DEVELOPMENT AND RESEARCH OF TEXTILE MATERIALS WITH SPECIFIED SHIELDING PROPERTIES FOR PROTECTION AGAINST ELECTROMAGNETIC INFLUENCES

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Abstract. Was conducted the analysis of special clothing used for protection against electromagnetic influences for employees of the energy industry and operators of high-frequency electronic equipment. As a result of the analysis of the existing special protective clothing, regulatory framework and experimental studies, the feasibility of designing and developing textile materials for the manufacture of special protective clothing with specified shielding properties is substantiated. Criteria to be met by protective clothing were named: sufficient shielding factors, acceptable ergonomic characteristics, increased durability, preservation of shielding properties during operation. The work used as a screening substance enriched iron ore, obtained as a result of flotation at a mining and processing plant.

In the laboratory, was developed the technology of applying a shielding substance to the textile material and was testing the protective properties of textile material with specified shielding properties. The studies were performed on a mobile communication frequency (1,8 GHz) using a calibrated energy flow density meter D3-31 and at a frequency of 50 Hz using a calibrated electric and magnetic field strength meter D3-50. Was determined the shielding coefficient of the magnetic component of the electromagnetic field for the industrial frequency. Have been determined shielding factors. The technology of manufacturing a suit with shielding properties has been developed structurally removable safety features are provided in the process. The advantage of the developed design is the ability to change the degree of protection depending on the specific production conditions. Laboratory studies on the possibility of fabrication of textile material using ferromagnetic nanostructures have been carried out.

Keywords: *protective clothing, electromagnetic screen, shielding factor, latex, textile material, electromagnetic field.*

Introduction

To date, a paradoxical situation has arisen in Ukraine: along with the development of high-frequency communication, increasing the number and increasing the operating voltages of transmission lines and other electrical equipment, there is a shortage of protective clothing for performing regular and repair work in the conditions of electromagnetic fields. To a certain extent, this is due to the fact that most attention is paid to the means of collective protection against electromagnetic influences - materials for facing large surfaces (including composite ones), shielding of individual technical means, solving problems of technical protection of information. However, such materials are of little use for the production of personal protective equipment, in particular shielding suits, which requires the development of new materials, the study of their protective properties and the creation of clothing to protect workers from the influence of electric, magnetic and electromagnetic fields of the wide frequency range According to the requirements of the EU-wide directive [1], it is mandatory to provide energy workers and operators of high-frequency electronic equipment with personal protective equipment against the action of electromagnetic fields, namely special clothing, special footwear and other personal protective equipment.

Problem statement. In recent years in Ukraine several types of clothes for shielding from the electromagnetic fields were developed - electric welder apron and shielding kit for electrical engineers [2, 3]. These products are made of amorphous soft magnetic alloy wickerwork. Having acceptable shielding factors they still have a number of disadvantages: they are designed to protect against the influence of magnetic fields only of low frequencies and are not ergonomic due to the rigidity of the structure. Modern composite materials are more suitable [4, 5]. But they use micro- and nanotubes woven into the fabric, that is, built on the principle of fabric with wires, which is used in Ukraine in the energy sector and requires grounding, not sufficiently resistant to mechanical influences, etc. In addition, the aforementioned materials and articles are of great value. In recent years, there has been a number of studies and applications on composite metal-polymer isotropic materials [6, 7]. But these materials are designed to protect against very high and ultra high frequency screens. However, they have a sufficiently large thickness and cost and are entirely composed of polymer fibers, which is not entirely acceptable for the manufacture of workwear. The production of protective materials using shielding particles in a polymer matrix is promising [8, 9]. But, for example, ferrite particles are large enough, so the material must have a large thickness to obtain an acceptable shielding factor. Recently, a number of studies and developments have been carried out showing that fine iron ore dust is very good filler for shielding materials, while increasing dispersion increases the shielding coefficients. For iron and iron-containing particles this figure is even better [10, 11]. But the general disadvantage of these developments is the use of exclusively polymeric media. Therefore, it is promising to develop a protective metal-containing coating on a textile carrier.

The purpose of the work is to develop a material for shielding electromagnetic fields on a textile basis, to study its protective properties and to create protective clothing from it.

Research results. The material to be used for production of special clothes for protection against influence of wide-range electromagnetic fields must meet the following requirements:

- sufficient shielding coefficients for the low and high frequency electromagnetic fields, and suitable for the protection of workers operating under the influence of industrial frequency electromagnetic fields and its harmonics and servicing wireless communication equipment (ultrahigh frequencies);
- acceptable ergonomic characteristics - thin, elastic;
- high tensile strength and heat resistance, acceptable thermoregulatory properties;

- protective properties stability after washing.

Thus, it is hard to create protective material, which can satisfy all these requirements. That's why, it is better to provide the first and second requirements, and to design combined protective clothing, with protective inserts into the suit between the layers of the base material and the substrate. Such technology is well developed for the production of armor protection [12].

For production of protective elements a special technology has been developed. The carrying fabric is linen, which is the most widely used for production of working cloths. Its advantage is high porosity of the fibers, which increases the adhesion of the screening substance to the base.

The screening substance chosen for the development is enriched iron received by flotation at the Poltava Mining and Processing Plant. Unlike iron ore, which settles on filter curtains, there is much more iron in this concentrate (up to 73%) and its compounds (up to 20%). In addition, its dispersion is higher. This makes it possible to obtain a material of small thickness with sufficient shielding factors.

Iron ore is dissolved in standard liquid latex in quantity 15-20%. This mixture is applied to a linen cloth, rolled through the rollers and dried.

As compared with the technology described in the work [13], the amount of iron substance is increased and the pressure during rolling is increased. This made it possible to obtain more elastic and thin material (up to 0,25 mm).

The protective properties of the material have been tested. The research was performed for the mobile communication frequency (1,8 GHz) using the calibrated energy flow density meter D3-31 and for the frequency of 50 Hz using the calibrated electric and magnetic field strength meter D3-50.

For the industrial frequency, the shielding coefficient of the magnetic component of the electromagnetic field has been determined (shielding of the electrical component is not a problem because of the nature of the electric field).

The results of material's protective abilities research are shown in Table 1 and 2.

Table 1

The dependence of the shielding factor K_s of the 1,8 GHz electromagnetic field on the number of layers of protective material *n* *

n	**1**	**2**	**3**	**4**
K_s	2,8	5,6	9,6	17,0

* *The shielding factor is the ratio of the energy flux density in front of the screen to that in the protected area. The output energy flow density is 190 – 210 μW / cm^2.*

Table 2

The dependence of the shielding factor K_s of the 50 GHz magnetic field on the number of layers of protective material *n* *

n	**1**	**2**	**3**	**4**
K_s	2,9	8,0	16,2	23,0

* *The shielding factor is the ratio of the induction of the magnetic field in front of the screen to this indicator in the protected area. Output magnetic field induction is 230 – 240 μT.*

As it is seen from these data, shielding factors in both situations is higher than data from [13]. This is explained by the location of shielding particles in the material.

The samples of the required linear dimensions have been cut from the developed material and placed between the fabric surface and lining.

The design of the suit with protective elements is presented in Figure 1.

Technological and structural features of the presented protective suit are the presence of a two-layer lining with special holes for the insertion of protective elements. The protective elements are fully consistent with the linear dimensions of the jacket base and trousers.

As can be seen from the schematic representation of the outfit's appearance, the protective elements are missing in the jacket strap and trouser belt, which is explained by the impossibility of changing the protective elements, but given the jacket length, protection will be provided in these areas by imposing one type of clothing on another.

The safety elements are attached to the details of the base of the protective suit with button fastener, which does not affect the operational properties.

The advantage of this design is the possibility to change the degree of protection depending on the specific production conditions. The number of layers of material will not affect the ergonomic and physic-mechanical properties of the protective suit, since the protective clothing according to the technology is made with lining, the main function of which is to increase the wear resistance and protection of the human body from the negative impact of the environment. According to the specifications, the substrate is made of natural cotton or linen.

The measurements of the protective properties of the designed suit have been also performed. Measuring antennas for recording the high-frequency electromagnetic field and the magnetic field of industrial frequency were placed between the layers of the jacket material package in the chest area.

The two-layer safety elements have been used. This is explained by the fact that the minimum shielding factor must be 5 at the most common workplaces of the energy industry workers in the production environment with operating electrical installations up to 750 kV. And according to Table 2, it is provided by two layers of material.

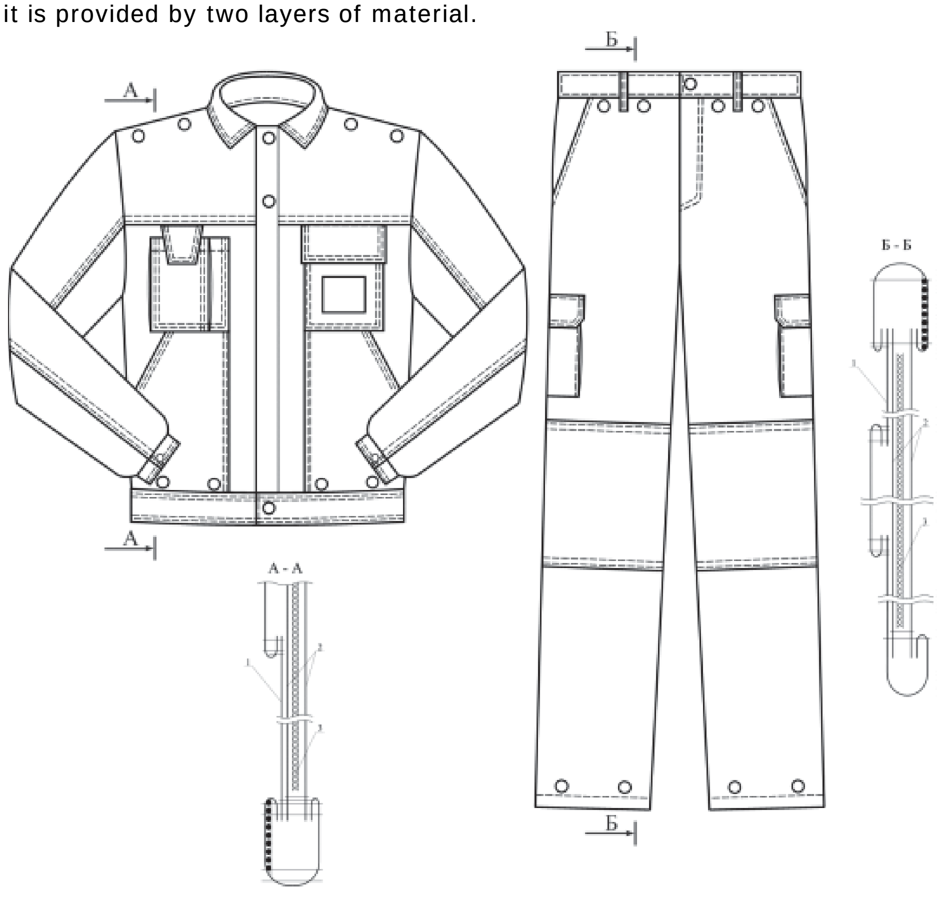

Fig. 1. – Design of the suit for the protection against electromagnetic fields.
1 – Textile base material; 2 – Lining textile material;
3 – Textile material with shielding properties.

The advantage of the suit is that the protective elements are easily removed, which provides the possibility of washing without losing the protective properties of working cloths.

Application of the developed technology allows obtaining the protective material with the required parameters.

For this purpose, the screening coefficients of the material are experimentally determined, depending on its thickness and the content of the screening substance.

For this the known ratio for a long cylindrical screen can be used:

$$K_s \approx \frac{\mu_{ef}(b^2 - a^2)}{4b^2}, \tag{1}$$

where: K_s – is the shielding factor;

μ_{ef} – efficient magnetic permeability of the material;

b and a – are the outer and inner radius of the screen (b–a is the wall thickness).

Experimental data on the shielding factor using the Comsol software package determine the dependence of the magnetic permeability on the geometric and physico-chemical parameters of the screen.

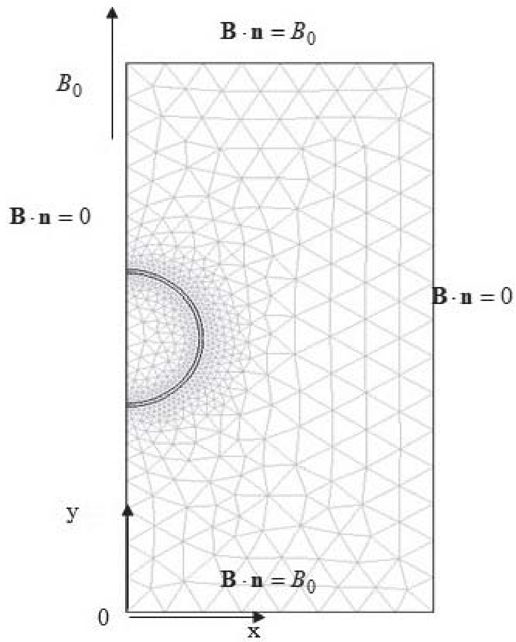

Fig. 2. – Area for the calculation of the magnetic field of a cylindrical screen indicating the finite element grid

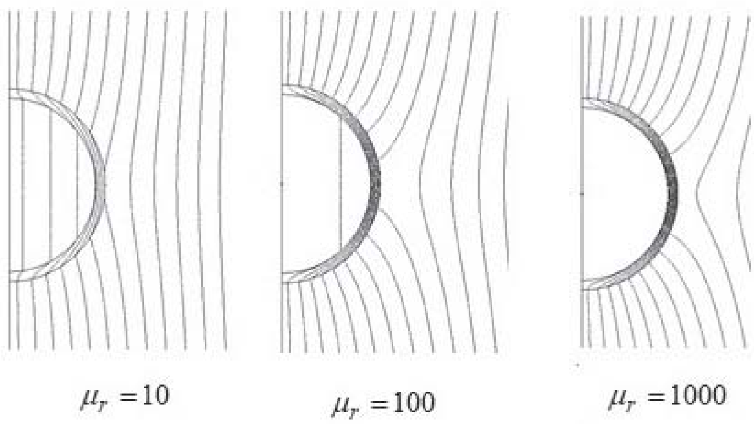

Fig. 3. – Distribution of magnetic field lines for different values of magnetic permeability of a cylindrical screen

This dependence is subsequently used to obtain shielding material with a shielding factor corresponding to the protective clothing operating conditions.

A study was conducted on the possibility of fabrication of a textile protective material using ferromagnetic nanoparticles (average particle size is 10 nm). For this linen fabric was impregnated with a magnetic fluid based on ethyl alcohol. Testing of the protective properties was carried out for the electrical and magnetic components of the electromagnetic field of industrial frequency. The results of the tests are given in Table 3.

Table 3

Dependence of the shielding coefficients of the electromagnetic field with a frequency of 50 Hz on the number of layers of protective material n.

	E, V / m			B, μT		
n	E_f , v / m	E_s , v / m	K_s	B_f, μT	B_s, μT	K_s
1	720	525	1,42	146	76	1,92
2	720	290	2,48	146	29	5,03
3	720	190	3,78	146	18	8,11

In this case, the flow of magnetic fluid was 50 g / m^2 of fabric. Therefore, the given coefficients of shielding can be considered acceptable. But for practical use of such material it is necessary to solve one problem. Magnetic fluid is a colloidal solution of ferromagnetic particles in ethyl alcohol. To prevent the particles from sticking together, a surfactant, fatty oleic acid, is added to the solution. Therefore, the finished material must be treated in such a way as to neutralize the acid. This is a separate technological challenge that will be addressed in future research.

Conclusions

1. The need for development of the shielding textile material for the protection against the effects of electromagnetic fields of a wide frequency range have been developed; the material is suitable for manufacturing personal protective equipment for workers of the energy industry and operators of high-frequency electronic equipment
2. The obtained textile material with specified shielding properties has the shielding factor (K_s) of 2,8 – 17,0 for the mobile communication frequency of 1,8 GHz (with increasing number of layers of material increases K_s), and 2,9 – 23,0 for the frequency 50 Hz.
3. The developed clothing has acceptable protective properties and ergonomic characteristics. The detachable elements of the protective clothing design enhance the screening properties by increasing number of the protective material layers and enables dry cleaning and washing of the clothing without the loss of protective properties.
4. It has been established that a promising direction for the manufacture of protective material without the use of removable elements is magnetic fluid. The shielding coefficients of such material of a magnetic field of industrial frequency 2 ÷ 8 for 1 ÷ 3 layers of material are acceptable. The problem of neutralization at the end of the technological cycle of the surfactant needs to be solved.

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