EXPERIMENTAL MEASUREMENTS OF LOW-FREQUENCY MAGNETIC FIELDS IN TERMS OF SAFETY

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Low-frequency electromagnetic fields and their effect on the employee are paid minimal attention. In this work will measure and describe the influence of low-frequency. Our experiments show necessity of controlling the frequency not only in devices but also on their power supply and cables. All measures were made on VEMA-041 measure equipment with computer software. Measurements were made with the respect to various aspects. From the measured gas welding unit the cable acts as the antenna with characteristic frequencies of 100 Hz and its harmonics. Due to this knowledge we can increase production efficiency of the employee and also their health will improve.

KEYWORDS

magnetic flux density, low frequency magnetic field, personal safety, the influence of the magnetic field to a human, welding

1. INTRODUCTION

Nowadays, source of electromagnetic (EMG) field especially technical equipment is very width. Attention is mainly paid to the frequencies in the GHz internet equipment (Wi-Fi), information transfer etc. Energy transfer is realized at 50, resp.60 Hz, which is powered by low-voltage, high juiced equipment. Frequency below 50 Hz is devoted by minimal attention, because it is recognized as an area of poor EMG influence on humans.

On the one hand development of techniques leads to that one cannot quickly adapt to these new environmental influences and therefore it generated some dysfunction in a body. On the other hand, there are norms that define the boundaries of the limit values. If there are limits, they must be measurable according to the procedure. Increasing impact of the surrounding EMG fields forces improving of knowledge and the methods for measuring parameters of EMG field. In 2009 and 2010, the ICNIRP (International Commission for Non-Ionising Radiation Protection) issued Guideline [ICNIRP 2010]. In [ICNIRP 2010] is recommended for staff measure induction on the head. For the area of the peripheral nervous system are likewise determined EMG limit value and reduction factor. Reference values [ICNIRP 2010] for variables EMG fields are in table 1. Applicable safety guidelines, ICNIRP are based on thermal effects of microwave radiation, or extremely low frequency magnetic field, which could be in the human body to create an electrical circuit.

Frequency	Intensity of electric field E [V.m^{-1}]	Intensity of EMG field H.[Am^{-1}]	Magnetic induction B [μT]
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 EMG fields time dependent for employees

The World Health Organization (WHO) before, opens International Commission for Non-Ionizing Radiation Protection ICNIRP to know EMG fields and non-ionizing radiation exposure at the human. The limits drawn up by the European Commission ICNIRP, the European Commission CENELEC (European Committee for Electrotechnical Standardization), which authored the European standard ENV 50166/95 and US ACGIH (American Conference of Governmental Industrial Hygienists) with very small differences.

1.1. Exposure limit values in Slovakia

Slovak Decree 534/2007 set limits (Table 2) for the frequency range EMG fields ranging from 0 Hz to 300 GHz

- f is the frequency EMG of the field,
- The frequency of 100 kHz to 10GHz, the value Seq, E, H and B must be averaged over a 6-minute interval,
- For frequencies above 10 GHz, the value Seq, E, H and B must be averaged over 68 / f 1.05 - minute period.
- Exposure action value for static electric field is not introduced. It is necessary to reduce the impact of discomfort caused by electric charge induced on the body surface and prevent it in our houses.

According to the decree 534/2007 in the exposure assessment with the simultaneous action of EMG field of the same frequency, or field with different frequencies, according to the identified action levels must be considered separately the impact of electrical stimulation that is applied over a frequency interval from 0 Hz to 10 MHz, and thermal exposure field applicable in the range from 100 kHz to 300 GHz. Electrical stimulation [Regulations 2007] according to the induction of the juiced in the tissue does not exceeds the action values, if they under the limit levels:

$$\sum_{1Hz}^{1MHz}(E_i/E_{Li})+\sum_{f\geq 1MHz}^{10MHz}(E_i/a)\leq 1 \qquad (1)$$

$$\sum_{1Hz}^{65kHz}(B_j/B_{Lj})+\sum_{f\geq 1MHz}^{10MHz}(B_j/b)\leq 1 \qquad (2)$$

Where

E_i - the electric field strength and the frequency,

$E_{L,i}$ - action value of the electric field for the i-th frequency

B_j - magnetic induction at a frequency j,

$B_{L,j}$ - action value of the magnetic induction for the j-th frequency

a - 87 [V.m^{-1}],

b - 6,25.10^{-6} [T].

Frequency	Intensity of electric field E [V.m^{-1}]	Intensity of EMG field H [A.m^{-1}]	Magnetic induction B [µT]	Power flux density of equivalent plane wave S_{eq} [W.m^{-2}]
< 1Hz	-	$3.2\ .10^4$	$4\ .\ 10^4$	-
1Hz - 8Hz	10 000	$3.2\ .10^4 / f^2$	$3.2\ .10^4 / f^2$	-
8Hz - 25Hz	10 000	$4\,000 / f$	$5\,000 / f$	-
25Hz - 0.8kHz	$250 / f$	$4/f$	$5 / f$	-
0.8kHz - 3kHz	$250 / f$	5	6.25	-
3kHz - 150kHz	87	5	6.25	-
0.15MHz - 1MHz	87	$0.73 / f$	$0.92 / f$	-
1MHz - 10 MHz	$250 / f^{1/2}$	$0.73 / f$	$0.92 / f$	-
10MHz - 400MHz	28	0.73	0.92	2
400MHz - 2 000MHz	$1.375\ .\ f^{1/2}$	$0.0037\ .\ f^{1/2}$	$0.0046\ .\ f^{1/2}$	f / 200
2GHz - 300GHz	61	0.16	0.20	10

Table 2. Action values for exposure EMG fields (effective values for continuous exposure)

Constant values a and b in this case are also used for the frequency greater than 1 MHz, as the sum include the density of induced juiced, and does not include the thermal effect of EMG field.

1.2. *The selected symptoms of magnetic fields on human beings*

Low-frequency magnetic fields penetrate easily into the tissue, which then results circulating juiced. These streams are not directed to the ground. If they are strong enough they can stimulate nerves, muscles and affect some biological processes (seeing faint luminous points due to stimulation of the retina). This phenomenon occurs when exposed to strong fields (induction heating, electric arc welding). When high-power fields (experimental situation) can be induced currents so strong that induce contractions and muscle tremors. Nature during evolution used the light field of the EMG to manage metabolism [IAER] and biological structures. Humans due to these activities, artificial EMG fields, leads back to the bioregulation. These fields with an increasing number and power of overlap and disturb the balance of power structures. Medical research confirms that the human body has both a solid mass of molecules, cells and tissues, as well as components of the EMG fields [Popp 2003]. The EMG field body is in constant contact with each other with fields, acting on it from outside. All living cells and tissues make the sensitive antenna systems to interact with the environment.

Scientists in the field of neurological research found that biological systems defies simple and clear logic, that stronger incentives should elicit stronger reaction. In living systems strong effect can have weak fields, while strong fields often cause only minor or no reaction [Oschman 2009].

Trials in volunteers exposed to strong EMG radiation [Sostronek 2006] demonstrated that the body temperature is increased only during the first six minutes of exposure. Then, even after prolonged exposure, temperature is stabilized. Human body has receptors for the perception of EMG field, so there is a threat to the internal body heating does not work thermoregulation. When the power absorbed 4-1 W.kg tissue leads to its heating by 1 °C. In contrast to high frequency fields, low frequency EMG fields affect humans through induced juiced in the human body.

2. USED PRINCIPLES OF MAGNETIC INDUCTION MEASUREMENT. GENERAL DESCRIPTION OF EMG FIELD

Theoretical and experimental knowledge of EMG phenomena applicable to engineering practice summarized into a coherent theory J.C.Maxwell [Tirpak 2011]. Maxwell's differential equations 4-7 are a plot of electrical and magnetic phenomena, the dynamic interaction between electricity and magnetism. Electric and magnetic fields are a special case EMG field.

$$div\vec{D} = \rho \tag{3}$$

$$rot\vec{E} = -\frac{\partial\vec{B}}{\partial t} \tag{4}$$

$$div\vec{B} = 0 \tag{5}$$

$$rot\vec{H} = \vec{j} + \frac{\partial\vec{D}}{\partial t} \tag{6}$$

where

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

Mathematical tools to describe the magnetic field in area with more resources and interaction are complicated. The current methods for solving systems of nonlinear differential equations are mathematical and numerical limitations. So we need simplification of the real situation and physical models. Measurements of specific objects enable a picture of the magnetic field in the vicinity of the EMG field source.

3. DESCRIPTION OF THE MEASUREMENTS

Experiment model of the next composition (Fig. 1) was built to measure electromagnetic in the electromagnetic welding.

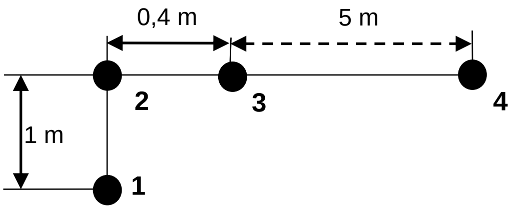

Figure 1. Layout of the experiment equipment, 1 location of the welding machine, 2 welding, 3 3-axis measuring prism, 4 location VEMA 041

Fig. 2 shows the welding measuring prism to the distant 0.4 m. Measuring sensors are arranged in a left-handed Cartesian Cross (direction A, B, C). Figure 3 shows the magnetometer VEMA 041 (left), connected to the evaluation computer program.

Figure 2. Measuring prism with inductive sensors

Figure 3. VEMA 041 with laptop

From equations 6 and 7 we can see that the maximum magnetic induction density is reached at maximum juice. On this basis we have made next measurements of the magnetic induction:

1. Measure of the background impact
2. The measurement of the 5th juice step welding, the length from arc to the prism is 0.4 m, of Fig. 1
3. Measure of the induction at the top side of the welding machine,
4. Measurement at the cable between the welding machine and welding material. The prism was placed on the cable.

4. USED MEASURING DEVICE

Equipment of VEMA-041 series is designed for measurements of vector oscilloscope and magnetic induction stationary and low-frequency magnetic field [VEMA 2012]. Allows you to record files temporal and spatial measurements and analysis in time, frequency domain. The device allows to measure simultaneously three user-defined component of magnetic field. The sensors consist of a core of an amorphous, soft magnetic alloy metal used in the alternating magnetization saturation [Miglierini 2006]. Magnetometer operates with a constant sampling rate of 1 kHz to 250 Hz at a sensitivity ≥ 2 nT. For post-processing and analysis of the measured data can be exported in standard file. Limiting the capacity is only media that is written record. The basic operating parameters magnetometers VEMA-041 are shown in Table 3.

Following evaluation and treatment is possible by linking with standard statistical programs. It allows processing of data obtained from the magnetometer.

Parameter	Unit
range	± 100 μT
sensitivity of direct measurements	≥ 2,0 nT / 1 kHz
mean sensitivity	≥ 0,2 nT / 5 Hz
sample rate	1 kHz
frequency range	0 - 250 Hz
linearity error (max.)	0,5 %
temperature measurement range	+10 to +40 °C
mains power supply	230 V / 50 Hz / 15 VA - adapter
battery /power supply	12 V / 500 mA
device dimensions	390 x 180 x 70 [mm]
mass	2,8 kg
number of sensors	3
communication interface	USB 2.0 (3.0)

Table 3. The basic parameters of magnetometer VEMA-041 [9]

4.1. The source of EMG field

The source of EMG field was welding apparatus, Tab. 4, allowing weld MIG (Metal Inert Gas) and MAG (Metal Active Gas). Welding is going in a protective atmosphere.

Parameter	Unit
voltage	1 x 230 V in 50 - 60 Hz
the welding juice range	30 A / 15 V - 165 A / 22.5 V
circuit voltage	23 V - 41 V
the number of gears	7
winding	Cu
fusing	20 A
grounding cable	3 m
cable length to the burner	4 m

Table 4. Selected parameters of the field EMG source

5. THE RESULTS OF EXPERIMENTAL MEASUREMENTS

5.1. The background impact in the induction measuring (measure 1).

Fig. 5 shows the time course of the magnetic induction for different directions of A, B, C source welding was running at 5th juice step. This measurement is performed in order to monitor the impact of the background, environmental influences and potential interference measurement at surrounding influences. From top to bottom the time course of the magnetic induction in the direction C, A, B, Fig. 5. Display range of the time axis (horizontal axis) is 0.1 sec. per division. Display range values of the 10^{-7} T induction per division (vertical axis).

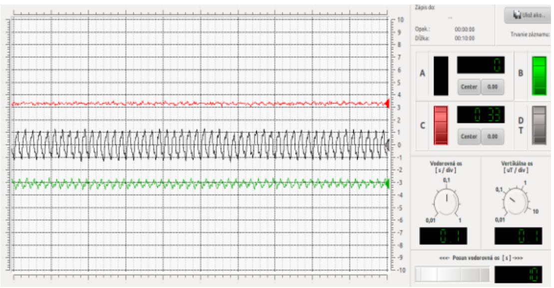

Figure 4. Time course of magnetic induction (without welding, background)

The oscillating signal is the most significant of sensor A, then B, and the lowest magnetic induction has sensor C, as shown in Fig. 4. Frequencies of components oscillation of the resultant magnetic vectors are at the figures 5A, 5B, 5C.

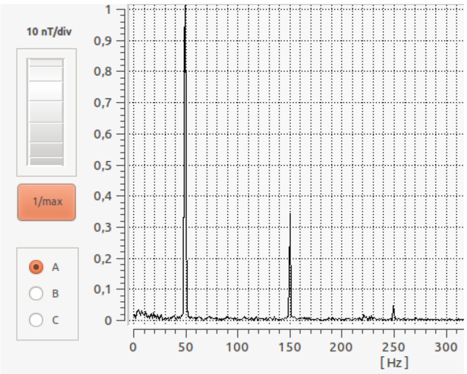

Figure 5A. Induction spectrum

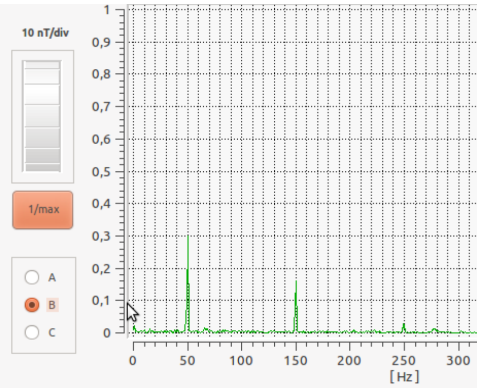

Figure 5B. Induction spectrum

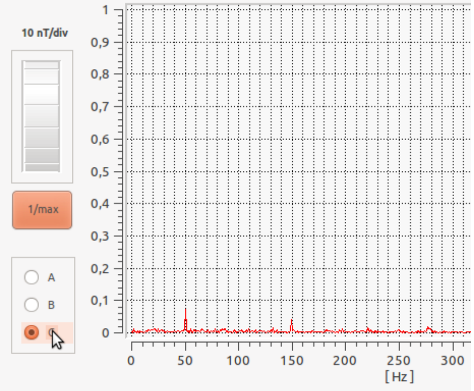

Figure 5C. Induction spectrum

All three spectrums show a 50 Hz frequency with the third and fifth harmonic (150, 300 Hz). The amplitude of the A spectrum is predominant. The values of the maximum amplitude spectrum are at the 1.10^{-8} T at 50 Hz.

6. WELDING OF THE FIFTH GEAR WELDING, THE ARC LENGTH IS 0.4 M FAR FROM THE PRISM, AS SHOWN IN THE FIGURE 1 (MEASURE 2)

Fig. 6 shows the time course of the magnetic induction for each path A, B, C. Source was on the 5th juice step. This measurement is performed in order to monitor induction welding in place, as in manual welding the welder's head is about 0.4 m away from the welding point. We have measure the electromagnetic field strength, to the welder's head.

In the Fig. 6 you can see from top to bottom the results coming from the sensors A, B, C. Display range of the time axis (horizontal axis) is 0.1 sec. per division. Display range of the magnetic induction value is 10^{-5} T per division (vertical axis).

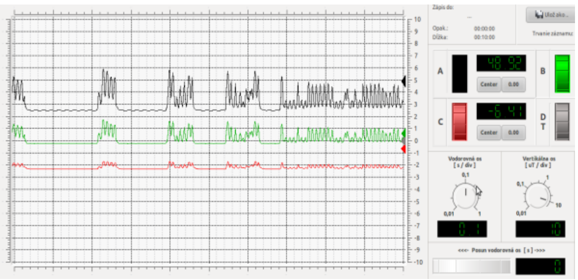

Figure 6. Time course of magnetic induction with welding

As it shown in the Fig. 6, the most significant oscillating signal is at sensor A, then B and the lowest induction has sensor C. Significant value of the induction we can see in time, when there is a first connection of the material and arc. The arc vibrant frequency is much lower than 50 Hz.
Frequencies of components oscillation of the resultant magnetic vectors are at the figures 7A, 7B, 7C. The range of all the spectrums A, B, C are the same as to we can visually compare all frequencies.

The frequency of 50 Hz is repressed in all three spectrums. We can see significant frequency range of 0-25 Hz. The frequency of induction below 25 Hz is generated by pulse in the spot of arc welding according to our analysing of the detailed time course and the spectrums. The appearance of harmonics (100, 200 Hz) of induction occurs is formed by construction and the energy supply source in the welding spot.

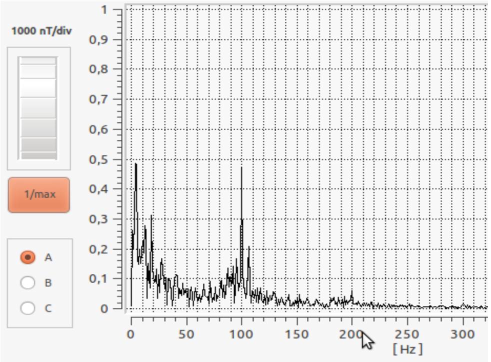

Figure 7A. Induction spectrum

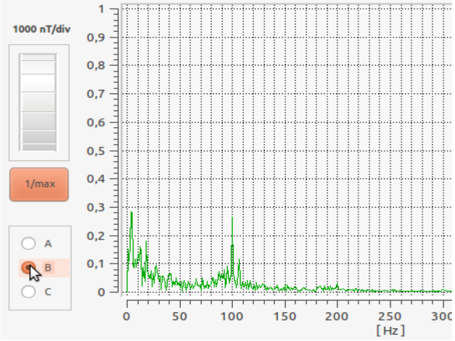

Figure 7B. Induction spectrum

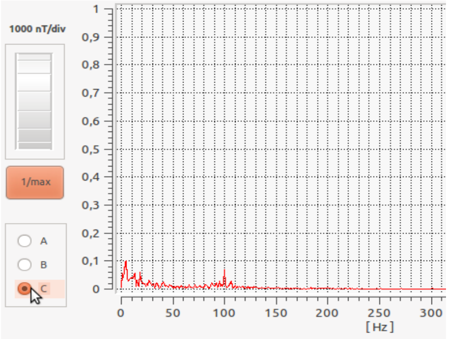

Figure 7C. Induction spectrum

Amplitude of the A spectrum is prevailing. The value of the maximum amplitude of the induction of the spectrum A is 5.10^{-7} T at 5 Hz. Maximal induction value of the spectrum A at 100 Hz is $4.5.10^{-7}$ T.

From the time and frequency side, values of frequency range at the 0-8 Hz can be detected, 8-25 Hz and the subsequent, which are necessary for the calculation in equation 2.

We have repeated measure for verification, to provided that the inductions source 100 Hz and its harmonics is the other part of the device as a welding transformer.

6.1. Measure of the induction at the top side of the welding machine (measure 3).

Figure 8 shows the time course of the magnetic induction for each path A, B, C. In Figure 8 displayed measurement of the magnetic flux density of the transformer welding machine. From top to bottom, are entries of the sensors A, B, C, figure 8. Display range of the time axis (horizontal axis) is 0.1 sec. per division. Display range values 5.10^{-7} T induction per division (vertical axis).

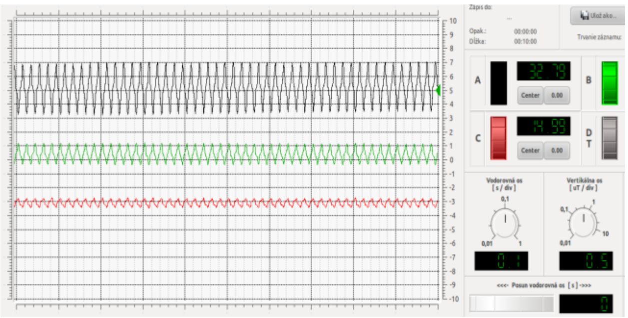

Figure 8. Time course of magnetic induction without welding

As it shown in Figure 8, the oscillating signal is the most significant on sensor A, B, and consequently the lowest induction has sensor C. This is a similar pattern of induction in the directions A, B, C comparing with the case of the background measurement, but with higher induction.

Frequencies of components oscillation of the resultant magnetic vectors are at the figures 9A, 9B, 9C. The range of all the spectrums A, B, C are the same as to we can visually compare all frequencies.

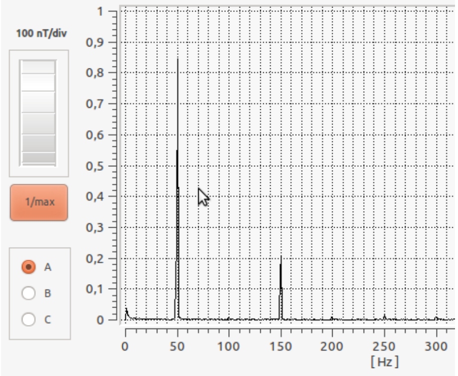

Figure 9A. Induction spectrum

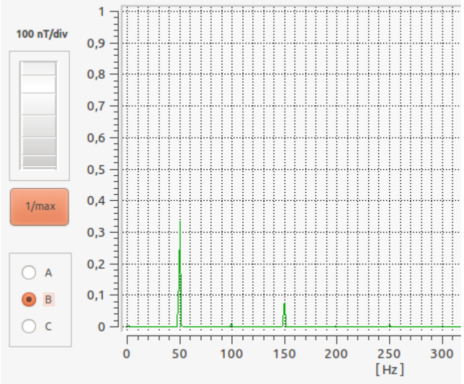

Figure 9B. Induction spectrum

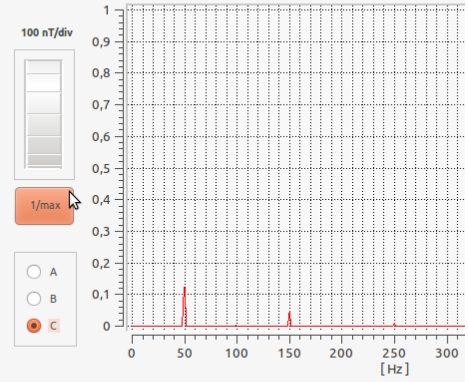

Figure 9C. Induction spectrum

In all three spectrums a characteristic frequency is 50 Hz. Based on the comparison of the values of individual lines of induction and oscillating components we can see that the source of the frequency is welding machine.

All three spectrums show a frequency in 50 Hz and in the third and fifth harmonic (150, 300 Hz). The amplitude of the spectrum A is predominant. The value of the spectrum A amplitude is $8.5.10^{-8}$ T at 50 Hz. Similarly, we can say about the other amplitudes.

6.2. Measuring prism with sensors placed on the cable (measure 4).

Figure 10 shows the time course of the magnetic induction for different directions of A, B, C source welding was running at 5th juice step. This measurement is performed in order to monitor induction in on the cable between the welding machine and the welding spot (not earth cable). It was assumed that the cable acts as an antenna and radiates EMG fields. Towards the top, Figure 10, below are the results from the sensors A, B, C respectively. Display range of the time axis (horizontal axis) is 0.2 sec. per division. Display range of the induction values 2. 10^{-5} T is per division (vertical axis).

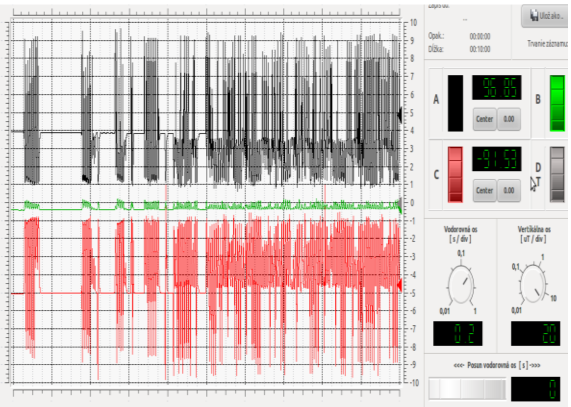

Figure 10. Time course of magnetic induction on cable

As it is shown in Figure 10, the oscillating signal is the most significant in the sensor C, then A, and shows the lowest induction in B. To confirm the assumption that the cable is the greatest source of radiation induction we have analysed spectrums.

Frequencies of components oscillation of the resultant magnetic vectors are at the Figures 11A, 11B, 11C. The range of all the spectrums A, B, C are the same as to we can visually compare all frequencies.

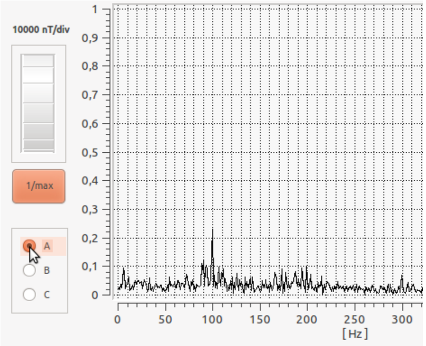

Figure11A. Induction spectrum

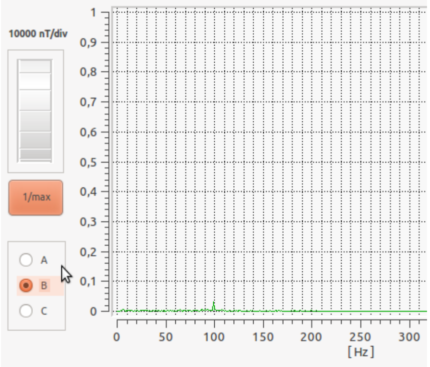

Figure 11B. Induction spectrum

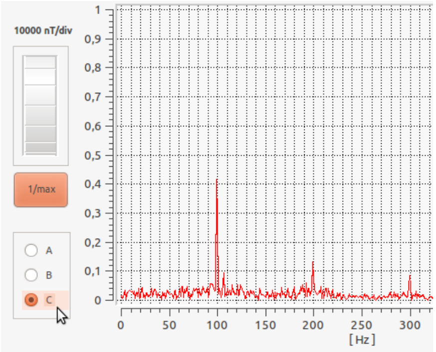

Figure 11C. Induction spectrum

In all three spectrums a characteristic frequency is 100 Hz. From comparison of the values of individual lines of induction and oscillating components we can see that the cable acts as an antenna. Comparing induction values in the range of 100 Hz at the fig. 11C, 11A confirm equation 5. The amplitude of the spectrum C is the predominant, reaching 4.2.10^{-6} T at 100 Hz. Similarly, we can say about the other amplitudes.

7. RESULTS DISCUSSION

In Tab. 5 summarizes the value of available measurements which are also compared with the exposure limits in force in the Slovak Republic defined in Decree 534/2007 Induction measured values with respect to those defined in Tab. 2 indicate insufficient technical solution. In this case, the cable has a characteristic as an unacceptable source of magnetic field. Consequently, it is possible with respect to the equation 6-7 that it is necessary to test the device not only partial, but to demonstrate the magnetic field at maximum juice for the system as a whole.

Frequency range	Magnetic induction limit		Measured value	Measurement No.
	Generally B [μT]	B [T] / f [Hz]		
< 1Hz	4.10^{4}	0.04 / < 1 Hz	-	-
1Hz - 8Hz	3.2 .10^{4} / f^{2}	6.10^{-5} / 8 Hz	5.10^{-7} T in 5 Hz	2
8Hz - 25Hz	5 000 / f	8.10^{-6} / 25 Hz	-	-
25Hz - 0.8kHz	5 / f	1.10^{-7}/ 50 Hz	1.10^{-8} T in 50 Hz	1
			8.5.10^{-8} T in 50 Hz	3
		5.10^{-8} / 100 Hz	4.2.10^{-6} T in 100 Hz	4
		5.10^{-8} / 100 Hz	4.5.10^{-7} T in 100 Hz	2

- f is EMG frequency as indicated in the column of the frequency range

Table5. The values for the magnetic field and the measured values of the magnetic induction

The source of EMG will bend but, optionally inappropriately designed power supply to the place of welding, as is clear from a comparison of measurements 2 and 4, Tab. 5. From a structural point of view, it is necessary to solve the electrical part of the equipment and make a classification to according to the request safety parameters. Other respects, knowing the direction of the resulting vector magnetic field characteristic of a particular device (exhibiting a pronounced effect against the background, circumstances) will allow placing the employee in an area where there is the intense of magnetic flux in the smallest. The manufacturer should provide this knowledge to the user device. This vector can be calculated from the values of the components of magnetic induction.

8. CONCLUSION

The results show that the measurements were made with the respect to various aspects. From the measured gas welding unit the cable acts as the antenna with characteristic frequencies of 100 Hz and its harmonics. The characteristic frequency of 50 Hz is reflected in the measurement of the induction welding to the top of the apparatus. Subsequently, when measured at the fifth gear of the welding arc and the distance from the prism measuring is 0.4 meters can be monitored attenuation frequency of 50 Hz, with significant frequency range up to 25 Hz. The subsequent analysis of the time course and spectra can be stated that the induction frequency to 25 Hz generated by pulsing of the arc spot welding.

Based on the experiments it is possible to point a number of important aspects and verified knowledge. Currently, there are not enough research entire spectrums defined by decree, and especially in the magnetic field below 50 Hz. When product on the market has an obligation in the user guide, resp., in the section describing the residual threat defines these parameters. For devices operating in the GHz band is more favourable to give the value of W.kg^{-1}, respectively or is fulfilled a legal obligation. In the directions for use in a number of products, the mains power supply voltage with a frequency of 50 Hz, it is not possible to understand if the product meets the requirements defined by Equation 2 or not. The supervisory authorities should not be satisfied with the fact that it is a frequency of 50 Hz, which is powered by a source. As shown in the frequency spectrum of the welding apparatus at work, it is a dodging arc welding and that the frequencies below 10 Hz. As shown in the measurement results, the value of magnetic induction in the range below 50 Hz can be measured. OSH Act §4 saves the designer and creator of practices must make the machine work practices that are intended for use at work to meet the requirements arising from the rules to ensure the safety and health work.

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