Latest Progress of Research on Rockburst Experiment Mechanism and Its Control

Manchao He1, Jieyu Li1,2, Dongqiao Liu1*, Jie Sun1,2

1 State Key Laboratory for GeoMechanics and Deep Underground Engineering, China University of Mining and Technology, Beijing, 100083, China
2 School of Mechanics and Civil Engineering, China University of Mining & Technology, Beijing 100083, China

Email: liudongqiao@yeah.net

Abstract: Rockburst experimental research is an important method to understand rockburst and its mechanism. This paper proposes a rockburst classification method, which can be divided into strain burst and impact rockburst. Independently developed three true triaxial rockburst experimental systems, including the first-generation strain burst experimental system, the second-generation strain burst experimental system, and the impact rockburst experimental system. Successfully reproduced different types of rockbursts in experiments, including: single-face unloading strain burst, two-face unloading strain burst, three-face unloading strain burst, four-face unloading strain burst, impact rockburst, and rockburst of jointed rock mass induced by impact. Macro NPR anchors and micro NPR anchors with negative Poisson's ratio effect have been developed, and field rockburst simulation experiments have been performed. The anchor has good rockburst resistance. The rockburst experimental simulation and NPR anchor in this paper can provide reference for the study of rockburst mechanism and its control.

Keywords: Rockburst; rockburst experimental system; Strain burst; Impact burst; Rockburst control

1. Introduction

Rockburst is a non-linear dynamic phenomenon that energetic rock mass releases energy instantly along the excavation free surface. It has the characteristics of the surrounding rock being ejected, thrown and ejected into the excavation space suddenly and violently [1-3]. Rockbursts often pose a serious threat to the lives of workers in excavation activities and cause catastrophic damage to building equipment [4, 5]. For instance, a number of intense strain bursts occurred during the excavation of tunnels in the Jinping II Hydropower Station, which caused casualties and fatalities, damaged equipment and ceased operations due to the high geo-stress [6-8]. Due to the complexity of rock burst and its induction mechanism is still a worldwide problem, which makes it difficult to make substantial progress in the prevention and control of rockburst, which seriously hinders the development of national economy.

Because of the sudden, random and violent characteristics of rockburst, it is extremely difficult to study in the field. Therefore, it is very important to reproduce the rockburst phenomenon in the laboratory and study it. With a better understanding of rockburst phenomena, the experimental equipment and experiments used to investigate rockburst are also continuing to develop. Scholars have studied rockburst from uniaxial, biaxial, and triaxial experiments [9-13]. Rockburst is an engineering problem. However, the experimental study of rockburst mentioned above is from the perspective of
material failure, ignoring the three-dimensional stress state before excavation and the unloading effect caused by excavation under high pressure. Kaise et al. [14] suggested that the excavation free surface is generated during the excavation process of underground engineering, and rockburst will eventually occur due to stress concentration and energy accumulation at the excavation rock mass. True triaxial tests with one free surface can better simulate the true stress state of the deep surrounding rock unit. He et al. [15] developed true triaxial rockburst test equipment that can achieve sudden unloading and produce one free surface. With this equipment, they successfully reproduced the rockburst phenomena process of deep underground cavern excavation and described the strain burst process as consisting of several stages, including particle ejection damage, flake splitting, and block ejection, they used the developed equipment to conduct a large number of rock burst studies [16, 17]. The complex deep underground rock mass project also has multiple free surfaced rock mass structures. These rock mass structures with multiple free surfaces experience multiple unloading effects, and the stress concentration is higher than that of a single free surface. Therefore, it is easier to induce rockburst disasters. However, at this stage, there is no report that the true triaxial rockburst experimental equipment can carry out rapid unloading on multiple surfaces under high pressure. Since stress concentration and energy concentration are important factors for rockbursts, some rockbursts that not occur after the stress concentration completed, and occur after some engineering disturbances. Performing this type of rockburst simulation experiment requires experimental equipment that can apply dynamic loads while in a static state.

In this paper proposes a rockburst classification method, which can be divided into strain burst and impact rockburst. Independently developed three true triaxial rockburst experimental systems, including the first-generation strain burst experimental system, the second-generation strain burst experimental system, and the impact rockburst experimental system. Successfully reproduced different types of rockbursts in experiments. Macro NPR anchors and micro NPR anchors with negative Poisson's ratio effect have been developed, and field rockburst simulation experiments have been performed.

2. Rockburst classification

Rockburst phenomena have been investigated by many researchers based on in-situ and laboratory tests. Rockburst is classified into three types: strain burst, fault-slip burst, and pillar burst [18]. Strain burst, which is the most prevalent type of rockburst, occurs due to the sudden release of stored strain energy within the rock mass when the induced major principal stress exceeds the rock mass strength [19]. This type of detrimental failure process has been observed in deep, hard rock mines and tunnels in different locations all around the world and is considered to be the biggest unsolved problem in deep underground excavations [20]. Fault slip burst is caused by shearing on geological structures like faults and dykes, and shear failure is the mechanism. Pillar burst depends on the size and the location of the pillars in a mine [21].

In recent decades, a common and comprehensive understanding of rockburst has gradually formed in academia, i.e., the presence of a large amount of strain energy in rocks is an internal factor of rockburst, while a dynamic disturbance is a key external factor [22, 23]. During the construction of underground projects, many mining-related events, such as blasts, vehicle-induced vibrations, stress waves from adjacent rockburst, and seismic events, can dynamically disturb highly stressed rock masses near an excavation boundary and thus induce rockburst [24]. These kinds of rockburst are usually denoted as remotely triggered rockburst or dynamically induced rockburst [25, 26].

In this paper, rockburst is classified into two major types: strain burst and impact burst, as shown in Figure 1. This rockburst classification is based on the triggering mechanisms and physical modeling approaches have been developed to reproduce them in the laboratory. Rockburst may occur in the following two conditions: (1) failure of highly stressed rock masses that store a large amount of strain energy during tunnel excavation, and (2) for less stressed and deformed rocks that store less strain energy after excavation, failure is induced by external disturbances such as blasting, caving, and tunneling in adjacent areas [27].
3. Rockburst experiment

Laboratory rockburst experiments play an important role in investigating its mechanisms. The transformation of the stress state of rock mass before and after rockburst is necessary to be considered in rockburst simulation experiment. Our laboratory (State Key Laboratory for Geomechanics & Deep Underground Engineering, Beijing) independently developed three rockburst experimental systems. The first generation strain burst experimental system to simulate the phenomenon of strain burst with a single free surface; The second generation of strain burst experimental system to simulate the strain burst with multiple free surfaces; The impact rockburst experimental system is used to simulate rockburst caused by impact disturbance and rockburst caused by dynamic loading of jointed rock masses. Figure 2 shows the rockburst experiment system and the classification of rockburst experiment.

3.1 Strain burst experiment

3.1.1 First generation strain burst experiment system. The first-generation strain burst experiment system is shown in Figure3 [2]. Figure 3 (a) shows the main units of the machine, which is a modified true-triaxial apparatus (MTTA). Figure 3 (b) shows an overview of the strain burst experiment system.
Figure 3. Strain burst experiment system (a) Schematics of the test machine, and (b) A photograph taken in laboratory showing an overview of the test machine and the periphery monitoring instruments.

Single-face unloading strain burst experiment: The experimental loading and unloading process can be summarized as follows: (1) Loading step by step to the initial pressure state. (2) Maintain initial pressure for 30 minutes, fast unloading the minimum principal stress $\sigma_3$ in the horizontal direction, and load the maximum principal stress $\sigma_1$ in the axial direction to simulate the concentration process after unloading. The unloading surface is completely exposed, keep the state for 15 minutes, and open the high-speed photography system for observation. If burst occurs, the experiment ends. If not, it is necessary to reinstall the horizontal loading rod to simulate the stress state at the next depth. (3) To avoid the influence of cyclic loading and unloading of axial maximum principal stress on rock, $\sigma_1$ still maintains the concentration value after the last unloading, only changes the stress levels of $\sigma_2$ and $\sigma_3$, and maintains the state for 15 minutes, and fast unloading the minimum principal stress $\sigma_3$ to zero. If there is no rock burst occurs, the simulation depth will continue to increase, until burst occurs [16]. (Figure 4) (a) shows the three-dimensional distribution of amplitude and frequency in full-time domain. It can be seen that at the beginning of the experiment, due to the closure of internal voids in rocks, more acoustic emission events will occur, and more high amplitude signals will occur. In the middle of several loading and unloading stages, the amplitude will decrease, a large number of degree signals are generated when burst.

Figure 4. Single-face strain burst AE (a) Amplitude and frequency three-dimensional scatter plot, (b) Stress curve key point, and (c) AE cumulative energy key point

When the energy curve grows slowly, it indicates that local small-scale damage is occurring inside the rock. When the energy curve increases sharply, it indicates that the energy released inside the rock increases instantly, and the damage intensifies. The inflection point of the curve evolution process caused by the slow change is a characteristic point of rock damage. (Figure 4) (b) and (Figure 4) (c)
shows the key points determined by the stress loading characteristics and the characteristics of the cumulative emission energy curve of acoustic emission in the rock burst experiment. Combined with the stress loading curve, six key inflection points (T_1 ~ T_6) can be found. Energy increases sharply when the rock is loaded to depth 500m, the characteristic point is T_1; After the first unloading, the axial loading AE energy increases, the characteristic point is T_2; When the third reload simulates a 1500m deep state, the characteristic point is T_3; The axial loading energy increases suddenly after the third unloading, the characteristic point is T_4; The energy continues to increase when the fourth reloading, the point is T_5; The fourth unloading until the rockburst occurs, the energy increases sharply to the peak, and the characteristic point is T_6.

![Figure 5. Single-face unloading strain burst process](image)

Figure 5 shows a high-speed photograph of single-face unloading strain burst process. It can clearly observe the dynamic failure process of rock surface crack propagation, penetration, spalling, and fragment ejection. In case of sudden unloading a small amount of fragment ejection occurs before the specimen is destroyed, then an irregular-shaped fragment bends and falls, accompanied by louder sound. The whole process lasts for about 11 seconds.

3.1.2 Second generation strain burst system. The second-generation strain burst system has three independent loading systems. In the loading process, the four horizontal planes can be suddenly unloaded to form free surface, simulating the formation of free surface in the process of underground engineering. The performance parameters of the experimental system are listed in Table 1. Under the condition of true triaxial loading, it can be realized single-face, two-face, three-faces and, four-face fast unloading which can simulate rock burst at a roadway, roadway intersection, a pillar with three faces, and a pillar with four faces, respectively. Table 1 is the performance parameters of the high-pressure servo true triaxial rockburst experimental apparatus. Figure 6 shows a schematic diagram and a physical picture of the rockburst apparatus.
### Table 1. Performance parameters of the high-pressure servo true triaxial rockburst experimental apparatus

| Performance parameter                                      | Vertical direction | Front and rear direction | Left and right direction |
|------------------------------------------------------------|--------------------|--------------------------|--------------------------|
| Maximum experimental force                                 | ≥5000kN            | ≥2000kN                  | ≥2000kN                  |
| Range of force measurement                                 | 1~100%FS           | 1~100%FS                 | 1~100%FS                 |
| Accuracy of force measurement                              | Indication value≤ ±0.5% | <Indication value±0.5% | <Indication value±0.5% |
| Force Resolution                                           | ≤20N               | ≤10N                     | ≤10N                     |
| loading rate                                               | 10N/s~10kN/s       | 10N/s~10kN/s             | 10N/s~10kN/s             |
| Displacement control range                                 | 0~400mm            | 0~300mm                  | 0~300mm                  |
| measurement accuracy                                       | ≤±0.5%FS           | ≤±0.5%FS                 | ≤±0.5%FS                 |
| Measurement resolution                                     | ≤0.001mm           | ≤0.001mm                 | ≤0.001mm                 |
| cylinder stroke                                            | ≥400mm             | ≥300mm                   | ≥300mm                   |

**Figure 6. Second generation strain burst system**

Two-face unloading strain burst experiment: Figure 7 shows the stress transformation process of rock mass element and the corresponding loading path under the condition of two-face unloading. (Figure 8) shows the ejection failure process of the free surface of two-face unloading strain burst. The sample contains two free surfaces, left and right. From Figure, it can be seen that surface cracks, fragment peeling, fragment ejection, surface bulging, full-scale burst and pit formation on the surface are typical phenomena of strain burst damage process. The ejection failure process of the two free surfaces is not exactly the same, because of the anisotropy of the rock sample.
Figure 7. Stress transformation process and the loading path of two-face unloading

Figure 8. Strain burst process of two-face unloading

Three-face unloading strain burst experiment: strain burst occurs in long arm face or roadway on both sides of working face in the coal mine. The strain burst stress transformation can be simplified as three-sided unloading of sample under true triaxial condition. Figure 9 shows the stress transformation process of rock mass element and the corresponding loading path under the condition of three-face unloading. (Figure 10) shows the process of three-face unloading strain burst is as follows: firstly, cracks occur on two sides, with the gradual expansion of cracks, small pieces of rock flake, and when the surface cracks of rock sample extend to penetration, strain burst occurs. The time from crack to rock burst is more than one second, which means that the energy release rate of strain burst is faster and the phenomenon of burst is more intense.

Figure 9. Stress transformation process and the loading path of three-face unloading
Four-face unloading strain burst experiment: There will be pillars in the room-pillar mining method of metal mine, and the stress concentration will lead to pillar burst after excavation. The stress transformation can be expressed as four-face unloading of rock samples under true triaxial conditions. (Figure 11) shows the stress transformation process of rock mass element and the corresponding loading path under the condition of four-face unloading.

From figure12 it can be seen that the pillar burst process as follows: firstly, cracks occur at the top and bottom corners of rock samples; with the gradual expansion of cracks, small pieces of rock exfoliate; and when the surface cracks of rock samples extend to penetration, burst occurs. The time from crack to strain burst is less than 1 second, which means that the energy release rate of strain burst is faster and the phenomenon of strain burst is very violent.
3.2. Impact burst experiment

3.2.1 Impact burst experiment system. Figure 13 (a) shows schematically the main unit of the impact burst experiment system. The main unit is a dynamic true-triaxial apparatus (DTTA) which can accommodate a cubical specimen of 110×110×110mm with a tunnel-like hole inside. Each loading device for DTTA consists of a pair of loading platens and rods, a pressure cell, and all the loading devices can produce independently the wave-form dynamic loads in the three perpendicular directions. As mentioned above, a rock burst at the excavation surface can also be triggered by a remote seismic source such as blasting, roof falling, and adjacent caving, etc. DTTA was designed to create dynamic stress states analogous to that in the field. Figure 13 (b) shows a photograph of the impact burst test machine, showing the main unit and the periphery controlling and monitoring instrument (the servo-controlled stress wave loading device (beyond the figure), the data monitoring system, and the imaging system) [28].

Figure 13. Impact burst experiment system (a) Schematics of the dynamic true-triaxial apparatus (DTTA), and (b) a view of the test machine.

3.2.2 Impact burst experiment. DTTA is capable of producing the dynamic stress wave in any or all of the principal directions, providing flexibilities for investigators to design different static and dynamic stress combinations of the principal stresses (σ₁, σ₂, σ₃). With the programmed computer code, the servo-controlled DTTA dynamic loading device can simulate stress waves generated by different sources such as site excavation, blasting, caving, earthquakes. At present, sixteen types of the stress waves can be generated as shown in Table 2.

Table 2. Different impact waveforms for simulating rock burst induced by blasting, roof collapse and fault slip

| No. | Waveform name | Waveform | No. | Waveform name | Waveform |
|-----|---------------|----------|-----|---------------|----------|
| 1   | Ramp wave     | ![Ramp wave](image) | 9   | Ramp and circular wave | ![Ramp and circular wave](image) |
| 2   | Sine wave     | ![Sine wave](image) | 10  | Ramp and noise wave | ![Ramp and noise wave](image) |
| 3   | Triangle wave | ![Triangle wave](image) | 11  | Circular and noise wave | ![Circular and noise wave](image) |
Figure 14. Stress paths of impact burst

Figure 14 (a) shows a typical stress path of the impact burst in which $\sigma_1$ is stationery combined with a square stress wave and $\sigma_2$, $\sigma_3$ stationery. Granite impact burst experiments were carried out using impact burst system. First $\sigma_1$, $\sigma_2$, and $\sigma_3$ respectively loaded to 12MPa, 3MPa, 1.2MPa, and then the disturbance load (sinusoidal wave, frequency 0.5 Hz, amplitude 2.7 MPa) is applied vertically. If no rock explosion occurs, the level increases by 1 until the burst occurs. The actual stress path is shown in Figure14(b). Figure15 shown the granite impact rockburst process.

| No. | Wave Type                  | Diagram |
|-----|----------------------------|---------|
| 4   | Saw tooth wave             | ![Diagram](image1) |
| 5   | Square wave                | ![Diagram](image2) |
| 6   | Uniform white noise        | ![Diagram](image3) |
| 7   | Gaussian white noise       | ![Diagram](image4) |
| 8   | Cycle random white noise   | ![Diagram](image5) |
| 12  | Ramp and circular and noise wave | ![Diagram](image6) |
| 13  | Loading single pulse       | ![Diagram](image7) |
| 14  | Uninstall single pulse     | ![Diagram](image8) |
| 15  | Loading Laplace domain pulse | ![Diagram](image9) |
| 16  | Uninstall Laplace domain pulse | ![Diagram](image10) |
3.2.3 Jointed rock mass rock burst experiment. The phenomenon of ultra-low friction of rock mass is a feature of deep rock mass discovered in recent years, and the geological disasters caused by ultra-low friction often have a great range of damage [29]. In order to reproduce the phenomenon of ultra-low friction in the laboratory, the experiments of ultra-low friction under different experimental conditions were carried out by using the impact burst experiment system and taking the layered granite block with pore structure as the research object.

In this experiment, the direction perpendicular to the bedding is selected as the application direction of disturbance load, and the direction parallel to the bedding is the direction of speckle shooting, so the strain and deformation data on the plane in the vertical layer can be obtained. In figure 16, F1 and F2 are the friction forces on both sides of the falling block, and G is the gravity of the falling block. When \( F_1 + F_2 = G \), the falling block is in a stable state. When \( F_1 + F_2 < G \), the falling block slides down, and ultra-low friction occurs. Because the gravity of the falling block is constant, if the granite block above the hole displaces vertically and downward when the disturbance load is applied during the experiment, the reduction or disappearance of the friction force borne by the falling block is the root cause of the displacement. Therefore, the vertical displacement of the falling block can directly reflect the occurrence of ultra-low friction [30].

![Figure 15. Photographs showing the process of granite impact burst](image)
In order to study the effect of disturbance load amplitude on the ultra-low friction test results, this study used a digital speckle test to measure the surface displacement of rock samples. As shown in Figure 17 (a), we selected 48 points as data sampling points, all of which are located on both sides of the granite joint. The purpose is to calculate the changing trend of joint gap width with time during the experiment. Figure 17 (b) is the position diagram of the calculation points selected for calculating the gap width in this paper, in which the vertical displacement of the falling block is calculated by the coordinate data of point 25. The results of the ultra-low friction test at a disturbance frequency of 0.5 Hz and a disturbance amplitude of 0.5 mm are as follows:
Figure 18 is an experimental process picture taken by speckle equipment under the experimental conditions of a disturbance frequency of 0.5 Hz and a disturbance amplitude of 0.5 mm for a jointed granite sample. It can be seen from the above figure that the dropped block has a significant vertical displacement, thus reproducing the ultra-low friction phenomenon. In order to quantitatively analyze the vertical displacement of the falling block, the speckle data was processed here.

![Figure 18. Figures of test progress](image)

Figure 19. Vertical displacement of falling block and change curve of gap width on both sides
(a) Vertical displacement curve of falling block, and (b) Crack width curves of falling blocks on both sides

Fig 19 (a) shows the vertical displacement of the falling block with time, and it also verifies that the ultra-low friction phenomenon has occurred under this load condition. The first stage is before the initial stage of the disturbance before the 660s, the vertical displacement of the falling block is not obvious. In the second phase, during the test time of the 660s-1150s, the falling blocks decreased approximately linearly with time, but the rate of decrease was not fast. The third stage experienced a faster descent speed for the falling blocks in the 1150s to 1270s. Figure 19 (b) shows the change of the gap width at the point 1,2,3,4 of the sample drop block. It can be seen from the figure that the change of the gap width on both sides of the falling block shows the same phase as the vertical displacement change as the experiment proceeds. The first stage is the experimental time before the 660s. The gap between the two sides fluctuates around zero and there is no obvious change. The second stage is the
the experimental time the 660s-1150s. The four points of the gap width generally show a linear increase, but the growth rate at the left two points of the gap is significantly slower than the other three points. In the third stage, the experimental time is from the 1150s to 1270s, the width of the gap on both sides of the gap shows a significant difference. The right side continues to increase but the left side decreases. This trend also continues until the end of time.

4. Rockburst control

4.1 NPR bolt

Considering the characteristics of rockburst with a fleeting strong energy release, a negative Poisson's ratio (NPR) effect bolt was developed to mitigate and control rockburst damage. (Figure 20) shows schematically the structure of the NPR bolt which consists of the following components: a piston-like cone installed on a bolt shank (rebar), a sleeve pipe with its inner diameter slightly smaller than the large-end diameter of the cone, a faceplate, and a nut functioned as the retention device. The fixed length of the shank bar is bonded by grout. When the axial external load (tensile force) is applied on the far end (the faceplate) of the NPR bolt in the direction opposite to the anchored end, the sleeve pipe will displace in the same direction relative to the cone, resulting in an elongation of the NPR bolt. (Figure 21) shows the working principle of the NPR bolt in stabilizing the surrounding rock mass [31].

![Figure 20. Schematic of the three-dimensional view of the NPR bolt](image)
4. 2 Micro NPR bolt

Micro NPR material which needs to meet two conditions: 1 Poisson's ratio is $10^{-2}$; 2 strain material is greater than 25%. A material that satisfies the above conditions is referred to as micro NPR material. (Figure 22) shows the microscopic NPR crystals (cells) in a microscopic NPR material, as indicated by the black arrows in the figure.

As shown in (Figure 23), under the same loading conditions, the normal PR material has obvious necking. Because of the existence of NPR structural units in the micro-structure, the diameter of NPR material has no change under the same displacement condition, which has an obvious NPR effect. At the same time, the bolt has the function of non-magnetic and anti-strong magnetic field magnetization and anti-corrosion.
4.3 Test of NPR cables using simulated rock burst

The purpose of the rock burst research and the development of the NPR cable is to guide to practical project and improve safety. The NPR cable was tested at an abandoned working face, which was a mining area (Seam 7# North, No.1213 tunnel) of Hongyang #3 mine, located in Shenyang city, Liaoning province. The mining depth of Hongyang mine is more than 1,000 m. In recent years, large deformation of surrounding rocks and rock burst occurred in tunnels of the mine, which affected mining production and the safety of staff and machinery [32].

The support effects of the NPR cables are compared with that of the ordinary cables under the same geology and support conditions. Four test sections I to IV were in the No.1213 tunnel with a length of 40 and 850 m below ground surface, as shown in (Figure 24). Sections I and IV were supported with traditional strand anchor cables (Φ21.7 mm×6,500 mm), and Sections II and III were supported with the NPR cables (load capacity 350 kN, deformation capacity 6,500 mm and preload force 300 kN).

Figure 23. Microscopic NPR material effect (a) Poisson’s ratio comparison, and (b) Comparison of experimental results

After support installation, blasting cavities were excavated and blast holes drilled and filled within #3 emulsion explosives. Three test programs and the corresponding results are shown in (Figure 25). The
test programs are: (1) comparing different support effects in Sections I and II with 10 kg explosives; (2) analyzing the dynamic support strength of the NPR cables in Section III using repeated blasts (11.4 kg and 19 kg explosives); and (3) analyzing the dynamic support strength of the ordinary support in Section IV with a small charge (5 kg explosives).

![Figure 25. Comparison of the test sections before and after blasting](image)

The test results show that: (1) Section I which was supported by ordinary cables suffered obvious damage such as rock collapse and cable outstretch failure; on the other hand, the NPR cable supported Section II was stable and the deformation was under control under the same blasting intensity. This demonstrates that the NPR cables have a better dynamic loading resistance capacity than the ordinary one. (2) After repeated blasts, Section III remained stable and the deformation amount not excessive, which means that the NPR cable can absorb the energy from multiple impacts. (3) Comparing the damage conditions in Sections II and IV, it is seen that although the ordinary cables can keep the tunnel stable, some cables showed large deformation than the NPR cables with less explosives, which means the NPR cables can endure more impact energy than the traditional ones[27].

5. Conclusions
(1) Through the mechanism of rockburst induction, a classification method of rockburst is proposed, which is divided into strain burst and impact rockburst. The independently developed rockburst experiment system successfully reproduced different types of rockburst phenomena.
(2) The self-developed first-generation strain burst experiment system can realize single-face fast unloading under the three-way loading state to simulate the roadway strain burst phenomenon with single free surface, and analyze the strain burst evolution process through the AE system, record the burst process through high-speed camera system. The self-developed second-generation strain burst experiment system can realize multi-face fast unloading in the horizontal direction under high pressure to simulate strain burst with multiple free surfaces. Different types of strain burst phenomena have been reproduced through the strain burst experimental system, and it is of great significance to study the mechanism of strain burst.
(3) The self-developed impact rockburst experiment system is used to simulate the rockburst phenomenon induced by impact disturbance after tunnel excavation. A typical loading path of impact burst stress is proposed, and a granite impact burst experiment is carried out. Using the impact burst system, the rockburst phenomenon caused by ultra-low friction in the jointed rock mass was reproduced in the laboratory, and a series of studies on the ultra-low friction phenomenon were carried out through numerical speckle.
(4) A kind of NPR bolt and micro NPR bolt with negative Poisson's ratio effect are proposed. The bolt has the characteristics of constant resistance and large deformation, which can resist the problem of high impact energy caused by rock burst; by installing explosives on site to simulate rockburst. At the
same time, the impact resistance of the anchor was tested. The experimental results show that the NPR anchor has good impact resistance and can control rockburst.

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