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Study of Radiant Interference based on Model of Electric Locomotive in Underground Tunnel

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Abstract

This paper put forward a finite element method to study the radio transmission in tunnel electromagnetic environment. The author makes use of software simulation to study the rectangular tunnel model. When varying the electric parameters of tunnel wall, ceiling and floor, this may somewhat influence the propagation characteristics of electromagnetic wave.In order to study the interference properties of underground electric locomotive, this paper put forward a moment of method (MoM) model to analysis electromagnetic compatibility in roadway. The author makes use of FEKO software to simulate its time-varying and non-linear characteristics, the simulation results are in good agreement with experimental data. In the end it can be concludeed that this model has practical significance to estimate electromagnetic interference in coal mine.

Keywords: *electric locomotive, tunnel, electromagnetic interference, moment of method, coal mine*

1. Introduction

With frequency converter increasing in coal mine, harmonic interference to underground power equipment has become a universal concern. For the existing communication systems, signal systems, integrated automation system, these high-power equipment produce different levels of electromagnetic interference, radiated interference and coupling of electromagnetic interference. Some has brought hazards to Safety Production (such as underground electromagnetic pulse interference), and some may cause misstatement and omission to Security System, or even seriously affect Gas Outburst Prediction System to forecast error [1]. Therefore the study of underground electromagnetic environment, is an important issue for electromagnetic interference of coal mine.

Electric spark generated by underground electric locomotive pantograph and overhead line has strong electromagnetic interference in the roadway, and often cause turnout malfunction, which has become a major problem of coal mine safy production [2]. With extensive use of underground electronic equipment, this harmful effects of arc interfere will be further expanded, this issue merits a close attention. However, due to underground conditions, air humidity and coal dust, to resolve electric arc interference is very difficult.

2. Mom Model of Rectangular Tunnel

2.1. Theory of Electromagnetic Field

Maxwell's equations is the basic theory to describe the macroscopic laws of electromagnetic fields. Differential form of Maxwell's equations can set up at any point in space, which is composed of the following four equations:

$$\nabla \times H = \frac{\partial D}{\partial t} + J \tag{1}$$

$$\nabla \bullet B = 0 \tag{2}$$

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$$\nabla \bullet D = \rho \tag{3}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{4}$$

The corresponding auxiliary field equation is:

$$B = \mu H \tag{5}$$

$$D = \varepsilon E \tag{6}$$

$$J = \sigma E \tag{7}$$

Where *E* is electric field strength, *D* is electric displacement, *B* is magnetic flux density, H the magnetic field intensity, J is current density, ρ is charge density, *ε* is dielectric constant, *μ* is permeability, *σ* is the conductivity.

Before reaching the receiver, wireless signals inside the tunnel may go through direct, reflection, scattering. Tunnel walls play role of shield ing ,absorption and scattering to radio waves. In theory, tunnel is a large size of non-ideal waveguide, in which only electromagnetic wave higher than cut-off frequency can spread. In most tunnel the cut-off frequency is about dozens of MHz, UHF band electromagnetic wave spread in the tunnel, because of its wavelength is less than the tunnel cross-section size, tunnel can be treated as a loss dielectric waveguide. In waveguide model theory, this band signals spread in the near-field of tunnel for multi-mode transmission, and its loss of various modes is proportional to the square of their order [3, 4].

As shown in Figure 1, a straight tunnel model is 50m long, 3m high, and 4.2m wide [4]. For roof and floor, the relative dielectric constant remains 5, while side walls vary from 1 to 30 [5].

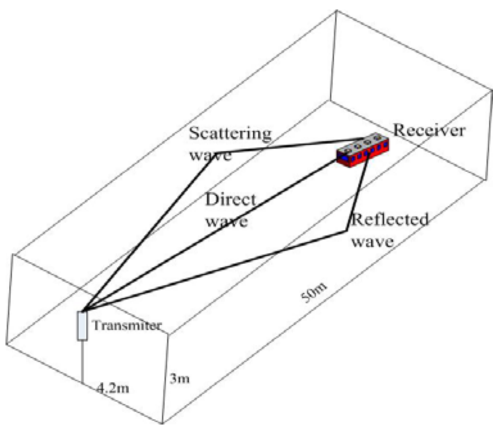

Figure 1. Model of Rectangular Tunnel

2.2. Experiment Results of Tunnel

The experiment uses Hewlett-Packard signal generator HP8601A+directional plate antenna as signal source. The directional antenna mounted on the side of tunnel, radiation signals towards the tunnel, receiver collecting data along the tunnel direction, which is simulating the current common design of tunnel directional antenna installation [6-8].

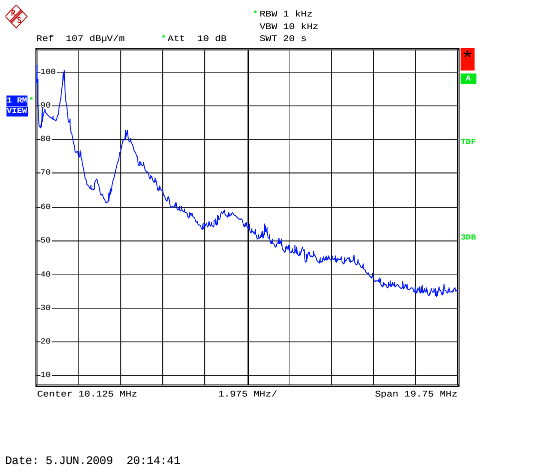

Figure 2. Plot of Low-frequency Expeiment

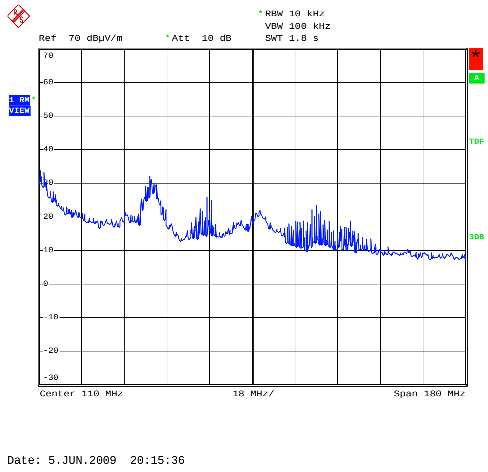

Figure 3. Plot of High-frequency Expeiment

After the test, each sampling data is arithmetic average to reduce the impact of fast fading data, and then analyze the data, filter out abnormal samples; receiving value of sampling points related with the distance into the model to be calibrate, iterative calculate the distance factor n and the constant A respectively.

2.3. Simulation Results of Tunnel

As Seen in Figure 4, within 10m, both in horizontal polarization mode and vertical polarization pattern the attenuation rate is very steep; in 10-50m, only vertical polarization mode changes, horizontal polarization pattern remains relatively stable,only about 1dB/km. This phenomenon indicates that in distance of 50m, electromagnetic waves of horizontal polarization transmit more stable, while electromagnetic waves of vertical polarization attenuate seriously.

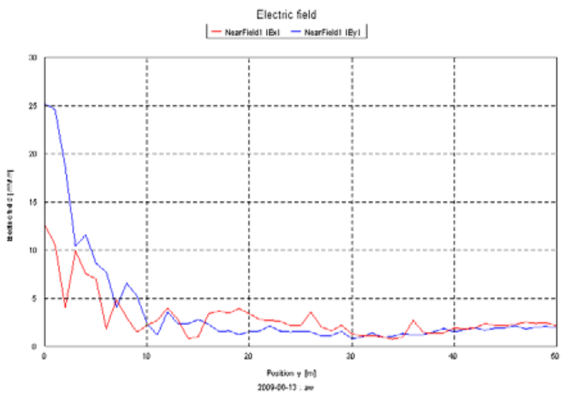

Figure 4. Attenuation Characteristics of Horizontal Distance

Mine roadway is a special environment for radio wave propagation. With a rectangular tunnel model, the author uses FEKO software to simulate cycle load on long wall face. The analysis of propagation constant showing that, TE_{10} mode has a flat frequency characteristics and larger attenuation. It is not difficult to conclude that we can make use of long wall face to achieve radio communications in band 900-3000MHz, this conclusion provides a theoretical guidance for setting up base stations and antennas in tunnel. Of course, in this analysis assuming the tunnel roof and floor electrical parameters have the same value, which is inconsistent with the reality of tunnel, and the future work should further optimized the model.

3. Analysis of Spark Interference

3.1. Emergence of electric locomotive Arc interference

Catenary, Locomotive electrical circuit , railway and power supply constitute electric circuit. When the pantograph and catenary contact, Locomotive get DC voltage from catenary and start working. Locomotive has three types of transmission:

a. DC power supply, drive by DC motor, control locomotive speed by changing the excitation current.
b. Through DC chopper device, control speed by armature voltage.
c. Through the DC inverter device, control AC motor by AC Drive implementation [9-11]. Vehicle in the test is the first one.

In the driving course of locomotive, as the road is not flat, contact between pantograph and catenary is unstable, just like a power switch, up and down occasionally, so electric spark is generated between them. However the spark size and strength have many factors,such as pantograph medium, pressure of pantograph, current parameters and speed of electric locomotive, as well as the media near the spark etc. Thus with the locomotive working, electric spark is inevitable and the interference is inevitable too.

3.2. Interference Form of Locomotive Electric Arc

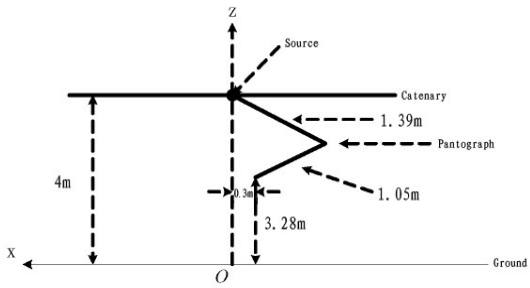

Figure 5. Electric Locomotive Model Size

The Arc interference have three forms, i.e. conduction, induction and radiation interference. Not separate these three interference occurs, there may be two forms at the same time. When the potential difference between pantograph and catenary is large enough to break down the insulation, there will be a spark.

a. Conducted interference

Arc interference enter the loop through power line, locomotive electrical circuit and, then transient pulse current will raise zero potential of power. So that electrical equipment near catenary or on both sides of the track, especially electrical control equipment, may lead to malfunction.

b. Radiant interference

Arc has a certain energy, and would have radiant interference. Arc energy is decided by the formula $E = L \cdot di/dt$, despite the equivalent inductance L arc is small, while di/dt is much greater, thus arc energy is considerable. Arc spectrum is abundant, its is a wide band, from a dozen kHz to several hundred kHz, even to hundreds of MHz [12-14].

4. Model of Electric Locomotive

To simplify the analysis we have adopted the model as shown in Figure 5, presumed harassment source in central of slide.Bearing cable and hanging strings affect both horizontal and vertical component of the interference field, while the impact of vertical component is greater.Interference sources in different locations of the contact line also have different impact. We directly consider a complete model, to comprehensively study the impact of spark on wireless communications.

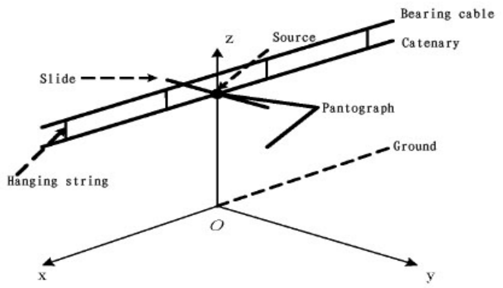

Figure 6. Electric Locomotive Spark Model

In modeling, we take the contact line as a commonly used type TGG110, which is copper line, cross-sectional area is 100mm2 and equivalent radius is 5.64mm. The distance between Contact line and ground is unified 6m. The model considered the impact of first arch and pantograph slide plate, but also taking into account the impact of bearing cable and hanging string. In figure 6, we have adopted the standard Cartesian coordinate system, z means height, x represents lateral distance, y denotes horizontal distance. Specific dimensions shown in Figure 5, 6, the source is added between two suspended string, suspended chord length is 1m, and its space 10m. Based on the above model, we make use of FEKO software modeling and analysizing far-field and near-field circumstances.

Due to the existence Insulating points, the length of contact line in this model can not be infinite. In order to make calculation convenient and model simple, we have adopted the wavelength of the highest frequency corresponding λ = 10m (30MHz). For five cases, the length of contact line as 10λ, 20λ, 40λ, 80λ, 160λ, respectively analysize the far-field radiation gain diagram of radio noise generated by pantograph 10m high from the ground, as well as its varietys with height and horizontal distance. Considering the Ohmic loss of contact line and the earth impact, we take interference here 100V, the earth conductivity $\sigma = 5\times10^{-3}\ s/m$[15-17], relative dielectric constant $\varepsilon_r = 10$ [16-19], it is between dry soil and gravel.

5. Experiment and Simulation

In order to study the characteristics of horizontal attenuation in underground tunnel, we have tested locomotive spark noise on the spot. As shown in Figure 7, band 60-160MHz is the main noise distribution.

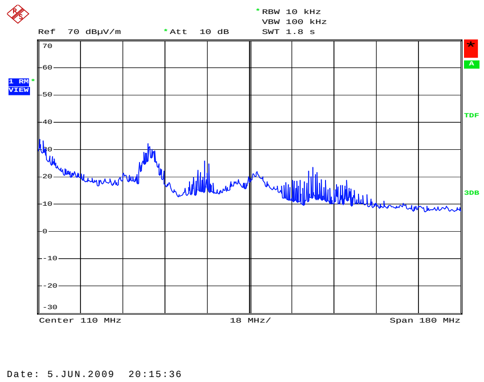

Figure 7. Plot of Testing Data in Near-field

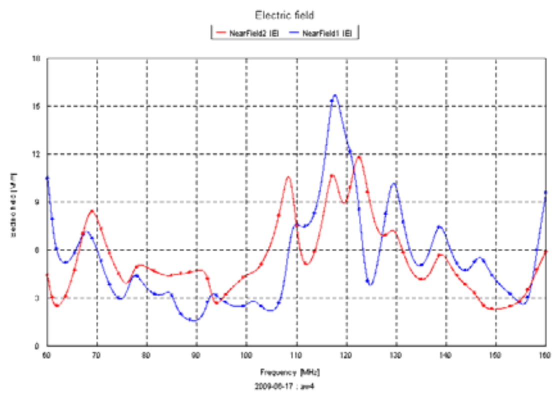

Figure 8. Attenuation Characteristics of Locomotive Spark

To make our research more rigorous,we select 60MHz, 70MHz, 100MHz and 160MHz as our concerned band to simulate locomotive spark. As shown in Figure 8, the red line is along the railway (Y direction), while vertical is the blue. Y direction is the most of interference sources we need study characteristics of radio noise varying with height. In band 100-130MHz, we could get the most radiation interference.

6. Conclusion

In this paper, spark interference and hazards is presented, characteristics and transmission of the interference is analysized,and model is established for theoretical analysis and experimental research. The results showed that; radiation interference and conduction interference of electric locomotive arc is the root causes of switch malfunction.

Acknowledgments

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