ANALYSIS OF LOW FREQUENCY MAGNETIC FIELDS GENERATED DURING WELDING

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The topic of the impact of electromagnetic fields on human body is nowadays very actual. One of the physical factors of the work environment is the electromagnetic fields emitted by the electric devices. The effect of electromagnetic fields on human body is various and depends mainly on frequency and intensity. Electromagnetic fields create a wide range of resources with which the workers can meet in their workplace. They are developed and used in many work activities including manufacturing processes, research, communication, medical applications, production, transmission and distribution of electricity, broadcasting, aviation and maritime navigation and security. This contribution describes the impact of electromagnetic fields on human body during welding. The shape and intensity of the generated electromagnetic fields were measured by a three-axis magnetometer.

KEYWORDS

safety, low frequency magnetic field, employee

1 INTRODUCTION

The man is more and more exposed to artificial electromagnetic fields of various intensity. A source of electromagnetic field radiation is the technical device designed for transmission of picture, sound, signal or data by means of electromagnetic waves. Each appliance powered by electric current acts by electromagnetic radiation.

The technical equipment, workflows that are the source of electromagnetic (EMG) field are now expanded. Electromagnetic fields can also be accidental - for example, the fields that arise near cables for distribution of electrical energy in buildings or at use of electrical devices and appliances. Since most fields are electrically generated, they are lost after switching off the power supply. Attention is nowadays paid mainly to GHz frequency bands, (WiFi), the Internet of Things, the transmission of information and the like. The energy transfer is carried out at frequencies of 50 or 60 Hz by which contemporary weak-current, heavy-current devices are powered. Minimum attention is paid to frequencies below 50 Hz as it is a poorly known field of EMG field effects on humans [Oravec 2016].

2 LOW FREQUENCY MAGNETIC FIELD

Electromagnetic field is understood like static magnetic field and time-varying electric field, magnetic and electromagnetic field with frequency up to 300 GHz. In terms of frequency range, the fields are divided into:

- static magnetic and electric fields with a frequency of less than 1 Hz,
- magnetic and electric field with an extremely low frequency (ELF) above 1 Hz to 60 Hz,
- low frequency electromagnetic field with a frequency above 60 Hz to 10 kHz,
- high frequency field with a frequency above 10 kHz to 300 GHz. [Drahos 2017]

ELF (Extremely Low Frequency) is the name for fields with extremely low frequencies in the range of 0-300 Hz. In common practice, fields with a frequency of 50/60 Hz are used. Only some sources use sources with frequencies below 50 Hz. There are also processes that produce lower frequencies than 50 Hz (demagnetization, welding, special drives and the like).

At low frequencies, electrical and magnetic fields can be considered as independent. As the frequency increases up to the radio frequency range, the time-varying electric field induces the magnetic field and vice versa.

By Directive 35/2013 / EU, the producer as well as the operator of devices with potential of ELF are obliged to measure ELF. The Act No. 124/2006 Coll. instructs designers, manufacturers and working procedure developers to develop devices designed to be used at work to meet the requirements of occupational safety and health regulations.

The Non-binding Handbook of the best practice for the implementation of Directive 2013/35 / EU on electromagnetic fields has been adopted to carry out the required activities under Directive 35/2013 / EU which also includes knowledge from the Guidelines for Limiting Exposure to Time Varying Electric, Magnetic, and Electromagnetic Fields (1Hz-100kHz), 2010. [ICNIRP 2010].

The theoretical and experimental findings on electromagnetic phenomena applicable to technical practice have been summarized by J. C. Maxwell to comprehensive theory [ICNIRP 2010]. Maxwell's differential equations (1-4) express the dependence of electrical and magnetic phenomena, the dynamic interaction between electricity and magnetism.

$$div\vec{D} = \rho \qquad (1)$$

$$rot\vec{E} = -\frac{\partial\vec{B}}{\partial t} \qquad (2)$$

$$div\vec{B} = 0 \qquad (3)$$

$$rot\vec{H} = \vec{j} + \frac{\partial\vec{D}}{\partial t} \qquad (4)$$

where :

$\vec{E}(\vec{r},t)$	intensity of electric field	$[V.m^{-1}]$
$\vec{H}(\vec{r},t)$	intenity of magnetic field	$[A.m^{-1}]$
$\vec{D}(\vec{r},t)$	electrical induction	$[C.m^{-2}]$
$\vec{B}(\vec{r},t)$	magnetic induction	[T]
$\vec{j}(\vec{r},t)$	current density	$[A.m^{-2}]$
$\rho(\vec{r},t)$	electric charge volume density	$[C.m^{-3}]$

The fact that the magnetic field has a zero divergence, equation (3), leads to the conclusion that the field of magnetic induction vector B has the character of a vortex field. Vector B is rightly called the magnetic flux density. It is evident from equation 3 and 4 that the magnetic induction vector B rotates in a specific space and time. Knowing the position of vector B and its size allows you to place an employee out of space with an ELF if it reaches over-limit values of ELF.

The views on the impact of ELF on the environment develops with learning and improvement of ELF parameters measurement methods. In 2009 and 2010, ICNIRP issued a Guideline, where it is recommended for the employees to measure induction in selected parts of the human body. For the peripheral nervous system, the values are similarly determined bymeans of the reduction factor. The reference values according to [ICNIRP 2010] for the ELF variables are in Table 1. The valid INCIRP guidelines are based on the thermal effects of microwave radiation or extremely low magnetic field frequencies which can create an electric circuit in the human body.

Frequency	Intensity of electric field E [kV m-1]	Intensity of magentic field H [Am-1]	Magnetic induction B [T]
1Hz – 8Hz	20	1,63 .10^5 / f ^{2}	0,2 / f ^{2}
8Hz – 25Hz	20	2 .10^4 / f	2,5 .10^{-2} / f
25Hz – 300Hz	5 .10^2 / f	8 .10^2	0,001
300Hz – 3kHz	5 .10^2 / f	2,4 .10^5 / f	0,3 / f
3kHz – 10MHz	1,7 .10^{-1}	80	0,0001

Table 1. Values for exposure by time-varying ELF for the employees [2]

Subsequently, Directive 2013/35/EU was published that assumed some knowledge and there were defined:

- lower action levels (LAL), tab.2.,
- upper action levels (UAL) tab.2.,
- action levels (AL).

Frequency band	LAL for density of magentic flow (B) [µT] (effective values)	UAL for density of magnetic flow (B) [µT] (effective values)	AL of density of magnetic flow for exposure of legs to local magnetic field) [µT] (effective values)
1 ≤ f < 8 Hz	2,0 . 105 / f 2	3,0 . 10^5 / f	9,0 . 10^5 / f
8 ≤ f < 25 Hz	2,5 . 104 / f	3,0 . 10^5 / f	9,0 . 10^5 / f
25 ≤ f < 300 Hz	1,0 . 103	3,0 . 10^5 / f	9,0 . 10^5 / f
300 Hz ≤ f < 3 kHz	3,0 . 105 / f	3,0 . 10^5 / f	9,0 . 10^5 / f
3 kHz ≤ f ≤ 10 MHz	1,0 . 102	1,0 . 10^2	3,0 . 10^2

Table 2. Action levels of exposure to magnetic fields from 1Hz to 10 MHz [15]

- f is a frequency expressed in hertz (Hz).
  - LAL and UAL are effective values of intensity which in the case of sinusoidal fields are equal to the peak values divided by √2. In the case of non-sinusoidal fields, we start from the weighted tip method.
  - AL for exposure to magnetic waves present maximum values in a workplace of the employee. The result is a conservative assessment of exposure and automatic limit values of exposure under all inconsistent exposure conditions.

In the conditions of the Slovak Republic, this issue is included in the Government of the Slovak Republic Regulation No. 209/2016 Coll. on minimum health and safety requirements for the protection of workers from the risks related to exposure to electromagnetic fields where limit values are defined.

3 EFFECTS OF ELECTROMAGNETIC FIELDS ON HUMANS

The effects of electromagnetic fields on humans are divided into thermal and non-thermal effects. The organs particularly sensitive [IAER] to temperature rise are: eye lens, brain and testicles. Because the lens of the eye is hard to get rid of heat, it can be relatively low in the radiation load to cause its cloudiness.

Non-thermal effects are predominantly determined by the instantaneous amplitude of high-frequency radiation. Their effect increases with repeated exposure at relatively low intensities, especially when exposed to a pulsed field where the overall radiated power is relatively small but the instantaneous amplitude is large.

Electromagnetic field of very low (5Hz - 2kHz) and low (5kHz - 60kHz) frequencies [Oravec 2012] are produced by various devices for metal heating, heating of dielectric materials (wood, food, plastics), transformers, power lines, electrical wiring, manufacturing equipment and the like. Radiation in the range of 30 kHz to 300 MHz is with radio and television transmitters. Radiation above 300 MHz is produced, for example, by radars, television transmitters, telecommunication devices (e.g. base stations of the public radiotelephony network in GSM), various equipment for high frequency warming of food and other material.

In spite of the overall difference of the individual bands of the electromagnetic wave spectrum for all bands, in principle, the same patterns apply - they travel in the open space at the speed of light, they are bent, broken and dispersed and are polarized. The reason for certain differences may be only the difference in the wavelength to the dimensions of the environment or particles of the mass or the different energy content.

Depending on the ability to ionize the molecules of an exposed object, electromagnetic radiation can be divided into two bands: ionizing and non-ionizing.

Ionizing radiation is able to ionize the atoms and molecules of the environment, i.e. to tear the electrons away from the atomic shell and create an ion pair - a negatively charged electron and a positively charged residue of the atom [Oravec 2017]. The non-ionizing radiation has not this property. Ionizing radiation includes corpuscular radiation (alpha, beta, neutron) and electromagnetic (gamma and x-ray radiation) with wavelengths less than tens of nm.

The non-ionizing electromagnetic radiation band is from the lowest frequencies to 1012 Hz, i.e., so called. radio radiation. Least explored area is that of non-ionizing radiation, especially extremely low frequencies of 3 ÷ 30 kHz [Drahos 2017].

4 ELF MEASUREMENT ON SELECTED WELDING EQUIPMENT

The used measuring instrument was VEMA-041. VEMA-041 instruments are designed for vector measurements and oscilloscopic displays of magnetic induction of stationary and low frequency magnetic fields. They allow recording of time and spatial measurement files, as well as analysis in a time, frequency area. The instrument allows simultaneous measurement of three user-defined components of the magnetic induction vector. The sensors are made of a core of amorphous, magnetically soft metallic alloy, using alternating magnetization to saturation. The magnetometer operates at a constant sampling rate of 1 kHz, from the frequency range up to 250 Hz at sensitivity ≥ 2 nT. For post processing and analysis, it is possible to export measured data in standard files. The limitation is only the capacity of the medium on which the record is written. The basic operating parameters of the VEMA-041 magnetometer are shown in Table 4.

Parameter	Value	Parameter	Value
range	± 100 µT	linearity error (max.)	0.5 %
sensitivity of direct measurements	≥ 2.0 nT / 1 kHz	temperature range of measurements	+10 až +40 °C
sensitivity of middle value	≥ 0.2 nT / 5 Hz	dimensions of instrument	390 x 180 x 70 [mm]
sampling frequency	1 kHz	number of sensors	3
frequency range	0 - 250 Hz	communication interface	USB 2.0 (3.0)

Table 3. Technical specifications of magnetometer VEMA-041

Placing of the sensors on the used measuring triassic instrument (Figure 1) is in the sense of the right-handed Cartesian system. The measured values were evaluated and processed by means of linking measurement outputs with standard statistical software.

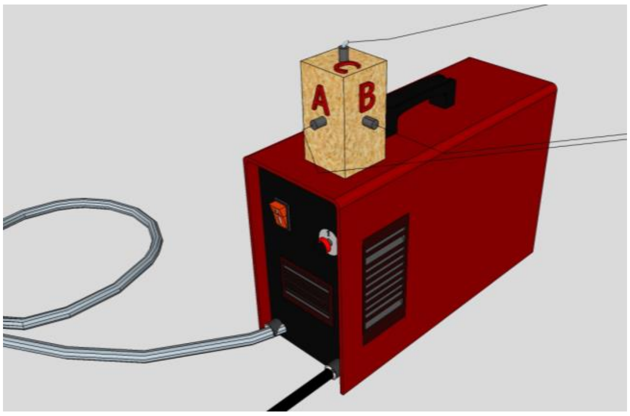

Figure 1. Arrangement of EMG field sensors in a non-magnetic measuring instrument

The analysis of low-frequency magnetic fields has been carried out on three selected welding devices welding by means of electric arc but working on different principles.
Following three devices were selected:

1. Triodyn – transformer welding machine. Supply voltage 3x380V.
2. Omicron OMI 166.- welding semi-automat for welding in protective atmosphere MIG-MAG. Supply voltage 230V.
3. Inverter (ARC 120). – welding inverter. Supply voltage 230V.

The aim of the magnetic induction measurement was to find real magnetic induction values at frequencies ranging from 0 to 50 Hz and their harmonic frequencies.

Measurement was performed in a standard welding workplace (Figure 2). The placement of measurement sensors was chosen based on the nature of handling and the nature of work with the welding device as follows:
- placement of sensors directly on or near the welding device,
- placement of sensors directly on the electric arc supply cables (approximately in the middle),
- placement of sensors at a distance of 0.4m from the welding head in the direction of the electric arc.

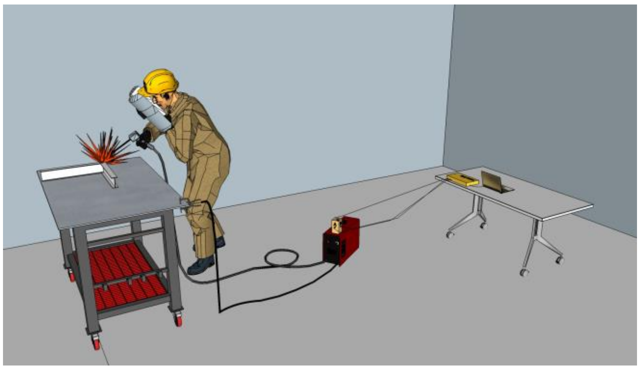

Figure 2. Situation scheme of measurement

During the measurement, the impact of various work operations during the welding process was also examined. We focused on the influence of power supply, and local values when operating the device in standby and operating mode.

4.1 Result

Results of measurement are shown in Table No. 4.

Device	H[Tesla] / f[Hz]		
Transformer welding machine (welding current 70A)	direction A	direction B	direction C
	Welding machine (without welding)		
	8.10^{-7}/50 $2.6.10^{-7}$/150	6.10^{-7}/50 $2.5.10^{-7}$/150	$1.0.10^{-6}$/50 $2.2.10^{-7}$/150
	Welding cable (at welding)		
	$2.0.10^{-7}$/5 9.10^{-7}/100	$1.0.10^{-7}$/5 5.10^{-7}/100	$1.0.10^{-7}$/5 $9.8.10^{-7}$/100
	0.4m from the head of welder (at welding)		
	$1.6.10^{-7}$/5 $0.5.10^{-7}$/100	$2.6.10^{-7}$/5 $0.6.10^{-7}$/100	$1.0.10^{-7}$/5 $0.6.10^{-7}$/100
	380 V power supply cable (without welding)		
	$5.6.10^{-8}$/100	$4.0.10^{-8}$/100	$1.2.10^{-8}$/100
Welding semi-automat (welding current 70A)	Welding machine (without welding)		
	$1.0.10^{-8}$/50 $4.8.10^{-9}$/150	$3.0.10^{-9}$/50 $1.6.10^{-9}$/150	$0.8.10^{-9}$/50 $0.4.10^{-9}$/150
	Welding torch cable (at welding)		
	$3.2.10^{-7}$/5 $4.8.10^{-9}$/100	$4.6.10^{-6}$/5 $4.0.10^{-6}$/100	$4.3.10^{-6}$/5 $4.2.10^{-6}$/100
	0.4 m from the head of welder (at welding)		
	$5.0.10^{-7}$/5 $4.8.10^{-7}$/100	$3.0.10^{-7}$/5 $2.8.10^{-7}$/100	$1.0.10^{-7}$/5 $0.8.10^{-7}$/100
Welding inverter (welding current 80A)	Inverter (without welding)		
	5.10^{-9}/50 3.10^{-9}/150	$1.0.10^{-8}$/50 $5.2.10^{-9}$/150	$1.0.10^{-8}$/50 $5.2.10^{-9}$/150
	Welding cable (at welding)		
	$8.8.10^{-8}$/5 $0.7.10^{-8}$/50	$4.4.10^{-8}$/5 $0.4.10^{-8}$/50	$6.6.10^{-8}$/5 $0.6.10^{-8}$/50
	0.4 m from the head of welder (at welding)		
	$2.2.10^{-8}$/5 $1.0.10^{-9}$/50	$3.2.10^{-8}$/5 $1.5.10^{-8}$/50	$1.0.10^{-8}$/5 $0.5.10^{-8}$/50
	220 V power supply cable (without welding)		
	$8.8.10^{-8}$/5 $0.8.10^{-8}$/50	$4.2.10^{-8}$/5 $0.6.10^{-8}$/50	$6.6.10^{-8}$/5 $0.4.10^{-8}$/50

Table 4. Sources with EML – Welding measurements carried out in 2016 (Right-angled Cartesian system AxBxC)

From the results, one can deduce the unique vector character of the magnetic field and the justness of its three-part measurement.
Furthermore, at the measurement an influence of the device structure on the measured values was shown. For the transformer device, we measured the highest values near a device that were not dependent on a working mode. The welding semi-automatic machine with an additional CO_2 atmosphere and automatic welding wire supply showed the highest deflections of the measured devices and the vicinity of the electric arc supply cables during welding. It is a clear demonstration of the device structure (supply of additional material and electric arc wiring).

Although none of the measurements exceeded the defined limits, the measurement highlighted a spatial character of rising emerging magnetic fields, depending on the available workplace and influenced by the surrounding objects. In some cases, objects of a linear nature in the workspace may function as antenna systems and will generate frequencies completely different from the source, process frequencies.
This directive does not take into account the dynamics of the magnetic field, it points to the vector nature of the field, but in the approaches to the measurement, field display does not use adequate tools. It remained only with scalar quantities, which does not allow for a more detailed time and space arrangement of the workplace and the position of the employee.

5 CONCLUSIONS

Based on the findings, it can be concluded :

- A minimal attention is paid to the threat of ELF, especially magnetic field, at the interval below 50 Hz, although there are recommendations and norms. Equations are not considered in these norms.
- When placing a product on the market, manufacturers are obliged to define also these parameters in the operating instructions or,in the section describing residual risks. For devices operating in the GHz band, this is more favorable, the values $W.kg^{-1}$ are shown or whether the statutory obligation is met.
- In the operating instructions for multiple products powered by a 50 Hz frequency network, it is not possible to determine whether the product meets the requirement defined by law.
- - Supervisory bodies should not be satisfied with the frequency of 50 Hz, which is the power supply. As it is evident from the frequency spectrum of the welding apparatus at work, it is a skipping arc at welding, and these are frequencies below 10 Hz.
- The magnetic induction value below 50 Hz can be measured. Legislation requires designers and developers of workflows to produce machines [Blecha 2009], working procedures designed to be used at work to meet the requirements of occupational safety and health regulations.

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REFERENCES

[Blecha 2009] Blecha, P., et al. 20th International Danube-Adria-Association-for-Automation-and-Manufacturing Symposium Location: Vienna, AUSTRIA Date: NOV 25-28, 2009.
[Drahos 2017] Drahos, R. Electromagnetic fields in industry. [05.06.2017].<http://www.d2r.sk/texty/elektromagenticke_polia_v_priemysle.pdf>. (in Slovak : Elektromagnetické polia v priemysle.http://www.d2r.sk/texty/elektromagenticke_polia_v_priemysle.pdf>.)
[IAER] International Association for Electrosmog-Research.
[ICNIRP 2010] ICNIRP Guidelines for Limiting Exposure to Time Varying Electric, Magnetic, and Electromagnetic Fields (1Hz–100kHz), Health Physics 99(6):818-836, 2010.
[Oravec 2012] Oravec, M., et al. Low frequency magnetic fields and their influence on a man. 2012. Safe work. Vol. 43, no. 5 (2012), p. 8-13. - ISSN 0322-8347, (in Slovak : Nizkofrekvencne elektromagneticke polia a ich vplyv na cloveka. Bezpecna praca. Roc. 43, c. 5 (2012), s. 8-13. - ISSN 0322-8347)
[Oravec 2016] Oravec, M. Low frequency magnetic fields and their influence on a man at welding. Current issue of safety at work. - Kosice : TU, 2016 S. 1-8. - ISBN 978-80-553-3006-8
[Oravec 2017] Oravec, M., Kotianova, Z. Measurement of low frequency magnetic fields for the purposes of the Directive 352013EU / - 2017. In: Occupational Safety and health 2017. - Ostrava : The association of fire & safety engineering, 2017 p. 71-76. - ISBN 978-80-7385-182-8
(in Slovak : Meranie nizkofrekvencnych magnetickych poli pre potreby Smernice 352013EU / - 2017. In: Bezpecnost a ochrana zadravi pri praci 2017. - Ostrava : Sdruzení pozarního a bezpecnostniho inzenyrstvi, 2017 s. 71-76. - ISBN 978-80-7385-182-8)

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