Research on lightning numerical simulation of wheeled armored vehicle based on CST simplified model.

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Abstract. In order to further improve the all-weather combat capability of army armored equipment, the paper adopts the compact model of the CST MICROSTRIPES studio. The CST MICROSTRIPES studio is based on the numerical simulation technology of transmission line matrix algorithm and the paper has a study on the full-scale lightning strike numerical modeling and simulation. The distribution of surface current, the induced electric field in the key parts of vehicle are analyzed. The simulation results showed that the method could effectively simulate the lightning response of armored vehicles, the law of lightning current conduction was given, the distribution law of electromagnetic field of the inside vehicle was studied and analyzed. It can provide reference for lightning protection design of armored vehicles and has a certain engineering application value.

1. Introduction
Lightning is generated by discharging in the air or clouds, including three types of lightning: cloud to ground lightning between clouds and the earth, cloud to cloud lightning between different clouds and cloud to cloud lightning within the same cloud layer. Especially in thunderstorm, cumulonimbus accumulates a lot of charges. Generally, positive charges accumulate at the top of cumulonimbus, while negative charges and a few positive charges accumulate at the bottom. Charge in clouds can change the electric field in the atmosphere, and the effect of induced electric field can cause other metal objects to accumulate charges with opposite polarity. When the charges on other objects accumulate to a certain extent, air will be broken down and a lightning channel will be formed between clouds and metal objects, which is called cloud to ground lightning, so it can be seen that armored combat vehicles may also suffer lightning strike.

The existing research on lightning protection of whole level mainly focuses on aircraft, America, Europe and other countries have promulgated many standards and regulations for trial voyage[1-4]. Chen Xiaoning et al[5] made a numerical simulation study on the lightning strike attachment area of a helicopter, the lightning strike attachment area of a helicopter was divided by CST simulation software electrostatic studio. Huang Liyang et al[6] studied the indirect lightning effect of a helicopter, analyzed and studied the electromagnetic field distribution inside and outside the airframe and the coupling effect of airborne cables. Guo Fei et al[7] carried out numerical simulation analysis on indirect lightning strike effect of a certain airliner, studied the coupling of lightning electromagnetic through holes and slots, the distribution of electromagnetic field inside and outside the airframe and the coupling law of airborne cables. Gao Cheng et al[8] studied the lightning attachment point of composite aircraft, the results showed that composite structure reduced the probability of lightning strike. Nie Ru
and Marc Meyer[9-10] studied the intensity and distribution of lighting electromagnetic at different positions of fuselage. At present there is no research result on lightning strike of armored vehicles, in the absence of a large number of measured data, it has a great significance to carry out full scale lighting strike simulation research on armored vehicles.

CST MICROSTRIPE Studio based on the Transmission Line Matrix Method(TLM) is a software specializing in system level EMC simulation[11]. Its unique compact model can accurately simulate holes, seams, metal shielding meshes and other structures without meshing. The lightning current waveform specified in SAE-ARP5412 was used to simulate the lighting of full-scale armored vehicles. the distribution of surface current and the electromagnetic field distribution inside and outside the vehicle were analyzed.

2. Principle of numerical simulation

Transmission Line Matrix Method(TLM) was first proposed by Johns P B and Beurle R L based on Huygens principle, through gradual improvement to become a method of electromagnetic wave propagation and dispersion characteristics[12-14]. When TLM algorithm is used to solve the electromagnetic field of dielectric, the dielectric properties are replaced by TLM matrix, which is composed with many nodes, each node has a different physical properties of dielectric, the transmission line is responsible for energy storage and redistribution. By iterated operation, the field distribution in the computational region can be solved, and the time domain results can be transformed into the frequency domain results in a certain frequency domain by Fourier transform.

The two-dimensional TLM algorithm is composed of parallel transmission line grids, pulse from four branches with the same characteristic impedance coming into one node, then come into the adjacent nodes by scattering, the formula is deduced as follows[15]:

$$iV^r = S \cdot iV^i$$

$$C \cdot V^i = C \cdot iV^r$$

In the formula, $iV^r$ is the incident pulse voltage vector of each node at $k$ time, $iV^i$ is the reflected pulse voltage vector of each node at $k$ time, $S$ is the impulse scattering matrix, $C$ is the connection matrix of network topology, $k$ is the discrete time interval of scattering.

The three-dimensional TLM algorithm consists of three parallel nodes and three series nodes in three coordinate axes, the voltage on three parallel nodes are the electric field component, the current on three series nodes represent the magnetic field component, the scattering process and inhomogeneous field are the same as two-dimensional TLM algorithm.

3. Construction of the simulation environment

3.1 Source excitation

Referring to the waveforms and methods of SAE 5412 and SAE 5416, which define the aircraft lightning indirect effect test, the lightning attachment points are usually located in the protruding parts of the body, such as turrets, guns, deck protruding parts and so on. The lightning current is a double exponential waveform, the waveform function is shown in formula 3 and the waveform diagram is shown in figure 1.

$$I(t) = I_0(e^{-\alpha t} - e^{-\beta t})$$

In the formula, $I_0$ is 218810A, $\alpha$ is 11354s$^{-1}$, $\beta$ is 647265s$^{-1}$, the duration of lightning current is set to 100 $\mu$s , which is the same as the simulation time.

The injection mode of lightning current in the simulation is shown in figure 2, the lightning current is injected into the gun of the body and released through the rear deck of the body. In the simulation process, two slender ideal conductors are used to simulate the process the lightning current injection and discharge.
3.2 Simulation settings

The full-scale model of an armored vehicle is used in the simulation, its length, width and height are 5450mm, 2174mm and 2340mm, the vehicle is made of steel and its thickness is 10mm. In order to accurately simulate the electromagnetic field of lightning coupling into the vehicle through holes and slots, all the glass of the vehicle are equipped with a 20-grid metal screen, the mesh size is 1.223mm width, 0.001mm depth and 0.927 in coverage.

The simulation frequency is 30MHz, and the simulation time is the same as the time of the lightning current waveform, the discretization model of armored vehicle is obtained by meshing, the maximum mesh size is 363mm, the minimum mesh size is 50mm, the number of meshes is 323.51k, the time step is 1200000.

The boundary conditions are all expanded by 30%, armored vehicles travel on the ground, which is different from the lightning process of aircraft, therefore, the direction pointing to the ground should be set as electric wall and the other directions should be set as absorbing boundary. In order to eliminate the effect of electrostatic field caused by charge accumulation, the two ideal conductor extensions, which simulate the injection and discharge of lighting current are all in contact with the absorbing boundary, thus forming a current loop to eliminate the charging effect.
4. Analysis of simulation results

4.1 Distribution of surface current
As shown in figure 1, the lightning current will reach its peak value at 6.4 $\mu$s, so the distribution of surface current at 2 $\mu$s, 6.4 $\mu$s, 20 $\mu$s are shown in figure 3.

![Distribution of surface current at different times](image)

Figure 3. Distribution of surface current at different time

As shown in figure 3, the surface current of the vehicles is the largest at the time of 6.4 $\mu$s, the surface current increases from a small instant to a large one, then gradually decreases, which is consistent with the trend of lightning current waveform in figure 1. The surface current at the attachment and separation points of lightning current are large, reaching hundreds of kiloamperes per meter, the lightning current mainly conducts along the edge of the vehicle, and eventually flows to the separation point for discharge.

Taking three typical positions of driving window glass, cabin door glass and rear deck into consideration, the surface current waveform is shown in figure 4.

4.2 Distribution of electromagnetic field inside the vehicle
Taking five typical positions of cockpit, copilot, middle cabin, front cabin and rear cabin into consideration, Peak value of induced electric field at different positions are shown in table 1. From
Table 1, the peak value of the induced electric field in the front cabin is the largest, and the peak value in the middle of the cabin is the smallest. The peak value in the middle of the cabin is equivalent to 67.7% of the peak value of the front cabin. The distribution of the electric field is regular, the induced electric field near the attachment and separation points of the lightning strike are large, the difference of induced electric field inside the vehicle is not particularly obvious.

![Figure 4. Waveform of surface current at different positions](image)

| Position  | Cockpit | Copilot | Middle cabin | Front cabin | Rear cabin |
|-----------|---------|---------|--------------|-------------|------------|
| Peak value (kV/m) | 1.22    | 1.32    | 1.11         | 1.64        | 1.45       |

5. Conclusion
By using the CST MICROWAY Studio, the electromagnetic field of the inside and outside the vehicle can be simulated accurately. This method is simple, convenient, economical and efficient. Without the support of large number of test data, numerical simulation can provide reference for lightning protection design of armored vehicles.

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