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EXPERIMENTAL STUDY ON QUANTITATIVE APPLICATION OF ELECTROMAGNETIC RADIATION EXCITED BY COAL-ROCK FRACTURE

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ABSTRACT: A coal-rock uniaxial compression experimental investigation was conducted in laboratory. Electromagnetic radiation (EMR) and acoustic emission (AE) signals were gained during coal-rock fracture under different antenna types and arrangements. The results show that EMR excited by coal-rock fracture are broadband frequency, the EMR and AE signals are from the same source, but their generation mechanism is different. Under the same frequency band of antenna, the EMR amplitude from antenna parallel with crack plane is bigger than from antenna vertical to crack plane. Thus, EMR signals from developing crack propagates along the crack surfaces, which are principle contributions to total EMR signals and the EMR signals from antenna reflect the crack state parallel with receiving direction plane of antenna in coal-rock under uniaxial compression. A quantitative relationship between EMR frequency along the major crack plane and crack was derived by previous studies, which can be used into applications for coal-rock dynamic disaster prediction in the future.

INTRODUCTION

Electromagnetic radiation from materials fractured under stress was first observed by Stepanov in 1933 (Urusovskaja, 1969). The generation mechanism of EMR from rock fracturing and deformation is very complex, and is still unknown very clear today. A number of researchers attempt to explain the EMR mechanism. For example, acceleration and deceleration of dislocations (Perelman and Khatiashvilli, 1981), electro stress effects and electro kinetic effect (Гохберг, *et al.*, 1985), rupture of bonds effect (Gershenzon, *et al.*, 1985), charge and discharge of electrical dipole (Ogawa, *et al.*, 1985), compress model of atom (Guo, *et al.*, 1988) and synthesis effect of electrical dipole transient, acceleration and deceleration of electric charge (He, *et al.*, 1995). All the results of research show that electromagnetic radiation (EMF) comes from synthetic contribution of electrical dipole transient, variable motion of charge and rupture of bonds and so on. In fact, EMF is affected by internal microcosmic condition (He and Liu, 1995) and properties of materials (Misra and Ghosh, 1980; Frid, *et al.*, 1999). The research of EMR generation mechanism, which can develop the basic rock fracture electromagnetic subject, and another important task is, be applied into fields of industry. For example, prediction of geological dynamic disasters, especially, the coal-rock dynamic disasters in coal mines.

In present, the EMR applications were focused on statistic relationship between EMR and stress in macrocosm (Frid, 1997; Liu, *et al.*, 2001), and a few researches considered the quantitative relationship between EMR and failure degree of rock during deformation and fracture in microcosm or mesoscale. Because of EMR signals are abundant very much, which one kind of EMR signals is available and accurate to be used to predict dynamic phenomenon is key question. This paper try to find out the useful EMR signals and give application guide of the quantitative relationship between EMR signal and crack propagation during deformation and fracture of coal-rock. A coal-rock uniaxial compression experimental investigation was conducted in laboratory. A kind of EMR classified from abundant EMR is presented, which can be seen as useful EMR signal to predict coal-rock failure degree and a quantitative relationship between this kind of EMR frequency and failure degree is derived according to previous studies.

EXPERIMENTAL SYSTEM AND COAL-ROCK SAMPLES

Based on previous experimental system, a novel gas-loading system for coal-rock is designed and which is made of servo-controlled testing system, EMR and AE data acquisition system, load stress recording system, and EMR shielding system. Figure 1 shows a schematic diagram of experimental setup. A servo-controlled 1 700 kN testing system (MTS815.02) was used to load the specimens. The signal of EMR from coal-rock deformation and fracture is weak, and can be affected by outer environment

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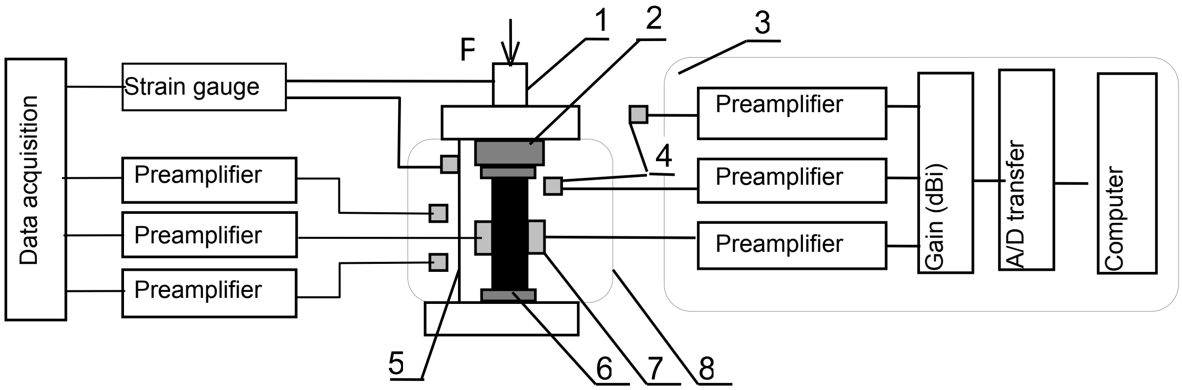
(wireless broadcast, electric machine and electricity). Thus, the forward gain is set to 40 times, a copper shielding net, the size of grid is 0.5 mm, thickness is 0.5 mm, is as shielding system, is designed and the shielding net is connected to ground. Sketch map for EMR experiment system such as Figure 1.



1-Pressure plateau; 2-Stress sensor; 3-Data acquisition system; 4-Line type EMR antenna;
5-Displacement sensor; 6-Insulating paper; 7-Acoustic emission sensor; 8-Copper shielding net

Figure 1 - Sketch map of EMR experiment system

In order to compare EMR signal of different directions from sample, four line type antennas and one circle antenna are selected, and the parameters of antenna are shown in table 1.

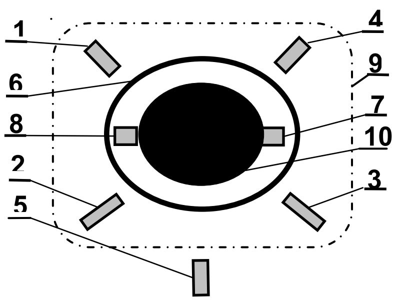
Table 1 - Characteristic parameters of antenna in experiment

No.	Antenna type	Resonance frequency (kHz)	Attenuation coefficient (K)	Remark
1	EMR antenna(Line)	150	61	
2	EMR antenna(Circle)	Broadband	39	R=60 mm
3	AE sensor	50		
4	AE sensor	150		

The samples of coal-rock were gained from several Chengzhuang coal mine in China. Ten coal-rocks were examined in this study- original coal-rock sample (hard coal-rock) from coal mine. All of cylindrical test specimens were 50 mm in diameter and 100 mm in length, with ends parallel to within ±0.02 mm.

EXPERIMENTAL DESIGN AND PROCESS

In order to obtain effects of shielding system, one EMR antennas are fixed in outer of shielding copper net. The four EMR antennas (Frequency is 150 kHz) are fixed in the shielding system, and distance away from the coal sample is 5 cm respectively. Two AE sensors (Frequency is 50 kHz and 150 kHz respectively) are fixed close to the coal-rock sample. The circle antenna is fixed around of the sample, which distance away from sample is about 3 cm, sketch map of the position for antenna such as Figure 2.



1, 2, 3, 4 and 5-line type EMR antenna; 6-circle EMR antenna; 7 and 8-AE sensor;
9-copper shielding net; 10-sample

Figure 2 - Sketch map of the position of the antenna

This test was carried out under ordinary room conditions, and loading with constant strain rate. The contents of test include:

- Study on influence of copper shielding net for EMR when loading system is working.
- Study on EMR and AE rule from deformation and fracturing of uniaxial compression on coal-rock and sandstone samples.
- Study on fracturing type and crack propagation rule of coal-rock.

EXPERIMENTAL RESULTS AND ANALYSIS

Ten coal-rock specimens were conducted in laboratory, which belong to middle hard coal-rock. Data acquisition channel 1, 2, 3, 4 and 5 correspond to antenna 1, 2, 3, 4 and 5 respectively. Channel 6 corresponds to circle antenna. Channel 7 and 8 correspond to AE sensor 7 and 8 respectively. Before starting to loading samples, EMR amplitude of line antenna inner and outer copper shielding net under working state of loading machine, results are shown as Figure 3 and Figure 4. According to a lot of group experimental results, Figure 5 to Figure 9 are examples of result for one same coal-rock specimen under uniaxial compression.

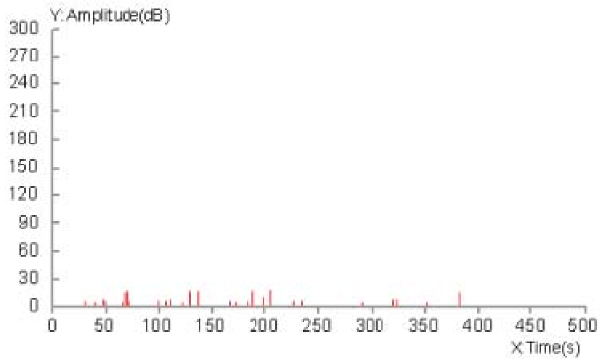


Figure 3 - Changes in EMR amplitude with time (Channel 1 is located in copper shielding net)

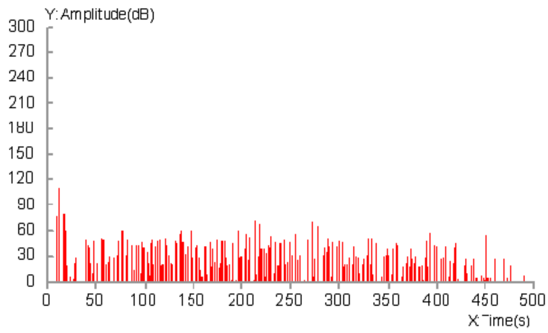


Figure 4 - Changes in EMR amplitude with time (Channel 5 is located in outer of copper shielding net)

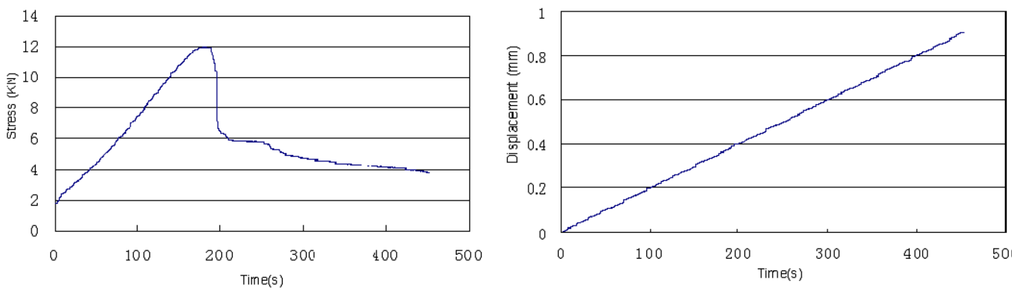


Figure 5 - Changes in stress and displacement with time

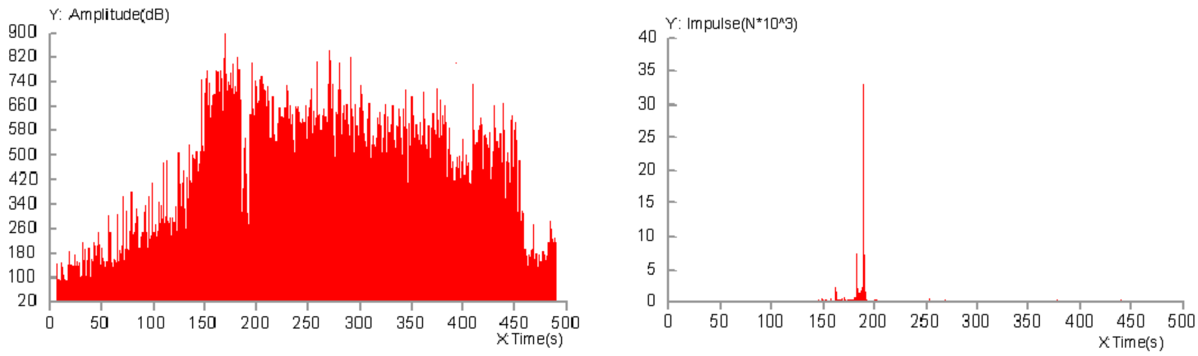


Figure 6 - Changes in AE amplitude and impulse with time (Channel 7-150 kHz)

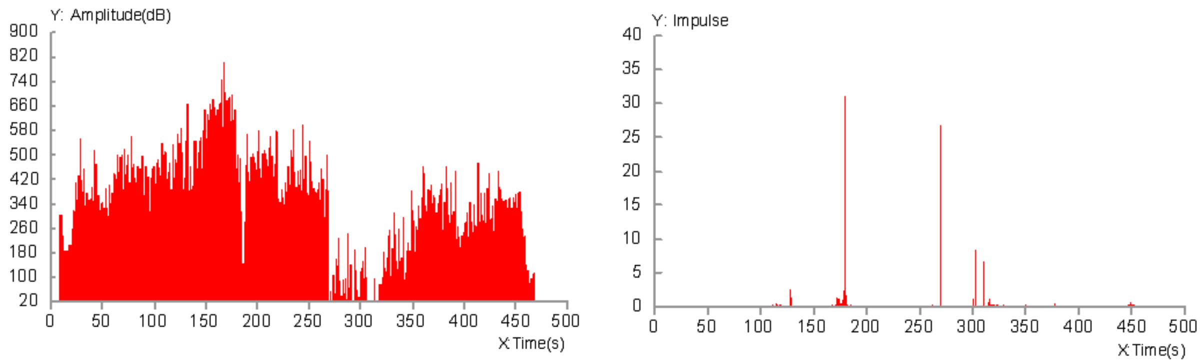


Figure 7 - Changes in EMR amplitude and impulse with time (Channel 2-150 kHz)

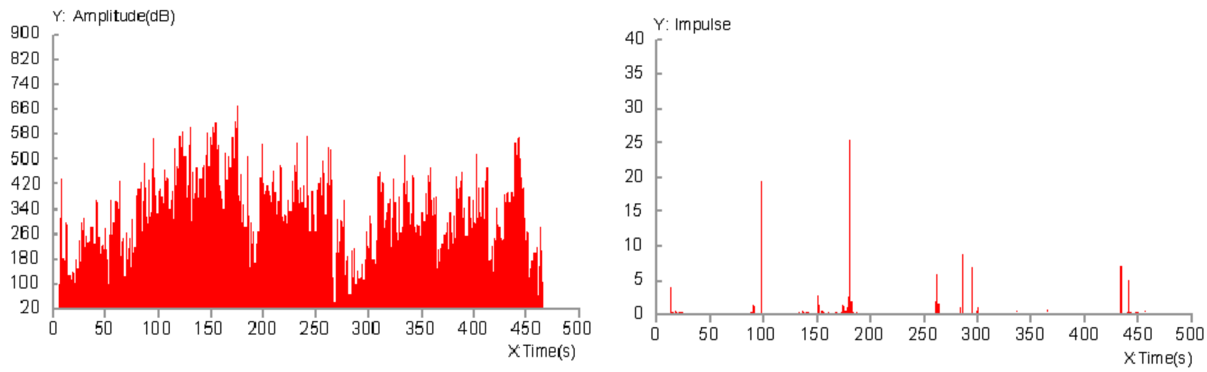


Figure 8 - Changes in EMR amplitude and impulse with time (Channel 3-150 kHz)

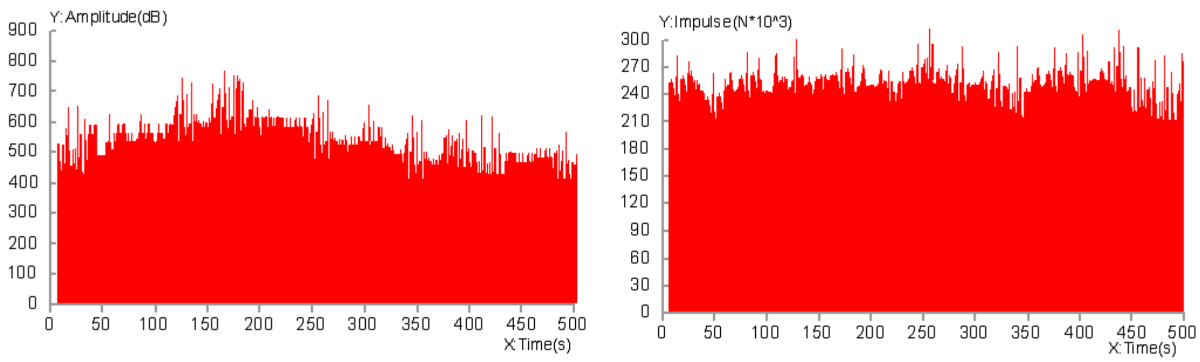


Figure 9 - Changes in EMR amplitude and impulse with time (Channel 6: circle antenna-broadband)

Experimental results were classified into several cases to be analysed based on Figures 3 to 9, such as follows:

Influence of copper shielding net to EMR events

Figure 3 is EMR amplitude changes with time, which comes from line antenna (channel 1) locating in the copper shielding net. Figure 4 is EMR amplitude changes with time, which comes from line antenna (channel 5) locating in outer copper shielding net. The EMR events from line antenna in copper shielding net is apparent less than from line antenna out of copper shielding net. Figure 5 shows that the peak of EMR event happened at around 20s of time, at the same time, the loading machine was launched. The launch of machine did not work for the EMR event changes. Thus, the copper shielding net can be used as shielding net to prohibit EMR events from outer environment.

Relationship between EMR and AE with stress

From Figures 5, 6 and 7, it can be known that the changes in EMR or AE signal are basic accordance with loading stress and displacement with time under coal-rock uniaxial compression condition, which is similar with other rock fracture. And EMR signal and AE signal are pulsed and noncontinuous mode. EMR amplitude and impulse are accordance with AE's, but not completely accordance. Thus, the events of EMR and AE are coming from the same source and the generations of EMR and AE are different.

EMR relationship between line antenna channel 2 and channel 3

Figure 7 and Figure 8 are EMR results from experiment under same loading conditions, but different acquisition positions of antenna (channel 2 and channel 3). Change trends in EMR of channel 2 and channel 3 are basic accordance with stress, but the amplitudes and impulse of EMR from channel 2 are apparent higher than from channel 3. Comparing the channel 2 and 3 antenna positions relative to specimen, channel 2 position was parallel with crack plane of coal-rock (mainly failure direction) and channel 3 position was located in the front of minor failure direction of coal-rock and vertical to crack plane.

EMR relationship between line antenna and circle antenna

Circle antenna is a broadband frequency antenna. Figure 9 shows that there are a lot of EMR events happened with variety frequency in the process of uniaxial compression of coal-rock. The EMR signals are obvious more than line type antenna received. Such as Figure 10, the fitted curve of antenna 6 is higher antenna 2 and antenna 3 received by line type antenna. Thus, though the line type antenna only can get single frequency EMR events, it can reflect the change of stress. The circle antenna can get enough EMR events, yet cannot reflect the change of stress obviously yet.

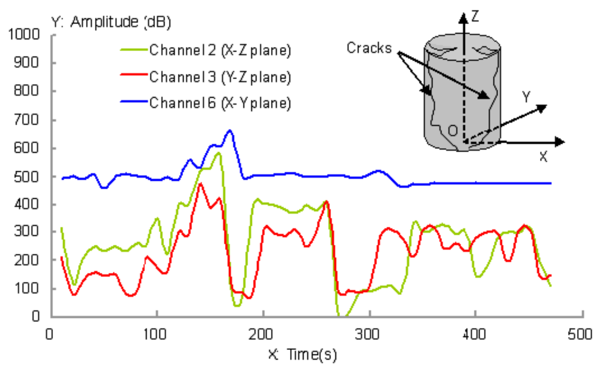


Figure 10 - EMR fitted curves from circle antenna (Channel 6) and line antenna (Channel 2 and 3)

APPLICATION DISCUSSIONS

Many researches, such as dislocations and charged electrons model (Misra, 1977; Ghosh, 1980), discharge model (Finkel, *et al.*, 1975) based on crystals splitting experiment, movement of fracture tips (Gershenzon, *et al.*, 1986) and capacitor model (Gershenzon, *et al.*, 1986; O'Keefe, 1995), which attempt to explain the origin of EMR from fracture were, unfortunately, unable to explain all the features of the detected radiation. According to critical analysis of experimental observations, a better satisfied model for generation of EMR was presented by V Frid and A Rabinovitch, *et al.* 2003, which resolve the weakness of previous models and presented EMR's characteristics. According to these models, it can be known that the EMR amplitude increases as long as the crack continues to grow. The EMR waves from developing crack propagates along the crack surfaces, which are principle contributions to total EMR signal and it's frequency is the same as that of the oscillating ions of the crack sides (Rabinovitch, *et al.,* 1998). Comparing EMR amplitudes of channel 2 and channel 3, the same conclusion is gained under uniaxial compression of coal-rock, the EMR amplitude from the line antenna in parallel with crack plane is far big from the line antenna vertical to crack plane. This law is obvious fitted better before specimen failure (time at around 180s), such as Figure 10. Thus, during the time before coal-rock failure, it is available to calculate relationship between crack and EMR.

Studies show that the atomic perturbation creating the EMR is limited by the crack width 'b' (since at both sides of the crack, atomic movements are restricted), then Equation (1) is gained (Frid, *et al.*, 2000; Rabinovitch, *et al.*, 2000).

$$\mathrm{b} \approx \frac{\lambda}{2} = \frac{\pi v_R}{\omega} \tag{1}$$

Where, v_R is Rayleigh wave velocity, ω is frequency and λ is wavelength.

Indeed, since the Rayleigh wave velocity v_R in a material with a given Young's E, poisson ratio μ and density ρ, is given by Equation (2).

$$v_R = \frac{0.87 + 1.12\mu}{1+\mu}\sqrt{\frac{E}{2\rho(1+\mu)}} \tag{2}$$

The frequency ω of EMR is derived by Equations (1) and (2).

$$\omega \approx \frac{\pi(0.87 + 1.12\mu)}{b(1+\mu)}\sqrt{\frac{E}{2\rho(1+\mu)}} \tag{3}$$

Equation (3) shows that the frequency of EMR should be inverse proportional to the crack width. Thus, considering application of EMR, the EMR frequency received by antenna in front of coal-rock can reflect the crack size inner coal-rock. The relationship between EMR (major contributions to the total EMR) and cracks can be as one potential approach to predict the state of coal-rock deformation and fracturing in front of working face in coal mines.

CONCLUSIONS

(1) EMR and AE signals measured in coal-rock fracture are similar to other rock fracture in laboratory. EMR and AE are coming from the same source and the generation mechanism of EMR and AE are different.

(2) The EMR amplitude from the line antenna in parallel with crack plane is bigger than from the line antenna vertical to crack plane. This law is obvious fitted better before specimen failure (time at around 180s). Thus, the changes in EMR amplitude before coal-rock fracture with time are available information to predict dynamic fracture inner coal-rock.

(3) A quantitative relationship between EMR along the major crack plane and crack was derived by previous studies, which is an approximate equation and may be used into applications for coal-rock dynamic disaster prediction in the future.

The research described in this paper is a preliminary effort to clarify quantitative application of EMR excited by coal-rock fracture. Because of coal-rock's property and complicated inner structure, further study of quantitative relationship between EMR and failure degree is needed in laboratory.

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