The Exposure Level of High Power Microwave Pulses

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Abstract— In the paper the investigation of dosimetry of exposure to high power microwave (HPM) pulses has been discussed. The dosimetry was based on recommendations of the International Commission of Nonionizing Radiation Protection and by the Institute of Electrical and Electronics Engineers. Taking into account the high values of amplitude of HPM pulses and their very short durations the modification of assessing technique was presented. Two parameters considered as basic restriction parameters, i.e., specific absorption rate (SAR) and specific absorption (SA) have been analyzed.

1. INTRODUCTION

Currently more and more institutions and EMC laboratories investigate the high power microwave (HPM) pulsed radiation [1,–6, 10, 11, 15, 17]. Such radiation has unique electrical parameters, i.e., extreme power in peak (hundreds kV/m) and very short duration of pulses (nanoseconds) and it is obvious that such radiation should be investigated taking into account the electromagnetic compatibility as well as the biological damages in exposed tissues [8, 9, 12–14, 18, 19]. From this point of view the dosimetry assessment is necessary to investigate potential health hazard and to compare with established guidelines where the permissive exposure levels (PEL) have been predicted. The important difficulty is that the literature does not provide sufficient information about human health hazard when exposed to HPM pulses and because of this guidelines propose only conservative attempt taking into account the thermal effect, deeply recognize for exposure to long-term radiation.

To protect against electromagnetic radiation in the human exposure the permissive exposure limits have been recommended by the International Commission of Nonionizing Radiation Protection (ICNIRP) and by the Institute of Electrical and Electronics Engineers (IEEE) and also by national regulations. The maximum permissible limitations have been based on the highest peak of electric or magnetic field strengths or the plane-wave equivalent to power densities. The most authoritative exposure guidelines recommend also specific absorption rate (SAR) as a basic restriction. The SAR is the time derivative of the incremental energy absorbed by an incremental mass contained in a volume element of given density. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz in order to limit or avoid auditory effects caused by thermoelastic expansion, the threshold level of specific absorption (SA) is also recommended.

Electromagnetic pulse-radiation emitted from HPM generators can also be treated as ultra-wideband (UWB) signals. The UWB signals have different forms of interaction with biological structures compared with continuous signals because the frequency spectrum of harmonics of such radiation sometimes exceeds 500 MHz.

Taking into account that the electrical properties (complex permittivity) of biological tissues change its values in function of frequency the attempt of dosimetry should be redefined. Values of the real and imaginary part of permittivity of blood in the frequency from 100 MHz to 600 MHz have been presented in Figure 1.

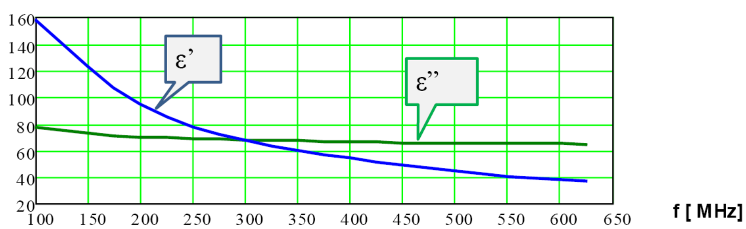

Figure 1: Permittivity of blood in function of frequency.

2. PEMISSIVE EXPOSURE LEVEL

At microwaves, for long-term exposure the exposure limitations are described by the electric field strength expressed in V/m, the power density in W/m^2 or additionally by the SAR in W/kg and SA in J/kg. Established values are derived with consideration of adverse effects thresholds and are considered protective for all human exposure. They were established after the thorough review and consideration of the literature. When the exposure is a short-term or pulsed radiation regime the specific absorption (SA) expressed in J/kg is especially recommended. In case of pulsed exposure, e.g., radar exposure the maximum peak in time should not exceed values of long-term exposure multiplied by a factor of 32. For radar pulsed exposure the SA should not exceed 10 mJ/kg averaged over 10 g of tissue in order to limit and avoid auditory effects caused by thermo-elastic expansion.

In the guidelines the general limitations of pulsed exposure are done in the following way — for exposures to pulsed RF fields, in the range of 100 kHz to 300 GHz, the peak (temporal) electric field strength or power density are limited only by the use of time averaging and the limit on peak E field value of the electric field strength is 100 kV/m.

Nevertheless, there exists an exception to this limitation allowing exposure to higher strength pulsed field but additional investigation of SAR or SA must be derived basing on the following regulation — the total incident energy density during any one-tenth second period within the averaging time shall not exceed one-fifth of the total energy density permitted during the entire averaging time for a continuous field, i.e.,

$$\sum\nolimits_0^{0.1\,\mathrm{s}}(\mathrm{SAR}_{pk} \times \tau) \leq 28.8\,\mathrm{J/kg} \tag{1}$$

where τ is the pulse width, SAR_{pk} — SAR in peak.

Additional conditioning to this exception states that a maximum of five pulses with pulse durations less than 0.1 s is permitted during any period equal to the averaging time. If there are more than five pulses during the averaging time, or if the pulse duration is more than 0.1 s, normal averaging time calculations apply and the limitation is SA = 144 J/kg.

The assessment of dosimetry of the exposure to HPM pulses will be presented for pulses emitted by commercially available Marx generator type DS110 (DIEHL, Germany). Pulses emitted by such generator have the pulse widths from 4 to 100 ns and frequency pulse repetition depending on the demand but typically it is 10 Hz. The value of 200 kV/m of the electric strength in peak can be obtained. During the experiments it is possible to emit few pulses (less than 5 pulses) as well as more than 5 pulses. For such emissions two cases of exposure assessments will be analyzed:

- dosimetry of 1 pulse,
- dosimetry of a series of pulses.

According to IEEE recommendations the investigation of SAR and SA should be derived in a volume called planar slab model. This model is a parallelepiped with a frontal surface area of 0.9 m^2 and depth of 7.8 cm, which is representative for a man of 70 kg weight. In the work a modification of dimensions of the model is proposed. The proposed planar slab model is also a parallelepiped but with a frontal surface area of $L1 \times L2 = 0.47\,\mathrm{m}^2$ and a depth of $L3 = 15\,\mathrm{cm}$, as shown in Figure 2(a). The new model has a smaller frontal surface area, but on the other hand dimension $L3$ is bigger and it is four times bigger than the skin depth in the investigated tissue in the range of MHz frequencies. The dimension $L3 = 15\,\mathrm{cm}$ allows to reduce the rays reflected from the back side of the model and simplifies the calculation of the dosimetry.

Electromagnetic field incident to the planar slab model surface is reflected according to the boundary condition. The remaining part propagates inside the material and is attenuated due to imaginary part of permittivity. Electric field strength decreases in function of z, thus SAR is also a function of z as follows.

$$\mathrm{SAR}(z) = \frac{\sigma}{\rho}|Ein(z)|^2 \tag{2}$$

where: σ — conductivity, ρ — density of tissue, Ein — electric field inside the tissue.

When determining compliance with the guidelines the specific absorption rate (SAR) should be averaged over the averaging volume. In this case the maximum local SAR should be averaged over any ten-grams of tissue in the shape of a cube (SARav). Taking into account the density of tissue of 1 g/cm^3 the side of averaging cube is $Lav = 2.14\,\mathrm{cm}$ (Figure 2(b)). The averaged value of SAR

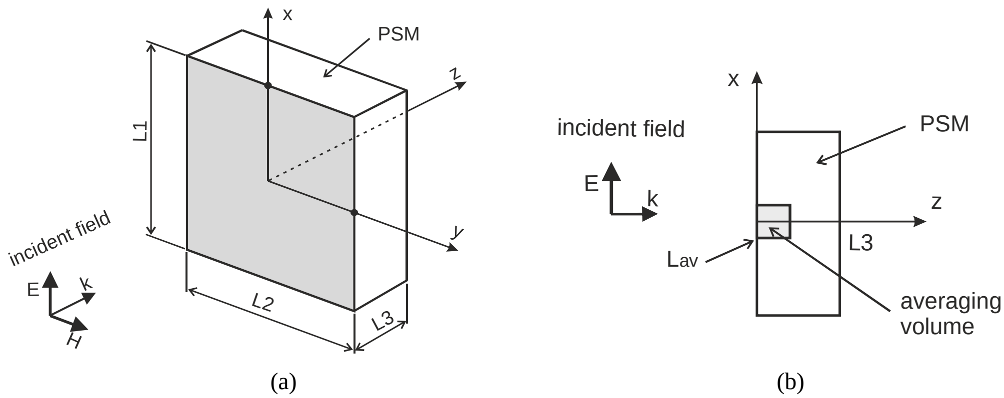

Figure 2: Planar slab model (PSM): (a) general view, (b) cross section in plane xz, where: $Lav = 2.14\,\text{cm}$.

can be determined using the following formula:

$$\text{SARav} = \frac{1}{Lav}\int_0^{Lav} \text{SAR}(z)dz \tag{3}$$

In this attempt the assumption that SARav does not change its value inside the averaging volume in function of x and y is taken into account.

3. DOSIMETRY ASSESMENT

The method proposed for assessing the dosimetry of HPM exposure was realized in the following way.

- Analyzed HPM pulse (Figure 3(a)) has been expanded in to Fourier series. Fourier transform allows to determine the amplitudes of harmonics in the frequency domain.
- Calculation of SAR(z) and SARav was realized for each harmonic treated as a plane wave for suitable frequency. Permittivity values of blood have been also taken for the frequency of harmonics.
- Calculation of SA.

In Figure 3(b), the values of specific absorption rate averaged over 10 g (SARav) have been presented for all harmonics. The total SAR_{tot} of signal presented in Figure 3(a) can be obtained by summing all values of SARav for all harmonics. In the analyzed case of HPM pulses the SAR_{tot} is of 110 kW/kg. This value is extremely high but it should be underlined that investigated pulse widths are very short in time and from this point of view rather specyfic absorption (SA) should be analyzed. For a single pulse the SA has value of 0.5 mJ/kg. Such value of SA is much lower than permissive exposure level which is of 28.8 J/kg. On the other hand, for series of pulses in averaging time, the SA is of 1.9 J/kg. The obtained value is also lower than the limitation which has been recommended as 144 J/kg.

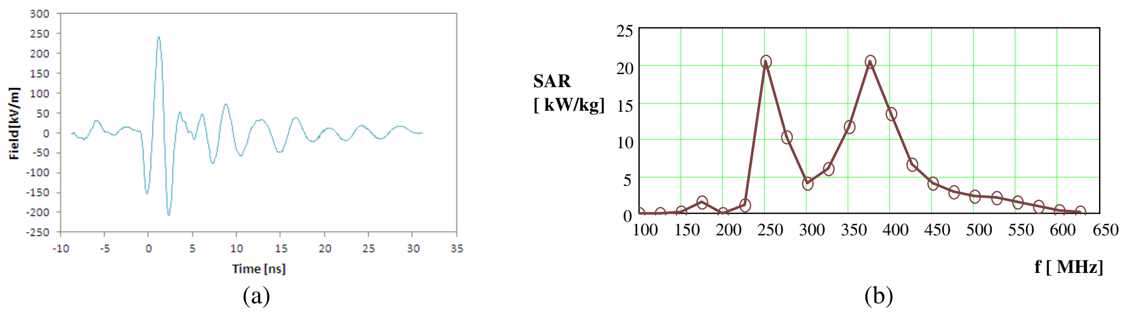

Figure 3: (a) HPM pulse in the time domain, (b) averaged values of SARav for all harmonics in function of frequency.

4. CONCLUSIONS

In the paper the investigation of dosimetry of exposure to high power microwave (HPM) pulses has been discussed. The dosimetry was based on recommendations of the International Commission of Nonionizing Radiation Protection and by Institute of Electrical and Electronics Engineers. Taking into account the high values of amplitude of HPM pulses and their very short durations in time the modification of assessing technique was presented. Two parameters as basic restriction parameters, i.e., specific absorption rate (SAR) and specific absorption (SA) have been analyzed.

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