Research Article

Energy Distribution Law of Dynamic Failure of Coal-Rock Combined Body

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The rock burst must be generated by energy. In order to explore the distribution law of energy in coal-rock system, based on the structural characteristics of coal and rock and the mechanical characteristics analysis of coal-rock combined body model, the calculation formula of energy distribution was given before the damage of same diameter coal-rock combine body and nonsame-diameter coal-rock combined body; the uniaxial compression experiments were carried out on the combined body, and the energy distribution before the failure of the combined body was calculated by using the energy distribution calculation formula. The results show that the greater the difference in hardness between the components of the combined body, the stronger the outburst proneness; the energy mainly accumulates on the weak component before the combined body is destroyed, and the hard components act as a clamping device. When the soft layers and the hard rock layers are interbedded, the energy accumulation ability of the soft rock layer is stronger than that of the hard rock layer, and the weak rock layer is the main carrier of energy accumulation. According to this, from the perspective of energy accumulation layer, for the energy-bearing structure, direct release energy and indirect release energy two kinds of rock burst prevention and control concepts and corresponding antiburst measures were proposed. At the same time, engineering practice, microseismic monitoring, and on-site measurement were conducted in Junde Coal Mine. The results show that the blasting pressure relief for the weak coal seam and the hard roof destroys the energy-bearing structure formed by the fine sandstone-coal-fine sandstone and effectively releases the energy and has a remarkable antiscour effect.

1. Introduction

With the deepening of coal mining depth and the increase of coal mining breadth, the frequency and intensity of geological dynamic disasters are gradually increasing; especially, the rock burst is the most serious [1–4]. On October 20, 2018, the “10.20” rock burst accident in Longyun Coal Mine of Shandong Province caused 21 deaths and 1 injury, which seriously affected the safe production of mines and caused huge economic losses and casualties. On June 9, 2019, a coal mine accident occurred in Longjiaobing Mining Company of Jilin Coal Group, causing 9 deaths and 10 injuries. The rock burst is a serious threat to the production and personnel safety of coal mines and is a major problem that needs to be solved urgently (Bo-Hyun et al., 2018; [5–7]).

Rock burst is that the coal-rock system accumulates a large amount of elastic energy under the pressure of the mine [8–11]. When the energy reaches the energy storage limit of the system, the impact dynamic phenomenon was formed by the instantaneous release under the condition of external disturbance [12–16]. Many experts used the major disasters of coal mines-rock burst as the research background and analyzed the energy conversion characteristics of coal-rock unstable failure and dynamic disasters. You and Hua [17] used experimental methods to analyze the variation of energy in the process of rock sample failure; Zhao and Xie [18] studied the energy conversion form of the specimen from loading to failure; Xie et al. [19] analyzed the relationship among the form of energy dissipation and the strength and failure mode of coal rock; Yin et al. [20] studied the internal energy...
conversion mechanism of coal and rock mass and used the damage energy index as the impact discrimination condition; Li et al. [21] constructed the initial fracture mechanics model of the hard roof, based on which the energy distribution formula was derived; Sun et al. [22] gave the criterion for the elastic pressure of the rock burst but did not consider the influence of the loading process; Wang et al. [23] analyzed the energy variation of rock burst, considering the effect of post-peak softening stage and loading rate on the peak stress of rock mass; Lu et al. [24] believed that the occurrence of rock burst is closely related to the local energy accumulation in coal and rock mass; Gao et al. [25] believed that hypocenter energy and hypocenter distance are the two most critical factors affecting the rock burst of roadway. Chen et al. [26] considered that with the increase of the radius of the loose zone after the excavation of circular roadway under uniform confining pressure, the coal body in the elastic zone always absorbs energy; the plastic deformation and failure of the coal body in the loose zone of roadway was the internal mechanism of the roadway impact, and far-field hypocentre played a role in the disturbance. Chen et al. [27] applied testing machine MTS 815 to carry out uniaxial compression and cyclic loading-unloading compression for coal-rock combined body. Energy evolution characteristics of different coal-rock combined body were studied. Li et al. [28] carried out the uniaxial impact compression tests of coal-rock-like combined body with pre-existing cracks by using a split Hopkinson pressure bar (SHPB). The energy evolution characteristics with different preexisting cracks are investigated, and the influence of position and dip angle of cracks on fractal dimension of the combined body is analyzed.

The coal-rock system is composed of a variety of interbedded layers of soft and hard rock layers. The energy accumulation capacity of each rock layer is different, which inevitably causes the problem of uneven distribution of energy in the coal-rock system. It is well known that rock burst must occur under the influence of energy [29–32]. In this case, where does the energy that causes the rock burst accumulate? In order to find the energy source of the rock burst, it is necessary to clarify the distribution of energy in the coal-rock system. Although the above experts have revealed the energy conversion mechanism of the rock burst from the pregnant disaster to the catastrophe, the distribution of energy in the coal-rock system before the impact of the rock burst has not been studied.

Based on this, this paper took the serious disasters of rock burst in coalmires as the research background. Based on the analysis of coal-rock structure characteristics and mechanical properties, the energy distribution calculation methods of two combined models were given. And relying on Junde Coal Mine to carry out uniaxial compression experiments on the self-constructed binary and ternary coal-rock combined bodies, the energy distribution calculation method was used to calculate the energy accumulation of the components before the coal-rock combined body failure, and the energy distribution law before the failure of coal-rock system was explored. This has important reference value and guiding significance for locking the origin of impact energy and reducing the anti-scour area.

2. Calculation Method of Energy Distribution before Coal-Rock Combined Body Failure

Many experts have carried out much research on coal-rock combined body from the perspective of energy, but the energy distribution law before coal-rock combined body failure is still unclear. The main reason is the lack of reasonable observation methods and calculation methods of energy distribution. Therefore, in order to analyze the energy accumulation on the components before the destruction of the combined body, it is necessary to explore an energy distribution calculation method.

2.1. Calculation Method of Energy Distribution before Failure of Coal-Rock Combined Bodies with Same Diameter. The combined test pieces can be divided into two types: the same diameter combined body and the nonsame diameter combined body according to the diameter of the components. The same diameter combined body model is shown in Figure 1.

The combined test piece is subjected to an axial load, and the weak coal component is first destroyed. At this time, the hard rock component of the upper and lower sides is still in an elastic stage, which can be simplified into a spring structure. The mechanical model of the combined test piece is shown in Figure 2.

The force transfer between objects is equal; therefore,

$$F_1 = F_2 = F.$$  \hspace{1cm} (1)

Moreover, since the contact areas of the components of the combined test piece are equal, the stress on the intermediate component is equal to the peak stress of the combined test piece, that is,

$$\sigma_{\text{middle}} = \sigma = R_C.$$  \hspace{1cm} (2)

As shown in Figure 3, the stress-strain curve of the intermediate component is known, and the accumulated energy of the intermediate component under $\sigma_C$ can be obtained.

$$E_{\text{middle}} = S(OM \epsilon_1).$$  \hspace{1cm} (3)

The total energy of the combined test piece is

$$E = S(OM \epsilon_2).$$  \hspace{1cm} (4)

Therefore, the accumulated energy in the remaining components is

$$E_{\text{surplus}} = E - E_{\text{middle}}.$$  \hspace{1cm} (5)

For a binary combination, the roof and floor components are the same component, and assuming that the accumulated energy is also equal, then

$$E_{\text{roof}} = E_{\text{floor}} = \frac{1}{2}E_{\text{surplus}}.$$

$$E_{\text{roof}} = E_{\text{floor}} = \frac{1}{2}E_{\text{surplus}}$$  \hspace{1cm} (6)
For the ternary assembly, the roof and floor components are different, and can be solved by referring to the energy obtained in the binary component.

\[ E_{\text{floor}} = E_{\text{surplus}} - E_{\text{roof}}. \]  

(7)

It is worth noting that the size of the uniaxial compression test B monomer test piece is the same as the size of the component B in the combined test piece.

2.2. Calculation of Energy Distribution before Failure of Coal-Rock Combined Body with Nonsame Diameter. Another combination of the combined test pieces is a nonsame diameter combination. In the uniaxial compression experiment, in order to avoid stress concentration between the components, it is necessary to erect a steel plate with extremely large rigidity and small deformation between the contact faces. The combined test piece model is shown in Figure 4.

The mechanical analysis of the combined test piece shown in Figure 4 is shown in Figure 5.

The force is transmitted evenly between the objects, so the forces acting on the components of the combined test piece are equal. That is,

\[ \sigma_1 \times S_1 = \sigma_2 \times S_2. \]  

(8)

From equation (8), the \( \sigma_2 \) acting on the component B can be calculated. According to the stress-strain curve of the component B under uniaxial compression, the energy \( E_B \) of component B accumulated under the \( \sigma_2 \) stress condition can be obtained. The total energy accumulated by the combined test piece minus the energy accumulated by the component B is equal to the energy accumulated by the remaining components, i.e.,

\[ 2E_A = E - E_B, \]  

(9)

where \( E \) is the total energy accumulated by the combined test piece can be obtained by the stress-strain curves of the test piece.

\( E_A \) is the energy accumulated in the component B of the combined test piece can be obtained by the stress-strain curve under the uniaxial compression condition of the component B.

3. Coal-Rock Specimens Uniaxial Compression Experiment

3.1. Coal/Rock Monomer Uniaxial Compression Experiment. The 17 coal seam of Junde Coalmine of Hegang Branch of Heilongjiang Longmay Mining Holding Group Co., Ltd, the fine sandstone, and gritstone in the roof and floor were selected for experiments. In accordance with the national standard methods of determining the physical and mechanical properties of coal and rock, the test piece was disturbed as little as possible in the preparation process, and it was processed into a standard test piece through cutting, grinding, and other processes. The core-drilling machine, cutting machine, and grinding machine used in the processing of the test piece are shown in Figure 6. The prepared coal, fine sandstone, and gritstone standard test pieces (\( \varphi = 50 \text{ mm}; h = 100 \text{ mm} \)) were each 6 pieces, and some test pieces are shown in Figure 7.

The test equipment selected was TAW-2000KN microcomputer-controlled electro-hydraulic servo rock test machine (as shown in Figure 8), and the three standard test pieces of coal, gritstone, and fine sandstone were completely destroyed by the displacement loading rate of 0.005 mm/s. The stress-strain curves of the three test pieces were obtained.
as shown in Figure 9. The average of the experimental data is in Table 1.

As can be seen from Table 1:

(1) The compressive strength of coal is the smallest, 12.47 MPa, followed by gritstone (57.89 MPa), and the compressive strength of fine sandstone is the largest, which is 127.85 MPa. The elastic modulus of the three test pieces is from big to small: fine sandstone, gritstone, and coal. The fine sandstone has the largest elastic modulus and the coal has the smallest elastic modulus. The law of variation of the elastic modulus is consistent with the compressive strength

(2) From the accumulation energy before the peak, the fine sandstone accumulates the most energy before the damage, followed by the gritstone, and the coal accumulates the least energy. This indicates that the fine sandstone needs the most energy when it is destroyed, and it is the least likely to be destroyed; the coal requires the least energy and is easily destroyed

(3) The impact energy index of the test piece is the ratio of the prepeak energy to the postpeak energy in the stress-strain curve, which can reflect the possibility of rock burst on the test piece. The impact energy index of coal is 6.240, which has strong outburst proneness; the impact energy indices of gritstone and fine sandstone are 3.071 and 2.210, respectively, which have weak outburst proneness

3.2. Coal-Rock Combined Body Uniaxial Compression Experiment. In practical engineering, the coal, the roof, and the floor form a coal-rock system. To simplify the practical situation of the engineering, a coal-rock combined body model was constructed independently, as shown in Figure 10. Among them, F stands for fine sandstone; G stands for gritstone; C stands for coal.

Combination experiment requirements are as follows:

(1) The coal, gritstone, fine sandstone in the combined body, and the test pieces in Section 3.1 were taken from the same location to ensure the homology of the test pieces

(2) The intermediate component of the combined body is a standard test piece, and the size of the upper and lower test pieces is \( \varphi = 50 \text{ mm}; h = 25 \text{ mm} \)

(3) The combined body is in the original superimposed layer state, the direct contact between the
components of the combined body without using the binder can effectively avoid the influence of the amount, nature, and adhesion of the binder on the combined body.

Figure 11 is a physical map of the combined body.

Six test pieces were made for each type of test piece. Six experiments were carried out in the same way as in Section 3.1. The most representative stress-strain curve of the combined body was obtained, as shown in Figure 12; the average of experimental data in Table 2 are shown in Table 3.

It can be seen from Figure 12 that the FCG, FCF, and GCG assemblies all have obvious compaction stages, because there are a large number of voids in the coal components in
the combined body, and these voids are continuously closed under pressure, while the FGF combined body has not obvious compaction phase. That is due to the very few voids in the fine sandstone and gritstone components of the combined body. All four test pieces have a distinct elastic phase. The FCG and FGF test pieces are discontinuously broken, presenting a “stepped” instability failure, and there is an accumulation-release-reaccumulation-rerelease process of energy in the combined body.

From Table 3, we can see the following:

(1) The compressive strengths of FCF, GCG, and FCG test pieces are 12.68 MPa, 13.04 MPa, and 13.38 MPa, respectively, which is basically equal to the compressive strength of coal (12.47 MPa); the compressive strength of FGF test piece is 58.25 MPa, which is basically equal to the compressive strength of gritstone (57.89 MPa). From this point of view, the compressive strength of the combined test piece is substantially equal to the compressive strength of the intermediate fracture component, and the upper and lower components can be regarded as a cushion that only deforms without breaking. In addition, the compressive strength of the combined test piece is slightly higher than the compressive strength of the fractured component, which indicates that the hard component without damage has an increasing effect on the overall compressive strength of the combined test piece.

(2) From the perspective of the impact energy index, the impact energy index of the FCF combined body is 8.538, which has the strongest outburst proneness. The impact energy index of the FGF combined body is 3.148, which has the weakest outburst proneness, and the magnitude of the impact energy index of the FCG combined body is between that of FCC and GCG. This shows that the greater the difference in hardness among the components of the combined body, the stronger the impact tendency of the combined body.

4. Energy Distribution Law before Combined Body Failure

According to the energy calculation formula, the calculation process is introduced by taking the FCF combined body as an example.

According to the stress-strain curve of the FCF combined body, the compressive strength of the combined body is 12.68 MPa, and the total energy before the peak is 0.131 J. The stress-strain curve of the intermediate coal component shows that the energy accumulated by the intermediate coal component under the stress of 12.68 MPa is 0.118 J, accounting for 90.0% of the total energy of the combined body, the energy $E_{\text{surplus}}$ accumulated by the fine sandstone component is 0.113 – 0.118 = 0.013 J. Because the upper and lower components are all fine sandstone components taken from the
same location, then the accumulated energy of the upper and lower fine sandstone groups is equal, $E_{\text{roof}} = E_{\text{floor}} = 0.013/2 = 0.0065$ J, accounting for 5.0% of the total energy.

The energy distribution of the four combined test pieces can be obtained, as shown in Table 4. The proportion of energy in the combined body is shown in Figure 13.

It can be seen from Table 4 and Figure 13 that the energy of the FCF, GCG, and FCG combined bodies is mainly accumulated on the coal components before the failure; the energy of the FGF combined body is mainly accumulated on the gritstone component before the failure. Before the FCG combined body is destroyed, the coal component accumulates the most energy, followed by the gritstone component, and the fine sandstone component accumulates the least energy. Regardless of the combined body, the fine sandstone component accumulates the least amount of energy. The coal component of the FCF combined body has a higher proportion of energy accumulation than the coal component of the GCG combined body, which also confirms the viewpoint that the hard component does not easily accumulate energy. From this point of view, the energy of the combined body before the failure mainly accumulates in the weak component. In the coal-rock system composed of different layers of soft and hard rock layers, the energy that causes the rock burst mainly accumulates in the soft rock layer, and the hard rock layer mainly plays the role of clamping. The distribution law of energy in the coal-rock system can predict the energy accumulation horizon, determine the source of impact energy, and reduce the antishock area.

5. Discussion

5.1. Energy Distribution Law Analysis. Many experts have carried out amount of research on the energy conversion

| Serial number | Compressive strength/MPa | Elastic modulus/MPa | Prepeak energy/KJ | Postpeak energy/KJ | Impact energy index |
|---------------|--------------------------|--------------------|-------------------|-------------------|-------------------|
|               | 12.3                     | 1324.25            | 0.123             | 0.021             | 5.857             |
|               | 14.05                    | 1421.05            | 0.129             | 0.011             | 11.727            |
|               | 14.21                    | 1209.88            | 0.135             | 0.009             | 15.000            |
|               | 11.48                    | 1506.21            | 0.125             | 0.019             | 6.579             |
|               | 11.11                    | 1432.01            | 0.151             | 0.017             | 8.882             |
|               | 12.95                    | 1231.29            | 0.123             | 0.011             | 11.182            |
| FCF           | 13.24                    | 1211.32            | 0.159             | 0.028             | 5.679             |
|               | 14.25                    | 1325.86            | 0.154             | 0.038             | 4.053             |
|               | 14.21                    | 1258.39            | 0.172             | 0.033             | 5.212             |
|               | 12.33                    | 1405.38            | 0.181             | 0.029             | 6.241             |
|               | 12.11                    | 1109.85            | 0.159             | 0.041             | 3.878             |
|               | 12.12                    | 1245.04            | 0.178             | 0.022             | 8.091             |
| GCG           | 59.14                    | 3012.25            | 2.921             | 0.901             | 3.242             |
|               | 56.24                    | 2845.89            | 2.854             | 1.071             | 2.665             |
|               | 62.15                    | 2903.24            | 2.821             | 1.021             | 2.763             |
|               | 58.04                    | 3021.33            | 2.669             | 0.901             | 2.962             |
|               | 57.28                    | 3102.14            | 3.055             | 0.809             | 3.776             |
|               | 56.63                    | 2854.56            | 3.011             | 0.804             | 3.745             |
| FGF           | 13.25                    | 1245.66            | 0.162             | 0.021             | 7.714             |
|               | 14.62                    | 1424.01            | 0.142             | 0.029             | 4.897             |
|               | 11.05                    | 1333.25            | 0.139             | 0.022             | 6.318             |
|               | 13.24                    | 1420.13            | 0.162             | 0.021             | 7.714             |
|               | 13.22                    | 1203.89            | 0.168             | 0.028             | 6.000             |
|               | 14.88                    | 1302.11            | 0.151             | 0.022             | 6.864             |

| Serial number | Compressive strength/MPa | Elastic modulus/MPa | Prepeak energy/KJ | Postpeak energy/KJ | Impact energy index |
|---------------|--------------------------|--------------------|-------------------|-------------------|-------------------|
| FCF           | 12.68                    | 1354.16            | 0.131             | 0.015             | 8.538             |
| GCG           | 13.04                    | 1259.31            | 0.167             | 0.032             | 5.256             |
| FGF           | 58.25                    | 2956.57            | 2.889             | 0.918             | 3.148             |
| FCG           | 13.38                    | 1321.51            | 0.154             | 0.024             | 6.537             |
law, energy dissipation form, energy release mechanism, and coal-rock damage and failure form during the occurrence of rock burst or after the rock burst. This research is important for the comprehensive analysis of the mechanism of rock burst, but it is more important to study the disaster-pregnant process before the occurrence of rock burst to control the rock burst efficiently. At present, there are some defects in rock burst control, such as large control area and low precision. Studying the accumulation layer of rock burst is of great significance for locking the energy source of rock burst, reducing the treatment area, reducing coal mine capital investment, and effectively preventing rock burst.

According to the experimental results of coal-rock combined body, the energy accumulation before the failure of coal-rock combined body was analyzed and calculated. It is found that the energy of coal-rock combined body mainly accumulates on the weak rock before the failure, and the weak rock is easier to accumulate energy than the hard rock. The hard rock plays a role in clamping the weak rock formation. The accumulation of energy in soft rock is based on the clamping clamped by the upper and lower hard rock. The energy accumulation of single weak rock is significantly less than that of single hard rock, but when weak rock is combined with hard rock, the energy accumulation ability of soft rock is stronger than that of hard rock, and this combination form is consistent with the coal-bearing stratum structure in the actual engineering, so it can better reflect the energy accumulation law in underground engineering.

The experimental results reflect the energy accumulation before the coal-rock combined body of the same diameter. The weak rock layer accumulates more energy than the hard rock layer, and the experimental results are consistent with the theory. The stress on the components in the same-diameter coal-rock combined body is equal. The softer the rock layer (coal layer), the greater the strain and the more energy is accumulated. Based on the structural characteristics of coal-rock mechanics, the calculation formula of energy distribution of composites was analyzed. The experimental study was carried out by taking the same-diameter coal-rock combined body as an example. However, the energy accumulation law of nonsame-diameter coal-rock combined body needs further study. In addition, the influence of loading rate, confining pressure, and coal-rock properties on the energy distribution law is the focus of the next step.

### 5.2. Rock Burst Prevention and Control Concept

Based on the energy distribution law of coal-rock system, from the perspective of energy accumulation horizon, for the energy-bearing structure formed by hard rock layer-weak rock layer-hard rock layer, two kinds of rock burst prevention and control concepts of direct release energy and indirect release energy were proposed.

Figure 14 is a schematic diagram of energy distribution of coal-rock system. Under the action of ground pressure, a large amount of elastic energy accumulates in the coal-rock system. It is known from the research conclusion that this energy is mainly distributed in the soft rock layer. The weak rock layer that accumulates the most energy and dominates the rock burst is called the “energy critical layer.” The weak rock layer next to the energy critical layer is called “energy sub-critical layer,” and the other rock layers are called “energy accumulation layer.”

Hard rock layer-weak rock layer-hard rock layer forms a unique energy-bearing structure, which accumulates a large amount of elastic energy under the ground pressure. When disturbed by external power, the accumulated energy is instantaneously released to form rock burst, with

| Combined body | Prepeak total energy/KJ | Energy accumulated by intermediate component/KJ and proportion | Energy accumulated by other components/KJ and proportion |
|---------------|-------------------------|-------------------------------------------------------------|--------------------------------------------------------|
| FCF           | 0.131                   | C: 0.118KJ, 90%                                            | F: 0.0065, 5%                                          |
| GCG           | 0.167                   | C: 0.137KJ, 82%                                            | G: 0.015, 9%                                           |
| FGF           | 2.889                   | G: 2.196KJ, 76%                                            | F: 0.347, 12%                                          |
| FCG           | 0.154                   | C: 0.131KJ, 84.9%                                          | F: 0.016, 10.4%                                         |

![Figure 13: Energy distribution histogram of combined test pieces.](image)
the coal and rock thrown into the mining space. From this point of view, the essence of the rock burst is the rapid release of energy. Therefore, taking certain measures to reduce the accumulated energy or reduce the energy release rate is of great significance for the prevention of rock burst. For the energy-bearing structure, two energy release concepts, direct release energy and indirect release energy, were proposed, and the corresponding anticour measures under two concepts were given, as shown in Figure 15.

(1) For the soft rock layer in the energy-bearing structure, the anticour concept of direct energy release was proposed. Take appropriate measures to directly release the energy accumulated in it, such as changing the physical properties of weak rock layer or mining weak rock layer. Specific measures include mining protective layer, loose blasting, drilling pressure relief, and coal seam water-infusion softening.

(2) For the hard rock formation in the energy-bearing structure, the anticour concept of indirect release energy was proposed, mainly by destroying the hard rock layer and, then, destroying the energy-bearing structure to achieve the purpose of releasing energy. Specific measures include roof-oriented crack, roof blasting, roof cutting, and pressure relief blasting.

Both of these prevention and control concepts achieve the purpose of energy release by destroying the energy-bearing structure formed by hard rock layer-weak rock layer-hard rock layer or changing the properties of the bearing structure. The introduction of these two prevention and control concepts has narrowed the anticour zone of rock burst, making the rock burst more pertinent.

It should be pointed out that in practical engineering, it is far from enough to rely on the above methods to control the rock burst. It must also cooperate with the monitoring and early warning means of rock burst, such as drilling bits method and SOS microseismic monitoring method. In addition, Various factors such as the actual geological characteristics of the project, the conditions of the mining space, the level of mining technology, the degree of impact hazard, and the safety production management of coal mines should be considered to make reasonable selection and matching of the above measures.

5.3. Engineering Application and Effect Analysis. A rock burst accident occurred in the early stage of the excavation of the 106 tunneling face in Junde Coal Mine. One person was injured and the roadway destroyed 41 m. On the basis of fully understanding the cause of the rock burst, using the research conclusions, the corresponding monitoring and prevention measures were taken in the late stage of the excavation to ensure safe tunneling of roadway.

106 tunneling face was tunneled along the 3 coal roof and separating the coal pillar width from the upper gob by about 5 m. The coal seam is stable, with inclination angle α 30°~33°, and the coal seam thickness is 3.42 m. The lithology and thickness of the coal roof and floor is shown in Table 5. By consulting the comprehensive column chart of coal strata of Junde Coal Mine, Table 5 can be obtained. The roadway support method is combined support by belt with wire meshes and cable anchor.

5.3.1. Analysis of Rock Burst Energy Accumulation. The rock burst of the 106 tunneling face is greatly affected by the geological structure such as hard roof, folds, faults, and the speed of advancement. The main factor is the hard roof. From the coal seam geological structure Figure 16, it can be seen that there is only a coal seam in the soft rock layer near the roof and the floor of the coal seam. The immediate roof of the coal seam is 8.82 m thick fine sandstone, and the main roof is 50 m thick conglomerate, which belongs to thick hard roof and is difficult to fall. The hard floor of the coal seam is 30 m thick fine sandstone. This forms the energy-bearing structure of the hard roof-coal seam-hard floor, i.e., the energy-bearing structure of fine sandstone-coal-fine sandstone. Under the action of ground pressure, the coal body is clamped by the roof and floor, accumulating a large amount of energy.

5.3.2. Rock Burst Prevention and Control Measures. For the energy-bearing structure of fine sandstone-coal-fine sandstone, direct release energy measures such as head-on pressure relief and low sidewall pressure relief for weak coal seam was adopted, and indirect pressure relief like low sidewall roof pressure relief for hard roof (fine sandstone) was
implemented. At the same time, during the tunneling process, the tunneling speed was limited, which is no more than 6 m per day.

5.3.3. Effect Analysis of Rock Burst Prevention and Control. After the abovementioned antishock measures were implemented in 106 tunneling face, according to the SOS microseismic monitoring system (as shown in Figure 17), the impact energy is gradually released during the late tunneling, and there is no mine earthquake exceeding 10^5 J. The risk of rock burst is greatly reduced.

Figure 18 shows the amount of roof subsidence before and after the 106 working face is subjected to antishock measures. Before the implementation of the measures, the displacement amount of two sides is 0.82 m, 0.99 m, and 0.84 m, and the average displacement amount of two sides is 0.89 m. After the implementation measures, the displacement amount of two sides is 0.23 m, 0.27 m, and 0.20 m. The average displacement amount of two sides is 0.23 m, which is 0.66 m lower than that before the implementation of measures. The displacement amount of two sides is within the allowable range.

By implementing the abovementioned antiscour measures, the amount of roof subsidence, the volume of tunnel floor heave, and the displacement amount of two sides are greatly reduced, within the allowable range. The microseismic monitoring and field test results show that the pressure relief blasting for the hard roof and the pressure relief blasting for the weak coal body destroy the hard roof (fine sandstone), weak coal seam (coal), and hard floor (fine sandstone) formed energy-bearing structure and effectively release the energy therein, preventing the rock burst, and ensure the safe excavation of the 106 tunneling working face.
**Figure 16:** Schematic diagram of the roof and floor of the working face.

**Figure 17:** Microshock energy release diagram of the 106 working face.

**Figure 18:** Comparison of the amount of roof subsidence before and after the implementation of antiscour measures on the working face.
6. Conclusion

(1) Based on the analysis of structural and mechanical properties of coal and rock, the energy distribution calculation formula of the same-diameter and nonsame-diameter coal-rock combined body is derived by means of the stress-strain curve, which can calculate the energy accumulation before failure of the coal-rock combined body in each component. The calculation formula also lies a theoretical foundation for exploring the energy distribution law before the coal-rock combined body failure.

(2) The compressive strength of the combined body is basically equal to the compressive strength of the damaged components. Under the same stress condition, the weak rock layer reaches the damage limit first, and the hard rock layer is still in an elastic phase at this time. The greater the difference in hardness of each component in the coal-rock combined body, the stronger the outburst proneness of the combined body.

(3) Before the failure of the coal-rock combined body, the energy is mainly distributed in the weak component. The weak rock layer is the main carrier of
energy, and the energy accumulation ability of the weak rock layer is obviously stronger than that of the hard rock layer. In practical engineering, the coal-rock system is composed of different layers of soft and hard rock layers. Under the ground pressure, the energy that causes rock burst mainly accumulates in the weak rock layers, and the hard rock layers is mainly used for clamping.

(4) In the actual project, the hard rock layer-weak rock layer-hard rock layer forms a special energy-bearing structure. For the bearing structure, from the perspective of energy accumulation horizon, two kinds of rock burst prevention and control concepts are proposed: direct release energy and indirect release energy. The corresponding antiscour measures under each concept, providing new ideas for effective prevention and control of rock burst.

(5) Starting from the concept of rock burst prevention and control, the antiscour measures are head-on blasting pressure relief, low sidewall blasting pressure relief, and low sidewall roof blasting pressure relief on the 106 tunneling work face of Junde coal mine. Microseismic monitoring and on-site measurement results show that the blasting pressure relief for weak coal seams and hard roofs destroys the energy-bearing structure formed by fine sandstone-coal-fine sandstone, effectively releasing the energy, avoiding the occurrence of rock burst, and has significant antiscour effect.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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