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FMEA AND FUZZY LOGIC APPLIED IN RISK ASSESSMENT OF EXPOSURE TO ELECTROMAGNETIC POLLUTION

BY

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Abstract. The aim of this approach is to evaluate the humans' exposure risk to the microwave electromagnetic fields using the case of a microwave oven as an example of radiation source. Measurements and Failure Modes and Effects Analysis (FMEA) were performed aiming the assessment and classification of the exposure risks and finally to identify some exposure reduction measures. Use of risk priority numbers (RPN) in combination with fuzzy logic aims to find a better risk prioritisation technique. This approach is also a proposition for a management technique that can be adapted and applied in other cases of electromagnetic pollution.

Key words: exposure to electromagnetic fields; fuzzy logic; FMEA; microwave; risk assessment.

1. Introduction

The exposure of people to electromagnetic fields is increasing due to growing availability and diversity of tools, gadgets and appliances that incorporate new technological advancements. In this context the exposure to electromagnetic fields becomes an important risk factor for people health and concerns of scientists and authorities on it are as great (Cucurachi *et al.*, 2013; ICNIRP, 1998; ICNIRP, 2010; EC, 2004). The risk assessment of exposure is performed for the particular case of a microwave oven and a management

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technique is proposed that can be adapted and applied for other sources of electromagnetic fields. Also, continuing an earlier approach (Nica, 2014), it will contribute to the building of a knowledge data base, which will serve to develop a risk of exposure assessment questionnaire that can be used as a tool in the management of electromagnetic pollution.

The electric field measurements were performed in the proximity of the microwave oven in order to evaluate its emissions and subsequently the exposure levels.

After characterising the source, a risk assessment is performed using FMEA (Failure Modes and Effects Analysis) method (Mil-Std-1629, 1980). A new way of risks prioritization was proposed using fuzzy logic in combination with RPN (Risk Priority Number) expecting better results.

2. Instrumentation and Methods

The electric field measurements were performed using a 9 kHz,...,3 GHz spectrum analyser, and a 0.7,...,2.5 GHz radial isotropic antenna (Fig. 1).

Fig. 1 – The electric field measurement system.

Measurement points, Fig. 2, were chosen in a horizontal plane trough the centre of the microwave oven, at 0, 2, 50, 100 and 400 centimetres from the oven enclosure, on eight radial directions. For every point the maximum value of the electric field was measured by setting the spectrum analyser in max hold mode and holding the sensor for few seconds in each of the three orthogonal planes, as a measure to compensate the sensor’s anisotropy.

The FMEA risk assessment method used to evaluate the risk of exposure to the electromagnetic fields generated by the microwave oven is based on the identified failure modes. Failure modes are the manoeuvres that someone can make or situations that may occur during oven usage and that lead to a higher level of exposure (higher field levels and/or longer exposure time). For each identified failure mode three scores are given for severity (S), frequency (F) and detectability (D). The scales used for scoring are given in Table 1 for severity, in Table 2 for frequency and in Table 3 for detectability. These scores are used to compute the RPN (Risk Priority Number) for each failure mode:

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

In order to use fuzzy logic in risk prioritisation the three characteristics above need to be normalized and fuzzified. The fuzzification is done by multiplying each of them with three fuzzy weights, $\tilde{k}_S, \tilde{k}_F, \tilde{k}_D$, given for each failure mode based on a survey conducted among specialists. The S, F and D characteristics could be also fuzzy sets if the scores were given by several people in a survey.

Table 1
Effects Severity Scale

Value	Description	Criteria
1	No effect	Exposure to fields less or equal to natural background
2	Far minor	Exposure to fields a little above natural background
3	Minor	Exposure to fields four orders of magnitude smaller than recommended limits
4	Very low	Exposure to fields three orders of magnitude smaller than recommended limits
5	Low	Exposure to fields two orders of magnitude smaller than recommended limits
6	Moderate	Exposure to fields 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

Using the fuzzified scores, the failure modes can be prioritized using decisional techniques as Bayes-Laplace, Wald, Max-Max or Hurwicz.

Also an fRPN (fuzzy Risk Priority Number) is formed for each failure mode as a triangular fuzzy number. The fRPN is obtained multiplying, according to fuzzy arithmetic (Gherasim, 2013), the three normalised and fuzzified scores given for severity (S), frequency (F) and detectability (D), as characteristics of each failure mode:

$$fRPN = \tilde{S} \bullet \tilde{F} \bullet \tilde{D} \tag{2}$$

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 if it is detected.

3. Results and Discussions

3.1. Emissions

The maximum values of the electric field measured as described in section 2 are presented in Fig. 2, where the *X*, *Y* horizontal plan contains the oven centre and all the forty measurement points. The field values are in the vertical direction *Z*, in a colour scale (blue to red), doubled, for each direction by graphics E1-8 representing electric field intensity vs. distance from source. As expected, a decrease with the distance of the maximum electric field intensity is observed. Values are between 0.2 and 42.3 V/m.

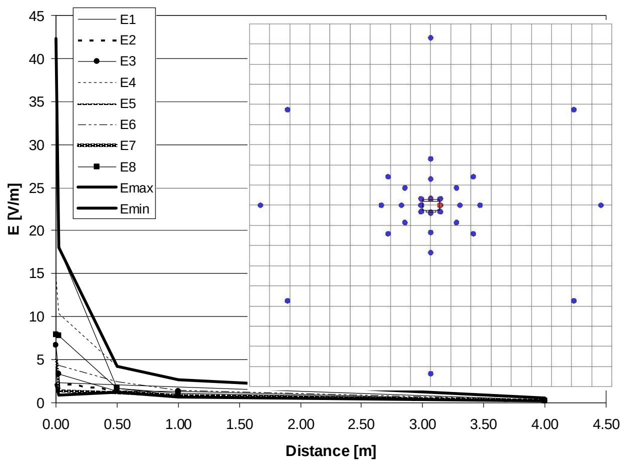

Fig. 2 – The intensity of electric field on 8 directions (40 points) around a microwave oven.

The frequency of the generated electric field is 2.46 GHz. The maximum value recorded for this oven is 42.36 V/m, and is of the same order as the recommended limit (ICNIRP, 1998), (EC, 2004) of 61 V/m.

3.2. FMEA Analysis and Fuzzy Logic

The FMEA risk assessment on exposure to the electric fields generated by the considered microwave oven 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 RPN (Risk Priority Number) and recommendations to avoid each situation.

Table 4
FMEA Applied in Risk Assessment on Exposure to Electric Field Generated by a Microwave Oven

Failure modes	Potential effect	S	Potential cause	F	D	RPN	Recommendations
a) The user looks trough oven window from a distance of 2 cm or smaller	Exposure to fields over 3.3 V/m	6	- lack of information;	2	1	*a*=12	Avoid looking closer trough oven window. Keep at least 1 m distance from it when is turned on.
b) User is seating closer than 50 cm from oven during heating	Exposure to fields over 1.5 V/m	6		4	2	*b*=48	Keep at least 1 m distance from oven when is heating
c) User holds its hand on the oven case when is turned on	Exposure to fields over 42 V/m	7		3	1	*c*=21	Do not touch the oven when is turned on. Keep at least 1 m distance.
d) The oven is placed under 1 m distance from a very frequented place/zone	Exposure to fields over 1.4 V/m	6		2	3	*d*=36	Place the oven as far as possible from frequented zones. Keep at least 1 m distance.

The risk prioritization can be done using RPN, a higher value for RPN means a higher priority due to greater danger. According to Table 4 the resulted order of priority for the considered situations is b, d, c and a.

In Table 5, a triangular fuzzy number is obtained for each situation by normalizing the scores for S, F and D (translating in the [0,100] interval) and applying eq (2). Using triangular fuzzy numbers the risk prioritization is done in the same manner as above but using fuzzy ordering operations (Gherasim, 2013).

Table 5

FuzzyFMEA for the microwave oven.

Fail mode	S	F	D	fRPN
	$\tilde{k}_S = (0.4,0.6,0.7)$	$\tilde{k}_F = (0.2,0.3,0.4)$	$\tilde{k}_D = (0.1,0.1,0.2)$	
a)	$\tilde{S} = (24,36,42)$	$\tilde{F} = (8,12,16)$	$\tilde{D} = (2,2,4)$	$\tilde{a} = (767,943,1488)$
b)	$\tilde{S} = (24,36,42)$	$\tilde{F} = (16,14,32)$	$\tilde{D} = (4,4,8)$	$\tilde{b} = (2571,2769,5000)$
c)	$\tilde{S} = (28,42,49)$	$\tilde{F} = (12,18,24)$	$\tilde{D} = (2,2,4)$	$\tilde{c} = (1341,1650,2604)$
d)	$\tilde{S} = (24,36,42)$	$\tilde{F} = (8,12,16)$	$\tilde{D} = (6,6,12)$	$\tilde{d} = (2300,2828,4464)$

For a better view over the priorities, all fRPN-s are represented in Fig. 3.

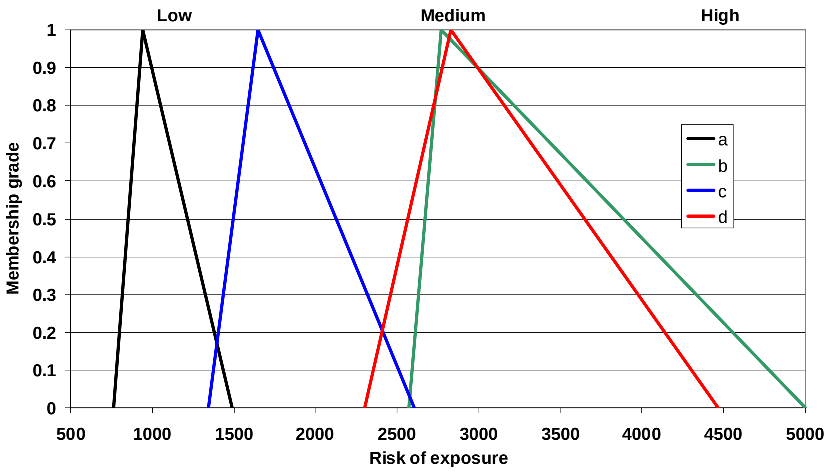

Fig. 3 – The fRPN-s (fuzzy Risk Priority Numbers) for each failure mode.

In this case the obtained priority is the same as in case of classical FMEA, namely b, d, c and a.

4. Conclusions

It was proposed a technique for evaluation of humans' exposure risk to the electromagnetic fields. This method was applied for the case of an microwave oven. Some failure modes (risk situations) were identified and classified by priority, priority which is established based on potential danger expressed by the fuzzy Risk Priority Numbers.

The advantages of proposed approach are: the possibility of evaluating risks by a single person or by a group using a survey, a clear overview of results due to fuzzy numbers graphical representation without loosing any detail about the survey, creates a database of information that can be used in other analyses, multi-criteria decisional techniques as Bayes-Laplace, Wald, Max-Max or Hurwicz can be applied.

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APLICAREA ANALIZEI FMEA ŞI A LOGICII FUZZY ÎN EVALUAREA RISCULUI DE EXPUNERE LA POLUARE ELECTROMAGNETICĂ

(Rezumat)

Scopul acestei abordări este de a evalua, în cazul oamenilor, riscul de expunere la câmpuri electromagnetice în domeniul de frecvență al microundelor, utilizând ca exemplu de sursă de radiații cazul unui cuptor cu microunde. Au fost efectuate măsurări şi analize FMEA (Failure Modes and Effects Analysis – Analiza Modurilor de Defectare şi a Efectelor), cu scopul de a evalua şi clasifica riscurile de expunere şi în final de a identifica câteva măsuri de reducere a expunerii. Utilizarea scorurilor de prioritate (RPN - Risk Priority Number) în combinație cu logica fuzzy urmăreşte găsirea unei mai bune tehnici de prioritizare a riscurilor. Prin această abordare se propune deasemenea o tehnică de management ce poate fi adaptată şi aplicată şi pentru alte situații de poluare electromagnetică.