INTERNATIONAL STANDARD

NORME INTERNATIONALE

IEC
CEI

62226-3-1

First edition
Première édition
2007-05

Exposure to electric or magnetic fields in the low and intermediate frequency range – Methods for calculating the current density and internal electric field induced in the human body –

Part 3-1:
Exposure to electric fields – Analytical and 2D numerical models

Exposition aux champs électriques ou magnétiques à basse et moyenne fréquence – Méthodes de calcul des densités de courant induit et des champs électriques induits dans le corps humain –

Partie 3-1:
Exposition à des champs électriques – Modèles analytiques et numériques 2D

Reference number
Numéro de référence
IEC/CEI 62226-3-1:2007

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE
CODE PRIX
XA

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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International Standard IEC 62226-3-1 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

This standard is to be used in conjunction with the first edition of IEC 62226-1:2004, *Exposure to electric or magnetic fields in the low and intermediate frequency range – Methods for calculating the current density and internal electric field induced in the human body – Part 1: General.*

The text of this standard is based on the following documents:

FDIS	Report on voting
106/125/FDIS	106/128/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard constitutes Part 3-1 of IEC 62226 series, which will regroup several international standards and technical reports within the framework of the calculation of induced current densities and internal electric fields.

A list of all parts of the IEC 62226 series, published under the general title *Exposure to electric or magnetic fields in the low and intermediate frequency range – Methods for calculating the current density and internal electric field induced in the human body,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

Public interest concerning human exposure to electric and magnetic fields has led international and national organisations to propose limits based on recognised adverse effects.

This standard applies to the frequency range for which the exposure limits are based on the induction of voltages or currents in the human body, when exposed to electric and magnetic fields. This frequency range covers the low and intermediate frequencies, up to 100 kHz. Some methods described in this standard can be used at higher frequencies under specific conditions.

The exposure limits based on biological and medical experimentation about these fundamental induction phenomena are usually called “basic restrictions”. They include safety factors.

The induced electrical quantities are not directly measurable, so simplified derived limits are also proposed. These limits, called “reference levels” are given in terms of external electric and magnetic fields. They are based on very simple models of coupling between external fields and the body. These derived limits are conservative.

Sophisticated models for calculating induced currents in the body have been used and are the subject of a number of scientific publications. These models use numerical 3D electromagnetic field computation codes and detailed models of the internal structure with specific electrical characteristics of each tissue within the body. However such models are still developing; the electrical conductivity data available at present has considerable shortcomings; and the spatial resolution of models is still progressing. Such models are therefore still considered to be in the field of scientific research and at present it is not considered that the results obtained from such models should be fixed indefinitely within standards. However it is recognised that such models can and do make a useful contribution to the standardisation process, specially for product standards where particular cases of exposure are considered. When results from such models are used in standards, the results should be reviewed from time to time to ensure they continue to reflect the current status of the science.

EXPOSURE TO ELECTRIC OR MAGNETIC FIELDS IN THE LOW AND INTERMEDIATE FREQUENCY RANGE – METHODS FOR CALCULATING THE CURRENT DENSITY AND INTERNAL ELECTRIC FIELD INDUCED IN THE HUMAN BODY –

Part 3-1: Exposure to electric fields – Analytical and 2D numerical models

1 Scope

This part of IEC 62226 applies to the frequency range for which exposure limits are based on the induction of voltages or currents in the human body when exposed to electric fields.

This part defines in detail the coupling factor K – introduced by the IEC 62226 series to enable exposure assessment for complex exposure situations, such as non-uniform magnetic field or perturbed electric field – for the case of simple models of the human body, exposed to uniform electric fields. The coupling factor K has different physical interpretations depending on whether it relates to electric or magnetic field exposure. It is the so called "shape factor for electric field".

This part of IEC 62226 can be used when the electric field can be considered to be uniform, for frequencies up to at least 100 kHz.

This situation of exposure to a "uniform" electric field is mostly found in the vicinity of high voltage overhead power systems. For this reason, illustrations given in this part are given for power frequencies (50 Hz and 60 Hz).

2 Exposure to electric field

Alternating electric fields are generated by energised conductors (i.e. under voltage). In the immediate vicinity of domestic electrical equipment, such as lights, switches, food mixers and irons, local electric-field strengths about 100 V/m may be found. Such fields are non-uniform, but their strengths are far below the levels recommended in safety guidelines, so there is no need of calculation of induced currents in such exposure situations.

Higher electric-field strengths may be found in the vicinity of high voltage equipment such as electric power line. In the frequency range covered by this standard, it is considered that exposure from power lines is the only significant exposure source for public regarding safety guidelines limits.

Guidelines on human exposure to electric fields are generally expressed in terms of induced current density or internal electric field. These quantities cannot be measured directly and the purpose of this document is to give guidance on how to assess these quantities induced in the human body by external (environmental) electric fields E_0.

The induced current density J and the internal electric field E_i are closely linked by the simple relation:

$$J = \sigma . E_i \tag{1}$$

where σ is the conductivity of the body tissue under consideration.

For reason of simplification, the content of this standard is presented in terms of induced current densities J, from which values of internal electric field E_i can be easily derived using the previous formula.

All the calculation developed in this document use the low frequency approximation in which displacement currents are negligible, such that $\varepsilon\omega/\sigma$ is less than 1 in the body. This approximation has been checked using published tissue data [29,31] [1)] in the low frequency range and it has been found to be valid for frequencies up to at least 100 kHz and is probably valid at higher frequencies.

Computations based on sophisticated numerical models of the human body [24] also demonstrate that this assumption is valid at frequencies up to more than 100 kHz by showing that the relationship between the induced current density in the body and the product of frequency and external electric field hardly varies at all between 50 Hz and 1 MHz, and is only slightly altered at 10 MHz.

Analytical models can be used for simple cases of calculations.

Electric fields cause displacement of electric charges in conductive objects (including living bodies) and, because these fields are alternating, the electric charges move backwards and forwards. The result is an “induced” alternating current inside the conductive object. This current depends only on:

– the shape and size of the conducting object;
– the characteristics (magnitude, polarisation, degree of non-uniformity, etc.) of the unperturbed field (field which is measured in the absence of any conducting object);
– the frequency of the field
– the variation of conductivity of the object (in homogeneous media, the current density induced by electric fields does not depend on conductivity).

Figure 1 illustrates this induction phenomenon for the case where the body is in electrical contact with the ground.

[1)] Figures in square brackets refer to the Bibliography.

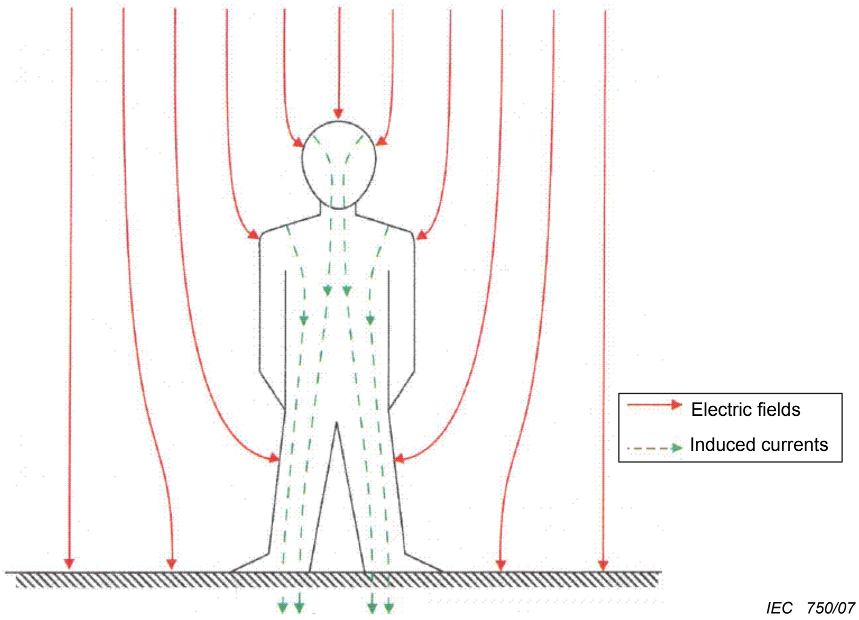

Figure 1 – Illustration of the phenomenon of currents induced by an electric field in a human body standing on the ground

The typical case of public exposure to an electric field is under high voltage power transmission lines. In this case, the distance between the source of field and the human body is large and the field in the zone close to the ground, in the absence of any conductive object, can be considered to be uniform (see Figure 2).

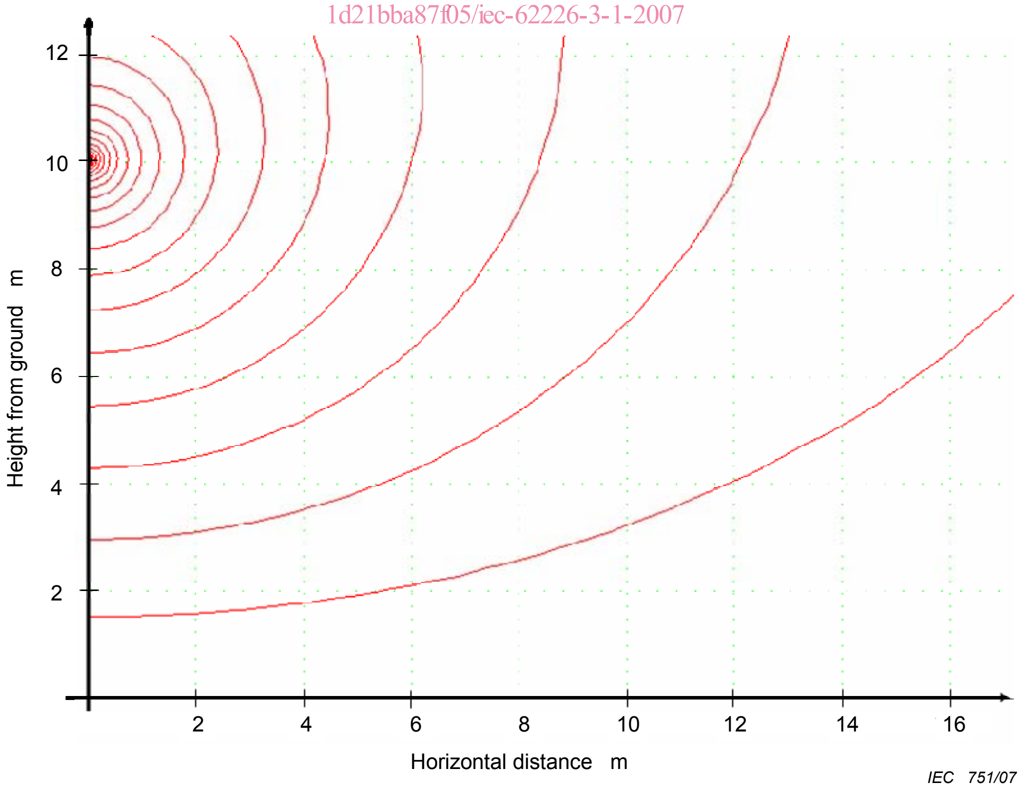

Figure 2 – Potential lines of the electric field generated by an energised wire in the absence of any objects (all distances in metres)

3 General procedure

3.1 Shape factor

In the low and intermediate frequency range, the relation between the induced current in the human body (J) and a uniform electric field (E_0) can be reduced to:

$$J = K_E . f . E_0 \tag{2}$$

Where:

f is the frequency;

E_0 is the magnitude of the unperturbed electric field;

K_E is defined as the "*shape factor for the electric field*".

K_E is dependant on the size, the conductivity, the form and the position of the model of the human body. It is also dependant on the location within the body where the induced current density is evaluated. K_E is independent of the frequency for analytical assessment of the induced current produced by electric fields (see Annex A).

K_E is given in units of $A \cdot s \cdot V^{-1} \cdot m^{-1}$ or Farad per metre (F/m), which relates to the fact that the exposure to the electric field corresponds physically to a capacitive coupling between the field source and the conductive object exposed to the field.

3.2 Procedure

The current density inside an individual can be estimated analytically, following a three stage process. The first stage is to compute the current density in a semi-spheroid, whose dimensions are chosen to best represent the particular body. As it will be shown in 5.3 of this standard, the current density is uniform throughout the spheroid but depends on the ratio L/R of its semi-major axis and semi-minor axis.

The second stage is to use a realistic axisymmetrical model of a human body to determine the current density as a function of vertical position within the body.

The third stage is to convert the average current density at a particular vertical position to the local current density in the different tissues at that height. Health guidelines on exposure to EMF refer specifically to current density in the central nervous system, so the particular area of interest within the body is the spinal cord in the neck, due to the small cross section of the neck, which concentrates the current in that region.

Induced currents are calculated for men and women as well as children using reference values for their height, mass and surface area published by ICRP [38]. Sufficient information is given here to apply the method to persons of any weight and height.

Numerical calculations are also presented demonstrating the validity of the analytical procedure.

4 Human body models

4.1 General

In scientific literature, many models of different complexity have been used for the assessment of currents and internal fields induced by electric or magnetic field (Figure 3). Examples of such sophisticated calculations are given in the bibliography. It must be emphasised that these computations have been performed using dedicated softwares which require highly specialised competences and are not widely available. Therefore, it is considered that such computational techniques are not relevant with regard to standardisation objectives.

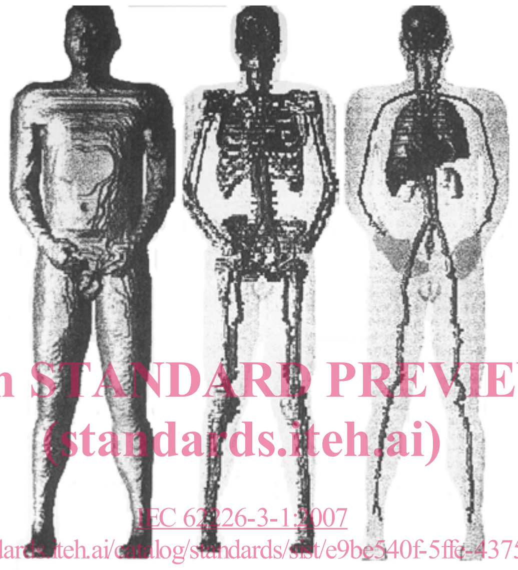

Figure 3 – A realistic body model

Analytical calculations are possible when using simple models, such as the model of a spheroid in a uniform electric field.

4.2 Surface area

The surface area of a body (SB) is used to scale both the spheroidal and the axisymmetrical body models for different sized bodies. It depends on the height and the mass of the body. The report of the ICRP [38], *Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values*, provides an algorithm giving the total surface area (SB_T) of a person as a function of its height L (in metres) and mass M (in kg):

$$SB_T = 0{,}164\,4\ M^{0{,}514\,56} L^{0{,}422\,46} \tag{3}$$

In our case, only the outwards-facing surface area of the body is considered, which is approximately 82 % of the total surface area SB_T. The 18 % reduction comprises 3 % for excluding the soles of the feet, 6 % for excluding the touching surface of the legs, and 8 % for excluding the inner surface of the arms and hands and 1 % for the perineum. The reduced surface area (SB_R) is therefore:

$$SB_R = 0{,}82\, SB_T \tag{4}$$

Table 1 gives the results for the reference man and the reference woman which are introduced in 4.4 and Annex B.

Table 1 – Data for reference man and reference woman

	Reference man	Reference woman
Height, m	1,76	1,63
Mass, kg	73	60
Total surface area SB_T, m^2	1,889	1,662
Reduced surface area SB_R, m^2	1,557	1,363

4.3 Semi-spheroidal model

To calculate the induced current density inside a human standing on a conducting plane it is necessary to model the reflection of the body in the ground. Thus the body is represented by half of the spheroid (Figure 4) and the reflection by the other half (Figure 7). The semi-major axis L of the spheroid is set to the height of the person being represented.

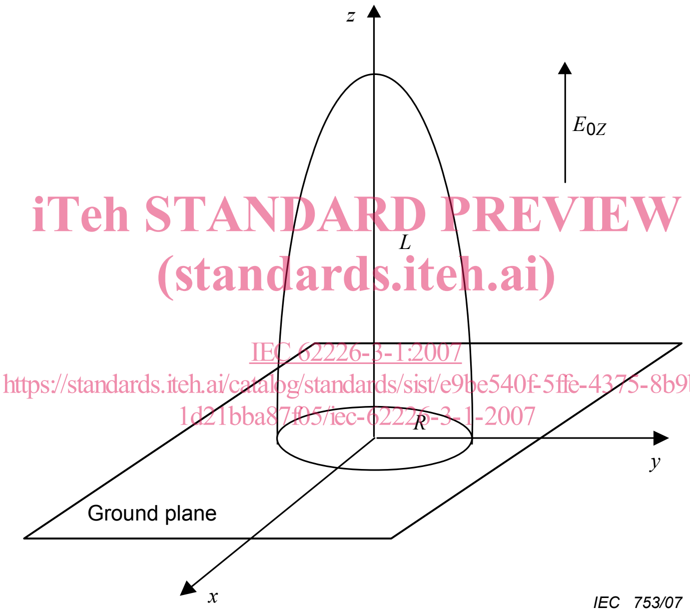

Figure 4 – Scheme of the semi-spheroid simulating a human being standing on a zero potential plane

The semi-minor axis (i.e. the radius) R is chosen to give the same total current flowing into the ground through the feet when the body is grounded as for the body it represents. This is achieved by ensuring that the spheroid has the same outward-facing surface area SB_R as the body it represents.

The surface area SB_S of a half spheroid of height L and radius R is given by:

$$SB_S = \pi R^2 \left[1 + \frac{L}{R} \frac{\arcsin(e)}{e} \right] \quad (5)$$

where e is the eccentricity: