PLASMA TECHNOLOGIES FOR THE PROTECTION OF RADIO ELECTRONIC MEANS FROM EXPOSURE TO HIGH-POWER ELECTROMAGNETIC RADIATIONS WITH ULTRASHORT PULSE DURATION

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Abstract: The urgency of the improvement of methods and means of protection of radio electronic means (REM) due to the development and application of high-power electromagnetic radiation (EMR) generators with ultrashort pulses duration (UPD) is substantiated. It is pointed out that it is possible to solve the problem of REM protection by the complex application of plasma technologies using gaseous and modified solid-state media.

By analyzing the known achievements in the field of developing effective methods and creating protection facilities for REM, a number of unresolved problems in the field of creation of plasma protection technologies have been determined.

The technique of solving the formulated problems is presented and the main relations are obtained to determine the expediency of using the proposed technology in the interests of the REM integrated protection from the powerful EMR UPD.

A relation is made for the breakdown criterion in a gaseous plasma medium that relates the value of the breakdown field to the concentration of charged particles determined by the ionization source. The structure of a solid-state plasma medium is described, which can be used as a protective shield. The order of finding the REM screening coefficient is shown, based on the determination of the distribution function of charged particles for finding the main macroscopic properties of plasma by solving the kinetic equation of the Lenard-Balescu equation. A relation is given for the damping coefficient of an electromagnetic wave in solid-state plasma. Numerical estimates are presented in the form of graphs showing the possibility of using plasma technology to protect the REM from a powerful EMR through possible channels of penetration. The discussion of the obtained results is presented and it is indicated on the possibility and prospects of using the proposed technology for REM protection, especially with limitations on the weight dimensions of protection devices.

Keywords: radio electronic means, electromagnetic radiation, ultrashort pulse duration, plasma protection technologies, gaseous and solid-state plasma media, hexaferrite inclusions.

1. Introduction

Development, creation and use of generators with a radiation power of the order of and more than 1 GW with pulse duration of 10^{-9} to 10^{-15} seconds necessitates the further development of methods and devices for the protection of radio electronic means. This is due to the possibility of both accidental and deliberate (as a result of terrorist acts) use of such generators, which can lead to the REM disruption at considerable distances. At the same time, the threat of REM serviceability disruption is usually created when electromagnetic radiation (EMR) interacts with antennas, communication lines, conductors and radioelements of equipment. This interaction leads to the transformation of the electromagnetic field into voltages and currents.

The most vulnerable to the EMR influence are the REM elements directly connected to the antenna output, to the cables and conductors. In addition to these elements, the cables themselves are exposed to impulse voltages, which in certain cases can damage their insulation and cause a short circuit between its cores and the sheath. The most dangerous in terms of its impact on radio electronic equipment (REE) is a powerful EMR of the ultrashort pulse duration (UPD) [1].

Proceeding from this, the problem of ensuring the durability and reliability of modern REM to the impact of powerful EMR of ultrashort pulse duration acquires a pronounced systemic character.

REE features, as a protection object, determine the requirements for the applied protective devices, which must:

– have high speed;

– not influence the characteristics of the protected radio facilities;

– have stability of characteristics in a wide range of temperatures under the action of damaging EMR factors;

– have ability to quickly restore its electrical strength in conditions of multiple exposure to EMR;

– have overall dimensions and weight smaller than the overall dimensions and mass of the protected equipment.

An analysis of the capabilities of the methods and means of protection developed to date has shown that they do not fully meet the requirements for the REM protection.

The issues of development of methods and means for REM protection from the impact of a powerful EMR have been devoted to a significant number of publications. So in [2] for the first time the radioisotope-plasma technology of creation of absorbing materials for REM protection from EMR is proposed. However, the results of the studies do not take into account the possibility and necessity of controlling the electrophysical properties of the material by changing its magnetic permeability. In [3], the results of creating a number of multilayer materials that ensure the EMR absorptio in the frequency range 8–80 GHz are more than 10 dB. In [4], an approach is proposed to evaluate the effect of structural inhomogeneities of an electromagnetic shield on its protective properties. In [5], studies of composite materials based on hexaferrite and barium aluminates are carried out. The possibility of effective protection of biological and technical objects from EMR in the frequency range 70–90 GHz is shown. In [6], the results of the investigation of the interaction of EMP with matter are presented. In [7], the frequency dependences of the dielectric and magnetic permeabilities of composite radio materials, which are a mixture of nano-sized powders of ferroelectrics and ferrites, are given. In [8], the possibility of changing the electromagnetic characteristics of composite radio materials by adding a ferroelectric to a ferromagnetic material is shown. In [9], broadband absorbing coatings are proposed that provide for the absorption of EMR more than 10 dB in the frequency range 8–80 GHz. In [10], the structure of broadband coatings using a semiconductor matrix with radioisotope inclusions is considered.

Thus, despite a wide range of ongoing research in the development of effective methods and the creation of means for REM protection from the impact of a powerful EMR, there is no protection technology. In turn, the protection technology should provide a unified methodological position for solving the problem of reducing the level of electromagnetic field intensity affecting the REM. The solution of the existing problem is proposed on the basis of the complex application of plasma protection technologies using gaseous and modified solid-state media.

The aim of the work: assessment of the possibility of using plasma media for complex REM protection from the impact of a powerful pulsed EMR.

To achieve this aim, the following research objectives are solved:

– assessment of the possibility of using gaseous plasma media to REM protection by the main reception channels and cable penetration channels;

– evaluation of the possibility of using solid-state plasma media with the use of hexaferrite inclusions in the dielectric matrix as protective shields of the REM cases.

2. Methods

The basic idea of using a gaseous plasma medium for the REM protection is use of ionization source and to create conditions for the appearance of a breakdown in an ionized medium. As a result, the EMR does not penetrate into the subsequent cascades or into the enclosure. Under the EMR influence, it closes in an ionized environment with high conductivity and prevents further penetration. After the termination of the EMR action, the conductivity of the gaseous plasma is sharply reduced, and the REM continues to operate in the normal mode.

The solution of the problem of assessing the possibility of using gaseous plasma media to REM protection by the main reception channels and cable penetration channels is based on the Krook model

$$\frac{\partial f_a}{\partial t}+V\frac{\partial f_a}{\partial x}+\frac{q_a}{m_a}\left(E+\frac{VxB}{C}\right)\frac{\partial f_a}{\partial V}=\frac{f_a(x,V,t)-f_{a_0}}{\tau_a},$$

where q_a – the particle charge; m_a – the particle mass.

This approach corresponds to the notion that some distribution of particles relaxes to an equilibrium distribution and there is some time between collisions with momentum transfer.

The Crook model allows to determine:

– distribution function f_a, necessary for estimating the main macroscopic layers of the ionized medium;

– establish a connection with the intensity of the electromagnetic field;

– determine the conditions of ignition and the occurrence of breakdown.

The value of the breakdown field E_b is taken to be the value at which the maximum plasma concentration in the perturbed region is equal to the critical value n_{cr}, and corresponds to the frequency at which the spectrum has a maximum:

$$4\pi n_{cr}e^2/m_e=\left(2\pi/\tau_p\right)^2.$$

The breakdown criterion has the form:

$$\ln\frac{n_{cr}}{n_{e_0}}=\frac{a\tau_p}{2\pi}\int_0^{\theta_m}\varepsilon(\theta)d\theta+(b+\nu_a)\tau_m, \tag{1}$$

where τ_m – the time at which $n_e=n_{cr}$, $\theta_m=\tau_m 2\pi/\tau_p$.

Investigation of the use of solid–state plasma as protective shields is based on the basic model of the material with the following structure, as seen in **Fig. 1.**

The dielectric matrix contains both hexaferrite inclusions and radioisotope elements. The first are necessary for controlling the magnetic permeability of the shield, the latter for creating a non-equilibrium state of the electronic subsystem with the aim of increasing the dielectric losses. The state of a solid–state ionized medium is described by the Lenard-Balescu kinetic equation. In the case of a gaseous plasma medium, this equation makes it possible to determine the distribution function and the finding of frequency–dependent dielectric, magnetic permeabilities. This, in turn, makes it possible to determine the EMR damping rate γ/ω through the parameters of the medium

$$\frac{\gamma}{\omega}=0.5\sqrt{\frac{\pi}{2}}\frac{1}{\left(k/k_{dq}\right)^3}\exp\left(-\frac{3}{4}\left(k_{dq}/k\right)^2\right), \tag{3}$$

where k – the wave vector; k_{dq}– the Debye wave vector.

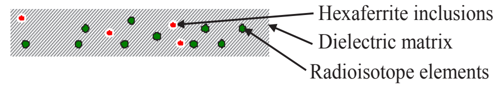

Fig. 1. Structure of the protective material

3. Results

1. The case of a gaseous plasma medium. The dependence of the logarithm of the ratio of electron densities to the pulse amplitude for different pulse durations, obtained using (1), is shown in **Fig. 2.**

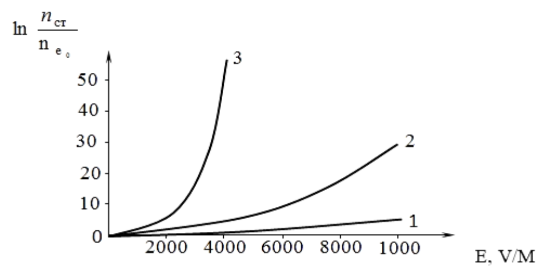

Fig. 2. Dependence of the logarithm of the ratio of the electron density to the electric field strength for times: 1 – 0.01; 2 – 0.1; 3 – 1 in fractions of the pulse duration τ_p=3 ns

It is established that the breakdown intensity of the electric field depends on the initial concentration of electrons in the discharge volume and the EMR duration. When the ratio of the critical concentration to the initial concentration is changed only by a factor of 5 and the air pressure is 750 mm Hg, the breakdown strength of the field decreases from 30 kV/m to 20 kV/m. With an increase in the pulse duration by an order of magnitude, the breakdown field strength is reduced by a factor of 5 lg n_{cr}/n_{e0}=20. As the EMR duration is increased by a factor of 10, the breakdown strength of the electric field decreases by a factor of 3.

2. The case of a solid-state plasma medium. The dependence of the EMR damping γ/ω on the non-equilibrium parameter is shown in **Fig. 3.**

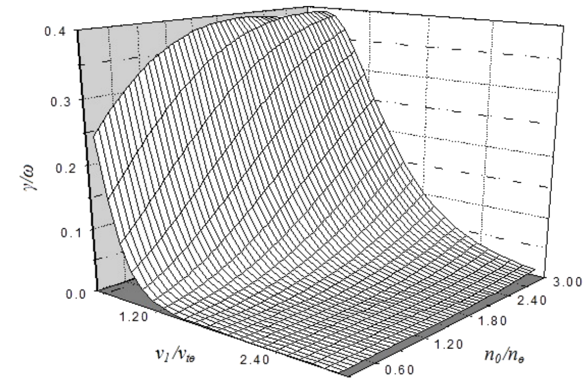

Fig. 3. Dependence of EMR damping on the non-equilibrium parameter of solid-state plasma

In accordance with (3) for the intensity of the radioisotope source of 70 μCu/cm^2, due to the non-equilibrium properties of solid-state plasma, the EMR damping coefficient can reach values of the order of 70 dB.

4. Discussion

1. The performed theoretical evaluations testify to the principle possibility of using the proposed technologies for creation of means for REM protection from the EMR influence. The choice of the required initial electron concentration in the gaseous plasma leads to a decrease in the breakdown field strength. Consequently, when creating the necessary initial electron concentration inside the waveguide or between the walls of the case and the cable braiding, a real possibility of REM protection from the impact of powerful EMR appears.

2. The use of a solid-state plasma medium as a shielding material by selecting the intensity of the radioisotope source, as well as the number of layers of the dielectric matrix, allows controlling the absorbing properties of the material. The promising nature of the proposed technology lies in the possibility of its integrated use to protect against possible penetration channels, with limitations on the weight dimensions of protection devices.

References

1. Balyuk, N. V., Kechiev, L. N., Stepanov, P. V. (2007). Moshhnyy elektromagnitnyy impul's: vozdeystvie na elektronnye sredstva i metody zashhity. Moscow: OOO «Gruppa ITD», 478.
2. Vorobiov, O., Savchenko, V., Sotnikov, A., Tarshyn, V., Kurtseitov, T. (2017). Development of radioisotopic–plasma technology for the protection of radio electronic means from powerful electromagnetic radiation. Eastern–European Journal of Enterprise Technologies, 1 (5 (85)), 16–22. doi: 10.15587/1729–4061.2017.91642
3. Skoblikov, O., Knyazyev, V. (2012). Shielding Properties of Conductive Shells Exposed to Electromagnetic Impulse of Lightning. International Conference on Lightning Protection (ICLP'2012). Vienna, 1–8.
4. Makhno, S. N., Gorbik, P. P. (2010). Vzaimodeystvie elektromagnitnogo izlucheniya s veshhestvom: nekotorye napravleniya razvitiya issledovaniy i perspektivy prakticheskogo ispol'zovaniya. Poverkhnost', 2 (17), 14–18.
5. Barsova, Z. V., Cwhanovskaya, I. V., Barsova, Z. V., Iluoykha, N. G. (2012). Chemistry and technology of magnetite and barium-containing composite materials on its basis. European Science and Technology. Wiesbaden, 80–87.
6. Fazaeli, R., Eslami-Farsani, R., Targhagh, H. (2015). Microwave Absorption Properties of Low Density Polyethelene-Cobalt Ferrite Nanocomposite. International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 9 (12), 1450–1453.
7. Liu, T., Zhou, P. H., Xie, J. L., Deng, L. J. (2011). The hierarchical architecture effect on the microwave absorption properties of cobalt composites. Journal of Applied Physics, 110 (3), 033918. doi: 10.1063/1.3622144
8. Petrov, V., Nikolaychuk, G., Yakovlev, S., Lutsev, L. (2008). Issledovanie radiopogloshhayushhikh svoystv materialov na osnove nanostruktur. Komponenty i tekhnologii, 12, 141–146.
9. Mazov, I. N., Kuznetsov, V. L., Moseenkov, S. I., Ishchenko, A. V., Romanenko, A. I., Anikeeva, O. B. et. al. (2010). Electrophysical and Electromagnetic Properties of Pure MWNTs and MWNT/PMMA Composite Materials Depending on Their Structure. Fullerenes, Nanotubes and Carbon Nanostructures, 18 (4–6), 505–515. doi: 10.1080/1536383x.2010.488184
10. Sotnikov, O. M., Kryzhnyi, A. V., Vorobiov, O. M. (2013). Rozrobka struktury materialu zakhysnykh ekraniv radioelektronnykh zasobiv ozbroiennia i viiskovoi tekhniky vid vplyvu potuzhnykh elektromahnitnykh vyprominiuvan ultrakorotkoi tryvalosti impulsu. Trudy Universytetu. Kyiv: Natsionalnyi universytet oborony Ukrainy, 6 (120), 187–191.