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STUDY ON SEISMIC WAVE PROPAGATION CHARACTERISTIC OF DEEP-HOLE LOOSE BLASTING IN COAL MINE

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ABSTRACT

According to the distribution of faults in coal face, deep-hole loose blasting scheme is formulated and vibration monitoring is conducted. Obtained seismic wave attenuation rule of deep-hole loose blasting, HHT method is adopted for vibration signal decomposition to research the characteristic of spectrum and the energy distribution of the signal. Research results show that seismic wave propagation characteristic of deep-hole loose blasting accords with hard rock spread rule in Safety Regulation for Blasting, the linear component of the ligature between survey point and explosion source is the largest in the three direction components of vibration velocity, which is resulted from the difference of energy loss between different kinds of seismic wave in propagation process; the duration of blasting vibration is about 150 ms, main energy is concentrated in the low-frequency area of less than 100 Hz, and energy can be divided into several "sub-bands" with frequency distribution. According to attenuation law, the biggest single shot charge of deep-hole loose blasting in the site can be calculated inversely, and measures for reducing blasting seismic hazard in construction are proposed, which would provide a reference for the construction.

Keywords: *Coal Mine; Deep-Hole Loose Blasting; Vibration; HHT Method; Spectrum; Energy*

1. INTRODUCTION

Currently, studies on blasting seismic effect at home and abroad mainly focus on the aspects of surface rock-soil, open-air mining[1、2], tunnels[3、4] and metal ores[5、6], while the research data on underground blasting vibration in coal mine are precious little, Document [7] analyzes the influence of blasting seismic effect on coal and gas outburst, and Document [8] analyzes the influence of blasting vibration of working face on the stability of chamber.

In the coal mining process, due to the complexity of engineering geology, deep-hole blasting technique has been applied in many places, such as gas extraction in coal face[9、10、11] , overhead caving [12、13、14] , dispose of thick hard parting and fault in coal seam[15] and so on; the depth of blastholes ranges from ten meters to dozens of meters, single shot charge is between 20 ~ 50 kg, and a small number of which would arrive at hundreds of kilograms.

A mine coal face is influenced by faults, and deep-hole loose blasting is proposed to blast rocks after scheme comparison, so as to realize mechanized propulsion, reduce costs and save time. Through preliminary design, the single shot charge amounts to 150 ~ 200kg, the total shot charge is above 500kg, and the shortest distance from the cutting is 25 ~ 30m. In order to avoid the hidden dangers to safe production and ensure the stability of the roadway rock (coal) mass around the blasting area, 1 to 2 blastholes are detonated in the initial stage of blasting construction, and blasting vibration is monitored at the same time. The propagation law of blasting seismic wave of the site is studied, and HHT method is adopted for the tested vibration signal decomposition to research the characteristic of spectrum and the energy distribution, to provide a reference for the parameters design of deep-hole loose blasting and the construction optimization.

2. DEEP-HOLE BLASTING TEST ON SITE

The coal face is influenced by faults, 55m-long rock section is located along the wind roadway, the

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main lithologic character is medium sandstone, and the ruggedness coefficient f=8~10. Deep-hole loose blasting is conducted in the wind roadway, blastholes are arranged in three rows, rows of the upper and lower level are charging hole, the holes of middle row are empty, three rows of blastholes are in triangular layout, diameter of blasthole is Φ75 mm, array pitch of blasthole is 800mm, separation distance is 1500mm, and the holes are drilled along the designed working face. A row of prospect holes are firstly drilled before drilling, to explore the relationship between the fault and the seam (mainly to see the depth of the coal drilling) and determine the depth of blasthole; then, it is also to check gas situation, and these prospect holes are applied as the empty holes in blasting afterwards. Special shot volume —diameter is Φ63mm and weight is 3kg / m—is applied, with three-level coal mine water gel explosives and millisecond delay detonators inside. Blasthole depth, shot charge of the largest segment, detonating number of blastholes and some other parameters at each blast are shown in Table 1, and vibration monitoring is conducted at the same time of blasting.

Tab. 1 Basic Situation Of Blasting Working

Number	1	2	3	4	5
Largest Blasthole Depth /m	30	33	46	42	41
Longest Shot Charge Length /m	23	25	38	32	33
Largest Detonation Shot Charge of Single Section /kg	69	75	114	96	99
Total Detonation Shot Charge /kg	69	138	165	96	168
Detonating Number of Blastholes at One Time	1	2	2	1	2
Segments of Detonator	2	2、5	2、5	2	2、5

3. VIBRATION MONITORING OF DEEP-HOLE BLASTING

3.1 Selection of Test Instrument

Blastmate Series III vibration monitor is selected as blasting vibration test instrument, and the physical quantities need to be tested are vibration velocity, acceleration speed and frequency of particle. And the test components at vertical (V) direction, linear (L) direction and tangential direction (T) need to be recorded at the same time.

3.2 Vibration Survey Point Arrangement of Blasting

Survey point is arranged at the foot of roadway in the blasting side, the relative positional relationship of the survey points and the detonating blasthole is shown in Figure 1, the specific distance from the survey points to the tunneling blasting face at each blasting and the test results are shown in Table 2, Figure 2 is the waveform diagram of measured typical vibration velocity.

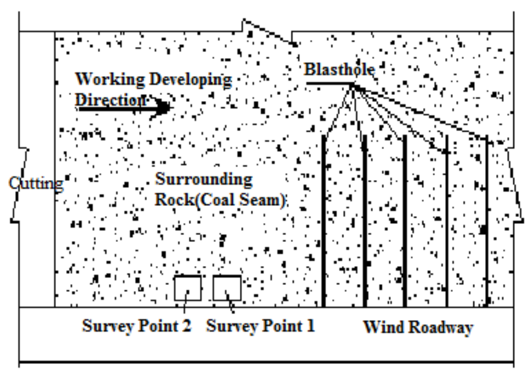

Fig.1 Arrangement Of Survey Points (Unit：M)

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Tab.2 Test Results Of Blasting Vibration

Number	Shot Charge of Single Section *Q*/kg	Range *R*/m	Vibration Velocity *V* / cm·s^{-1}				Frequency *f* / Hz		
			Tangential Direction *T*	Vertical Direction *V*	Linear Direction *L*	Resultant Velocity	*T*	*V*	*L*
1	69	15.2	3.58	1.85	4.7	5.44	26	64	57
2	69	17.6	2.07	2.26	3.68	4.72	47	73	47
3	75	19	3.2	3.38	3.91	4.84	73	47	57
4	75	21.3	2.4	3.24	3.64	4.92	43	57	39
5	114	24	2.76	3.34	2.78	4.07	64	51	47
6	114	26.9	1.75	2.08	2.54	3.82	64	51	43
7	96	24	4.32	1.82	4.14	5.02	73	64	51
8	96	27.15	2.67	2.16	2.1	3.57	73	85	57
9	99	15	3.80	2.77	4.8	5.10	117	57	86
10	99	16.5	2.20	3.78	3.82	4.16	37	57	64

4. ANALYSIS ON THE ATTENUATION LAW OF BLASTING SEISMIC WAVE

As can be seen from Table 1 and Figure 2, among the three directions, the vibration velocity peak of linear direction is the maximum and the peak of vertical direction is the minimum; vibration frequency is mainly concentrated in 40~80 Hz. It can be obviously observed from the waveform diagram of vibration velocity that the duration of vibration is approximately 150ms, and two peaks are present, which accords with the application of two segments of detonator in blasting.

Regression analysis is conducted on the measured blasting vibration resultant velocity and direction components by using Sa Road Hargreaves Formula[16], attenuation law of loose blasting vibration velocity under corresponding construction condition is obtained, and K and α value are shown in Table 2

Tab. 2 K And α Value By Regression

Site	Resultant Velocity	Tangential Velocity	Radial Velocity	Linear Velocity
K	26.3	18.4	22.7	23
α	1.17	1.26	1.33	1.29
Related Coefficient *R*	0.918	0.895	0.853	0.933

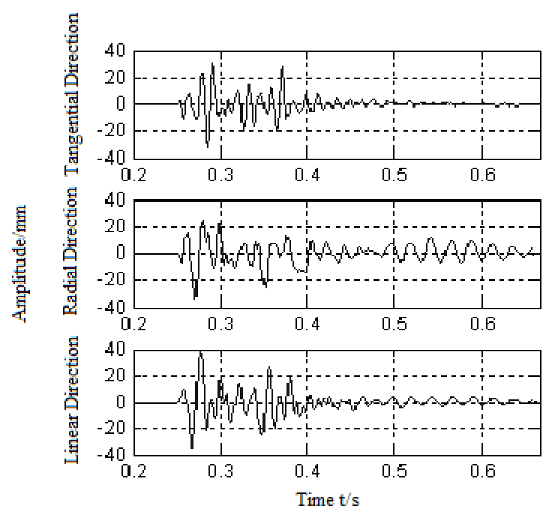

Fig.2 Typical Vibration Waveform

Comparing K and α value of deep-hole loose blasting seismic wave in Table 2 to the reference values in Safety Regulation for Blasting[17], the results show that K and α value by regression are smaller than the value of hard rock in the table. The analysis indicates that as the medium sandstone in test site is hard, its ruggedness coefficient f = 8, its completeness is good and propagation and attenuation of blasting seismic wave are fast, attenuation coefficient and index of blasting seismic wave are smaller.

Since the nearest distance from blasting location to the coal face is only 30m, the distance from blasthole orifice to rig is approximately 5m, the plugging length of blasthole is 6~8m. Safety Regulation for Blasting[18] rules that the safe vibration speed of mine workings is 15~30 cm/s.

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Considering the safety of working face and construction equipment, the safe vibration speed 25cm/s at the location of 6m is selected by combing the frequency distribution interval in Table 1; according to the K and α value of resultant velocity in Table 2, that the largest shot charge of single segment in blasting is 189.6kg can be calculated reversely, shot charge of single segment should be no more than 160kg in the actual construction, and adjacent blastholes should use different segments of detonators.

5. SPECTRUM AND ENERGY ANALYSIS

Given the linear direction component of vibration velocity is the maximum, HHT method is applied to the EMD decomposition[18] for the component of linear direction velocity in Figure 2, and 12 IMF components and a remainder R are obtained. The first four components are shown in Figure 3, and as the vibration amplitude of the remaining IMF components is very small, they are not listed. Figure 4 is the power spectrum diagram of the signal, Figure 5 is the distribution diagram of speed and frequency, and the following points are obtained through the comparative analysis of the figures.

①Component c1 is a major component of the signal, the maximum amplitude is 10mm. Energy mainly focuses within 100Hz, its frequency can be roughly divided into three bands —0~50（48.75）Hz, 50（48.75）~70（68.75）Hz, 70（68.75）~125Hz — in accordance with the undulation of PSD values, and the figures in brackets are the actual frequency of the curve in the drawing. PSD values within each band have experienced three steps of trough, crest and new trough. Among them, growth process of the third step has skyrocketed, the starting point coordinates are (68.75, 18.186), and the end coordinates are (74.25, 717.2).

② Vibration velocity amplitude of component c2 ~ c4 is in millimeter level, they are auxiliaries, frequency distribution is mainly in less than 50Hz, and PSD energy is higher.

③ By comparing the first two stages of the PSD of component c1 in Figure 3 with the first undulating phase in Figure 4, it can be seen that the frequency coordinates of each point of the first two undulating stage in Figure 8 are 0, 17.25 (first peak), 48.75 , 58.75 (second peak), 68.75, while the frequency coordinates of starting and ending point of first stage in Figure 9 are 0,16 (lowest point), 25.99 (peak), 68. Obviously, the PSD of C1 component dominates the distribution of the entire signal power spectrum.

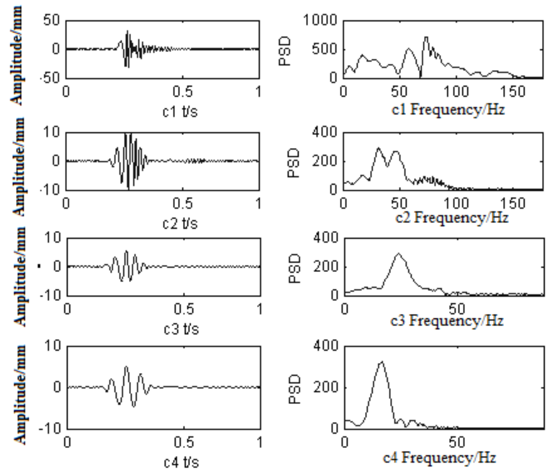

Fig.3 Result Of EMD Decomposition

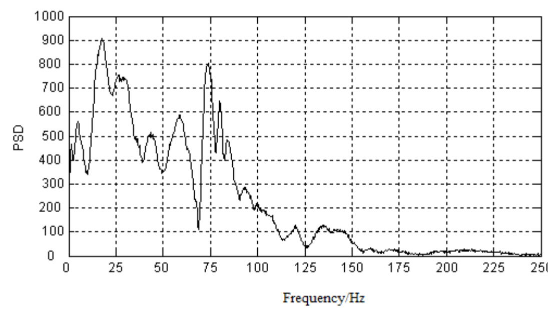

Fig.4 Power Spectrum Of Vibration Signal

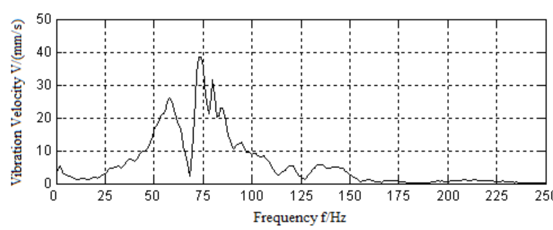

Fig.5 Relationship Between Vibration Velocity And Frequency

④ Figure 5 shows the relationship between vibration velocity distribution and frequency, which is in accordance with the vibration velocity of linear direction in Figure 2, there are two peaks and the corresponding frequency of the peak value with big vibration velocity is higher, the band of 50 ~ 100Hz is the range of higher vibration velocity (bigger than 10mm / s). At the same time by comparing with Figure 9, it is found that the amplitude value of vibration velocity is in consistency with the increase and decrease of energy with the increasing frequency when the frequency is greater than 50Hz; amplitude has an inverse relationship with the

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increase of energy with the increasing frequency when the frequency is less than 50Hz.

Figure 6 shows the change of blasting vibration signal energy over time, that is, the instantaneous energy of vibration signal. It can be seen from the figure that the vibration energy is concentrated within 0.20s ~ 0.35s, reaches a peak at 0.26s and drops to trough after about 30ms, followed by a small peak, which is in accordance with the linear direction vibration velocity curve in Figure 2. This verifies the fact that two segments of detonators are applied, with the shot charge of first segment is large and the second one is small.

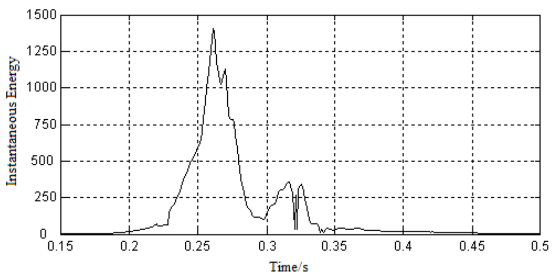

Fig.6 Instantaneous Energy Spectrum Of Vibration Signal

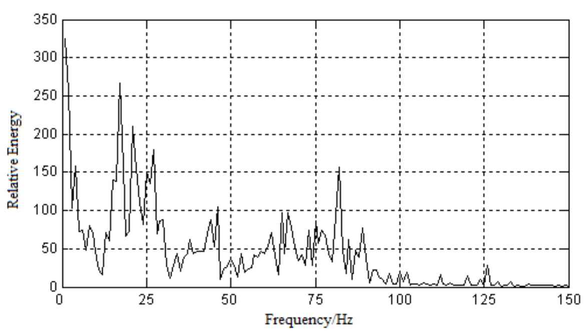

Fig.7 Hilbert Spectrum Of Margin Energy

Figure 7 is the Hilbert spectrum of margin energy, which represents the concentration ratio of energy in frequency. As is shown in the figure, the energy is concentrated within 100Hz, a number of fluctuating sub-bands are formed, the width of each sub-band ranges from 10 Hz to dozens of Hertz; obviously, a large amount of energy is concentrated in the low frequency region which is less than 30Hz, so attention should be paid in the construction.

6. VARIANCE ANALYSIS ON DIFFERENT DIRECTION COMPONENTS OF VELOCITY

Test results and waveform diagram show that for the peak value of vibration velocity, component of horizontal linear direction is the maximum, the tangential direction is the second and the vertical direction is the minimum. The analysis indicates it is caused by the propagation way of blasting seismic wave, and the explanation is as follows.

Blasting seismic wave types can be divided as primary wave (P-wave), shear wave (S-wave), Rayleigh wave (R-wave) and Love waves (L-wave) [16]. Among them, the particle vibration P-wave is the same as the direction of wave propagation; S-wave is divided into SV wave that is perpendicular to the surface and SH wave that is parallel to the surface; R-wave does elliptical motion in an opposite direction within the plane constituted by wave propagation direction and surface normal direction; L-wave does in-plane shear movement in lateral direction that is perpendicular to propagation direction. In the test, the ligature from explosion source to the survey point is in horizontal linear direction, the normal direction of ligature is tangential, vertical roadway floor is in vertical direction; thus, the energy of particle radial vibration is constituted by P-wave, SH wave and part of the R-wave energy; the energy of particle tangential vibration is from L-wave; the energy of particle vertical vibration is constituted by SV wave and part of R-wave energy. Among which, P-wave, SH wave and R-wave spread along the ligature between the explosion source and the survey point, the route is the shortest, and the energy dissipation is the least; SV wave is perpendicular to the ligature, spreads to the infinite space, and reaches the survey point with the minimum energy after multiple refractions.

7. CONCLUSION

Through the monitoring on deep-hole loose blasting seismic wave in coal mine, vibration velocity attenuation law of deep-hole loose blasting seismic wave is obtained by regression; HHT method and EMD decomposition are applied to analyze typical vibration signal, distribution characteristic of spectrum and energy is obtained. The main conclusions are as follows.

(1) Regression analysis is conducted on the test results of vibration velocity, the resultant velocity and attenuation law of different direction components are obtained, which is consistent with the propagation in hard rock; that the largest shot charge of single segment in deep-hole loose blasting is 160kg is calculated reversely, to provide a reference for the construction.

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(2) The duration of blasting vibration is approximately 150ms, and spectrum analysis shows that the main energy is concentrated in the low frequency area of less than 100Hz.

(3) EMD 12 IMF components are obtained from EMD decomposition, c1 component occupies the majority of energy and dominates the distribution characteristic of energy; energy presents several undulation sub-bands with frequency distribution.

(4) To prevent serious hazard to roadway surrounding rock and devices caused by excessive explosive in the same segment, the number of detonating blastholes at one time should be no more than 5 when the shot charge length of blasthole is longer than 30m. When blasthole depth is too large, decking in blasthole can be adopted to reduce seismic effect, meanwhile, the plugging should be strengthened.

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