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RISK ASSESSMENT OF EXPOSURE TO LOW FREQUENCY MAGNETIC FIELDS

BY

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Abstract. The aim of this approach is to propose a methodology to evaluate the humans' exposure risk to the low frequency magnetic fields. The proposed methodology is applied for the case of magnetic field generated by an electric iron. The generated magnetic field was in the range of 0.28 to 4.45 μT and the background magnetic field was varying in the range of 0.2,…,0.39 μT. Field measurements were followed by a FMEA (Failure Modes and Effects Analysis) in order to evaluate and classify the exposure risks and to identify protection measures. Risks classifying was performed using classical ordering by risk priority number an also using fuzzy logic. The use of fuzzy logic and fuzzy numbers brings the advantage of considering all the three components of the risk priority number when the priority of risks is stabilised.

Key words: exposure to low frequency magnetic fields; fuzzy logic; FMEA; risk assessment.

1. Introduction

An important risk factor appearing in the context of growing technological development is the exposure to electromagnetic fields. As started in an earlier approach (Nica, 2014) in this paper a risk of exposure assessment is performed for the particular case of an electric iron, as part of a knowledge data base which will be used to develop a risk of exposure assessment questionnaire.

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This questionnaire could be used for a quick and simple exposure evaluation in a particularly situation when one knows the type of electromagnetic field sources and its positions.

In the first stage of this approach a characterization of the electric iron, as a low frequency magnetic field source is made, namely some field measurements were performed in its proximity.

In the second stage a risk assessment using FMEA (Failure Modes and Effects Analysis) method is performed (Mil-Std-1629, 1980), (Bilal, 2003). The prioritization of risks was made using the classical RPN (Risk Priority Number) and supplementary for better results fuzzy logic (Gherasim, 2013) was used. Fuzzy logic was previously used in combination with FMEA in an expert system for risk assessment (Haq *et al*., 2015). In this approach only the risk prioritisation is made by mean of fuzzy numbers in order to add some improovements.

2. Instrumentation and Methods

The measurements were performed using an automatic triaxial magnetic field measurement system (Fig. 1). This instrument was developed and tested in our team's previous researches (David *et al*., 1996), (David *et al*., 2006), (David *et al*., 2009), (Nica, 2012). Designed for monitoring the magnetic environment in the 50 Hz,...,100 kHz frequency range, it records the waveforms and computes the frequency characteristics of the three magnetic field components, the rms and peak to peak values of the components, and the resultant magnetic field magnitude.

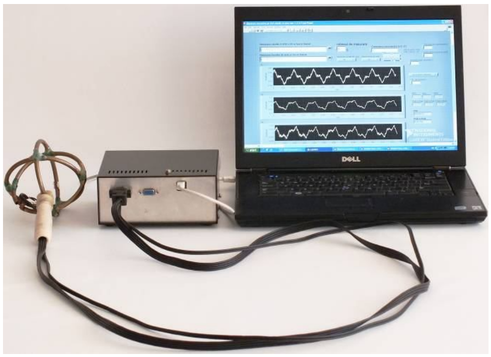

Fig. 1 – The automatic triaxial magnetic field survey system.

Measurement points, Fig. 2, were chosen in the plane of iron's soleplate on eight radial directions from five to five centimetres (32 of them), the 33rd point is near the handle and the 34th is at five centimetres under the soleplate. For every point an approximately 30 seconds record was performed, including the iron heating period and the before and after background field as can be seen in Fig. 4.

In order to apply the FMEA risk assessment method to evaluate the risk of exposure to the magnetic fields generated by the electric iron, the failure modes need to be identified. Failure modes are the manoeuvres someone can make or situations that may occur during ironing and that lead to a higher level of exposure (higher field levels and/or longer exposure time). A RPN (Risk Priority Number) is computed for each failure mode as a product of the three scores given for severity (S), frequency (F) and detectability (D), eq (1).

$$\mathrm{RPN} = S \times F \times D\,. \tag{1}$$

The scales used for scoring the three characteristics of the failure modes are in Table 1 for severity, in Table 2 for frequency and in Table 3 for detectability.

Table 1
Effects Severity Scale

Value	Description	Criteria
1	No effect	Exposure to fields lees or equal than natural background
2	Far minor	Exposure to fields a little above natural background
3	Minor	Exposure to fields of for orders of magnitude smaller than recommended limits
4	Very low	Exposure to fields of tree orders of magnitude smaller than recommended limits
5	Low	Exposure to fields of two orders of magnitude smaller than recommended limits
6	Moderate	Exposure to fields of one order of magnitude smaller than recommended limits
7	High	Exposure to fields of the same order of magnitude as recommended limits, but not above
8	Very high	Exposure to fields above recommended limits
9	Catastrophic detectable	Predictable exposure to fields high above recommended limits
10	Catastrophic undetectable	Hardly predictable exposure, to fields high above recommended limits

Table 2
Probability Scale

Value	Description	Criteria
1	Very rare	Situation which has a very low probability of occurrence
2	Rare	Situation which has a low probability of occurrence
3	Occasional	Occasionally situation
4	Moderately frequent	Situation that occur frequent during every use
5	Frequent	Situation that occur very frequent during every use

Table 3
Detectability Scale

Value	Description	Criteria
1	Very easy	The subject consciously put himself in this situation
2	Easy	Needs minimum of attention to avoid the situation
3	Difficult	To avoid the situation a reasoning and a minimum of knowledge is needed, possibly some measurements
4	Very difficult	Avoidance is possible only using field surveillance systems
5	Almost impossible	Accidental situation that is too short to be avoided even is detected.

3. Results and Discussions

3.1. Field Measurements

The characterization of the electric iron from generated magnetic field point of view is presented in Fig. 2, where *X* and *Y* are the coordinates of the iron's soleplate plan and *Z* is representing the magnitude of magnetic induction vector in a colour scale (blue to red), doubled, for each point by the numeric value expressed in µT. It can be observed that, as expected, the magnetic induction magnitude is decreasing with the distance and values are between 0.28 and 4.45 µT. The background magnetic field was varying in the range of 0.2,...,0.39 µT.

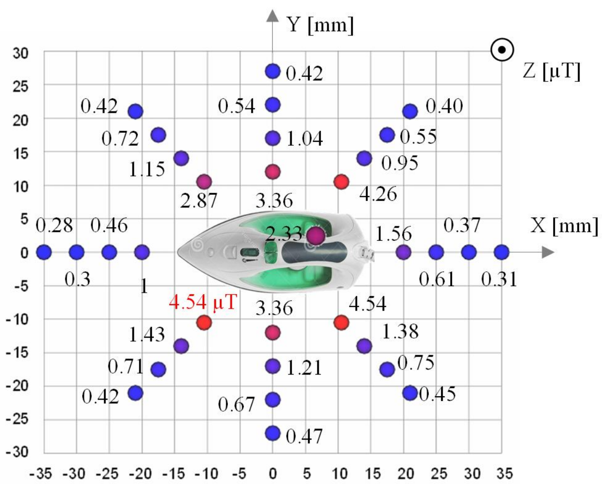

Fig. 2 – The maximum r.m.s values of the resultant magnetic field vector around an iron. Values corresponding to each measurement point are expressed in µT.

For the point near the handle a time domain spot measurement of the three components of the magnetic induction vector is presented in Fig. 3 and the magnitude measured was 2.33 µT. It can be clearly seen the 50 Hz operating frequency of the power network (the 20 milliseconds period of the signal).

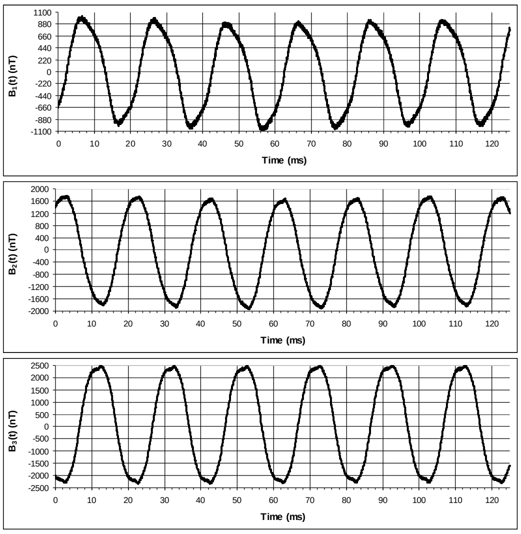

Fig. 3 – The three orthogonal components of magnetic induction vector, in time domain, measured on the iron handle

For the point situated 5 cm under the iron's soleplate, a record for approximately 30 s of the rms values of the magnetic induction vector is presented in Fig.4. In this record the background magnetic induction of about 0.39 µT can be seen before and after the heating period when the maximum magnitude recorded was of 10.25 µT. This is the maximum value recorded for this iron and is below the 100 µT recommended limit (ICNIRP, 1998; EC, 2004).

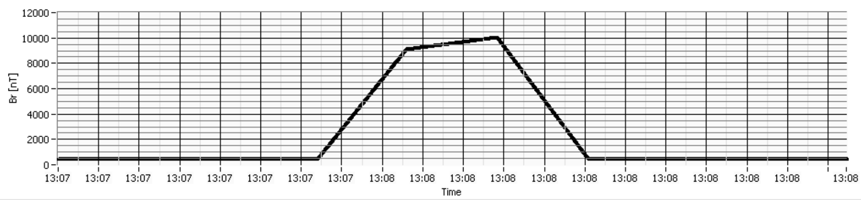

Fig. 4 – A 30 s record of the rms values of the resultant magnetic induction vector at 5 cm under the iron's soleplate. Background 397 nT.

3.2. FMEA Analysis

The FMEA risk assessment on exposure to the magnetic fields generated by the considered electric iron is presented in the Table 4 which contains the identified failure modes, potential effects and causes, the scores for the Severity, Frequency and Detectability, the computed RPN and also some recommendations to avoid each situation.

Table 4

FMEA Applied in risk assessment on exposure to magnetic field generated by an electric iron.

Failure modes	Potential effect	*S*	Potential cause	*F*	*D*	RPN	Recommendations
The hand is on handle during heating	Exposure to fields over 2 μT	5	– lack of information; – no heating indicator;	4	2	*a*= 40	Avoid handling the iron and keep at least 30 cm distance from it when is heating
The iron temperature is tested by hand during heating	Exposure to fields over 10 μT	6		3	1	*b*= 18	Do not test the iron temperature by hand. Keep at least 30 cm distance from it when is heating
The iron is held closer than 15 cm during heating	Exposure to fields over 0.7 μT	4		3	2	*c*= 24	Avoid ironing during heating or keep at least 30 cm distance from it when is heating
The iron is placed on vertical position when clots are manipulated	Exposure to fields over 2 μT	5		3	2	*d*= 30	Keep at least 30 cm distance from it when is heating

Risk priority is stated by the value of the RPN for each situation; higher RPN means higher priority. In this case the order of priorities, is from high to low, a**,** *d***,** *c* and *b*.

3.3. Fuzzy Logic Used on Risk Prioritisation

The risk prioritisation can be done using triangular fuzzy numbers and fuzzy ordering operations (Gherasim, 2013). Following this aim each RPN need to be transformed in a triangular fuzzy number by normalize its components, *S*, *F* and *D* (translating in the [0,100] interval), order them and build a fuzzy Risk Priority Number as fRPN = ordered (*S*,*F*,*D*). In this way all RPN-s become fRPN, represented in Fig. 5.

Ordering the obtained fRPN-s a new order of priorities is obtained, namely *a*, *b*, *d* and *c*. Compared with the order obtained first (*a***,** *d***,** *c* and *b*) can be observed that keeping all the three components of the RPN the b situation that has the biggest severity is on second place even is easy to detect and prevent.

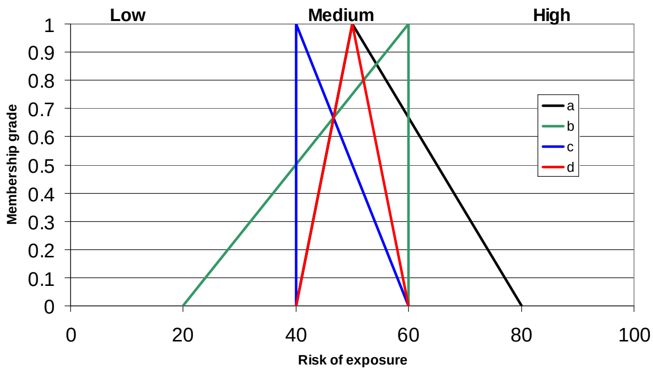

Fig. 5 – The fRPN-s (fuzzy Risk Priority Numbers) for each failure mode.

4. Conclusions

A methodology to evaluate the humans' exposure risk to the low frequency magnetic fields was proposed and applied for the case of magnetic field generated by an electric iron.

The use of classical risk priority number in some situations that have equal or very closed scores can not offer a clear order of priorities. To improve the risk prioritisation by keeping all the three components of the RPN in ordering, triangular fuzzy numbers were used in stead of classical RPN-s. This approach leads to a clearer and a better view over the risk priority further more through graphical representation.

Fuzzy logic applied to risk management can be a better tool in stating the risk priority because none of the RPN components are missed.

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EVALUAREA RISCULUI DE EXPUNERE LA CÂMPURI MAGNETICE DE JOASĂ FRECVENȚĂ

(Rezumat)

Scopul acestei abordări este de a propune o metodologie de evaluare a riscului de expunere umană la câmpuri magnetice de joasă frecvență. Metodologia propusă este aplicată în cazul câmpului magnetic generat de un fier de călcat electric. Câmpul magnetic generat are valori între 0,28 şi 4,45 μT, funcție de distanță, cu frecvență de 50 Hz iar câmpul de fond variază între 0,2 şi 0,39 μT. Măsurările de câmp au fost urmate de o analiză FMEA (Failure Modes and Effects Analysis – Analiza Modurilor de Defectare şi a Efectelor) pentru a evalua şi clasifica riscurile de expunere şi pentru a identifica măsuri de protecție. Clasificarea riscurilor s-a făcut prin ordonarea clasică în ordinea scorurilor de prioritate (RPN - Risk Priority Number) şi suplimentar folosind logica fuzzy. Utilizarea logicii fuzzy şi a numerelor fuzzy aduce avantajul considerării simultane a celor trei componente ale scorului de prioritate la stabilirea priorităților.