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To cite this article: Qingxiu Liu 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **490** 062057

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Development and Application of Manned Hoisting Capsule used for Large and Deep Drilling Borehole

Qingxiu Liu^{1,2,*}

¹China Coal Research Institute, Beijing, China

²Xi'an Research Institute of China Coal Technology and Engineering Group, Xi'an, China

*Corresponding author e-mail: liuqingxiu@cctegxian.com

Abstract: At the basis of analysis on acquired hoisting capsule parameters home and abroad, manned hoisting capsule used for large and deep drilling borehole was integrated and designed, it can meet the demands of drilling borehole diameters of 580mm to 620mm, depths of 700s and single man hoisting each time. In the condition of safety and reliability, cabin, guide device, rope breaking protection device, main cabin and disconnect device, buffer device and other devices were specially designed and introduced. And the key part of upper link of hoisting capsule was simulated, function tests of capsule were did in field test. It was validated through simulation and field test that the cabin was stable, the upper and lower guide device were smooth, the functions of rope breaking protection device, disconnect device, and buffer device can meet the demands of design expect, key part was under normal running. Worker safety and quick hoisting rescue requirements can be met under depth of 700m.

1 Introduction

On August 5th, 2010, a copper mine accident occurred in San Jose, Chile. During the rescue process, the diameter of the drilling borehole was 660mm and a 550mm outer diameter hoisting capsule named Phoenix was used. All 33 miners were lifted and rescued. The Phoenix hoisting capsule has a guide wheel structure. On the one hand it can play a supporting role on the shaft wall. On the other hand, it can prevent the cabin to be stuck in the hole. The hoisting capsule communicates with the driller and the headquarters on the ground through the wireless communication system during the lifting process. A safety belt is arranged inside the hoisting capsule, and a compressed air damping cabin is arranged at the bottom. The outer diameter of the capsule is 540mm, and the internal diameter is 530mm[1,2].

Jizhong Energy Shijiazhuang Coal Mine Machinery Co., Ltd. has also developed a hoisting capsule, named JYC-54, for the escape of trapped personnel. The hoisting capsule is 540mm in diameter, 3800mm in height and 1950mm in inner net height. It can carry one person each time. It has built-in



air supply device, emergency escape system and real-time communication system. Oxygen capacity can be used for breathing for 90 minutes. The emergency escape system is used in the process of lifting accidents. Rescued personnel can emergency escape back to the bottom of the well. The escape height is 500 meters. In addition, the life-saving system can be equipped with mine flameproof camera. After the rescue hole is completed, the 360-degree camera can be set to observe whether the shaft wall has the conditions of lowering the lifting cabin to save people and ensure the rescue safety.

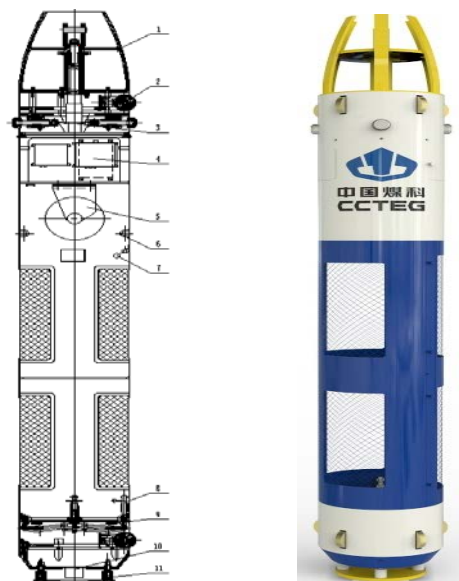
Domestic mine accidents are frequent, but there are limited ways to solve the mine emergency rescue. With the increasing coal mine safety investment, many coal mines are building rapid rescue channel from ground to underground. The lifting equipment will become a key link in mine emergency rescue. Hoisting capsule is a direct carrier for rescuing. Its reasonable structure and reliability are directly related to the success of rescue work.

2 Determination of the parameter

The design parameters of hoisting capsule are determined according to the principle of ergonomics after full investigation and study about the structure of coal mine roadway. The hoisting capsule developed by our company is 550mm in outer diameter, 3915mm in height, 1902mm in inner net height. It can carry one person each time. It has built-in air supply device, emergency escape system, real-time communication system and the escape height is 700 meters. It can be used for 580 to 620mm borehole diameter[3,4].

3 Structural design[5-9]

In order to meet the needs of large diameter borehole rescue, the hoisting capsule (as shown in Figure 1.) is designed as a cylinder structure. It is made up by the following parts: 1.Cabin, 2.Guide Device, 3.Break Prevention Protector, 4.Signal Transmission equipment, 5.Slow Down Machine, 6.Camera in Cabin, 7.Intercom Earphone, 8.Safety Pin, 9.Disconnect Device, 10.Camera at Bottom of Cabin, 11.Buffer Device at Bottom of Cabin. The diagram and outside view drawing of the hoisting capsule is shown in figure 2.

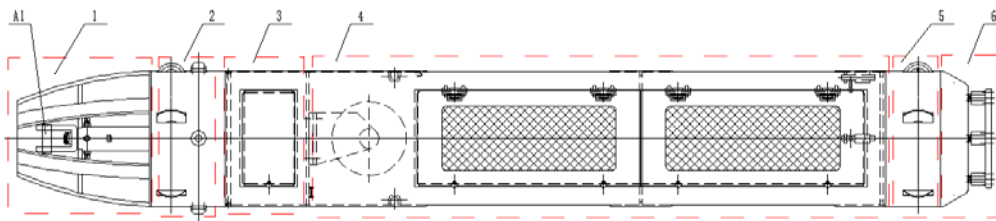


1-Cabin; 2-Guide Device; 3-Break Prevention Protector; 4-Signal Transmission Equipment; 5-Slow Down Machine; 6-Camera in Cabin; 7-Intercom Earphone; 8-Safety Pin; 9-Disconnect Device; 10-Camera at Bottom of Cabin; 11-Buffer Device at Bottom of Cabin

Figure 1. Diagram and Outside View Drawing of Hoisting Capsule

3.1 Cabin

The cabin (shown in Figure 2.) can be classified according to the function and installation order as 1-Upper Guide; 2- Upper Guide Coat; 3- Equipment Cabin; 4- Column Cabin; 5- Lower Guide Coat; 6-Base. A wedge joint is installed on the lifting pin A1, and is connected with hoisting capsule through a cable and wire rope. During the rescue process, the hoisting capsule is controlled by hydraulic winches to lifting and lowering. The upper guide has a streamlined conical structure to achieve the purpose of guidance, which can minimize the stuck and collision between the hoisting capsule and the shaft wall during lifting and lowering.

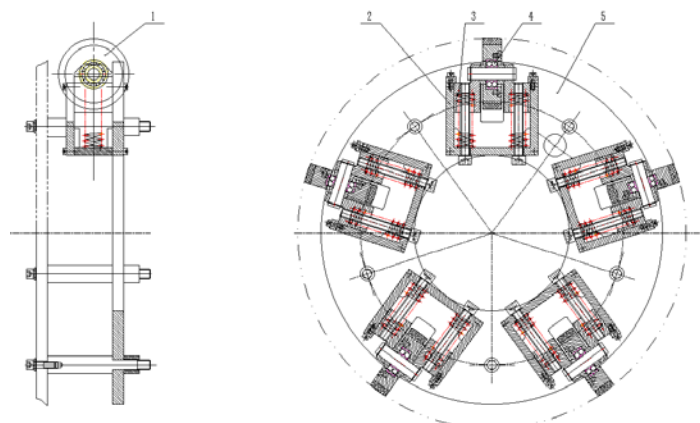


1-Upper Guide; 2- Upper Guide Coat; 3- Equipment Cabin; 4- Column Cabin; 5- Lower Guide Coat; 6-Base; A1-Lifting Pin of Hoisting Capsule

Figure 2.Cabin Layout Plan

3.2 Guide Device

The upper and lower guide sleeve are respectively equipped with a set of guiding devices (as shown in Figure 3.). The guiding device is constituted by spring and roller. It has a guiding and cushioning function for lifting and lowering. The guiding devices is made up by the following parts: 1-Guide Wheel, 2- Pedestal, 3- Spring, 4- Bearing, 5- Mounting Plate. The five pedestals are uniformly arranged on the mounting plate in the circumferential direction. And the outer edge of the mounting plate is welded on the hoisting capsule. When the hoisting capsule is lifted and lowered in the rescue borehole, the spring thrust compacts the steering wheel on the hole wall. When there is an accident such as necking on the hole wall, the hoisting capsule guidance can ensure the hoisting capsule moves smoothly.



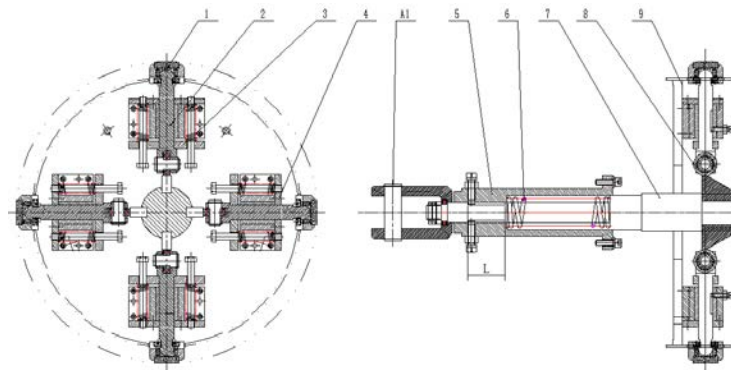
1-Guide Wheel; 2- Pedestal; 3- Spring; 4- Bearing; 5- Mounting Plate

Figure 3. Schematic Diagram of Guiding Device

3.3 Rope Breaking Protection Device

The broken rope protection device (shown in Figure 4.) is installed on the back of the guiding device. The broken rope protection of the hoisting capsule is completed by pushing the spring to increase friction between the head restraints and the hole wall.

The broken rope protection device is made up by the following parts: 1-Head Restraints; 2-Push Rod; 3-Compression Spring; 4-Pedestal; 5-Loose Coat; 6-Lifting Spring; 7-Hoisting Rod; 8-Roller; 9-Mounting Plate. The four pedestals are uniformly arranged on the mounting plate. The Head restraints and the roller are installed at both ends of the putter, and the compression springs push the rollers to the lower ends of the lifting rods. During the working process, the capsule is lifted by the cable rope through the lifting pin. The lifting rod is raised when the lifting spring is compressed. The compression amount L is equal to the length of the lower end of the lifting rod on axis direction. At this point, the compression spring is extended, the push rod drives the head restraints to retract, and the hoisting capsule can move freely up and down. When breakage or stagnation of the rope occurs, the lifting spring will press the lifting rod down. The lower end of the lifting rod inclined to push the roller radial movement. The push rod drive the head restraints outward. And the hoisting capsule clamped on the shaft wall of the rescue hole. The lifting rope protection device can provide extra insurance and time for the second rescue of coal mine accidents.

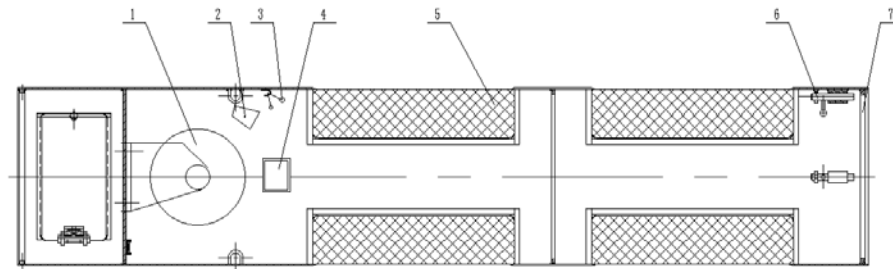


1-Head Restraints; 2-Push Rod; 3-Compression Spring; 4-Pedestal; 5-Loose Coat; 6-Lifting Spring; 7-Hoisting Rod; 8-Roller; 9-Mounting Plate; A1-Lifting Pin of Hosting Capsule

Figure 4. Schematic Diagram of Rope Breaking Protection Device

3.4 Main Cabin and Disconnect Device

The main cabin (shown in Figure 5.) is the passenger carrying compartment. It installs the following parts: 1-Slow Down Machine; 2-Camera; 3-Intercom Earphone; 4-Multi-gas Concentration Measuring Instrument; 5-Hatch; 6-Safety Pin; 7-Mounting Plate of Disconnect Device. The main cabin has a large volume and is equipped with emergency breathing equipment. It can maintain the normal breathing of the crew for 120 minutes. Cameras and intercom headphones in the cabin are wired to the well console for real-time contact between rescuers and crews. Multi-gas concentration meter can detect the concentration of toxic gases and transmit the gas concentration signal to the console through signal transmission equipment. According to the actual situation, the operator reminds the crew to wear emergency breathing equipment and guide the rescue.

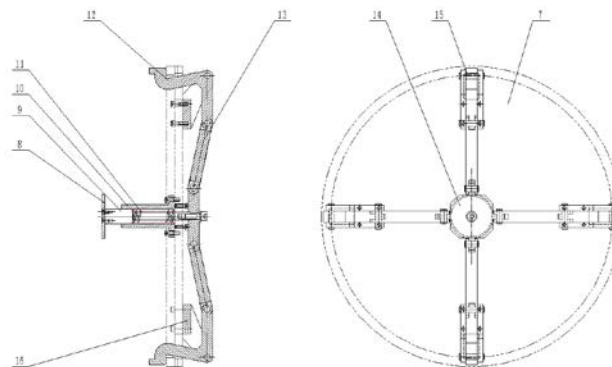


1-Slow Down Machine; 2-Camera; 3-Intercom Earphone; 4-Multi-gas Concentration Measuring Instrument; 5-Hatch;

6-Safety Pin; 7-Mounting Plate of Disconnect Device

Figure 5. Schematic Diagram of Main Cabin

The outer edge of the mounting plate on disconnect device (shown in Figure 6.) is matched with the bottom of the main cabin. The main working parts including the following parts: 7-Mounting Plate; 8-Pedal; 9-Force Transmission Rod; 10-Bushing; 11-Compression Spring; 12-Hook; 13-Connecting Rod; 14-Connecting Plate; 15-Pin; 16-Pedestal. Four groups of hooks and connecting rods are evenly distributed on the mounting plate. The installation plate is connected with the hoisting capsule base by radial tightening screws. Normally, the safety pin installed inside the main cabin holds the hook, the compression spring lifts the pedal and the power transmission rod upward, disconnect device and the base as a whole with the main cabin of the hoisting capsule. In the rescue process, when there are accidents such as stuck and breaking of wire rope, the rope breaking protection device clamps the hoisting capsule on the hole wall. And the passengers in the hoisting capsule are in suspension state, which is not conducive to the safety and the second rescue. At this point, the crew can release the safety pin in the main cabin and step the pedal. The transmission rod press down the connecting plate. It drives the connecting rod and the hook movement. The hook will be loosen. The release device and the base as a whole with the main cabin will fall off. The Slow Down Machine will lift the crew safely to the bottom of the well, waiting for the second rescue.



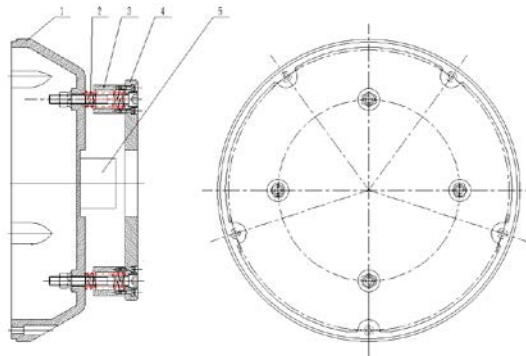
7-Mounting Plate; 8-Pedal; 9-Force Transmission Rod; 10-Bushing; 11-Compression Spring; 12-Hook; 13-Connecting Rod; 14-Connecting Plate; 15-Pin; 16-Pedestal

Figure 6. Schematic Diagram of Disconnect Device

3.5 Buffer Device

The buffer device (shown in Figure 7.) is mounted on the base. It is made up by the following parts: 1-Base; 2-Support Spring; 3-Spring Sleeve; 4-Floor; 5-Bilge Camera. When the hoisting capsule is normally lowered, or the passengers in the hoisting capsule open the release device for a second escape due to stuck or broken rope, the support spring can effectively reduce the violent collision and

vibration caused by excessive speed or instability. The spring sleeve acts as the guide body supporting the spring on the one hand, and on the other hand restrains the compression of the spring to protect the bilge camera. The bilge camera can help the operator to observe and record the video below the hoisting capsule and adjust the release speed of the hoisting capsule according to the specific situation.



1-Base; 2-Support Spring; 3-Spring Sleeve; 4-Floor; 5-Bilge Camera

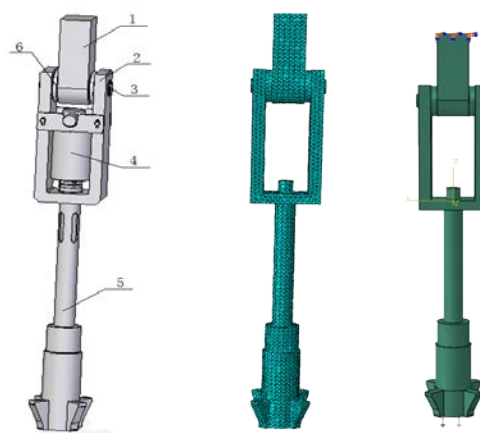
Figure 7. Schematic Diagram of Buffer Device

3.6 Communication Element

The signal transmission equipment is installed in the equipment compartment. Transmission of three electrical signals comes from the inside and outside camera, the talkie headset and the multi concentration gas meter. It is used for real-time monitoring of toxic gas content in the underground area and connecting with the personnel in capsule.

4 Analysis of key components

The schematic diagram of the upper connection structure is shown in Figure 8-(1). The rescue wire rope is articulated on the pin shaft through the wedge joint, and both ends are blocks. The wire at the lower end of the electric slip ring enters the inner part of the hoisting capsule through the slender holes in the hoisting rod. It provides a signal transmission channel for the camera, intercom headset and multi-gas concentration meter.



(1)Connection structure

(2) Grid Partition

(3) Constraint

1-Wedge Joint; 2-Joint Body; 3-Pin Shaft; 4-Electric Slip Ring; 5-Hoisting Rod; 6-Block

Figure 8. Schematic Diagram of Upper Connection Structure and Grid Partition

During the lifting and lowering process, the gravity of the cabin and the wire rope acts on the lifting rod. The upper end of the lifting rod is connected with the joint body of the hoisting capsule through

the nut. It can be seen that the main force components of hoisting capsule are wedge joint, joint body, pin shaft and lifting rod.

By simplifying the connection model of the hoisting capsule and importing it into the ANSYS WORKBENCH, the meshing structure can be obtained as shown in Figure 8-(2).

In the rescue process, the weight of hoisting capsule and the human body can be regarded as a quantitative. When the rescue wire rope is in the longest state, the lifting rod is subjected to maximum pulling force.

$$F_{\max} = G_{\text{capsule}} + G_{\text{human}} + G_{\text{rope}}$$

The weight of hoisting capsule is 720Kg, assuming the weight of human is 100Kg, and the weight of rescue rope is 1.3Kg per meter (the maximum length is 700m). The maximum pulling force received by the lifting rod is as follows:

$$F_{\max} = 7200 + 1000 + 700 \times 1.3 \times 10 = 17300\text{N}$$

The fixed wedge joint applies the vertical downward pull force of 17300N to the lifting rod, as shown in figure 8-(3).

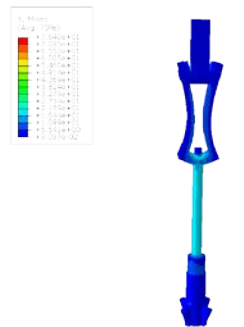


Figure 9. Stress Nephogram of the Upper Connecting Part

The stress nephogram of the connecting part of the cabin can be calculated as shown in Figure 9. The results show that the maximum stress of wedge joint, joint body, pin shaft and lifting rod is 76.4 MPa, which is lower than the allowable stress of 40Cr and Q345. The design of hoisting capsule and related accessories meets the strength requirements, and the structure reliability is stable.

5 Field Application

From October 20 to 28, 2015, the manned hoisting capsule accompanied with the supporting ZMK5200QJY40 type mining rescue vehicle was tested in Pingshang Coal Mine of Jincheng Qinxu Coal Industry Co., Ltd. The field industrial test of hoisting capsule is shown in figure 10.



Figure 10. Field Industrial Test of hoisting capsule

The hoisting capsule was lowered and lifted more than 20 times during the field industrial test. The maximum depth of lowering was 297.8 meters. The traveling speed and structural function under different working conditions were simulated with the interval velocity of 0-2m/s. During the test, the structure of the cabin is stable, which ensures the safety of the passengers. And the upper and lower guide smoothly, the anti-broken rope protection device, release device, buffer device and other components can meet the design requirements. The key components are in normal operation and it can meet the safety and rapid lifting rescue needs within 700 meters depth.

6 Summary

At the basis of analysis on acquired hoisting capsule parameters, manned hoisting capsule used for large and deep drilling borehole was integrated and designed, it can meet the demands of drilling borehole diameters of 580mm to 620mm, depths of 700s and single man per hoisting. In the condition of safety and reliability, manned tank, guiding arrangement, anti-banging device, main tank, release device, damping device and other devices were specially designed and introduced. And the key part of upper link of hoisting capsule was simulated, function tests of capsule were did in field test.

Acknowledgment

This work was supported by the key national research and development plan of China under Grant No.2018TYFC080087.

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