Structure Analysis of Transmitter Coil in Electromagnetic Launch Interceptors

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Abstract. This paper introduces the composition and working principle of, electromagnetic emission interceptors, establishes the three-dimensional model of transmitter coil, analyzes magnetic - structure coupling of the transmitter coil, gives the transmitter coil magnetic field and stress field distribution and finally comes to preliminary conclusions.

Introduction

Since the 80s, with the development of pulse power and power electronic technology, electromagnetic launch technology research gets more and more widely attention of the developed countries in the world, and its research scope penetrated from the original electric gun, electromagnetic cannon, and other fields gradually into the solid propellant electrothermal chemical gun (ETC Gun), aircraft ejection, electromagnetic launch interceptor technology and other fields. Because of electromagnetic launch interceptor technology has a good military application prospect; this technology has been the attention of the developed countries in the world. Transmitter coil is a key component of electromagnetic emission interceptors, in launching instant, the coil bears tens of thousands, even hundreds of thousands of Ann under pulsed high current shock, so its strength can meet the requirements which will be a direct impact on the performance of interceptors, therefore, the strength analysis of the transmitter coil is one of the important research contents of electromagnetic launch interceptor technology.

With the rapid development of computer technology and finite element analysis technology, the numerical simulation by finite element technique in engineering problem becomes a convenient and effective way. Entity model of the transmitter coil is presented in this paper, and by using commercial finite element analysis software, magnetic - structure coupling analysis of transmitter coil under 60 kA transient current shocks is done.

Electromagnetic Emission Interceptors

The electromagnetic launching interception device is mainly composed of high power pulse capacitor group C, high voltage switch K, electromagnetic transmitter coil and block board. Selections of copper and bronze are good conductors for transmitter coil with conductive performance, and the cross sections are rectangular, circular, etc. [1]. Transmitter coil is usually made spiral and placed in the launch box of insulating material, and insulating materials such as epoxy resin are fixed with fire box, two ends of mission coil respectively connect with energy storage capacitor C and high voltage switch K series, above the transmitter coil, place metal materials block board; Block board can also be made from non-metallic materials such as ceramic, but at the moment, inductive ring should be at the bottom of intercept plate.

Electromagnetic emission interceptors, detection system and control system together constitute the electromagnetic launching interception system. When the detection device of electromagnetic launching interception system gets the arrival of the projectile, judged by control system the type of projectile, calculate the direction, speed and distance of the incoming projectile, and determine the

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launch time, energy and direction of interceptors, and timely launch out the impact of incoming projectile intercept board to ensure the safety of the weapon equipment [1].

Figure 1 shows the launch principle of electromagnetic emission interceptors: before high voltage switch is closed, charge power to high power pulse capacitor first. When the control system's trigger signal closes the switch K, energy storage capacitor C, switch K and transmitter coil and forms a closed loop, the loop will produce powerful pulse current. The pulse current establishes strong pulsed magnetic field around the transmitter coil, the magnetic field will induce in the induced current in a clockwise out of aluminum block board (looking), namely produce eddy current in the block board. If select a bit on the board and get its current element Idl, and its direction is perpendicular to the paper faces (see Figure 2), the electromagnetic force current element gets is

$$\mathrm{d}\boldsymbol{F} = I\mathrm{d}\boldsymbol{l} \times \boldsymbol{B} \qquad (1)$$

The direction is perpendicular to the direction of magnetic field B in paper [1].

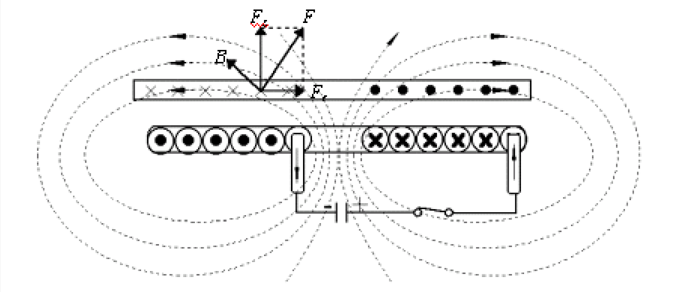

Figure 1 launch principle of electromagnetic emission interceptors

Decompose dF into horizontal and vertical two components: dFr and dFz. Due to the distribution of magnetic field and electric current has good symmetry on the z axis, so by the current element ring, the horizontal component dFr vector of electromagnetic force dF is zero. Because the current elements' dFz directions are the same, the total size of the electromagnetic force the intercept plate gets is

$$F = F_z = \oint \mathrm{d}F_z \qquad (2)$$

Z direction resultant force direction is vertical upward, and under the action of the force, intercepts plate pops up above to impact the incoming projectile so the safety of the weapon equipment is guaranteed [2].

Transmitter Coil Structure Analysis

A. Transmitter coil entity model is set up

Transmitter coil's shape is spiral, and coil has a total of ten turn's models. Cross section is rectangular, with width of 10 mm and 3 mm respectively, which is made of red copper. Coil turn-to-turn is casting with epoxy resin; Figure 2 shows the transmitter coil entity model. Because the shape of the coil is complex, and it can be hard to establish directly in the finite element analysis software, therefore, transmitter coil entity model using three-dimensional modeling software Solidwoks platform is set up, and the file is stored as sat format. Then, using the commercial finite element analysis software and Solidwoks software interface function, import the proposed model file. Specific operations are as follows: under the GUI interface of the software, select menu "File > Import >. sat", open software interface sat file dialog box, which is shown in Figure 3, enter all the information, then click "OK" button to confirm. After input geometric model, complete the import process of the transmitter coil entity model.

Figure 2 Transmitter coil model

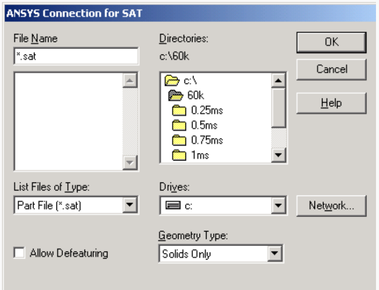

Figure 3 sat file interface dialog box

B. Transmitter coil electromagnetic field analysis

1. Finite element model is established

Create an insulator entity model in commercial software; through the software provided by Boolean operations command launch a component combined with coil and epoxy resin (transmitter coil components). According to the software analysis steps, before finite element model is generated, first choose the type of analysis, method, and set elements type of coil and insulator, material properties and mesh subdivision. Here choose cell edge based method to analyze. Therefore, choose SOLID117 unit, and set coil relative permeability (MURX) and resistivity (RSVX) to 1 and 3e-8; set insulators relative permeability (MURX) is to 1. Transmitter coil component shape is more complicated, and will be on the 3 d finite element analysis, so use free mesh subdivision. In order to obtain reasonable subdivision mesh density and get a more accurate calculation result, control respectively the coil, insulators for grid subdivision. Choose freedom grid subdivision of transmitter coil component and set the coil unit length to 1.5 mm, and subdivision of insulation level is set to "6" level. After subdivision, form finite element model of transmitter coil component. Total model units are 221448, of which the transmitter coil unit number is 117033. Figure 4 and Figure 5 give the finite element model of transmitter coil and transmitter coil component respectively.

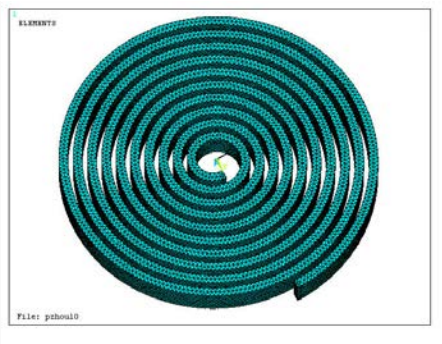

Figure 4 Transmitter coil finite element model diagram

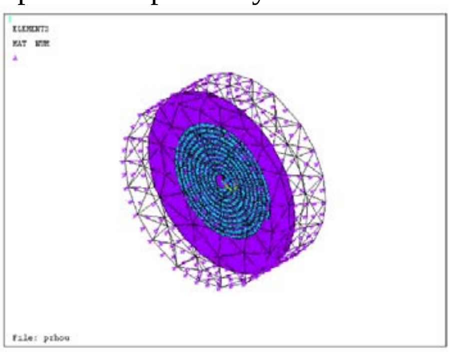

Figure 5 transmitter coil components after the subdivision

2. Finite element model solutions

(1) Apply load and boundary conditions

Finite element analysis task is system solution response to the load, so load form is an important step to solve, and for more step load, loading method is a relatively complex load step. Under multiple load step loads, every load step must be to generate the corresponding step load file. When solving, load by reading load step file. According to the analysis of the situation, set load form as triangular load, and maximum peak current value is slope 60000 amp. Concretely there are two load steps, first load step end time is 0.5 ms, and the second load step end time is 1 ms, and each step load is averagely divided into two children steps. Apply electric current load on finite element model, Figure 7 shows the waveform figure to be applied load. Parallel to the boundary of the model and the lines of magnetic force conditions, namely setting AZ = 0, magnetic lines force vertical boundary conditions occur naturally.

(2) Solve

According to the load imposed by the transmitter coil, choose transient analysis type, select software provided incomplete conjugate gradient solver (ICCG) solution. After solving, enter general post-processing module for calculation results. General post-processing module of software can be used to easily see every moment's electromagnetic field analysis results in the transmitter coil loading process; Figure 6 shows the magnetic clouds figure when 0.5 ms of transmitter coil components.

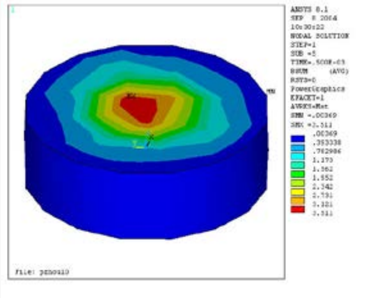

Figure 6 Magnetic clouds figure of transmitter coil component at 0.5 ms

The electromagnetic field analysis results of transmitter coil indicate: with the increase of current, the magnetic flux density and current density of transmitter coil component are increased gradually. With the decrease of the current value, the transmitter coil magnetic flux density and current density decreases. Time current peaks at 0.5 ms, and the magnetic flux density and current density of the transmitter coil also achieve the maximum.

C. Transmitter coil stress field analysis

Due to the electric current gets by in a coil conductor, therefore, electromagnetic field and structure field are coupled to each other. When load current is larger, analyze the change of conductor cross section structure and displacement to determine whether the coil meets the requirements of strength and deformation. So based on the analysis of transmitter coil model transient electromagnetic field, use magnetic - structure coupling analysis function of the software, stress field analysis is carried out on the transmitter coil.

Analysis method chooses software provided physical environmental law. For this, change physical environment to structural analysis module, change SOLID117 unit to SOLID45 unit and electromagnetic force generated by transient electromagnetic field analysis is the force load of structure analysis. According to the actual working condition of transmitter coil to, impose all constraints at coil component bottom, calculate, and then count, enter general post-processing module for the analysis results. Figure 7 and Figure 8 give respectively the transmitter coil displacement nephogram and strain nephogram when 0.5 ms.

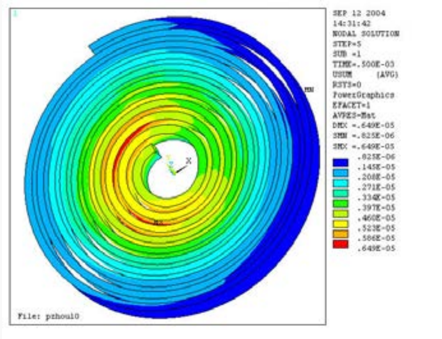

Figure 7 0.5 ms transmitter coil displacement nephogram

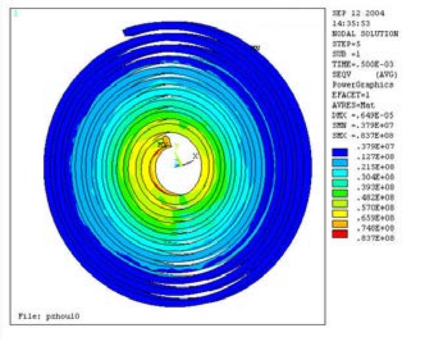

Figure 8 0.5 ms transmitter coil stress nephogram

It can be seen from the analysis results: with the increasing of magnetic field, the transmitter coil model displacement and stress increase, and with the weakening of the magnetic field, it decreases. The maximal displacement of coil is 60700 nodes of the third ring, coordinates are (0.0169213, 0.014933, 0.0169213), the maximal displacement value is 6.49 x 10-3 mm; Maximum stress position of the first lap's 101113 nodes with coordinates (0.0050397, 0.0050397, 0.00974932), the most rice jersey (Von Mises stress) stress value is 83.7 Mpa. By material manual, the yield strength of copper is 235.5 Mpa. Take safety coefficient as 1.3, and the ultimate strength [σ] of the coil is 182 Mpa. And under 60 ka current loads, the biggest rice jersey stress (Von Mises stress) value is 83.7 MPa, within the limit of material's strength, meet the strength requirement.

Conclusion

The size of transmitter coil carrying capacity directly determines the protection performance of electromagnetic launching interception device. If singly from the perspective of improving the protective ability of electromagnetic emission interceptors, transmitter coil load is the bigger the better, but the size of the load value must satisfy the ultimate strength requirement of the transmitter coil material. In this paper, by using magnetic - structure coupling function of a commercial software, the strength question of a transmitter coil has carried on preliminary exploration, simulate conditions while the transmitter coil is under 60 ka impact current, and the simulation results show that the coil is within the limit of stress in the strength of the material and satisfies the requirement of strength.

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