Design and Research on the Detection and Early Warning Device for Mine Road Collapse

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Abstract: With the rapid economic development, the pace of mining in mining areas has accelerated continuously. Coupled with inadequate management of the progress of mining area governance, road subsidence in mine shafts has occurred. Research on detection and early warning devices for road collapse in mine areas aims to provide technical support for taking timely measures to avoid road subsidence in mine shafts. To eliminate the shortcomings in existing technologies where the connection points are prone to loosening and detachment due to external forces and vibrations, an advanced detection device for road collapse in mine areas has been designed.

Keywords: mining area; road collapse; detection device; design

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The advancement and development of technology have driven the accelerated exploitation of mineral resources. As non-renewable resources, the gradual depletion of mineral resources and the lack of effective preventive measures have led to road collapses in mining areas, resulting in a series of safety and environmental issues.

Mine resources are interconnected with sustainable development. If advanced detection and early warning devices are not adopted, there will be a serious risk of collapse, potentially leading to more major accidents.

Currently, when conducting collapse detection on roads in mine areas, stress sensors are commonly used for real-time monitoring. However, most existing devices, when in use, are prone to loosening and detachment at the connection points due to external forces and vibrations, resulting in the inability of the devices to monitor the roads in real time. Improvements are therefore needed based on the current situation.

1 Analysis of Current Mining Status and Subsidence in Mining Areas

At present, most theories and treatment technologies regarding surface subsidence and mining-induced damage are based on research on metal ore deposits. The formation of these ore deposits stems from hydrothermal activities associated with magma intrusion. Due to the intertwining of various rock masses within the surrounding rock, the lack of distinct characteristics, and significant differences in their physical and mechanical properties, the interactions between rock strata are complex and lack a clear layered structure. From the perspective of rock mechanics, mining such ore deposits often disrupts surface stability, thereby increasing the risk of geological disasters. High-intensity mining operations mainly include underground and open-pit methods. Geological disasters that may be triggered by underground mining primarily include surface subsidence and fissures, while disasters within mine shafts are typically manifested as collapses, gas explosions, and heat hazards. After underground stopes are mined out and closed, geological movements continue, which may lead to disasters such as road collapses and landslides over time. The same is true for open-pit mining.

Firstly, during mining operations, the accumulation of gangue to excessive heights with steep slopes can easily trigger mountain collapses and landslides. Secondly, disasters in mine shafts mainly originate from intense mining activities that damage the safety protection system of the mining area, leading to excessive concentration of ground stress and causing disasters such as roof collapses and rock bursts. Thirdly, the slopes formed in high-intensity mining areas are relatively steep. As the mining depth gradually increases, the area of the slopes expands, disrupting the natural balance of ground stress. Meanwhile, under the combined influence of heavy rainfall and gravity, mountains are more prone to deformation and collapse. Finally, a large amount of waste rock accumulates during mining activities, which cannot be properly disposed of due to financial and spatial constraints, thereby increasing the risk of disasters. Figure 1 shows the open-pit mine in Fuxin City, Liaoning Province.

Figure 1: Fuxin Open-pit Mine

2 Design of Mine Area Collapse Detection Device

To effectively prevent areas prone to collapse accidents during the modern mining process, an advanced detection device has been designed. By providing early warnings, timely support or filling measures can be taken to effectively avert disasters, significantly reducing losses and ensuring the safety of relevant personnel.

2.1 Device Design

The device primarily consists of an installation baseplate, a detection element, and a protective structure. The detection element is mounted on one side of the baseplate, while the wiring is located on the other side of the detection element. The protective structure covers the detection element and is mainly composed of a fixing ring that is closely attached to the upper surface of the detection element. A positioning ring is installed on the outer side of the wiring, featuring two guide holes on its surface and slidable stopper blocks on its inner wall. The surface of the positioning ring also has rectangular openings. This innovative design, by incorporating a protective structure, not only facilitates the protection of the device's joints but also effectively reduces connection loosening caused by external forces or vibrations. Additionally, it mitigates issues of poor contact resulting from loose connection points, thereby enhancing the detection performance and ensuring the overall stability of the device.

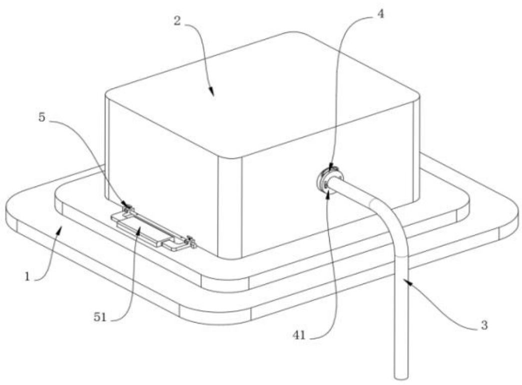

Figure 2: System Diagram of the Mine Road Collapse Detection Device

2.2 Specific Content

First, one side of the stopper is fixedly connected to a pull rod, whose longitudinal cross-section is in the shape of a C. By setting the pull rod, it is convenient to control the movement of the two stoppers.

Second, one side of the fixed ring is fixedly connected to a fixed rod. The surface of the pull rod has circular holes, and the fixed rod is slidably connected to the inner wall of the circular holes. By setting the fixed rod, it is convenient to improve the stability of the pull rod's movement.

Third, a first spring is sleeved on the surface of the fixed rod, with both ends connecting the fixed rod and the pull rod, which is convenient for controlling the pull rod and the stopper to return to their original positions and improving the stability of the stopper.

Fourth, an auxiliary structure is designed on the part of the base adjacent to the sensor, including two square blocks, which are firmly attached to the surface of the base. The surface of the sensor has square holes that fit and lock with the square blocks. In addition, the surface of the sensor has two protrusions, each of which is connected to a sliding rod, and the sliding rod has two slidable inserts. The square blocks have insert holes that fit and lock with the inserts. This design enables the sensor to be quickly and easily preliminarily positioned.

Fifth, the inserts have connection holes, and the inner walls of the holes have slidable insert rods, while the sliding rods have four insert slots for the insert rods to fit into. Through the design of the insert rods, the precise positioning of the inserts can be achieved, thereby increasing their stability.

Sixth, a second spring is sleeved on the surface of the insert rods, with both ends connecting the insert rods and the inserts, which is convenient for controlling the insert rods to return to their original positions and enhancing the binding effect of the insert rods.

2.3 Advantages and Advanced Features

When operating the equipment, a safety protection mechanism is equipped, and the operator needs to pull the operating rod away from the fixed support. This action activates the pull rod, guiding the two stoppers to move. As the first spring deforms due to force, it generates a restoring force, causing the rectangular holes on the limit ring to fit into the stoppers. Then, release the operating rod, and the spring returns to its original shape, pushing the stoppers to closely contact the surface of the limit ring, thus completing the operation process. Moreover, this protection mechanism is beneficial for protecting the connection parts of the equipment and effectively reducing the loosening of connections caused by external forces or vibrations. Such a design reduces the problem of poor contact caused by loose connections, minimizing the impact on the detection work and enhancing the overall stability of the equipment. See Figure 3, a partial view of the device.

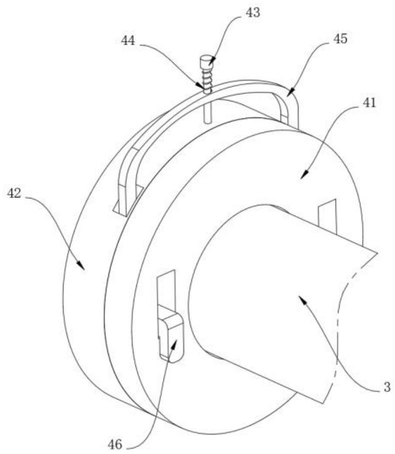

Figure 3: Partial View1

With the aid of specific auxiliary facilities, when the equipment operation is required, the square component is placed into the preset square hole on the top surface of the sensor, and the plug rod is pulled. This causes the second spring to deform under force and generate elastic force. This force action makes the plug block slide within the slide rod and then be embedded into the mating hole on the surface of the square component. Then, the plug rod is released, and under the action of the spring, it is securely placed in the slot of the slide rod, thus completing the operation process. The introduction of this auxiliary device makes the assembly of the auxiliary equipment more convenient, significantly reduces the reliance on numerous tools during the assembly and disassembly of the equipment, solves the problem of low efficiency, and thereby enhances the overall operational convenience of the equipment. For detailed information, please refer to the partial diagram and legend in Figure 4.

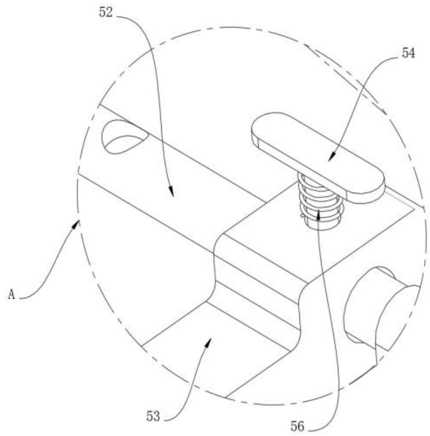

Figure 4: Partial View2

Legend:

1. Installation plate; 2. Sensor; 3. Connecting wire; 4. Protective device; 41. Limiting ring; 42. Fixed ring; 43. Fixed rod; 44. First spring; 45. Pull rod; 46. Stopper; 5. Auxiliary device; 51. Square block; 52. Sliding rod; 53. Insert block; 54. Insert rod; 55. Convex block; 56. Second spring.

3 Significance of the Design of the Detection Device

3.1 Enhancing Accuracy

By applying innovative technological methods to investigate the engineering geological environment and conduct disaster monitoring, and analyzing the collected information, a detection device for road collapse in mining areas is designed to implement disaster prediction. During the evaluation of engineering geological disasters, continuous monitoring can be carried out to ensure the accuracy of the obtained data, improve work quality and efficiency. Based on the actual situation of the surrounding environment, scientific and effective monitoring methods are adopted, and the requirements of geological exploration are taken as an important basis.

3.2 Human-Machine Integration

The effective connection of human-machine integration enhances the monitoring and early warning efficiency of geological disasters in mining areas. The meteorological risk warning of geological disasters achieves full coverage, and the warning information is released through multiple channels to ensure timeliness and accuracy. It is sent vertically to disaster prevention personnel and dedicated monitors, and horizontally to the person in charge of the geological disaster command center, as well as to mining construction units. The risk warning of the disaster prevention responsibility network achieves full coverage. The inspection and investigation of geological disasters in mining areas are further strengthened, and the monitoring and early warning are carried out with the combination of human and technology. The work process is continuously optimized, and the management system is constantly improved. Professional monitoring equipment is maintained to ensure its functionality, and the early warning platform operates normally. The role of human-machine integration is played to enhance the prevention ability of geological disasters in mining areas.

3.3 Geological Environmental Protection

The development of advanced monitoring systems for road collapse in mining areas helps prevent major safety accidents. In the work of geological safety construction and rational utilization of resources in mining areas, construction personnel need to adhere to the fundamental principle and concept of sustainable development. Considering the diverse geological disasters in mining areas and the interference of natural factors, as well as the significant impact of human activities on geological safety, integrating detection technology with these factors can enhance the safety of mining operations.

4 Conclusion

The research results show that China has unique advantages in mineral resources. By using advanced technological means for the exploitation and rational utilization of mineral resources, not only can the needs of all aspects of society be met, but also the rapid development of society can be promoted. However, over a long period of time, the geological conditions in mining areas have undergone significant changes due to human activities. When developing mineral resources, it is necessary to accurately predict the possible collapse of mine passages and implement corresponding preventive and emergency measures to ensure the safety of construction personnel. In this process, it is crucial to use advanced theories and advanced detection equipment to assess the risk level of geological disasters in mining areas. The application of this device in practice can provide early warnings of geological disasters, prevent potential dangers from escalating into accidents, effectively protect the ecological environment and personnel safety, and significantly improve the overall benefits of mining projects.

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