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THE FRACTAL RULE OF AE DURING THE DEFORMATION AND FRACTURE OF COAL OR ROCK

Summary. In the paper, the acoustic emission (AE) during coal or rock deformation & fracture is measured and analyzed. The results show that AE follows statistics fractal rule, and it basically exhibits gradually enhance tendency during the process. The rule is very important to the prediction of coal or rock catastrophic phenomena.

FRAKTALNY CHARAKTER EMISJI SEJSMOAKUSTYCZNEJ PODCZAS DEFORMACJI I PĘKANIA WĘGLA I SKAŁ

Streszczenie. W artykule przedstawiono wyniki pomiarów i analiz emisji sejsmoakustycznej (AE) podczas deformacji i pękań węgla i skał. Otrzymane wyniki wskazują, że emisja sejsmoakustyczna podlega prawu statystyki fraktali i wykazuje tendencję rosnącą w trakcie procesu deformacji. Prawo to ma duże znaczenie dla przewidywania katastrofalnych zjawisk dynamicznych związanych z procesami pękania skał i węgla.

1. Introduction

Deformation and fracture of coal and rock occur due to exterior and interior forces. Subsequently, the strain energy is released in the form of stress wave. That procedure is called acoustic emission (AE). The fact that coal and rock under load can yield AE signals has already been proved by large quantity of experiments and theoretical results. Some valuable achievements are also obtained in the applicable area, for example, AE used to predict burst of rock and outburst (Xueqiu, Mingju 1995), (Enyuan 1997). Also we can see, there are large application fields for AE technology: disclosing the fracture mechanism of coal and rock, predicting and forecasting the dynamical procedure of coal and rock damage, such as coal and

gas outburst, roof sink, wall rock deformation, shock bump, earth sliding, earth quake and building of rock and concrete destabilizing etc (Enyuan, Xueqiu 1999). These procedures all take place in the time of stress and strain changing of in the stage of their inoculation, prepare and development, which can cause the change of strain state. Inevitably, that will change some characteristics of AE signal. AE signals yielded due to the fracture of coal and rock under load are quite abundant. The data obtained by data acquisition instruments is in a great quantity, at random and without apparent rule. This paper's purpose is to determine AE'S changing tendency during the process and to provide a means of predicting the catastrophic dynamic phenomena.

Fractal is a new way for human thought, its central idea is the invariance and self-similarity of division. Fractal geometry has an important parameter i.e. fractal dimension. For instance, during measuring complex graph such as coastline, if r is measuring dimension, $N(r)$ is the number of measuring times. Obviously, $N(r)$ increase with the decrease of r, i.e.

$$N(r) \propto r^{-D} \tag{1}$$

On the fractal problem in fracture mechanics have been played much attention of many researches (Enyuan 1997). It is confirmed by Brown that the face of fault and joint is fractal, and that the fractural face of rock by Xie He-ping, and that the dispersion in space of acoustic emission by Hirata. Thus Fractal theory is the most likely to be the breaking through in predicting the rock fracture.

2. The fractal characteristics of AE of coal or rock

H.E.Hurst put forward the *R/S* (rescaled range analysis) method in 1965 (Youyu,Xianguo 1992). For a temporal signals of AE $\{x(t), t=1, 2, \ldots N\}$, its mean value is given by

$$\langle X \rangle_k = \frac{1}{k}\sum_{t=1}^{k} x(t) \qquad k=1, 2, \ldots N, \tag{2}$$

Its cumulative deviation by:

$$X(n,k) = \sum_{i=1}^{n}\left(x(i) - \langle X \rangle_k\right) \quad 1 \le n \le k, \tag{3}$$

Its maximum deviation:

$$R(k)=\max_{1\le n\le k} X(n,k)-\min_{1\le n\le k} X(n,k) \tag{4}$$

It's standard deviation:

$$S(k)=\sqrt{\frac{1}{k}\sum_{t=1}^{k}\left(x(t)-\langle x\rangle_k\right)^2} \tag{5}$$

Hurst found out the following relation:

$$R(k)/S(k)\propto k^H \tag{6}$$

where H called Hurst index.

The physical meanings of R/S:

When $H=1/2$, the signals of time series is an independent random series with limited variances.

When $H>1/2$, the signals of time series are not independent with increasing tendency in the past.

When $H<1/2$, the signals are negatively related, i.e. they decrease later if they reveal an increasing tendency formerly, vice versa.

The signals of time series above behave as fBm, random stroll or just same as the height changes in a track. Random stroll has already been tested comforting to fractal of self-affinity (Youyu,Xianguo 1992).

Assuming time series $\frac{R(\tau)}{S(\tau)}$ defined in time domain T, if $\frac{R(\tau)}{S(\tau)}=E(\tau)$, one obtains:

$$E(T)\propto T^H \tag{7}$$

First considering a rectangular box with T of width and h of height, dividing the T into number n domains, i.e. $T_n=T/n$, then a smaller box is considered with T_n of width and $E_n=E_T/n$ of height, which has the same ration of height to width but different E_{T_n} with E_n, $E_{T_n}=E(T_n)=E(T/n)$. The box number N_n needed to cover the area of $T\times E_{T_n}$ with box of $T_n\times E_n$ is:

$$N_n=\frac{T\cdot E_{T_n}}{T_n\cdot E_n}=n^2\frac{E_{T_n}}{E_T} \tag{8}$$

from equation (7):

$$\frac{E_{T_n}}{E_T} = \frac{E(T/n)}{E(T)} = \left(\frac{T/n}{T}\right)^H = \frac{1}{n^H} \tag{9}$$

on substitution of equation (9) into equation(8)

$$N_n = n^{2-H} = \left(\frac{T}{T_n}\right)^{2-H} \tag{10}$$

comparing T_n and r_n, equation (10) is the basic equation of fractal. Again comparing equation (10) and equation (1), it is found that:

$$D=2-H \tag{11}$$

equation (11) is the relationship between fractal dimension D and Hausdorff measure or the Hurst index H.

3. The fractal statistics rule of AE during the deformation and fracture of coal or rock

Upon the suitable rearrangement of equation (6), one obtains:

$$H = d\log(R(k)/S(k))/d\log(k) \tag{12}$$

The equation (12) shows that Hurst index H is the tangent of curve of **log** *(R(k)/S(k))* to **log** *(k)*. H can be obtained by regression analysis of the experimental data using equation (12). Fractal dimension D can be calculated by equation (11). Fig.1 shows the statistics result of the pulse number of the longitudinal wave (P, fig.1a) and the transversal wave (S_1, fig.1 band S_2, fig.1c) of AE within a period of time during deformation of sample coal 6# from kongzhuang. The R represents the regression coefficient. The calculating result of different characteristic waves of AE is given in Table 1.

Table 1

Results of R/S statistics and fractal analysis of AE of raw coal sample
(No.6, from kongzhuang coal mine)

Characteristic wave of AE	Longitudinal wave P	Transversal wave S_1	Transversal wave S_2
Hurst index *H*	0,65	0,54	0,71
Fractal dimension *D*	1,35	1,46	1,29
Regression coefficient *R*	0,98	0,97	0,98

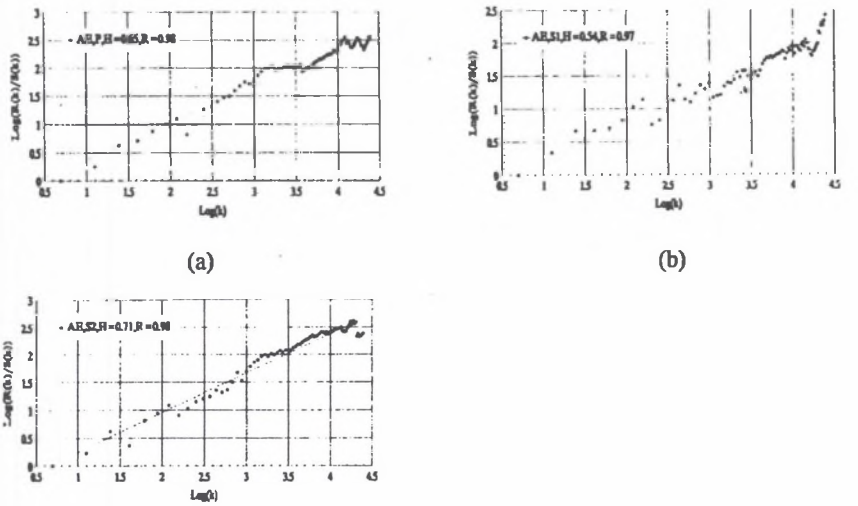

Fig.1. The statistical rule of AE of raw coal sample (No.6, from kongzhuang coal mine)

Fig.1 shows the statistics result of the pulse number of the longitudinal wave (*P*, fig.2a) and the transversal wave (S_1, fig.2 band S_2, fig.2c) of AE within a period of time during deformation of sample coal 2# from huainan. The *R* represents the regression coefficient. The calculating result of different characteristic waves of AE is given in Table 2.

Table 2

Results of R/S statistics and fractal analysis of AE of moulded coal
(No.6, from huainan coal mine)

Characteristic wave of AE	Longitudinal wave P	Transversal wave S_1	Transversal wave S_2
Hurst index *H*	0,66	0,55	0,95
Fractal dimension *D*	1,34	1,45	1,05
Regression coefficient *R*	0,94	0,96	0,95

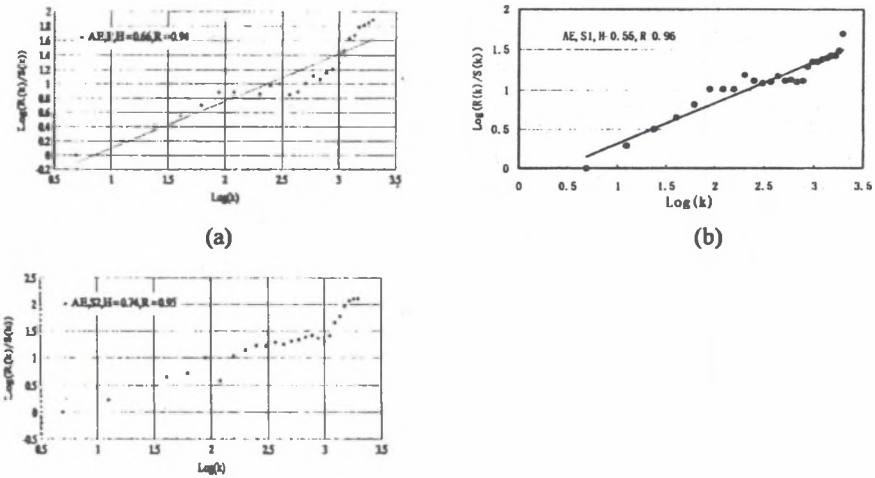

Fig.2. The statistical rule of AE of moulded coal (No.2, from huainan coal mine)

From Fig.1, Fig.2, Table1 and Table2, it is found that the characteristics wave of AE conforms to Hurst statistics rule and fractal rule during deformation and fracture of coal, with fractal dimension D between 1,0÷1,5, and regression coefficient R above 0,94. Present results show that AE exhibits gradually enhance tendency during the process with the increase of the deformation and fracture. The statistics fractal rule of AE provides a new means of predicting the catastrophic dynamic phenomena of coal or rock. But we can also see, the Hurst index of different characteristic waves of AE are also different. The biggest Hurst index is the transversal wave, S_2, is, then of the longitudinal wave P, the smallest is the transversal wave, S_1. That means that S_2 increases much more apparently in erect the direction of axial stress, and that S_1 increases much more slowly in the parallel direction of axial stress. The reason may be derived to the influence of axial loads and flaws. Under the condition of single axle compression, the flaws spread along the axis. Although different characteristic waves have different Hurst index, the Hurst index s, H, are all between 0,5 and 1,0. Therefore, the AE of coal outburst also has a much more perfect Hurst statistic law. This also shows: when coal is deformation under loads, acoustics emission signals scale with the loads (deformation).

The Hurst statistic rule and fractal rule of AE signals in the procedure of rock and coal outburst provides new means and methods to predict and forecast the dynamic phenomena of coal and rock's damage. We can see, from the results, it is much better to choose the transversal wave of erect axial stress, S_2, as the study object under the condition of single axial

stress. Yet, the longitudinal wave spreads fast, and can be easily received (Jiankai, Qianlin, 1993). In the practical spot, because the work face is under a much more complicated three axial stresses condition, it needs further study to choose a characteristic wave that is much more appropriate for analysis of the statistical and fractal rule.

4. Conclusions

1. AE signals yielded due to the fracture of coal and rock under load are quite abundant, and conforms quite well to the statistics fractal rule, with fractal dimension D between 1,0+1,5, Hurst index, H, are all between 0,5 and 1,0.
2. AE is positively correlated with the charge and deformation i.e. AE enhances with the increase of deformation. The statistics fractal rule of AE signals yielded during the break of coal and rock provides new methods and means that can be applied to predict and forecast the coal and rock dynamical phenomena.
3. To apply the statistical fractal method to the practical prediction, there is much work to do. This paper is just a basic study.

REFERENCE

1. He Xuieqiu, Liu Mingju: Fracture electromagnetic dynamics of coal or rock containing gas. China University of Mining & Technology Press. China, Xuzhou. 1995.
2. Wang Enyuan: The effect of EME & AE during the fracture of coal containing gas and its applications [Doctorate thesis]. China University of Mining and Technology. 1997.
3. Wang Enyuan, He Xuieqiu, etc: Experimental research and R/S statistic analysis of AE during the fracture of coal and rock. Tournal of China Coal Society, Vol.24. No 6. 1999.
4. Jin Youyu, Meng Xianguo: The quantitative analysis of geological time series. China Geology Press. 1992. 120-140.
5. Hu Jiankai, Zhang Qianlin: Theory and method of ultrasonic inspection. China University of Science and Technology Press. China, Hefei. 1993. 14-15.

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Podsumowanie

Emisja akustyczna (AE) już od dawna była wykorzystywana do ostrzegania przed dużymi wstrząsami górniczymi. Niszczone skały emitują zarówno fale podłużne typu P, jak i poprzeczne typu S, spolaryzowane równoległe S_1 i prostopadle S_2 do osi przyłożonych naprężeń. Emisja akustyczna podlega rozkładowi fraktalnemu i może być opisana przez wykładnik Horsta powiązany z wymiarem fraktalnym zbioru sygnałów akustycznych.

Prowadzone badania pokazują, że za najlepszy predyktor może być uznany wykładnik Horsta fal S_2.