DOI: https://doi.org/10.37434/tpwj2023.02.05

HYGIENIC CHARACTERISTIC OF MAGNETIC FIELDS AT DIFFERENT ARC WELDING METHODS

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ABSTRACT

The levels and spectral composition of magnetic fields, generated by equipment for arc welding by different methods were determined, in order to assess their influence on the welder's body. Published data on electromagnetic safety of electric arc welding were analyzed. A description of the proposed methodological approaches to determination of magnetic field levels, their measurement means and methods of assessment of their influence on the welder's body is given. Modern standards are characterized as to evaluation of the electromagnetic field impact on man, and their difference from the earlier applied standards. It is shown that new publications began to appear recently, which are devoted to the harmfulness of electromagnetic fields at application of electric production equipment. Hence the need to conduct new studies of electromagnetic fields, in particular their magnetic component (magnetic field intensity, A/m), when using welding equipment. This is required for hygienic assessment of the magnetic fields and development of the respective methods and means of welder protection. For this purpose, it was necessary to choose new generation instruments for determination of the intensity of magnetic fields, generated by welding equipment proper. Proceeding from analysis of the obtained oscillograms and spectrograms of the magnetic fields, evaluation of their levels was performed at application of different arc welding methods. It is shown that the spectral composition of the magnetic field signal is determined, predominantly, by the welding process proper, features of arc burning and mode of electrode metal transfer in the arc gap, as well as output parameters of the welding arc power source.

KEYWORDS: arc welding, electromagnetic field, field intensity, oscillograms, spectrograms, welder protection

INTRODUCTION

Welding production is characterized by a continuous increase in the scope of applications of electric and electronic equipment, operation of which is accompanied by generation of higher levels of electromagnetic radiation [1, 2], harmful and in some cases hazardous for the human body. Therefore, special attention is given to the issues of electromagnetic safety of production and household equipment, impact of electromagnetic fields (EMF) on man [3–5], as well as development of respective measures and means of protection from them.

Unsolved issues of harmful and hazardous effect of EMF on the welder's body [1] require special attention, as welders are exactly one of the groups of workers exposed to the impact of highly intensive EMF, particularly, when they are located close to welding equipment and at direct contact of cables with their body [2, 6]. Depending on the welding process, type of welding equipment and distance from the worker to it, the levels of EMF magnetic component, i.e. magnetic field (MF) intensity can exceed the maximum permissible levels and can be hazardous for the human body.

The main MF sources are heavily loaded circuits, and particularly the welding circuit. The amplitude value of MF intensity in the welder workplace depends on welding current, welding circuit dimensions and shape, as well as on the distance between the worker and the field source [7]. Operation of electric equipment for arc welding is accompanied by generation of high level MF, predominantly, in the superlow frequency range [6] that creates a certain hazard for welders. So, work [2] presents the results of measurement of MF levels in the workplace for MAG welding (metal electrode in active gas) in keeping with the current European Directive 2013/35EU [3]. Obtained results of MF levels in the frequency band from 5 Hz to 400 kHz showed that they significantly exceed the MF levels generated by other types of electric equipment. This is attributable to the fact that relatively high electric currents (up to several hundred amperes) are used in arc welding. In work [2] in order to study the MF impact on the welder, its level in the workplaces was measured by a 3-axis Hall magnetometer, fastened to the welder's wrist, i.e. in the position closest to MF source (near the current source cable). Measurement results showed that MF magnetic induction in this point was equal to 1.49 mT that is below the limit permissible level (LPL) by the standards of 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] that were valid until 2002, specified MF only at 50 Hz frequency. The new Ukrainian standards cover the entire frequency range characteristic for welding processes and all the required factors: frequency, intensity and time of MF action on the human body. It enables their objective hygienic characterization for the human body.

Previous publications on MF were based on outdated procedures and they do not provide an adequate idea of MF impact. At present some, new publications on EMF harmfulness at application of household appliances began to appear, but there are no data on EMF in welding. This is attributable to absence of the respective instruments, which would allow fixing the magnetic field levels, characteristic exactly for the welding equipment (not on the level of μT, but predominantly, on the level of mT). It necessitated performance of new studies of MF (magnetic field intensity, A/m) at application of both the currently available and new welding equipment. Such studies need to be conducted in wide frequency ranges in the workplaces at application of different kinds of welding. Here, the influence of welding process features, distance from the welder workplace to MF source and time of his staying in the hazardous impact zone on MF level and frequency should be taken into account. Such data are required to develop the methods and means for protection from MF.

The objective of this work is investigation of magnetic field intensity at different arc welding methods for their hygienic assessment in keeping with the new standards.

The following tasks were posed in order to reach this goal:

● define the optimal conditions for conducting experiments on determination of the intensity of MF, generated by welding equipment;

● determine the permissible time of welder working in the zone with higher MF level;

● provide hygienic evaluation of MF in keeping with the new standards for further development of recommendations on welder protection from MF.

EXPERIMENTAL PROCEDURE

Assessment of MF parameters in the welder workplace was performed in the following sequence:

● determination of the possible zone of the worker being near the electric equipment during the welding current flowing;

● identification of points as close as possible to MF source in this zone;

● determination of radiation frequency ranges and measurement of MF intensity in these points and ranges;

● determination of MF time characteristics.

Measurements of MF intensity at arc welding methods should be conducted, taking into account the electric cable layout.

MF intensity was measured using a remote sensor (magnetic field converter), integrating *RC*-circuit and a recording device, which was a digital storage oscillograph with the function of fast fourier transformation (FFT) with extension block. The following instruments were used:

● magnetic field sensor DMP-1 (Ukraine);

● magnetic field induction meter GFI-1 (Ukraine);

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

● oscillograph PCS-500 with PC (Velleman, Belgium);

● digital storage oscillograph TDS 1002 (Tektronix, USA).

During measurement of MF intensity, the sensor was brought into the studied field, and oriented in space by the maximum readings of the recording device. Three measurements were taken in the form of short pulses with a long period. The sensor was placed successively in three planes normal to each other, and its readings were recorded in each plane. The amplitude value of MF intensity vector was determined by the following formula [8]:

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

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

Total value of magnetic field *H* was found from the following expression [8]:

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

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

The exposure duration of workers during the shift was determined by conducting chronometric observations. The sum of total welding time shows the exposure time during the day.

Experiments were conducted in PWI welding laboratories in typical workplaces. MF intensity measurements were performed at manual, automatic and semi-automatic arc welding methods at direct and alternating current. Parts for welding were installed on the working surface of the metal table. Layout of welding equipment (power source, ballast rheostats, steel gas cylinders, etc.) was independently optimal. In connection with free layout of the power sources and ballast rheostats, the layout of the welding cables was also free in space and relative to the welder.

The main task of measurement of MF intensity is its comparison with the modern sanitary standards [8]. Here, MF scattering from the power sources, magnetic interference from neighbouring stations and impact of ferromagnetic masses, having a great influence on measurements, were not of fundamental importance at this stage of investigations. This is due to the fact that at manual welding the level of MF induced on the surface of different body parts of the welder and inside his body, is determined predominantly by welding current. In addition, the MF level is significantly influenced by the area of the radiating circuit, welders

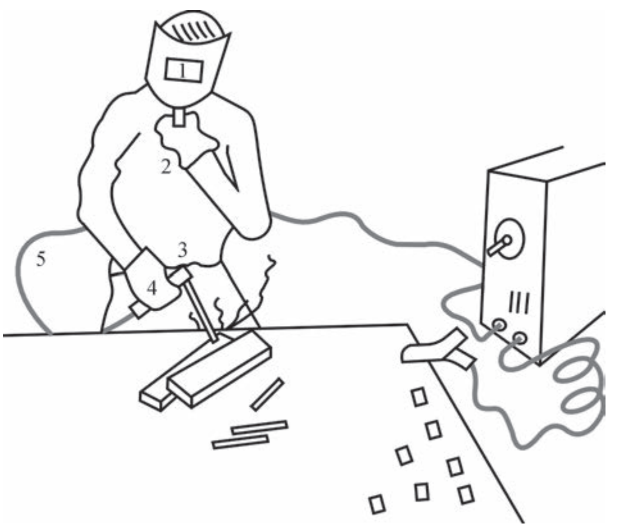

Figure 1. Layout of the zones of magnetic field intensity measurement: 1 — head (forehead); 2 — breast; 3 — abdomen; 4 — wrist; 5 — cable

position relative to the main radiation sources and the distance from the radiator to the welder body.

The layout of the zones where measurements were performed at manual and semi-automatic welding is shown in Figure 1.

The given description of experimental conditions allows correct measurement of MF levels in all the sensitive points of the human body, which can be exposed to the hazardous and harmful impact of MF. Such points mostly include those marked in Figure 1: 1 — brain; 2 — heart and lungs (breast); 3 — urogenital organs (abdomen); 4 — wrist. As the electric cable can touch the welder's body, we also have to measure the MF intensity on it.

Evaluation of the obtained results of MF intensity measurement was performed by their comparison with LPL standard values [8], which required knowledge of the welder exposure time in these fields. For this purpose, chronometric observation of the specific technological process which could be implemented under the real production conditions, was performed. However, earlier studies of welder employment show that the MF impact on the body is of intermittent nature. So, on the whole during an eight-hour working shift, the manual arc welding personnel stays in the zone of MF unfavourable impact for not more than two hours, which is due to the need to perform preparatory operations and welding equipment duty cycle (DC, %). Usually, it is equal to 20–60 % of the five-minute working cycle for manual arc and semi-automatic welding.

Table 1. Requirements to magnetic field levels in keeping with DSN 3.3.6.096–2002 [8]

Parameters	Limit amplitude values in the spectral ranges		
	0–5 Hz	5–50 Hz	0.05–1.0 kHz
$EH_{H_{LP}}$, $(A/m)^2 \cdot h$	$1.4 \cdot 10^8$	$1.6 \cdot 10^7$	70000
H_{LP}, (A/m) for 2 h	11832	2828	187

Note. $H_{LP} = \sqrt{\frac{EH_{H_{LP}}}{T}}$, where $EH_{H_{LP}}$ is the limit admissible value of energy load during the work day; T is the exposure time, h.

Thus, taking 2 hours per shift as the net welding time, the normed parameters, in keeping with the sanitary standards, will have the values, given in Table 1.

Such conditions of performance of experimental measurements of MF intensity, i.e. net welding time, which is equal to 2 hours per shift, allows objective determination of the real values of MF LPL.

EXPERIMENTAL RESULTS AND THEIR ANALYSIS

Investigation of MF intensity was performed at arc welding by different methods (automatic submerged-arc, manual coated-electrode, semi-automatic gas-shielded welding) at electric current of industrial frequency (50 Hz), and direct current. The conditions of experiment performance (welding methods, brand of welding consumables and equipment, welding modes), as well as the results of determination of MF intensity are given in Tables 2–5.

Results of determination of MF intensity at automatic submerged-arc welding, using a thyristor transformer TDF-1002 with phase control, were derived by the method of analysis of oscillograms and spectrograms, obtained using the above-mentioned instruments. Measurements were conducted at 0.5 m distance from the axis of welding nozzle of TS-17 semi-automatic machine. The magnetic field, induced by welding current, is visually perceived as sinusoidal in the oscilloscope screen (Figure 2). However, its discrete spectrum (Figure 3) is characterized both by a pronounced predominantly right harmonics with 50 Hz frequency (H_{m50}), which reaches the maximum value in the area of the welder's abdomen H_{m50} = 360 A/m, and by harmonics H_{m100}= 180 and H_{m150} = 150 A/m. Obtained measurement results (Table 2) were compared with MF standard values.

Thus, determination of MF levels at automatic a.c. submerged-arc welding in the mode of medium power showed results satisfactory in hygienic terms (Table 2). One can see from the tabulated results that no exceeding of MF LPL was found in any of the studied ranges.

Here, it was taken into account that the automatic welding operator does not have to be continuously present in MF impact zone, i.e. he can be protected by distance from the welding equipment, minimizing the harmful impact of MF on the body.

Effective value of magnetic field H, calculated by expression (2), is equal to 404 A/m, that is much lower than the standard values (1400 A/m).

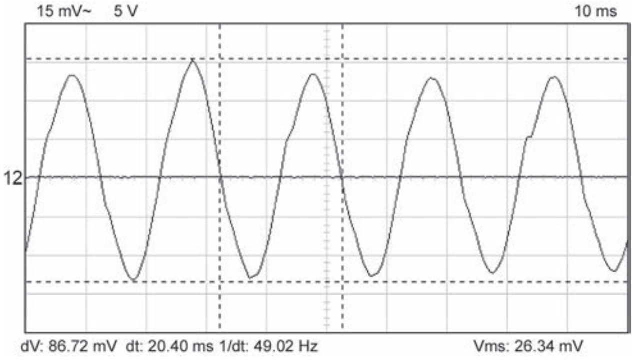

Figure 2. Oscillogram of the magnetic field at automatic submerged-arc welding

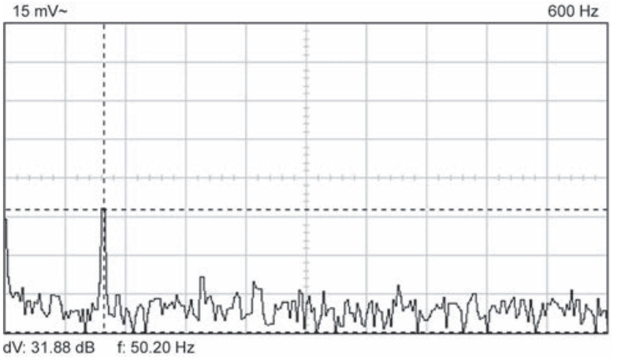

Figure 3. Spectrogram of the magnetic field of automatic submerged-arc welding

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

$$\sum H_n^2/\text{LPLs}^2 \leq 1, \qquad (3)$$

where LPLs are the limit permissible levels of MF of the respective ranges.

So, for the highest MF intensities, in this case in the region of the welder's abdomen, the value of ratio (3) is more than a unity at a two-hour exposure. Thus, in this zone at automatic submerged-arc welding the permissible values of MF intensity are exceeded, which requires application of protection means of the welder (in this case automatic welding operator).

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

It is understandable that in this case there is no need for the welding operator to stay in the above-mentioned zone, and the so-called distance protection can be used. In other cases, for instance, for manual and semi-automatic welding, the question of welder protection from MF will be more complicated.

Analysis of oscillograms and spectrograms, characteristic for other arc welding processes, was performed in a similar manner (Tables 3–5).

Results of studying MF levels (Table 3) at coated-electrode manual arc welding, using electrodes of ANO-2 grade in the optimal mode, showed no exceeding of standard MF levels in the frequency range of 0–5 Hz. In the frequency range of 5–50 Hz there is no exceeding either: all MF intensity values are below LPL at a two-hour or even eight-hour exposure. However, MF intensity near the cable proper (current conduit), which connects the welding current rectifier VDU-506 with the electrode holder, is equal to 3977 A/m along the entire cable length in the frequency range of 0–5 Hz, i.e. the stress intensity in this zone almost reaches LPL (4200 A/m). Now, in the frequency range of 50–1000 Hz, for which LPL is equal to 94 A/m for an eight hour working shift, individual harmonics H_{300} = 896 A/m and H_{600} = 179 A/m were found, which greatly exceed LPL. It shows that if the welder is close to the cable (wraps it around his body or winds it on the arm holding the electrode), it will be hazardous for his health.

Investigations of MF intensity (Table 4) in semi-automatic CO_2 welding with Sv-08G2S wire showed that MF LPL are exceeded in all the studied zones of the welder's body in the frequency range of 50–1000 Hz.

Table 2. Results of determination of magnetic field intensity in automatic submerged-arc welding with AN-65 flux (wire diameter of 4.0 mm, TS-17automatic machine, current source — TDF-1002 transformer, alternating current, 700 A, 36 V)

Spectral composition of the magnetic field and amplitudes of harmonic components H_{mn} in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (breast)			3 (abdomen)			4 (wrist)			5 (cable)		
Frequency ranges, 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. * in this frequency range no magnetic field signal was found.														

Table 3. Results of determination of magnetic field intensity at manual arc welding with ANO-21 electrodes (electrode diameter of 4.0 mm, current source is VDU-506 rectifier, direct current of 200–220 A, 32–34 V)

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

Presence of such a large number of harmonics in this frequency range is attributable to the influence of the characteristics of the welding process proper on MF signal shape. In particular, the MF signal shape is influenced by the features of arc burning, nature of electrode metal transfer in the arc gap, and, certainly, by the initial parameters of the welding arc power source. The welding process can be characterized by the presence of the arc gap short-circuiting, size of molten metal drops and other factors [10], which affect the frequency of the generated MF.

The results of determination of the intensity of MF, generated in manual nonconsumable electrode argon-arc welding of steel, using MAGIC WAVE-3000 current rectifier (Austria), are given in Table 5. These results are indicative of a complete absence of exceeding the MF level in all the frequency ranges and zones of the welder's body. This is attributable to improved electric characteristics of the above-mentioned modern current rectifier with welding current modulation.

At the same time, presence of MF signal of the magnitude of 160 A/m (H_{320}) in the frequency range of 50–1000 Hz, in the zone of the wrist, with which the welder holds the electrode (see Figure 1), does not mean that LPL is exceeded. It is attributable to the fact that in keeping with the sanitary standards in the case of local MF action on the wrists the following multiplying coefficient is used:

Table 4. Results of determination of magnetic field intensity at semi-automatic CO_2 welding (Sv-08GS wire of 1.2 mm diameter, current source is VDG-3-3 rectifier, direct current of 220 A, 20–22 V)

Spectral composition of the magnetic field and amplitudes of harmonic components H_{mn} in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (breast)			3 (abdomen)			4 (wrist)			5 (cable)		
Frequency ranges, 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. * in this frequency range no magnetic field signal was found.														

Table 5. Results of determination of magnetic field intensity at manual nonconsumable electrode argon-arc welding (electrode diameter of 3.0 mm, current source is MAGIC WAVE-3000 rectifier (Austria), direct current of 100 A, 10 V)

Spectral composition of the magnetic field and amplitudes of harmonic components H_{mn} in measurement zones by frequency ranges, A/m														
Measurement zones														
1 (forehead)			2 (breast)			3 (abdomen)			4 (wrist)			5 (cable)		
Frequency ranges, 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. * in this frequency range no magnetic field signal was found.														

$$H_{LP\,LOC} = 5H_{LPGEN}, \qquad (4)$$

where $H_{LP\,LOC}$ is the LPL of a variable magnetic field of 50 Hz frequency at local impact (wrists); $H_{LP\,GEN}$ is the LPL of a variable magnetic field at general impact [8].

Therefore, in this case LPL is not exceeded: this harmonic is located much lower than the permissible level of 470 A/m, which is lower than LPL. Thus, for manual argon-arc welding at direct current the standard MF values are not exceeded even at an eight hour exposure.

The low MF levels in this case are attributable to application of a low direct current and low arc voltage, as well as the features of MAGIC WAVE-3000 current rectifier.

On the other hand, in these experiments manual nonconsumable electrode argon-arc welding was performed without filler wire. Now in other experiments at filler feeding into the arc gap additional modulation of MF signal and complication (by the number of harmonics) of its spectrum are possible due to wave processes.

Obtained results show that in semi-automatic CO_2 metal-arc welding MF are generated in the welder workplace, which exceed LPL in the frequency range of 50–1000 Hz. This is due, predominantly, to the presence in the induced MF composition of rather intensive high-frequency (compared to 50 Hz frequency) harmonic signals, as MF norm in this frequency range, decreases abruptly (becomes more stringent) by approximately 15 times in keeping with the regulations [8].

The spectrum of all the studied welding processes is characterized by presence in MF signals of components with the main (first) of harmonics of 20, 50, 60, 300 Hz, multiple to primary frequencies and combination frequencies. The origin of these harmonics in arc welding can be attributed to the following features of the welding process:

- 20–25 Hz is the frequency of the arc gap short-circuiting, arising during metal-electrode CO_2 welding;
- 50 Hz is the frequency of the mains voltage, powering the welding transformer, rectifier, inverter, etc.;
- 60 Hz is the frequency of voltage in the secondary circuit of foreign arc power sources (for instance, MAGIC WAVE-2600);
- 300 Hz is the frequency of the first harmonic of the alternating component of rectified voltage at application of a six-phase circuit of alternating current rectification.

We should be also take into account the influence on MF shape of filler wire, used in all of our experiments, except for manual nonconsumable electrode welding in argon, which promotes additional modulation of MF signal and makes its spectrum more complicated.

Analyzing the regularities of running of the welding processes, it becomes clear that the spectral composition of the signal of MF generated by the welding equipment is predominantly determined by two principally inseparable factors:

- welding process proper, features of arc burning and mode of electrode metal transfer in the arc gap;
- output parameters of welding arc power sources: transformers, rectifiers, as well as additional electric devices included into the welding circuit (choke, capacitors, stabilizers, oscillators; arc ignition devices, ballast rheostats, etc).

It is natural that for developers of electric welding equipment of greatest interest is the method of lowering the intensity of higher harmonics due to weakening of the influence of the second factor. Therefore, from the viewpoint of electromagnetic safety, the developers of such equipment should reduce the steepness of the rising front of current and voltage pulses in welding arc power sources, operating in key modes. When designing the power sources, it is necessary to find compromise solutions, selecting some optimal values of the converter working frequency and welding current pulse shape. As regards the influence of the methods of manual and semi-automatic welding proper on MF frequency spectrum and intensity in the working zone, in our opinion, it is necessary to:

● constantly limit application of processes with short-circuiting of the arc gap, and wider apply welding in gas mixtures (Ar + CO_2, Ar + O_2, Ar + O_2 + CO_2) by small-diameter wires, which will ensure absence of these short-circuits;

● consider (in terms of hygiene) the applicability of other welding and surfacing processes with welding mode modulation, in order to achieve a more stable and predictable process of MF generation;

● apply automation and robotization of the welding processes.

CONCLUSIONS

1. The necessary conditions for measuring the levels of MF, generated by welding equipment, for their correct hygienic assessment, were determined. It is shown that for objective assessment of the magnetic field levels, the net welding time should be 2 hours per shift.

2. Results of hygienic assessment of the magnetic fields, in keeping with the new standards, are as follows:

● semi-automatic CO_2 metal-arc welding is characterized by exceeding the limit permissible level of the magnetic field in the frequency range of 50–1000 Hz;

● at automatic submerged-arc welding there is no exceeding of the limit permissible levels of individual magnetic field harmonics, but the total value of all the harmonic components of the magnetic field is exceeded;

● manual nonconsumable electrode DC argon-arc welding is characterized by a medium level of the magnetic field in the workplace;

● during manual coated-electrode arc welding the magnetic field level is exceeded only in the electrode cable proper.

To minimize the harmful impact of the magnetic field on welders, the following recommendations should be followed (as far as possible):

● increase the distance from the power source and welding equipment to the welder's body;

● avoid the electrode or return cable wrapping around the worker's body;

● avoid the welder's body being between the electrode cable and any other cable; all the cables should be kept together from one or the other side.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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SUGGESTED CITATION

O.G. Levchenko, Yu.O. Polukarov, O.M. Honcharova, O.M. Bezushko (2023) Hygienic characteristic of magnetic fields at different arc welding methods. *The Paton Welding J.*, **2**, 34–40.

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Received: 25.02.2023
Accepted: 30.03.2023