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Research on Electrical Characteristics of Water Conducted Crack Zone in the Coal Seam

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Abstract Water disaster is one of the five natural disasters in coal mines, and it badly threats the lives safety of miners. As well known, the main reason of evoked flooding is water conducted fractured zone in the coal seam. Based on the Maxwell equation, we try to study the relationship between apparent resistivity and stratigraphic dip as well as strata direction. The numerical results show that the apparent resistivity has a good indication of direction of fracture for the fractured formation. Finally, the rules which are between distribution of apparent resistivity and anisotropy of the earth are concluded. According to the rules, the anisotropic characters of crack zone can be analyzed.
Keywords electrical anisotropy characteristics, layered formation, apparent resistivity, numerical simulation, physical experiments

Introduction

Although coal is the main energy resource in China, it has been a high risk industry due to its frequent accidents. According to the statistics, China is the most coal mining disasters country in the world, and it accounts for 80% of all global coal mining disasters (Liu et al. 2006). Recently, coal mining safety has attracted high attention of government and it has been invested a large of manpower, financial and material resources (Dong et al. 2011). Though the situation of coal mining safety has been improved a lot, the coal mining accident still occurs frequently. Water flooding is one of five natural disasters in the coal mining; also it is the first issue to be resolved during the coal mining production. However, geologic structure of water conducted fractured zone in the coal seam is very complex and the electrical anisotropy is very strong so that some wrong geologic conclusions to be deduced from the data measured using electrical method. Hence, lives of miners have been badly threatened. If the rule of direction of formation's fracture can be obtained, it will be significant for water hazard prevention of mine shaft.

Yin (1999) and Shen (2009) had deduced the formula used to calculated apparent resistivity of anisotropic formation. Based on above researches and with the purpose of introducing the electrical anisotropic characters of layered formation to the coal formation, we studied the electrical anisotropic characters of layered formation using numerical simulation and physical experiments respectively. Finally, we obtained the same conclusion from both study methods of numerical simulation and physical experiment. Hence, it definitely shows that the method is totally fit to be used to study the fractured layer in the Coal Seam.

Methodology

In the direct current exploration, the electromagnetic field and current density can be described using Maxwell equation:

$$\nabla \times \boldsymbol{E} = 0, \quad \nabla \bullet \boldsymbol{J} = 0 \tag{1}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J}, \quad \nabla \bullet \boldsymbol{B} = 0 \tag{2}$$

$$\boldsymbol{J} = \hat{\sigma}\boldsymbol{E} + \boldsymbol{J}_e, \quad \hat{\sigma} = \hat{\rho}^{-1}, \quad \hat{\rho} = \begin{bmatrix} \rho_{xx} & \rho_{xy} & \rho_{xz} \\ \rho_{xy} & \rho_{yy} & \rho_{yz} \\ \rho_{xz} & \rho_{yz} & \rho_{zz} \end{bmatrix} \tag{3}$$

Where, μ is magnetic conductivity and $\mu_0 = 4\pi \times 10^{-7} H/m$. Besides, $\hat{\sigma}$ is conductivity tenser and $\hat{\rho}$ is resistivity tenser. And $\boldsymbol{E}$ and $\boldsymbol{H}$ are electric field and magnetic field respectively. $\boldsymbol{J}$ is total current density and $\boldsymbol{J}_e$ is source current density.

Considering the conditions of boundary between different layers and source coupling on the ground surface (Shen, 2009), the express of current density and electrical field can be obtained:

$$\begin{bmatrix} \tilde{E}_x \\ \tilde{E}_y \\ \tilde{E}_z \end{bmatrix} = \begin{bmatrix} \rho_{xx} & \rho_{xy} & \rho_{xz} \\ \rho_{yx} & \rho_{yy} & \rho_{yz} \\ \rho_{xz} & \rho_{yz} & \rho_{zz} \end{bmatrix} \begin{bmatrix} \tilde{J}_x \\ \tilde{J}_y \\ \tilde{J}_z \end{bmatrix} \tag{4}$$

Then, the field in the time domain can be obtained by inverse Fourier Transformation:

$$\boldsymbol{F}(\boldsymbol{x},\boldsymbol{y}) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \tilde{\boldsymbol{F}}(\boldsymbol{u},\boldsymbol{v}) \boldsymbol{e}^{-i(ux+vy)} \boldsymbol{dudv} \tag{5}$$

The apparent resistivity of anisotropic layer can be calculated using above calculated results:

$$\rho_a(\boldsymbol{r}) = \boldsymbol{G}\frac{\boldsymbol{E}_r(0^+)}{\boldsymbol{I}}, \quad \boldsymbol{E}_r(0^+) = \sqrt{\boldsymbol{E}_x^2(0^+) + \boldsymbol{E}_y^2(0^+)} \quad (\boldsymbol{r} = \sqrt{\boldsymbol{x}^2 + \boldsymbol{y}^2}) \tag{6}$$

Here, $\boldsymbol{G}$ is the array factor.

Modeling

In the modeling, measurement of Schlumberger array is employed to do the modeling to simulate the geological model with layered formation. According to the changing of stratigraphic dip, electrical anisotropy of different models has been studied. For each model, the numerical simulations are carried out respectively.

Model 1

As shown in the fig. 1, the length of spacing between two source electrodes is 60 m（AB=60 m）. The stratigraphic dip of layers in the geological model is α. Moreover, the longitudinal resistivity ρ_T and the transverse resistivity ρ_N are 100 ohm-m and 400 ohm-m respectively. With the changing of stratigraphic dip: $\alpha = 0$, $\alpha = 30$, $\alpha = 60$ and $\alpha = 90$ respectively, the apparent resistivity are measured and the results are expressed in polar coordinates as shown in fig. 2. It is to be noticed that the length between origin of coordinates and measured points indicates the value of apparent resistivity and radial direction shows the direction of measuring line. When $\alpha = 0$, the geological model is transversely isotropic media, hence the distribution of apparent resistivity present a totally perfect circle and the values are equal to geometry average of formation resistivity. With the changing of stratigraphic dip from 0 degree to 90 degree, the perfect circle become into ellipse. Moreover, the larger of the stratigraphic dip, the difference between longer axis of ellipse and shorter axis become much more and the long axis of ellipse indicates the direction of strata strike.

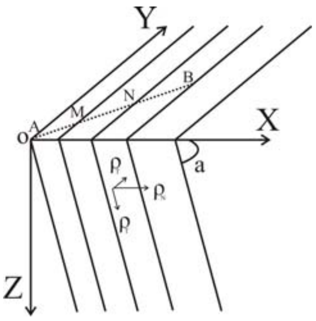

Fig.1 Lareyed anisotropy geological model

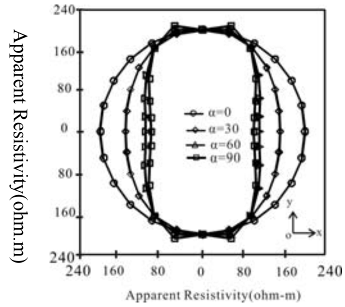

***Fig. 2** The modeling results of the model with changing the stratigraphic dip α*

Model 2

In the above research, we only consider the stratigraphic dip of layer. However, strike of strata also is very important factor of the structure, particularly for the water conducted fractures. Based on above model, we change the strike of strata which is from $\beta = 0$ to $\beta = 45$, as shown in fig. 3. And the distribution of calculated apparent resistivity is presented in fig. 4 which obviously indicates the strike of strata. Moreover, it is supposed that stratigraphic dip is constant value which is $\alpha = 45$ and anisotropy of the model is checked by changing strata strike direction, as shown in fig.5. The character of anisotropy of the model is described in fig.6 which clearly exhibits the relationship between distribution of apparent resistivity and formation strata strike as well as stratigraphic dip.

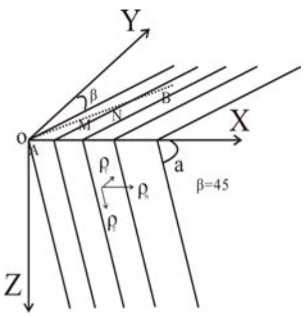

***Fig.3** The model with fixed direction of strata strike and variation of stratigraphic dips*

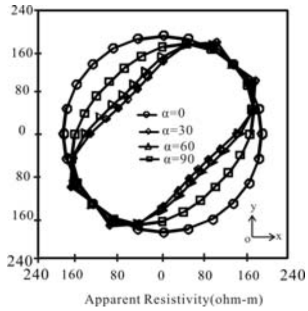

***Fig.4** The numerical results of the model*

Conclusions

Based on above researches, the following conclusions can be obtained. Firstly, it is totally possible to use the DC resistivity method to explore the anisotropy of earth. Secondly, electrical anisotropy of formation caused by stratigraphic dip and strike direction exhibit obvious characters in the polar coordinates. Exactly speaking, the shape of ellipse is decided by stratigraphic dip and inclining direction of long axis of ellipse is controlled by strata strike. Hence these anisotropic characters can be used to analyze earth information in detail, such as the direction of water conducted fractures.

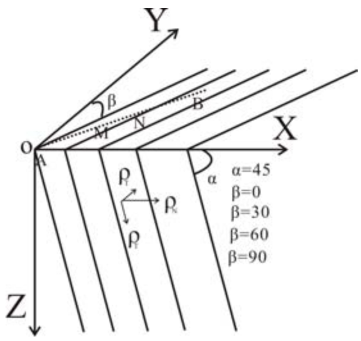

Fig.5 *The model with fixed stratigraphic dip and variation of strata strike*

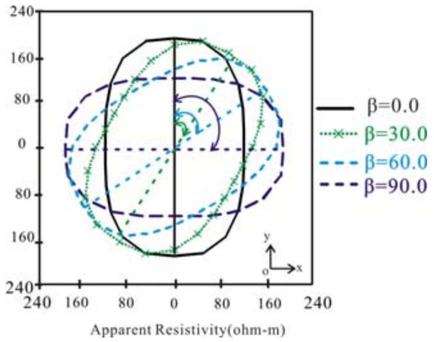

Fig.6 *The numerical results of the model described in Fig. 5*

Acknowledgements

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