Behavior Regularity of Dynamic Pressure based on Three-zone Structure Loading Theory for a Typical Mine

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Abstract: In terms of problems concerning safety production caused by strata behaviors in the process of digging on working face 31102 in a certain mine, the author tries to find its behavior regularity of dynamic pressure by theoretical study, field observation and practical analysis. Through dynamically analyzing deformation and failure process of surrounding rock and theoretically analyzing rule of broken and evolution of overlying rock and stress distribution based on three-zone structure loading theory, it is concluded that: First, when the thickness of immediate loading zone on 31102 working face is 60-70m, its influence distance in advance is 30-40m. The periodicity is short. When the height of delay loading zone is 280-320m, the distance is 150-170m. The periodicity is long. Second, The roof movement in low position of the working face determines the intensity of its strata behaviors. Third, the relation between digging speed of working face and energy release of overlying rock’s fracture is obtained, which is that as the digging speed gets faster, the energy and frequency of microseismic events appears liner growth. These research achievements have been applied to testing mines and the effect turns to be good.

1. Introduction
The behavior of rock burst has always been a major problem that restricts mine safety production [1-3]. Since 2011, there have been more than 20 major rock burst accidents in China, resulting in more than 200 casualties, destroying several kilometers of roadways and seriously affecting the safety of production. In recent years, the dynamic pressure of several mines in the western region has brought serious hidden dangers to the safe production of mines. Chinese scholars have carried out a series of studies on the behavior mechanism of rock burst, behavior regularity of mine pressure, and treatment measures. Jiang Fuxing[4] et al. obtained the mechanism of realizing on-site warning according to the sudden change regularity of coal before the occurrence of mining earthquakes, by means of studying the relationship between the fracture characteristics of key strata and the stress changes of coal mass. Given the increasingly serious rock burst of coal mine, Dou Linming[5] studied the energy and stress of inducing rock burst under the condition of dynamic load and static load superposition,
systematically proposed the principle of rock burst induced by dynamic and static load superposition, analyzed the changing characteristics of dynamic and static loads of coal mine and divided them into two categories, and discussed the monitoring and prevention methods of rock burst. Qi Qingxin[6], based on the existing theory and field practice of rock burst, proposed the control theory of rock burst stress characterized by unit stress gradient, centering on stress control, and conducted on-site practice of preventing and controlling rock burst, from the perspective of stress control. On the basis of summarizing the occurrence characteristics of rock burst disasters in China, Jiang Yaodong[7] analyzed the relationship and difference between rock burst and mine earthquakes, established three kinds of mechanical models: material-instability rock burst, slip-dislocation rock burst, structural-instability rock burst. The above research results have played a positive role in the prevention and control of rock burst, but have relatively poor applicability in the western hard rock mass, large and long working faces, large roadway-protection coal pillar and strong digging speed. 

Aiming at the special geological conditions in the west, based on the comprehensive analysis of frequent dynamic pressure of a certain mine, this study used the three-zone loading theory[8] to study the induction mechanism of rock burst in the western mine and behavior regularity of mine pressure, providing reference for the prevention and control of rock burst in the western mine.

2. Project Overview
The main coal seam in a certain mine is the coal 3, and the working face 31102 is the second continuous surface of the mine production. The working face has a length of 3099m and a slope length of 241m. The north is the goaf 31101, while the south side is solid coal, and the width of coal pillar between the two working faces is 20m. The thickness of the coal seam is 5.5m, and there is a sandstone roof of 22m at 70m of the roof. The average digging depth of the working face is about 560m, provided with the buried depth condition of the rock burst's occurrence. According to the identification results, the coal seam has an impact energy index of 2.41 and a uniaxial compressive strength of 26.02MPa on average, with a strong impact tendency. In addition, the average extraction speed of the working face 30102 in August 2018 reached 8.65m/day. The high-strength mining of the large and long working face easily caused stress concentration and induced rock burst.

During the extraction on the working face 31102, a total of 4 small dynamic pressure events occurred, all of which occurred on the side of the coal pillar along the roadway (air return way). The coal body appeared to be flushed out from the side of the coal pillar to the roadway, resulting in damage to the roof steel beam, sinking of the roof, bending of the unit bracket, destroy of the support system etc. The damage of the roadway after several dynamic pressures behaviors is shown in Fig. 1.

![Fig.1  Dynamic pressure diagram underground](attachment:image)

In summary, the working face has a number of basic conditions for the occurrence of rock burst, and a series of factors, such as the large and long working face, large roadway-protection coal pillar and strong digging speed, have buried hidden dangers for the later dynamic pressure on the working face. In view of the above typical characteristics, this paper applies the three-zone loading theory to systematically analyze and study the behavior regularity of mine pressure on the working surface.

3. Analysis of "three-zone height" based on the three-zone loading theory and influence distance

3.1 Estimation of "three-zone height"
According to the typical geological characteristics of the mine, the mechanism of rock burst is systematically analyzed and studied by introducing the three-zone loading theory [9]. This theory mainly analyzes the influence of the stress applied by the overlying rock on the roadway and its
surroundings in the mining project, and divides the entire overlying rock into “immediate loading zone (ILZ)”, “delay loading zone (DLZ)” and "static loading zone (SLZ)”, namely "three loading zones". The theory is mainly to study the behavior regularity of dynamic pressure on the working surface under the influence of different layers, to obtain the discrimination and division criteria for different layers controlling dynamic pressure. The model of the three-zone loading theory is shown in Fig. 2.

The thickness of the three-zone loading is determined by the mining height, the mining depth and the mining width of the working face, so it is very important to grasp the migration and evolution of the overlying strata under the influence of mining on the prediction and prevention of rock burst. Therefore, based on the existing three-zone loading theory, the development height of the three-zone loading under the influence of overburden mining is estimated by the calculation formula shown as follows[9].

\[
H_{ILZ} = \frac{h}{K_A - 1} \tag{1}
\]

\[
M_{ILZ} = H_{ILZ} \approx 10h \tag{2}
\]

\[
M_{DLZ} = H_{DLZ} - H_{ILZ} = \frac{L}{2} - 10h \tag{3}
\]

\[
M_{SLZ} = H - M_{ILZ} - M_{DLZ} \tag{4}
\]

where:
- \( h \)—the mining height (m);
- \( K_A \)—the broken expansion coefficient of the rock;
- \( L \)—the width of the goaf

The calculation based on the three-zone loading theory and the analysis of on-site comprehensive histogram determine the height of the three-zone loading, shown as follows:

Through the above comparative analysis and theoretical calculations, it can be seen that the microseismic events under the influence of the immediate loading zone are mainly distributed in the range of 70m of the roof, and the behavior of dynamic pressure appears to be short-period; The microseismic events under the influence of delay loading zone are mainly distributed in the range of 320m above the immediate loading zone and the roof of the coal seam. The existence of the thick sandstone group in high position leads to the long periodicity of the pressure under the influence of the delayed loading zone; The thickness of the static loading zone is 320m to the surface, and the main influence angle of the overburden fracture is 62°.

3.2 Analysis of influence distance in advance

For the air return way of the working face 31102, the superimposed stress of the bearing pressure in advance and the lateral stress of the goaf is the main force to induce the rock burst. Combined with the three-zone loading theory, the stress peak area within the advanced influence range of the working face is divided, that is, the distribution range of different bearing pressure in advance under the influence of three zones is obtained.

Through the analysis model of the influence distance in advance with three-zone loading theory, taking the main influence angle in advance as 62°, the influence distance in advance of the immediate loading zone is calculated and to be 32-37m; The influence distance in advance of the delay loading zone is 148-170m; The influence distance in advance of the static loading zone is about 300m, with
aperiodicity. Considering that the distance in advance of the static loading zone is far beyond the stress monitoring area and has little effect on the working surface, so it is not analyzed.

According to the measured data, the peak areas of the stress in advance of immediate loading zone and the delay loading zone are 30-40m and 150-160m, respectively.

3.3 Relationship between dynamic pressure behavior and three-zone loading model
Among the 4 dynamic pressure events occurred during the extraction on the working face 31102, 3 ones appeared in the range of 30m ahead of the air return way, within the advanced influence range controlled by the immediate loading zone. According to the microseismic positioning result, the hypocenter location is within 60-70m from the roof; The position of the other one is located at 120-150m ahead of the air return way, within the advance influence range controlled by the delay loading zone, and according to the microseismic positioning result, the hypocenter location is within 90-100m from the roof. Therefore, combined with the analysis of three-zone loading theory and on-site monitoring results, the dynamic pressure of the working surface is mainly controlled by the roof movement in low position within the immediate loading zone.

4. Influence of digging speed on the strength of mine pressure behavior
According to the statistics, when the working face has a extraction speed of 7.79 knives and a monthly extraction of 241.5 knives, a total of 283 microseismic events were received within the immediate loading zone of the overlying rock, with a cumulated energy of 2824395J; When the extraction speed of the working face is 11.9 knives and the monthly cumulated extraction is 370 knives, a total of 516 events were received, and the total energy of the events was 3951745J. With the increase of the mining speed, the vitality of the microseismic events in the immediate loading zone enhanced. Under the premise of 1.5-times increase in propulsion, the frequency of the microseismic events was added by 1.8 times, and the energy of the microseismic events was increased by 1.4 times, basically presenting a linear growth trend. The effect of the digging speed on the microseismic distribution of the delay loading zone was opposite to that of the immediate loading zone. The number of events under low-speed extraction conditions is 221, with the energy of 4517024J, and the number of events under high-speed extraction conditions is 46, with the energy of 845794J. Under the premise of 1.5 times increase in propulsion, the frequency of events was reduced to 20%, and the event energy is lowered to 19%. It indicates that with the increase of propulsion, the release energy of the overlying rock’s migration in the delayed loading zone under the influence of mining is reduced, resulting in a large amount of energy accumulation in the immediate loading zone near the coal seam, burying hidden dangers for rock burst.

Therefore, it is necessary to control the reasonable digging speed, and the daily propelling speed should be controlled within 7 knives, making the energy accumulated in the rock body with the delay loading zone in high position fully released, which is an important measure to ensure the safe extraction on the working face 31102.

5. Conclusion
1) By theoretical study, field observation and practical analysis, the thickness of immediate loading zone on the working face 31102 is 60-70m, and its influence distance in advance is 30-40m. The behavior regularity of mine pressure shows short periodicity; The development height of the delay loading zone is about 280-320m and its influence distance in advance is about 150-170m, and the mine pressure shows a long periodic law. The behavior regularity of mine pressure shows lone periodicity;

2) Through the analysis of field situation and microseismic hypocenter positioning of the 4-times dynamic pressure behavior events, the dynamic pressure of the working surface is mainly controlled by the roof movement in low position within the immediate loading zone;

3) According to the statistics, with the increase of the mining strength on the working face, the release intensity of the microseism in the delayed loading zone was reduced. On the contrary, the
released energy of the overlying rock’s migration in the immediate loading zone near the coal seam significantly increased, which has adverse effect on prevention and control of rock burst. Therefore, the daily propelling speed should be controlled within 7 knives.

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