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A HIGH POWER ELECTROMAGNETIC PULSE SIMULATION MODEL

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Abstract *- The paper presents a calculus and a simulation model to generate a great power electromagnetic pulse – one of the frequent causes of the electromagnetic interferences in case of electronic equipment; these phenomena being usually produced by natural phenomena, such as thundering, but also by the electromagnetic pulse weapon, in case of military conflicts. As a source of this type of pulse, it is used a flux compression generator (FCG), whose resistance and inductivity will vary linear parametrically, during the magnetic flux compression. This one being produced by an ultra-rapid short-circuit process of the FCG coil by means of one metal framework, using a controlled explosion.*

1. Introduction

One of the important problems of the Electromagnetic Compatibility (EMC) is focused on the behavior of the electronic circuits, devices, equipment and systems in case these are affected by the great power electromagnetic pulses, generated by natural phenomena (lightning) or of the pulse of electromagnetic weapons. In these cases it is necessary to know how such pulses are generated and their features.

In this context, our work presents a calculus and a simulation model of the great power electromagnetic pulse, generated by a device especially designed for this reason i.e. flux compression generator (FCG).

The used method consists of obtaining this pulse by the *compression,* respectively by the ultra-rapid amplification of the initial current, and of the associated magnetic flux, produced into a specially designed coil, which has at its end a electrical current loop, by discharging upon it of a super-capacitor (0,1 F). Inside the coil there is a metal cylinder of copper or iron, named *framework*. *The compression* of the magnetic flux is progressively developed by an ultra-rapid short-circuit process of the coil aided by the framework, using a controlled explosion. Finally, a very great power pulse of electrical current is obtained and, as a result, one can obtain a magnetic flux that can produce negative effects upon the nearby electronic equipments.

2. The establishment of the parametric relations for the resistance and coil of the generator

The initial electric current into the coil is obtained by the discharge of a super-capacitor of 0,1 Farad upon this, and the final current is obtained by an ultra-rapid short-circuit process of the coil aided by the framework, using a controlled explosion. The simulation of these currents was performed by a transitory regime analysis, using parametric components of the circuit, because while the process of short-circuit is developed, the values of the resistance and coil are modifying themselves (are decreasing to zero).

In the following it is considered the case where the resistance and the coil have a linear parametric evolution during the flux compression process:

$$R(t)=R_0(1-kt) \tag{2.1}$$

$$L(t)=L_0(1-kt) \tag{2.2}$$

where it is noted below:

$R_0=R$; $L_0=L$;

$k=\frac{1}{t_i}=\frac{1}{52,14\cdot10^{-6}}=1,9178\cdot10^4\,(s^{-1})$;

$t_i=\frac{l}{v_C}=\frac{0,365}{7000}=52,14\cdot10^{-6}(s)=52,14(\mu s)$ represents the duration of explosion propagation.

The real electrical parameters (the measured parameters) of the coil with internal copper cylinder (the framework) and the final electrical current loop are the following:

- the coil inductivity: L_0=42 (µH); the coil resistance: R_0=0,097 (Ω);
- the inductivity of the current loop (the charge): L_b=0,1498 (µH);
- the resistance of the current loop: R_b=0,006466 (Ω);
- the loss and residual inductivity of real circuit: L_p=2 (nH).

They note below:

$$R_c=R+R_b;\ L_c=L+L_b+L_p \tag{2.3}$$

because these parameters are constant.

With these notations one can write:

$$R_T(t)=R(t)+R_b=R_c-kR_0t;\ L_T(t)=L(t)+L_b+L_p=L_c-kL_0t \tag{2.4}$$

3. The study of the transitory regime during the coil short-circuit

In this chapter, the transitory regime of the short-circuit coil, starting from an initial known current I_0 is analyzed. The homogeneous differential equation of the parametric series circuit R, L is the following:

$$\frac{d}{dt}L_T(t)i(t)+R_T(t)i(t)=0 \tag{3.1}$$

Taking into an account the above relations, one can write:

$$\frac{d}{dt}\left\{\left[L(t)+L_b+L_p\right]\cdot i\right\}=\left[L(t)+L_b+L_p\right]\cdot\frac{di}{dt}+i\frac{d}{dt}\left[L(t)+L_b+L_p\right] \tag{3.2}$$

$$\frac{d}{dt}\left[L(t)+L_b+L_p\right]=-kL_0 \tag{3.3}$$

The (3.1) formula becomes:

$$\left(L_c-kL_0t\right)\frac{di}{dt}-kL_0i+\left(R_c-kRt\right)\cdot i=0 \tag{3.4}$$

or:

$$\left(L_c-kL_0t\right)\frac{di}{dt}+\left[\left(R_c-kL_0\right)-kRt\right]i=0 \tag{3.5}$$

The (3.5) equation can also be written:

$$\frac{di}{dt}+\frac{(R_c-kL_0)-kRt}{L_c-kL_0t}i=0 \tag{3.6}$$

or:

$$\frac{di}{dt}+\left[\frac{R_c-kL_0}{L_c-kL_0t}-\frac{kRt}{L_c-kL_0t}\right]\cdot i=0 \tag{3.7}$$

It is noted below the square parenthesis (2.12) with P(t):

$$P(t)=\frac{R_c-kL_0}{L_c-kL_0t}-\frac{kRt}{L_c-kL_0t} \tag{3.8}$$

As a result the (3.7) equation, one can write the following:

$$\frac{di}{dt}+P(t)\cdot i=0 \tag{3.9}$$

The solution of the (3.9) homogeneous equation, in other terms – the free response to a null excitation, corresponding to an initial state of the transitory regime has the form [1]:

$$i_1(t)=I_0\cdot e^{-\int_0^t P(t')dt'} \tag{3.10}$$

The current I_0 is obtained from the initial condition $i(0)=I_0$ and represents the starting current.
Further on, they compute the integral from the (3.10) formula:

$$\int_0^t P(t')dt'=\int_0^t\left[\frac{R_c-kL_0}{-kL_0t'+L_c}-\frac{kRt'}{-kL_0t'+L_c}\right]dt'=$$
$$\left(R_c-kL_0\right)\int_0^t\frac{1}{-kL_0t'+L_c}dt'-kR\int_0^t\frac{t'dt'}{-kL_0t'+L_c} \tag{3.11}$$

The (3.11) relation can be written as in the following:

$$\int_0^t P(t')\,dt'=(R_c-kL_0)\cdot I_1-kR\cdot I_2 \tag{3.12}$$

where:

$$I_1=\int_0^t\frac{1}{-kL_0t'+L_c}dt' \tag{3.13}$$

and:

$$I_2=\int_0^t\frac{t'dt'}{-kL_0t'+L_c} \tag{3.14}$$

Taking into an account that:

$$\int_0^t \frac{dx}{ax+b} = \frac{1}{a}\cdot \ln(ax+b)\Big|_0^t = \frac{1}{a}\cdot \ln\left(\frac{a}{b}\cdot t+1\right) \qquad (3.15)$$

and:

$$\int_0^t \frac{x\cdot dx}{ax+b} = \left[\frac{x}{a} - \frac{b}{a^2}\cdot \ln(ax+b)\right]\Bigg|_0^t = \frac{t}{a} - \frac{b}{a^2}\cdot \ln\left(\frac{at+b}{b}\right) = \frac{t}{a} - \frac{b}{a^2}\ln\left(\frac{a}{b}t+1\right) \qquad (3.16)$$

as well as the fact that in the analyzed case: a = - kL_0 and b = L_c, they result for I_1 and I_2 the following expressions:

$$I_1 = \frac{1}{-kL_0}\cdot \ln\left(\frac{-kL_0\, t}{L_c}+1\right) \qquad (3.17)$$

$$I_2 = -\frac{t}{kL_0} - \frac{L_c}{(-kL_0)^2}\cdot \ln\left(\frac{-kL_0}{L_c}t+1\right) \qquad (3.18)$$

Further on, one can write:

$$e1(t) = -\int_0^t P(t')\,dt' = -(R_c - kL_0)\cdot I_1 + kR\cdot I_2 \qquad (3.19)$$

Taking into an account the (3.17) and (3.18) formula, (3.19) relation becomes:

$$e1(t) = \frac{R_c - kL_0}{kL_0}\cdot \ln\left(\frac{-kL_0\, t}{L_c}+1\right) + kR\left[-\frac{t}{kL_0} - \frac{L_c}{(-kL_0)^2}\cdot \ln\left(\frac{-kL_0}{L_c}t+1\right)\right] =$$
$$\left(\frac{R_c - kL_0}{kL_0} - \frac{kRL_c}{(-kL_0)^2}\right)\cdot \ln\left(-\frac{kL_0}{L_c}t+1\right) - \frac{R}{L_0}t \qquad (3.20)$$

As a result, the formula of the transitory regime current into the coil will be:

$$i_l(t) = I_0\cdot e^{-\int_0^t P(t')dt'} = I_0\cdot e^{e1(t)} \qquad (3.21)$$

4. Calculus of the initial electrical current imposing various final currents into the coil

The next procedure will be followed when one wants to calculate the initial current imposing different final currents into the coil:

- it is calculated the value of (2.24) formula, imposing the final values $i(t_i)$=130kA; 75kA; 30kA, 15kA and t=$t_{i,}$ (after the time interval $t_{1,}$ corresponding to the explosion propagation):

$$e1(t)\Big|_{t=t_i} = e1(t_i) = \left(\frac{R_c - kL_0}{kL_0} - \frac{RL_c}{kL_0^2}\right)\cdot \ln\left(-\frac{L_0}{L_c}+1\right) - \frac{R}{L_0}\cdot t_i \qquad (4.1)$$

- using the coil parameters, it is obtained: $e1(t_i)$=5,4486;
- then, using the (3.26) formula it is obtained the expression of the initial current:

$$I_0 = \frac{i(t_i)}{\exp[e1(t_i)]} \qquad (4.2)$$

where the final current is: $i(t_i)$=130kA; 75kA; 30kA; 15kA.

- finally, the following values of the initial currents are obtained:

$$I_{01} = \frac{130000}{\exp[e1(t_i)]} = 559{,}2480(A);\ I_{02} = \frac{75000}{\exp[e1(t_i)]} = 322{,}6430(A)$$

$$I_{03} = \frac{30000}{\exp[e1(t_i)]} = 129{,}0572(A);\ I_{04} = \frac{15000}{\exp[e1(t_i)]} = 64{,}5286(A)$$

5. The graphic representation of the final current into the FCG coil

For the graphic representation of the final current into the loop of the coil, an initial current into the coil of value I_0=551(A) is considered. The graphic i(t) for the time interval $t \in [0.00, 52.14 \cdot 10^{-6}]$ seconds is presented in fig. 5.1 and for the time interval $t \in [0.00, 52.14 \cdot 10^{-6}]$ seconds - in fig.5.2.

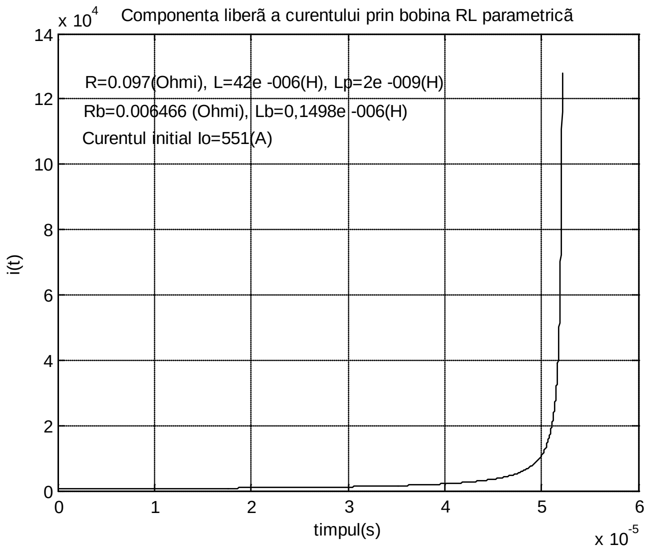

Fig. 5.1 Evolution of the final current for the time interval
$t \in [0, 52.14 \cdot 10^{-6}]$

It results from these graphs that the final value of the current that *was accumulated* into a loop of the coil is: I_{fin}=128.158,84 A. The intensity of the adequate magnetic field into the center of the loop will be H_{fin} = 4,22x10^5 Asp/m. The loop will be finally destroyed by explosion and will produce an instantaneous interruption of this flux, having a negative effect upon the functionality or physical integrity of nearby electronic equipment.

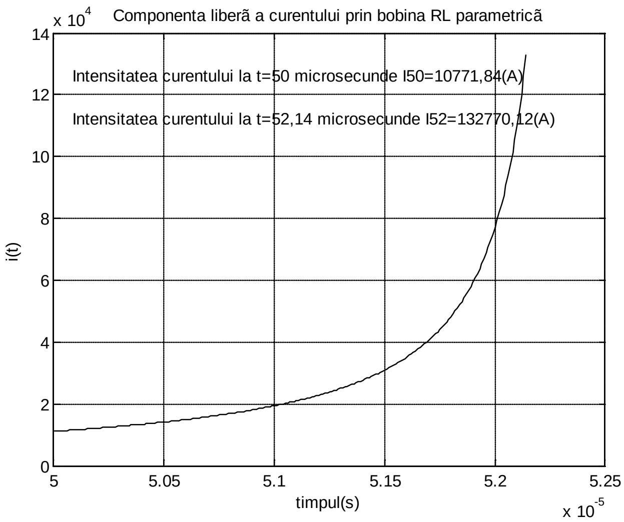

Fig.5.2. Evolution of the final current for the time interval
$t \in [50 \cdot 10^{-6}, 52.14 \cdot 10^{-6}]$

6. Conclusions

In this work it is demonstrated the fact that it can be obtained, using a Flux Compression Generator and an adequate calculus and simulating model, a great power electromagnetic pulse, which can, in its turn, to functionally disturb, or even destroy the nearby electronic equipment.

The experimental tests carried out in a military location emphasize the fact that the model is valuable and, as a result, it can be used to develop similar tests on a large range of military or civilian electronic equipment, which must conform to the EMC directives.

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