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Original Citation

Pati, Prasanta and Mather, Peter (2010) Time-domain Transient Magnetic Field Analysis of Metallic Weapons. In: Proceedings of Electric Power Engineering & Control Systems 2010" (EPECS-2010). Publishing House, Lviv Polytechnic National University, Ukraine, Ukraine, pp. 40-41. ISBN 9786176070061

Time-domain Transient Magnetic Field Analysis of Metallic Weapons

Detection of complex metallic weapon geometries is a challenging task for public security. Current metal detectors namely walk-through and hand-held detectors are good in detecting metal objects but fail to identify between threat and non-threat metal objects e.g. key rings, knife, belt buckles etc. The difficulty is that; at present these systems detect almost all metal objects, while at times miss many important threat metal objects. Although, sensors are available for detection of metal objects, but the ability to use the information that the sensors produce is limited. This increases number of false alarms in the detection system. Identification of threat and non-threat metal objects is a great-unsolved problem. Therefore it is necessary to analyze the secondary magnetic field behaviour of metallic weapons in transient magnetic field environment for the design a sensor system for detection on threat metal objects.

Metallic weapons in a time varying magnetic field develop eddy currents. A method of identification of field behaviour and eddy currents in metallic weapons is established by the application of finite element analysis in time-domain transient magnetic field environment. A model of a weapon and a transmitter coil was designed in Opera 3D software is shown in fig.1. Time stepping algorithm was developed in transient electromagnetic field analysis program. Time-domain step pulse was sent to transmitter coil to generate transient magnetic field from an external current driven circuit. The secondary field behaviour of complex metal structures and decay time of eddy currents was analyzed in this paper. A sensor system is being designed using the results achieved in this paper for identification of metal objects.

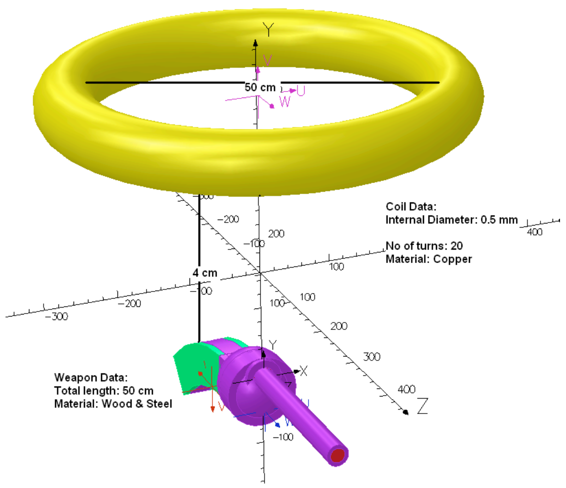

Fig.1 Model of a weapon and transmitter coil developed in Opera software

Time-domain Transient Magnetic Field Analysis of Metallic Weapon

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Abstract – ***Metallic weapons in a time varying magnetic field develop eddy currents. A method of identification of field bahaviour and eddy current in metallic weapons is established by the application of finite element analysis in time-domain transient magnetic field environment. The secondary field behaviour of complex metal structures and decay time of eddy currents was analysed in this paper. A sensor system is being designed using these results to determine the properties of secondary field and eddy currents of complex inter-metallic weapon geometries.***

Keywords – Electromagnetic fields, Finite element Analysis, Metal Detection.

I. Introduction

The detection of complex metallic weapon is a challenging task for public security. Current metal detectors namely walk-through type portal detectors and hand-held metal detector are generally unable to determine the types of metallic weapons.

In this paper a complex shape of a weapon with both metalic and non-metallic part was modelled and anlysed in time-domain transient electromagnetic simulation software. The secondary field behaviour and eddy current decay time was analyzed to design an appropriate sensor system to detect these complex shape metallic weapon geometries.

II.Modelling & Simulation

In this experiment, model of a weapon was created in Opera 3D modeller [1] electromagnetic simulation software. The barrel of weapon was defined as steel and handle was defined as wood. The model of weapon is shown in fig.2.

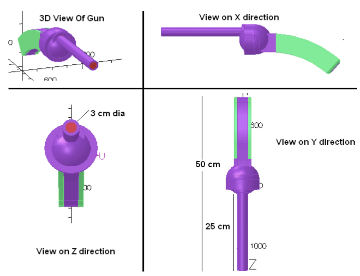

Fig.2 Model of gun developed in Opera software

A transmitter model of a coil was made of 20 turn of copper wires with internal diameter 0.5mm and external diameter 50cm. The model of the weapon was placed 4 The transmitter coil was supplied with 5 A of step pulse for 0.1 msec and then transmitter coil was switched off to observe the secondary current in the weapon.

The analysis was completed in transient time-domain electromagnetic environment. A mixed combination of total and reduced vector potential was used to model time varying magnetic fields for the model. The magnetic field produced by transmitter coils with source current is calculated from the Biot-Savart's equation given in Eq. (1)

$$H_s = \int_{\Omega_J} \frac{J \times R}{|R|^3} d\Omega_J \quad [1] \qquad (1)$$

Where H_s is conductor field intensity, J is current density, R is distance from transmitter to weapon and $d\Omega_J$ is derivative volume of the weapon.

The vector potential describing the magnetic field excluding the fields from source transmitter coils is known as reduced vector potential (A_R) and is defined by Eq. (2)

$$B = \mu_0 H_s + \nabla \times A_R \, [1] \qquad (2)$$

The total vector potential is given by Eq. (3)

$$\nabla \times \frac{1}{\mu} \nabla \times A = -\sigma \frac{\partial A}{\partial t} - \sigma \nabla V \, [1] \qquad (3)$$

The transmitter coils are incorporated into the finite element mesh, represented by 20 winding filaments and are connected to an external current driven circuit.

The transient analysis program analyse eddy current in the weapon, where current driven external circuit changes with time according to a 'switch' function defined in the modeler. The resulting equation is solved using a time-stepping algorithm.

Applying the Galerkin procedures [2] to Eq. (3) produces a matrix equation of the form

$$RA + S\frac{\partial A}{\partial t} + b = 0 \qquad (4)$$

where A is a vector of unknown potential and b is a vector driving terms. Discretising A and B as first order function in time:

$$A(t) = (1-\tau)a_n + \tau a_{n+1} \qquad (5)$$

$$B(t) = (1-\tau)b_n + \tau b_{n+1} \qquad (6)$$

where $\tau = \dfrac{t - t_n}{t_{n+1} - t_n}$

and a_n and b_n are values of A and b at time t_n. Using τ as the weight in a Galerkin weighted residual solution of Eq. (4) leads to recurrence relationship between a_{n+1} and a_n:

$$(R(1-\theta) - \frac{S}{\Delta t})a_n + (R\theta + \frac{S}{\Delta t})a_{n+1} + b_n(1-\theta) + b_{n+1}\theta = 0 \qquad (7)$$

where the time step $\Delta t = t_{n+1} - t_n$.

III. Result and Analysis

The secondary current distribution after 0.1 msec of analysis is shown in fig. 3. The internal region within the barrel of the weapon was modelled as air region, this assist in illustrating the effect of internal cavities within the weapon. The secondary field of interior region of weapon in shown in fig. 4. The decay time secondary field of weapon was calculated in fig. 5 and it was determined that the secondary field of weapon decays to zero after 40 msec of transmitter was switched off.

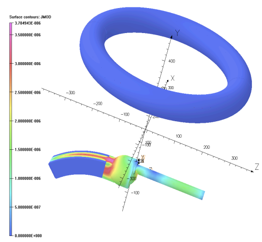

Fig.3 Current distribution in weapon after transmitter is off

The secondary current distribution of the weapon is shown in fig. 2. The secondary current is higher near the extremities of weapon and in the intersection between two metal parts in the weapon.

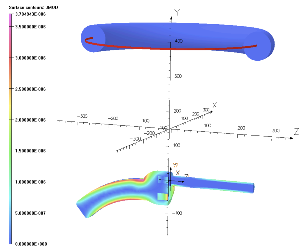

Fig.4 Inside view of current distribution in weapon after transmitter is switched off

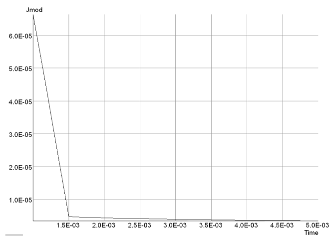

Fig.5 Eddy current decay of weapon

Conclusion

In this paper, the transient time-domain electromagnetic analysis of a weapon with mutilple metallic and non metallic part was achieved to determine decay time of eddy currents of weapon. This way of determining eddy current decay time in complex metallic object can be achieved to determine the secondary field behaviour and eddy current decay time for metal with complex geometries. Similar simulations are to be made for various metals to analyse behaviour in time-domain transient electromagnetic field environments, which will assist in the design of sensors to measure decay time from complex metal structures in time-domain transient electromagnetic field environment.

References

[1] Opera 3D User Guide Version 13.0, "Vector Field Softwares Ltd,", Oxford, Jul. 2009.

[2] J. Jinn, "The finite element method in electromagnetics",John-Wiley & Sons, 2002, ch. 2.