ANALYSIS OF THE EUQIVALENT CIRCUIT OF PRISHCHEPENKO-TYPE SPIRAL MCGs

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Abstract

The explosive and implosive magnetic generators of frequency (EMGF and IMGF) consist of a spiral magnetocumulative generator (MCG) with a small capacitive load. The simplest model describing the operation of these devices is based on their equivalent circuit diagram. By selecting the proper parameters of the IMGF and EMGF, it is possible to calculate the current in the coil and to obtain good agreement between the calculated and measured envelopes of the current waveform. The particular mechanism by which current is generated in these devices is understood, unlike other similar sources of electromagnetic radiation. In this paper, circuit model of the IMGF and EMGF will be presented and analyzed. The results of the analysis will be compared to data in tests conducted in June 1997 and August 1998.

I. INTRODUCTION

Some years ago it was reported about new modification of the MCGs, the IMGF and the EMGF created by Dr. Prishchepenko [1]. Despite, as it follows from the publications of the author of the devices, it was introduced the only unit additional to design of conventional MCGs, namely the capacitor, essentially changes operation of the generator. For example, it is reported in some publications after testing these devices about presence of the HF radiation [2, 3]. By the way, some authors claim that the HF radiation is too weak [2].

However, it must be noted that before any discussion of the level of the power of the HF radiation from the EMGF and IMGF, it is diserable to understand the real cause of the radiation with the frequencies higher 10 MGz. It is commonly accepted after series of many experiments that in the electrical circuit of the EMGF the oscillations of the current with the frequency to 10 MGz are being excited during operation of the device. But the main puzzle of operation of the device is presence of the HF radiation.

The explosive magnetic generator of frequency (EMGF) was first described in the paper by Prishchepenko and Shchelkachev [4]. They also presented a theoretical model, based on its equivalent circuit diagram, describing its operation. However, this model does not explain some of the experimental results, such as how it radiates frequencies greater than 10 MHz and the "fish-shaped" current waveform generated in its coils. If one considers the equivalent circuit model with more accuracy, then solving the differential equation for the voltage (Kirchoff's voltage law) yields the "fish-shaped" current waveform. This solution can then be compared to experimental data to determine information about the real parameters of the EMGF.

The circuit model for both devices does not enable one to explain how it radiates frequencies greater than 10 MHz. However, measurements conducted with spectrometers developed by "Sirius" in Moscow unambiguously show that most of the energy radiated by the EMGF is in the frequency range from 1 - 150 GHz. Why this is true will not be discussed, but some possible approaches to solving this puzzle will be examined.

II. BASING THE EQUIVALENT CIRCUIT FOR THE EMGF

The basic equation for the equivalent circuit of the EMGF can be written in the form:

$$\frac{d\Phi}{dt} = -U = -L_C \frac{dI_C}{dt} - RI_C - \tfrac{1}{c}\int I_C dt\ ; \quad (1)$$

where Φ is the of the magnetic flux, R is the resistance of the whole circuit, C the capacity of the capacitor, L_C a part of self-inductance of the coil and I_C the current in the coil.

Now we must introduce the connection between the magnetic flux and the current in the coil. In this device the magnetic flux is created by two currents, I_C and the current in the liner I_L. It is caused by certain effect of loss of 'diffusion resistance' of the coil. We consider this effect in more details.

It is known that changing of the magnetic flux while the latter crosses the coil creates the electric field directed along the turn of the coil in accordance with the Maxwell equation:

$$\frac{1}{c}\frac{\partial B}{\partial t} = -[\nabla \times E]$$

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14. ABSTRACT
The explosive and implosive magnetic generators of frequency (EMGF and lMGF) consist of a spiral magnetmulative generator (MCG) with a small capacitive load. The simplest model describing the operation of these devices is based on their equivalent circuit diagram. By selecting the proper parameters of the lMGF and EMGF, it is possible to calculate the current in the coil and to obtain good agreement between the calculated and measured envelopes of the current waveform The particular mechanism by which current is generated in these devices is understood, unlike other similar sources of electromagnetic radiation. In this paper, circuit model of the IMGF and EMGF will be presented and analyzed, The results of the analysis will be compared to data in tests conducted in June 1997 and August 1998.

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This electric field creates additional current δI preventing penetration of the magnetic field through the material of the coil. For conventional MCGs, crossing of the magnetic flux through the external coil always causes increasing of the current in the latter. However, in the EMGF, there is the capacitor which, while its charging by the current in the coil, creates own electric field in the material of the coil. So under sufficient voltage created by the capacitor in the coil, crossing the magnetic flux no more generates additional current in the coil, therefore, the magnetic field will penetrate through the coil. In the other words, the length of diffusion becomes infinite and the magnetic flux will flow out of the interior area between the coil and the liner, and the faster the stronger the electric field created by the capacitor.

Despite the current in the coil is equal to zero at certain instants, the current in the liner is described by the first order equation of which zeros do not coincide with zeros of I_C.

But the liner could be approximated by the solenoid for which, if the 'external force' i.e. the field of the external coil is eliminated, the current tends to distribute in such a way that the magnetic field created by this current is concentrated only inside the solenoid. So the current I_L will redistribute from the outer side of the liner to the inner side and, therefore, it will be eliminated from the process of compression of the magnetic flux. The process of redistribution of the current I_L is difficult to describe so we assume that the current I_L repeat behavior of the current I_C but with some delaying:

$$I_L(t) = \alpha I_C(t-\tau)$$

where $\alpha < 1$ and the value of the parameter τ is determined by the time of penetration of the current I_L from the outer side of the liner onto the inner one. Then the magnetic flux in the area between the coil and the liner can be described as:

$$\Phi = \chi[\alpha I_C(t-\tau) + I_C(t)]; \quad (2)$$

where the parameter χ depends only on the geometrical sizes of the coil and the liner and on the speed of detonation V in such a way that the magnetic flux becomes equal to zero at the end of operation of the EMGF. It reflects the fact that most of losses of Φ is due to the edge effects: when the liner goes to contact with the turns of the coil some amount of the magnetic flux contains between neighbour turns and the liner and after it eliminates from the process of compression.

Now we make some approximation,

$$\Phi = \chi[\alpha I_C(t-\tau) + I_C(t)] \approx \chi[\alpha I_C(t) + I_C] = \chi(\alpha+1)I_C = \chi' I_C(t)$$

Thus, after simple calculations the voltage equation becomes:

$$L\frac{d^2 I_C}{dt^2} + \left[\frac{dL}{dt} + R\right]\frac{dI_C}{dt} + \tfrac{1}{C} I_C = 0; \quad (3)$$

where we take into account that $L = L_C + \chi$ and omit small terms $d^2\chi/dt^2$ and dR/dt.

To analyse the above equation, we note that it is similar to the Schroedinger equation for the wave function of the quantum mechanics. The coefficient at the second time derivative has no zeros at the considered time interval so according to Pickard theorem [5], the Eq. (3), as linear differential equation, has no singularities and we are able to use the methods of the quantum mechanics for its analysis. It is known from the experiments with Rogowski belt that the current has a big number of oscillations, therefore, the solution must have a big number of zeros at the considered time interval. Because it is known that the more zeros the wave function has the better it is described by the WKB or quasiclassical approximation, the same is correct for the Eq. (6). So the WKB solution for the Eq. (3) will be:

$$I = \sqrt{\frac{L(t=0)}{L(t)}} \times \exp\left[-\int_0^t \frac{R(\tau)}{2L(\tau)} d\tau\right] \frac{Cos[\int_0^t \omega(\tau)d\tau]}{\sqrt{\omega(t)}} \quad (4)$$

where:

$$\omega(t) = \sqrt{\frac{1}{LC} + \frac{d}{2dt}\left[\frac{R}{L} + \frac{d\ln(L)}{dt}\right] + \tfrac{1}{4}\left[\frac{R}{L} + \frac{d\ln(L)}{dt}\right]^2}$$

Obviously, the envelope of the current does not depend on the capacity of the capacitor but only on two parameters of the device R and L. So we can compare the dependence (4) to the experimental data, i.e. the envelope of the Rogowski current. To obtain the "fish-shaped" diagram, we must assume that the inductance, i.e. the parameter χ drops very fast at times $T \ll t_{operation}$ and then tends to the constant $L = L_C$ and then the exponential term "cuts" the value of the current. The formulae (4) is very simple so it is convenient for the analysis of the experimental data.

About the Cos term (4), we can conclude that despite of changing with time the frequency, this term has no singularities of "meandring type". The effect of 'meandring'could be explained by appearing the effect of loss of and, therefore, by the doubling the frequencies but it cannot yield the highest frequencies responsible for radiation.

III. COMPARISON TO EXPERIMENTAL RESULTS

Despite the results of this theoretical model and the results of other analyses of the EMGF [1, 3, 4], it should be pointed out that there might be unknown factors that have not been taken into account that would explain the experimental data. Therefore, in this section, a brief description of the test results is presented.

Four EMGFs (June 1997) as well as ten EMGFs (August 1998) were tested at a range belonging to the High Mountain Geophysical Institute (VGI) in Russia. "Sirius" supplied a single channel spectrometers having a voltage readout. Using calibration curves, the voltage can be used to calculate the energy radiated in a given frequency band.

To estimate influence of the HF radiation to the electrical components of the spectrometers, "Sirius" has been given the measurement results of the Nalchik test. These results are presented in the Table 1 and 2.

Table 1. Energy density *D(E)* in picoJ/cm^2 measured by the "Sirius" spectrometers with the given center frequencies. Test 1997, radiation from the EMGF.

	2.3 GHz	11.4 GHz	37.5 GHz	150 GHz
Shot # 1	2.5	20	2.5	20
Shot # 2	0.5	10	0.5	0
Shot # 3	0.5	11.2	0.2	10

Table 2. The energy density *D(E)* is expressed in picoJ/sq.cm, Test 1998, radiation from the EMGF.

	2.3 GHz	11.4 GHz	37.5 GHz	150 GHz
Shot # 3	1.0	4.4	-	> 25
Shot # 4	0.5	5.3	0.5	10.8
Shot # 5	0.5	-	0.2	2.5
Shot # 6	0.4	29.4	0.2	2.0
Shot # 7	-	-	-	2.5
Shot # 8	0.3	-	-	> 25
Shot # 11	0.35	17.5	-	> 25
Shot # 12	0.8	4.7	0.3	-

Now it is interesting to analyse some experimental data which have been never analysed before but which can be a key to explanation of the HF radiation from the devices.

Because it follows from the analysis of the equation for the equivalent circuit that even despite of possible effect of doubling the frequency the current in the coil cannot contain highest Fourier harmonics corresponding to Gegahertz oscillations. Hence, there were some suggestions that the HF radiation is caused by the breakdown whether between the turns of the coil or between the coil and the liner. However, the physical cause of such breakdowns is not found. Here, it should be noted that some experimental data can be treated in favour of existence of breakdown in the IMGF and EMGF. During the joint test in Nalchik in 1997, there have been used three channel spectrometers which can measure the number of oscillations N of the instant power of the radiatied signal. In some experiments with the IMGF and EMGF, these spectrometers detected big number of oscillations, greater 50, which has been considered as error in measurements because such a large N contradicts to existing theories of operation of the EMGF. However, if we assume that the breakdowns occur at the instants of connecting the liner with turns of the coil and, therefore, the radiation coincides with these instants we obtain that the number N should be of order of the number of turns of the coil. Thus, we accept this hypothesis and try to explain the existence of the breakdown.

Most of the scientists insisting on existence of breakdown in the above devices assume that the breakdown is caused due to the high voltage created by the capacitor. However, simple calculations of the voltage between two neightbour turns or the voltage between the liner and the turn being at the edge of the coil (as the turn closest to the liner) show that such a voltage is much smaller than the 'breakdown voltage' of the capacitor itself, by the way, for the current there is a bypass way along the wire. However, it should be noted one possible mechanism of breakdown which does not depend on the voltage in the capacitor. Firstly such a mechanism was suggestd by Lorentz in his paradox of Einstein theory. Lorentz showed that the current in the wire creates the electrical field directed in the plane normal to the wire. This effect is caused by the difference between the electric fields of the charge at rest (Coulomb potential) and moving charge (Liennard-Wiechert potentials) and can be checked by simple calculations of the electrical field of the ring with the current. It must be noted that in the systems with direct current supported by the power surce such an effect disappears because additional (noncompensated) amount of charges inputs from the source to the wire. However, for the considered system, the pulse of the current in the turn can be treated as adiabatic process so there is no compensation of the field by noncompnsated charges. According to Lorentz's calculations, the strength of such an electrical field is comparable to the strength of the magnetic field created by the current so it can be strong (due to lack of space we do not give the corresponding calculations). Therefore, the breakdown is possible in the devices especially when the insulation layer of the turn is in pre-destructive state. It should be noted that two conditions for the breakdown must be fulfilled at the same instant:

- the insulation layer of the uttermost turn of the coil connects with the surface of the liner;
- the current in the coil has one of its maxima;

Fulfilling both these conditions assumes that the number of acts of breakdown and, therefore, the radiation pulses N is of order of the number of the turns in the coil. Finally we note that such a mechanism of breakdown do not involve into process of radiation, at least, directly, the current in the coil so after data of the Rogowski current diagram we cannot make any conclusion does the breakdown occur or not. If the breakdown does occur the radiation is caused by the plasma created in the insulation layer of turns.

It can be stated a question: why does not display such a type of radiation due to breakdown in conventional MCGs? It is known that in multisectional MCGs the current can achieve the values to 0.5 MA so it seems that in the latter MCGs the conditions for such a type of radiation are better. Here, we should note that in our thought consideration we do not take into account the fields in near zone (i.e. non-radiative fields) creatd by accelerating charges. In the conventional MCGs, the acceleration of the charges is too low in comparison to values of accelerations of the charges due to fast oscillations of the current with the frequency to 10 MGz. However, exact calculations of the fields created by accelerating charges are impossible because, to the author's knowledge, in the classical electrodynamics there is no mathematically strict derivation of the formulas similar to those ones of the Liennard-Wiechert potentials.

So this problem requires additional investigation.

IV. CONCLUSIONS

Because the calculations based on the EC can predict the highest frequency of radiation about 10 MHz and the experiemtal data note on that the maximum of the EM radiation from the EMGF should be being in the frequency range higher 10 GHz we are obliged to conclude that the model based on the equivalent circuit cannot explain the operation of the device.

We point out the disadvantages of the model of the EC developed above. (1) There are some simplifications of the process of compression of the magnetic field. (2) For the frequencies higher 100 MHz, the coil cannot be treated as an ideal solenoid. Depending on the value of the current I, certain amount of the magnetic field is penetrating during compressing through the turns of the coil. So the uniformity of the force lines of the magnetic field is being broken which must lead to appearence of the EM oscillations between neightbour turns. Therefore, for better accuracy, one must consider the device as a system with distributed electrical parameters.

Despite the above disadvantages of the EC model, the latter can be useful for studying the device. (1) This model is able to describe, with certain accuracy, the envelope of the current ("fish-shaped" waveform) in the coil. So after comparison of the experimental data (diagrams of the Rogowski belt current) to the calculations, some information about the electrical parameters of the device (the time dependence of L, R and) can be obtained. Because the time dependences of L and R are comparatively weak with respect to the time dependence of χ it is possible to assume, for zeroeth approximation, L and R as constant, and to find χ. Then (2) This model is able to describe, with certain accuracy, the oscillations (with changing in time frequency to 10 MHz) of the current. Because it is purposed that namely these oscillations determine the conditions for penetration of the magnetic field through the turns, i.e. the conditions of exciting of the oscillations of the EM field concentrated between the turns, and therefore, with the frequency of GHz range, after Rogowski belt current it can be estimated duration of the HF radiation.

The authors intend to develop the model of the EC with distributed parameters give some possible explanation of the HF radiation in the EMGF in the future papers.

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