Coupling Effect of Transmission Lines by HEMP Based on CST

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Abstract: High-altitude nuclear electromagnetic pulse(HEMP) has a significant effect on electronic devices by cables. This paper makes an analysis of field-wire coupling. With the software of Computer Simulation Technology(CST) constructing the model, coupling current has been acquired. The effect of length, height and impedance on coupling current has been gained. To our surprise, the rise time of HEMP is faster than the time of coupling current. This provides HEMP hardening with the crucial basis.

Keywords: high-altitude nuclear electromagnetic pulse(HEMP) CST field-wire coupling

0 INTRODUCTIONS

The HEMP is a kind of high power electromagnetic pulse, which is a by-product of nuclear explosion. The field that HEMP produces has characteristics of high strength(kV/m) and short rise-time(nanosecond). Even though there are integral enclosures over precise electronic devices, by necessity external cables can couple with outer pulse field. Once the incoming strong transient electromagnetic field, the antenna effect of cables will transform high field into high voltage and high current. The high strength current in the circuit has damages on delicate devices.

The modern devices consist of massive semiconductor apparatuses, so after coupling with the HEMP it is semiconductors that are damaged by HEMP. It is so deep the damage effect of HEMP on electronic equipment, therefore to study the coupling between HEMP and cable is of great significance.

The field-cable coupling problem of HEMP, the domestic and foreign research mainly confined to the analytical calculation, the lack of specific experiments and numerical simulation[1-5]. This paper is mainly based on numerical simulation and model calculation is more close to the practical engineering. In this paper, available and reliable coupling value has been acquired, the coupling current influence factors has been analyzed and the delay effect of coupling current compared with excitation signal(HEMP) has been discovered. Those conclusions provide the essential guidance and reference.

1 THE ANALYSIS OF FIELD-CABLE COUPLING MODEL

There are two methods to analyze the field-cable coupling model: field method and circuit method. The field method is based on Maxwell's equations, which need to mesh the calculation domain. Discrete Maxwell's equations will be transformed into enormous matrix equations. To solve equations we can acquire the results.The field method is more rigorous but to calculate large matrices need vast computer resources. However, the circuit method is based on the transmission-line method. With distributed parameter theory, mathematical calculation is much simpler. The latter one is commonly adopted. Aimed at different excitation sources in the circuit method, Taylor, Agrawal and Rachidi put forward three kinds of transmission-line coupling model.

Because high-altitude nuclear explosion is far from sensitive devices, outer transient field is regarded as the transverse electro-magnetic wave(TEM). Simple point is the distribution model of excitation source for voltage source. The foundation of circuit model still is a transmission-line model, but outer field excitation is equivalent to voltage in every micro unit, which is the essential of Agrawal's model[6][7]. The model assumes that the ground is infinite. The circuit model is as shown in Fig. 1.

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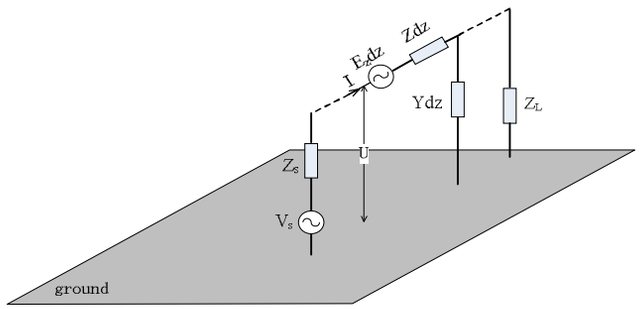

Fig.1 Agrawal field-cable coupling equivalent model

When the plane wave where frequency is ω (transform time domain into frequency domain when considering HEMP coupling) acts on the cable as is shown in Figure 1, voltage over the circuit and current in the circuit meet the following second-order differential equations:

$$\frac{d^2U}{dz^2} - \gamma^2 U = \frac{dE_z}{dz} \tag{1}$$

$$\frac{d^2I}{dz^2} - \gamma^2 I = -YE_z \tag{2}$$

In those equations, Z and Y represent cable impendence and admittance per unit length. $Z = R + j\omega L$ $Y = G + j\omega C$. R, L, G and C are cable resistance, inductance, conductance and capacitance per unit length respectively. E_z is a transient field strength. The propagation constant is $\gamma = \sqrt{ZY}$. Equation (1) and (2) are similar to the traditional transmission-line wave equations. By applying mathematical physics equation method we can get the results.

2 SIMULATION OF COUPLING EFFECT HEMP ON CABLE PORTS BASED ON CST

At present, domestic papers which calculate field-cable coupling mainly adopt analytical methods [8]. But this paper changes thoughts and takes advantage of the simulation software of CST to gain the coupling.

The simulation studios in CST associated with the field-cable coupling are Cable Studio and Design Studio. The studio co-simulation is performed with TLM(based on Transmission Line Method) solver.

A single cable is designed in Cable Studio(distributed parameter model). In this problem one finite PEC (perfect electronic conductor) board is imitated as the ground, which is shown as Figure 2.

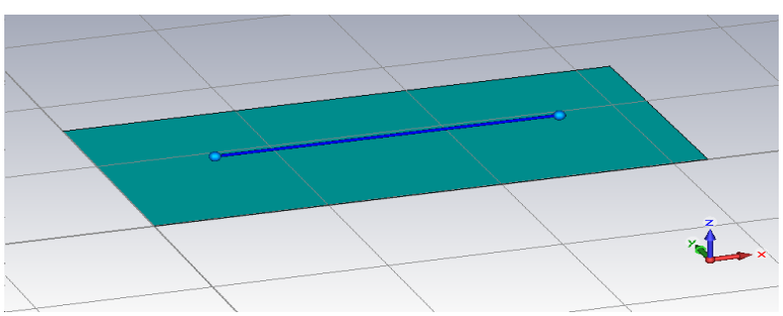

Fig.2 Single cable model

The excitation source is assumed as a plane wave. The electric field waveform expression that HEMP produces is commonly used double exponential function to fit. The equation is

$$E(t) = E_0 k\left[\exp(-\alpha t) - \exp(-\beta t)\right] \tag{3}$$

In which, $E_0 = 50kV/m$, $k = 1.3$, $\alpha = 6.0\times10^8 s^{-1}$ and $\beta = 4.0\times10^7 s^{-1}$.

2.1 INFLUENCE CABLE LENGTH ON THE COUPLING CURRENT

Let the direction of incident electromagnetic field be –Z and the size of the ground is represented by 16m×8m board that is PEC and has no thickness. The height of cable from the ground is 0.5m. The resistors at the cable end are 50Ω.

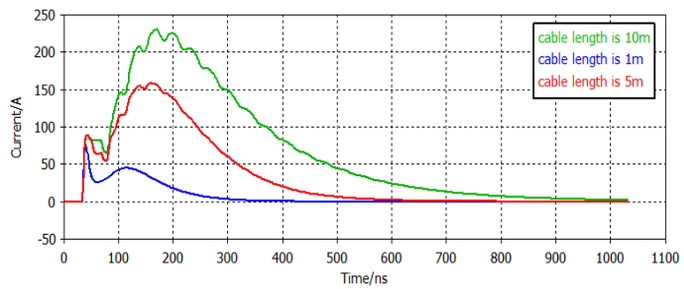

Fig.3 Coupling currents at the port vary with cable length under the HEMP

From Fig. 3 we see that with the increase of cable length, the coupling current increases completely. When the time is less than 33ns, cable doesn't induce the current. With cable length increasing, the disturb signal attenuates more lentitude.

From the definition of field strength we can conclude: When the electromagnetic field comes into being, the longer the operating distance is, the greater the voltage is. In term of system class EMC problem, outer cables are longer so it is obvious that the effect of field-cable coupling is! It is necessary that a transient suppressor is installed at the sensitive device port[8].

2.2 INFLUENCE GROUND HEIGHT ON THE COUPLING CURRENT

Keep the direction of incident field, the ground and the load stay the same. Let cable length be 10m. Change height from the ground and current is monitored.

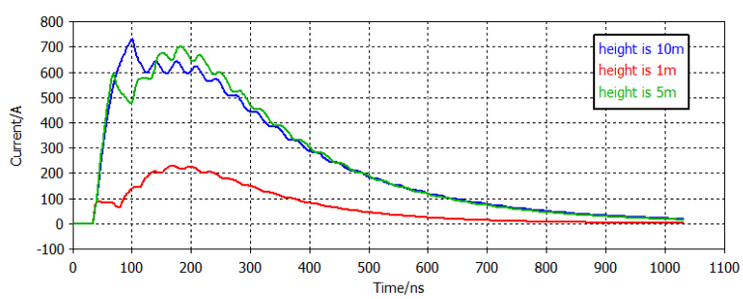

Fig.4 Coupling currents at the port vary with cable height under the HEMP

With the increase of cable height, the peak current of coupling increases. From the perspective of EMC, the increasing cable height means that loop area of cable and earth increases. The loop area is equivalent as a loop antenna so that coupling current increases[9].

2.3 INFLUENCE PORT LOAD ON THE COUPLING CURRENT

Keep the direction of incident field and the ground. Assume cable length as 10m and cable height as 0.5m. Change both ends of cable resistance and the current is monitored.

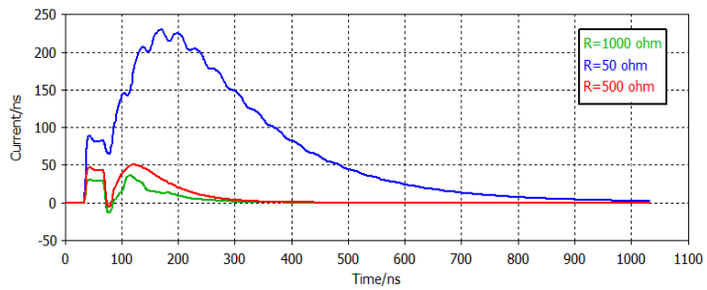

Fig.5 Coupling currents at the port vary with cable port impendence under the HEMP

From Fig. 5 we see that with impendence of load increasing, the peak current of coupling decreases. Obviously, when the excitation field is constant, the conclusion complies with the Ohm's law. In order to achieve the power matching, general electronic equipment has a small resistance. This also is the reason why coupling current destroy elements easily.

3 CONCLUSION

The coupling current between HEMP and cable usually is hundreds Amperes. The coupling current increases with cable length and height increasing and with port impendence decreasing. For a sensitive system in a real work condition, it's a good choice to use the method of this paper to determine the coupling value and take measures to harden.

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