Master thesis

Development of organizational and technical measures to protect workers from electromagnetic fields at the enterprises of the fuel and energy complex

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Declaration of Authorship

„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet."

Abstract

The thesis is devoted to developing measures to protect workers of the mine operated by Belaruskali OJSC from the effects of the electromagnetic fields of industrial frequency.

The purpose of the thesis is to study the features of the distribution of electromagnetic fields in industrial conditions and determine measures to protect personnel from their effects. To achieve this goal, the existing database of Russian and foreign studies in the field of non- ionizing radiation exposure was studied, measurements were taken directly at the workplaces of shearer operators, and effective measures were proposed to protect workers.

Zusammenfassung

Die Dissertation widmet sich der Entwicklung von Maßnahmen zum Schutz der Arbeiter der von Belaruskali OJSC betriebenen Mine vor den Auswirkungen elektromagnetischer Felder industrieller Frequenz.

Ziel der Arbeit ist es, die Merkmale der Verteilung elektromagnetischer Felder unter industriellen Bedingungen zu untersuchen und Maßnahmen zum Schutz des Personals vor deren Auswirkungen zu ermitteln. Um dieses Ziel zu erreichen, wurde die vorhandene Datenbank russischer und ausländischer Studien auf dem Gebiet der Exposition gegenüber nichtionisierender Strahlung untersucht, Messungen direkt an den arbeitsplätze der Bergleute und wirksame Maßnahmen zum Schutz der Arbeitnehmer vorgeschlagen.

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Introduction

Currently, there is a continuous increase in the number of electrical devices used by people and the latest technologies, both for personal and industrial needs. The presence of a variety of electrical appliances and industrial equipment, on the one hand, is the main engine of economic and social progress, which certainly improves the quality of life of each individual, but on the other hand, contributes to the emergence of sources of low-frequency electromagnetic fields.

The rapid development of technologies and the increase in energy capacity lead to a lack of empirical data on the degree of exposure of electromagnetic fields of industrial frequency to residents who use electrical appliances in everyday life, and workers who maintain equipment in production conditions. Since the human body has to react to environmental changes, the compensatory mechanisms of the body, which are aimed at mitigating the effects of changes and the resulting stress, can be weakened. Thus, obtaining a real picture of the impact of a variety of sources of electric and magnetic fields on a person is one of the most important tasks in the current conditions.

Scientists' opinions on the impact of EMF on human health are divided. There are claims about the need for additional research in the field of the effects of non-ionizing radiation and the expansion of the database. The results of epidemiological studies of leukemia susceptibility are the basis for attributing low-frequency electromagnetic fields to the status: they have a potential carcinogenic effect. On the other hand, in some sources of scientific literature there are data that indicate the absence of adverse effects when exposed to low-frequency EMFs on humans. However, knowledge about the biological effect on the body is insufficient.

There is a possibility of exposure to a harmful factor on human health, which is the basis for studying the risk of consequences when exposed to electromagnetic fields. Scientific risk assessment implies a critical and balanced consideration of the data obtained from the largest number of reliable sources. The assessment process consists of the following stages: determining the hazard or exposure scenarios, assessing the dose-effect relationship, assessing the impact of a harmful factor in real conditions, collecting information, determining the degree of risk management ability. Many solutions have been developed in the field of risk control and management, however, additional efforts are required to fully assess the impact of invisible EMFs to humans. It is recommended, first of all, to be guided by precautionary principles, which are a strategy to minimize or prevent potential impacts on the environment and human health in the future.

In this work, following the basic principles of risk assessment, a study of the impact of electromagnetic fields on the mine workers of the Belaruskali company will be conducted.

The purpose of the study is to determine the degree of exposure of electromagnetic radiation to workers in production conditions, as well as the development of protective measures for personnel from non–ionizing radiation.

1 The state of knowledge of the problem

A significant number of studies relates to the effects of electromagnetic fields, both on the environment and on human health. The main sources of non-ionizing radiation are not only of natural origin, but also man-made. The levels of annual exposure to non-ionizing electromagnetic radiation have increased significantly over the past three decades. Non–ionizing radiation includes a wide range of frequencies - from extremely low to radio frequencies.

The impact of any of these frequencies individually or in combination, a cumulative effect, causes close attention of scientists from all over the world about potentially harmful consequences and is the subject of intensive scientific research, both epidemiological and clinical.

The development of the modern world is happening quite quickly and is accompanied by an increase in the number of equipment used, the latest equipment, as well as production capacities. In this regard, sources of electromagnetic radiation spread in the technosphere, thereby affecting a person in the production environment.

In the created conditions, the possibility of studying the nature of the impact of electromagnetic fields on the human body, their rationing, control, which are produced for workplaces and residential areas, acquires significant importance.

Assessment of the risk of occurrence of an event is a fundamental principle for the management of occupational safety.

The main problem with EMF measurements in the workplace is the lack of proper accounting of the total impact of fields of various origins. In the current reality, all fields are controlled, which cannot be assessed separately for compliance with the norms due to the absence of these norms.

Therefore, it is important to thoroughly and step-by-step study of the problems of the chosen topic, analysis of possible hidden and noticeable consequences of exposure to non-ionizing radiation on the human body.

1.1 Analysis of existing studies

The significance of research in the field of exposure to low-frequency electromagnetic fields is proved by the presence of recommendations of the World Health Organization regarding EMF of various ranges developed by the

International Commission for Protection against Non-Ionizing Radiation (ICNRIP) in 1999.

Low frequency electromagnetic fields were classified as potentially carcinogenic to humans (Group 2B) by the International Organization for Research on Cancer (IARC) in 2002 (Figure 1) [3].

Group 1	Known Carcinogen
Group 2A	Probable Carcinogen
Group 2B	Possible Human Carcinogen
Group 3	Insufficient Information
Group 4	Not a Carcinogen

Figure 1: Cancer classification [3]

Over the past 20 years, researchers have adopted more than 20 documents outlining the position of resolutions concerning the effects of electromagnetic fields on human health [12]. These include:

- Vienna Resolution on the Electromagnetic Field, Austria, 1998;
- Stewart Report, Great Britain, 2000;
- Salzburg Resolution, Austria, 2000;
- Freiburg Appeal, Germany, 2002;
- Catania Resolution, Italy, 2002;
- Statement of the Irish Association of Environmental Physicians, Ireland, 2005.;
- Helsinki Appeal, Finland, 2005;
- Benevento Resolution, Italy, 2006.;
- Venice Resolution, Italy, 2008;
- Porto Alegre Resolution, Brazil, 2009;
- Resolution of the Russian National Committee for Protection against Non-Ionizing Radiation, Russia, 2001;
- International Appeal of Doctors, Europe, 2012;
- Report of the Standing Committee on Health, Canada, 2015.

Experts from 10 countries have published evidence of the effects of low-frequency electromagnetic fields on various systems of the human body, and also considered the possible consequences.

Several international laboratories have conducted studies and reflected the results of the adverse effects of radio frequency EMF on the reproductive systems of men and women [9]. Under the influence, first of all, is DNA, which is not restored and has an impact on further reproduction and the health of offspring. Young children are more vulnerable to non-ionizing radiation.

In studies conducted since 2006, there is evidence of the effects of low-frequency EMF on the fetus and newborns [4]. According to observations, changes in heart rate variability, a decrease in melatonin levels in newborns, as well as a higher susceptibility to leukemia and asthma in children whose mothers were exposed to sources of low-frequency and radiofrequency electromagnetic fields were recorded.

Scientists have identified the following symptoms of electrohypersensitivity due to the influence of EMF - pain in the temporal region, a feeling of anxiety, palpitations, difficulty concentrating, muscle twitching and severe headaches. In people with the presence of abnormalities in the autonomic nervous system, the possibility of developing electrosensitivity is much more often observed.

A team from Lund University in Sweden conducted research on the effects of radio frequency fields on the protective shell of the human brain – a barrier that protects the brain from large molecules and toxins released in the blood. The heme-encepal barrier prevents the penetration of toxins into sensitive brain tissues. Increased permeability caused by exposure to EMF sources can lead to damage to neurons [11].

There are several hundred published papers that investigate the effect of non-ionizing radiation on cellular oxidative processes (genetic damage). With age, in the aging process, as a result of a decrease in the level of antioxidants, oxidative damage occurs, which leads to the body's susceptibility to the harmful effects of EMF [10].

Factors acting directly or indirectly cause morphological, chemical or electrical changes in the nervous system, cause adverse neurological consequences, as well as changes in the behavioral functions of humans and animals [6].

Long-term (chronic) exposure to low-intensity radiofrequency radiation currently exceeds the threshold values and the risk of developing certain diseases is increasing. Changes in human homeostasis and gene damage occur, mutations occur that interfere with genetic recovery and healing mechanisms. Such effects disrupt the normal functioning of the heart and brain; alter circadian rhythms that regulate sleep and hormonal balance; impair short-term memory, concentration, learning ability and behavior; provoke allergic and inflammatory reactions in tissues; slow down brain metabolism; increase the risk of reproductive failure; are one of the main causes of stress.

1.2 Theoretical study of the problem solution

Each electrical device generates an electromagnetic field, since a magnetic field arises around the conductor through which the current flows, and an electric field is formed between points having different voltage potentials. The higher the field strength and the smaller the distance from the field source, the stronger the effect on the human body [7].

People cannot see or hear electromagnetic fields. The effects mainly depend on the intensity, type and duration of the action.

There are direct and indirect effects of exposure to ionizing radiation. There are two types of direct biophysical effects: thermal effects caused by frequencies from 100 kHz and 300 GHz, and non-thermal (sensory) effects in the range from 1 Hz to 10 MHz.

The most susceptible to changes as a result of exposure to EMF systems of the body: nervous, endocrine, immune and sexual.

Typical low-frequency fields in most cases occur in an industrial environment and are often pulse-type fields. There is a need to protect workers in the production environment from this factor. First of all, it is recommended to assess the risk for each workplace and repeat the assessment at certain intervals, documenting the results. According to the rules, it is necessary to evaluate the parameters of the electromagnetic field separately by the magnetic and electrical components.

In the European Union, the supervision of the health of workers exposed to electromagnetic fields is established by Directive 2013/35/EU, aimed at preventing known direct biophysical and indirect effects.

A huge number of workers are exposed to non-ionizing radiation in the modern world. In accordance with these prerequisites, as in the case of other occupational risks, the possibility of developing and implementing appropriate health monitoring programs based on exposure data and risk assessment should be considered.

If the remote control of electromagnetic fields is exceeded at the workplace, suitable protective measures of an organizational and technical nature should be developed.

The main methods are: the allocation of an EMF exposure zone, the choice of a rational mode of operation of equipment, the location of workplaces at a safe distance.

If necessary, engineering and technical measures are developed. To weaken electromagnetic fields, a special design is used – an electromagnetic shield. Personal protective equipment can also be used – suits, robes, raincoats, helmets, glasses, etc., depending on the impact (general or local). Time protection reduces the risk of developing an occupational disease due to the electromagnetic factor and is also one of the most frequently used protective measures.

1.3 International experience in solving the problem

At this stage of the technical level of development, means of protecting a person from the effects of electromagnetic fields are being developed using the most effective materials in the working environment, both for special clothing fabrics and for screens installed directly at the emitting equipment. It is important to note the main difficulties that arise when choosing any method of protection:

- workwear, as a rule, is quite bulky due to the special structure of the protective material, which causes inconvenience to personnel when performing duties at the workplace;
- special screens installed directly at the equipment have special structural forms, which can be difficult to integrate into the production process.

Therefore, scientists are exploring new forms and structures for the introduction of protective measures, and at the same time having the greatest effectiveness.

The patent of the Russian Federation No75509, IPC N01Q17/00, H05K9/00 presents a protective device having a folded structure with the possibility of changing the geometry of protrusions and depressions. This property of the material, made of several layers with relief surfaces and alternating protrusions, allows you to maintain its shape and resistive features.

The protective coating with a mesh base presents in the patent of the Russian Federation No69327, IPC H01Q17/00. Absorbing elements in the form of a two-layer tape woven into each cell of each unidirectional row are fixed on the base. A distinctive feature of this invention is the greatest efficiency of the shielding coating, as well as the ability to stretch the most.

The patent of the Russian Federation No. 22816776, IPC A41D presents the invention of protective shielding clothing from electromagnetic radiation, made in the form of a jumpsuit made of multilayer conductive fabric with insulation between the layers. High-quality protection of the worker and at the same time convenience of working clothes is provided.

The shielding device in the patent of the Russian Federation No2381601 IPC H01Q17/00 consists of layers, where: the flat shielding outer layers are made of sheet magnetic steel with a permeability of at least 2 × 10^3, and the volumetric shielding layer placed between them is made in the form of a rectangular steel lattice, the cells of which are formed by guides and jumpers, which are prohibitive waveguides according to relative to the fundamental harmonic of the frequency of the shielded field. The scope of this invention is industrial and residential premises from low–frequency electromagnetic fields induced by electrical equipment.

Patent US20060264137A1, IPC H05K9/009 presents a garment made of knitted material that has the properties necessary for shielding electromagnetic waves. The front side consists of a yarn of conductive and elastic fibers that are intertwined with each other. Natural fiber yarn is used for the wrong side. The efficiency of the shielding property of the protective material is not less than 20 dB.

1.4 Key points of chapter 1

1) Research of influencing electromagnetic fields in production conditions is a priority task of the modern world in accordance with the basic provisions of WHO;

2) Low frequency electromagnetic fields are classified by the International Organization for Research on Cancer (IARC) as potentially carcinogenic to humans (Group 2B);

3) The effects of non-ionizing radiation are divided into direct and indirect;

4) The most effective measures to protect a person from EMF are engineering and technical.

2 Measurement results

The problem of the impact of electromagnetic fields on living organisms is being investigated by specialists from various fields of activity: medicine, engineering, biology, legislation, etc. This problem takes on a specific character, and requires a more detailed study for each specific situation. It is necessary to be guided by the basic principles, as well as to approach the assessment of the impact of EMF more comprehensively, taking into account the relationship between the factors of the working environment.

It was decided to conduct a study at the selected site of the treatment excavation of the third potash lava horizon No1-3 of the first mine management of the Belaruskali OJSC enterprise.

2.1 Characteristics of electromagnetic fields

According to the Lorentz force, in an air environment, the electromagnetic field is characterized by a vector of magnetic flux density (magnetic induction – B, nTl) and electric field strength (E, V/m).

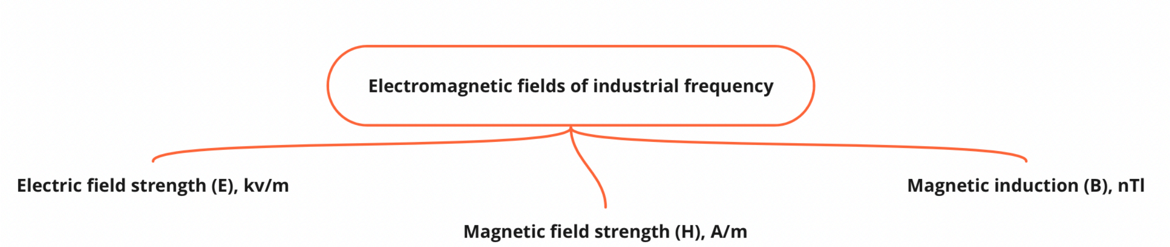

Figure 2: Parameters of electromagnetic fields 50 Hz

EMF, depending on the frequency of radiation from the source, is divided into three zones: near (induction); intermediate (interference); far (radiation zone).

In the induction zone, the electromagnetic wave has not yet been formed, so there is no definite relationship between the components. For example, one component may reach a maximum, while the other may reach a minimum. Measurements should be made separately for the electrical and magnetic components.

An electromagnetic wave is formed in the radiation zone. The components turn out to be similar in phase and having data only on the electrical component of the tension, it is possible to calculate the values of the magnetic component, also vice versa.

In industrial conditions, workers are more often exposed to low-frequency electromagnetic fields, which means that they are almost always under the influence of near-field radiation. The values are measured separately by the magnetic and electrical components.

To obtain information about the energy characteristics, the following ratio should be used:

$$E = 377H \quad (1)$$

2.2 Preparation for study

To achieve the research goal, after analyzing the problems of the chosen topic, the task of assessing the impact of a potentially harmful factor in real conditions should be performed. It is important to consider additional factors affecting employees.

Measurements of EMF parameters are carried out in accordance with the requirements of regulatory documents of Russia:

• SanPiN 1.2.3685-21 "Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans",

• GOST 22261-94 "Measuring instruments of electric and magnetic quantities. General technical conditions",

• GOST R 51070-97 "Electric and magnetic field strength meters. General technical requirements and test methods",

• GOST 8.736-2011 "Direct measurements with multiple observations",

• GOST 34100.1-2017 "Measurement uncertainty. Part 3. Manual according to the expression of measurement uncertainty".

For the frequency range from 5 Hz to 300 kHz, the controlled EMF indicators are: the RMS value of the electric field strength and the RMS value of the magnetic field strength.

When measuring the parameters of electric and magnetic fields, additional factors of the working environment should be considered. It is technological: what is the phase of the technological process, how the power supply systems function; hygienic: what is the temperature and speed of air movement in the lava; industrial: how the worker moves through the lava during the shift.

The workplace should be divided into several controlled zones. The height for the "standing" working pose when measuring the EMF intensity is 0.5; 1.5 and 1.7 m from the ground surface and at a distance of 0.5 m from the working equipment.

2.3 Data collection

According to SanPiN 3359-16 "Sanitary and epidemiological requirements for physical factors in the workplace", assessment and rationing are carried out separately according to the electric field strength and magnetic flux density. Since the equipment is energy-intensive, it was decided to make measurements in the frequency ranges from 5 Hz-2 kHz and 2-400 kHz. The normative values for such frequency ranges apply to the total electromagnetic fields that occur at the workplaces of combine machinists and miners.

The IEP-05 device was used to measure the intensity of the alternating electric field of the low-frequency range (Fig.3).

Figure 3: Electric field meter

The data obtained did not exceed the standard values, since the values of the electric field intensity vector were no more than 0.4 V/m throughout the entire working shift, for the frequency range of 5 Hz – 2 kHz. In the frequency range of 2-400 kHz, the values also did not exceed the standard indicators. Standard value is 5 kV/m.

The component of the electric field is minimal in the induction zone, because the electromagnetic wave has not yet been formed.

The next step was to measure the values of magnetic induction with IMP-05 devices for two frequency ranges (Fig.4).

Figure 4: Magnetic field meter

2.4 Measurements results

During the measurements carried out for the frequency range 2-400 kHz, no exceedances of the maximum permissible level were detected. However, measurements for the frequency range from 5 Hz – 2 kHz exceed the remote control by 7.9 times. The maximum measured value is 1999 nT, while the standard value is 250 nT.

The measurement results are presented in the appendix. The results are graded by color, where green means that the values are normal, red means the maximum permissible level is exceeded.

Magnetic flux density measurements were made at the operator's workplace next to the combine control panel and displays in the following cases:

- with shearer turned off;
- with the included equipment directly next to the combine;
- with the included equipment, the shearer is 15 m away from the operator.

Based on the data obtained, the magnetic flux density vector can have a maximum value, while the electrical component is minimal.

2.5 Key points of chapter 2

1) Workers are in the near zone (induction) EMF;

2) The parameters characterizing the EMF are: magnetic flux density, electric field strength; magnetic field strength;

3) According to the results of the measurements, the values of magnetic induction exceed the maximum permissible level by 7.9 times, while the values of the electrical component are within acceptable limits.

3 Development of protective measures

Based on the data on the conducted research, scientists have studied the main trends in the protection of workers from the electromagnetic factor at the enterprises of the mineral resource complex.

The measures taken by the company in order to protect personnel from EMF are divided into:

- organizational;
- technical;
- preventive.

Technical measures are more popular. This type of protection involves the introduction of the latest technologies, the development of the most effective methods and means of protection that coincide with the individual characteristics of the enterprise, depending on the conditions and the combination of influencing factors of the working environment.

An important element at the stage of the introduction of new developed tools is to obtain a sanitary and epidemiological conclusion for compliance with the requirements of basic norms and rules of Russia.

If an EMF level exceeding the established regulatory values has been detected at the workplace, it is necessary to identify areas with the lowest risk of exposure to radiating devices, choose the most optimal routes for workers involved in the preparation, maintenance and operation of radiation sources, and highlight at what distances the values correspond to the norms.

3.1 Choice of protection methods

In this paper, a number of organizational and technical measures are proposed, which corresponds to the topic of the master's thesis. First of all, organizational measures were proposed:

- monitoring of non-ionizing radiation was carried out;
- analyzed the degree of risk and consequences of exposure to EMF;
- zones with an increased level of radiation are designated.

Since the data obtained do not correspond to the regulatory parameters, it is worth considering and implementing the most appropriate technical measures.

Quite often, local methods are used, such as partial shielding of the radiation source. However, such constructions significantly complicate a number of works, affect the technological process of the enterprise, are an expensive and time-consuming event for implementation in already formed conditions.

In mine conditions, the introduction of additional shielding screen designs is impossible due to the complexity of technological operations performed by equipment and miners, as well as the lack of additional space for the movement of workers during the work shift.

Accordingly, it was decided to modernize the personal protective equipment of employees: cotton suits made of dust-proof fabric. The task is to develop a shielding fabric from the effects of the magnetic component of EMF, and to preserve the properties of the current fabric.

There are fabrics purposefully designed to shield workers from exposure to non-ionizing radiation of various frequency ranges. The basis of materials for sewing special clothes of employees are natural and synthetic threads with additives from metals. For the manufacture of clothing that protects against the effects of EMF, dense woven fabric with metals is used in a large percentage ratio. Depending on the material used, it is possible to choose a fabric with the necessary shielding properties. To achieve the greatest efficiency, metal is additionally sprayed onto the fabric fiber, or a micro-wire (metallized thread) is woven into the fiber instead of the thread.

The microfibre has an extremely small thickness of several units-tens of micrometers, which is either woven with a thread or used instead of the thread itself. That allows you to maintain the strength and durability of clothing, however, the shielding efficiency is limited to fifty decibels.

Applying a special coating on synthetic fabrics (polyester) has its advantages and disadvantages. For example, spraying of various metals and oxides can be done from the reverse and front sides. Such means of protection have the highest attenuation coefficient of 110 dB. A negative quality can be the staining of the spray with third-party exposure to poorly painted products.

In order to study in detail the characteristics of shielding materials and compare the properties of fabrics on the market that reduce the effects of EMF, tissue samples with a detailed description were requested from Measuring Systems and

Technologies LLC. The photos show the structure of the material, enlarged by 4 and 400 times.

Figure 5 shows the HNG100 shielding material.

Figure 5: Shielding material HNG100

The cost of this fabric with a width of 90 cm is 7,600 rubles. The attenuation of the electromagnetic field is quite high = 110 dB, since the synthetic material (polyester) is dense with an additional coating of copper and nickel. Shields low-frequency electric fields in the range from 0 Hz to 100 GHz. Additional grounding is required during use.

Figure 6 shows the HNG80 shielding fabric.

Figure 6: Shielding material HNG80

Woven metallized material with a attenuation coefficient of 80 dB.

The cost is 5,500 rubles for a width of 90 cm. The thickness of the fabric is 0.07 mm.

Shielding of low-frequency electric fields and high-frequency radiation.

Figure 7 shows the shielding material HG 80-90 GL with an adhesive substrate.

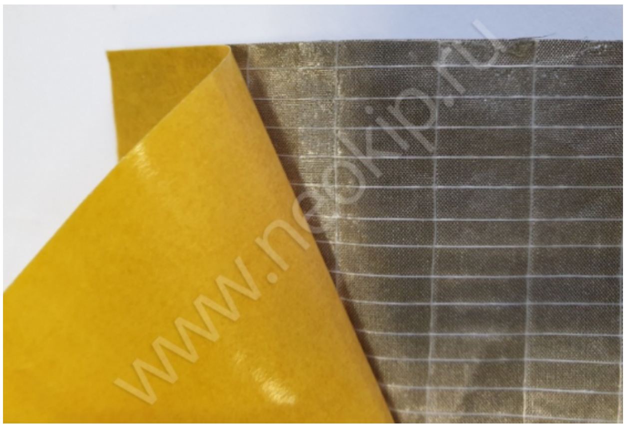

Figure 7: Shielding material HNG80-90 GL

The cost of fabric with a width of 90 cm is 6500 rubles. Weakens the fields of a wide frequency range. The adhesive layer with reinforcing mesh has high strength. It is especially good for shielding low-frequency electromagnetic fields. Preliminary grounding is required.

Figure 8 shows the STEEL-GRAY material, when magnified, you can see the steel threads woven into the fabric fiber.

Figure 8: Shielding material STEEL GRAY

The advantages of this material are in the small thickness of the fabric, as well as in the composition: cotton, stainless steel, polyester. The cost of fabric with a width of 150 cm is 9350 rubles. EMF attenuation in 1 layer: 35 dB, in two layers: 50 dB. Grounding of clothing is required.

In the process of analysis and consultations with production specialists, the main drawback of the materials considered was revealed, which consists in the impossibility of shielding the magnetic component of electromagnetic radiation, since the properties of fabrics allow to weaken the effect of electric fields only. In our case, the measurements of radiation by the electrical component turned out to be normal, while the magnetic flux density indicators noticeably exceed the maximum permissible level of 250 Nt. Therefore, it is worth studying the features of shielding the magnetic component of the electromagnetic field.

3.2 Analysis of magnetic shielding

Shielding of a constant and alternating magnetic field is a rather problematic issue even in the present conditions. A large number of materials – fabrics, nets, paints – do not help to achieve the necessary reduction in MF values due to the fact that the nature of the formation and distribution of such a field is quite specific.

There are three types of magnetic field shielding materials available:

1) Electrical sheet steel with a thickness of 2-3 mm and above (Fig.9). This type of shielding is not suitable for our conditions in the mine environment, as it will have a direct impact on the technological process, which will make mining operations much more complicated.

Figure 9: Electrical sheet steel

2) Permalloys are alloys of high magnetic permeability. Sufficiently dense materials, however, the main disadvantage is the lack of the possibility of mechanical action on them, since with any deformation, the magnetic properties of the alloys are lost. Before using the material, it is necessary to mold the material and anneal it.
3) Amorphous alloys with high magnetic permeability are innovative soft magnetic and nanocrystalline alloys that can serve as the basis for thin screens (Fig.10).

Figure 10: Tapes of amorphous alloys

Permalloy screens can lose their magnetic properties during mechanical deformations. The use of ferrites is possible only when creating screens for radiating equipment, and cannot be used when sewing PPE for workers.

According to the studied properties of materials, amorphous alloys turned out to be the most suitable for the manufacture of personal protective equipment according to the magnetic component. They are created by rapid cooling, spraying molten metal onto a rotating drum-refrigerator, thereby skipping the crystallization phase of the material, and a solid substance is obtained.

The basic principle for achieving the maximum effect of shielding the magnetic field is to create a closed loop, i.e. the lines of force are closed in the thickness of the metal itself. The resistance of the material is much less than the resistance of the air.

Figure 11 shows the highly efficient MMR-50 material, which is designed to shield constant and alternating magnetic fields.

Figure 11: MMR-50

The material is similar to foil, thick and durable enough, but it is easily cut and does not lose its properties under various deformations. The cost is 62 cm wide = 5600 rubles. At this stage, it is planned to develop an elongated protective vest, which will ensure the weakening of the magnetic field by at least two to three times (Figure 12). The thickness of the material itself is 38 microns, and with the application of an additional coating in one or two layers, it increases to 88-138 microns.

Figure 12: Preliminary view of waistcoat

Protective properties for this vest model are planned to be studied and tested in laboratory conditions at the Federal State University "Research Institute of Labor" of the Ministry of Labor of Russia. Studies of the screening material MMR-50 according to the test report dated 10.08.2018 were carried out at the IMC of the Vega Concern. The essence of the experiment was to connect the coil to a 50 Hz low-frequency amplifier, and create a closed screen around it from the material under study. The measuring device was placed at a distance of 20 and 50 cm from the radiation source with and without a screen.
The data of the study are presented in Table 1.

Distance from the source	Magnetic field induction without a screen, nT	Magnetic field induction with screen, nT	Shielding coefficient, dB
20 cm	2400	800	9,54
	2600	830	9,91
	2540	710	11,08
50 cm	841	210	12
	810	208	11,8
	624	145	12,68

Table 1: Results of the efficiency study of MMR-50

3.3 Key points of chapter 3

1) Technical measures are the most effective for the protection of employees of enterprises of the mineral resource complex;

2) The main types of protective materials that shield low-frequency magnetic fields are identified and proposed.

4 Calculation of the shielding coefficient

To begin with, it is necessary to analyze the process that occurs during the shielding of the electromagnetic field in order to determine the necessary value of the effectiveness of the proposed measures.

The incident magnetic wave encounters a screen on its way, through which it is absorbed, re-reflected, reflected and passed through the remaining part, the value of which directly depends on the properties of the selected shielding material (Figure 13) [11].

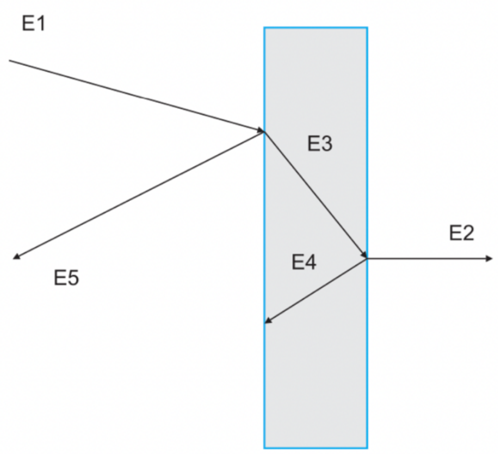

Figure 13: The process of passing a wave through the screen

In our case, the values of the magnetic flux density are taken into account in relation to the wave transmission scheme.

The shielding coefficient (Ks), measured in dB, reflects the ratio of the EMF intensity before the installation of the screen and after its installation:

$$K_s = 20 \lg \left(\frac{B_r}{B_s} \right), \quad (2)$$

where B_r – the real values of the magnetic flux density;

B_s – the maximum permissible level of the magnetic flux density.

To determine the necessary screening efficiency, the highest real measured value should be taken as 1999 nT and the normative value as 250 nT:

$$K_s = 20 \lg \left(\frac{1999}{250} \right) = 18\, dB, \quad (3)$$

The screening efficiency condition for a screen located in the near–induction zone is 18 dB.

4.1 Checking

Using a tabular processor by extrapolation of data, it was revealed that at a distance of 0.5 m from the operator, the induction of the magnetic field with the screen exceeds the maximum permissible values (250 nT). The shielding efficiency is 10.2 dB, which does not correspond to the required efficiency.

Magnetic field induction without a screen, nT	Magnetic field induction with screen, nT	Shielding coefficient, dB
624	13	624
810	12	810
841	12	841
1200	11	1200
1345	11	1345
1400	11	1400

Table 2: Checking the effectiveness of shielding by extrapolation

The following dependence was revealed: with an increase in the values of the magnetic flux density, the shielding efficiency decreases.

4.2 Development of protective equipment with the required efficiency

In the course of theoretical studies, the obtained values of the induction of MF with a screen exceed the remote control, which means that it is impossible to create personal protective equipment for workers from a single layer of MMR-50 material. It is planned to conduct additional studies already experimentally, and there is a possibility of divergence of results.

According to the data provided by the manufacturer of the material, the shielding efficiency when coated with one layer is up to 18 dB, and when coated with 5 layers up to 37 dB. Accordingly, it is necessary to create several additional layers to increase the magnetic field attenuation coefficient, which will also lead to an increase in the thickness of the protective vest (up to 288 microns).

In order to preserve the best ergonomic properties of personal protective equipment, it is proposed to create a material that will be used instead of the current lining of synthetic materials, 38 microns thick, on the contrary, consisting of fibers of natural fabrics with the interweaving of thin amorphous wire, which is created by pulling fibers from the melt. The diameter of the resulting fiber from the amorphous tape (60 microns) reaches 2-5 microns.

The proposed fabric structure consists of a mixture of 60% synthetic aramid fibers, which provide heat resistance and have low flammability, and 40% amorphous wire. The structure of the fabric in Figure 13 is the most suitable, since it minimizes the occurrence of gaps between the fibers during various deformations of the fabric due to this type of weaving.

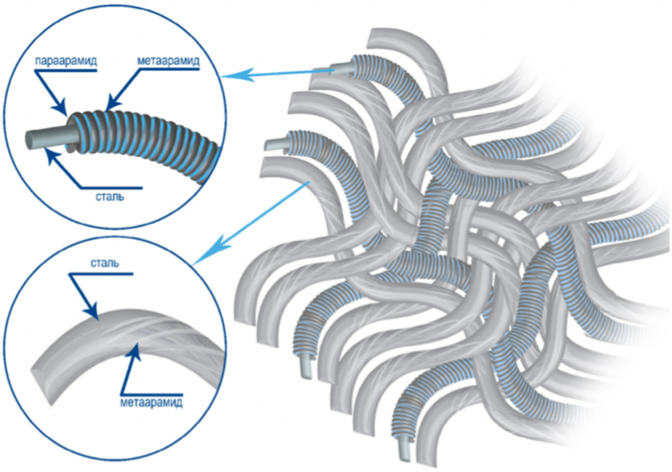

Figure 14: Fabric weave model

4.3 Key points of chapter 3

1) The required efficiency of the shielding material is calculated, which is 18 dB;

2) The values of magnetic flux induction with a theoretically installed screen are obtained by extrapolation;

3) The condition for the required efficiency when using the protective material MMR-50 will be met when applying amorphous tapes in 5 layers.

4) An individual protective device has been developed (with a shielding efficiency higher than required) – a protective vest made of lining fabric, the structural elements of which are synthetic aramid fibers and thin amorphous wire with high magnetic permeability.

5 Ending

The scientific works of leading scientists and universities around the world indicate that there is a threat from sources of non-ionizing radiation on the health of each individual, on the environment, as well as future generations.

Production equipment, as a rule, is characterized by high energy intensity and is a source of low-frequency electromagnetic fields of 50 Hz. Therefore, it was decided to consider the impact of this production factor on employees of enterprises of the mineral resource complex. The draft of the proposed measures is aimed at improving the working conditions of personnel who find themselves in the zone of non-ionizing radiation exposure.

During the study, the following results were obtained:

- the analysis of research in the field of the influence of electromagnetic fields on human health has been carried out;

- defined points for measuring EMF levels at the locations of the employee;

- full-scale measurements were made by the IMP-05 and IEP-05 devices of the main EMF 50 Hz indicators: electric field strength and magnetic flux density;

- the received data has been processed;

- magnetic flux density distribution maps are constructed, visualized and highlighted in color;

- the required effectiveness of shielding materials to protect workers from EMF exposure has been established;

- protective measures have been developed – personal protective equipment – with the necessary level of shielding.

In the end, the goal of the project was achieved – the peculiarities of the distribution of electromagnetic fields in the production environment were investigated and protective measures were developed for workers who are in the zone of influence of the magnetic flux density.

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7 List of Figures

8 List of Tables

9 List of Abbreviations

EMF	Electromagnetic field
EF	Electric field
IPC	International Patient Classifier
MF	Magnetic field
MFD	Magnetic flux density
MPL	Maximum Permissible Level
WHO	World Health Organization

10 Annex

Height from the floor	Distance from employee, m																		
	Magnetic flux density, nT																		
	4,5	4,0	3,5	3,0	2,5	2,0	1,5	1,0	0,5	0*	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5
	The shearer is turned off																		
1,7	20	45	77	126	132	140	225	245	252	260	250	190	178	135	143	87	55	24	15
1,0	47	68	120	140	165	157	246	270	300	380	196	203	224	237	201	140	115	87	54
0,5	120	110	124	145	180	198	230	235	203	275	180	198	190	187	170	198	135	120	105
	The shearer is turned on																		
1,7	35	50	90	147	170	280	645	835	1400	1600	1420	845	756	470	250	157	70	46	25
1,0	65	80	130	155	160	390	710	950	1920	1999	1970	990	820	547	302	260	170	95	70
0,5	147	140	147	189	200	407	725	1020	1800	1750	1610	1130	857	550	370	210	190	187	165
	*The shearer is located 15 meters from the operator**																		
1,7	60	54	105	155	164	170	249	298	420	560	370	335	301	245	220	140	67	38	19
1,0	85	98	148	150	155	166	256	302	425	520	362	320	297	277	257	166	105	90	66
0,5	150	166	185	180	185	200	247	330	467	645	405	367	340	310	235	178	140	98	125