements of relevant requirements parameters, the measurement information can also be displayed and fault alarm function can be achieved according to the standard shown in Table 1.

| Parameters       | Cell voltage | Cell temperature | Battery pack current | Battery pack voltage | Battery capacity |
|------------------|--------------|------------------|----------------------|---------------------|-----------------|
| error            | ≤0.5%        | ±2℃              | ≤0.5%                | ≤0.5%               | ≤5%             |

According to the above requirements, LTC6811-1 chip produced by analog devices is used to monitor the voltage, temperature and other data of single lithium battery. A piece of LTC6811-1 can measure up to 12 batteries. The connection form of 12 batteries must be in series. The total measurement error of battery voltage is not more than 1.2MV, and the voltage measurement of 12 batteries can be completed within 290us. In order to achieve high noise suppression, a lower data acquisition rate can be used.

Multi chip LTC6811-1 point-to-point link is realized through the connection structure of transformer isolation daisy chain. Different chip addresses are set through corresponding address pins to communicate between CPU and LTC6811-1. In this way, hundreds of strings of lithium-ion batteries can be monitored at the same time. Therefore, 8 pieces of LTC6811-1 can be used to realize the data acquisition of 96 series lithium batteries.

The connection diagram is shown in Figure 3.
Since one LTC6811-1 can collect 12 series of lithium batteries, in this design, 12 series of lithium batteries are used as a collection group, and eight LTC6811-1 can complete the voltage monitoring of 96 series of lithium batteries.

LTC6811-1 provides five GPIO pins, which can be configured as analog input or digital input and output to collect battery temperature data. In order to collect the temperature information of 12 series batteries, the 5-channel analog input can not meet the requirements obviously. The analog channel can be expanded by adding multi-channel analog switch. The analog switch uses CD74HC4067 chip, which is a 16 channel analog selector. Its four address pins can be connected to gpio1- gpio4 pins of LTC6811-1. By changing the input state of the address pins, 12 channels of analog information can be measured.

A 10k precise resistor is connected in series with a NTC (Negative temperature coefficient thermistor), one end of which is grounded, and the other end is connected to the vref1 pin of LTC6811-1 to form a typical voltage divider circuit. The NTC resistance can be known by measurement and calculation, and then the temperature data of the battery can be obtained by looking up the table. The voltage of each battery string can be measured by fixing such a circuit on the polar ear of each battery string Temperature.

The circuit connection diagram is shown in Figure 4.

The S1 pin to S12 pin of LTC6811-1 can be used for passive equalization of single cell. If one of the batteries in a series is overcharged, the s pin can drive an external p-channel MOSFET switch device to control the appropriate discharge resistance to discharge the single battery, so as to achieve the purpose of passive equalization, as shown in Figure 5. Among them, RD is the discharge resistance, which can achieve a maximum of 120mA balanced discharge current.

![Figure 4. Multiplex analog switch expands battery temperature acquisition channel.](image)

![Figure 5. Passive equalization circuit.](image)
5.3. Battery current acquisition circuit

Due to the large output current of lithium battery pack, the current may reach more than 100A. Within the allowable error range, the closed-loop Hall current sensor with upper acquisition limit of 200A is adopted, and its maximum error is 0.3%, which is less than the regulation of 0.5% in Table 1. Hall current sensor reduces the battery pack current according to the ratio of 2000:1. In order to facilitate the main controller to sample and reduce the sampling error, the reduced current value is transformed into the voltage value through the high-precision sampling resistance, and then amplified to a certain multiple by the operational amplifier for the ad of the main controller to collect. Because it is necessary to collect both the discharge current and the charging current of the lithium battery pack, the operational amplifier should not only indicate the amplitude of the detected current, but also indicate the direction of the detected current, that is, whether the current is the discharge current or the charging current.

The LT1999-10 produced by analog devices can meet the above requirements. It can work in the whole temperature range of -40 ℃ ~ 125 ℃. The gain error is less than 0.5%, and the input offset voltage is less than 1.5MV. The current sampling circuit of battery pack is shown in Figure 6.

![Figure 6. Battery current sampling circuit.](image)

5.4. Battery current acquisition circuit

In practical use, the lithium-ion battery management system needs to store the battery pack voltage, current, battery pack SOC, charging voltage, charging current and other important information, so that it can be loaded directly at the next start, and also needs to store the system operation log. Therefore, an external flash chip is needed to store these data, the flash chip model is GD25Q32, which is produced by Giga Device company, the storage capacity is 32Mbit. It is connected with the main control MCU STM32F105VCT7 through SPI bus. The connection circuit is shown in Figure 7.

![Figure 7. SPI flash memory circuit.](image)
6. Software design of lithium battery management system

In this lithium battery management system, in addition to collecting battery voltage, temperature, current, battery balance and other tasks with high real-time requirements, there are also two-way communication, liquid crystal display, input and output control and other tasks. In view of the complexity of the system, in the lithium battery management system, the real-time operating system is needed to schedule these tasks. In this design, RT-thread real-time operating system.

6.1. RT-thread real time operating system

RT thread is an open source embedded real-time operating system (following the gplv2 license agreement) developed by China open source community. It not only contains the kernel of real-time operating system, but also has some special peripheral components, such as SPI bus standard interface, optimized file system, USB protocol stack, fish shell, etc, both kernel and peripheral components can be configured and tailored through configuration files.

The kernel of RT thread real-time operation is written in ANSI C language, which has strong portability and is suitable for processors and compilers of various architectures. Users can configure and tailor them as required, and the real-time operating system has high reliability and stability. It has a set of interactive tools called fish shell. It is similar to the operation interface on the command line of Linux platform. It can realize system debugging, check the running status of each task or thread, such as the remaining stack and task status, and print out some parameter information in real time. It provides great convenience for developers. These advantages make it stand out in many real-time operating systems and widely used. It is also recognized by many colleges, enterprises and developers in China. At present, RT thread has been supported to run on STM32F105VCT7 platform.

To sum up, it can be seen that the functions of RT thread real-time operating system can fully schedule and run the tasks of collecting battery voltage, temperature, current and other information, battery balancing, can communication, LCD display and so on.

6.2. Main thread design

In this system, a total of 6 threads are designed to meet the functions of lithium battery management system, including system power on initialization thread, main controller and LTC6811-1 communication thread, charging and battery equalization thread, main controller and vehicle controller can communication thread, insulation resistance detection module can communication thread and LCD display thread. The following mainly introduces the workflow of initialization thread, communication thread between main controller and LTC6811-1, charging and battery balancing thread.

① The main function of the system power on initialization thread is to initialize the necessary hardware peripherals such as serial port, system clock, SPI bus interface, can bus controller, system kernel, FatFs file system, fish shell and other system components when the system is just powered on, and carry out system self check, such as whether the insulation resistance exceeds the limit, whether the communication with LTC6811-1 is normal, etc. the flow chart is shown in Figure 8.
The main function of communication thread between the main controller and LTC6811-2 is to obtain the voltage and temperature data of each cell of the corresponding battery collection group. Once every 100ms, it communicates with one LTC6811-1. 800ms completes the collection of all battery voltage and temperature data. After obtaining these data, it is necessary to judge whether there is battery overvoltage, undervoltage, high temperature and low temperature, whether there is overvoltage protection failure and undervoltage Protection failure and voltage, temperature acquisition line open circuit fault, and to make the corresponding alarm indication. The flow chart is shown in Figure 9.
The main function of the charging and battery equalization thread is to communicate with the charging pile, set the charging voltage, current, charging time, etc., control the start and stop of the charging pile, and control the battery equalization according to the voltage and temperature data of the battery until the battery reaches the upper threshold voltage and the difference between the maximum voltage and the minimum voltage is less than the set value, and complete the SOC estimation in the charging process. The flow chart is shown in Figure 10.
7. Conclusion
On the premise of meeting the relevant standards and technologies, the lithium-ion battery management system of mine explosion-proof vehicle is designed. The actual test shows that the lithium-ion battery management system can effectively improve the consistency of the battery, extend the battery life and battery life, and has the advantages of accurate data sampling, fast sampling speed, accurate SOC calculation and fast battery balancing speed.

In addition, for the lithium-ion battery management system is installed in the explosion-proof chamber, which is inconvenient to maintain, the can bootloader boot program is also designed. The lithium-ion battery management system can be upgraded and maintained through the CAN bus, which greatly reduces the workload of on-site maintenance.

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