NUMERICAL MODELLING OF CURRENT FLOWING IN HUMAN EXPOSED TO EXTERNAL ELECTRIC FIELD FOR EVALUATION OF OCCUPATIONAL EXPOSURE

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ABSTRACT

Numerical modelling of current flowing through the feet of human exposed to electric field was done. Computer calculations were carried out using the finite element method for the homogeneous cylindrical model of the human body. Geometrical and electrical parameters of model were changed. Results of numerical calculations were compared with experimental measurements inside the laboratory vertical polarised sinusoidal electric field of high frequency and at the real work stands.
These investigations have been carried out to obtain suitability of numerical simulations as alternative method of evaluation of occupational exposure to a strong electric field.

BACKGROUND

In an external electric field an induced current flows through the human body. Routine evaluation of occupational exposure to electric field is based on measurements of electric field strength unperturbed by the presence of people or by environmental elements. The permissible values of field strength are determined so that under the most unfavourable conditions the most unfavourable current induced in the human body by a uniform electric field does not exceed the levels that are admitted as far as the health effects are concerned. The most adverse case is the one when a person stands in the electric field of a vertical polarization. It was found both experimentally and analytically that such a person concentrates in his or her body the lines of forces found in an area of some 5.5 m^2 [1]. This kind of evaluation omits the fact that there is no direct correlation between electrodynamics effects inside human body and values of field strength outside it.
Of this reason when a more precise assessment of the actual risk is needed, the evaluation that is based on measurements of the field strength is replaced by a more objective evaluation that is based in turn on the so-called internal measures, among others the induced current, including the so-called “foot current” which flows through the exposed human body into the ground. The induced current depends not only on the mean strength of the field that affects the human but also on the size and the shape of the human body and the electric properties of the shoes or the insulating base, uniformity of the field in the particular area where the person remains, position of the exposed body in relation to electric field polarisation, while it is difficult to determine the functional relation between the flowing current and, for instance, the strength of the field or the height of particular person. The value of current can be the measure that is more approximate to results of field interactions with people.
The permissible values of the induced current (including the foot one) were fixed for the occupational exposure and for the general public in the international ICNIRP recommendations [2], in the American IEEE [3] and ACGIH [4] ones and in the CENELEC draft standard [5].

METHODS OF INVESTIGATIONS

Presented investigations were orientated at establishing the conditions, in which the measurements of “foot current” can be replaced by numerical calculations of cylindrical homogeneous model of human body and it’s surroundings in 2D and 3D geometry, accurately enough to evaluate the occupational exposure according to numerical simulations results [6, 7, 8].
Numerical calculations were carried out using the finite element method within sub-resonance frequency range (below 40 MHz). Program FAT (Field Analysis Translator, Technical University of Warsaw, Poland) for electrostatic models 2D and program OPERA (Operating Environment for Electromagnetic Research and Analysis, Vector Field Limited, UK) for electrostatic and with waves effects models 3D were used [6]. Geometrical and electrical parameters (high, radius and electric permittivity – corresponding to human body) were appointed for the homogeneous models of the body. This procedure permits simulation of human exposition. The calculations took into account the vertical field polarisation. Capacitive model of analysed object is given in Fig. 1.

Contract grant sponsor: State Committee for Scientific Research of Poland; grant number: 8T10A 048 20

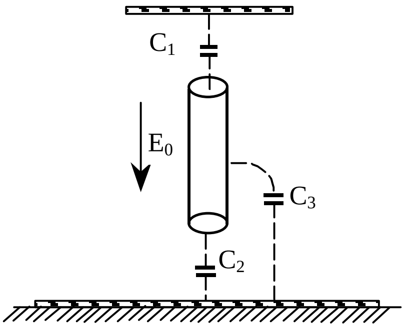

Fig. 1. Capacitive model of analysed object (C_1, – capacity coupling cylindrical model with powered upper plate of the field source, C_2, C_3 – capacities coupling cylindrical model with low plate of field source and substrate).

Calculations were carried out for the model short-circuited to the substrate (a case where a man has his or her bare feet on a conductive substrate) and for situation where the model is insulated from the substrate (this case takes into account shoes or an insulating substrate). Various permittivities of typical materials were assumed (ranging from 2 to 3). Numerical calculations were compared with measurement results.
The walls of the laboratory room, floor and the bottom plate of the capacitor were simulated as the equipotential surfaces (reference potential equals 0). 1/8 part of geometry of numerical model used in simulation is given in Fig. 2..

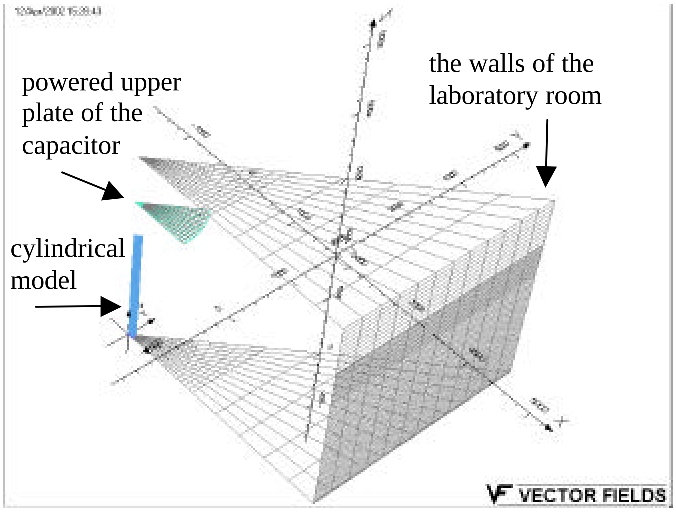

Fig. 2. Sector (1/8) of geometry of model used in numerical calculations.

Experimental investigations inside the laboratory vertical polarised electric field source and at the real work stands in the field of unlimited polarisation were carried out on volunteers and phantoms, too. The laboratory source of the vertically polarised sinusoidal electric field was a parallel-plate capacitor, where the wave effects resulting from dimensions of the capacitor and laboratory room (7x4 m maximum) were negligible. The powered electrode of the capacitor could be varied from 0.5 to 5 m^2. The induced current meter Narda model 8850 was used in the experimental investigations. The measurements were carried out in the of unlimited polarisation field conditions of the actual exposure found at: dielectric welders and presses (~27 MHz), electrosurgery equipment (~300 kHz), physiotherapeutic short-wave diathermy (~27 MHz), radio broadcasting devices (in the frequency range 220 kHz – 12 MHz).

RESULTS

The results of computer calculations and laboratory experiments indicate that the value of current flowing through the body into the ground substantially depends on the high of the people and insulation of the base. For example the reduction of the height of the cylindrical model short-circuited to the ground by 25% was the reason of the reduction of the induced current by 43% (fig.3a). Insulation of the base reduced the "foot current" several times in comparison to the worst case, when feet are short-circuited (Fig. 3 b). For the non-insulated model of human, value of calculated "foot current" were about 0.78-0.87 of measured "foot current" for exposed people (Fig. 4).

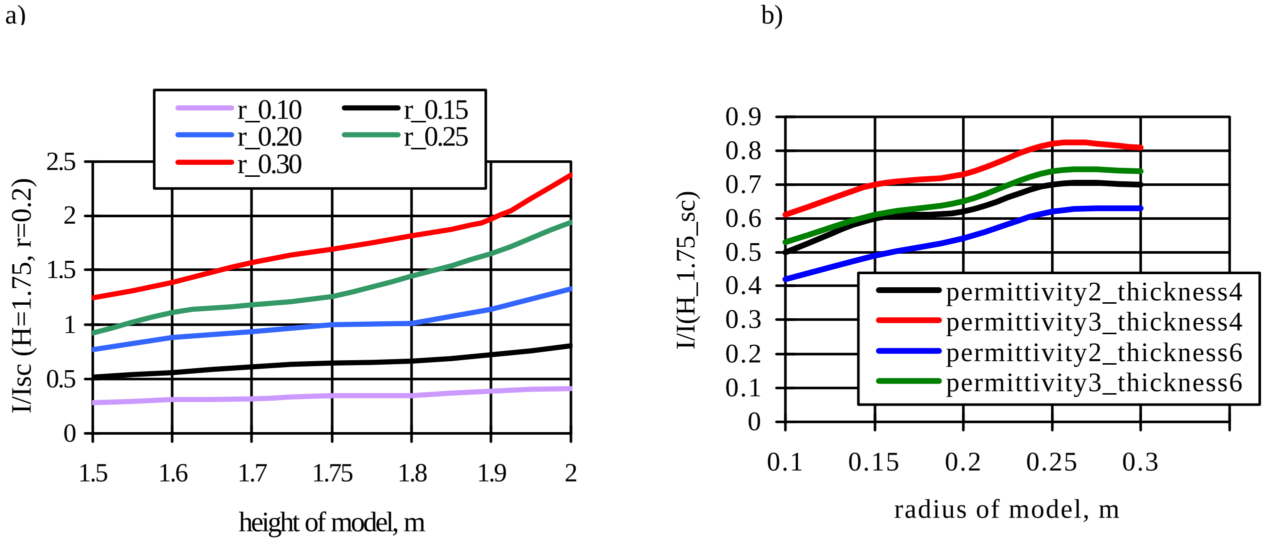

Fig. 3. Results of numerical calculation of „foot current" of cylindrical model: a) model short-circuited: relation of "foot current" in model of various height and radius to standard model (height 1.75; radius 0.2 m); b) model insulated from the substrate: relation of "foot current" in model of various radius and various parameters of insulation to short-circuited model of height 1.75 m (relative permittivity of human model is $80\varepsilon_o$ - permittivity of the water).

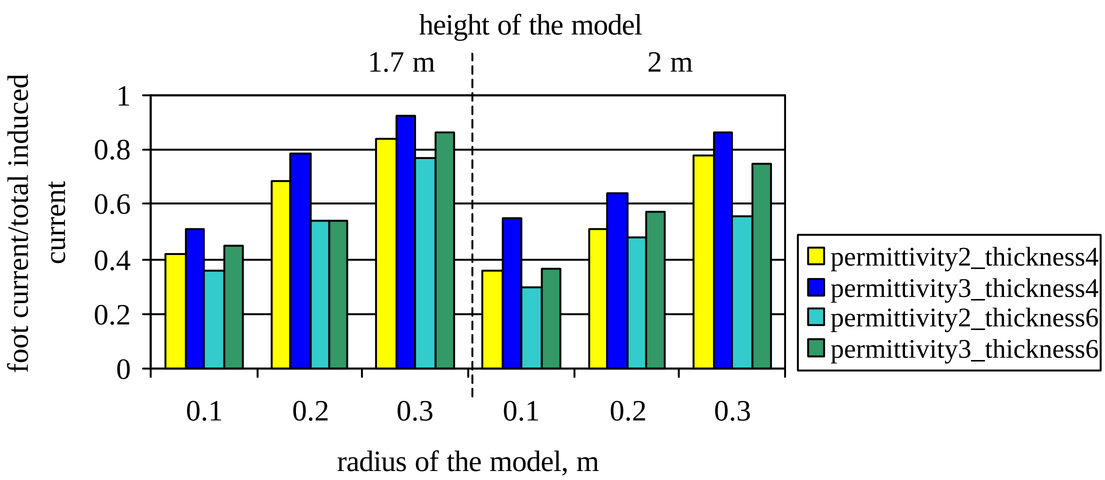

Fig. 4. Comparison of the value of the current flowing through the feet with the total value of the current induced in a insulated from the base model of human body (parameters of insulation and model selected for presentation: electric permittivity - $2\varepsilon_0$ or $3\varepsilon_0$; thickness of insulation - 4 or 6 cm; electric permittivity of model - $80\varepsilon_0$).

"Foot current" investigations carried out in real conditions of occupational exposure to vertically polarised electric field did not give the direct correlation between current flowing through insulated from the ground people and through phantoms. The reason is that "foot current" depends on position of exposed person in relation to field polarisation and on human-ground impedance (because of different kinds of base and shoes). Computer simulation showed that only even (30-85)% of entire induced current flows through the feet – depending on geometrical parameters of the model of human body and insulation from the substrate. Remaining part of the current flows through capacity coupling lateral area of human body or his model with substrate (capacity C_3 from fig. 1). Numerical simulations showed that current flowing through coupling capacity is observed beginning from half of height model.

CONCLUSIONS

The results of computer calculations indicate that assumption of human body model with homogeneous structure and suitable electrical parameters of it, can be sufficient for estimation of current that flow through exposed worker. The results of numerical calculation have showed that use similar homogenous models can be helpful to evaluate human exposure in the electric field and for managing of safety and health at work.

BIBLIOGRAPHY

[1] H. Korniewicz, Om. P.Gandhi, “Foot current”, grant Maria Sklodowska-Curie Polish-American Joint Fund MZ/HHS- 96240, 1996-1997, unpublished.

[2] ICNIRP (International Commission on Non-Ionizing Radiation Protection), “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)”, *Health Physics, vol. 74*, No. 4 (April), pp.494-522, 1998

[3] IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300GHz. IEEE Std C95.1, 1999 Edition Published by the Institute of Electrical and Electronics Engineers, New York, USA, 1999.

[4] ACGIH (American Conference Government Industrial Hygienists). “TLVs and BEIs. Based on the Documentation for Threshold Limit Values for Chemical Substances and Physical Agents Biological Exposure Indices,” Cincinnati, OH, 2001.

[5] ENV 50166. CENELEC EUROPEAN PRESTANDARD. “Human exposure to electromagnetic fields. Low–frequency (0 Hz to 10 kHz). High–frequency (10 kHz to 300 GHz)”, 1995.

[6] K. Gryz, S. Wincenciak, “Numerical modelling of current flowing in human exposed to external electric field,” Central Institute for Labour Protection, Warsaw, 2000-2001, unpublished.

[7] K. Gryz, J. Karpowicz, “Experimental and Theoretical Investigations of "Foot Current" in a Human Body Exposed to an Electric Field”, EUROEM 2000 Euro Electromagnetics, Edynburg, 2000.05.30-06.02, pp. 74.

[8] K. Gryz, J. Karpowicz, “"Foot Current" in a Human Body Exposed to an Electric Field”, 3rd International ELMECO 2000 "Electromagnetic Devices and Processes in Environment Protection", Naleczow, 04-06.06.2000, pp. 53-57