Methods and techniques of energy calculation in models of electromagnetic influences on radio-electronic equipment of technical means of logistic support

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Abstract

The purpose of the article consists of analyzing existing scientific approaches, methods, methods, models of electromagnetic influences on radio-electronic equipment, and technical means of logistical support to determine and justify the most appropriate equations and expressions for calculating the energy induced by electromagnetic weapons. The article reveals the scientific approaches and views of many scientists regarding the theory and practice of electromagnetic influence on radio-electronic equipment and circuits of electrical equipment of technical means and ways to create protection against these influences. The shortcomings of this process are indicated and a number of promising ways to improve it are proposed. The results of the study are a starting point for increasing the efficiency (quality) of protection of radio-electronic equipment and circuits of electrical equipment of technical means of armaments and military equipment, in particular technical means of logistics.

Key words: technical means, weapons and military equipment, logistical support, radio-electronic equipment, electromagnetic influence, radio-electronic influence, weapons.

Introduction

Protection of weapons and military equipment (WME) from the striking effect of electromagnetic weapons (EMW), acting with the help of powerful, short-term pulsed electromagnetic influence (EMI) on radio-electronic equipment, semiconductor, electrovacuum, electromechanical, electrochemical devices, micromechanical systems, electrotechnical devices, photosensitive elements and thermocouples, switching and installation devices, is becoming more and more important (Vorobyov, O.M., 2010). Therefore, for the repelling large-scale armed aggression of the russian federation against Ukraine, the probability of the enemy using this type of weapon increases significantly, since the facilities and technical means of logistical support are the primary targets for damage by the enemy. The effective use by the enemy of EMW by technical means of logistical support can lead to the complete cessation of support for the operation by technical means of logistics and in general with samples of WME, that is, it will completely disrupt the implementation of the tasks of logistical support of the operation. Therefore, a successful solution to the problems of creating the protection of technical means of logistical support will ensure the necessary level of combat capability of the Armed Forces (AF) of Ukraine with serviceable military operations due to replenishment from the anti-aircraft defense bases during the conduct of hostilities and the performance of tasks as assigned in EMI conditions. And, today, research on the problems of protecting personnel and technical means of logistical support against damage by these weapons is becoming more and more relevant.

Theoretical foundations of research

In works (Vavilov, V.S., 1988:Weapons based, 2006), the limit parameters of the resistance of radio-electronic equipment to the influence of EMI are given, a principled approach to solving the problem of WME protection is defined, and the energy definition of the interaction of electromagnetic fields with physical objects (targets) that are affected is proposed. In work (Selivanov, V.V., 1990) directions for solving the problem of protection are determined, and in work (Kravets, I.A., 2010) a scientific hypothesis for the creation of WME protection against EMW action is formulated. However, they do not have a reasonable apparatus for calculating the energy of induced EMI, which is necessary for building physical and mathematical models of the interaction between a powerful EMI and the affected object.

Formulation of the problem

The proposed study continues the solution of the scientific problem of developing and creating protection of WME samples from external EMI.

The purpose of the article is to conduct an analysis of existing scientific approaches, methods, methods, EMF models for radio-electronic equipment, technical means of logistical support to determine and justify the most appropriate equations and expressions for calculating the energy of induced EMI.

Research methodology

To realize the goal of the research, we will carry out its decomposition and investigate the following questions:

1) we will analyze the main scientific approaches, methods, methods, and models of existing scientific approaches, methods, methods, and EMI models for radio-electronic equipment of technical means in order to determine the concept of protection of these units;

2) substantiation of the most appropriate equations and expressions for calculating the energy of induced EMW.

The methodological tools of the conducted research were methods of analysis and methods of the relativistic theory of electrodynamics.

Result

It is known that electrodynamics is divided into classical, relativistic and quantum. Classical electrodynamics considers a variable or stationary electromagnetic field (in the latter case – electrostatic or magnetic) in a fixed frame of reference. Relativistic electrodynamics considers electromagnetic phenomena in moving media, relying on the invariance of charge in different reference systems and the invariance of basic laws with respect to Lorentz formulas of coordinate transformation. Quantum electrodynamics is the quantum theory of the electromagnetic field and its interaction with charged particles. The main ideas of quantum electrodynamics are quantization of field energy and momentum, quantization of energy exchange during electromagnetic interaction of microsystems (Tatur, T.A., 1989; Filipov, V.S., 2002).

The greatest generalization of the laws of electrodynamics is Maxwell's equation and the equation of electromagnetic potentials. From these equations, as a consequence, the relationship between the characteristics of the electromagnetic field follows. Accordingly, in each theory, the views on the creation of energy and the very calculations of the given energy will be different. In this particular case, to determine the EMI energy on the affected object, the quantitative measure of the energy and its impact on radio-electronic equipment and circuits of electrical equipment, WME devices and technical means of logistical support, and not the mechanisms of influence (quanta, photons, waves) are primarily important. Therefore, we will consider the interpretation of the energy of electromagnetic phenomena in moving media (relativistic electrodynamics).

It is known that the electromagnetic field, like one of the types of matter, is associated with energy. This energy can be accumulated by the field, transferred by the field and transformed into other types of energy. The relationship between the energy of the electromagnetic field and the quantities characterizing this field is determined by Poiting's theorem. It can be obtained from Maxwell's equation. For this, it is necessary to multiply Maxwell's first equation scalar by, the second – by and subtract the first from the second term by term. After that, using the identity

$$div[\vec{E}\vec{H}] = \vec{H} rot \vec{E} - \vec{E} rot \vec{H},$$

where $\vec{E}$ – is the electric field intensity vector;
$\vec{H}$ – electric field intensity vector.

integrate the obtained equation over the volume V bounded by the surface S, while converting the volume integral from the divergence into an integral over the surface using the Gauss-Ostrogradsky theorem [8].

As a result, we obtain a mathematical formulation of the Poiting theorem for instantaneous values in the following form:

$$-\int_V \vec{\delta}_e^{cm} \vec{E} dV - \int_V \vec{\delta}_м^{cm} \vec{H} dV = \int_V \sigma E^2 dV + \frac{d}{dt}\int_V \left(\frac{\varepsilon_a E^2}{2} + \frac{\mu_a H^2}{2}\right) dV + \oint_S [\vec{E}\vec{H}] \overrightarrow{dS} \quad (1)$$

Where V – volume;
S – surface area bounding the volume;
$\vec{\delta}_e^{ст}$ – the charge density vector of the electric field generated by an external source;
$\vec{\delta}_м^{ст}$ – magnetic field density vector generated by an external source;
σ – electrical conductivity of the medium;
ε_a – dielectric permittivity of the medium;
μ_a – magnetic permeability of the medium.

Since the vectors $\vec{E}$ and $\vec{H}$ determine the field at points where there are no sources, then in fact the volume integrals in the right-hand part of (1) must be taken over the volume V, that is not occupied by sources; the volume integral in the left part should obviously be taken only over the part of the volume occupied by extraneous sources, i.e. over $V_e^{ст}$ and $V_м^{ст}$.

Consider the physical content of each component of equation (1). The integrals on the left side are related to extraneous electric and magnetic currents, which have the dimension of power and determine the power of extraneous sources that diverges in the volume V:

$$P^{cm} = -\int_V (\vec{\delta}_e^{cm}\vec{E} + \vec{\delta}_м^{cm}\vec{H}) dV$$

Extraneous sources at the point under consideration give energy to the electromagnetic field, provided that the field acts against the extraneous current.

In this case, the scalar product $\vec{\delta}_e^{cm}\vec{E}$ and $\vec{\delta}_{\text{м}}^{\text{ст}}\vec{\text{H}}$ will be negative values, and $\text{P}^{\text{ст}}$ will be a positive value. If external forces coincide with stresses, then P^{cm} will be a negative value. This means that the sources absorb the energy of the field.

In the future, we will operate with the power transmitted from the field source, and not with the power taken from the field.

In the first integral on the right-hand side, the integral expression represents the Joule-Lenz law known from physics in a differential form, which determines the power of heat losses per unit volume $\text{p}_0 = \sigma\text{E}^2$.

Thus, the first integral in the right-hand side (1) $P_n = \int_V \sigma E^2 dV$ determines the power of heat losses to the medium filling the volume V, due to finite conductivity σ.

The second integral of the right-hand side of (1) represents the power associated with the change in energy accumulated by the electromagnetic field in the volume V, which is considered:

$$P_{EH} = \frac{dW}{dt} = \frac{d}{dt}\int_V (\frac{\varepsilon_a E^2}{2} + \frac{\mu_a H^2}{2}) dV,$$

where W – electromagnetic energy.

just like the electromagnetic energy in the volume V is equal to

$$W = \frac{1}{2}\int_V (\varepsilon_a E^2 + \mu_a H^2) dV,$$

that is, the amount of electrical energy

$$W_e = \frac{1}{2}\int_V \varepsilon_a E^2 dV$$

and magnetic energy $$W_м = \frac{1}{2}\int_V \mu_a H^2 dV.$$

Quantities under the sign of the integral $\omega_e = \frac{\varepsilon_a E^2}{2}$ and $\omega_{\text{м}} = \frac{\mu_a H^2}{2}$ have similar contents of density, electric and magnetic energy, respectively.

The third integral in the right part determines the radiation power from the volume V through the surface that limits it

$$P_\Sigma = \oint_S [\vec{E}\vec{H}] \quad dS \qquad (2).$$

This power is equal to the vector flux

$$\vec{\Pi} = [\vec{E}\vec{H}].$$

Vector $\vec{\Pi}$ received the name of Poiting. Its direction coincides with the direction of propagation of the energy of the electromagnetic field, and its value is equal to the amount of energy flowing per unit of time through a unit of surface area perpendicular to the direction of the vector, that is, it determines the power density. From equation (2), the radiation power is determined only by the projection of the Poiting vector onto the external normal to the surface and, accordingly, only tangents to the surface S components of vectors $\vec{E}$ i $\vec{H}$ (Microwave electrodynamics and physics, 1983).

Using the above notation, we will write the expression in abbreviated notation

$$P^{cm} = P_{\Pi} + \frac{dW}{dt} + P_{\Sigma}.$$

Discussion

The scientific novelty of the research results and their practical significance were supported during the discussion between the scientific and pedagogical staff of the Defense Management Center of the National Defense University of Ukraine, including: I. Tkach – Dr of Economic Sciences, Professor, Honored Economist of Ukraine; M. Tkach – Dr of Economic Sciences.

Conclusions

On the basis of the analysis of existing scientific approaches, methods, methods, models of electromagnetic influences on radio-electronic equipment of technical means of logistic support, the most appropriate equations and expressions for calculations of induced EMW energy were defined and substantiated.

Thus, for the study of the problems of protecting objects from EMW using physical and mathematical models of changes in the technical state and operational properties of WME and technical means of logistical support, the procedure for conducting EMI energy calculations is substantiated. They are based on the relationship between the energy of the electromagnetic field and the values characterizing this field, which are obtained from Maxwell's equations and can be used for energy calculations in these models.

The results of research (Modeling of electromagnetic fields, 2007; Methods of modeling electromagnetic fields, 1990) on the determination of the energy of the electromagnetic field showed that the determination of energy according to the relativistic theory of electrodynamics in moving media, based on the invariance of the charge in different reference systems and the invariance of the basic laws and formulas of coordinate transformation, are completely reliable and equal to the real indicators of radiation energy .

In the future, on the basis of the scientific hypothesis of protection and the defined energy calculation algorithm, the task is to build physical and mathematical models of the interaction of the object with the means of damage at the energy level through the guidance of EMI to determine the fundamental laws of change and control of the energy state of objects (samples of WME and technical means logistic support).

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