The forming and emission of high power electromagnetic pulses

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Abstract. An impulse energy source, a power conditioning system and an electromagnetic field emitter are essential to generate an electromagnetic field pulse (EMFP) with a specific frequency bandwidth. Selected simulation results for a power conditioning system consisting of a fuse opening switch and a paraboloidal electromagnetic emitter have been presented in this article. The synthetic system examined in the simulation is powered by an impulse capacitor instead of a flux compression generator (FCG) used in practice. The obtained results confirm that pulse generation and emission of high-power EMFP is possible.

1 Introduction

Generation of bandwidth-specific (e.g. in the order of MHz [3, 4]) high-power electromagnetic field pulse (EMFP) is essential in various technical applications. FCG are the most widely used energy sources in such systems [4]. They generate current pulses with the duration of several or tens of µs (substitute frequency in the order of hundreds of KHz) [4]. In order to decrease the duration of such pulse to the fraction of a µs (substitute frequency in the order of several MHz) it has to be properly formed. It is possible to accomplish this with a system incorporating fuse opening switch [4] or Blumlein transmission line which in turn provides the properly formed current pulse for the EMFP emitter (Figure 1). The used emitters must have the features of a mono-pulse radiator, and therefore have appropriate directivity, high efficiency and relatively low natural frequency (of hundreds of kHz or several MHz). Selected simulation results of the pulse-forming of a signal and its subsequent emission in the form of EMFP have been presented in this paper.

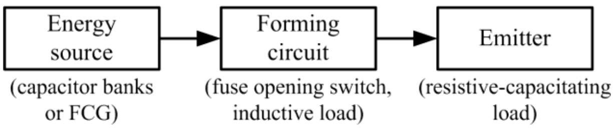

Fig. 1. The block diagram of forming system idea.

2 Model of the pulse-forming system

The substitute scheme of the examined circuit along with the adopted values of its parameters have been presented in Figure 2. Low-inductance capacitor C_0 charged to the voltage U_0 serves as an energy source. The fuse B modelled as non-linear resistance described by formulae (1) is located on the source node along with the elements L_C and R_C. The current i in the loop with the additional operating node containing the elements L_R and R_R is rapidly reduced to zero by the quickly increasing resistance of the fuse which leads to the voltage spike in the additional operating node, causing the ignition of the spark gap *IS* situated on the same node as the EMFP emitter. The emitter is modelled as elements R_L and C_L which parameters' values have been determined based on the results of numerical simulation regarding only the near field region of the emitter. Detailed studies of HVR (High Voltage Radiator) emitter solutions have been described in [5].

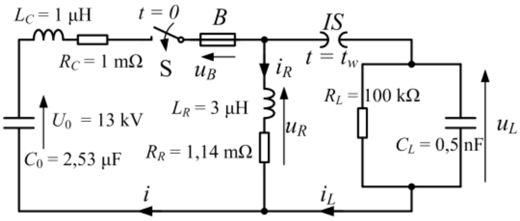

Fig. 2. Substitute scheme of the circuit enabling the analysis of the pulse-forming and emission of EMFP (the description of the elements in the text).

Calculations presented in detail in the papers [1, 2] have been performed in Matlab Simulink software. Fuse B is modelled as a non-linear resistor which resistivity depends on the integral of current action h described by formulae (1) [3, 4]:

$$\rho(h) = \begin{cases} \rho_0 \left(1 + A\left(\frac{h}{h_e}\right)^B\right) & \text{dla} \quad h \le h_e \\ \rho_0 \left(A + e^{C\left(\frac{h-h_e}{h_e}\right)}\right) & \text{dla} \quad h > h_e \end{cases} \tag{1}$$

$$h = \frac{1}{S_f^{\,2}} \int_0^t i(t')^2 \, dt'$$

where: ρ_0 - the resistivity of the material of the fuse element in the temperature of 0°C, S_f - surface area of fuse element, A, B, C, h_e - constants based on the experimental research [4].

The analysis of the effects of construction parameters of the fuse on the parameters of the pulse-forming circuit has been presented in the papers [1, 2].

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3 Computational results

Exemplar computational results for the circuit with values of parameters proposed in Figure 2 and the fuse element of diameter d = 0,16 mm and length l_f = 20 mm have been presented on Figures 3 and 4.

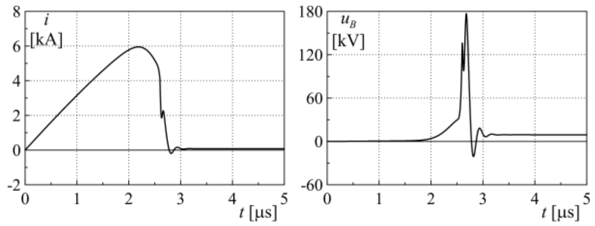

Fig. 3. Waveforms: current i a) and voltage drop u_B on fuse B b): i_{max} = 5.95 kA, $|u_B|_{max}$ = 268 kV.

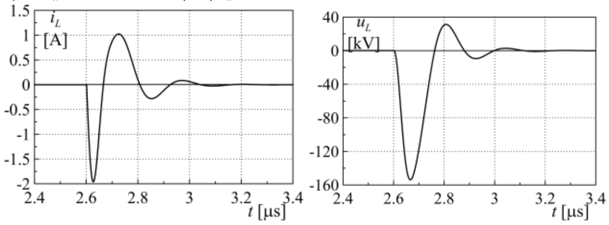

Fig. 4. Waveforms: current i_L a) and a load voltage u_L b), i_{Lmax} = 1.98 kA, $|u_L|_{max}$ = 154 kV, f_{eq} = 4.4 MHz.

4 Studies of an electric field emitter

Due to the criterion of the maximum value of the electric field, the withstanding voltage and the proper directivity of a beam, the topology of the HVR electric field emitter which consists of paraboloidal, conductive reflector and the armature in the form of a conductive tube has been chosen. The discrete emitter simulation model and a prototype at the test stand are shown in Figure 5.

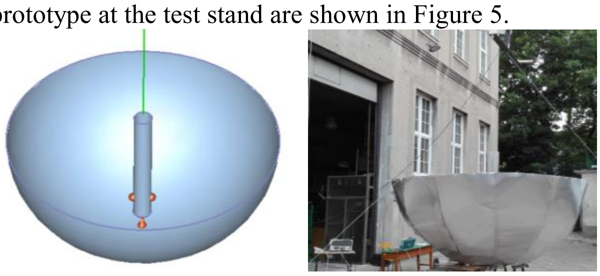

Fig. 5. Discrete emitter simulation model a) and a physical prototype b) at the test stand.

The load voltage pulse obtained from the Matlab Simulink simulation results has been used to supply the emitter simulation model implemented in the EMCOS AntennaVLab [6] software, which uses the Method of Moments in the frequency domain and inverse FFT to solve issues in the time domain.

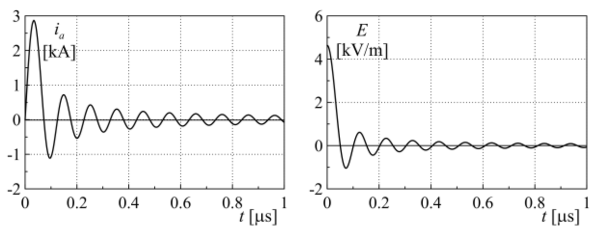

Fig. 6. Waveforms: Emitter current i_a a) and a the dominant component of the electric field E b), at a distance of 2 m; i_{amax} = 2.82 kA, E_{max} = 4.6 kV/m, f_{eq} = 3.7 MHz.

The simulation results in a form of current waveforms of the emitter and a dominant component of the electric field at a distance of 2 m from the emitter are shown in Figure 6. The results of the experimental tests performed with the use of the paraboloidal emitter prototype and a synthetic pulse-forming system are shown in Figure 7.

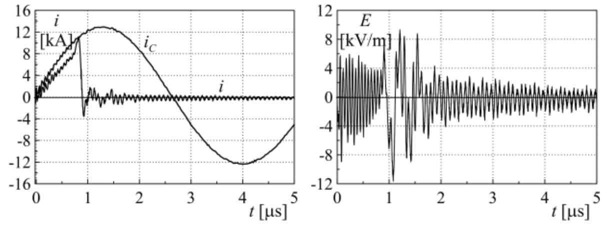

Fig. 7. Waveforms: Fuse i and calibration i_C current a), the dominant component of the electric field E b), at a distance of 2 m; i_{Cmax} = 13 kA, i_{max} = 9,2 kA, E_{max} = 10.6 kV/m, f_{eq} = 12.1 MHz.

5 Conclusions

1. Based on the presented simulation and experimental research following conclusions have been drawn:
   - Application of a fuse opening switch is an effective high-power pulse-forming method allowing to achieve over tenfold reduction of pulse duration with concurrent over tenfold increase in its peak voltage.
   - The considerable energy loss in the fuse is a major flaw of the examined system that reduces electrical efficiency of the pulse-forming process.
   - A proposed solution of the emitter with a paraboloidal reflector was appropriate in terms of electrical strength, high value of emitted electric field, low natural frequency and directivity.

The research has been performed as a part of the project financed by the Polish National Centre for Research and Development – contract DOB-1-1/1/PS/2014.

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