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Exposure to electric field from frequency range 0 – 1 Hz, analysis of human body penetration

Abstract. *Dependence of electrostatic and quasi-electrostatic field strength inside the tissues of human exposed to such field was derived from the current continuity law taking into consideration natural air ionization and influence ion concentration by the field strength. For plane model of air-tissue boundary and electric field strength up to 1 MV/m, it was shown that field strength inside tissues does not exceed the peak value 1.1 V/m which is the inner limit for health effects in human body tissues by Directive 2013/35/EU, in frequency range 1 Hz – 3 kHz. The highest strength (up to 0.3 V/m) was found in dry skin. It cannot be excluded the excitation of sensory neurons in the skin at higher field strength or air ionization caused by appearing electric discharge or elevated level of ionizing radiation.*

Streszczenie. *Wyprowadzono zależność natężenia pola elektrostatycznego i quasi-statycznego we wnętrzu tkanek ciała ludzkiego eksponowanego na takie pole, korzystając z zasady ciągłości prądu i uwzględniając naturalny poziom jonizacji powietrza oraz wpływ zewnętrznego pola elektrycznego na stężenie jonów. Dla płaskiego modelu granicy między tkanką i powietrzem atmosferycznym i natężeniu pola nieprzekraczającym 1 MV/m, wykazano, że natężenie w tkankach nie przekracza wartości szczytowej 1,1 V/m, która ze względów ochrony zdrowia jest określona jako maksymalne natężenie pola w tkankach osoby eksponowanej, przez Dyrektywę 2013/35/EU, w paśmie 1 Hz – 3 kHz. Największe natężenie pola (do 0,3 V/m) stwierdzono w tkance skórnej. Nie można wykluczyć pobudzenie zakończeń nerwowych w tkance skórnej w przypadku wzrostu stężenia jonów w powietrzu (wzrost poziomu promieniowania jonizującego lub wyładowania elektryczne). Tytuł:* ***Ekspozycja na pole elektryczne z pasma 0 – 1 Hz, analiza wnikania pola do wnętrza ciała człowieka***

Keywords: electrostatic field, penetration of living tissue, air admittance.
Słowa kluczowe: pole elektrostatyczne, wnikanie pola elektrostatycznych do tkanki żywej, admitancja powietrza.

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Introduction

The assessment of potential biological and behavioural effects of exposure of human body to electrostatic and "static around" frequencies need the analysis of electric field strength inside the tissues. Especially increased voltage drop across the cell membranes is a crucial question. In the macro-scale the simplified assumption of ideal conducting tissues and non-conducting atmospheric air are accepted. In fact both of them are conducting dielectric, so even electrostatic field can penetrate the human body to some extent. The most number of regulations concerning exposure limits for electromagnetic field do not consider electrostatic field, mainly because of above assumptions. For example, the last EU Directive 2014/35/EU [1] leaves out of the regulations electric field from 0 – 1 Hz. On the other hand the Polish regulations covers electric field down the frequency range to 0 Hz, but because of lack of methods of measurement the electrostatic field strength, the exposure assessment to electrostatic field has not being done yet. To evaluate the need of establishing exposure limits for electrostatic field, the analysis concerning the penetration the human body by that field. The natural human movements in electrostatic field can be analysed as an exposure to the varying field of frequency from the range about 0 – 1 Hz.

Analysis of Boundary conditions

In Fig. 1, there the simple model to be analysed was shown.

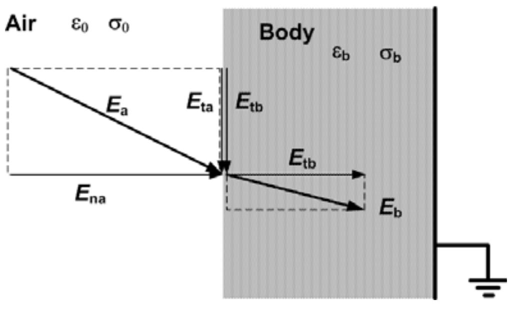

Fig. 1. Boundary conditions for the static and quasi-static electric field at the human body surface

where ε_a – air permittivity, ε_b – permittivity of human tissue, σ_0 – air conductivity, σ_b – conductivity of human tissue, $\boldsymbol{E}_a$ – electric field strength in the air, $\boldsymbol{E}_b$ – electric field strength in the human tissue, $\boldsymbol{E}_{nx}$ and $\boldsymbol{E}_{tx}$ normal and tangential components of the field vector at the border surface.

The current density in the conducting dielectric can be expressed in time and frequency domains as a sum of conducting and displacement components:

(1) $j(t) = \sigma\, E(t) + \varepsilon\, dE(t)/dt \qquad j(\omega) = (\sigma + i\omega\epsilon)E(\omega)$

In frequency domain the specific admittance of the medium can be defined as follows:

(2) $$\gamma(\omega) = j(\omega)/E(\omega) = \sigma + i\omega\,\varepsilon$$

Following the rule of current flux continuity the boundary conditions can be form:

(3) $$j(\omega)_{na} = j(\omega)_{nb}, \quad \text{and,}$$

(4) $$(\sigma_0 + i\omega\epsilon_0)E_{na} = (\sigma_b + i\omega\epsilon_b)E_{nb}$$

In this case the tangential components of the field strength and current density disappear, so the ratio of normal component of field strength in both media can be derived:

(5)

$$k_n = \frac{E_{na}}{E_{nb}} = \frac{(\sigma_b + i\omega\epsilon_b)}{(\sigma_0 + i\omega\epsilon_0)} \quad |k_n| = \left|\frac{E_{na}}{E_{nb}}\right| = \sqrt{\frac{({\sigma_b}^2 + (\omega\epsilon_b)^2)}{({\sigma_0}^2 + (\omega\epsilon_0)^2)}}$$

The conductivity of the air results from presence of air ions (cluster ions) due to natural ionizing radiation. At relatively small field strength and large space an air conductivity can be expressed as a function of positive and negative ion concentration and their mobility:

(6) $$\sigma_0 \cong e\,[n_+\,\mu_+ + n_-\,\mu_-\,],$$

where e is an electronic charge, $1.6{\cdot}10^{-19}$ C, n_+, n_- are positive and negative air ions concentration and μ_+, μ_- positive and negative ions mobility.

At the typical air ion generation rate q = 10^7/s m^3, air conductivity is dependent on concentration of aerosol particles and can cover the range 10^{-17} S/m (in industrial polluted air) up to 10^{-15} S/m in clean rural aerial, and in the environment where the natural radiation level is elevated (e.g. rocky mountains) an air conductivity can be even more than 10^{-13} S/m. In [2] there is *a priori* put that value of air conductivity.

The available number of electric charge carriers in the atmospheric air is strongly limited (see q above). In the atmospheric air, if electrostatic field strength is a few hundred volts per meter or higher, the maximum available current density (saturation effect) can be estimated as [3] follows:

$$j_{air\,max} \cong e\,q\,L/E, \qquad (7)$$

where L is the distance between electrified object and the human body and q *is* air ion generation rate.

On the other hand the electrical characteristics of human tissues have to be known. Their strong dependence on frequency is caused by tissues cells, insulated with lipid membranes. For very low frequency the calculated electric conductivity and permittivity of some typical tissues are given in Table 1.

Table 1 Electrical parameters of some living tissues, at the frequency 10 Hz, after [4]

Tissue	Conductivity, S/m	Relative permittivity
Muscles	0.2	25 700 000
Dura	0.5	510 180
Cornea	0.41	20 105 000
Brain grey matter	0.028	40 699 000
Dry skin	0.0002	1136

Substituting (Eq. 7) to (Eq. 5), the field strength in the specific tissues can be calculated as a function of frequency and external field strength.

Results

For specific strengths and frequencies of electric field at the body surface, outside the body, the field strength inside the specific tissues was calculated in this work. The results are shown in Table 2 and Figures 1 – 4.

All calculations concerns the typical air ion generation rate q = 10^7/s m^3. At this rate the maximum possible ion concentration, limited by recombination, in clean air (no aerosol particles in it), is [5]:

$$n_+ = n_- = \sqrt{q/\alpha} = 2.5 \cdot 10^9\ /\mathrm{m}^3 \qquad (8)$$

where α is a recombination factor, equal to $1.6 \cdot 10^{-12}$ m^3/s.

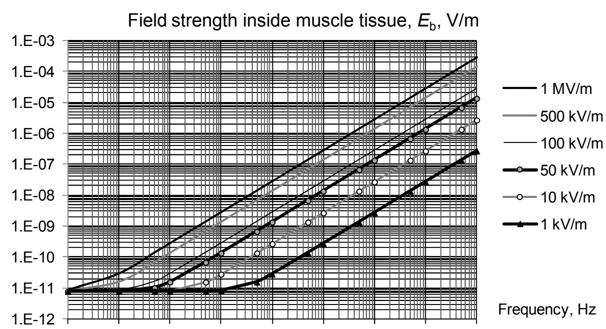

Fig. 1. Dependence of inner field strength inside muscle body tissue on field frequency and external field strength at the tissue/air boundary, for distance between the tissue and source of the filed about L = 1 m

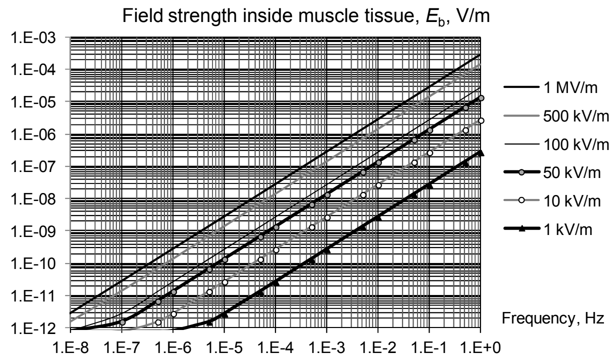

Fig. 2. Dependence of inner field strength inside muscle body tissue on field frequency and external field strength at the tissue/air boundary, for distance between the tissue and source of the filed about L = 0.1 m

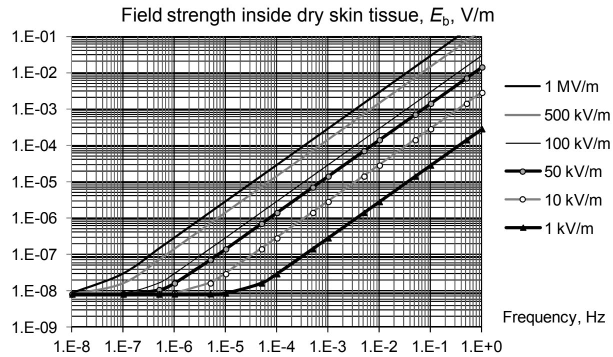

Fig. 3. Dependence of inner field strength inside dry skin on field frequency and external field strength at the tissue/air boundary, for distance between the tissue and source of the filed about L = 1 m

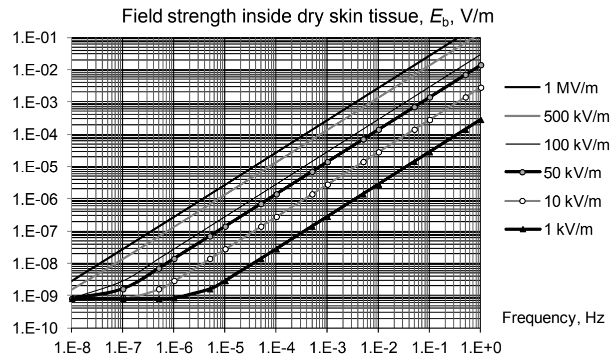

Fig. 4. Dependence of inner field strength inside dry skin on field frequency and external field strength at the tissue/air boundary, for distance between the tissue and source of the filed about L = 0.1 m

Table 2. Electric field strength inside the tissue at the external field strength equal to 1 MV/m and at the distance L = 1 m between the body and source of the field, V/m

Tissue\Frequency	Static field	0.1 Hz	1 Hz
Muscles	8.0×10^{-12}	2.8×10^{-5}	2.8×10^{-4}
Dura	3.2×10^{-12}	1.1×10^{-5}	1.1×10^{-4}
Cornea	3.9×10^{-12}	1.4×10^{-5}	1.4×10^{-4}
Brain grey matter	5.7×10^{-11}	2.0×10^{-4}	2.0×10^{-3}
Dry skin	8.0×10^{-9}	2.8×10^{-2}	0.28

Discussion and conclusions

The internal electric field strength was calculated in this work at the assumption of typical, natural rate of ions generation. There was no kind of electrical discharges analysed. In case of any discharge present, even only the weakest discharge like corona, the air conductivity can increase a few orders of magnitude. Then the field strength inside the tissues can achieve the level of cellular membranes excitation. In the absence of discharge, even at so extremely high field strength like 1 MV/m (very close to the air dielectric strength) the inner field strength does not exceed 0.3 V/m at 1 Hz and 8 nV/m at static field. Those are the values consider at this time as safe according to [1]. The attention should be paid on the fact that at field strength of the order of several kV/m or higher, there can appear electrification of the exposed body by electric induction, resulting spark discharge between the body and conducting objects if human attached those objects. The secondary hazards caused by involuntary movements can appear.

Acknowledges

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