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DETERMINING PATTERNS IN THE GENERATION OF MAGNETIC FIELDS WHEN USING DIFFERENT ARC WELDING TECHNIQUES

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This paper reports a study into the levels of magnetic fields induced by arc welding equipment in various ways in order to assess their impact on the body of welders. It is known that welders are exposed to a magnetic field of high intensity. Depending on the welding technique and the type of welding equipment, it may exceed the maximum permissible levels (MPL). Note that new Ukrainian sanitary standards for magnetic fields have been introduced, which regulate their levels depending on the frequency range. Therefore, it became necessary to carry out their hygienic assessment according to the new standards in order to devise appropriate methods for protecting welders. To this end, it was required to choose a new generation of devices to determine the intensity of magnetic fields induced by welding equipment. Based on the analysis of the constructed oscillograms and spectrograms of magnetic fields, it was found that semi-automatic welding with a metal electrode in carbon dioxide is characterized by an increased level of magnetic field in the frequency range of 50–1000 Hz. With automatic arc welding under the flux, there are no excess of the maximum permissible levels of individual harmonics of the magnetic field but there is an excess of the total value of all harmonic components of the magnetic field. Manual arc welding with direct current involving a non-melting electrode in argon is characterized by a moderate level of magnetic field in workplace. During manual arc welding with coated electrodes, the exceeded level of the magnetic field is observed only on the electrode cable itself. It is shown that the spectral composition of the magnetic field signal is determined mainly by the welding technique itself, the peculiarities of arc combustion, and the nature of the transfer of electrode metal in the arc gap, as well as the initial parameters of the power supplies of the welding arc

Keywords: arc welding, magnetic field, field intensity, oscillograms, spectrograms, welder protection

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1. Introduction

Industrial production is characterized by a constant increase in the volume of use of electrical and electronic equipment, the operation of which is accompanied by the generation of elevated levels of electromagnetic radiation, harmful, and, in certain cases, dangerous to the human body [1]. Therefore, special attention is paid to the electromagnetic safety of production and household equipment, the effect of electromagnetic fields (EMF) on humans [2, 3], as well as to devising appropriate measures and means of protection against them.

The object of special attention recently is the issue of harmful and dangerous effects of EMF on the welder's body [4] since welders are one of the groups of workers who are exposed to EMF of high intensity, especially when they are located close to the welding equipment and by direct contact of cables with their body [5, 6]. Depending on the welding technique, the type of welding equipment, and the distance from worker to it, the levels of the magnetic component of EMF, that is, the intensity of magnetic fields (MF) may exceed the maximum permissible levels and can be dangerous for the human body: they can cause diseases of the central nervous and cardiovascular systems, destroy human tissue cells, have a carcinogenic effect, etc. [7].

Therefore, it became necessary to carry out hygienic assessment of MF in accordance with the new standards [8], harmonized with European ones, in order to devise appropriate methods of protection of welders.

2. Literature review and problem statement

Work [5] shows that the operation of electrical equipment for arc welding is accompanied by the generation of magnetic fields (MFs) of high levels, mainly in the ultra-low frequency range. This poses a certain danger to welders. Paper [6] reports the results of measuring MF levels at a welding site using a MAG method (metal electrode in active gas) in accordance with the current European Directive 2013/35/EU. The results of MF levels in the frequency band from 5 Hz to 400 kHz showed that they significantly exceed the levels of MF created by other types of electrical equipment. This is due to the fact that in electric arc welding relatively high electric currents are used (up to several hundred amperes). To study the effect of MFs on the welder, their levels in workplace was measured using the Hall three-axis magnetometer attached to the wrist of the welder's hand, that is, in the nearest position to the source of MF (near the current source cable). The results of measurements [6] showed that the magnetic induction of MF at this point was 1.49 mT, which is slightly lower than MPL according to the standards set by DSN 3.36.096-2002 [8] (1.75 mT for an eight-hour working shift).

It should be noted that the old sanitary standards [9], which were in force until 2002, regulated MF only at a frequency of 50 Hz. The new norms [8] take into consideration the entire frequency range characteristic of welding processes, as well as all the necessary factors: the frequency, intensity, and time of action of MF on the human body. This makes it possible to give their objective hygienic assessment on the human body.

Earlier studies on MFs were based on outdated procedures and do not give an adequate idea of the effect of MF. Now, some new papers have been published about the harmfulness of EMF when using household appliances; however, there are no data on EMF during welding. This is due to the lack of appropriate devices that would allow registering the levels of the magnetic field characteristic of welding equipment (not at the level of μT but mainly at the level of mT).

This explains the need for new studies into MFs (magnetic field intensity, A/m) when using both existing and new welding equipment. It is necessary to investigate the patterns and features of MF generation during arc welding in various ways. Such data are necessary for devising methods and designing means of protection against EMF.

It is necessary to investigate MF levels in wide frequency ranges at workplaces when using different types of welding. At the same time, one must take into consideration the impact on the level and frequency of MF exerted by the features of welding techniques, the distance from the welder's workplace to MF, and the time of his stay in the dangerous zone.

As regards the measures and means of protection of welders, it is known that to protect against the harmful effects of MF, they mainly use the shielding of MF sources (welding equipment or welders themselves) [10]. To that end, one can use both well-known metal materials and the latest metal-containing nanostructured shielding materials [11].

For welding specialists and welding equipment developers, technological recommendations are an important element in the system of protection of welders from MF. They make it possible to minimize their dangerous effect in simpler ways. These include the choice of welding technique, the type of welding equipment, welding current sources, a welding mode, etc. To substantiate and implement these capabilities, it is necessary to determine the patterns of generating MF depending on those factors.

3. The aim and objectives of the study

The aim of this study is to determine the patterns of creating magnetic fields with different arc welding techniques for their hygienic assessment in accordance with the new standards.

To accomplish the aim, the following tasks have been set:

– to determine the necessary conditions for measuring the intensity of MF induced by welding equipment;

– to give a hygienic assessment of MF in accordance with the new standards for further development of recommendations for the protection of welders against MFs.

4. The study materials and methods

Our experiments were carried out in welding laboratories at the Institute of Electric Welding named after E. Paton in typical workplaces. We measured MF intensity when using manual, automatic, and semi-automatic arc welding techniques while applying direct and alternating current. We placed parts for welding atop the working surface of a metal table. The location of welding equipment (power supplies, ballast rheostats, steel gas cylinders, etc.) was independently optimal. Given the free location of power supplies and ballast rheostats, welding cables also took a free position in space and relative to the welder.

The main task of measuring the intensity of MF is to compare it against modern sanitary standards. Therefore, the dispersion of MF from power supplies, magnetic interference from neighboring posts, and the influence of ferromagnetic masses, which exert a great influence on measurements, were not of fundamental importance at this stage of research. This is due to the fact that during manual welding, the level of MF induced on the surface of different parts of the welder's body and in the middle is determined mainly by the amount of welding current. In addition, the level of MF is significantly affected by the area of the radiating circuit, the location of welders relative to the main radiation sources, and the distance from the emitter to the welder's body.

The layout of the zones in which measurements were performed for manual and semi-automatic welding is shown in Fig. 1.

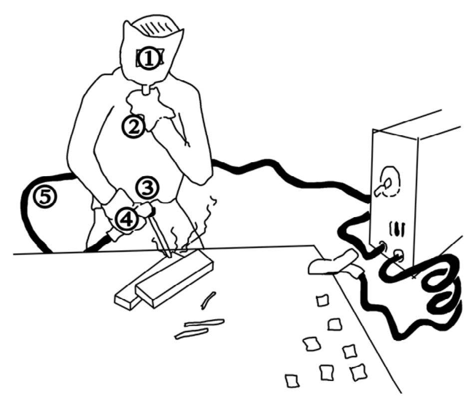

Fig. 1. Layout of magnetic field intensity measurement zones: 1 – head (forehead), 2 – chest, 3 – abdomen, 4 – arm, 5 – cable

The above description of the conditions of the experiments makes it possible to correctly measure the levels of MF in all sensitive points of the human body, which can be exposed to the dangerous and harmful effects of MFs. These points mainly include points marked in Fig. 1: 1 – brain, 2 – heart and lungs (chest), 3 – genitourinary organs (abdomen), 4 – arm. Since the electrical cable can touch the body of the welder, it is also necessary to determine the intensity of MF on it.

We estimated MF parameters at a workplace of welders in the following sequence:

– determining the zone of possible location of the worker near the electrical equipment during the passage of the welding current;

– determining points in this zone that are as close as possible to the source of MF;

– determining frequency ranges of radiation and measurement of MF intensity at these points and ranges;

– determining the time characteristics of MF.

Measurement of MF intensity when using arc welding techniques should be carried out taking into consideration the placement of the electrical cable.

To measure the intensity of MF, a remote sensor (magnetic field converter), an integrating RS circuit, and a recording device were used, specifically a digital storage oscilloscope with the Fourier rapid transform function (FFT) with an expansion unit. The following devices were applied:

– the magnetic field sensor DMP-1 (Ukraine);

– the magnetic field induction meter GFI-1 (Ukraine);

– the magnetic field induction meter TP2-2U-01 (Ukraine);

– PCS-500 oscilloscope with PC (Velleman, Belgium);

– the digital memorizing oscilloscope TDS 1002 (Tektronix, USA).

In the process of measuring the intensity of MF, the sensor was entered into the field under study and oriented in space to the maximum of the readings of the registering device. Three measurements were performed in the form of short pulses with a long period of duration. In this case, the sensor is located sequentially in three mutually perpendicular planes; we recorded its readings in each plane. The amplitude value of the MF intensity vector was determined from the following formula [8]:

$$H_m = \sqrt{H_x^2 + H_y^2 + H_z^2}, \quad (1)$$

where H_x, H_y, H_z are the values of MF intensity in each plane.

The total value of the magnetic field H was determined from the following expression [8]:

$$H = \sqrt{H_1^2 + H_2^2 + \ldots + H_n^2}, \quad (2)$$

where H_n is the magnetic field intensity of a separate harmonic.

The duration of irradiation of workers during a shift was determined by conducting timing observations. The sum of all the time spent on welding shows the time of irradiation during the day.

We studied the levels of MF induced by the equipment for electric arc welding.

5. Results of studying the magnetic field levels

5. 1. Determining the necessary conditions for measuring MF levels

We estimated the results of measuring the MF intensity by comparing them to the normative values of the maximum permissible levels (MPL) [8]; to that end, it was necessary to know the time of stay (exposure) of the welder in these fields. To do this, timekeeping of a specific technological process was carried out, which could be carried out under actual conditions of industrial production. However, earlier studies into the timing of welders show that the effect of MF on the body was intermittent. Thus, in general, electric welders working manually are in the zone of adverse effects of MF for no more than two hours during the eight-hour working shift, which is due to the need to perform preparatory operations and the coefficient of duration of switching on welding equipment (PV, %). Typically, for manual arc and semi-automatic welding equipment, it is 20...60 % of the five-minute cycle of work.

So, assuming 2 hours per shift for a net welding time, the values of the normalized parameters according to sanitary standards would take the following values (Table 1).

Table 1

Requirements for magnetic field levels according to DSN 3.3.6.096-2002 [8]

Parameter	Limit amplitude values in spectral ranges		
	0–5, Hz	5–50, Hz	0.05–1.0, kHz
The maximum allowable value of energy load during the working day, $(A/m)^2 \cdot h$	$1.4 \cdot 10^8$	$1.4 \cdot 10^8$	70,000
Magnetic field intensity MPL, (A/m) over 2 hours	11,832	2,828	187

Note: $H_{mp} = \sqrt{\frac{EH_{Hmp}}{T}}$, *where* EH_{Hmp} *is the maximum permissible value of energy load during working day, T – time of action, hour*

Such conditions for performing experimental measurements of MF intensity, that is, the net welding time, which is 2 hours per shift, makes it possible to objectively determine the real values of MF MPL.

5. 2. Results of the hygienic assessment of magnetic fields under different arc welding techniques

We studied the intensity of MF when using various techniques of arc welding (manual, with coated electrodes, automatic welding under flux, semi-automatic in protective gases) involving electric current of industrial frequency (50 Hz) and direct current. Conditions for our experiments (welding techniques, brand of welding materials and equipment, welding modes), as well as the results of determining the intensity of MF are given in Tables 2–5.

The results of determining the intensity of MF during automatic welding under flux using the thyristor transformer with phase control TDF-1002 were obtained by analyzing oscillograms and spectrograms acquired with the help of these devices. Measurements were carried out at a distance of 0.5 m from the axis of the welding mouthpiece of the TC-17 machine. The magnetic field induced by the welding current is visually perceived on the oscilloscope screen as sinusoidal (Fig. 2). However, its discrete spectrum (Fig. 3) is characterized both by a pronounced predominantly right-hand harmonic with a frequency of 50 Hz (H_{m50}), reaching the maximum value in the abdomen of the welder of H_{m50}=360 A/m, and by harmonics H_{m100}=180 A/m and H_{m150}=150 A/m.

Thus, the results of determining the levels of MF when automatically welded on alternating current under flux under an average power mode showed satisfactory hygienic results (Table 2). The results in the table demonstrate that no excess of MF MPL was detected in all studied frequency ranges.

At the same time, it was taken into consideration that the automatic welding operator is not obliged to constantly be in the zone of MF influence, that is, it can be protected by the distance from welding equipment, minimizing the harmful effects of MF on the body.

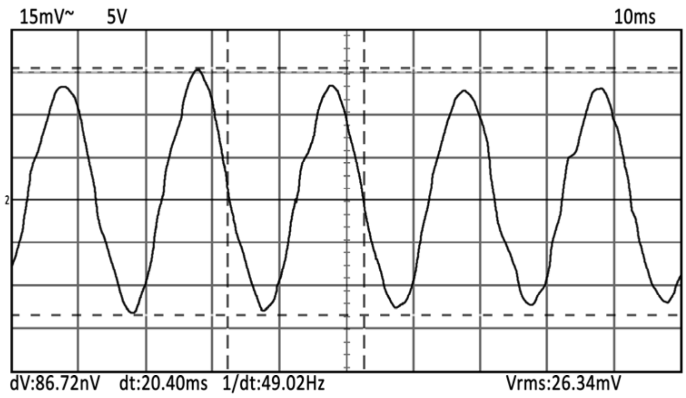

Fig. 2. Oscillogram of the magnetic field of automatic arc welding under flux

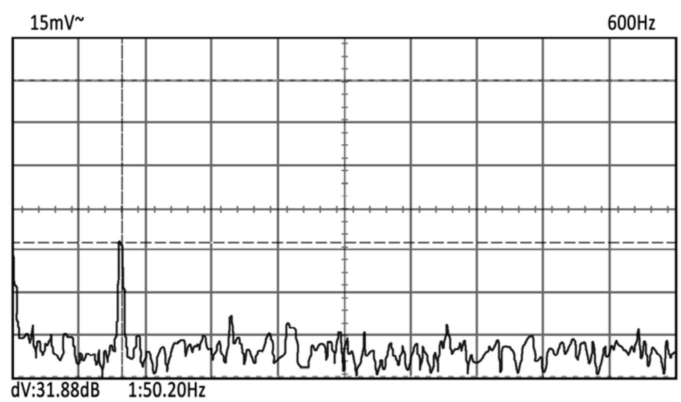

Fig. 3. Spectrogram of magnetic field of automatic arc welding under flux

In the spectrum of MF, there are harmonics in the range of 0–5 Hz, H_5=230 A/m. The presence of this, in fact, permanent, component indicates a malfunction of the power supply of the welding arc (adjustment is required).

The current value of the magnetic field H, calculated from expression (2), is 404 A/m, which is much lower than regulated (1400 A/m).

Further verification in accordance with DSN 3.3.6.096-2002 implies checking the balance of energy load by frequency ranges and exceeding the norm in the range of 0–1000 Hz from expression [8]:

$$\sum H_n^2 / \mathrm{MPL}^2 \le 1, \qquad (3)$$

where MPL is the maximum permissible levels of MF of the corresponding ranges.

So, for the greatest MF intensity, in this case the abdomen of the welder, under a two-hour exposure, the value of ratio (3) exceeds unity. Thus, in this zone, with automatic arc welding under the flux, there is an excess of the permissible values of the MF intensity, which requires the use of welder protection measures (in this case, the automatic welding operator).

Exceeding the permissible level of MF in the case under consideration is due to the non-sinusoidal shape of welding current and the presence in the spectrum of the second and third harmonics of MF, H_{m100}=180 A/m and H_{m150}=150 A/m.

It is clear that, in this case, there is no need for the welder operator to be in the specified zone; the so-called "distance protection" can be applied. In other cases, for example, the manual and semi-automatic welding, the issue of protecting the welder from MF would be more complicated.

Similarly, the analysis of oscillograms and spectrograms characteristic of other arc welding techniques (Tables 3–5) was performed.

The results of studying the levels of MF (Table 3) for manual arc welding with coated electrodes of the ANO-21 brand under the optimal mode showed that in the frequency range of 0-5 Hz there are no excesses of normalized levels of MF. In the frequency range of 5–50 Hz, there are also no excesses: all MF intensity values are lower than the MPL of two-hour and even eight-hour exposure. However, the intensity of MF near the cable (current line), which connects the welding current rectifier VDU-506 with the electric holder, in the frequency range of 0–5 Hz, along the entire length of the cable is 3977 A/m. That is, the intensity of MF in this zone almost reaches MPL (4200 A/m). And in the frequency range of 50–1000 Hz, for which MPL is 94 A/m for an eight-hour working shift, separate harmonics H_{300}=896 A/m and H_{600}=179 A/m were detected, which are significantly higher than MPL. This indicates that if the welder is close to the cable (wraps it around his body or winds it on his hand, with which the electrode is held), it will be dangerous to his health.

Table 2

Results of determining the magnetic field intensity during automatic arc welding under the AN-65 flux; wire diameter, 4.0 mm; TC-17 automatic; current source, the transformer TDF-1002; current, alternating, 700 A, 36 V

Spectral composition of the magnetic field and amplitude of harmonic components H_{mr} in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (chest)			3 (abdomen)			4 (arm)			5 (cable)		
Frequency range, Hz														
0–5	5– 50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
H_5=83	H_{50}=12	H_{100}=62	H_5=130	H_{50}=210	H_{100}=98 H_{150}=70 H_{200}=48	H_5=230	H_{50}=360	H_{100}=180 H_{150}=150	*	*	*	*	*	*

*Note: * – no magnetic field signal frequencies detected in a given frequency range*

Table 3

Results of determining the intensity of the magnetic field during manual arc welding with ANO-21 electrodes; the diameter of the electrodes, 4.0 mm; the current source, the VDU-506 rectifier; current, direct, 200... 220 A, 32... 34 V

Spectral composition of the magnetic field and amplitude of harmonic components H_{mr} in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (chest)			3 (abdomen)			4 (arm)			5 (cable)		
Frequency range, Hz														
0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
H_5=397	H_{50}=28	H_{150}=20 H_{300}=32 H_{600}=15	H_5=658	H_{50}=40	H_{100}=49 H_{150}=64 H_{250}=31 H_{300}=82 H_{450}=15	H_5=2386	H_{25}=283 H_{50}=159	H_{100}=127 H_{300}=710 H_{400}=113 H_{500}=113	H_5=1531	H_{50}=113	H_{100}=50 H_{300}=357 H_{500}=43	H_5=3977	H_{25}=253	H_{100}=90 H_{150}=56 H_{200}=63 H_{300}=896 H_{350}=23 H_{400}=25 H_{425}=15 H_{500}=21 H_{600}=179

Our study of MF intensity (Table 4) in semi-automatic welding in carbon dioxide using the wire Sv-08G2C showed that in all areas of the body of the welder there is an excess of MF MPL in the frequency range of 50–1000 Hz.

The presence of such a large number of harmonics in this frequency range can be explained by the influence exerted on the shape of MF signal by the characteristics of the welding technique itself. In particular, the shape of MF signal is influenced by the peculiarities of arc combustion, the nature of the transfer of electrode metal in the arc gap and, of course, the initial parameters of the power supply of the welding arc. The welding process can be characterized by the presence of short circuits of the arc gap, the size of drops of molten metal, and other factors [12] that affect the frequency of the induced MF.

The results of determining the intensity of MF induced by manual argon-arc welding of steel with a non-melting electrode in argon using the MAGIC WAVE-3000 current rectifier (Austria) are given in Table 5. These results indicate a complete absence of excesses of MF level in all frequency bands and zones of the welder's body. This can be explained by the improved electrical characteristics of the specified modern current rectifier with welding current modulation.

At the same time, the presence in the area of the hand with which the welder holds the electrode (Fig. 1), the MF signal in the frequency range of 50–1000 Hz with a value of 160 A/m (H_{320}=160) does not mean that there is an excess of MPL. This is due to the fact that according to sanitary standards, in the case of local action of MF on the arm, an increased coefficient is applied

$$H_{mp\ loc}=H_{mp\ tot}\cdot 5, \quad (4)$$

where $H_{mp\ loc}$ is the MPL of a variable magnetic field with a frequency of 50 Hz at local action (arm), $H_{mp\ tot}$ is the MPL of a variable magnetic field at a total action [8].

Therefore, there are no excesses of MPL in this case: this harmonic is much lower than the permissible level of 470 A/m, which is lower than MPL. So, for manual argon-arc welding at direct current, there are no excesses of normalized MF values even with an eight-hour exposure.

The low levels of MF, in this case, are explained by the use of direct current of low force and low arc voltage, as well as the peculiarities of the MAGIC WAVE-3000 current rectifier.

At the same time, in our experiments, manual welding with a non-melting electrode in argon was performed without a filler wire. In other experiments, when feeding a filler in an arc gap, due to wave processes, additional modulation of MF signal and complications (by the number of harmonics) of its spectrum are possible.

Table 4

Results of determining the intensity of the magnetic field during semi-automatic welding in carbon dioxide; wire, Sv-08G2C; diameter, 1.2 mm; current source, rectifier VDG-303; current, direct, 220 A, 20.22 V

Spectral composition of the magnetic field and amplitude of harmonic components H_m in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (chest)			3 (abdomen)			4 (arm)			5 (cable)		
Frequency range, Hz														
0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50– 1000
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
H_5=477	*	H_{75}=318 H_{200}=202 H_{300}=126 H_{400}=51 H_{480}=63 H_{600}=32	H_5=560	H_{46}=356	H_{66}=226 H_{80}=253 H_{210}=224 H_{232}=126 H_{266}=89 H_{276}=63 H_{300}=561 H_{350}=80	H_5=1193	H_{46}=450	H_{56}=450 H_{114}=316 H_{134}=201 H_{158}=201 H_{178}=201 H_{184}=201 H_{222}=201 H_{300}=201	H_5=768	H_{20}=127 H_{40}=318	H_{60}=357 H_{120}=253 H_{186}=253 H_{216}=143 H_{242}=113 H_{276}=113 H_{300}=159 H_{350}=127 H_{400}=63 H_{462}=71 H_{520}=51	*	*	*

*Note: * – no magnetic field signal detected in a given frequency range*

Table 5

Results of determining the magnetic field intensity during manual arc welding with non-melting electrode in argon; electrode diameter, 3.0 mm; current source, MAGIC WAVE-3000 rectifier (Austria); current, direct, 100 A, 10 V

Spectral composition of the magnetic field and amplitude of harmonic components H_m in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (chest)			3 (abdomen)			4 (arm)			5 (cable)		
Frequency range, Hz														
0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000	0–5	5–50	50–1000
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
H_5=416	H_{25}=33	H_{85}=45 H_{100}=35 H_{115}=45 H_{295}=20	H_5=310	*	*	H_5=636	H_{40}=21	H_{95}=29 H_{160}=29 H_{270}=40 H_{320}=80	H_5=1081	H_{40}=39	H_{95}=49 H_{160}=51 H_{290}=71 H_{320}=160 H_{550}=41	*	*	*

*Note: * – no magnetic field signal detected in a given frequency range*

6. Discussion of results of studying the levels of magnetic fields induced by arc welding equipment by various techniques

The results of our analysis of the acquired oscillogram (Fig. 2) and spectrogram (Fig. 3) of MF signal indicate that when automatically welded under the flux using an alternating current, there are no excess of normative values of individual MF harmonics (Table 2), but there is an excess of the total value of the ratios of all its harmonic components compared to their MPL calculated from formula (3).

For manual arc welding with covered electrodes using a direct current, the elevated level of MF (Table 3) is indicated only on the electrode cable itself along its entire length, as shown in Fig. 1.

At semi-automatic welding in carbon dioxide with a direct-current metal electrode, at the welder's workplace, MF is induced that exceeds MPL in the frequency range of 50–1000 Hz (Table 4). This is mainly due to the presence in the composition of induced MFs of rather intense high-frequency (compared to the frequency of 50 Hz) harmonic signals since the rate of MF in this frequency range according to the regulations set out in [8] is sharply reduced (becomes more rigid), by about 15 times.

Manual arc welding with a direct current using a non-melting electrode in argon is characterized by a moderate level of magnetic field (Table 5), not exceeding MPL.

Thus, our analysis of the above studies has made it possible to define some regularities of the processes of occurrence (creation) of MF during arc welding.

It is established that the spectrum of all investigated welding processes is characterized by the presence in the signals of MF of harmonic components with the main (first) harmonics with a frequency of 20, 50, 60, 300 Hz, multiple to the main and combination frequencies of the welding current.

The origin of these harmonics in arc welding in the investigated ways can be explained by the following features of the welding process:

– 20–25 Hz is the short circuit frequency of the arc gap that occurs during welding with a metal electrode in carbon dioxide;

– 50 Hz is the frequency of voltage of the network that feeds the welding transformer, rectifier, inverter, etc.;

– 60 Hz is the voltage frequency in the secondary circuit of foreign arc power supplies (for example, MAGIC WEVE-2600);

– 300 Hz is the frequency of the first harmonic variable component of the rectified voltage when using a six-phase AC straightening scheme.

It is also necessary to take into consideration the effect exerted on the shape of MF by the presence of filler wire in all our experiments, except for manual welding with a non-melting electrode in argon, which contributes to additional modulation of MF signal and complicates its spectrum.

Analyzing the patterns of welding processes, it becomes clear that the spectral composition of MF signal generated by welding equipment is mainly determined by two fundamentally inseparable factors:

– the welding technique itself, the peculiarities of arc combustion, and the nature of the transfer of electrode metal in the arc gap;

– the initial parameters of the power supplies of the welding arc: transformers, rectifiers, as well as additional electrical devices included in the welding chain (throttle, capacitors, stabilizers, oscillators, "arc ignition devices", ballast rheostats, etc.).

Naturally, for developers of electric welding equipment, the greatest interest is the way to reduce the intensity of higher harmonics by reducing the influence of the second factor. Therefore, for reasons of electromagnetic safety, the developers of such equipment should reduce the steepness of the front of the build-up of current pulses and the voltage of the power supplies of the welding arc operating in key modes. In the process of designing power supplies, it is necessary to find compromise solutions, choosing some optimal values of the operating frequency of the converter devices and the shape of welding current pulses. As regards the impact of the techniques of manual and semi-automatic welding on the frequency spectrum and the intensity of MF in a working area, one needs:

– to constantly limit the use of short-circuit processes, arc gap, and more widely use welding in the mixtures of gases ($Ar+CO_2$, $Ar+O_2$, $Ar+O_2+CO_2$) with small diameter wires, which would ensure the absence of these circuits;

– to consider, in hygienic terms, techniques of welding and surfacing with a modulation of the welding mode in order to obtain a more stable and predictable process of MF generation;

– to apply automation and robotics of welding processes.

7. Conclusions

1. The necessary conditions for measuring the levels of MFs, which are induced by welding equipment, for their correct hygienic assessment have been defined. It is shown that for an objective assessment of the levels of magnetic fields, the net welding time should be 2 hours per shift.

2. The results of the hygienic assessment of magnetic fields in accordance with the new standards are as follows:

– semi-automatic welding with a metal electrode in carbon dioxide is characterized by exceeding the maximum permissible level of the magnetic field in the frequency range of 50–1000 Hz;

– with automatic arc welding under the flux, there are no excess of the maximum permissible levels of individual harmonics of the magnetic field but there is an excess of the total value of all harmonic components of the magnetic field;

– manual arc welding with direct current using a non-melting electrode in argon is characterized by a moderate level of the magnetic field in a workplace;

– during manual arc welding with coated electrodes, the exceeded level of the magnetic field is observed only on the electrode cable itself.

To minimize the harmful effects of magnetic fields on welders, as far as possible, it is necessary to follow the following recommendations:

– to increase the distance from the welder's body to the source of electrical energy and welding equipment;

– not to allow the electrode or reverse cable to wrap around the body of a worker;

– not to allow the welder's body to be between the electrode cable and any other electrical cable; all cables must be held together on one side or the other.

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