Application and signal transmission of the VLF electromagnetic wave in mine rock

Zheng Zhang

School of Civil and Environment Engineering, University of Science and Technology Beijing, 100083, China

syszzvip@sina.com

Abstract

Mining strata of VLF electromagnetic wave propagation characteristics have great influence, the research and analysis to determine the transmission characteristics of very low frequency electromagnetic wave in mine strata transmit frequency is of great significance, research different frequencies of very low frequency effect on the accuracy of the signal transmission. By VLF directional transmission test, the results show that the VLF propagation, the lower the frequency spread in the same horizontal layers, the better, the smaller the electromagnetic wave attenuation, very low frequency of directional transmission, the more accurate the periodic law; Along with the depth increasing, the rock resistivity, the greater the influence on the transmission of signals received.

Keywords

VLF, the anisotropy of rock, attenuation coefficient, the signal transmission.

1. Introduction

The formation of a directional signal transmission, especially in the directional signal transmission mine, since the formation of anisotropic media, complex, varied, when the VLF electromagnetic wave propagation in rock oriented, often produce inaccurate signal transmission delay phenomenon. VLF electromagnetic wave propagation technology because of its penetration in the rock, the precise positioning of significant value has been widely developed and utilized. Electromagnetic wave propagation is the theoretical basis for signal transmission, each of the opposite sex in different frequency ranges, different formations and where the nature of the electric field, the transmission, the influence of noise VLF electromagnetic wave signal is different. So clearly VLF electromagnetic waves having a frequency corresponding to transmitting and receiving important practical significance for the development of the system accurate signal transmission. Currently, rock media for electromagnetic signal transmission mechanism there is no uniform understanding, in order to more accurately understand the electromagnetic signals, this article analyzes the theoretical study and different strata directional signal transmission monitoring data, VLF electromagnetic wave propagation were discussed.

2. Basic Theory

Electromagnetic wave is oscillating in phase with each other and perpendicular to the electric and magnetic fields in space in the form of wave movement, its electric field perpendicular to the direction of propagation of electromagnetic waves in a vacuum seed rate is fixed [1]. Electromagnetic waves in the rock spread follow Maxwell's equations, changing electric field produces a magnetic field, the changing magnetic field can produce an electric field, time-varying field source may produce varying electric and magnetic fields in the actual electromagnetic wave transmission, the transmission is lossy media constituted space, follow the transmission characteristics of media space consumption signal, Maxwell's equations equation [2].

$$\begin{aligned} &\nabla \times H = \sigma E + j\varepsilon\omega E \\ &\nabla \times E = -j\omega\mu H \\ &\nabla \cdot H = 0 \\ &\nabla \cdot E = 0 \end{aligned} \qquad (1)$$

When $\varepsilon_c = \varepsilon - j\dfrac{\sigma}{\omega}$

Called dielectric constant, then

$$\nabla \times H = j\varepsilon_c \omega E \qquad (2)$$

When $k_c^2 = \mu\varepsilon_c\omega^2$ then

$$k_c = \omega\sqrt{\mu(\varepsilon - j\frac{\sigma}{\omega})} = \beta = j\alpha \qquad (3)$$

Where in

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}(1+(\frac{\sigma}{\omega\varepsilon})^2 - 1)}$$

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}(1+(\frac{\sigma}{\omega\varepsilon})^2 + 1)}$$

Order $E = E_x e_x$, from the nature of a uniform plane wave can be obtained directly lossy media for the electric and magnetic fields

$$E_x = E_{xm}\mathrm{e}^{-jk_z z} = E_{xm}\mathrm{e}^{-\alpha z}\mathrm{e}^{-j\beta z} \qquad (4)$$

$$H_y = \frac{j}{\omega\mu}\frac{\partial E_x}{\partial z} = \sqrt{\frac{\varepsilon}{2}(1-j\frac{\sigma}{\omega\varepsilon})}E_{xm}\mathrm{e}^{-\alpha z}\mathrm{e}^{-j\beta z} \qquad (5)$$

Where: H the magnetic field strength (A/m); j , the conduction current density ($\mathrm{A/m^2}$); E the electric field strength (V/m); Electromagnetic frequencies ω .

2.1 VLF propagation attenuation in the formation

Roadway form usually ROCK lossy materials, electromagnetic wave propagation in the empty tunnel is equivalent to the natural spread of the hollow waveguide media, experience different media when the electromagnetic wave refraction, cause energy attenuation. Because of tunneling, mining and transport of mining, roadway inevitable rock dust are the main lossy media, and metal mines in itself have an impact on the electromagnetic field inside the tunnel, metal mines will absorb part of the signal energy[3]. So when the VLF electromagnetic waves into the rock mine, since the media signal absorption intensity of the electromagnetic wave will enter with increasing distance attenuation, a phenomenon also known as the absorption of electromagnetic waves on the rocks[4]. VLF signals have a portion of the signal will be absorbed in the process of formation of media transmission, so when the media absorb more signal, the signal transmission distance farther, the received signal deviation, the greater the accuracy.

Absorption or attenuation coefficient β , the frequency of electromagnetic waves ω , Rock conductivity σ , Rock permeability μ , the relative dielectric constant ε . So the expression β :

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}(\sqrt{1+(\frac{\sigma}{\omega\delta})^2} + 1)} \qquad (6)$$

In the media can be simplified to:

$$\beta = \sqrt{\frac{\omega\mu\sigma}{2}} \qquad (7)$$

Mine rock magnetic field intensity H_y ,

$$H_y = \frac{j}{\omega\mu}\frac{\partial E_x}{\partial z} = \sqrt{\frac{\varepsilon}{2}(1 - j\frac{\sigma}{\omega\varepsilon})}E_{xm}e^{-\alpha z}e^{-j\beta z} = H_0 e^{-\alpha z}e^{-j\beta z} \approx H_0 e^{-\beta z} \quad (8)$$

Where: H_y the magnetic field strength is measured point (A/ m); z scene distance from the source (m); H_0 the source magnetic field intensity (A/ m).

From the equation (2),

Table 1 Media Dielectric Properties

medium	Relative permittivity ε_r	Propagation time(ns/ m)	Conductivity $\sigma / (10^{-3}$ S/ m)
Vacuum	1	2.3	0
Air	1.000585	3.3	0
Water	80	29.81	1.00 ~ 40.00
Quartz	3.8	6.5	0.01
Biotite	5.4	7.75	050 ~ 2.00
Calcite	7.5	9.1	1.00 to 100.00
Sandstone	4.65	7.2	0.001 to 0.1
Mudstone	5 ~ 25	7.46 - 16.6	1.00 to 100.00
Limestone	7.5 to 9.2	9.1 to 10.2	2.00 to 1000.00
Dolomite	6.8 to 6.9	8.7 ~ 8.75	2.00 to 1000.00
Granite	5-8	1.06 to 1.2	0.10 to 20.00
Basalt	8	1.06	0.1 0 ~ 20.00

In the mine rock, the transmitted signal at the depth increases, changes in the magnetic field strength decreases, changing electric field generates a changing magnetic field. In the drilling process, often encountered in the formation conductivity is $1\times10^{-3} \sim 1$S/m [5]. While considering transmit signals using very low frequency, frequency 3 k-30 kHz. VLF electromagnetic waves in the rock penetration and frequency of electromagnetic waves ω and the conductivity of the medium σ. The lower the conductivity, the higher the frequency of electromagnetic waves, the more severe attenuation, and the shorter the distance traveled. Different geological conditions, mine rock, causing its conductivity σ different, so that the electromagnetic wave penetration effect is different. Therefore, the formation of electromagnetic waves in mine operating frequency must be selected in the very low frequency (VLF 3 k-30 kHz) in order to have a certain degree of penetration, so that the lowest signal loss, the deeper the depth of transmission of electromagnetic waves, in field trials, but also according to the actual site conduct frequency modulation.

3. The characteristics from VLF signals received

VLF signals transmitted mainly related with propagation velocity and attenuation. Research shows that: VLF signal transmission main signal and transmit frequency, the size of the coil, the formation of the media and other factors. In order to analyze the transmission VLF signals in the formation of media consumption, taking into account the formation of anisotropy, respectively, to transmit a signal with a frequency 6k Hz and 10k Hz penetrate different rock formations, and then analyzed [6-7].

From the above fig., we can conclude that at the same time and the same vertical position VLF transmitter signal, as the depth increases, since the transmission medium under the influence of the formation of the signal becomes unstable and the gradual emergence of intermittent, appeared attenuation [8]. In the same formation, when the signal transmission frequency increases, the signal reception becomes unstable, the deviation of the received signal becomes high, the resolution becomes low. In practical tests, since stratification of the air and transmission interference rock, uneven, and reasons for changes in media VLF transmitting and receiving system, VLF radio signals received in addition to containing the characteristic information, but also there are some other interference noise and number, which is the impact factor of the received signal.

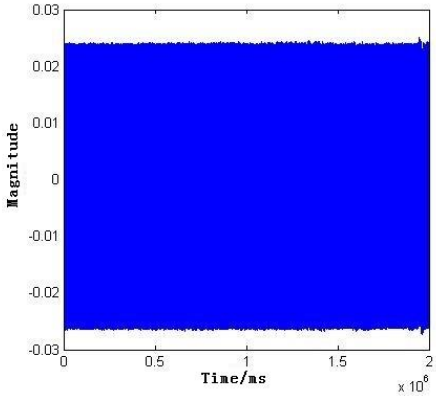

Fig. 1 VLF signal transmission frequency 6k Hz signal reception when the depth of 150m in the rock

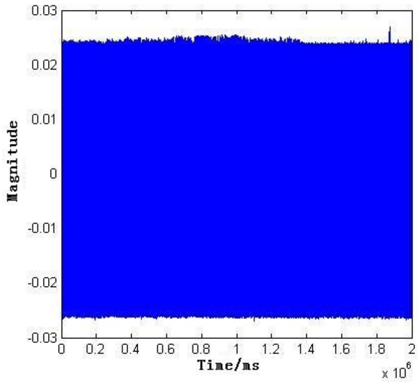

Fig. 2 VLF signal transmission frequency 10k Hz signal reception when the depth of 150m in the rock

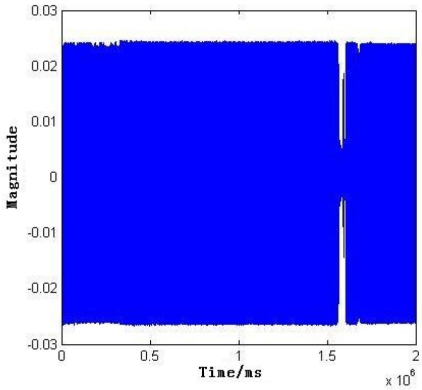

Fig. 3 VLF signal transmission frequency 6k Hz signal reception when the depth of 30 0m in the rock

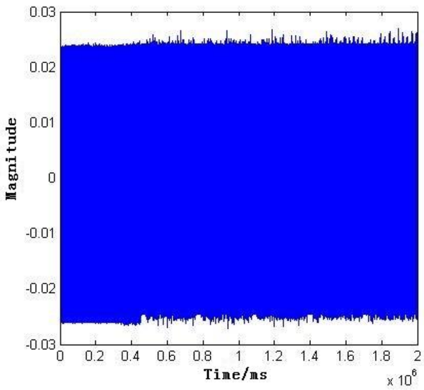

Fig. 4 VLF signal transmission frequency 10k Hz signal reception when the depth of 300m in the rock

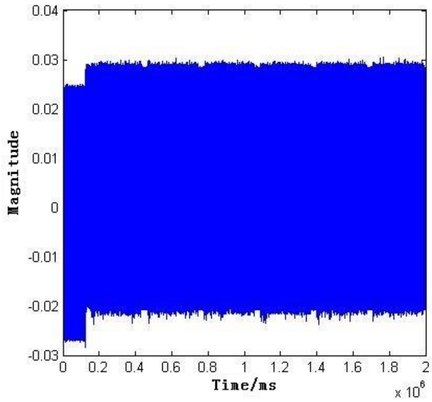

Fig. 5 VLF signal transmission frequency 6 k Hz signal reception when the depth of 45 0m in the rock

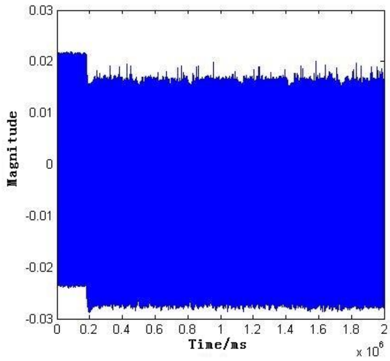

Fig. 6 VLF signal transmission frequency 10k Hz signal reception when the depth of 450m in the rock

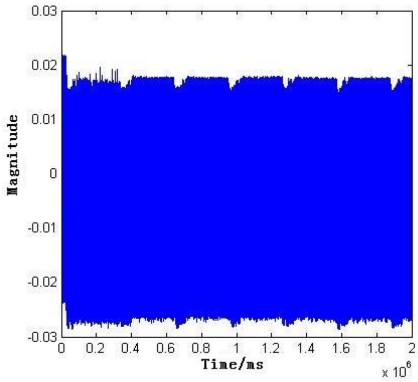

Fig. 7 VLF signal transmission frequency 15k Hz signal reception when the depth of 450m in the rock

4. Conclusion

(1) VLF electromagnetic wave propagation near the ground, the signal has gone through three major media, surface rock and soil media layer, an intermediate layer of dense rock, deep highly aqueous medium layer. VLF signals propagate formation increases with depth and phased variation. Design analysis process VLF radio communication system is a very complicated system engineering, in the actual design work in addition to the above characteristics have been analyzed, but also in the coil connections, modulation, filtering method, weak signal reception, etc. be considered.

(2) Due to the transmission of electromagnetic waves on the impact of metal mines obvious, so when the electromagnetic wave signal transmission, emission point should try to avoid the metal layer, reducing the impact of the metal layer.

(3) Through the analysis from high and low frequency VLF signals, we can get the entire VLF signal transmitting and receiving frequency characteristics. At the same rock VLF signal transmitting and

receiving, with increasing frequency, lower strata receiver receives signals gradually loud noise increases. Description The lower the frequency of the signal transmission in the formation is more favorable. This conclusion provides for very low frequency communications in the formation theory, should be based on the case of rock anisotropy and media to set the frequency to reduce the size of the attenuation coefficient, the transmission of information to play a greater role in the formation.

References

[1] HU Shi-lei, YAN Tai-ning, LI Xiao. Study on Strata Affected to Electromagnetic with Drilling Measuring Signal, Coal Science and Technology, Vol. 39 No. 9, p.114-117

[2] LIU Guosheng, YANG Haidong,TANG Jianchao. Numerical investigation for responses of electrical logging–while–drilling in complex formations. Vol.44 NO.2, p.656-661

[3] WEI Bao-Jun, TIAN Kun,ZHANG Xu, LIU Kun. Physics of directional electromagnetic propagation measurements-while-drilling and its application for forecasting formation boundaries. CHINESE JOURNAL OF GEOPHYSIS. Vol.53. No.10. p.2507-2515

[4] ZHENG He-hua, FENG Qi-ning, SHANG Zuo-yuan, Frequency prorerty and its potential application of the complex resistance of reservoir rocks[J]. J of the University of Petroleum, 1993, 17 :p.23-28.

[5] Tao Jinyi. Design of Mine Radio Communication Through Stratum, JOURNAL OF TAIYUAN UNIVERSITY OF TECHNOLOGY, Vol. 31 No. 1, p.39-42

[6] Tao Jinyi. Study on Antenna Equipment for Communication of Very-low-frequency (VLF) Electromagnetic Wave Propagation through Earth. JOURNAL OF TAIYUAN UNIVERSITY OF TECHNOLOGY, Vol. 30 No. 2, p.139-143

[7] ZHAO Hongyu, PENG Hui, Voice Compression Technology in Wireless Through-the-earth Communication in Mines. SHANXI COAL. Vol. 35 No. 6, p.14-16

[8] YI Bin, LIU Yong, CHEN Jing. Op Design of Through-the-earth Mine Communication Receiving Circuit. Ship Electronic Engineering. Vol.34 NO.3, p.72-75