Feasibility Study on the Prediction of Coal Bump with Electrical Resistivity Method[1]

Wang Yungang, Wang Enyuan, Li Zhonghui, Liu Xiaofei, Liu Zhentang
School of Mining and Safety Engineering, CUMT, Xuzhou, Jiangsu (221008)
E-mail：cumtwyg@163.com

Abstract

The resistivity experiment of rock and its application were narrated in this paper. According to the method, the electrical resistivity method of predicting coal bump was brought forward. Experiments results are as follows: (1) the resistivity of horizontal stratification are smaller than that of vertical stratification, (2) the electrical resistivity values of coal sample under unsaturated state amount to about half of the nature state values, (3) the electrical resistivity changes of coal samples in the uniaxial compression show that coal samples' electrical resistivity decreases with increasing uniaxial compression press, and begins to increase while reaching half of rupture press, and the electrical resistivity increase continuously if keeping on loading until rupture.

Electric mechanism of loaded coal smaples and mechanics mechanism of coal bump were analyzed and gain the inherent relationship between the electrical resistivity changes and the fracture process of coal. The quadratic fitting stress-electrical resistivity function of under the uniaxial compression is more reasonable. Therefore, the method with electrical resistivity anomaly to predict the occurrence of coal bump is feasible.

Keywords: coal bump prediction; stress changes; coal samples; electrical resistivity; feasibility

1. Introduction

The electrical resistivity is a vital electric parameter of rock. The foreign and domestic scholars have done the massive work, which include experiment investigation of the electrical resistivity change in loading rock rupture and its application in predicting earthquake and the collapse prediction of rock mass.

Brace and Orange[1] measured the electrical resistivity changes of water-saturated igneous rock and sedimentary rock samples during their cracking under the application of pressure with two electrodes, obtained its reduction over an order of magnitude and the variation which mostly being at the half of the failure stress. So they proposed rock electrical resistivity changes could reveal the details of rock fracture process and to a greater extent send out impending warning information. Пархомеи ко И. Ф. and Bondarenko observed the electrical resistivity change of the diabase, basalt and peridotite in uniaxial compression stress reducing at 5%-30%, which is far less than half of the rupture stress[2]. Dokoupil et al . reported the electrical resistivity change of dried granite and diabase on the impact of uniaxial stress (1MHz) in 1967. Yamasaki Yoshio proved experimentally the abnormal electrical sensitivity along with a kind of special tuff strain and its electricity changes with stress[3]. Qian Jiadong et al . indicated before impending earthquake the electrical resistivity anomaly was not a direct result of the temperature effect during the development of earthquake process. In such cases, stress variation become possibly a more important factor[2]. The experiments results from Chen Dayuan, Feng Chen, An Jinzhen are as follows: (1) the whole shape of the electrical resistivity changes of both experiments with water replenishment or not are similar. (2)the directivity of the change of electrical resistivity is obvious. (3)during loading pressure, the anisoeropic main axis direction of the electrical resistivity varies with the increase of the pressure and such varies are regular jump change [4~9]. Hao Jinqi[10~11]also indicated the apparent resistivity of rock usually shows marked variations under the application of

1 This study was supported by National Natural Science Fund (50427401), National "973" Project (2005CB221505), National "The Fifteenth" Science Key Project (2004BA803B0105).

pressure and the electrical resistivity tomography was introduced to the present simulating experiment at every stage of the electrical resistivity measurement experiment of magnetite-quartzite rock sample. The images well reveal the microscopic structure in the medium and explain the reason of changes of apparent resistivity. Du Yungui in Chongqing University studied the electrical conductivity of the coal from Nantong colliery[12]. Chongqing branch China coal research institute studied the dielectric constant and the electrical resistivity of 8 different types of metamorphic coal samples from the different coal colliery in China[13]. He Jishan of Central South University et al . built an advanced and practical surveying system for measuring the electrical properties of the outburst coal mainly by means of digital dual frequency IP instrument, and researched the electric conductivity nature of outburst coal[14].

In 1970, in order to monitor and analyze the changing law of stress field and rockburst in Lubin copper mine, Polish scholar stopinski et al . observed the resistivity varies of rock. It is the first that recorded and analyzed the resistivity varies at the impending of a rockburst[15]. Geophysical research office in Peking University tested the resistivity varies of the silicified limestone sample in uniaxial experiments and in-site experimental study with the press increasing in Hunan province in 1978, the observation results are similar to

the electrical effect in earthquake preparation[16].

Researches show that the development of earthquake is firstly a mechanics process. In the process of earthquake's preparation, stress concentration, strain energy accumulation and fault displacement and other factors will cause a variety of physical and chemical changes of this nature. Moreover, the stress changes in the shallow and deep crustal earthquake preparation process may be more important than other factors, which cause the change of the resistivity anomaly before the earthquake. The physical foundation of ground resistivity method for earthquake prediction is based on the intrinsic relationship between stress changes of rock masses in earthquake preparation and their electrical variation[2].

Coal bump is a kind of mine earthquake induced by mining activities, whose stress mechanism is the same as that of earthquake preparation. Coal bump prediction is to make a judgment on different risk level of dynamic disasters prior to their occurrence. To some extent, the resistivity mothed may provide a new geophysical method for coal bump prediction. However, study on the resistivity varies of coal, which has coal bump proneness, is still a blank at home and abroad.

Based on these, uniaxial compressive experiments on resistivity vary rules of coal samples with coal-bump proneness and the electrical resistivity mechanism of them under uniaxial compressive pressure are studied. It is proved feasible to predict occurrence of coal bump with the electrical resistivity anomaly varies.

2. Experiment Principle

2.1The electrical resistivity experiment of loaded coal samples

Huating coal mine in Gansu province had once several coal bumps, 5 coal samples were from the working face of the colliery. Cylindrical-shaped coal samples length are 16.8cm, 17.8cm, 18.4cm, 16cm, 15.4cm respectively and are 5.0 cm in diameter. The top surfaces of coal samples are parallel to the bottom made of coal, and both surfaces are smooth so that they can well contact with the insulative plates and are under stress uniformity.

2.1.1Experiment method

Experimental apparatus include mainly press machine, concrete resistivity tester(resitets-4000) and a computer. The screen displaying result of resitest-4000 is the electrical resistivity of the coal samples.

Firstly, test the electrical resistivity of the unloaded coal samples at room temperature with Resitest-4000 from 4 lines, as shown in Fig1. The test results are as reported in Table 1. In the process of testing prevent the water in sponges flowing down, or else the flowed-down water can conduct with the next electrode, resulting in the inaccurate result. Then make coal samples immersed in water for 24 hours, and test the electrical resistivity of moist coal samples with DC electrical instrument, as showed in Table 2.

Table 1 The electrical resistivity of coal samples in natural state

Sample number / Electrical resistivity	1#	2#	3#	4#	5#
Line 1	12700	13380	5070	18500	17920
Line 2	12220	10110	5160	14410	11610
Line 3	16600	14630	4700	16610	17800
Line 4	10400	9840	5110	16380	14050
averge	12980	11990	5010	16475	15345

Table 2 The electrical resistivity of coal samples in unsaturated state

Sample number	1#	2#	3#	4#	5#
Electrical resistivity	5511.674	5980.517	2973.843	9828.864	9798.328

A uniaxial compressive experiment system on electrical resistivity measurement of coal samples with coal-bump proneness is established, which is shown in Fig.2. Dry 1#、4＃、5＃coal samples at room temperature, and put them on a cap of press machine and insulating pads on both sides of the coal sample. Start press machine, and make the cap contact close with the insulating pads. Due to restriction of experiment condition, during the uniaxial compressive process the electrical resistivity test line is shown in Fig.3.

When the pressure reached respectively 0.1*kN*,1*kN*,2*kN*,3*kN*,4*kN*,5*kN*,6*kN*,7*kN*. 8*kN*,9*kN*, make the press pause and maintain the pressure value, immediately recording electrical resistivity value, then increase the pressure till the unstable failure of the coal samples occur. Regard the average electrical resistivity of the 3 lines as the electrical resistivity of the coal sample, as shown in Fig.4-6.

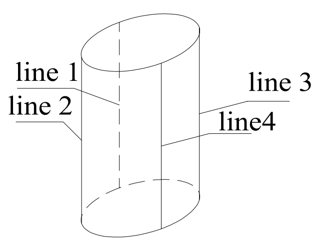

Fig.1 Test line

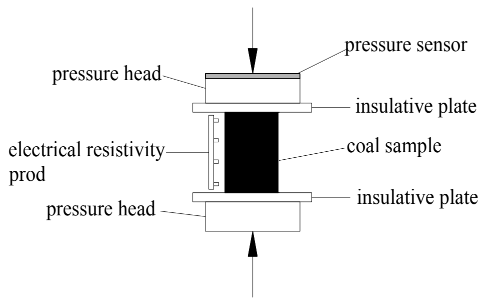

Fig.2 Experiment system

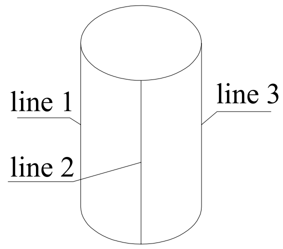

Fig.3 Test line

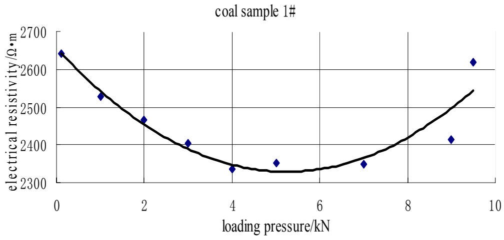

Fig.4 the electrical resistivity of 1＃ coal sample

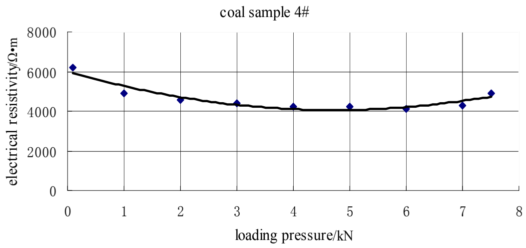

Fig.5 the electrical resistivity of 4＃ coal sample

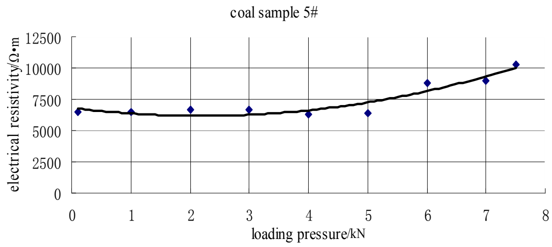

Fig.6 the electrical resistivity of 1＃ coal sample

By comparison, The fitting stress-electrical resistivity function of under the uniaxial compression is quadratic to be more reasonable, as shown in Table 3.

Table 3 The fitting function between stress and electrical resistivity

Coal sample number	Fitting functions	correlation
1＃	$y = 17.024x^2 - 181.96x + 2827.4$	$R^2 = 0.9158$
4＃	$y = 88.062x^2 - 830.57x + 6013.9$	$R^2 = 0.8926$
5＃	$y = 136.37x^2 - 596.61x + 6821.8$	$R^2 = 0.891$

2.2 Analysis of Experiment results

From Table1, the resistivity difference of the coal samples between diagonal lines is relatively small, and the adjacent lines is relatively large in resistivity, which indicates the resistivity of horizontal stratification are smaller than that of vertical stratification.

From Table 1 and Table 2, coal samples soaked are under unsaturated state, due to physichemistry effect of the water, the electrical resistivity values decrease to half of the nature state. Coal is a kind of special sedimentary rock, with the existence of a large number of pores, cracks, where there are various minerals and liquid mixing materials, and by reason of capillary effect and hydraulic wedging force, which make micro-pore the capacity of absorbing and saveing water, some minerals dissolved in water, which form conduction circuit, which obviously make the electrical resistivity decrease.

Fig.4-9 show that with the pressure increasing, the electrical resistivity of coal samples decreases. Arriving at about half of rupture stress, the electrical resistivity is the minimum, and continue loading, the electrical resistivity increase resistance, finally being broken compressively. Under uniaxial compression conditions, the biggest change rate of coal samples' electrical resistivity is 11.5%, 32%, 38.7%. After the rupture of coal samples and ejecting fractured coal blocks, go on loading, the electrical resisitivity will continue to rise. This fully shows the mechanism of the fracture coalescence in the failure process of coal samples is an important factor resulting in the electrical resistivity changes of coal samples.

In short, the electrical resistivity changes in the rupture process of coal well reflect the mechanism of the fracture coalescence and the characteristic of the internal structure changes. This fully shows there must be a significant relationship between the electrical resistivity change of the coal samples and the compressive stress under uniaxial compressive conditions. In other words, for the compressive stress effect, space section changes of the pore and whether solution is formed by pore water and cements and their concentration lead to the electrical resistivity change of coal samples.

3. Feasibility of the Prediction of Coal Bump with Electrical Resistivity Method

3.1 Electric Mechanism Analysis of Loaded Coal Smaples

First of all, loaded coal samples enter into the nonlinear compression and linear elastic stage. In these two stages, natural defects (microcracks, microporosity) and epigenetic cracks existing in coal samples are gradually closed under compressive press, lead to changes in its internal structure—even closer contact between the particles, pore volume dwindling, growing proportion of water, forming a partial saturation state, the resistivity decreases, when reaching about half the peak of compressive stress, the resistivity of coal samples is minimum. During the developmenting stability stage of the microcracks in coal samples, with the compressive stress increasing and due to the high stress state of the ends of preexisting and secondary cracks or defects, local stress concentration zones are inevitably formed and shearing action of the fractures are increasing, which lead to primary cracks development and new fissures forming. At the moment, the formed conductive liquid commonly is impossible to inpour into the cracks in time. Therefore, the resistivity of coal samples is increasing gradually.

With keeping on the compressive press increasing, the fissures in the coal samples develop rapidly along the parallel and diagonal direction of fissures. Thus, the loaded coal samples enter into unstable developing stage of the fissures, some coalescence cracks in some part of the coal samples form macro-fissures, sequentially enter into fissures accelerated fraturing stage until rupture, because of this the resistivity of coal samples increase. If main macro-cracks are increase greatly, which lead to a very large resistivity.

According to the different conductivity nature of coal, there can be divided into two types－electronic conductivity and ion conductivity. Electronic conductivity of coal depends fundamentally on the free electronic in the basic material ingredient of coal. The ion conductivity is on ionic conductivity of the pore solution of coal. Under certain stress, the internal structure of coal samples change, the roles lie in two aspect: (1) the space between molecules of coal samples is becoming narrow, which makes ions transition more harder, and the ionic conductivity is weaken; (2) the increasing stress make the electron clouds between molecules overlapped, which results in the migration increase. Under uniaxial compression conditions, the first two states belong to low-stress, which is largely based on ionic conductivity, electronic conductivity secondarily. In the later two stages because of fractures occurrence chemical bonds in the coal samples are undermined, and particle radiation was produced, so it mainly on electronic conductivity, ionic conductivity secondarily.

3.2 Mechanics Mechanism of Coal Bump

From the viewpoint of mechanics, coal bump is a special process of physical mechanics, the earthquake early preparation process can be regarded as quasi-static process, late preparation process and its occurrence are dynamic. That is to say, it is a process from quasi-static deformation to rupture. In the mining process, the overlapped stress between the mining stress and tectonic stress act on coal mass. When the stress is within the elastic range, the fissures are closed for compressive press. When the stress is beyond its elastic limit, high stress zone and a number of new fissures must be formed in coal mass, which lead to internal structural change in coal mass. The resistivity of coal mass varies subsequently. When load keep on increasing or the formation of micro-cracks due to mining activities, the injury can be transmitted to weakening and damaging the coal or rock around and result in their deformation and partial fracture. Ultimately, the external disturbance break the mechanics equilibrium state, and the high stress of internal coal mass reduce suddenly from maximum value to theoretically zero value, and make rock mass brittle failure and part of them eject, resulting in release of accumulated elastic energy. In the process, the resistivity of coal or rock mass changes inevitably, whose vary rules is similar to that under uniaxial conditions.

Study the rupture process of coal and rock resistivity characteristic is the precursor to the impact resistance prediction method based on the physical pressure. For the underground rock coal, mining is a set before resistivity values. Mining, due to deformation and failure to changes the internal structure of coal and rock, humidity changes. Thus, there is a change in resistivity.

The above studies show, the resistivity changes of coal mass can well reflect the stress state of coal mass and the mechanism of the fracture coalescence. Therefore, survey the resistivity vary in different time or location near the laneway or stope and analyse their laws, may judge the stress state of coal mass and its deformation and rupture process, and predict current and future danger tendency in some region. Meanwhile, destress blasting, coal seam effusion and oriented fractures are the effective way to prevent coal bump occurring. However, in factual projects the test effect of these mothods lack of effective approachs. The resistivity method will undoubtedly provide a new way for these.

4. Conclusion

The experiments about rock samples' resistivity and their effective application were analyzed. Based on these experiments, an innovative idea to predict the coal bump is brought forward.

A experiment system about testing the electrical resistivity of coal samples with the changes of stress is established. Experiments results are as follows: (1) the resistivity of horizontal stratification are smaller than that of vertical stratification; (2) the electrical resistivity values of coal sample under unsaturated state amount to about half of the nature state values; (3) the electrical resistivity changes of coal samples in the uniaxial compression show that coal samples' electrical resistivity decreases with increasing uniaxial compression press, and begins to increase while reaching half of rupture press, and the electrical resistivity increase continuously if keeping on loading until rupture.

By analyzing the experimental results, we can gain that the method with electrical resistivity anomaly to predict the occurrence of coal bump is feasible.

References

[1] Brace W F. and Orange A S. Electrical resistivity changes in saturated rocks during fracture and frictional sliding. J .Geophys .Res . (in English) , 1968 , 73: 1433～1445

[2] QIAN Jiadong , CHEN Youfa , JIN Anzhong. Application of Earth Resistivity Method in Earthquake Prediction. Beijing: Seismological Press(in Chinese) , 1985, 10～31

[3] Yamasaki Yoshio. Electrical resistivity of deformating rock(二) Further research of sedimentary rock [J]. Bullet in of the Earthquake Research Inst itute, University of Tokyo（in English）, 1966, 44 (3): 44～49

[4] CHEN Dayuan , CHEN Feng , WANG Lihua. Studies on resistivity of rock under uniaxial pressure2the anisotropy of resistivity. Chinese J .Geophys. (Acta Geophysica Sinica) (in Chinese), 1983 , 26 (Suppl) ,783～792

[5] CHEN Dayuan , XIU Jigang , AN Jinyzhen , et al . Anisotropy property studies of rock resistivity changes during varing strain stage. In :Annual of the Chinese Geophysical Society (in Chinese) . Beijing :China Building Materials Industry Press (in Chinese), 1996. 207

[6] AN Jinzhen ,XIU Jigang ,CHEN Feng , et al . Study on Anisotropy of Rock Resistivity Changes under Uniaxal Pressure and Water Replenishment . Earthquake Research in China(in Chinese) , 1997 , 11(1): 77～85

[7] CHEN Feng , XIU Jigang , AN Jinzhen , et al . Detecting rupture precursors and determining the main fracture spread direction of rock with dynamic rock resistivity change anisotropy. Acta Seismologica Sinica (in Chinese), 2000 , 22 (2): 210～213

[8] CHEN Feng , XIU Jigang , AN Jinzhen , et al . Research on dependence of resistivity changing anisotropy on microcracks extending in rock with experiment . Acta Seismologica Sinica(in Chinese) , 2000 ,22 (3): 310～318

[9] CHEN Feng , AN Jin-Zhen , LIAO Chun-Ting , et al . Resistivity negative anomaly with precursors of rock rupture Paper Abstract of the Chinese Seismological Society (in Chinese) , 1998. 265

[10] HAO Jinqi , FENG Rui , ZHOU Jianguo , et al . Study on the mechanism of resistivity changes during rock cracking. Chinese J .Geophys(in Chinese), 2002 , 45 (3) :426～434

[11] HAO Jin-Qi, FENG Rui, LI Xiao-Qin, et al. Resisitivity tomography study on samples with water-bearing structure. Acta Seismologica Sinica(in Chinese), 2000, 13(3):325 ~330

[12] Du Yun-gui, Xie Xue-fu et al. Studies on electrical conductivity of coal from nantong colliery, Journal of Chongqing University(in Chinese), 1993, 16(3): 145~148

[13] Jiang Chenzhan et al. Investigation on testing technology of electrical property parameter of coal seam [research report]. Chongqing: Chongqing branch China coal research institute(in Chinese), 1994

[14] HE Jishan, Lv Shaolin. Geophysics studies of gas outburst. Beijing: Coal industry press(in Chinese), 1999, 64

[15] QIAN Jiadong , CHEN Youfa et al. Translated paper on earthquake and geoelectricity. Beijing：Seismological Press(in Chinese), 1989，251～271

[16] Geoeletric Testing Group , Department of Geophysics , Peking University and Research Division , Seismological Brigade of Lanzhou. Laboratory study on relations between apparent resistivity of rock and pressure. Acta Scientiarum Naturalium Universitatis Pekinensis (in Chinese), 1978, (2): 92～100