Problems and Research on Underground Charging Safety of Power Battery for Coal Mine Robot

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Abstract. In order to further study the underground charging safety of power batteries for coal mine robots, this paper proposes to study the energy transfer mechanism of power batteries in confined space and the difference of energy distribution in flammable and explosive special gas environment. On the basis of theoretical research, the safety performance of the temporary flameproof chamber formed during the underground charging process of the robot is verified by constructing the detection experimental platform of the explosion-proof automatic charging device of the robot, so as to solve the problem of potential safety hazard assessment caused by exposed contacts or unreliable docking during the underground charging process of the coal mine robot, and provide theoretical and experimental basis for the underground charging safety.

1. Introduction
Huang Yuye, director of the State Administration of Coal Mine Safety, pointed out in the "2019 World Robotics Congress Special Forum on Coal Mine Robots" that "R&D and application of coal mine robots is an inevitable requirement of adhering to the people-centered development thought, an effective measure to achieve the intrinsic safety of coal mines, and the only way to achieve high-quality development of coal" [1]. After the coal mine disaster accident, the miners trapped underground need emergency rescue. Most of the traditional emergency rescue methods adopt rescuers to search and rescue directly. However, after mine fire and gas explosion accidents, the temperature in the disaster area is often high, the dust concentration is large, the roadway is full of explosive gas and high-concentration toxic and harmful gases such as CO, and the mine environment is unstable, and secondary explosions or multiple explosions may occur at any time [2]. The power battery used by coal mine robots is in a relatively limited space layout, which makes the fire and explosion caused by thermal runaway of lithium ion batteries more harmful. Especially, when the coal mine robots need to be charged, the safety problem has greatly restricted the use of coal mine robots, and has become the most critical neck sticking problem in the popularization and application of coal mine robots. Therefore, this paper studies and demonstrates the selection basis of underground charging operation site and the requirements of environmental parameters, and puts forward the online autonomous and fast charging method and charging safety guarantee technical scheme of robot underground, which provides a reliable basis for the revision of coal mine safety regulations and has a good promotion effect for the use of coal mine robots underground. Coal mine environment is complex and special, and battery life will be greatly reduced due to environmental particularity. Therefore, by exploring the distribution law of key safety risk points in the battery life
cycle, analyzing the impact of battery management system on the safe use of the battery, and forming a safety performance evaluation and detection method in the battery charging process, it plays an important role in the safe use of the power battery.

2. Research status at home and abroad

Foreign countries began to study coal mine robots in the late 1980s and early 1990s. Australia and the United States have successively developed a variety of coal mine rescue robots, which have been used in coal mine rescue work [3]. However, the research on coal mine robots started late in China, and China University of Mining and Technology started research in 2004, and successfully developed the first prototype of coal mine rescue robot in China. However, the application effect is not ideal due to the huge size, heavy weight, short circuit when encountering water and other reasons. On the contrary, in fire and earthquake rescue, there are many successful cases of fire-fighting and earthquake rescue robots. The main reason for these differences is that the underground coal mine has a special post disaster environment, and there are flammable and explosive gases such as gas. Once the content of these gases exceeds the limit, explosion accidents are likely to occur and greater losses may be caused [4].

According to Article 485 of Coal Mine Safety Regulations (2016), mobile devices such as locomotives must be charged in special charging chambers or on the ground, which greatly reduces the widespread popularization of robots/patrol instruments in coal mines. Many domestic experts put forward that the safety of coal mine robots mainly includes power safety, battery safety, battery explosion-proof safety, battery charging safety, etc. [5]. These problems restrict the acquisition of safety sign permit and explosion proof certificate of coal mine robot, and are the key technical problems and difficult problems that must be solved when coal mine robot is used in the well. At present, some scholars have proposed to optimize the charging chamber and charging mode in the research and application of underground battery charging technology, so as to realize the intelligentization of battery management [6]. In the past two years, citic heavy industries Kaicheng Intelligent Equipment Co., Ltd. has designed charging protection switch and communication docking to control charging safety when charging robots underground, which has achieved a preliminary breakthrough in underground autonomous charging safety.

3. Research significance and existing problems

3.1. The existing difficulties

At present, it is urgent to solve the explosion-proof safety of temporary explosion-proof chamber composed of robot charging process in coal mine. Without theoretical analysis and experimental system as support, the distribution law of lithium-ion battery explosion and methane and other explosive gas explosion in traditional flame-proof chamber can not be specified, and the dynamic and thermodynamic coupling mechanism of battery explosion shock wave and combustion heat on traditional flame-proof enclosure is not clear, which is not conducive to the safety analysis of mine power battery flameproof chamber. According to the energy and power demand of long-term continuous operation of coal mine robots, the online autonomous and fast charging method and charging safety guarantee technical scheme of robots underground should be found, and the selection basis of underground charging operation site and the requirements of environmental parameters should be studied and demonstrated. Based on the existing underground automatic charging device of coal mine robot, an experimental platform for detecting explosion-proof automatic charging device of robot is constructed, and the action reliability of charging plug, socket and mechanical locking mechanism of automatic charging system is studied, and the locking pressure of charging device and processing and installation process parameters of joint surface are proved. Therefore, the explosion-proof performance of the temporary explosion-proof cavity in the charging process is guaranteed, and the problem of potential safety hazard assessment caused by exposed contacts or unreliable docking in the underground charging process of the coal mine robot is solved.
3.2. Scientific problems to be solved

At present, the problem of underground charging safety is the main limitation for the popularization of coal mine robots in underground. By means of theoretical analysis, numerical simulation and experimental research, the dynamic and thermodynamic coupling mechanism of battery explosion shock wave and combustion heat on traditional flameproof enclosure is obtained, which provides basic parameters for the safety analysis of flameproof chamber of mine power battery. With the support of the detection experimental platform of the robot underground explosion-proof automatic charging device, the reliability of each mechanism and the explosion-proof performance of the temporary flame-proof chamber during charging are fully verified, so as to realize the evaluation of potential safety hazards during underground charging, analyze and study the environmental characteristics of different areas underground, and determine the reliable charging pile position, which provides reference for the safety of robot underground charging.

3.3. Application prospect

Combined with the characteristics of underground environment, through the study of the distribution law of key safety risk points in the battery life cycle and the mechanism of energy explosion transmission, the problem of potential safety hazard assessment caused by exposed contacts or unreliable docking during underground charging of coal mine robots can be solved, which provides theoretical and experimental basis for underground charging safety. Therefore, it provides theoretical and data support for the safety of power supply and underground charging of coal mine robots, and promotes the use of coal mine robots in underground.

4. Research on detection and inspection technology of underground charging system of coal mine robot

The charging safety of coal mine robot is one of the key problems that restrict the robot from going down. The underground charging scheme has always lacked safety verification. Taking the coal mine underground inspection robot jointly developed by citic heavy industries Tangshan Kaicheng Company as an example, a charging device is installed at one end of the inspection robot body. When charging is needed, the robot will automatically dock with the charging plug installed on the track for charging, but the explosion-proof performance of the temporary explosion-proof cavity formed during charging needs further research and demonstration.

4.1. Analysis of explosion shock characteristics of battery in flameproof chamber

Power batteries for coal mine robots generally have large capacity, and need to be built in a relatively narrow and closed explosion-proof space when used in underground dangerous gas environment. The fire and explosion characteristics of batteries are a gradual dynamic process. However, due to the limitation of the flame-proof chamber space, it is easy to cause local heat accumulation and explosion, resulting in great destructive power and secondary disasters.

Figure 1. Schematic diagram of energy transfer in the explosion process of power battery.
According to the power design requirements of commonly used coal mine inspection robots, lithium batteries with different capacities and energies are selected and placed in the battery explosion characteristic test system to carry out explosion experiments under extreme working conditions. According to the data obtained from the pressure and temperature sensing system in the test system, the equivalent impact pressure in the explosion process of lithium battery is calculated, and the spatial distribution law of temperature field and flame parameters in the deflagration process is studied, so as to analyze the explosion impact energy in the charging process of mine batteries with different specifications and capacities. At the same time, considering the gradual characteristics of lithium battery deflagration, the explosion dynamics characteristics in the dynamic process of battery deflagration are studied, and the difference of energy distribution in time axis between lithium-ion battery explosion and explosive gas explosion such as methane in traditional flameproof chamber is clarified. Finally, the pressure and temperature field in the explosion-proof chamber of the battery are comprehensively considered, and their destructive power to the explosion-proof shell is evaluated, which provides basic parameters for the safety analysis of the explosion-proof chamber of the mine power battery.

Figure 2. Experimental research platform for battery explosion characteristics.

4.2. Study on strength checking and testing of temporary flameproof chamber
There is no battery in the temporary explosion-proof cavity formed by the online charging device of coal mine robot, so the strength design of explosion-proof cavity can refer to the design criteria of conventional explosion-proof electrical equipment. The key to the problem is how to ensure that the explosion-proof joint surface does not break after the flameproof chamber is locked before it is closed and ready to be charged. By smearing slime water on the explosion-proof joint surface of the temporary explosion-proof chamber in the strong coal dust environment, the pollution working conditions under the severe working conditions in the underground are simulated, and different joint surface closing mechanism pressures are applied in the laboratory environment. Test the penetration effect of the joint surface into the flame inside the temporary flame-proof chamber, and obtain the surface cleanliness requirements when the explosion-proof joint surface is closed underground, thus providing the basis for the selection of underground charging operation site and the requirements of environmental parameters such as dust. At the same time, the locking pressure of the charging device and the processing and installation process parameters of the joint surface are obtained to ensure the explosion-proof performance of the temporary explosion-proof chamber during charging.
4.3. Research on reliability check and test of temporary flameproof chamber
The experimental platform for detecting the explosion-proof automatic charging device of robot is constructed, and the action reliability of the charging plug, socket and mechanical locking mechanism of the automatic charging system is studied. Through fatigue test in laboratory environment, the limit service life of online automatic charging device is studied, and the explosion-proof failure principle of temporary explosion-proof chamber under the condition of failure of key actuator parts is simulated experimentally, and the key components of automatic charging device are obtained. Reverse design optimization is carried out to find out the design requirements of explosion-proof devices, so as to fundamentally solve the problem of potential safety hazard assessment caused by exposed contacts or unreliable docking during underground charging of coal mine robots.

5. Conclusions
(1) Through the battery charging process explosion characteristic simulation experiment system, the explosion impact energy of mine batteries with different specifications and capacities during charging process is studied, and the dynamic and thermodynamic coupling mechanism of battery explosion shock wave and combustion heat on traditional flameproof enclosure is revealed, which has important scientific significance.

   (2) Based on the on-line automatic charging device of coal mine robot, the locking pressure of charging device and processing and installation parameters of joint surface are explored to ensure the explosion-proof performance of temporary explosion-proof chamber during charging process, which lays a scientific foundation for the research of underground charging safety technology of robot.

   (3) The energy transfer mechanism of power battery in confined space is studied in this paper. On the basis of previous research, we can further study the battery failure mode and possible secondary safety risks under extreme working conditions such as protection failure.

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