The shielding effectiveness of steel enclosure for pulsed magnetic field *

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Abstract: By global analysis of the generator, the loop antenna and the shielding enclosure with FDTD method, the small-loop approach for measurement of the magnetic field shielding effectiveness was simulated numerically in this paper. Non-uniform meshes and Reduced c FDTD Method were adopted to solve the contradiction of selecting space step and time step; this makes it possible to calculate the steel shielding efficiency of large dimension. The interaction of shielding enclosure and loop antenna was modeled. The setup of the simulation coincides with the real condition of engineering testing. The conclusions from the numerical calculation are: The waveform of EMP transparent though the steel shielding enclosure is greatly different with the incident EMP waveform. The rise time changes to be very slow and the width of pulse gets long. The calculating and real testing indicate that the shielding efficiency of steel enclosure to the EMP with longer rise time(μs) and wider duration(1ms) is only about 40dB, the rise time of transparent pulsed magnetic field reaches ms and the pulse width is more than 10ms. The shielding efficiency of the steel enclosure to low frequency electromagnetic field is much lower.

Key Words: shielding enclosure, shielding effectiveness, FDTD method, pulsed magnetic field

Along with the traction of EMC techniques, the advancing of computer and especially the developing of FDTD method, time domain method was introduced to numerical analysis of shielding property. It is becoming possible to calculating the shielding effectiveness of real conduct or ferro-magnetic enclosures. FDTD method is non-efficient in analyzing the very thin metal shielding layer because the time step is constrained by the Courant limit for stability, not by a physical requirement for fine temporal resolution. Non-uniform meshes and Reduced c Method[1,2] were adopted to solve the contradiction of selecting space step and time step, this makes it possible to calculate the shielding efficiency of large dimension.

By global analysis of the generator, the loop antenna and the shielding enclosure with FDTD method, the small-loop approach for measurement of the magnetic field shielding effectiveness was simulated numerically. The 2nd order Mur ABC was adopted to truncated the calculate domain. The interaction of shielding enclosure and loop antenna was modeled. The setup of the simulation coincides with the real condition of engineering testing.

1 Numerical modeling

The numerical model is show as figure 1, in which the loop antenna's plane is parallel to a wall of the shielding enclosure. The dimension of the enclosure is $2\text{m}\times 2\text{m}\times 2\text{m}$, the thickness of the steel wall is d=3mm. In numerical analysis the leakage cause by slots, the filter, cutoff window and other no-perfect part in the real shielding enclosure are neglected. The smallest spatial step is Δ=1mm, the radius of the discharge loop is r=5mm, FDTD mesh grid is show as figure 2.

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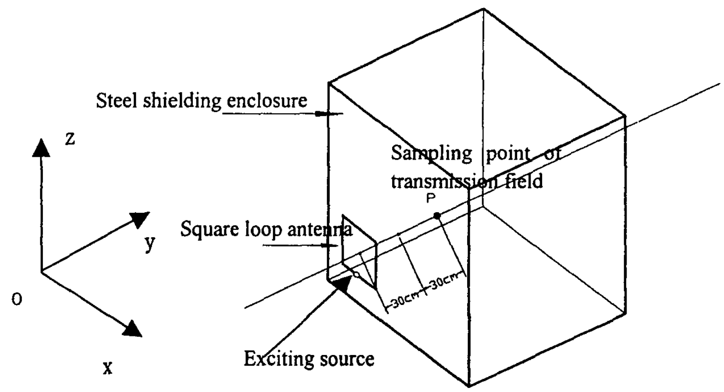


Fig. 1 Schematic of the relation positions of radiation antenna and shielding enclosure

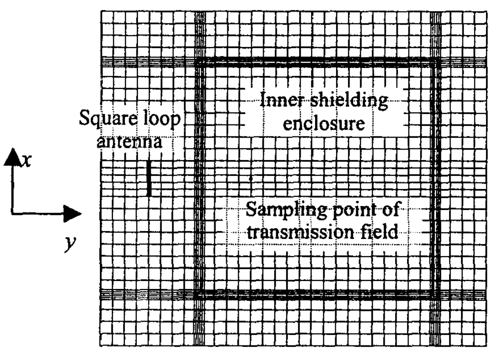


Fig.2 Mesh grid (planform)

We considered the permeability μ of steel expressed as formula (1) [2]:

$$\mu(H)=\frac{\bar{B}}{\bar{H}} \tag{1}$$

$$\mu(H)=\begin{cases}\mu_0(\mu_i+vH) & H\le H_{low}\\ v_0 & H_{low}<H<H_{high}\\ \dfrac{1}{a+b(H-H_0)}+\mu_0 & H\ge H_{high}\end{cases} \tag{2}$$

The parameters of steel in above equation are: a=400, b=1.22, v=13.369, $v_0=2.142\times10^{-3}$, B_{low} =0.257T, B_{high} =0.535T, H_0 =194A/m, $\mu_i=100$, $\sigma=2.5\times10^6$S/m, ε_r=1. The relation of $\bar{B}$ versus $\bar{H}$ is set nonlinear with no hysteresis. In FDTD model, it is necessary to advance by iteration $\mu(H_x^n(j))$ is first approximated by $\mu(H_x^{n+1}(j))$.

2 The global analysis of the loop antenna

The electric schematic of square antenna is shown in figure 3. In the first stage, the switch S2 is opened, switch S1 is on, the high voltage DC source charges the capacitance C *via* the switch S1, when the voltage of C reaches a demand value, opens S1 and closes S2, at that moment the capacitance C discharge through resistance R、inductance L and loop antenna。L is the sum of distributed inductance and inductance of the loop antenna. This circuit is a two order circuit which works in over dappling state.

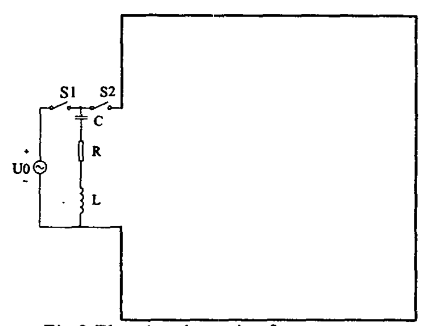


Fig.3 Electric schematic of square antenna and exciting source

The radiation field of loop antenna was modeled by FDTD method with lumped elements. That is the source was added in charging and discharging process of lumped circuit. The part of loop was modeled in common FDTD method. If the mesh range of source is from *nx4* to *nx5*, along the *x* direction the spatial step is Δx then we have

$$\begin{cases} I_D^{n+\frac{1}{2}} = \dfrac{\frac{L}{\Delta t} - \frac{R}{2}}{\frac{L}{\Delta t} + \frac{R}{2}} I_D^{n-\frac{1}{2}} + \dfrac{\frac{\eta_0}{2}}{\frac{L}{\Delta t} + \frac{R}{2}} (\widetilde{U}_D^n - \widetilde{U}_C^n) \\ \widetilde{U}_C^{n+1} = \widetilde{U}_C^n + \dfrac{\Delta t}{C} \cdot \dfrac{2}{\eta_0} I_D^{n+\frac{1}{2}} \\ \widetilde{U}_D^n = \Delta x \sum_{i=nx5}^{nx6} \widetilde{E}_x^n \end{cases} \tag{3}$$

The current density J equals I_D divided by the area of a mesh grid.

The radius of loop is 2.5mm and the edge length of the loop is 25cm. the thin wire approximation method[4-6] was adopted to analysis the loop antenna。

3 The calculating results of the steel shielding enclosure

Two different groups of magnetic pulses was modeled as the radiation wave. The first group is that the widths of pulses are same and the risetimes are different (as shown in figure 4(a)). The second group is that the risetimes are same and the widths are different(as shown in figure 5(a)). The parameters of exciting source and fictitious dielectric constant were shown in table 1.

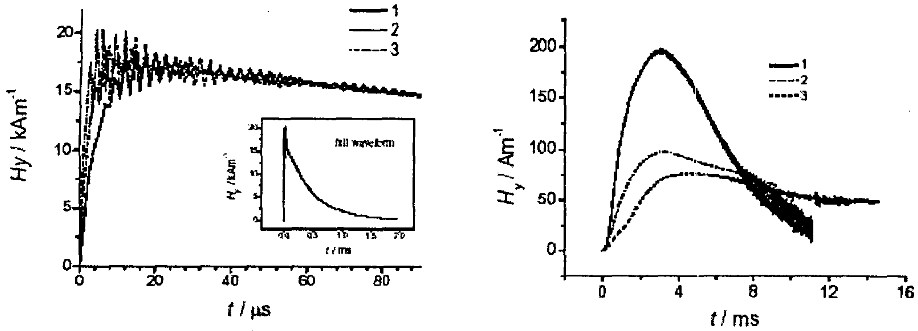
Table 1 The parameters of exciting source and fictitious dielectric constant

No.	R (Ω)	C (μF)	L (mH)	fictitious dielectric constant ε_r	Bottom width (ms)	Risetime (μs)	Remark
1	100	4.54	0.454	5×10^6	1.0	10	/
2	100	4.54	0.277	1×10^6	1.0	5.0	Changing the risetimes of pulse
3	100	4.54	0.138	5×10^5	1.0	2.5	
4	100	2.77	0.454	1×10^6	0.5	10	Changing the bottom width of pulse
5	100	1.38	0.454	5×10^5	0.25	10	

The initial voltage of the capacitance is 1.528MV, the time step of FDTD is calculated by formula $\Delta t = \frac{\Delta}{2c}\sqrt{\varepsilon_r}$, The y component of magnetic field in the point in the axis of the loop antenna and 60cm away from the center of the loop is H_{ip}=18kA/m. when the radiation field were in the form of that shown in figure 4(a) and 5(a) the transmission magnetic field in the same sample point were shown in figure 4(b) and 5(b) respectively. The calculate results can be summarized as table 2。

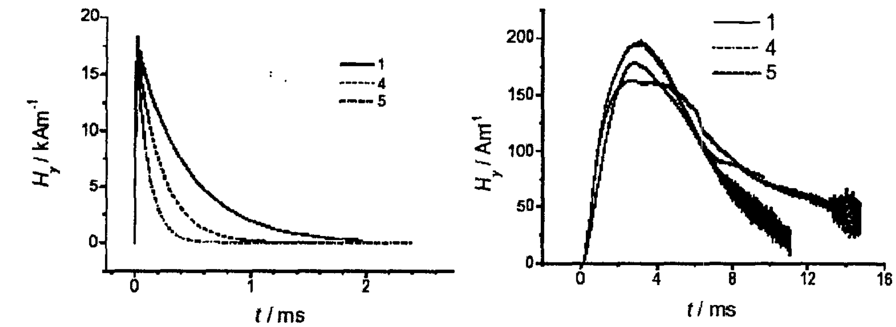
Fig.2 The peek value shielding results of steel shielding enclosure when the radiation pulsed magnetic waveforms are varying

No.	Incident pulsed magnetic			transmission pulsed magnetic			Peek value shielding effectiveness (dB)	Remark
	Bottom width (ms)	Risetime (ms)	Peek value (A/m)	Bottom width (ms)	Risetime (ms)	Peek value (A/m)		
1	1.0	10	18	10	1.5	197.8	39.2	/
2	1.0	5	18	>10	1.5	97.2	45.4	Changing the risetimes of pulse
3	1.0	2.5	18	>10	2.5	76.4	47.4	
4	0.5	10	18	>10	1.0	178.5	40.1	Changing the bottom width of pulse
5	0.25	10	18	>10	1.5	163.6	40.8	



(a) Without shielding (b) Inner shielding enclosure

Fig.4 Pulsed magnetic field waveform at the sampling point
(the incident magnetic wave with same bottom width and different rise time)



(a) Without shielding (b) Inner shielding enclosure

Fig.4 Pulsed magnetic field waveform at the sampling point
(the incident magnetic wave with different bottom width and same rise time)

4 conclusions

The conclusions from the numerical calculation are:

(1) The waveform of EMP transmission though the steel shielding enclosure is greatly different with the incident EMP waveform. The rise time changes to be very slow and the width of pulse gets long.

(2) The calculating indicate that the shielding efficiency of steel enclosure to the EMP with longer rise time(μs) and wider duration(1ms) is only about 40dB, the rise time of transmission pulsed magnetic field reaches ms and the pulse width is more than 10ms. That is to say the transparent energy is in low frequency under 1kHz. The shielding efficiency of the steel enclosure to low frequency electromagnetic field is much lower.

(3)The calculating results show that along with the decrease of the pulse width or rise time, the pulse peek value shielding efficiency of steel enclosure will increase. Especially with the decrease of pulse rise time, peek value pulse shielding efficiency of the steel enclosure increase much more.

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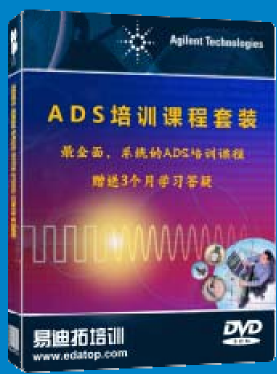

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