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Design of Automatic Safety Dismantling Device for Decommissioned Sodium-sulfur Batteries

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Abstract

Decommissioned sodium-sulfur batteries contain a large amount of sodium metal monomer, which is very easy to produce combustion and other chemical reactions in a high temperature (>90℃), humid, oxygen-rich environment, thus causing explosions and other accidents, and there is a great safety hazard. The traditional decommissioning sodium sulfur battery dismantling and recycling are carried out manually, and it is necessary to wait for the completion of the sodium tank part of the immersion, and then carry out the immersion of the ceramic tube, the dismantling efficiency is low, and the time cost is high. Therefore, in order to overcome the problems of low dismantling efficiency and high time cost of the existing technology, the team intends to develop an automatic and safe dismantling device for decommissioned sodium-sulfur batteries. The device can quickly and efficiently dismantle the retired sodium-sulfur battery automatically, so that its sodium canister part of the monomer sodium and ceramic tube part of the monomer sodium can be fully reacted with anhydrous ethanol, so as to remove the possible safety hazards of sodium-sulfur batteries, and to complete the dismantling work in a safe and efficient manner.

Keywords

Monomer Sodium; Decommissioned Sodium-sulfur Batteries; Dismantling Devices; Safety Hazards.

1. Introduction

With the improvement of China's scientific and technological level as well as the continuous development in the development and application of new energy sources, the power battery industry has witnessed rapid development. In the past five years, China's power battery demand and market has been located in the world's first place, is widely used in energy storage, new energy vehicles, industrial applications, electronic products, and sodium sulfur batteries are taking up a larger and larger share of the power battery market with the advantages of large storage capacity and low price. With the end of the service life of the first batch of sodium-sulfur batteries, the number of retired sodium-sulfur batteries is increasing year by year. In the face of the increasing number of decommissioned sodium-sulfur batteries, how to deal with these decommissioned sodium-sulfur batteries in a fast, effective and safe manner has become a pressing issue.

In recent years, there have been some experts and scholars at home and abroad who have carried out relevant researches in battery dismantling. Liu Shijing[1] et al. in the overview of waste lithium-ion battery pretreatment process based on further discussion in the use of pyrometallurgy, hydrometallurgy and direct regeneration and other deep treatment process related research progress.

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The current problems in the recycling process of waste lithium-ion batteries are analyzed, and in the future, in-depth research should be carried out on the recycling process and equipment, and systematic, intelligent, green and efficient recycling equipment should be developed. Song Huawei[2] et al. took the intelligent dismantling of retired power battery as the research object, and built a multi-robot cooperative dismantling workstation based on the joint simulation of SolidWorks and RobotStudio, which realized the flexible and cooperative dismantling of power battery packs by multi-robots and effectively improved the degree of automation of dismantling and dismantling efficiency, and had certain guiding significance for the research, development, and application of the intelligent dismantling equipment for power battery packs. It has certain guiding significance for the development and application of intelligent dismantling equipment for power battery packs. Pang Haifeng[3] and other lead-acid battery dismantling process and equipment to carry out a lot of research, design and practice, for the more mainstream lead-acid battery dismantling process and equipment, an overview of the advantages and disadvantages of different processes, the structural composition of different dismantling equipment, functional characteristics, and explain the advantages and disadvantages of their respective applications, in order to provide a reference for the optimization of designing more efficient, higher degree of automation of the dismantling of lead-acid battery equipment. The above research mainly focuses on the dismantling of lithium batteries, with less research on the dismantling of sodium-sulfur batteries, which can only provide some theoretical research programs.

In this paper, from the study of the structure of sodium sulfur batteries, we design a set of automatic and safe dismantling equipment for decommissioned sodium sulfur batteries, which can quickly and efficiently dismantle decommissioned sodium sulfur batteries automatically, and lay the foundation for the design of the fully automatic dismantling system in the future.

2. Overall Program Design

As shown in Figure 1, the retired sodium-sulfur battery contains a large amount of monomaterial sodium metal, which is highly susceptible to chemical reactions such as combustion in a high-temperature (>90℃), humid and oxygen-rich environment, thus causing explosions and other accidents, and there is a great potential safety hazard.

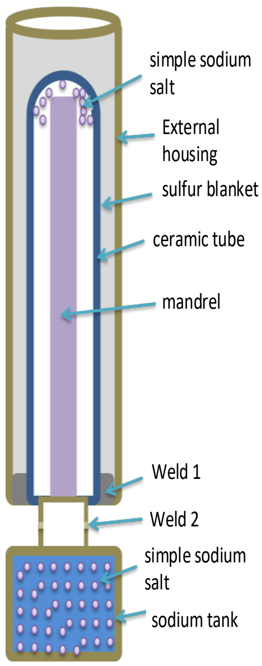

Figure 1. Structure of sodium-sulfur battery

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Therefore, in order to dismantle sodium-sulfur batteries quickly, safely and effectively, the following requirements must be fully considered.

(1) Since the sodium tank contains a large amount of sodium monomer (about 400 g), the dismantling temperature must be strictly controlled at <90℃. The sodium tank must be separated in an inert gas atmosphere and immersed in anhydrous ethanol together with the sodium tank and sodium monomer for 24 hours after a slow chemical reaction;

(2) A small amount of monosodium will remain in the upper end cap after the sodium tank is separated, requiring soaking of the upper end cap;

(3) There is no more than 150g of sodium monomer remaining in the ceramic tube, which needs to be disassembled and crushed and then immersed in anhydrous ethanol for treatment, and there is no need to strictly control the cutting temperature when cutting here, but it is necessary to effectively separate the sulfur felt and the ceramic tube.

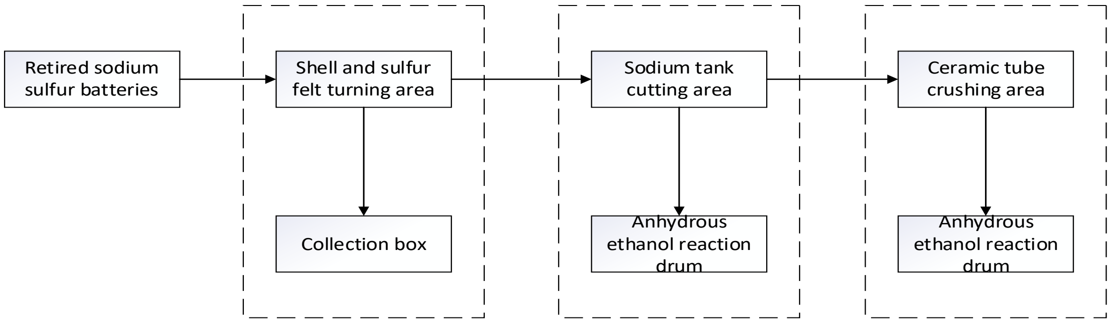

Figure 2. Overall processing scheme of sodium-sulfur battery

2.1 Equipment 1 Preliminary Program Design

Equipment 1 for sodium-sulfur battery shell and sulfur felt turning equipment, requiring the operator to use the chuck to fix the sodium-sulfur battery (sodium-sulfur battery parallel to the ground), the chuck can drive the sodium-sulfur battery together with the rotation of the knife can be shifted along the sodium-sulfur battery axial feed in accordance with the set feed rate, after the completion of the feed, the turning shell and sulfur felt debris into the bottom of the collection box, the schematic diagram of the equipment shown in Figure 3.

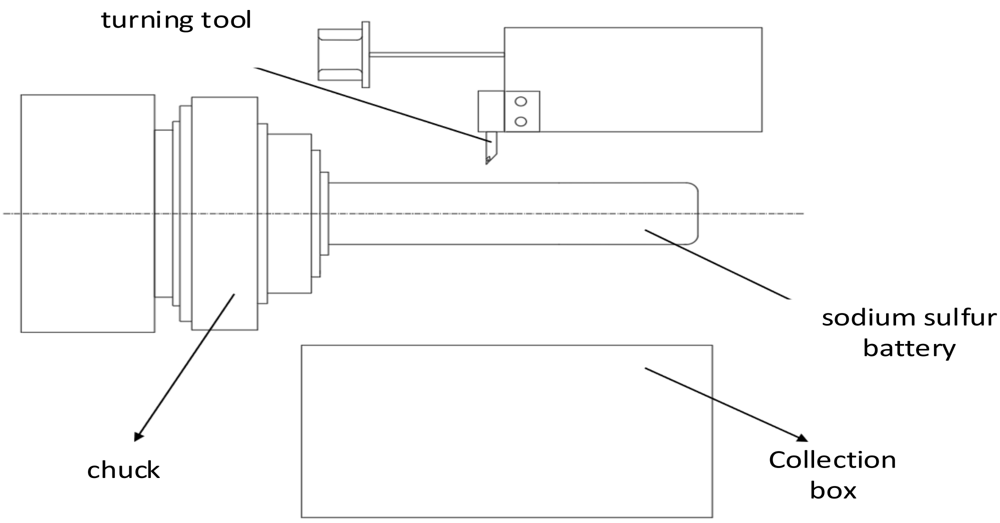

Figure 3. Schematic diagram of Device 1

ISSN: 2414-1895
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2.2 Equipment 2 Preliminary Program Design

Equipment 2 is the sodium tank cutting area and ceramic tube crushing area. In this part of the program design, the operator is required to remove the shell and sulfur felt after the battery reversal using the chuck will be sodium-sulfur battery clamping fixed in the equipment 2 (sodium-sulfur battery parallel to the ground), start the spindle rotation, the chuck can drive the sodium-sulfur battery together with the rotation of the cutter Y-axis can be controlled by the cutter row to do radial feed movement, and can be a certain feed speed movement to the set position, to complete the opening of the sodium cans Work. At the same time, taking into account the different models of sodium-sulfur batteries, this equipment can be adjusted according to the specifications of the battery, adjusting the knife row can be adjusted to tighten the ejector pin, to achieve the cutting position and the number of cut changes. According to the model with the largest number of batteries, the preliminary program sets the knife row to fix four knives, three of which are responsible for cutting the opening of the sodium canister, and the remaining one is responsible for cutting the neck from the sodium-sulfur battery, cutting off the neck completely, so that the sodium canisters along the infeed chute into the lower hopper, and when the hopper is opened, it will fall into the lower reaction drum containing anhydrous ethanol. After the sodium tank cutting is completed, the X-axis of the clamping claw moves along the axial direction, and then clamps the neck of the sodium-sulfur battery, and drags the battery from the sodium tank cutting area to the ceramic tube crushing area; the crushing of the ceramic tube is mainly realized by a crushing cylinder, and the crushing station has a squeezing plate fixed at one end, and the other piece of squeezing plate is connected to the crushing cylinder, and when the ceramic tube is put in place, the cylinder begins to press, and the ceramic tube is crushed, and the crushed fragments of ceramic tube drop into the lower hopper along the infusion slot, and fall into the reaction drum containing water ethanol below after the hopper is opened. The broken pieces of ceramic pipe will fall into the lower hopper, and after opening the hopper, they will fall into the anhydrous ethanol reaction barrel and fully react with anhydrous ethanol. The schematic diagram of this part of the equipment is shown in Figures4 and 5, of which Figure4 is the main view of the equipment and Figure 5 is the side view of the equipment.

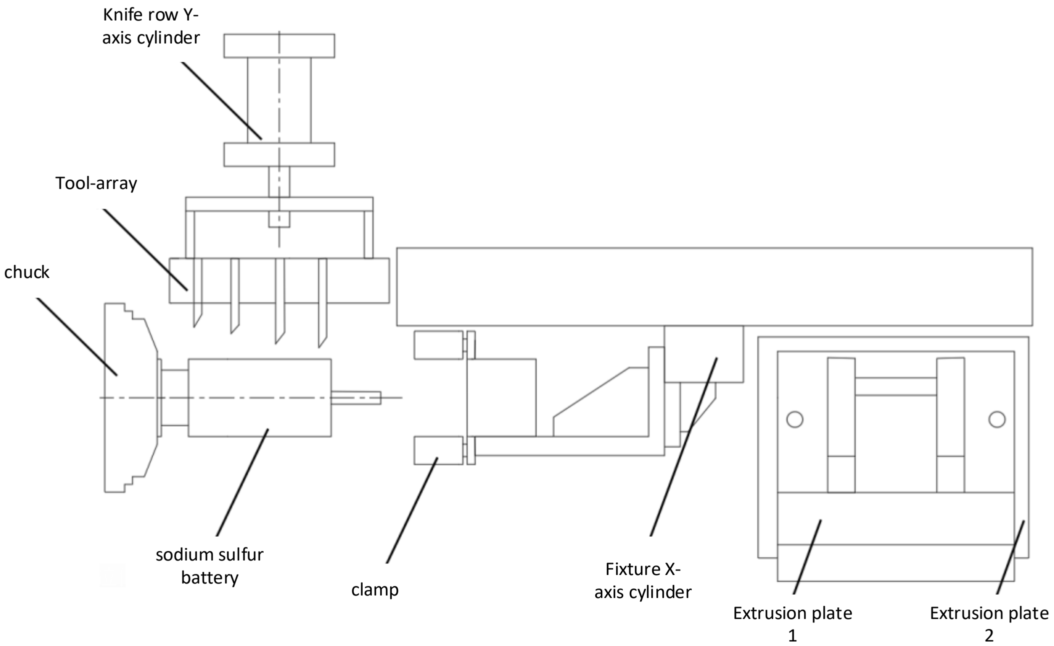

Figure 4. Main view of device 2

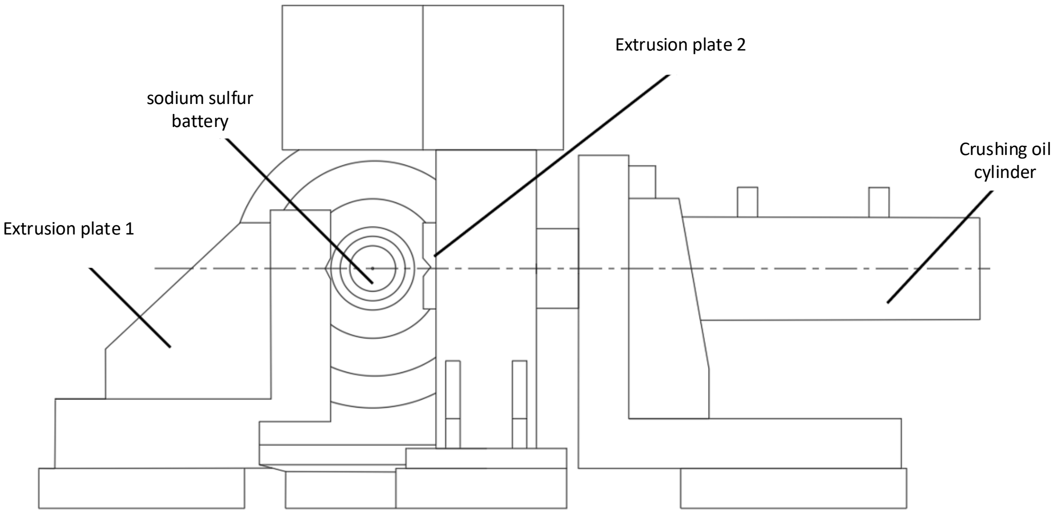

Figure 5. Side view of device 2

3. Mechanical Structure Design

3.1 Equipment 1 Mechanical Structure

Equipment 1, i.e., sodium-sulfur battery shell and sulfur felt turning equipment, mainly consists of a chuck and a movable turning tool, whose three-dimensional modeling is shown in Figure 6. In order to facilitate understanding, the movable turning tool will be selected for specific elaboration in the following.

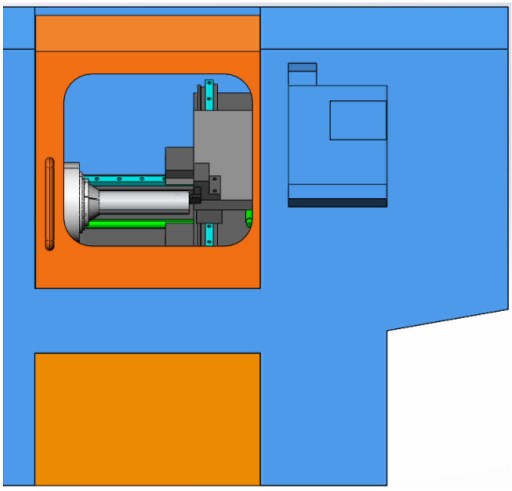

Figure 6. 3D model diagram of device 1

In equipment 1, the most important part is the design of the movable turning tool, the turning tool needs to move in the two directions of X and Y axes when it works, and in this program, four pairs of guide rails are used, and each two pairs of guide rails constitute a group, so that the platform of the guide rail can realize the translational movement of the X and Y axes upward, and the tool is fixed to the platform of the guide rail, and it follows the movement of the platform, to complete the cutting of the shell of the sodium sulfur battery and the sulfur felt. At the same time, in order to ensure safe production, it is required to control the turning speed and feed speed in a suitable range to avoid the burning of the sulfur felt due to the high temperature, but it is still necessary to pay attention to the turning efficiency.

ISSN: 2414-1895
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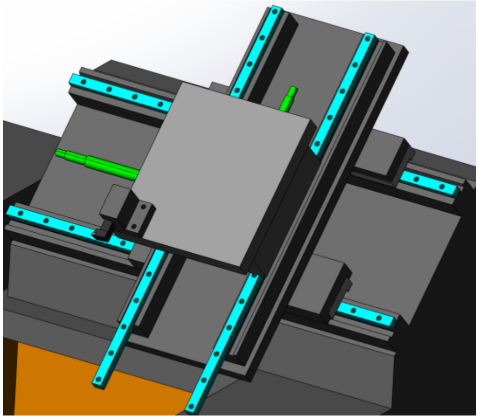

Figure 7. 3D model drawing of the removable turning tool of device 1

In addition, in consideration of sodium-sulfur battery manufacturing problems, and in response to possible sodium-sulfur battery rotation eccentricity problems, the design follows the center frame of the movable turning tool to limit the eccentric rotation of the cutting position and improve the cutting conditions of the shell and sulfur felts.

3.2 Device 2 Working Principle

The workflow of equipment 1: the operator uses the chuck to fix the sodium-sulfur battery after the chuck and the center frame (the sodium-sulfur battery is parallel to the ground), start the equipment, the chuck rotates to drive the sodium-sulfur battery to rotate, and the turning tool starts to feed radially according to the programmed feed amount, and then feeds axially along the sodium-sulfur battery at the set feed rate after it is in place, and after completing the cutting of the sodium-sulfur battery casing and sulfur felts, the operator shuts down the equipment, and the turned After completing the cutting of sodium-sulfur battery shell and sulfur felt, the operator will turn off the equipment and the turned shell and sulfur felt debris will fall into the collection box below.

3.3 Equipment 2 Mechanical Structure

Equipment 2, including sodium tank cutting area and ceramic tube crushing area, mainly by the cutter Y-axis drive, jaw X-axis drive, rotary chuck spindle and the opening and closing of the hopper, cutter switching, chuck, jaws and other auxiliary cylinders, as well as a crushing cylinder and the device lighting and so on, the specific model is shown in Figure 8 and Figure 9.

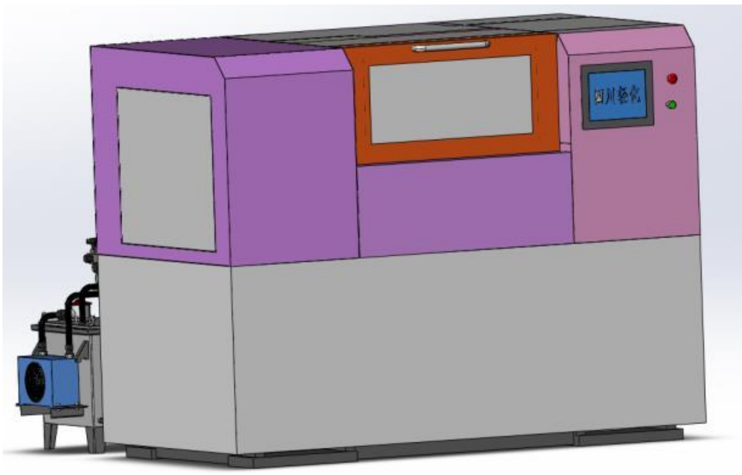

Figure 8. Appearance of Device 2

ISSN: 2414-1895 DOI: 10.6919/ICJE.202312_9(12).0066

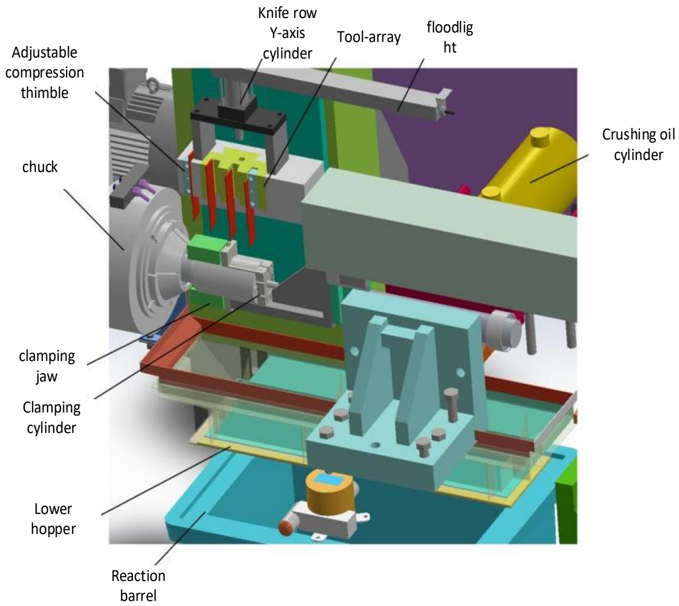

Figure 9. Main structure of equipment 2

The sodium tank cutting area is the core part of this automatic safety dismantling device for decommissioned sodium-sulfur batteries, which makes the device 2 the main equipment of this device, and the important parts of the device 2 will be described specifically below.

Cutter part, as shown in Figure 10, the main action is cutter switching and radial feeding, cutter switching is realized by cylinder, while radial feeding is driven by 86 stepping motor. At the same time, considering the different models of sodium sulfur batteries, this equipment can be adjusted according to the specifications of the battery, adjusting the knife row can be adjusted to press the thimble, to achieve the cutting position and the number of cutting changes.

It should be noted that the sodium tank contains a large number of monomer sodium, in the cutting, must be passed throughout the inert gas to play a protective role, this program is equipped with nitrogen bottles and the corresponding nitrogen piping, and there is a nitrogen switch solenoid valve, nitrogen switch shown in Figure 10.

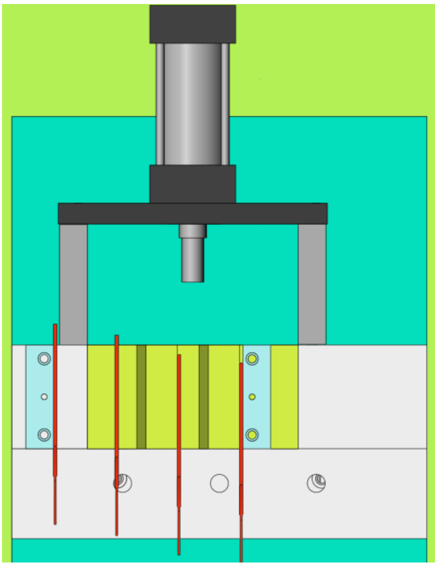

Figure 10. 3D model of the cutter part of device 2

 Volume 9 Issue 12, 2023
DOI: 10.6919/ICJE.202312_9(12).0066

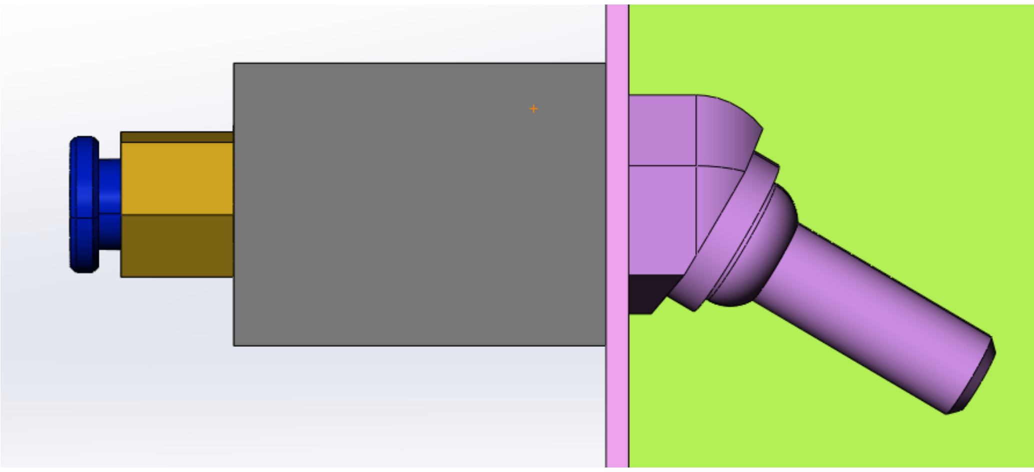

Figure 11. Device 2 Nitrogen Switch 3D Model Drawing

The clamping jaw part, as shown in Figures 12, 13 and 14, the main action is to clamp and loosen the neck of the sodium-sulfur battery and the X-axis upward translation movement. The action of clamping and loosening is realized by the cylinder, while the movement upward is driven by the guide rail and 86 stepping motor, and the clamping jaws are connected with the guide rail by a special support plate designed by ourselves.

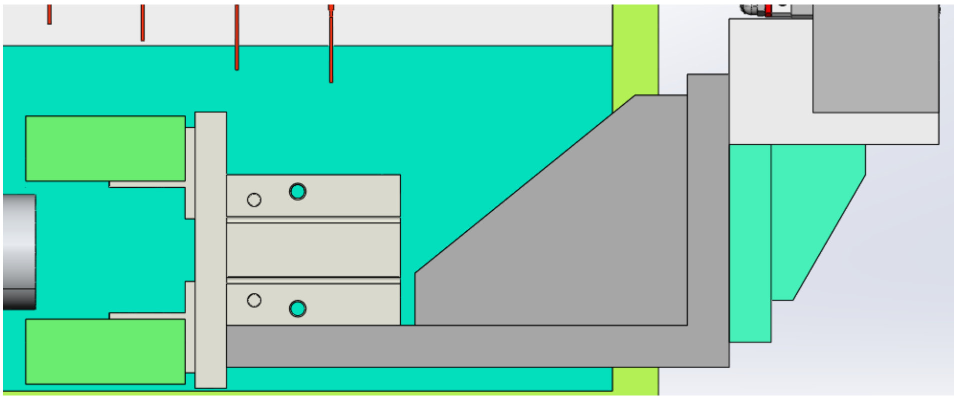

Figure 12. 3D model drawing of device 2 jaws

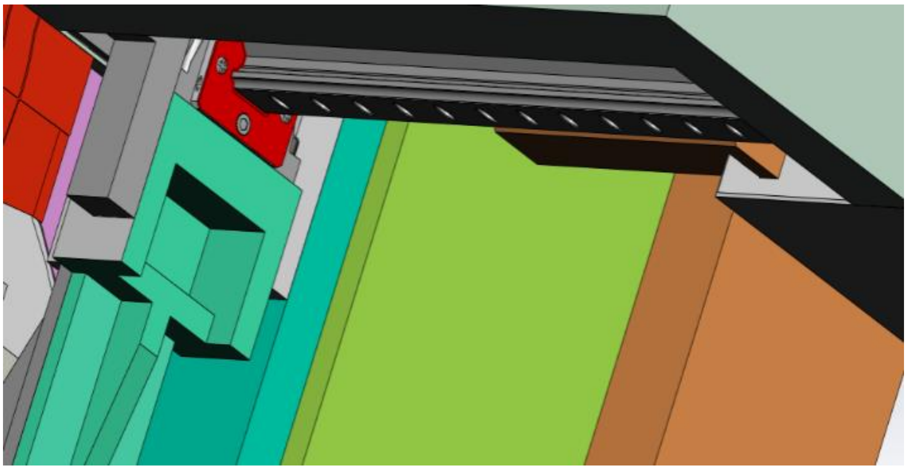

Figure 13. 3D model diagram of device 2 guideway vice

 Volume 9 Issue 12, 2023
DOI: 10.6919/ICJE.202312_9(12).0066

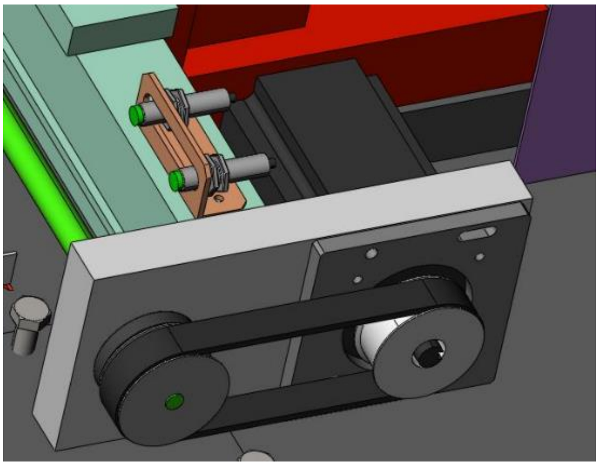

Figure 14. 3D model diagram of the drive source for the device 2 rail sub-drive

Crushing cylinder part, mainly composed of cylinder and extrusion plate, as shown in Figure 15, the left side of the extrusion plate 1, fixed with the body, the right side of the extrusion plate 2 and the cylinder is connected to the main action of this part of the cylinder solenoid valve to drive the extrusion plate to extend and retract, to complete the crushing of ceramic pipe.

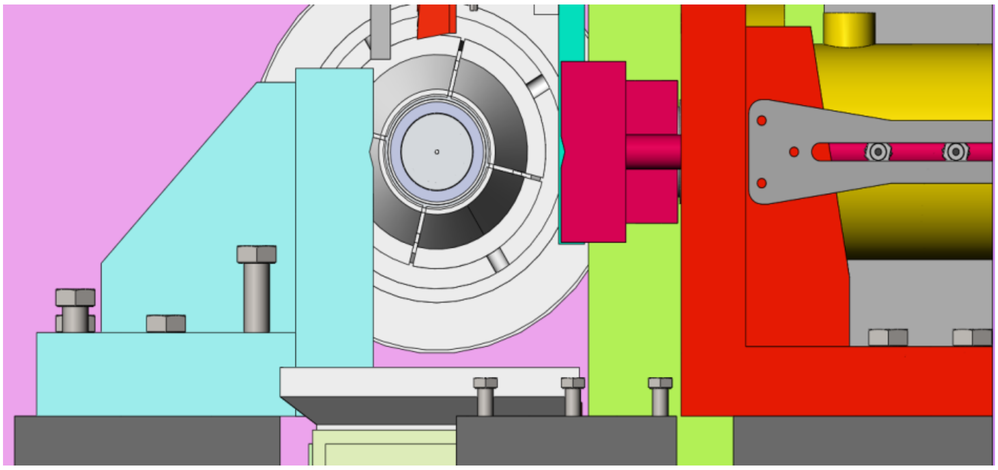

Figure 15. Equipment 2 crushing cylinder 3D model drawing

The lower hopper part, including the hopper and the flow channel, the main action is to open and close the hopper by opening and closing the cylinder, so that the ceramic tube fragments and mandrels along the flow channel into the reaction drum containing anhydrous ethanol, the driving mode and the structure of the hopper as shown in Figure 16, 17.

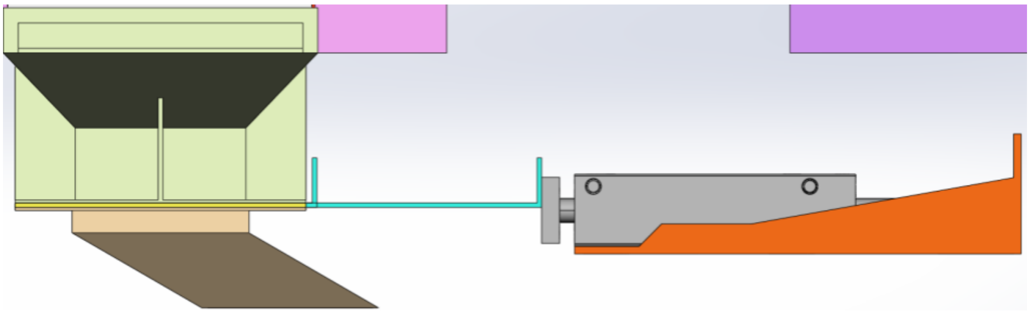

Figure 16. 3D model of the hopper opening and closing cylinder of device 2

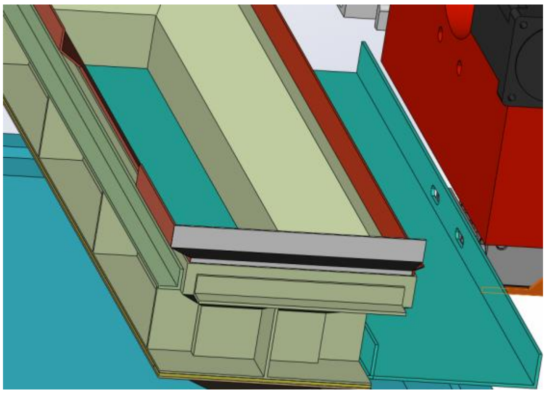

Figure 17. Equipment 2 hopper 3D model drawing

3.4 Device 2 Working Principle

For the sodium tank cutting area of the workflow is as follows: the operator from the equipment 1 to take out the battery, the battery will be reversed after the use of chuck will be sodium-sulfur battery clamping fixed in the equipment 2 (sodium-sulfur battery parallel to the ground), start the spindle rotating, chuck driven sodium-sulfur battery rotation; cutter Y-axis to control the cutter row of the three openings first cutter radial feed to a certain feed rate movement to the set position, to complete the opening of the sodium tank; and then control the remaining cutter row to complete the neck cutting, the neck is completely cut off, so that the sodium tank along the infeed chute into the lower hopper; open the hopper, fall into the bottom with an anhydrous battery, the neck is completely cut off, so that the sodium tank into the lower hopper; open the hopper, fall into the lower hopper with anhydrous battery And then control the remaining knife row of a knife to complete the neck of the sodium-sulfur battery cutting, the neck is completely cut off, so that the sodium canister along the guide groove into the lower hopper; open the hopper, fall into the bottom of the reaction barrel containing anhydrous ethanol; anhydrous ethanol from the opening of the sodium canister into the sodium canister, and the sodium for a full reaction to generate chemically stable sodium ethanol.

For the ceramic tube crushing area of the workflow is as follows: after the completion of the sodium tank cutting, the X-direction clamping jaws move to the left to the neck of the sodium-sulfur battery (at this time, the structure of the sodium-sulfur battery is the neck plus ceramic tubes); after clamping the sodium-sulfur battery, the battery will be sent from the sodium tank cutting area to the ceramic tube crushing area; when the ceramic tube is in place, the oil cylinder begins to press, the ceramic tube crushing, the crushed ceramic tube fragments along the infiltration groove into the hopper; after the hopper opens, it falls into the reaction barrel of anhydrous ethanol for a full reaction with anhydrous ethanol. The broken pieces of ceramic tube will fall into the lower hopper along the guide groove; after opening the hopper, the pieces will fall into the anhydrous ethanol reaction barrel and fully react with anhydrous ethanol.

4. Specific Implementation Programs

The decommissioned sodium-sulfur battery automatic safety dismantling equipment design program uses two independent equipment for dismantling sodium-sulfur batteries, in which the dismantling of the sodium part of the dismantling of the whole process in an inert gas atmosphere, the specific dismantling method and implementation steps are as follows.

(1) Shell and sulfur felt disassembly

1) Manually position and clamp the sodium-sulfur battery on the chuck and close the door of the processing bin.

2) Start the equipment, the chuck drives the sodium-sulfur battery to rotate at speed VI, while the turning tool reaches the limit of the proximity switch, and feeds along the sodium-sulfur battery axially at the set speed V2 , and stops and resets when it feeds to the limit switch, and the turned shells and sulfur felt crumbs fall into the collection box below immediately.

3) Manually remove the sodium-sulfur battery from the chuck and deliver it to Equipment 2 for standby for the next disassembly step.

Device 1 workflow diagram is shown in Figure 18.

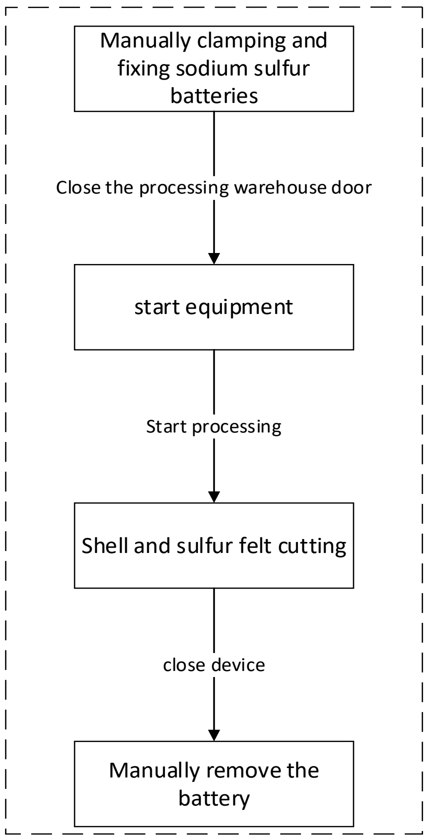

Figure 18. Device 1 Workflow Diagram

(2) Sodium tank and ceramic tube disassembly

1) Manually position and clamp the sodium-sulfur battery (here, the sodium-sulfur battery is the battery processed by Equipment 1) on the chuck, and close the processing bin door.

2) start the equipment, chuck drive sodium-sulfur battery with speed V3 rotation, three cutter according to the set speed along the sodium-sulfur battery radial feed, feed to the proximity of the switch limit, began to reset; reset cutter switching cylinder magnetic open to power, the tool switch to cut off the cutter for the neck, feed to the proximity of the switch limit, began to reset; cutting sodium canisters fall into the hopper first, hopper open/close the cylinder to start the action of getting a signal, open the hopper Sodium can fall into the reaction barrel with anhydrous ethanol below along the guide channel, the hopper opening and closing cylinder reset, close the hopper;

3) The cylinder located on the right side of the chuck and the chuck coaxial line will push the clamping jaws towards the neck of the sodium-sulfur battery, after reaching the left limit of the clamping jaws proximity switch, it will stop moving, and the clamping jaws cylinder clamping magnetic switch will be energized, and start to clamp the sodium-sulfur battery, the chuck will be released, and start to send it to the right into the ceramic tube crushing area for the next step of dismantling.

4) After arriving at the right limit of the jaw proximity switch, the crushing cylinder presses the solenoid valve to get power, the extrusion plate 2 extends to carry out ceramic pipe crushing, after arriving at the limit of the proximity switch, the press solenoid valve is de-energized, the release solenoid valve is energized and the extrusion plate is retracted, the ceramic pipe fragments and the mandrels fall into the hopper, the hopper opening and closing cylinders get signals to start the action,

open the hopper, and the sodium canisters along the infiltration groove fall into the bottom of the reaction drum containing anhydrous ethanol, the hopper opening and closing cylinders reset, closing the hopper, and processing is completed. The hopper opening and closing cylinder resets and closes the hopper, and the process is completed.

The Device 2 workflow diagram is shown in Figure 19.

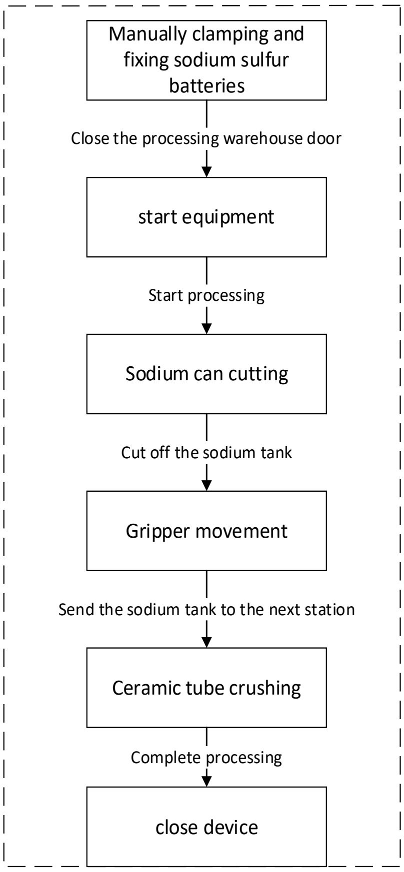

Figure 19. Device 2 Workflow Diagram

5. Conclusion

This automatic and safe dismantling equipment for decommissioned sodium-sulfur batteries can effectively realize automatic, efficient and safe dismantling of decommissioned sodium-sulfur batteries. The whole dismantling process of the equipment avoids manual participation as much as possible and realizes its automatic and efficient function. The dismantling of the sodium part is carried out in inert gas, which effectively improves the safety of dismantling the sodium part.

This automatic safety dismantling equipment for decommissioned sodium-sulfur batteries effectively solves the problem of how to safely and efficiently dispose of decommissioned sodium-sulfur batteries, and promotes the wide application of new energy sodium-sulfur batteries.

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