Запропонована технологія екранування приміщень покриванням внутрішньої поверхні радіопоглинаючими плитками цементу Сореля. Наповнювачем є дисперсний феритовий перетворювач енергії завадових електромагнітних полів в теплову. Ефективне екранування забезпечують: термохімічний синтез електропровідного феритового оксиду перехідних металів зі структурою оберненої шпінелі; полімеризаційне концентроване наповнення основи. Основою є суміш оксиду магнію і насиченого розчину хлориду магнію. Це запобігає втратам міцності затвердлих плиток

Ключові слова: поглинаюче екранування пунктів управління, феритові радіопоглинаючі матеріали, цемент Сореля, полімеризаційне наповнення

Предложена технология экранирования помещений покрытием внутренней поверхности радиопоглощающими плитками цемента Сореля. Наполнителем является дисперсный ферритовый преобразователь энергии помеховых электромагнитных полей в тепловую энергию. Эффективное экранирование обеспечивают: термохимический синтез электропроводного ферритового оксида переходных металлов со структурой обращенной шпинели; полимеризационное концентрированное наполнение основы. Основою является смесь оксида магния и насыщенного раствора хлорида магния. Это исключает потери прочности твердых плиток

Ключевые слова: поглощающее экранирование пунктов управления, ферритовые радиопоглощающие материалы, цемент Сореля, полимеризационное наполнение

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DEVELOPMENT OF A TECHNOLOGY FOR ABSORBING SCREENING OF COMMAND POSTS WITH ELECTRONIC EQUIPMENT

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1. Introduction

Under the term "control posts", the authors understand, first of all, "the posts of control of critical infrastructure facilities" and command posts of combat control of subunits of security agencies. For the first, radiation damage of the electronic equipment functions by terroristic electromagnetic interference is impermissible. It can cause an ecological catastrophe. For others, radiation damage of electronic equipment by the enemy's modern electromagnetic weapons which have already been added to arsenals of some countries is impermissible.

In addition, the intensive development of microwave technologies requires creation of technologies for protection of electronic equipment against industrial interferences. International standards specify permissible levels of background radiation of microwave equipment but compliance to these standards is controlled unsatisfactorily. The growing interest of society in protection of people and equipment against electromagnetic fields does not ensure solution of this problem.

In addition, society does not stimulate the measures ensuring electromagnetic compatibility in conditions of growing power and bandwidth of television and communication means. The massive spread of powerful radiation of mobile telephones is not limited.

The situation is complicated by the possibility of deliberate interference in operation of unprotected computer equipment.

Development of technological fundamentals of protection of the control post hardware requires development of theoretical and practical fundamentals of synthesis, manufacture and application of radiation absorbing materials which convert magnetic field energy into thermal energy. The demand for such materials is unlimited at present.

The widespread use of microwave heating equipment for industrial and domestic purpose requires a substantial reduction of background radiation for human protection.

Uncoupling of receiving and transmitting hardware components is required for radar and radio systems. It is necessary to ensure electromagnetic compatibility of television and communication equipment in telecommunication systems. In offices, the problem of screening protection against leakage of computer information is relevant.

However, the proposals of creation, production and delivery of materials of required quality for protection of equipment and people lag behind the society demands.

This situation, apparently, is caused by the plurality of the following scientific and technical factors:

– scientific and technological complexity of synthesis of a dispersed nonmetallic polymer-based filler with required magnetic properties and high electrical conductivity;

– complexity of choice and modification of the acceptable polymer-based radiation absorbing materials with required binding and operational properties;

– the necessity of using converters of magnetic field energy to heat energy in a wide frequency range of microwave and infrared bands;

– absence of acceptable criteria for assessing quality of radiation absorbing materials; the procedures currently regulating measurement of mechanical parameters of materials do not contain material absorption indicators;

– traditional influence of shortcomings of narrow-profile training of specialists on solving problems at the border between microelectrodynamics and materials science complicates comprehension between engineers and material scientists.

Thus, growth of the need for improving effectiveness of protection of the electronic equipment indoors against interference actions and the lack of substantiated recommendations emphasize relevance of the undertaken study.

2. Literature review and problem statement

Solution of the problem of reliable protection of electronic equipment is determined by a significant growth of relevance of the problem of ensuring safety of equipment operation and the existence of ray weapons. The malicious use of these means can turn the control point with electronic equipment having intelligent functions into an inactive unit.

Active search for methods and means of protection of modern electronic equipment against damage and interferences of various types is emphasized by the following publications.

A technology of radioisotope-plasma coatings for protection of radioelectronic hardware was proposed in [1]. The ways of implementation of protective materials were shown and estimation of effectiveness of practical application was given. However, the issues of the environmental friendliness of this protection remain unexplained which may cause the danger of screening large areas of the control point rooms.

Influence of electromagnetic radiation on environment was considered in [2]. Specific indicators of absorption of human tissue in the process of interaction of microwave radiation and humans were estimated. Planning of new safety rules for industry during operation of the sub-THz groups was considered. This emphasizes the international level of relevance of similar studies according to the programs of protecting not only electronic equipment but also people.

Paper [3] presented the study of the effect of screening on the internal parameters of quality of Al and TiN microwave resonators. Measurements were made in an adiabatic demagnetizing fridge where typical magnetic fields of 200 μT were present at the unsafe stage of sampling. Radiation protection consisted of 100 and 500 mK Cu cans coated with epoxy resin absorbing radiation in the infrared frequency range. Conduction of this experiment has shown presence of influence of electromagnetic waves in various frequency bands on the elements of electronic equipment and the necessity of scientific studies in the field of creation of protective absorbers of electromagnetic fields simultaneously in the microwave and the infrared frequency bands.

Analysis of electrically conductive polymers being widely studied as microwave absorbing materials due to their light weight, corrosion resistance, manufacturability and variability of electrical conductivity was made in [4]. Among these polymers, polyaniline (PANI) microwave absorption materials are studied most widely because of their simple and inexpensive manufacture, excellent physical-chemical properties and high conductivity at microwave frequencies. However, firstly, polyaniline absorbers do not have, as a rule, the required electrical conductivity (because of the considerable technological complexity of obtaining a molecular structure which should contain several hundred monomer chains) and secondly, such polymeric absorbers have poor thermal stability.

Publication [5] has provided an overview of the radiation absorbing composites of co-ferrite and carbonyl iron particles (CIP) as an absorbent where the aliphatic polyurethane resin is used as a matrix. The frequency band of the electromagnetic waves of this composite is 4...20 GHz. Reflection factor is −8...10 dB. These indicators are insufficient for the task of protecting electronic equipment in modern conditions of development of, e. g. ray weapons. Thermal stability and environmental performance are also unacceptable.

Absorbing properties of the medium of ferrite-polymer composites were investigated and the possibilities of improvement of the indicators of reflection of electromagnetic fields in a frequency band of 8...20 GHz were shown in [6]. The studies have shown that the conventional ferrite-polymer composites do not provide (because of low levels of their conductivity) required levels of absorption parameters sufficient for the task set in this work. Their heat resistance and environmental performance are unacceptable as well.

Production of an electromagnetic polyaniline composite with an absorbing capacity in a microwave frequency band containing magnetic nanocomposites was considered in [7]. The complex coefficient of reflection and transmission of electromagnetic waves in a frequency band of 30 MHz to 1 GHz in a composite medium was studied. It has been found that a composite with 28.12 wt. % of polyaniline containing filler in a form of magnetic nanocomposites had a maximum absorption of the field energy at a level of 23 dB at a frequency of 700 MHz and coating thickness of 2 mm. Therefore, the composites can be potentially applied for electromagnetic absorption but for the low-frequency interference fields. Studies in this area are not promising and practical application of the results obtained is limited because of the narrow band of wave frequencies that are absorbed by these coatings and an insufficient thermal stability and environmental friendliness.

Work [8] proposed development of a technology for construction of radiation absorbing materials, their characteristics were obtained, microwave properties of an absorbing nanostructured nickel ferrite were investigated and influence of the characteristics of frequency-selective surfaces (FSS) on absorption of microwave energy was evaluated. However, absorbing frequency-selective surfaces should be investigated and applied only for absorption of ultra-narrow band interference, otherwise, there are no prospects.

Paper [9] has provided an analytical review of the purpose of modern radiation absorbing materials (RAM) and radiation absorbing coatings (RAC). Analysis of theoretical foundations of creation and trends in development of radiation absorbing materials was given. Relevance and necessity of elaboration of scientific foundations for development of broadband absorbers based on ferrite materials was pointed out. General conclusions of this paper were not substantiated by concrete recommendations concerning the ways of forming scientific basis for development of broadband absorbers. Namely these references substantiate good prospects of the studies proposed and realized by the authors.

Basics of the technology for synthesis of dispersed ferrite oxides of transition metals with a molecular structure of spinel of inverse type were proposed in [10]. Analysis of the physical mechanisms acting during implementation of the technology and influencing the results of synthesis and practical application of a substance with required electrophysical properties were given. It is in this work that recommendations for practical application of this filler as a part of a composite coating were provided to reduce radiation interferences from microwave heating chambers. This paper has recommended ways to the use of advantages of this compound in its practical application as a filler of a polymeric matrix of radiation absorbing coatings. In particular, one of the recommendations [10] consisted in harmonization of the wave resistances of dielectric media at the air-medium interface. For this purpose, it is expedient to accurately measure parameters, complex permeabilities of the environments with electromagnetic losses. This is necessary for a purposeful correction of parameters, first of all to ensure the field energy reflection close to zero. Secondly, it is necessary to ensure linear absorption of the electromagnetic wave energy at a level of 12...15 dB/mm.

A method for correction of wave resistance of modified radioactive composites with heterogeneous fillers in a form of a suspended mixture of ferrite and silicon carbide in a thermoelastoplast matrix was proposed in [11]. The method helps to ensure that the field energy is not reflected from the surface of the absorbing coating by matching the relative dielectric and magnetic permeabilities normalized by corresponding air constants. It also helps to provide required significant level of linear absorption of the electromagnetic field energy by a coating with thickness of not more than a few millimeters. Disadvantages of this method include toxicity of soluble thermoelastoplast and its insufficient thermal stability not exceeding 200 °C.

A new approach considered in [12] facilitates microwave processing of the synthesized compound of $SiC\text{-}TiO_2$ type. This material is usually inert in a microwave field. Relationship between the material structure, the resulting physical properties and behavior in the microwave field were discussed. Excellent absorption characteristics of SiC are widely used not only as a material for activating interaction of electromagnetic fields with dielectric media but also as an acceptable material for crucibles widely used in the technology of pure fusion of non-ferrous metals in a microwave field. However, absence of magnetic properties in silicon carbide along with its high electrical conductivity does not contribute to the prospects of its use in reducing magnetic field reflection from absorbing coatings. This is explained by impossibility of matching the wave resistances at the air-SiC boundary where magnetic properties of the absorber are also required.

A procedure of a techno-economic choice of a method for saving functions of a combat command post during application of modern detection methods by the enemy using means of various physical natures was offered in [13].

Maintaining the functions of the control point is a daunting task. Protection of information on location and direction of movement of the control point in combat conditions ensures its survivability in presence of interferences or action of the ray weapons.

Sometimes, it is impossible to ensure survivability of the control point through its timely recovery in a case of violation of its functions. In the conditions of a dynamic change of situation, its restoration, even after average damage, will take days. It is for this reason that, in principle, a reliable preservation of the control point functions is essential, e.g. in the conditions of electromagnetic counteraction to its operation.

The necessity of comparing alternatives and choosing the method of maintaining serviceability of electronic equipment in conditions of action of control point detectors of various natures is brought about by several factors. The tools reducing detectability of facilities and increasing secrecy of their operation are often used. At the same time, these means more often do not satisfy the “cost-effectiveness” criterion. The illustrative examples are the Stealth program which is worth billions of dollars or the Pearlalarm program which does not protect duly but worsens mobility of the facility.

In recent decades, some Ukrainian scientific institutions are in an active search for this problem solution. Technologies for producing components of polymeric radiation absorbing coatings were developed, published, and patented [10, 11]. Laboratory samples of ferrite materials have been produced to reduce visibility of equipment and protect the control point hardware in the radar and IR wavelength bands [14]. By their basic indicators of quality and effectiveness of protection, the obtained results (laboratory samples) are not inferior to the known solutions. Manufacturability and absorbing properties of the samples are more competitive. But we definitely lag behind. The known means are widely used in practice and Ukrainian ones are still investigated in laboratories.

An overview of publications [1–12] revealed two main unresolved parts of the problem of absorbing screening the premises equipped with electronic hardware from interference of electromagnetic fields. First of all, there is a need for a scientific substantiation of expediency of synthesis of dispersible ferrite broadband fillers with electrical conductivity exceeding that of known fillers by several orders of magnitude. Besides, it is necessary to substantiate foundations of the technology of high-concentration fillers for the non-toxic and heat-resistant matrix of inorganic polymer without loss of coating strength after its solidification.

The results of the review of known publications as well as modern requirements to the characteristics of radiation absorbing screening of premises with electronic equipment emphasize the need for immediate solution of the three parts of the technological problem of creating an absorbing coating for protective screening of command points with electronic equipment, namely:

– significant (by several orders of magnitude) increase of electrical conductivity of the filler which does not require scarce raw materials;

– rise (three-fold) of concentration of the binding agent filler for absorbing coatings without loss of mechanical strength of the coating;

– use of a non-toxic and heat-resistant inorganic polymer with high binding properties and mechanical strength as the absorber base.

3. The aim and objectives of the study

The study objective was to provide scientific substantiation of physical-technical mechanisms that promote implementation of a technology for protection of electronic equipment of control points by increasing electrical conductivity of the filler, increasing concentration of the binding agent filler for absorbing coating without loss of mechanical strength of the coating, use of a non-toxic and heat-resistant inorganic polymer with high binding properties and mechanical strength as the absorber base. This will facilitate obtaining samples of inorganic polymer in a form of radiation absorbing tiles of Sorel cement without loss of strength of the tiles after their solidification and fixing on the walls and ceiling of the room.

To achieve this objective, the following tasks had to be accomplished:

– to substantiate the necessary and sufficient conditions for achieving the required level of reflection coefficient and the coefficient of transmission through a single-layer absorbing coating and quantitative requirements to electromagnetic parameters and electrical conductivity of the absorbing coating for a reliable screening of rooms with electronic equipment;

– to substantiate the physical and technical mechanisms which favors obtaining of an electrically conductive filler in a form of transition metal oxide with the structure of inverse ferrite-ferrite spinel which does not require scarce raw materials and catalysts for its synthesis;

– to substantiate the physical and technical mechanisms of mechano-chemical fusion of particles of the filler and the binding base which contributes to solving the problem of polymerization filling (highly concentrated) of the base as a mixture of compounds, magnesium oxide and saturated magnesium chloride solution and synthesis of an environmentally pure inorganic polymer in a form of Sorel cement tiles.

4. Requirements to electromagnetic parameters of the filler and the absorbing coating

Let us determine electrodynamic parameters of some dielectric medium to substantiate the required quantitative values of the reflection coefficient and the coefficient of transmission trough a single-layer absorbing coating. This medium is isotropic with electromagnetic losses, that is, it has extraneous currents.

In contrast to the electromagnetic field in the loss-free environment, the electromagnetic field in this medium depends on the length of the path **z** of the moving wave which propagates after passing the air-coating boundary.

The field also depends on the complex values of dielectric and magnetic permeabilities, i. e. on the parameters characterizing reflective and absorbing properties.

An important requirement to a radiation protection material consists in provision of a minimum reflection of electromagnetic waves from the air-coating interface in a wide frequency band.

Practical solution to the task of comparing the wave resistances of neighboring air and the coating material encounters significant technical difficulties in practice. Not a smaller difficulty arises when solving the task of significant reduction of the field energy in the radiation absorbing coating medium.

Let us first define the conditions necessary for matching the air resistance and resistance of the medium with losses.

It should be considered that the wave resistance for air medium depends on the magnetic and dielectric permeabilities, practically depends on the vacuum constants and is equal to

$$W_t \approx \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi \ \text{(Ohm)}. \tag{1}$$

In the medium with losses of electromagnetic field energy, the wave resistance has the form

$$W_2 = \sqrt{\frac{\mu_2}{\varepsilon_2}} \approx \sqrt{\frac{\mu' - i\mu''}{\varepsilon' - i\varepsilon''}}, \tag{2}$$

where the components of the field permeability depend on electrical conductivity σ_e and magnetic conductivity σ_m, constants of dielectric permeability ε_o and magnetic permeability μ_o of vacuum, relative dielectric permeability ε and magnetic permeability μ of the absorbing medium, corresponding absolute ε’, μ’ and the imaginary ε”, μ” values of permeability of the absorbing medium, angular frequency of electromagnetic wave oscillations ω and are equal to:

$$\mu' = \mu_0\mu; \ \ \varepsilon' = \varepsilon_0\varepsilon; \ \ \mu'' = \frac{\sigma_m}{\omega}; \ \ \varepsilon'' = \frac{\sigma_e}{\omega}. \tag{3}$$

Under conditions of using imperfect dielectrics as a medium with the field energy loss, it is fair to assume that $\varepsilon' \ll \varepsilon'; \mu'' \ll \mu'$. In this case, decomposition of (2) in a series with preservation of the first items gives the following formula:

$$W_t = \sqrt{\frac{\mu_0\mu}{\varepsilon_0\varepsilon}} \cdot \left[1 + 0.5i(\operatorname{tg}\delta_e - \operatorname{tg}\delta_m)\right], \tag{4}$$

where the tangents of the angle of dielectric and magnetic losses of the field energy are equal to

$$\operatorname{tg}\delta_e = \frac{\delta_e}{\omega\varepsilon_0\varepsilon}; \ \ \operatorname{tg}\delta_m = \frac{\sigma_m}{\omega\mu_0\mu}. \tag{5}$$

It follows from (1), (4) and (5) that the medium (air and the medium with losses) can be matched and the conditions of matching are of t he form

$$\mu = \varepsilon; \ \sigma_e/\varepsilon_o = \sigma_m/\mu_o. \tag{6}$$

These conditions are crucial for solving the tasks in practice, namely:

1) a significant weakening of reflection of the field energy from the coating medium with losses;

2) weakening of reflection of the field energy from the coating medium and weakening of the field intensity inside the coating medium under admissible values of thickness of the coating converting the field energy in the heat energy.

To solve the first task, it is enough to ensure fulfillment of condition (6). But for solution of the second task in the case when the radiation absorbing material is applied, e. g. on a metal surface, it is necessary to fulfill both condition (6) and the condition in a form of inequality:

$$\mathrm{tg}\delta_e=\mathrm{tg}\delta_m>>1. \qquad (7)$$

These requirements make it possible to provide the required high level of linear absorption of the field energy and a small level of reflection of the field energy from the radiation absorbing coating, even under the conditions of a metal floor covered with the radiation absorbing coating.

The coefficient of the field energy loss in the layer of the radiation absorbing medium with parameters matched in accordance with (1), (5), (6) is

$$K''=\frac{\omega}{2c}\sqrt{\varepsilon\cdot\mu}\left(\frac{\sigma_e}{\omega\varepsilon_0\varepsilon}+\frac{\sigma_m}{\omega\mu_0\mu}\right)= \\ =120\pi\sigma\ [\mathrm{Ohm}/(\mathrm{Ohm}\cdot\mathrm{m})]. \qquad (8)$$

Therefore, in order to ensure a significant weakening of the field in a matched medium with energy loss at the material layer thickness, e. g. z=2 mm, it is necessary to have electrical conductivity of the medium commensurate with several Siemens per meter. Indeed, for σ_e=5 S/m, taking into account (8), the required dimensionless measure of the degree of damping the field in the coating, is equal to

$$K''\cdot z=120\pi\cdot\sigma_e\cdot z=3.77.$$

A similar required level of electrical conductivity of the finished radiation absorbing coating can only be achieved with the use of fillers in a form of a ferrite-ferrite spinel of an inverse type. This is an assertion based on actual results of measurements of the coefficient of reflection of the electromagnetic field energy in a frequency band of 3.0...37 GHz for 1.0 mm thick radiation absorbing coatings with a filler in a form of ferrite-ferrite spinel of a reverse type. As a rule, electrical conductivity of this synthesized filler is σ_e=103...104 S/m or more.

Similar filler materials are magnetic semiconductors with commensurate levels of relative dielectric and magnetic permeability. This corresponds to the fairness of the requirements obtained in accordance with (6)–(8) and emphasizes the need to comply with these requirements. These fillers have a low level of activation energy, hence, high sensitivity and a wide allowable dynamic range of variation of the intensity of the input actions of the electromagnetic field on the radiation absorbing coating.

In addition, the technology of thermochemical synthesis of fillers of this type, namely Fe_3O_4, $NiCO_2O_4$, etc. does not require scarce raw materials and thermochemical reaction catalysts, complicated equipment and has an acceptable time-consuming factor.

5. The essence of thermochemical synthesis of the filler and polymerization filling of the binder

Thermochemical synthesis of the filler is aimed at providing the required complete level of reversing of the resulting oxide compound with a ferrite-ferrite spinel structure. In this case, trivalent iron cations must occupy a part of the octahedral positions of its elementary molecular nucleus and the other part of such positions should be occupied by divalent cations of iron.

Commensuration of ionic radii of these cations provides a high degree of inversion of this compound which is a condition for giving it semiconducting and magnetic properties.

The small ion radii of two- and trivalent cations promote high mobility of charge carriers in their diffusion jump from cation to cation, thus an unusually small level of activation energy of charge carriers takes place. This energy is equal to tenths and even hundredths parts of electron volts.

Low level of magnetic viscosity (inertia) of this material manifests itself in the small value of time of its relaxation. That is, the material has a short time for changing the direction of orientation of the magnetic spin-spin and spin-orbital moments under the action of the energy of the electromagnetic field falling on the surface of the radiation absorbing coating.

Effectiveness of interaction of this material with the field is explained by commensuration of the period of fluctuations of the electromagnetic field with the time of ferrite relaxation which is proportional to time

$$\tau\sim\exp(\mathrm{E}/\mathrm{kT})\leq10^{-9},\ (\mathrm{s}), \qquad (9)$$

where E is activation energy, k is the Boltzmann constant, T is the Kelvin temperature.

The filler technology consists in baking a mixture of a simple Fe_2O_3 oxide with chemically active carbon in presence of air oxygen for one hour (recovery reaction).

Such a technology has advantages over known ones (for example, the method of chemical co-precipitation of metal salts or hydroxides of these metals) not only in the quality of the material being obtained. Reproducibility and stability of the required high electrical conductivity, commensurate normalized magnetic and dielectric permeability are observed and the synthesis time is one hour according to the offered technology.

On the contrary, the time spent when using the conventional technologies, i. e. under the conditions of application of the deposition method, the process of co-deposition, washing, filtration, drying and milling of the finished filler takes a week.

The positive effect of the radiation absorbing coating significantly grows with the use of conductive ferrite filler, oxide of transition metals with a structure of a ferrite-ferrite spinel of the inverse type.

The multivariate structure of the molecular lattice and absence of the valence zone of this chemical absorption compound contribute to absorption of the energy of electromagnetic fields in a wide frequency band and in a wide range of the electromagnetic field force.

To solve the problems of reliable screening of rooms with electronic equipment, the operation of covering the interior of the room is carried out with the use of environmentally friendly radiation protective decorative tiles made on the basis of the technology of Sorel cement in a form of MgOHCl.

It is expedient to fill the tiles with a disperse ferrite oxide of transition metals with the structure of spinel of inverse type with a high volume concentration in Sorel cement, up to 70...80 %.

That is precisely what makes it possible to achieve linear absorption of the field energy by coating at a level of 10...15 dB/mm. This means that with the help of 4...5 mm thick radiation absorbing tiles, the potential resulting absorption can be 40...60 dB and even significantly more. Even if these tiles are applied on a metal surface in the room, after passing of waves of powerful ray weapons through the tile in the forward direction, its reflection from the metal surface and passing through the tile in the opposite direction, the total absorption of energy of the electromagnetic wave will be equal to 80...120 dB.

Practical implementation of such a highly concentrated, i. e. polymerization filling of the binder base, is done with the help of a vibration machine in a metal reactor with metal balls.

It is advisable to pre-mix the filler in a form of disperse conductive ferrite oxide with the binding base in a liquid phase. This base contains a mixture of magnesium oxide and a saturated aqueous solution of magnesium chloride. The mixture in the liquid phase of Sorel cement ingredients should be taken in a ratio of 2:3 by weight. The process conditions were established experimentally, tested at Morozov Design Office (Kharkiv) and patented in [14].

During this vibration treatment, the effect of creating chemical bonds between the molecules of the polymeric binder base of inorganic nature and the molecules of ferrite oxide filler with the structure of spinel of the inverse type is achieved.

The resulting mixture filled with disperse ferrite oxide is poured in flat plastic molds and solidified at room temperature for 15–17 hours.

The polymerization filling of the polymer medium with conductive ferrite oxide contributes to the achievement of a high absorber concentration in the polymer matrix. It thus contributes to achievement of a record level of field energy absorption without losing mechanical strength of the absorbing samples of Sorel cement tiles after their solidification.

6. An example of implementation of the technology of absorbing Sorel cement tiles

Let there be a task of screening a control point with electronic equipment. The surface area of the room is $S=(4\times4)\cdot2+(4\times3)\cdot4=80$ m^2. The absorbing tiles have thickness $h=0.4$ cm.

To implement the proposed technology, it is advisable to perform the following stages.

1. First, it is advisable to calculate the resulting specific density of absorbing tiles, P, taking into account density of the tile ingredients. It is known that disperse ferrite oxide has a bulk density of 0.2 g/cm^3 and Sorel cement has density of 2 g/cm^3. Therefore, according to the new technology, the resulting density is equal:

$$P=0.75\cdot0.2+(1-0.75)\cdot2=0.65 \text{ (g/cm}^3\text{)}.$$

2. It is necessary to synthesize the filler in a form of magnetite (complex dispersed transition metal oxide with the structure of spinel of the inverse type). It is expedient to obtain this electrically conductive filler according to the technology set forth in the Patent of Ukraine [15].

The filler has electrical conductivity of more than 10^3 S/m. According to the new screening technology, its quantity for realization of this example task is

$$M_1=0.75\cdot S\cdot h\cdot0.2=0.75\cdot8\cdot10^5\cdot0.4\cdot0.2=48 \text{ (kg)}.$$

Next, the following operations should be performed:

– prepare a water solution of a mixture of the binding base taking into account the features of the technology and the example, i. e. Sorel cement, in an amount:

$$M_2=(1-0.75)\cdot S\cdot h\cdot2=0.25\cdot8\cdot10^5\cdot0.4\cdot2=160 \text{ (kg)};$$

– verify correctness of calculations of the total weight of the mixture ingredients to ensure the desired level (0.65 g/cm^3) of the resultant specific density, P, of the composite ingredients. To this end, it is necessary to determine:

$$(M_1+M_2):(S\cdot h)=P;$$

$$(48+160):(8\cdot10^5\cdot0.4)=0.65 \text{ (g/cm}^3\text{)};$$

– determine quantity of Sorel cement components to provide conditions for the necessary reaction of its polymerization to a hard solidification in the form:

$$MgO+MgCl_2\cdot H_2O\rightarrow2MgOHCl,$$

therefore, according to the new technology, it is expedient to obtain the quantity of components for obtaining Sorel cement in the following form [12]:

$$MgO:M_{21}=(2/5)\cdot M_2=0.4\cdot160=64 \text{ (kg)};$$

$$MgCl_2\cdot H_2O:M_{22}=(3/5)\cdot M_2=0.6\cdot160=96 \text{ (kg)};$$

– perform vibration stirring (in a metallic reactor with metallic balls) of the mixture of dispersed ferrite filler, spinel of inverse type, with a binding base in a liquid phase with the help of a vibration machine. Before starting vibration stirring, the following technological requirements must be met. The metal reactor of the vibration machine must contain metal balls of various diameters (8, 10, 12) mm. The appropriate vibration frequency of the reactor should be 20–23 Hz. Amplitude of mechanical vibrations of the reactor should be 3...4 mm.

The process of vibration stirring causes the oxide polymer in the mechanical mixture to cause the so-called effect of the mechanochemical fusion (due to collision of metal balls in the reactor) of the ferrite filler and the binding base of Sorel cement. This has a positive effect on the process of polymerization filling of the composite. In this process, gaps in the polymer molecules appear and polymer chains are formed that differ in chemical activity. That is, such treatment of the mixture of ingredients promotes formation of chemical bonds between the particles of the oxide filler and the chains of inorganic polymer.

In this new medium, equilibrium, i. e. a balance between the chemical bonds and the new grain boundary phase of the polymer-oxide compound is observed.

Thus, a highly concentrated (up to 70...80 %) filling of an inorganic polymer with electrically conductive ferrite oxide is ensured without loss of strength of the radiation absorbing coating.

It is important that the absence of loss of mechanical strength of the material of the radiation absorbing decorative tiles after their solidification and applying on the room surface is guaranteed in comparison with its mechanical filling which can only be realized with low filler concentrations at a level of 20...25 %. Implementation of the screening process favors achievement of the required level of 70...80 %. That is why the coefficient of absorption of energy of the electromagnetic field is always higher (10...15 dB/mm).

Next, it is enough to complete the important final operations, namely:

– pouring the resulting mixture into flat square molds with dimensions of, say, 15×15...30×30 cm;

– solidifying the decorative tiles at room temperature for 15...17 hours;

– covering walls and ceilings with radiation absorbing tiles using a certain building solution, e.g. using an aqueous suspension of polyvinyl acetate with addition of surfactants.

7. Discussion of the results obtained in the study of a new technology for protection of electronic equipment of control points

Achievement of the desired results of synthesis of ferrite-ferrite oxide by thermochemical sintering in a shaft furnace with the help of a catalyst requires compliance with the technological requirements to its synthesis. This ensures production of a conductive superfine filler (particle size ≤1 μm) with commensurate values of dielectric and magnetic permeability. It is these properties of the filler that provide required levels of field energy absorption with a coating applied in the room with electronic equipment. The high level of absorption of the electromagnetic field energy is ensured even with a rather thin coating on the walls and ceiling of the room.

The experience of preparation of ferrite absorber demonstrates a reliable implementation of the technology of synthesis of an electrically conductive magnetic filler for radiation absorbing materials. The technology based on a thermochemical synthesis reaction is considerably simpler than the known technology. Its main advantage is the rapid preparation of this filler in arbitrary quantities with reproducible, stable in time electromagnetic properties and limiting temperature up to 800 °C.

Polymerization filling of the binding base of inorganic polymer based on Sorel cement in a liquid phase is successfully implemented in a metal reactor of a vibration machine with metal balls of various diameters.

Mechano-chemical fusion of particles of ferrite oxide with particles of magnesium oxide and chloride contributes to a significant increase in concentration of ferrite filler with no strength loss.

It has been practically established that the acceptable level of the filler concentration in the absorbing coatings, the Sorel cement tiles, can be increased three to four times. It also has a significant positive effect on the technical and economic indicators of the technology of screening rooms of the control points.

First of all, the technology as a whole contributes to a more reliable protection of electronic equipment against interferences occurring during its operation and an intentional damage from outside. The resulting levels of linear absorption of field energy ensure protection of equipment against existing powerful electromagnetic fields.

The offered technology of electromagnetic screening of the control point rooms with electronic equipment promotes rapid implementation of screening.

Thus, a guaranteed weakening of the energy of electromagnetic fields at the reflection coefficient equal to −40...50 dB is ensured. This result is achieved by the reliable absorption of energy from electromagnetic interference fields acting in an arbitrary direction. The value of the coefficient (40–50 dB) was measured in the frequency band of 2.5...18 GHz with the help of P2-56; P2-61; P2-67 panoramic meters of reflection and transmission coefficients. For example, the linear value of the absorption coefficient of the radiation absorbing coating in a form of the Sorel cement tiles with a ferrite-ferrite filler of spinel with a reverse structure was established at a level of 10...15 dB/mm. Thus, the 4 mm thick tile (as accepted in the proposed technology) absorbs [(10...15) dB/mm] 4 mm ≥(40...50) dB. This result was obtained with the help of above meters.

The broadband filler of the coating ensures protection of equipment in the microwave and infrared frequency bands against intentional, natural and industrial radiation.

9. Conclusions

1. Compared to the known technologies, effectiveness of screening rooms with electronic equipment increases hundreds of times with the technology offered. Consumption of the necessary materials is reduced three times. Time spent at the stages of material preparation and practical implementation of screening the premises with equipment is reduced ten times.

2. The thermochemical method of preparing a ferrite filler with required electromagnetic properties requires observance of the necessary and sufficient conditions for synthesis. First of all, it is necessary to use a simple oxide of trivalent iron with purity greater than 0.9 to ensure a high level of electrical conductivity and commensurate relative levels of magnetic and dielectric permeability. It is also necessary to use chemically active commercial carbon as a catalyst for the chemical reaction of recovery during synthesis.

3. The synthesized filler has electrical conductivity more than 10^3...10^4 S/m. Known fillers have electrical conductivity 10^{-6}...10^{-7} S/m. Thus, the electrical conductivity of the filler used in this method is nine orders higher than that of known fillers of a similar purpose. This particular parameter of the filler for the Sorel cement contributes to a guaranteed protection of electronic equipment.

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