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Assessing the in situ electric field strength caused by an EAS deactivator using a novel scaling method

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Abstract

In the work presented here, the magnetic field exposure caused by a deactivator for single-use acousto-magnetic electronic article surveillance systems is assessed by measurements of the generated magnetic field as well as the induced electric fields inside the body tissues of an anatomical hand model.

We use a common frequency domain numerical technique for computation of the induced electric field strength (E_i) and propose a scaling technique for the WPM-TD assessment of E_i to obtain the resulting exposure index (EI). An assessment of E_i finally leads to worst case EI up to 135 %, 93 %, 78 %, and 72 % when using the max$E_{i,avg}$, 99.9th, 99.5th, and 99.0th percentiles, respectively.

1 Introduction

Deactivators of electronic article surveillance (EAS) systems are used in retail to de-magnetize single-use labels for theft prevention. The associated labels that are placed on the goods contain two thin stripes of ferromagnetic metals, one of them specifically magnetized to enable mechanical resonance of the other stripe for a specific magnetic field (MF). When passing the EAS antennas at the exit of the store with a label in original state, it is detected, triggering an alarm. During the payment process, these labels are de-magnetized by a deactivator (as the one considered here), i.e., they cannot be detected by the EAS antennas anymore. This deactivation is executed by the cashier sweeping the goods with attached labels above the surface of the deactivator. As the cashier's hand is placed right on top of the deactivator at every deactivation process, the question of a potential exceeding of the legal limit values, especially regarding the limbs, comes to light.

In general, the assessment of occupational exposure to electric, magnetic, and electromagnetic fields is harmonized within the European Union (EU) by the European Directive 2013/35/EU [1], which had to be transposed into national law by the member states by 2016. In the frequency range of interest, it defines action levels (AL, relating to the external field) and exposure limit values (ELV, relating to the induced field inside the body tissues).

The deactivation pulse of the investigated EAS deactivator is of non-sinusoidal shape [2]. For exposure scenarios like this, several different assessment methods have been proposed in recent years [3, 4]. The EU [1] declares the so-called Weighted Peak Method (WPM) in Time Domain (WPM-TD) as the preferred method for assessing non-sinusoidal signals because it avoids overestimation of exposure, which may occur by using methods that neglect phase relationships of different spectral components, e.g., the Multiple Frequency Rule (MFR). The basics of the WPM-TD were published in [5, 6] and were derived from the fact that the frequency dependency of the AL can be approximated by first order filters. A detailed description and analysis of the WPM-TD as well as guidance for its practical implementation can be found in [7].

Furthermore, in exposure scenarios with highly localized magnetic fields as described here, an accurate exposure assessment is challenging not only due to the non-sinusoidal time course of the emitted field but also due to the high field gradients expected close to the field source. The high field gradients complicate representative measurement results due to their inherent averaging properties over the probe's cross section, which results in a dependence of the measured MF on the probe size.

2 Methods

2.1 Device under investigation

The considered AM-EAS system is used in retail to de-magnetize single-use labels for theft preventions (Figure 1). The removal of the top cover of the device's housing allows a view on the detection coil, which again covers the deactivation coil at the bottom of the housing.

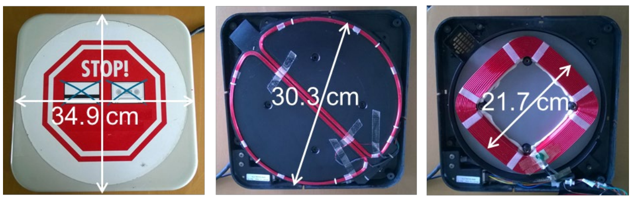

Figure 1. Investigated AM-EAS deactivator. Left: top view of the fully assembled device; center: removed top cover shows detection coil; right: removed detection coil shoes deactivation coil.

2.2 Measurements

The MF emitted by the detection and deactivation coils of the deactivator were measured along a measurement grid (10 mm step size) in three planes parallel to the deactivator surface (distances probe center to device surface of 15 mm, 35 mm, and 100 mm) using the Exposure Level Tester ELT 400 (Narda Safety and Test Solutions, Pfullingen, Germany) with a 3 cm^2 isotropic field probe. The probe-size-related differences in the MF measurements were distinguished at comparative measurements with a 100 cm^2 probe.

2.3 Numerical computations

A numerical model of the deactivator was developed and used for calculating the induced electric field strength (E_i) inside anatomical hand models using the quasi-magnetostatic solver of the simulation platform Sim4Life [8]. The anatomical hand models [9] were developed particularly for the assessment of occupational settings with localized MF exposure of the hand. They were built from MRT images in three different hand postures: P1, representative for holding a thick cylindrical object, e.g., cable; P2, representative for holding a small object between index finger and thumb; P3, representative for holding a sheet. Calculations were carried out for different orientations (palmar and ulnar) and distances on a 3 x 3 grid of 100 mm on the deactivator surface to cover the most common situations occurring in practice The appropriate dielectric properties for most of the body tissues were assigned according to the IT'IS Tissue Database [10]. According to most recently published papers, the electric conductivity of the skin was set as 0.2 S/m [11, 12]. The numerical model of the deactivator was validated using measurements of the magnetic induction along the surface of the real device, and an agreement within ± 10% could be achieved.

From these simulations, the maximum ($maxE_{i,avg}$), and the 99.9th, 99.5th and 99.0th percentile of the 2 x 2 x 2 mm^3 averaged electric field strength induced inside the body tissues were evaluated.

2.4 Mathematical scaling method

The results for $E_{i,avg}$ obtained from the numerical computations in frequency domain can be reported in terms of an induction factor (IF) for a sinusoidal source current normalized to current I and frequency f

$$IF = \frac{\hat{E}_{i,avg}}{\hat{I} \cdot f} \quad \left[\frac{(\frac{\mu V}{m})_{peak}}{A_{peak} \cdot Hz} \right] \tag{1}$$

where I denotes the total current through the coil in ampere turns.

The time course of an (arbitrary) waveform $E_{i,avg,arbitrary}(t)$ induced by a magnetic induction $B(t)$ is directly proportional to the time derivative of the magnetic induction $\frac{dB(t)}{dt}$ and, therefore, also directly proportional to the time derivative of the total source current $\frac{dI(t)}{dt}$.

For the temporal peak value $\hat{E}_{i,avg,arbitrary}$ it follows

$$\hat{E}_{i,avg,arbitrary} = k \cdot max\left(\frac{dI(t)}{dt}\right)_{arbitrary} \tag{2}$$

The maximum time derivative of a sinusoidal current with an amplitude of 1 A and a frequency of 1 Hz results in 2π.

$$max\left(\frac{dI(t)}{dt}\right)_{sinus} = 2\pi \cdot f \cdot 1A = 2\pi \quad |_{f=1Hz,\ \hat{I}=1A} \tag{3}$$

Equations (1), (2) and (3) result in

$$\hat{E}_{i,avg,arbitrary} = \frac{IF}{2\pi} \cdot max\left(\frac{dI(t)}{dt}\right)_{arbitrary} \tag{4}$$

and

$$E_{i,avg,arbitrary}(t) = \frac{IF}{2\pi} \cdot \left(\frac{dI(t)}{dt}\right)_{arbitrary} \tag{5}$$

Hence, $E_{i,avg,arbitrary}(t)$ can then be evaluated using the WPM-TD for the ELV, leading to a weighted signal $s_{TD\_ELV}(t)$ derived based on the remarks in [7] and normalized to the non-time dependent quantities, where "*" denotes the convolution operation and $w_{TD}(t)$ is the impulse response of the first order filter with frequency response $W_{TD}(f)$

$$s_{TD\_ELV,norm}(t) = \frac{s_{TD\_ELV}(t)}{IF/2\pi} = \left(\frac{dI(t)}{dt}\right)_{arbitrary} * w_{TD}(t) \tag{6}$$

The normalized exposure index

$$EI_{norm} = \max\left(|s_{TD_{ELV}}(t)|\right) \tag{7}$$

is finally used to obtain the EI for any of the considered exposure scenarios by simple scaling according to

$$EI = \frac{IF}{2\pi} \cdot EI_{norm} \tag{8}$$

It is noted that the procedure described above is strictly valid only under the assumption of constant (frequency independent) electric conductivity of the body tissues, which can be considered as fulfilled in the current exposure scenario as the frequency dependence of tissue conductivities is very limited in the considered frequency range (approx. 50 Hz – 1 kHz). Moreover, the proposed method only delivers reliable results for no significant variation of the spectral composition of the incident MF within the volume of the considered body part. When considering only one electric source current, as in case of the investigated device, this prerequisite is inherently met.

3 Results

The measurements of the magnetic induction close to deactivator surface with the 3 cm^2 probe showed peak values of magnetic induction B_{peak} of up to 97 mT, 67 mT, and 25 mT at distances 15 mm, 35 mm, and 100 mm (deactivator surface to probe center), respectively.

The maximum B_{peak} obtainable with the 100 cm^2 probe along the deactivator surface is 57 mT (probe surface touching the deactivator surface).

An WPM-TD-based assessment of the maximum measured magnetic induction based on the AL for limb exposure according to [1] results in an EI of 443 % when using the maximum obtainable with the 3 cm^2 probe (B_{peak} = 97 mT), compared to 260 % when using the maximum obtainable with the 100 cm^2 probe (B_{peak} = 57 mT).

The resulting $\hat{E}_{i,avg}$ was evaluated inside the three hand models in all considered positions and the IF were calculated for all exposure scenarios (9 positions x 2 orientations per hand model). The spatial distributions are shown with a logarithmic scale and normalized to the maximum value in Figure 2.

Table 1 finally summarizes the exposure indices EI for the different considered exposure scenarios and target quantities when evaluating the time course of the induced electric field strength based on the WPM-TD with respect to the ELV for peripheral tissues. The fact that the ELV-related EI (worst case 135 %) are substantially lower than the AL-related EI (worst case 443 % and 260 % with 3 cm^2 and 100 cm^2 probe, respectively) demonstrates the considerable overestimation of an AL-based exposure assessment in highly localized magnetic fields.

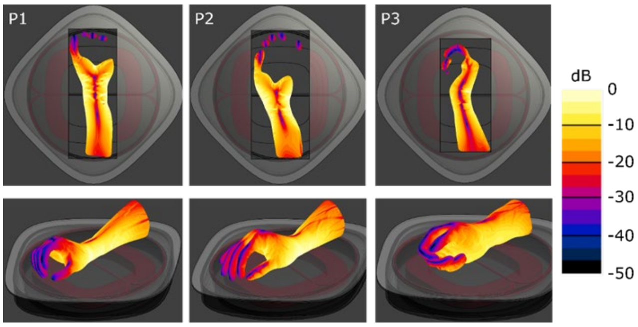

Figure 2. Spatial distribution of Êi,avg in cross sectional views (top row) and surface views (bottom row) inside the three hand models (dB scale for all plots normalized to a max$\hat{E}_{i,avg}$ = 1.419 (µV_{peak}/m)/A_{peak}/Hz).

Table 1. Computed worst case exposure indices for the three different hand models P1-P3 and target quantities (x = 100 mm, y = 0 mm).

Hand model	Worst case exposure index EI [%]			
	max$\hat{E}_{i,avg}$	**p99.9 ($\hat{E}_{i,avg}$)**	**p99.5 ($\hat{E}_{i,avg}$)**	**p99.0 ($\hat{E}_{i,avg}$)**
P1: palmar	132.3	93.1	78.4	71.5
P2: palmar	131.7	89.3	76.4	71.0
P3: ulnar	135.4	72.6	60.0	53.4

4 Discussion & Conclusion

A novel scaling method is proposed, which allows a WPM-TD-based assessment of $E_i(t)$ of non-sinusoidal time course, based on results from computations at a single frequency with common frequency domain numerical techniques under certain assumptions [2]. If these assumptions are met, as in the investigated case for exposure of the hands caused by a deactivator for single-use EAS labels, the method can contribute to an efficient and reliable exposure assessment with respect of the ELV.

It could be shown that the ELV-related EI (135 % worst case for max$E_{i,avg}$) are substantially lower than the AL-related EI (worst case 443 % and 260 % with 3 cm^2 and 100 cm^2 probe, respectively), demonstrating that the AL-based exposure assessment leads to an overestimation of the actual exposure in this particular case. From a practical perspective, however, it is difficult to answer the question of whether working with the deactivator under investigation is compliant with the requirements of EU directive 2013/35/EU. The first problem that arises is deciding which of the evaluated quantities (max$E_{i,avg}$ or a particular percentile) to use for the final decision. While it is recommended by the ICNIRP [13] and the Non-binding guide to 2013/35/EU [14, 15] to use the 99th percentile of $E_{i,avg}$, it has been repeatedly shown in the past that using p99.0 values can lead to a significant underestimation of actual exposure, especially in situations where exposure is highly localized [11], [16] –[18]. Originally, it was argued that the use of p99.0 values eliminates numerical artefacts in the field distribution of the induced electric fields in tissue due to errors in the segmentation of the anatomical body models available at the time the ICNIRP 2010 guidelines were written. However, such segmentation errors have already been widely eliminated in state-of-the-art anatomical body models as those used in this work. Nevertheless, the max$E_{i,avg}$ may still be prone to overestimation by local discretization errors. From recent work, the use of at least the 99.9th (if not the 99.99th) percentile can be derived as reasonably choice [19] to obtain a representative assessment of exposure. The second question that arises is whether the uncertainty due to uncertainty of the tissue conductivity data must be considered in the evaluation, i.e., whether it must be added to the obtained E_i before comparing with the ELV, or whether it can be assumed that this type of uncertainty is covered by the reduction factors included in the ELV as a safety margin to the effect levels for tissue stimulation. All in all, the investigated device must be considered at least borderline to non-compliance and precautionary measures are recommended, e.g., keeping a distance of 50 mm to the deactivator surface to ensure compliance.

Acknowledgements

The computational modelling was executed with Sim4Life [8].

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