भारतीय मानक

Indian Standard

IS 18483 (Part 3) : 2024
IEC 62822-2 : 2023

विद्युत वेल्डिंग उपकरण — मानव से संभंधित प्रतिबंधों का आँकलन विद्युत चुम्बकीय छेत्रों के संपर्क में (0 Hz से 300 GHz)

भाग 3 रेजिस्टेंस वेल्डिंग उपकरण

Electric welding equipment — Assessment of Restrictions Related to Human Exposure to Electromagnetic Fields (0 Hz to 300 GHz)

Part 3 Resistance Welding Equipment

ICS 25.160.30

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NATIONAL FOREWORD

This Indian Standard which is identical to IEC 62822-3 : 2023 'Electric welding equipment — Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) — Part 3: Resistance welding equipment' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Electric Welding Equipment Sectional Committee and approval of the Electrotechnical Division Council.

Other two parts of this series of standards covers:

Part 1 Product family standard
Part 2 Arc welding equipment

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60974-1 Arc welding equipment — Part 1: Welding powersources	IS 16593 (Part 1) : 2024/ IEC 60974-1 : 2021 Arc welding equipment: Part 1 Welding power sources (*first revision*)	Identical
IEC 60974-6 Arc welding equipment — Part 6: Limited duty equipment	IS 16593 (Part 6) : 2022/ IEC 60974-6 : 2015 Arc welding equipment: Part 6 Limited duty equipment (*first revision*)	Identical
IEC 62226-2-1 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 2-1: Exposure to magnetic fields — 2D models	IS/IEC 62226-2-1 : 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 2-1 Exposure to magnetic fields, Section 1 2D Models	Identical
IEC 62311 Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300GHz)	IS/IEC 62311 : 2019 Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz) (*first revision*)	Identical

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CONTENTS

Indian Standard

ELECTRIC WELDING EQUIPMENT — ASSESSMENT OF RESTRICTIONS RELATED TO HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS (0 HZ TO 300 GHZ)

PART 3 RESISTANCE WELDING EQUIPMENT

1 Scope

This part of IEC 62822 applies to equipment for resistance welding and allied processes designed for occupational use by professionals and for use by laymen.

More generally, this document covers equipment for which the welding current flows in an electrical circuit whose geometry cannot be changed and regardless of the technology of the current generator (for example LF-AC, MF-DC for spot or seam welding or capacitive discharge used for stud welding).

NOTE 1 Allied processes such as resistance hard and soft soldering or resistance heating achieved by means comparable to resistance welding equipment are included as well.

This document specifies procedures for the assessment of human exposure to magnetic fields produced by resistance welding equipment. It covers non-thermal biological effects in the frequency range from 0 Hz to 10 MHz and defines standardized test scenarios.

NOTE 2 The general term “field” is used throughout this document for “magnetic field”.

NOTE 3 For the assessment of exposure to electric fields and thermal effects, the methods specified in IEC 62311 or relevant basic standards will apply.

This document aims to propose methods for providing EMF exposure data that can be used to assist in the assessment of the workplace, especially when the conditions of use of the equipment are not known. When these are technically constrained (for example, a double hand control imposes the position and posture of the user), the data can be directly exploitable if they fall within the scope specified by the manufacturer or the integrator.

Other standards can apply to products covered by this document. In particular this document cannot be used to demonstrate electromagnetic compatibility with other equipment. It does not specify any product safety requirements other than those specifically related to human exposure to electromagnetic fields.

This document proposes several methods to assess the exposure to EMF, from simple to sophisticated, with the latter providing more precise assessment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-851:2008, *International Electrotechnical Vocabulary (IEV) – Part 851: Electric welding* (available at www.electropedia.org)

IEC 60974-1, *Arc welding equipment – Part 1: Welding power sources*

IEC 60974-6, *Arc welding equipment – Part 6: Limited duty equipment*

IEC 61786-1, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments*

IEC 61786-2:2014, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 2: Basic standard for measurements*

IEC 62226-2-1, *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 2-1: Exposure to magnetic fields – 2D models*

IEC 62311, *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz)*

IEC 62822-1:2016, *Electric welding equipment – Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) – Part 1: Product family standard*

3 Terms, definitions, quantities, units, constants and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-851, IEC 60974-1, IEC 60974-6, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
basic restriction
restriction on exposure to electric, magnetic and electromagnetic fields that is based directly on established health effects and biological considerations

Note 1 to entry: Basic restrictions are also named dosimetric reference limits (DRLs) and exposure limit values (ELVs).

3.1.2
coupling-coefficient
CC_{YX}
relation allowing to estimate Y from X

EXAMPLE CC_{EI} gives the maximum induced electric field inside a region of the human body according a unit welding current.

Note 1 to entry: Keeping in mind that the electric conductivity can be frequency dependent, a conversion between CC_{JI} and CC_{EI} or CC_{JB} and CC_{EB} is possible with the relation given in Formula (1)

$$\boldsymbol{J}(j\omega) = \sigma(j\omega) \cdot \boldsymbol{E}(j\omega) \tag{1}$$

where

J is the electric current density, expressed in ampere per square meter;

E is the electric field strength, expressed in volt per meter;

σ is the conductivity, expressed in siemens per meter;

ω is the angular frequency ($2 \cdot \pi \cdot f$), expressed in radians per second".

3.1.3
exposure index
EI
result of the evaluation of exposure to (both sinusoidal and non-sinusoidal) EMF, expressed as a fraction or percentage of the permissible values

Note 1 to entry: Fractions higher than 1 (100 %) exceed the permissible values.

3.1.4
general public
individuals of all ages and of varying health conditions

3.1.5
intracorporeal
situated or occurring within the body

3.1.6
layman
operator who does not weld in the performance of his profession and may have little or no formal instruction in welding

[SOURCE: IEC 60050-851:2008, 851-11-14, modified – "arc welding" was replaced with "welding".]

3.1.7
non-thermal effect
stimulation of muscles, nerves or sensory organs as a result of human exposure to EMF

3.1.8
occupational exposure
exposure of workers to EMF at their workplaces, generally under known conditions, and as a result of performing their regular or assigned job activities

Note 1 to entry: A worker is any person employed by an employer, including trainees and apprentices.

3.1.9
reference level
directly measurable quantity, derived from basic restrictions, provided for practical exposure assessment purposes

Note 1 to entry: Reference levels are also named exposure reference levels (ERLs) and action levels (Als).

Note 2 to entry: Respect of the reference levels will ensure respect of the relevant basic restriction. If the reference levels are exceeded, it does not necessarily follow that the basic restriction will be exceeded.

3.1.10
resistance welding system
combination of power source, transformer, cabling and welding circuit

3.1.11
sensory effect
transient disturbed sensory perceptions and minor change in brain functions as a result of human exposure to EMF

3.1.12
standardized configuration
configuration reflecting the normal operator positions

3.1.13
standardized distance
distance from the axis of a part of the welding circuit to the closest surface of the body in standardized configurations

3.1.14
welding circuit
conductive material through which the welding current is intended to flow

Note 1 to entry: In resistance welding, the workpieces are not part of the welding circuit for the purposes of this document.

[SOURCE: IEC 60050-851:2008, 851-14-10, modified – the two notes to entry have been deleted, and a new note to entry has been added.]

3.2 Quantities and units

The internationally accepted SI units are used throughout this document.

Symbols throughout this document set in bold type are vector quantities.

Physical quantity	Symbol	Unit	Dimension
Electric conductivity	σ	Siemens per metre	$S \cdot m^{-1}$
Electric current	I	Ampere	A
Electric current density	$\boldsymbol{J}$	Ampere per square metre	$A \cdot m^{-2}$
Electric field strength	$\boldsymbol{E}$	Volt per metre	$V \cdot m^{-1}$
Frequency	f	Hertz	Hz
Magnetic flux density	$\boldsymbol{B}$	Tesla	T ($V \cdot s/m^2$)
Magnetic permeability	μ	Henry per metre	$H \cdot m^{-1}$
Wavelength	λ	Metre	m

3.3 Constants

Physical constant	Symbol	Magnitude	Dimension
Permeability of free space	μ_0	$4 \cdot \pi \cdot 10^{-7}$	$H \cdot m^{-1}$

3.4 Symbols

Symbols used in this document are expanded hereafter.

Symbols	Meaning
*	Convolution product i.e. $B(t)*WL(t)$ means filtering $B(t)$ by $WL(t)$
t	Time
f	Frequency of a single frequency signal
$B(t)$	Magnetic flux density (magnetic field) in the time domain
$B(f)$	Magnetic flux density (magnetic field) in the frequency domain
$B_{\text{RL}}(f)$	B reference level at f
$W_{\text{RL}}(t)$	Time (impulse) response of the weighted filter according to the reference level
$W_{\text{RL}}(f)$	Frequency response of the weighted function according to the reference level
EI_{RL}	Exposure index according to the reference level
$I(t) / I$	Welding current in the time domain/frequency domain
CC_{BI}	Coupling coefficient from I to B (frequency independent)
$\mathcal{F}^{-1}$	Inverse Fourier transform
dB/dt	Time derivate of the magnetic flux density
R	Disk radius of 2D geometric model
E_{i}	Induced or internal electric field
dI/dt	Time derivate of the welding current
$W_{\text{BR}}(t)$	Time (impulse) response of the weighted filter according to the basic restriction
$W_{\text{BR}}(f)$	Frequency response of the weighted function according to the basic restriction
$CC_{\text{EB/2D}}$	Coupling coefficient from B to E_{i} with geometric model
$CC_{\text{EI/HM}}$	Coupling coefficient from I to E_{i} with human model
EI_{BR}	Exposure index according to the exposure limit value (basic restriction)
k_{E}	Exposure index coefficient
CEI_{BR}	Current exposure index according to the basic restrictions

4 Requirements

Equipment shall be assessed as defined in Clause 5.

If the assessment is conducted using measured or calculated external field levels, 5.2 shall be applied in conjunction with Clause 6.

If the assessment is conducted using corporal quantities, 5.3 shall be applied in conjunction with Clause 6 if measurements are performed and in conjunction of Clause 7 if a human model is applied.

The results shall be reported as specified in Clause 9.

5 Assessment methods

5.1 General

Clause 5 provides basic assessment methods considering the direct effects of electromagnetic fields [2], [3], [4], [5], [6], [7], [8][1]. Evaluations are made either against basic restrictions or against derived reference levels. In international guidelines, different limits on basic restrictions and reference levels are defined for stimulation effects which are considered for exposure to low frequency magnetic fields.

There are five methods to assess the welding equipment exposure and to demonstrate conformity or give enough information to demonstrate it with the reference levels or basic restrictions, or both. Any of the five methods can be selected, depending on which is the most relevant for the exposure assessment. If one of the first four methods does not lead to compliance, another can be chosen. The ultimate method is the fifth (dosimetry with human model).

While the evaluation based on measuring incident magnetic fields against reference levels is the easiest method (see 5.2.2), the evaluation based on computed magnetic field from the welding current can predict the exposure, and it does not require a field meter (see 5.2.3). Those methods are necessarily more conservative than the assessment of exposure according to induced quantities against basic restrictions.

Thus, the evaluation of internal (or induced) E-field or current density against basic restrictions (5.3) is performed with more realistic exposure conditions considering mainly the heterogeneity of the magnetic field.

Evaluations of induced fields against basic restrictions using simple (geometric) models are methods of intermediate complexity (see 5.3.2 and 5.3.3). As these methods have to cover a large number of situations, they are conservative most of the time and in extreme cases, they become accurate.

Lastly, evaluation of induced fields against basic restrictions with an electrical representative human body is the most rigorous and reduces uncertainties. It requires simulation after a faithful modelling of the environment (see 5.3.4).

5.2 Methods based on reference levels

5.2.1 General

The assessments are based on external (incident) magnetic fields against reference levels.

Reference levels have been derived from the basic restrictions considering the conditions which maximized the exposure (whole body exposure to a uniform field). Such an assessment is conservative under all non-uniform and local exposure conditions, which is the case in most occupational exposure situations. Therefore, this method is simple but it overestimates exposure to welding equipment most of the time.

The exposure level is determined by a comparison of the magnetic field and the relevant exposure limits applicable to the affected regions of the body.

[1] Numbers in square brackets refer to the Bibliography.

5.2.2 Assessment based on measured magnetic field

5.2.2.1 General

The method based on the measured magnetic field is convenient when the use of equipment is known. In general, the assessment is performed on one or two welder positions.

Exposure shall be performed on the trunk, near the head, on both hands and on the thighs when they are the closest part to the welding electric circuit. This leads to four, sometimes five, measurement points on each welder position as described in 5.2.2.2 to 5.2.2.4. The measuring points are the places where the measured level is the maximum (worst-case point) of the different parts of the body. In general, they are closest to the welding circuit. A scan on the surface of each body part can help determine these positions.

The reading values at these points should be recorded together with the positions in the compliance testing report in order to carry out reproduceable measurements.

In practice, a magnetic field meter is able to measure either the magnetic field (in tesla) or the exposure index directly according to the relevant exposure limit. Most often the meter incorporates the weighted peak method in the time domain (methods with an RMS detector shall not be used in the low frequency range). This method is relevant for any kind of magnetic field waveform (sine, burst, pulsed, or square). In particular, it takes into account the transients when the current starts and stops to flow. The meter applies directly the formula:

$$EI_{\mathrm{RL}} = \max\left|W_{\mathrm{RL}}(t) * B(t)\right| \tag{2}$$

where

* represents the convolution product, i.e. the filtering of $B(t)$ by $W_{\mathrm{RL}}(t)$;

$W_{\mathrm{RL}}(t)$ is the time response of a frequency weighting function $W_{\mathrm{RL}}(f)$ relevant to the reference level;

EI is a dimensionless number. Compliance is guaranteed when it is equal to or less than 1 or 100 % if expressed as a percentage;

$W_{\mathrm{RL}}(f)$ is the inverse peak value of the exposure limit (B_{RL} in RMS value) at the frequency f, i.e.

$$W_{\mathrm{RL}}(f) = \frac{1}{\sqrt{2} \cdot B_{\mathrm{RL}}(f)}$$

The probe is positioned on the region of the body or at defined positions on particular parts of the equipment as gun handles. It can also be positioned by hook-and-loop fasteners on the helmet, gloves or apron. An appropriate cable to attach the probe to the detector can be used, for example in a tight workspace or to prevent discomfort to the welders.

The results allow to conclude on the compliance according to the reference levels under the present situation.

5.2.2.2 Exposure of the head

The maximum exposure level should be sought around the head, and more specifically, if desired, around the central nervous system (CNS) of the head. The measurement point is located in contact with the head at a location closest to the welding circuit, as illustrated in Figure 1. A scan of the head surface can help.

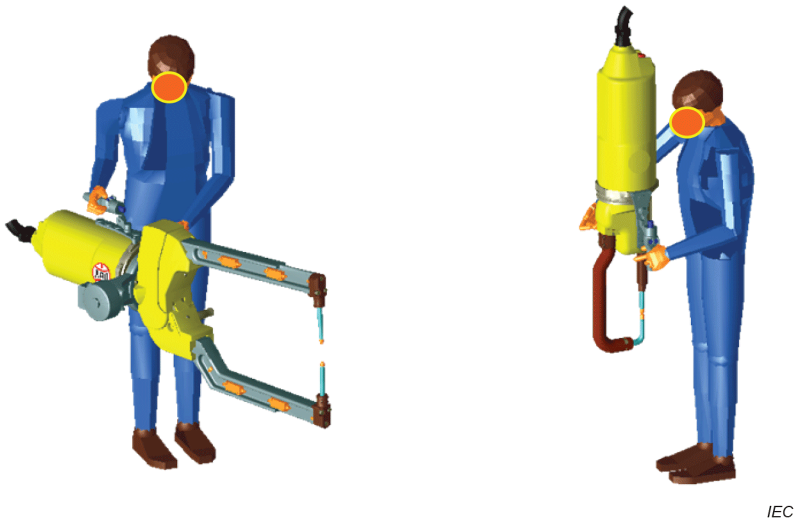


Figure 1 – Exposure measurement at the head position

5.2.2.3 Exposure of the trunk

Measurement points are on the trunk (chest, belly, hip or shoulder), at the closest part to the welding circuit, as illustrated in Figure 2. The most exposed points and their value shall be collected.

Figure 2 – Exposure measurement at trunk position

5.2.2.4 Exposure of the limbs

Measurement points are on the dorsum to both hands (control/right hand and handle/left hand), as illustrated in Figure 3. The probe can be fixed on the handles. An additional point shall be considered if the welding circuit is closer to the thighs than the trunk, as shown in Figure 3.

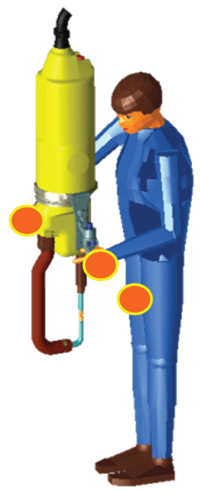


Figure 3 – Exposure measurement at limb positions (hands and thigh)

5.2.3 Assessment based on measured welding current

The method based on the calculated magnetic field is convenient when the use of equipment is unknown as in repair, for the realization of single assemblies such as prototypes, or when several people assist the welder. In these cases, there are no predefined working positions. This method should also be preferred by the manufacturer to provide information allowing the user to assess the risk of exposure.

This method involves defining the compliance perimeters around the equipment. The user is able in person to determine compliance and to implement preventive measures (such as minimum distances) if any.

This method also allows to determine exposure levels against reference levels at localized points as well, as described in 5.2.2.

The method consists in recording the welding current waveform by an appropriate tool compliant with 6.1.4.1 (e.g. a current probe connected to a scope) and to model the welding electric circuit as shown in 8.2 for a rectangular circuit. The most exposing current shall be selected (determined by the maximum exposure level obtained at an arbitrary position and an arbitrary reference level, e.g. low action level).

The model of the field source should be based on its original CAD (computer aided design) data. Alternatively, the electric circuit size and position (if stationary) are measured. All dimensions and shape can be rounded upwards (the larger the welding circuit, the higher the exposure level).

In this way, the magnetic field is calculated in the volume around the equipment according to the formula at each point:

$$B(t) = CC_{\mathrm{BI}} \cdot I(t) \tag{3}$$

where

$I(t)$ denotes the welding current over the time in ampere,

CC_{BI} is the coupling coefficient (expressed in tesla/ampere $\frac{\mathrm{T}}{\mathrm{A}}$) between the welding current and the magnetic field. It depends only on the circuit geometry (see Clause 8) and the spatial position. It can be calculated at a particular location, along an axis or in the entire volume around the welding equipment. Annex A, Clause A.3 gives an example.

$B(t)$ allows to calculate the exposure index according to the relevant exposure limit. Formula (2) and Formula (3) can be combined as follows:

$$EI_{\mathrm{RL}} = CC_{\mathrm{BI}} \cdot \max\left| W_{\mathrm{RL}}(t) * I(t) \right| \tag{4}$$

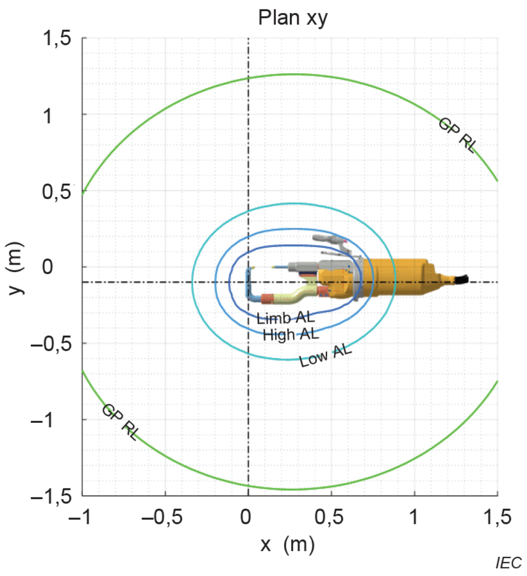
with the previous notations.

$\max\left| W_{\mathrm{RL}}(t) * I(t) \right|$ represents the current exposure index (CEI_{RL}) according to the reference level expressed in $\frac{\mathrm{A}}{\mathrm{T}}$. It is a constant value around the equipment depending on the current only. It can be provided by the current generator manufacturer.

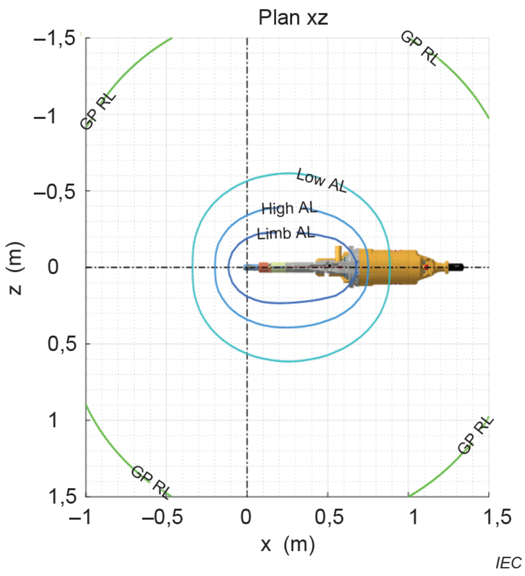
Formulae transcriptions in the frequency domain are given in Annex H.

This method allows to plot figures (see Figure 4) showing the compliance perimeters for example for four reference levels [9] where exposure indices are equal to 1 (100 %):

- LAL: Low action level. It is the compliance limit of the head to prevent sensory effects.
- HAL: High action level. It is the compliance limit of the head and the trunk to prevent health effects.
- Limb AL: Limb action as defined by European regulation [9]. It is the compliance limit of the hands, arms and thigh to prevent health effects.
- GPRL: reference level defined for the general public applicable in Europe [1]. This limit is also applicable to workers at particular risk, such as active implanted medical device holders [1]), and pregnant women where national laws can apply. This limit makes it possible to ignore the contributing effects of any neighboring equipment in the evaluation.



Side view



Top view

- Low AL: Low action level to prevent sensory effects
- High AL: high action level to prevent health effects on trunk and head
- Limb AL: Limb action level to prevent health effects on limbs
- GPRL: general public reference level including protection of workers at particular risks [29]

Figure 4 – Compliance perimeters according to reference levels (action levels)

It is possible to plot isometric magnetic field curves.

An advantage of this method is to define the compliance perimeters during the design before having the material in order to prepare its integration.

5.3 Methods based on assessment of corporal quantities (basic restrictions)

5.3.1 General

The reference levels of electromagnetic fields are derived from the basic restrictions considering the maximum coupling conditions between the fields and the human body, i.e. the maximum induced quantities in the human body exposed to the uniform electromagnetic fields. In many real exposure situations, such as in the vicinity of welding equipment where the field decreases rapidly with distance, the evaluations are too conservative when the maximum of the magnetic field is compared to the reference levels. Considering basic restrictions leads to more realistic results. Internal electric field or current density in the low frequency range (< 10 MHz) induced by the incident magnetic field are defined as corporal quantities. They are difficult, if not impossible, to measure directly. Their evaluation is often performed using dosimetry approaches based on computation or simulation. In some cases, it is possible to include in this approach measurement of magnetic fields around the radiating source.

These methods proposed are possible as the quasi-static approximation conditions are met (see 7.2). In addition, in the frequency range under consideration, the frequency dependency is linear.

The three proposed dosimetry approaches make it possible to best estimate exposure in a relatively simple to quite sophisticated way.

5.3.2 Method based on coupling coefficients

The method based on coupling coefficients is an adaptation of IEC 62226-2-1. The approach is based on the fact that the maximum induced electric field can be estimated analytically on a disk (2D model) in the time domain by a simple formula when the magnetic field is uniform:

$$E_{\text{i}}(t) = \frac{R}{2} \cdot \frac{dB(t)}{dt} \tag{5}$$

where

R represents the radius of a disk, in meter, with a given conductivity, and it depends on the region of the body requiring an exposure assessment (see Table C.1 in Annex C),

dB/dt is the time derivate of B (uniform magnetic flux density normal to the plane of the disk) in tesla (T),

E_{i} is the induced electric field in $\text{V}\cdot\text{m}^{-1}$.

NOTE Formula (1) allows to calculate the current density J from the induced electric field E_{i}.

When the magnetic field is not uniform, the maximum magnetic field on the disk shall be multiplied by a compensation factor K obtained by simulation.

Instead of estimating this factor by the heterogeneity of the magnetic field on a disk, it can be numerically derived by the incident magnetic field, the induced electric field of Formula (5) and comparison with the electric field induced in a human model. Details are given in Annex C. Formula (5) becomes:

$$E_{\text{i}}(t) = K \cdot \frac{R}{2} \cdot \frac{dB(t)}{dt} = CC_{\text{EB/2D}} \cdot \frac{dB(t)}{dt} \tag{6}$$

where $CC_{\text{EB/2D}}$ is the coupling coefficient between the derivative of the magnetic field and the induced electric field (expressed in $\frac{\text{V}\cdot\text{m}^{-1}}{\text{T}\cdot\text{Hz}}$). It depends on the spatial distribution of the magnetic field and it considers the dimension of the exposed region of the body. This coefficient is time independent.

Annex C describes an estimation of the compensation factor K and the coupling coefficients $CC_{\text{EB/2D}} = K \cdot \frac{R}{2}$ for different values of R.

To be conservative and in order to simplify the processing, the magnetic field module $|B|$ is taken into account instead of the perpendicular component (the relative orientation according to the magnetic flux density direction can be ignored as this condition considers the worst-case which maximizes the result).

Combining Formula (6) with $B(t)$ obtained by the welding circuit model of Formula (3), the induced electric field becomes:

$$E_{\text{i}}(t) = CC_{\text{EB/2D}} \cdot CC_{\text{BI}} \cdot \frac{dI(t)}{dt} \tag{7}$$

As for the reference level of Formula (4), the exposure index according to basic restrictions is

$$EI_{\mathrm{BR}} = CC_{\mathrm{EB/2D}} \cdot CC_{\mathrm{BI}} \cdot \max\left| W_{BR}(t) * \frac{dI(t)}{dt} \right| \tag{8}$$

where

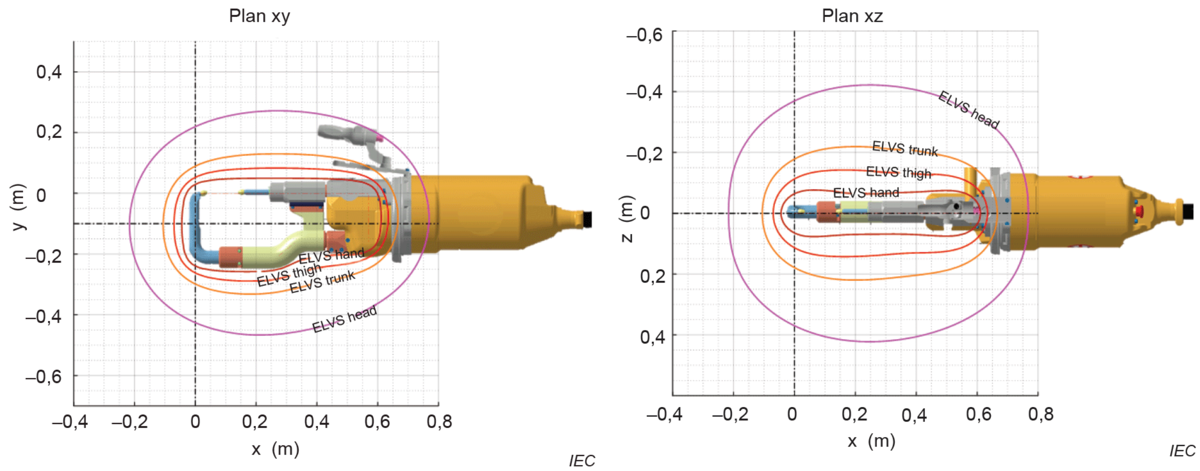
the previous notations are respected and $W_{\mathrm{BR}}(t)$ represents the time response of a frequency weighting function $W_{\mathrm{BR}}(t)$ relevant to the basic restrictions to be assessed.

$W_{\mathrm{BR}}(f)$ is the inverse peak value of the exposure limit ($E_{\mathrm{BR}}(f)$ in RMS value) at the frequency f, i.e.

$$W_{\mathrm{BR}}(f) = \frac{1}{\sqrt{2} \cdot E_{\mathrm{BR}}(f)}$$

$\max\left| W_{\mathrm{BR}}(t) * I(t) \right|$ represents the current exposure index (CEI_{BR}) according to the basic restriction of interest expressed in $\frac{\mathrm{A \cdot Hz}}{\mathrm{V/m}}$. It is a constant value around the equipment. It can be provided by the current generator manufacturer.

Hence, EI_{BR} can be calculated either from the record of $B(t)$ with Formula (6) or from the record of $I(t)$ with Formula (8). In the first case, it is a combination of magnetic field measurement and calculation. It can be applied on a few exposure points (see Clause A.1). In the second case, CC_{BI} is being computed by modelling the welding circuit. This allows to draw compliance perimeters as shown in Figure 5.



Side view **Top View**

– ELVS head: sensory effects ELV applicable on the head
– ELVH trunk: health effects ELV applied on the trunk
– ELVH hand: health effects ELV applied on the hands
– ELVH thigh: health effects ELV applied on the thighs

Figure 5 – Compliance perimeters according to basic restrictions (exposure limit values)

5.3.3 Method based on the correction factor

The method based on the correction factor is basically similar to the method presented in 5.3.2. It differs by using the reference level exposure index EI_{RL} as an alternative to the record of the magnetic field or of the current. It was originally introduced for exposure assessments in low frequencies in IEC 62226-2-1 and IEC 62311, then amended in IEC 62233 [28]. The proposed concept of compliance applied on current densities can be expandable to the induced electric field [11], [12].

Firstly, a correction factor k_E is predefined by Formula (9):

$$k_E = \frac{EI_{BR}}{EI_{RL}} \tag{9}$$

where

EI_{BR} is the exposure index according to the basic restriction (e.g. ELV or DRL);

EI_{RL} is the exposure index according to the reference level (e.g. AL or ERL);

k_E is dimensionless.

EI_{RL} is determined as described previously, by direct measuring or by calculation from the magnetic field or the current, considering also the worst-case scenarios. The exposure index obtained by direct measuring shall be carried out with a 3 cm^2 or smaller probe.

EI_{BR} is determined by simulation with the human model, taking into account field distributions and distances to the human body encountered around the welding equipment. Based on numerous evaluations, conservative values of the correction factor k_E were estimated (see Annex D).

Thus, k_E is predefined for resistance welding equipment only and it considers the effects of field non-uniformity. This factor is waveform independent, and so is the current or magnetic field frequency. It leads to a conservative result.

The compliance assessment can be performed by comparing the multiplied value of the measured or calculated exposure index according to the reference level of the magnetic field and the predefined factor as

$$EI_{BR} = k_E \cdot EI_{RL} \tag{10}$$

where

EI_{RL} is the measured or calculated exposure level/reference level,

EI_{BR} is the estimated exposure level/basic restriction.

The magnetic field or current welding waveform are considered in EI_{RL} when the weighted peak method is applied.

5.3.4 Method based on the human model simulation

In this method, a realistic human model is used to calculate induced quantities for the most representative of the real conditions.

Several realistic human models are available to derive induced quantities. The adult male model with a spatial resolution equal to less than 2 mm shall comprise at least of 50 different tissues including at least skin, brain white matter and brain grey matter. Each tissue has one particular electric conductivity value.

Different calculation methods can be carried out to determine induced quantities in the human body by an incident magnetic field emitted from welding equipment. Examples are the impedance method (IM) and scalar potential finite difference (SPFD) method. Annex F provides an overview of different calculation methods. As the information given is not sufficient for application, the source materials referred to should be reviewed.

Measured magnetic field data may be directly applied as a source in the IM. The SPFD uses vector potentials as a source to calculate the internal electric field. Vector potentials are obtained preferably by calculation from the source model or by default, also by measuring the magnetic field (H) or the magnetic flux density (B) in the volume occupied by the exposed body. In this case spatial coordinates of collected measurements are necessary.

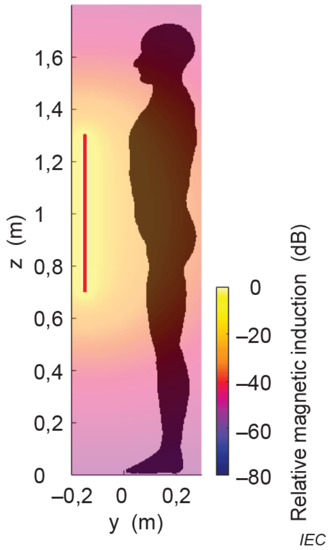


Figure 6 – Magnetic field around the human body obtained by source modelling

The general approach to assess the induced quantities consists in:

a) Modeling the magnetic field on the volume occupied by the model (welder) with the mesh resolution by:

   – recording the welding current and modeling the welding electric circuit from the CAD data or from the dimensions, shape and height from the ground; and

   – calculating the magnetic field vector (Figure 6);

   or

   – recording the magnetic field vector on several locations on the volume occupied by the human model; and

   – interpolating the recorded magnetic field on the whole volume occupied with the mesh resolution.

b) If required as for the SPFD, calculating the magnetic potential vector.

c) Selecting the human model with its physical and electrical properties. Conductivity at the frequency of the current generator shall be applied (e.g. 50 Hz for an LF generator or 1 kHz for an MF inverter).

d) Running the electric field calculation method with the model bathing in the magnetic field (see Figure 7). At this step, all tissues shall be considered.

e) Selecting tissues with regard to the basic restrictions, going back to the scientific literature (i.e. the health and sensory effects to be avoided, as explained in the ICNIRP guidelines [2], [3], [4]).

f) Calculating the maximum of the average of the internal quantities $E_{\mathrm{i,avg}}$ in the selected tissues for a unit current with the algorithm proposed in Annex G. Then calculating $CC_{\mathrm{EI/HM}}$:

$$CC_{\mathrm{EI/HM}} = \frac{\max E_{\mathrm{i,\ avg}}}{2 \cdot \pi \cdot f \cdot I} \quad \text{in } \frac{\mathrm{V \cdot m^{-1}}}{\mathrm{A \cdot Hz}} \qquad (11)$$

g) Calculating the current exposure index according to the relevant basic restrictions of Formula (8).

$$CEI_{\text{BR}} = \max\left|W_{\text{BR}}(t) * I(t)\right| \quad \text{in} \quad \frac{\text{A}\cdot\text{Hz}}{\text{mV/m}} \tag{12}$$

h) Calculating the exposure indices with the following formula:

$$EI_{\text{BR}} = CC_{\text{EI/HM}} \cdot CEI_{\text{BR}} \tag{13}$$

Figure 7 shows the induced electric field repartition on the body exposed to magnetic field. Yellow indicates the highest electric fields. Red represents the medium fields and dark blue shows the weakest fields.

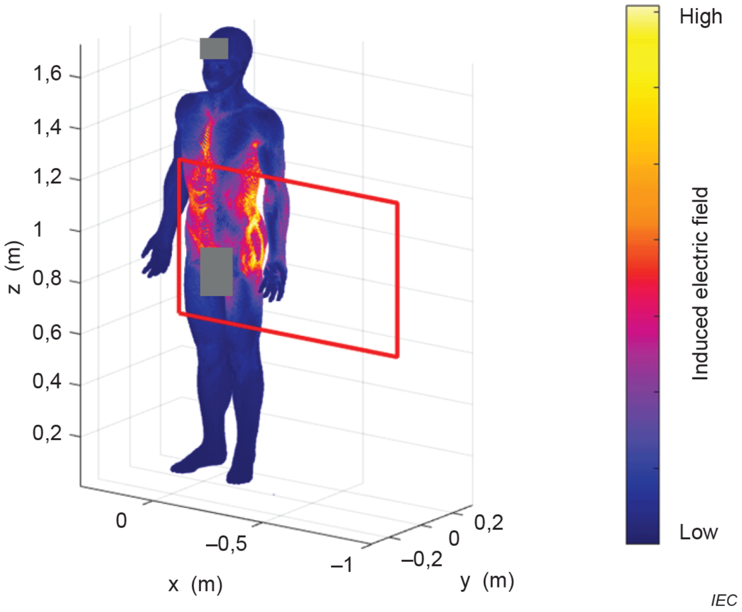


Figure 7 – Example of induced electric field in a human body exposed to a welding gun (I = 1kA to 50 Hz)

5.3.5 Result comparison

A comparison of the methods applied on a welding gun is given in Annex E.

6 Measurement considerations

6.1 Measurement instruments for magnetic fields or exposure levels

6.1.1 General

Instruments for magnetic fields or exposure levels are either a handheld field meter or a measurement system with separate elements. Both are able to provide field strengths or exposure indices.

Measurements of background levels are recommended to establish the presence of external fields. Influences of field sources not being under assessment shall be eliminated or, at least, minimized. Generally, increasing the distance to the external sources of magnetic fields will dramatically decrease the background field strength.

6.1.2 Probe(s)

Probes in which three sensors perpendicular to one another and concentric are required and shall be in accordance with IEC 61786-1 and IEC 61786-2. Such probes have the advantage of performing measurements irrespective of their orientation. Some measurement systems can include four probes or more.

Probe(s) shall be of an area equal to or less than 3 cm^2 ± 0,6 cm^2 when the measured exposure index is greater than twice the sensitivity of the measuring device. When the measurement exposure index is below this value or at a distance greater than 1 m to the welding circuit, measurement probe(s) shall be of an area of 100 cm^2 ± 0,6 cm^2. The field strength is given by the module of the RMS magnetic flux densities of the three-orthogonal axis. The exposure index shall be performed with the weighting function (filtering in time domain) applied on each axis before computing the module and then holding on the maximum.

6.1.3 Handheld field meter

The handheld field meter shall have a bandwidth from 10 Hz to 400 kHz or more.

An instrument with a peak-holding function shall be used. The automatic range selection, if any, shall be switched off.

6.1.4 Measurement system with separate elements

6.1.4.1 Frequency range and sampling rate

Assessments, depending on the type of welding current waveform, shall be made in the relevant frequency range and sampling rate.

The signal is sampled (in the time domain) as it is digitally processed regardless of the method. The sampling rate shall be at least twice the upper frequency of the signal (Nyquist law). The maximum upper frequency within the scope of this document is 10 MHz.

In low frequency exposure, the signal shall be processed in the time domain (except where some national regulations permit the frequency domain). In the time domain, it is easier to consider the minimum rise / fall time than to estimate the uppermost frequency, before choosing the sampling rate expressed in samples per second (sps).

The sampling rate shall be:

– equal to or greater than 100 ksps for
  - min (rise/fall time) ≥ 1 ms or
  - dI/dt < 1 000 A/ms

– equal to or greater than 1 Msps for
  - 1 ms > min (rise/fall time) ≥ 0,01 ms or
  - 1 kA/ms > dI/dt ≥ 100 kA/ms

– equal to or greater than 10 Msps for
  - min (rise/fall time) < 0,01 ms or
  - dI/dt > 100 kA/ms

Min(rise/fall time) or dI/dt are defined either by the manufacturer based on its knowledge of special techniques used in its apparatus or by the min(rise/fall time) or dI/dt observed on the waveform of the welding current.

In general, 100 ksps is suitable for any LF-AC and MF-DC welding systems using thyristors, IGBTs or inverters with a switching frequency less than 10 kHz. 1 Msps is relevant for capacitor discharge welding systems.

NOTE These sampling rates are based on prior experience of measurements made on resistance welding equipment.

The defined sampling rate is applicable to record the welding current as well as the magnetic field.

6.1.4.2 Duration

For each assessment requiring a post processing, it is not necessary to record the signal over a long period of time.

For LF-DC and MF-DC technologies, exposure levels are established firstly when the current starts or stops to flow and secondly by the current ripple generated by the inverter. For LF-AC, these levels can be achieved with just a single burst typically consisting of a few 50 Hz periods.

In general, a record of a few hundred milliseconds is enough for these two cases for each measurement point.

Capacitor discharges technology requires less than 10 ms.

The measurement resolution, duration and sampling rate determine the data memory requirements

6.2 Instruments for recording

6.2.1 Welding current recording

Instruments (current transducer and oscilloscope) used for recording the welding current shall have the capabilities of the predefined sampling rate (6.1.4.1) with respect to the frequency range, the resolution, and the peak current.

Measurement of welding current using voltage drop across a resistance is not recommended to avoid current magnitude and waveform modifications.

The recorded data shall be validated in order to exclude those with an excessive noise level or containing artifacts that could affect the exposure results. One possible method of validation is to analyze the derivative of this data (dI/dt in this case) immediately after saving it, before leaving the workstation.

6.2.2 Magnetic field recording

Instruments (probe(s) as defined in 6.1.2 and oscilloscope) used for recording the magnetic field around the equipment shall have the capabilities of the predefined sampling rate with respect to the frequency range, the resolution, and the peak value.

Recorded data shall be validated in order to exclude noise or artefacts on exposure results. A possible method for validation is to derive the maximum realistic dB/dt rate before processing the data.

6.3 Signal processing (applicable to any welding current waveform)

6.3.1 General

Several methods for the assessment of pulsed and non-sinusoidal fields are available (e.g. IEC 62311 and IEC 61786-2). For the purposes of this document, only the weighted peak method described in 6.3.2 is applicable. The result of this calculation method is the exposure index (EI).

NOTE Applications of the weighted peak method in the time domain or frequency domain are mathematically equivalent and give the same results, if using the same assumptions and applied correctly.

The maximum resulting EI over time shall be used for the assessment.

The weighted peak method is used for assessments based on external fields as well as for assessments based on internal quantities.

Electronic or digital filters can be used to realize the weighting functions representing the applicable limits.

The weighting function in the time domain is obtained by using Laplace transform or Z transforms.

The weighting function shall have an appropriate frequency response so that the weighting of spectral components occurs in the time domain. National or international regulations can apply.

6.3.2 Application of the weighted peak method in the time domain

The weighted peak method in the time domain executes a filtering (weighting functions) of the three field components in the time domain separately, a sum and a detection of the peak value over the observation time. The sampling rate shall be selected according to 6.1.4.1.

The exposure index shall not exceed 1,0 at any time within the evaluation interval to conclude the compliance.

NOTE Further information on this method is given in [10].

6.3.3 Spatial averaging

The measured field values may be spatially averaged over the exposed regions of the body, with the important provision that the basic restrictions for internal electric fields are not exceeded. Otherwise, the highest level shall be taken, i.e. the closest to the welding electric circuit on the exposed region.

6.3.4 Time averaging

Time averaging of exposure is not permitted for non-thermal effects. National or international regulations can apply for time averaging procedures.

6.4 Uncertainty of assessment

The expanded uncertainty of the assessment shall be calculated as defined in IEC 61786-2:2014, Clause 6.

If the expanded uncertainty is higher than the value specified IEC 62822-1:2016, 5.5, and the assessment is not proven to provide conservative results, the method to calculate penalties given in IEC 62822-1 or a simulation with a human model shall be applied.

7 Computational assessment methods

7.1 General

The internal electric field or the current density for comparison with basic restrictions shall be calculated by simulation using a representative set of anatomical human models. Calculations may be carried out using quasi-static methods depending on the relative electrical size of the problem. These methods are relevant as resistance welding radiates low frequency magnetic fields.

The main computational methods for exposure evaluation on human body based on quasi-static approximation are as follows:

- QS-FEM (quasi-static – finite element method);
- SPFD (scalar potential finite difference);
- IM (impedance method);
- hybrid method.

A brief description of computational methods is given in Annex F.

7.2 Quasi-static approximation

The dimensions of the exposed body region or person, the size of the field source and the distance between them are small compared to the lowest wavelength of the uppermost frequency of the field (~1/f). Sizes and distances are at most a few meters whereas wavelengths are at least a few kilometres.

This allows to apply computational methods based on the quasi-static approximation. That implies that:

- there are no propagation phenomena;
- the effect of the induced electric fields or induced currents in the human body on the incident magnetic field is assumed to be negligible, meaning:
  - incident fields and induced fields can be evaluated using separate computational methods. On one side, for the calculation of the incident magnetic fields, analytical or quasi-analytical methods can be applicable. On the other side, simulation is applicable to calculate the induced quantities in a human body and analytical or quasi-analytical methods can be applicable on geometric models;
  - the presence of the body does not modify the incident magnetic field;
- the induced fields in the body follow the incident field instantaneously (displacement current is assumed to be negligible compared to conduct current). Conductivities are the relevant parameters for the tissues of the body.

7.3 Human body models for simulation

The induced current density or intracorporal electric field-strength may be derived by simulation using a 3D human body model where the electric properties of the various tissues are considered. Examples of anatomical models are listed in Table 1 with their main physical characteristics.

NOTE The model names are explained in [14].

Table 1 – Examples of human models to determine induced electric fields in the low frequency range

Model name	**Height** (m)	**Weight** (kg)
Adult male ICRP	1,76	73
UVIC	1,77	76
NORMAN	1,76	73
MAXWELL	1,76	73
DUKE	1,74	70
TARO	1,73	62
ALVAR	1,76	72

The model shall represent the relevant region of the body (e.g. head, trunk or limbs) or the whole body, as appropriate, particularly with regard to the diversity of exposure limits.

The main requirements for these models are as follows:

- availability to represent a welder (bigger bodies usually have higher induced fields for coupling with low frequency magnetic fields);
- individual segmentation of the tissues of the central nervous systems (CNS) and the skin (peripheral nervous systems) for evaluation with the respective basic restrictions;
- posable or movable limbs for the modelling of realistic exposure scenarios (by default, a body region can be extracted and exposed with a representative orientation and position).

7.4 Computational assessment against the basic restrictions

There are two types of basic restrictions: 1) ELVs established to prevent sensory effects due to the stimulation of the CNS of the head and 2) ELVs established to prevent health effects due to the stimulation of the CNS and to the stimulation of the peripherical nervous system (PNS) of the whole body.

In case 1), relevant organs are the brain (separated into white and grey matter in some body models), the retina and the optical nerve. The spinal cord is mostly not in the head, so is therefore not included in considerations of the sensory effects of ELVs.

In case 2), the skin should be taken into account. ICNIRP 2010 [3] specifies that there currently is no conversion factor for peripheral nerve tissue available and so the skin, which does not have any nerve endings, is considered as a worst-case target tissue. Hence, the following organs were considered for the PNS ELVs: the brain, the retina, the optical nerve, the spinal cord and the skin. It should be noted that taking all organs into account raises a problem of coherence between models because the most critical organ depends on the model or because the results are not available for all organs.

In order to avoid particularly numerical singularities visible among the maximum values, reference [3] recommends to use the 99th percentile of the induced electric field distribution in each tissue as the criterion to express the maximum value. However, this value underestimates the exposure when the magnetic field is highly non-uniform. Hence, the maximum average is used as a conservative value.

This average depends on the applicable safety guidelines mainly on basic restrictions quantities defined in terms of:

- averaged current density on a surface (Clause G.1);
- averaged E-field in a cubical volume (Clause G.2);

- averaged E-field along a line (Clause G.3).

However, different limits can apply depending on the exposed body region. The computational code or the applied post-processing techniques shall implement the required averaging methods. As the descriptions of the averaging algorithms in the exposure guidelines that define them are generally not sufficiently detailed for an implementation as a computational algorithm, this document refers to the respective computational International Standards that define them or specifies its own algorithms if an appropriate definition is not available elsewhere. Details are given in Annex G.

The maximum value represents the coupling coefficient between a unit current or the magnetic field and the induced electric field or current density named, respectively, CC_{EI}, CC_{EB}, CC_{JI} and CC_{JB} as defined in 3.1.2. These values multiplied by the current or the magnetic field over time shall be compared to the basic restrictions by applying the weighted peak method as presented in Clause 5.

NOTE Since the coupling phenomenon is linear in the frequency range under consideration, the frequency and amplitude welding-current or magnetic field used for the assessment are not critical and can be changed arbitrarily as needed.

Simulations can be also applied to assess the incident fields with respect to the reference levels.

All computational algorithms should be verified for technically correct implementation by comparison between analytic results and simulation results. This comparison is direct when a geometric model (as spheres with different conductivities) is exposed in uniform fields.

8 Source model

8.1 General

The source of EMF is the welding current flowing through the welding electric circuit, generating a low frequency magnetic field. This field is non-homogeneous in close proximity to the equipment.

The parameters of the welding current (e.g. magnitude and waveform), and the welding circuit characteristics (e.g. dimensions), are determined by the equipment only. External factors, for example characteristics of the work piece, can have an influence on the magnetic field, but are not taken into account by this document.

This consideration allows the use of filamentary currents and the application of Biot-Savart's Law.

The source model allows to calculate the magnetic field around the equipment and the coupling coefficients CC_{BI}.

8.2 Source model example

The simplest source model of a welding gun is a rectangular loop (any shape is possible including 3D).

For conductors forming a rectangular loop, a source model as given in Figure 8 shall be used.

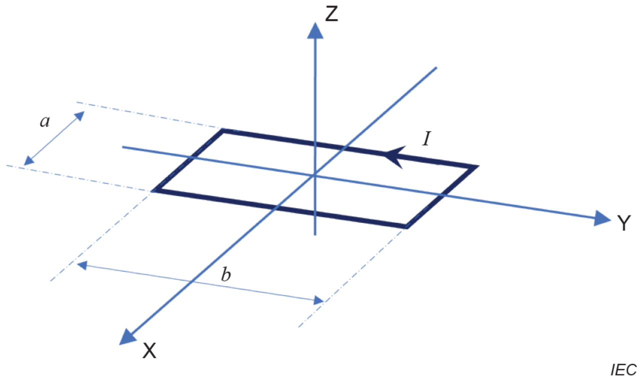


Figure 8 – Welding current flowing in a (a × b) rectangular loop configuration

Because of the properties of the field distribution, three distances (x, y, z) to the centre of the conductor along the X, Y and Z axes shall be considered.

The magnetic flux density $\boldsymbol{B}$ of any observation point around the model is calculated using Biot-Savart's Law**.** The magnetic field vector $\boldsymbol{B}$ is given in Formula (14). The magnitude of $\boldsymbol{B}$ is given in Formula (15) where:

a is the dimension of the loop in the X-direction as shown in Figure 8;

b is the dimension of the loop in the Y-direction as shown in Figure 8;

x, y, z are the coordinates of the observation point P on the X, Y and Z axes respectively.

$$x_0 = \frac{a}{2} - x \qquad D_1 = \sqrt{x_0^2 + y_0^2 + z^2} \qquad R_1 = \frac{\frac{x_0}{D_1} + \frac{x_1}{D_2}}{y_0^2 + z^2}$$

$$x_1 = \frac{a}{2} + x \qquad D_2 = \sqrt{x_1^2 + y_0^2 + z^2} \qquad R_2 = \frac{\frac{y_0}{D_2} + \frac{y_1}{D_3}}{x_1^2 + z^2}$$

$$y_0 = \frac{b}{2} - y \qquad D_3 = \sqrt{x_1^2 + y_1^2 + z^2} \qquad R_3 = \frac{\frac{x_1}{D_3} + \frac{x_0}{D_4}}{y_1^2 + z^2}$$

$$y_1 = \frac{b}{2} + y \qquad D_4 = \sqrt{x_0^2 + y_1^2 + z^2} \qquad R_4 = \frac{\frac{y_1}{D_4} + \frac{y_0}{D_1}}{x_0^2 + z^2} \tag{14}$$

The magnetic field vector $\boldsymbol{B}$ is as follows:

$$\boldsymbol{B}(x,y,z) = \begin{bmatrix} B_X(x,y,z) \\ B_Y(x,y,z) \\ B_Z(x,y,z) \end{bmatrix} = \frac{\mu_0 \cdot I}{4 \cdot \pi} \begin{bmatrix} z \cdot (R_4 - R_2) \\ z \cdot (R_1 - R_3) \\ R_1 \cdot y_0 + R_2 \cdot x_1 + R_3 \cdot y_1 + R_4 \cdot x_0 \quad) \end{bmatrix} \tag{15}$$

The magnitude of $\boldsymbol{B}$ is:

$$\left|\boldsymbol{B}(x,y,z)\right| = \sqrt{B_X(x,y,z)^2 + B_Y(x,y,z)^2 + B_Z(x,y,z)^2} \quad (16)$$

If I is a unit current (1 A), $\boldsymbol{B}(x, y, z)$ represents the coupling coefficient connecting I to $\boldsymbol{B}$ in $\frac{\mathrm{T}}{\mathrm{A}}$, named CC_{BI} in Clause 5. $\boldsymbol{B}$ is frequency independent.

The magnetic field vector $\boldsymbol{B}$ is applied for simulation on a human model especially to calculate the magnetic potential vector for the SPFD method.

These values multiplied by the welding current over the time give the magnetic field over the time at the considered position.

The result shall be compared to the reference levels by applying the weighted peak method as presented in Clause 5 to get the exposure index.

9 EMF data sheet and assessment report

The contents of the systems EMF datasheet are based on the mandatory compliance criteria and the required EMF data for the user, as specified in IEC 62822-1:2016, 7.1.5 and 7.1.6 and the decision of the manufacturer to provide additional data exceeding the mandatory amount of information. The minimum information to be collected during the assessment of the system is given in the list below:

a) For occupational use:
   - If the position and posture of the welder using the equipment are fixed or known:
     - exposure indices for head, trunk and limbs and a confirmation of compliance;
     - if compliance cannot be shown, distances where compliance is reached.
   - If the position and posture of the welder and of the people assisting the welder are unknown:
     - minimum distances to the electric welding circuit to reach compliance on the three axes where the exposures are the highest (in general, along an axis perpendicular to the middle of the circuit). Distance for head, trunk and limbs shall be provided;
     - compliance perimeters.
   - For equipment assessed using occupational exposure limits: the distance where the exposure index falls below 100 %, based on the reference levels for the general public.

b) For layman use:
   - Laymen are protected by general public exposure limits
     - distances where the exposure index falls below 100 %, based on the reference levels;
     - as an option: distances where the exposure index falls below 100 %, based on the basic restrictions.

NOTE All distances refer to the centre of the conducting material (due to physical laws).

An example for additional information that can be collected during the assessment is as follows:

– data for multiple operation modes.

The information collected shall be presented in an EMF datasheet. Examples of EMF datasheets based on the scenarios above are included in Annex B.

Annex A
(informative)

Example of assessment based on the individual components

A.1 General

This document allows an assessment of a complete welding system (Figure A.1) or an assessment based on the individual components (Figure A.2).

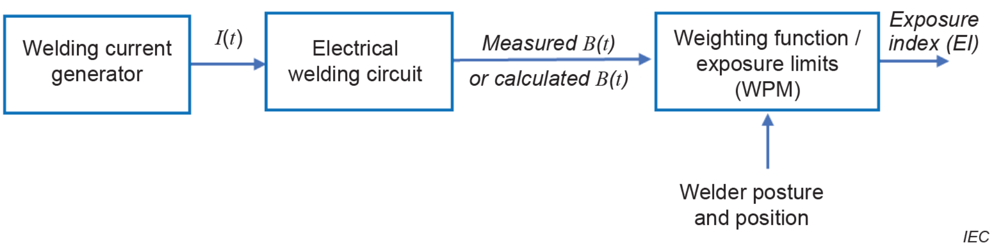


Figure A.1 – Assessment of a complete welding system

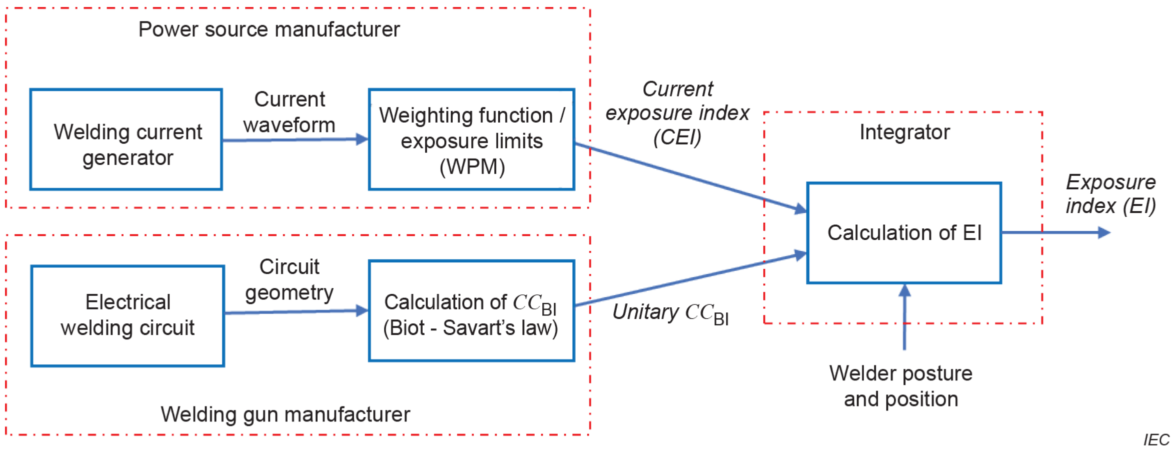


Figure A.2 – Typical component based assessment

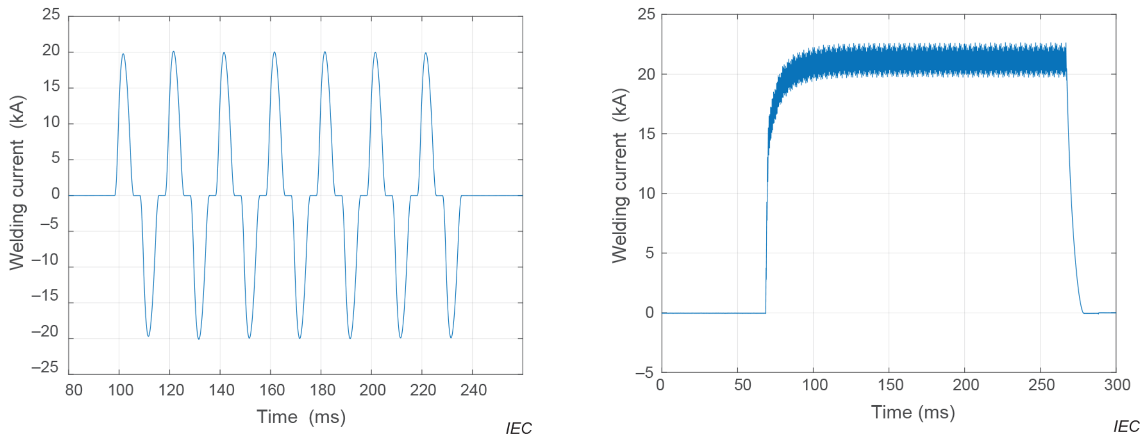
Annex A shows an assessment based on the individual components according to the methods presented in Clause 5.

A.2 Welding current generator

The first step is to determine the current exposure indices (CEI_{RL} and CEI_{BR}) according to basic restrictions (ELV) and reference levels (AL) by applying the weighted peak method in the time domain as introduced in Formula (4) and Formula (8) to Formula (12).

The welding current shall be recorded as described in 6.2.1. A representative impedance load of the electric circuit should be taken into account. It can be composed of a series circuit of a resistance and an inductance. Examples of values are 0,35 mΩ and 0,8 µH, respectively.

Figure A.3 shows the current waveform supplied by two different technologies that are usual in resistance welding systems: LF-AC and MF-DC. I_{rms} corresponds to $I_{welding}$.



I_{peak} = 20,1 kA and I_{rms} = 11,4 kA I_{peak} = 22,7 kA and I_{rms} = 21 kA (inverter: 1 kHz)

Figure A.3 – LF-AC (left) and MF-DC (right) current waveforms

The weighted peak method is then applied for these currents according to the exposure limits indicated in [9]. The CEI_{BR} associated to the ELV for sensory effects (Figure A.4) was chosen to illustrate a result.

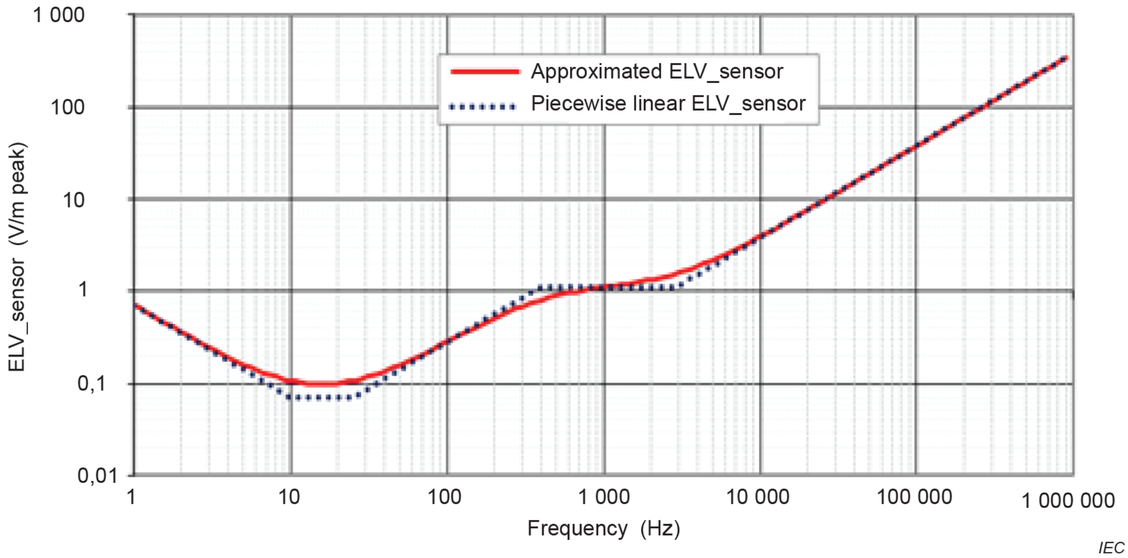
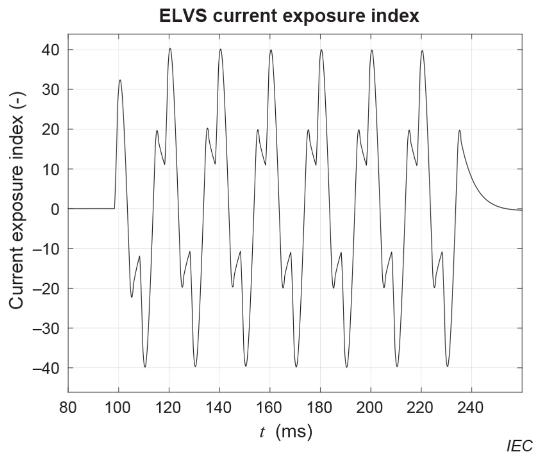


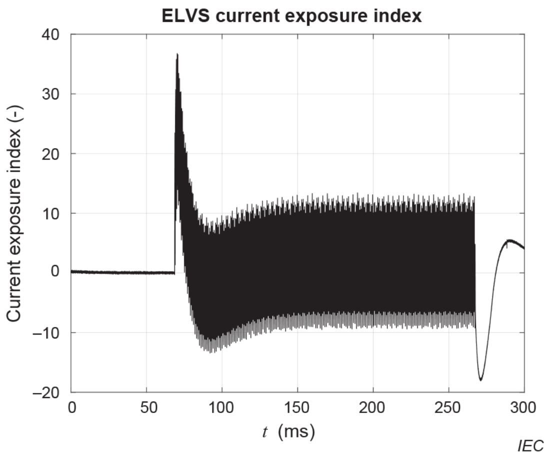
Figure A.4 – Combined ELV for the sensory and health effects applicable to the head

The current exposure indices over the time in Figure A.5 are obtained by digital filtering of the worst-case current given in Figure A.3 according to the limits given in Figure A.4.

NOTE An in-depth description of the weighted-peak-method in the time domain is provided in IEC 62311.



LF-AC technology: CEI = max| $CEI(t)$ | = 40,5



MF-DC technology: CEI = max| $CEI(t)$ | = 36,8

Figure A.5 – Current exposure indices over the time for two welding technologies

The different current exposure indices for the LF-AC technology are for the reference levels (AL) and for the basic restrictions (ELV) (see Table A.1):

Table A.1 – Current exposure index for LF-AC technology (I_{rms} = 11,4 kA)

Exposure limits [unit]	**Low AL** $\left[\frac{kA}{mT}\right]$	**High AL** $\left[\frac{kA}{mT}\right]$	**Limb AL** $\left[\frac{kA}{mT}\right]$	**ELV_sensor** $\left[\frac{kA\cdot Hz}{mV/m}\right]$	**ELV_health** $\left[\frac{kA\cdot Hz}{mV/m}\right]$
Current exposure index (CEI)	13,4	4,42	1,47	40,5	10,7

These values (CEI) represent theoretical exposure indices expressed in $\frac{A}{T}$ or in $\frac{A\cdot Hz}{V/m}$ according to the considered exposure limit. They shall be multiplied by a coupling coefficient CC_{BI}, CC_{EI}, CC_{JI} or CC_{JB} to provide exposure indices at the welder positions. The coupling coefficients are determined for a current equal to 1 A. Application examples are presented in Annex E.

In the same way, the current exposure index according to the reference levels for the general public [1] is (see Table A.2):

Table A.2 – GP current exposure index for LF-AC technology (I_{rms} = 11,4 kA)

Reference level **[unit]**	**General public** $\left[\frac{kA}{mT}\right]$
Current exposure index (CEI)	239,4

A.3 Coupling coefficient of welding circuit

The coupling coefficient CC_{BI} depends on the size and geometry of the welding circuit. Data can be extracted from CAD data or by default, by length measuring on a welding equipment. Since the coupling phenomenon is linear in the frequency range under consideration, the frequency and amplitude used for the calculation are not critical and can be changed arbitrarily. The simplest way is to calculate assuming a DC current of 1 A.

The coefficients represent the ratio magnetic field to a unit welding current and they are frequency independent.

NOTE 1 In the frequency range under consideration the frequency dependency is linear.

A stationary spot welding gun is used as an example (see Figure A.6).

Dimensions in metre

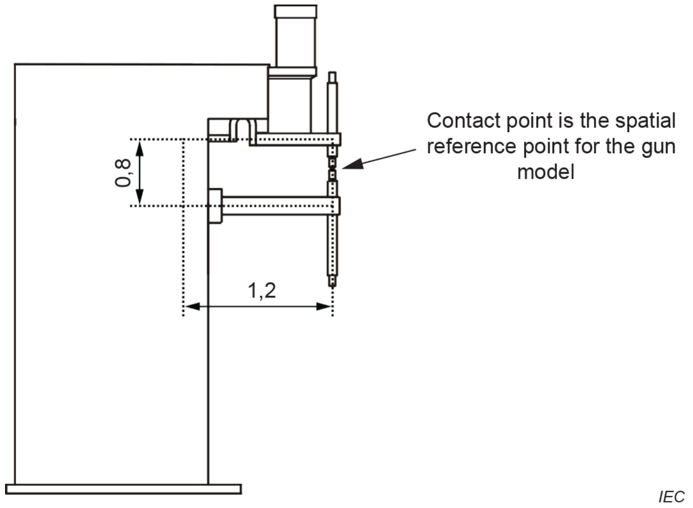


Figure A.6 – Geometry of the stationary spot welding gun

The welding circuit of this example is modelled by a 1,2 m × 0,8 m rectangular loop as shown in Figure A.7. The model corresponds to the neutral fibre (centre) of the circuit. The spatial reference chosen here is the point of contact of the two electrodes.

NOTE 2 The small loop on the top of the electrode has a negligible influence on the exposure to magnetic fields. It is therefore not taken into account. It is also difficult to size due to the construction of the machine.

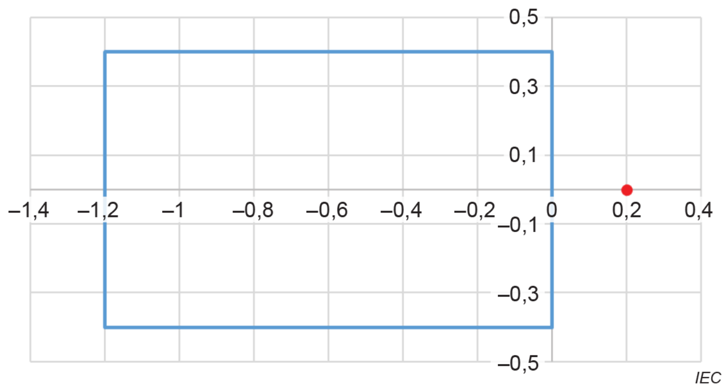


Figure A.7 – Welding electric circuit model (in m) and one point of interest along the X axis

By applying Formula (3), the coupling coefficient CC_{BI} can be plotted as illustrated along the X axis (Figure A.8).

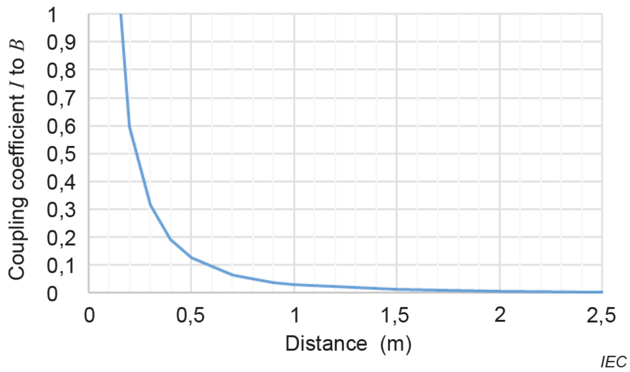


Figure A.8 – Coupling coefficient CC_{BI} along the X axis

A.4 Welding-system

The equipment integrator is able to assess the exposure to the welding system with the previous data, i.e. the current exposure indices and the coupling coefficient CC_{BI} as introduced in Clause 5.

Results according to reference levels (AL) from Table A.1 and Table A.2 using Formula (4) are summarized in Figure A.9 (I_{rms} = 11,4 kA).

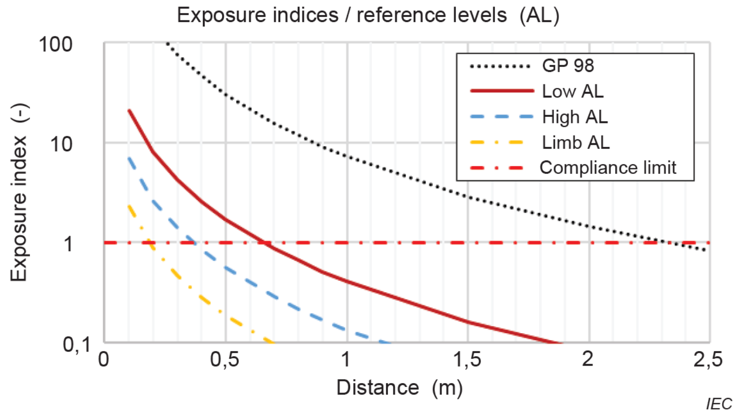


Figure A.9 – Exposure index (AL) along the X axis

Compliance with the action level is reached when the exposure index is equal to or less than 1, meaning:

– health effects on limbs are prevented at a distance greater than 0,20 m along the X axis (limb AL);

– health effects on trunk and head are prevented at a distance greater than 0,40 m (high AL);

– sensory effects on head are prevented at a distance greater than 0,65 m along the X axis (low AL);

– effects on general public and workers at particular risk are prevented at a distance greater than 2,3 m (GP98).

Results according to basic restrictions (ELV) using Formula (8) are summarized in Figure A.10.

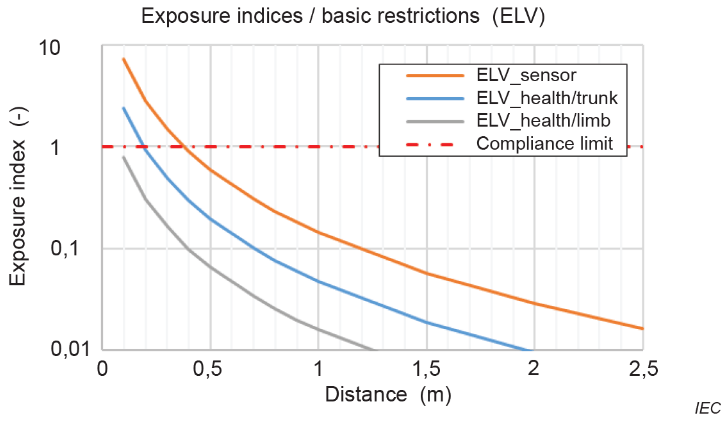


Figure A.10 – Exposure index (ELV) along the X axis

Compliance with exposure limit values is also reached when the exposure index is equal to or less than 1, meaning:

- health effects on limbs are prevented at a distance greater than 0,10 m along the X axis;
- health effects on trunk and head are prevented at a distance greater than 0,20 m;
- sensory effects on head are prevented at a distance greater than 0,40 m along the X axis.

Annex B
(informative)

Example datasheets

B.1 Example current generator datasheet

See Figure B.1.

EMF DATASHEET FOR RESISTANCE WELDING POWER SOURCE

Issued by Compaweld Ltd Patrick Tester
Valid from 2021-04-20 Revision A

Equipment information

Brand name Compaweld
Model name(s) Ultrawelder 2021
Model number(s) 21-6543-000-987
Intended use X for occupational use ☐ for use by laymen

Basic information

Applied regulation Directive 2006/95/EC
Referenced limits Directive 2013/35/EU, Recommendation 1999/519/EC
Applied standard(s) IEC 62822-1:2016, IEC 62822-3:2017, IEC 50527-x
Non-thermal effects need to be considered for workplace assessment X YES ☐ NO
Thermal effects need to be considered for workplace assessment ☐ YES X NO

☐ Data is based on maximum power source capability (valid unless firmware / hardware is changed)
☐ Data is based on worst case setting / program (only valid until setting options / welding programs are changed)
☐ Data is based on multiple settings / programs (only valid until setting options / welding programs are changed)
X Other (specify) : mode abc - welding current = 11,4 kA (2 bursts of 140 ms)

EMF data for non-thermal effects

Current exposure index (CEI) / Directive 2013/35/EU

Exposure limits	Low AL	High AL	Limb AL	ELV_sensor	ELV_health
Units of CEI	$\left[\frac{kA}{mT}\right]$	$\left[\frac{kA}{mT}\right]$	$\left[\frac{kA}{mT}\right]$	$\left[\frac{kA \cdot Hz}{mV/m}\right]$	$\left[\frac{kA \cdot Hz}{mV/m}\right]$
Current exposure indices	13,4	4,42	1,47	40,5	10,7

Current exposure index (CEI) / Recommendation 1999/519/EC

Exposure limit	General public
Unit for CEI	$\left[\frac{kA}{mT}\right]$
Current exposure index	239,4

IEC 62822-3 describes how to apply the current exposure indices to determine the exposure indices according the use cases.

1/1

IEC

Figure B.1 – Example datasheet of the power source

B.2 Example datasheet of the welding circuit

See Figure B.2.

EMF DATASHEET FOR RESISTANCE WELDING ELECTRODE ASSEMBLY

Issued by	Compaweld Ltd		Patrick Tester
Valid from	2022-06-10	Revision	A

Equipment information

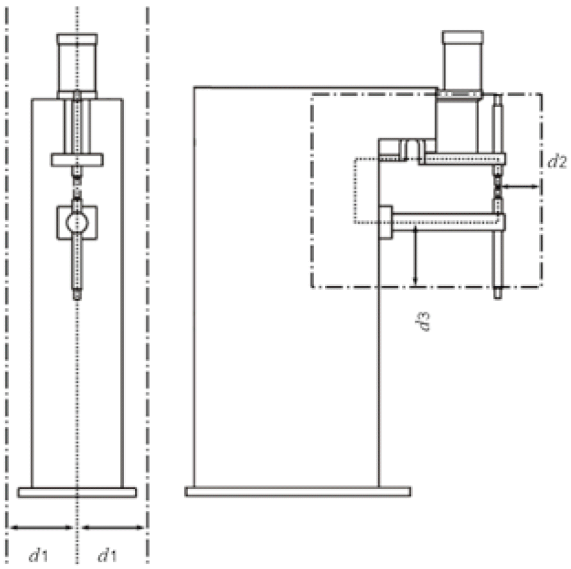
Brand name	Compaweld	
Model name(s)	Ultrawelder 2021	
Model number(s)	21-6543-000-987	
Intended use	X for occupational use	☐ for use by laymen

Basic information

Applied regulation	Directive 2006/95/EC
Referenced limits	Directive 2013/35/EU, Recommendation 1999/519/EC
Applied standard(s)	IEC 62822-1:2016, IEC 62822-3:2022, IEC 50527-x

EMF data for non-thermal effects

Distance (m)	Coupling coefficient CC_{BI} d1 axis (mT/kA)	d2 axis (mT/kA)	d3 axis (mT/kA)
0,10	1,132	1,539	N/A
0,20	0,962	0,598	
0,30	0,765	0,316	
0,40	0,588	0,192	
0,50	0,446	0,127	
0,70	0,259	0,065	
0,80	0,201	0,049	
0,90	0,157	0,038	
1,00	0,124	0,030	
1,50	0,046	0,012	
2,00	0,021	0,006	
2,50	0,011	0,003	



All distances refer to the centre of the welding circuit material (neutral fiber).
IEC 62822-3 describes how to use coupling coefficients to determine exposure indices according action levels or reference levels.

1/1

IEC

Figure B.2 – Example datasheet of the electrode assembly

B.3 Example datasheets of equipment assembly

See Figure B.3.

EMF DATASHEET FOR RESISTANCE WELDING SYSTEM

Issued by	Compaweld Ltd		Patrick Tester
Valid from	2022-06-10	Revision	A

Equipment information

Brand name	Compaweld	
Model name(s)	Ultrawelder 2021	
Model number(s)	21-6543-000-987	
Intended use	**X** for occupational use	☐ for use by laymen

Basic information

Applied regulation	Directive 2006/95/EC
Referenced limits	Directive 2013/35/EU, Recommendation 1999/519/EC
Applied standard(s)	IEC 62822-1:2016, IEC 62822-3:2012, IEC 50527-x

Non-thermal effects need to be considered for workplace assessment	**X** YES	☐ NO
Thermal effects need to be considered for workplace assessment	☐ YES	**X** NO

☐ Data is based on maximum power source capability (valid unless firmware / hardware is changed)

☐ Data is based on worst case setting / program (only valid until setting options / welding programs are changed)

☐ Data is based on multiple settings / programs (only valid until setting options / welding programs are changed)

X Other (specify): mode abc – welding current = 11,4 kA – 2 bursts of 140 ms

1/2

IEC

Figure B.3 – Datasheet example of the welding system

This first sheet is followed by one of two options (compliance distances in Figure B.4 or compliance perimeters in Figure B.5).

Option 1

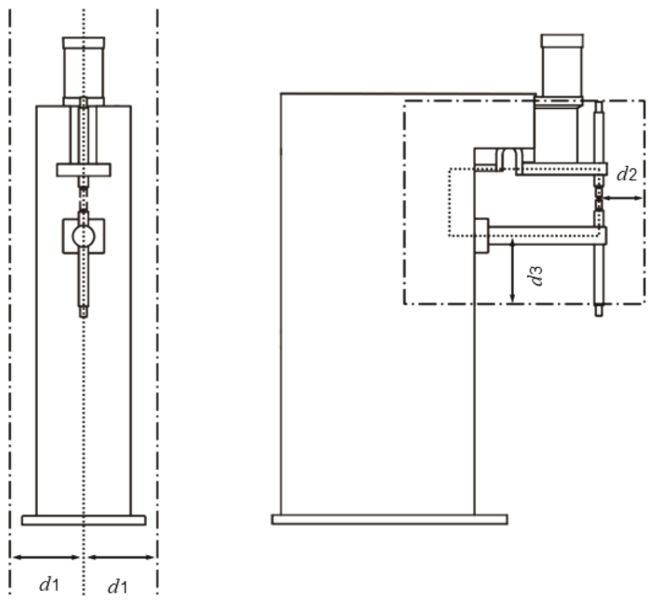
EMF DATASHEET FOR RESISTANCE WELDING SYSTEM (CONTINUED)

EMF data for non-thermal effects

Exposure indices and distances to welding system. All distances refer to the centre of the welding circuit material (neutral fiber).

		Head sensory and health effects	**Trunk**	**Right hand**	**Left hand**
EI at working position		N/A	N/A	N/A	N/A
Required minimum distance	d_1	35 cm	75 cm	5 cm	5 cm
	d_2	40 cm	20 cm	10 cm	10 cm
	d_3	N/A	N/A	N/A	N/A
Distance where compliance with general public limits is reached	d_1	2,8 m	2,8 m		
	d_2	2,3 m	2,3 m		
	d_3	N/A	N/A		

The distances established for the general public apply to workers at particular risks (active implanted medical devices holders and pregnant women) as well.



2/2

IEC

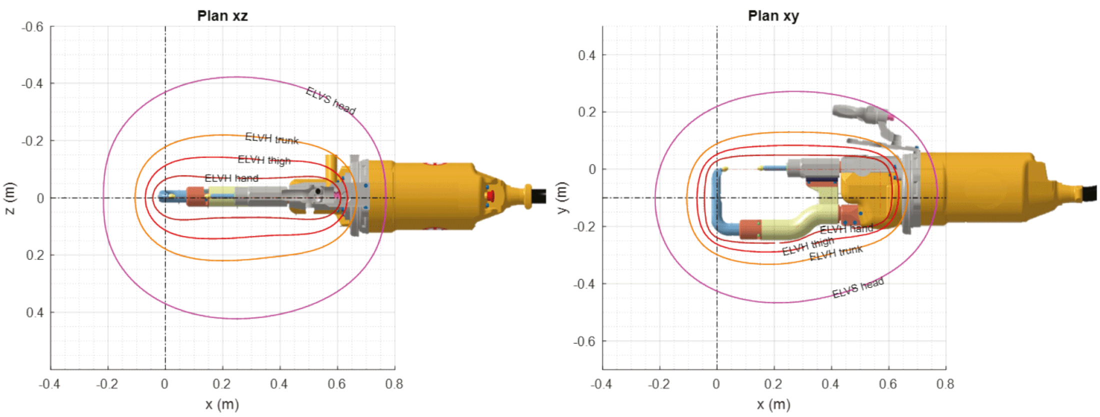
Figure B.4 – Example datasheet of the welding system (continuation)

Option 2 (alternative to option 1)

EMF DATASHEET FOR RESISTANCE WELDING SYSTEM (CONTINUED)

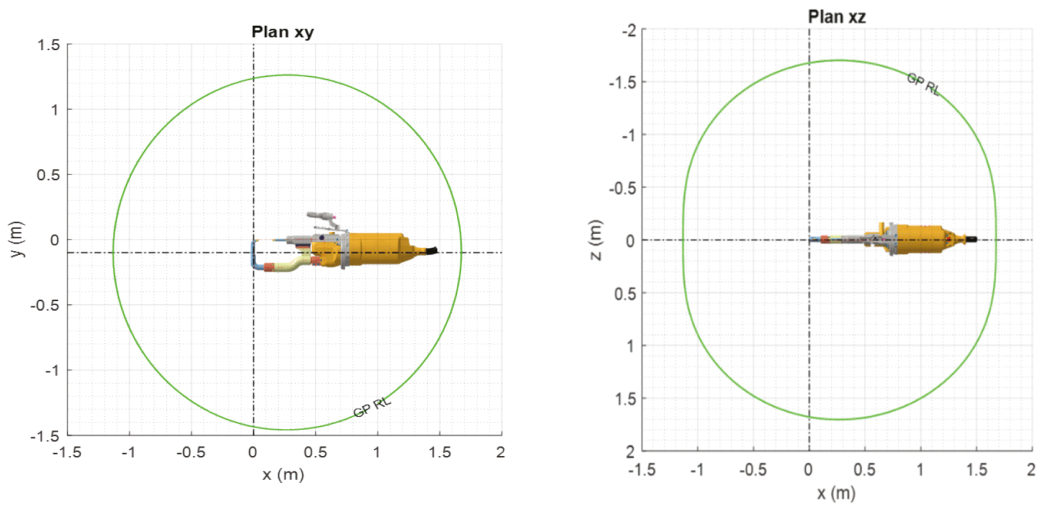
EMF data for non-thermal effects

Compliance perimeters



Compliance perimeters according exposure limit values of Directive 2013/35/EU

- ELVS head: sensory effects ELV applicable on the head
- ELVH trunk: health effects ELV applied on the trunk
- ELVH hand: health effects ELV applied on the hands
- ELVH thigh: health effects ELV applied on the thighs



Compliance perimeter according reference levels applicable to general public (GP RL).
This perimeter applies to the public as well as to workers at particular risk (active implanted medical devices holders and pregnant women).

2/2

IEC

Figure B.5 – Example datasheet of the welding system (continuation)

Annex C
(informative)

Coupling coefficient method

C.1 Principle

The coupling coefficient method proposed by IEC 62226-2-1 implements a 2D model, i.e. a disk whose radius is representative of the region of the body requiring an evaluation. The maximum induced electric field on the model is calculated by a simple analytic expression when the magnetic field is uniform and perpendicular to its surface:

$$E_\mathrm{i}(t) = \frac{R}{2} \cdot \frac{dB(t)}{dt} \qquad \text{(C.1)}$$

where

R represents the disk radius, in meter, according to the dimension of the region of the body requiring an assessment (see Table C.1);

$dB(t)/dt$ is the time derivate of $B(t)$ (uniform magnetic field) in tesla (T);

$E_\mathrm{i}(t)$ is the induced electric field in V/m.

Table C.1 – Representative disk radius (geometric model)

Region of the body	**Radius** m
Head	0,1
Trunk	0,2
Limb	0,1
Hand	0,05

A compensation factor K, depending on the degree of non uniformity of B should be added.

C.2 Validation of this method

C.2.1 Context

A campaign of assessment undertaken on 48 welding workplaces provided to close to 200 measurements points. The exposure limits of European regulation [9] were applied.

The equipment models were either portable spot welding guns or stationary spot welding guns. The technologies were LF-AC and MF-DC from different manufacturers and with different set-ups. Large and small arms (welding electric circuit) with several use conditions were encountered. The range of exposure indices against the relevant reference levels starts at a few hundredths of a percent to several hundred percent.

During this campaign, magnetic fields and welding currents were recorded (according to 6.1.4.1) as well the electric circuit geometries in order to compare dosimetric simulations on disk models and on a human model (Duke from IT'IS).

Compensation factors were calculated for each measurement point by:

$$K = \frac{EI_{\text{BR/HM}}}{EI_{\text{BR/2D}}} \quad \text{(C.2)}$$

where

$EI_{\text{BR/HM}}$ is the exposure index obtained from the simulation on the human model;

$EI_{\text{BR/2D}}$ is the exposure index obtained from calculation on a disk.

The number of results leads to reliable statistics. De facto, K includes a correction of the disk dimension if necessary.

C.2.2 Basic restriction against health effects

The exposure levels (indices) were calculated by the applied Formula (5), geometric model, and human model simulation with basic restrictions (exposure limit values) against health effects [9]. The curve in Figure C.1 shows the statistical distribution (142 cases) of the ratio of the human model results to the disk model results.

Figure C.1 – Distribution of human to disk model exposure index ratios (health effects of ELV on trunk and hands)

The human model results are mostly higher than those of the disk models. The statistical distribution is narrow with a bias.

C.2.3 Basic restriction against sensory effects

The exposure levels (indices) were calculated by the applied Formula (5), geometric model and human model simulation with basic restrictions (exposure limit values) against health and sensory effects [9]. The curves in Figure C.2 show the ratio of the human model results to the disk model results in the form of statistic distribution (over 48 inputs).

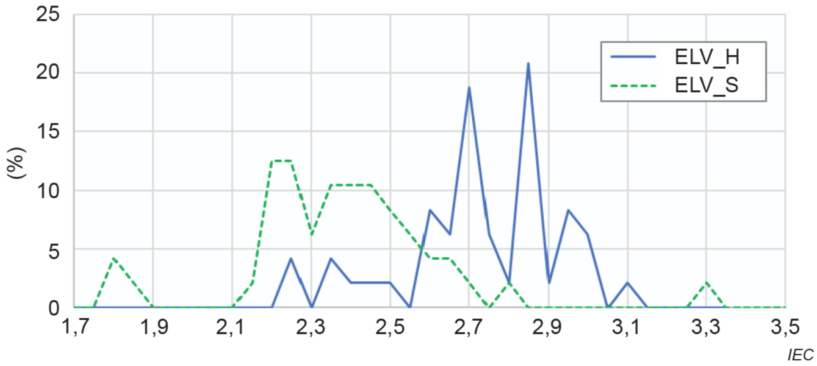


Figure C.2 – Distribution of human to disk model exposure index ratios (sensory and health effects of ELV on the head)

The human model results are higher than those of the disk model. The statistical distribution is relatively wide with a systematic bias.

C.3 Conclusion

The dosimetric method with a 2D geometric model (disk) is a valid method under the condition to apply factors (K) taking in account a conservative value of the statistic distributions. The electric field is estimated by:

$$E_i(t) = K \cdot \frac{R}{2} \cdot \frac{dB(t)}{dt} \qquad \text{(C.3)}$$

K is equal to 1,5 as an appropriate value to ELV health effects which can affect trunk, hands, arms and thighs. K equals 3,0 as an appropriate result to ELVs in relation with health effects and sensory effects of the head. 99 % of percentile values are selected. K is higher for the head as the magnetic field tends to be uniform farther from to the gun.

The coupling coefficient values $CC_{EB/2D} = K \cdot \frac{R}{2}$ are reported in Table C.2.

Table C.2 – Coupling coefficients

Body part	Radius m	K	$CC_{EB/2D}$
Head	0,1	3,0	0,15
Trunk	0,2	1,5	0,15
Thigh	0,1	1,5	0,075
Hand	0,05	1,5	0,0375

$CC_{\mathrm{EB/2D}}$ is expressed in $\frac{\mathrm{V/m}}{\mathrm{T \cdot Hz}}$

The formulation of $E_{\mathrm{i}}(t)$ is reduced as follows:

$$E_{\mathrm{i}}(t) = CC_{\mathrm{EB/2D}} \cdot \frac{dB(t)}{dt} \tag{C.4}$$

Annex D
(informative)

Correction factor method

D.1 General

The correction factor method was originally introduced for exposure assessments in low frequencies in IEC 62226-2-1 and IEC 62311, then amended in IEC 62233 where the concept applied on current densities is expandable to the induced electric field [11], [12].

D.2 Principle

A correction factor k_{E} is defined by the following ratio

$$k_{\mathrm{E}} = \frac{EI_{\mathrm{BR}}}{EI_{\mathrm{RL}}} \qquad \text{(D.1)}$$

where

EI_{BR} is the exposure index according to the basic restriction (e.g. ELV or DRL);

EI_{RL} is the exposure index according to the reference level (e.g. AL or ERL).

The correction factor k_{E} is the ratio of exposure indices: exposure index according to the basic restriction to the exposure index according to the reference level. The first index is obtained by dosimetry based on a representative human model while the second is obtained by calculation according to the reference levels. The result of the correction factor calculation is considered to be conservative.

The value of this factor is defined for resistance welding equipment only as it considers the specificities of the spatial distribution of the magnetic field and of the exposure situation.

The compliance assessment can be performed by comparing the multiplied value of the measured exposure index according to the reference level of the magnetic field and the correction factor as

$$EI_{\mathrm{BR}} = k_{\mathrm{E}} \cdot EI_{\mathrm{RL}} \qquad \text{(D.2)}$$

where

EI_{RL} is the measured or calculated exposure level / reference level;

EI_{BR} is the estimated exposure level / basic restriction.

The correction factor depends on the national regulations (i.e. according to the basic restrictions and references levels). It is not frequency dependent in Europe.

D.3 Example of correction factor finding

D.3.1 Context

A campaign of assessments undertaken on 48 welding workplaces provided to close to 200 measurements points. The exposure limits of European regulation [9] were applied.

The equipment models were either portable spot welding guns or stationary spot welding guns. The technologies were LF-AC and MF-DC from different manufacturers and with different set-ups. Large and small arms (welding electric circuit) with several use conditions were encountered. The range of exposure indices against the relevant reference levels starts at a few hundredths of a percent to several hundred percent.

During this campaign, magnetic fields and welding currents were recorded (in accordance with Clause 6) as well the electric circuit geometries in order to compare exposure indices from calculation and exposure indices from dosimetry simulation on a human model (Duke from IT'IS).

The number of input data leads to reliable statistics.

D.3.2 Correction factor for the trunk and limbs

Correction factors were calculated by the applied Formula (D.1). The numerator is obtained by human model simulation with basic restrictions (exposure limit values) against health effects. The denominator is calculated analytically from the magnetic field record. The weighted peak method is applied in both cases.

The curve in Figure D.1 shows the statistical distribution (142 cases) of the correction factor k_E for the trunk and hands for health effects.

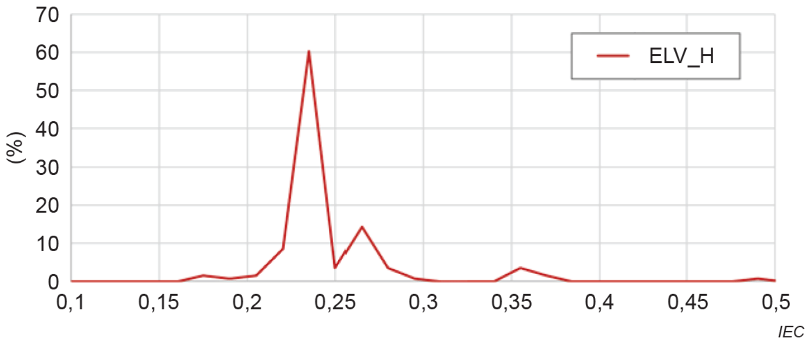


Figure D.1 – Distribution of correction factor k_E for health effects on trunk and hands

The statistical distribution is narrow with a bias. The median value is 0,23 and the 95th percentile is 0,34.

D.3.3 Correction factor for the head

The same method as in D.3.2 is applied for the exposure of the head. Both sensory and health effects are taken into account, see Figure D.2.

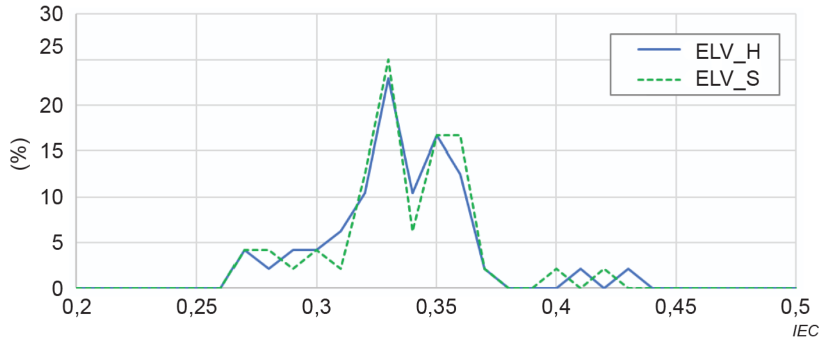


Figure D.2 – Distribution of correction factor k_E for effects on the head (sensory and health)

Both statistical distributions (sensory and health effects) can be considered identical. The distributions are narrow with a bias. The median value is 0,326 and the 95th percentile is 0,36.

D.4 Conclusion

A unique correction factor k_E of 0,35 is proposed to compensate the non-uniformity of the magnetic field on the body exposed. This value always leads to conservative analysis in all regions regardless of the adverse effects, whether sensory or health.

It is possible to determine k_E at an arbitrary frequency as it is frequency independent.

Annex E
(informative)

Example of exposure assessments on a welding machine

E.1 General

The assessment methods introduced in this document are applied onto a realistic situation, as described below. These methods are based on

- magnetic field calculation (see 5.2.3);
- coupling coefficients (see 5.3.2);
- correction factor (see 5.3.3);
- human model (see 5.3.4).

E.2 Description of the spot welding workstation

The welding machine is used to join metal parts by applying a high current to produce a spot weld. It consists of a pair of electrode arms which move in a clamping motion to clamp the ends of the electrodes to the workpieces. The equipment is kept stationary.

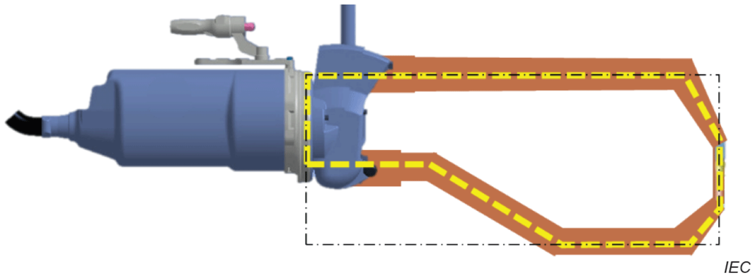
The operator is standing in front of the equipment, in its plane, 20 cm away from the welding electric circuit. The operator's hands are located 10 cm on either side of the electrodes to hold the parts during welding. The welding process is triggered by another operator.

The technology of the current generator is LF-AC (low frequency – alternative current). The welding current is set at 11,4 kA (RMS) or 60 % of its maximum available capacity and at a fundamental frequency of 50 Hz with harmonics. Its waveform is given in Figure A.3 (left). The weighted peal method (WPM) should be applied to establish exposure levels as other methods can underestimate the results.

E.3 Exposure conditions

- Trunk distance to the gun: 0,20 m
- Hand distance to the gun: 0,10 m
  - palm of right hand is vertical
  - palm of left hand is horizontal

Modeling of the welding gun (Figure E.1) is carried out to determine the distribution of the magnetic field around the gun, including in the area where the operator is located.



NOTE The electrical circuit model can be simplified by a rectangle of a size equal to the overall size of the circuit as shown (black mixed dash segments in Figure E.1). In this case, Formula (14), Formula (15) and Formula (16) apply.

Figure E.1 – Welding gun and its electric circuit model (yellow dash segments)

Figure E.2 superimposes the model, the welder and the magnetic field intensities in the selected y-z plane.

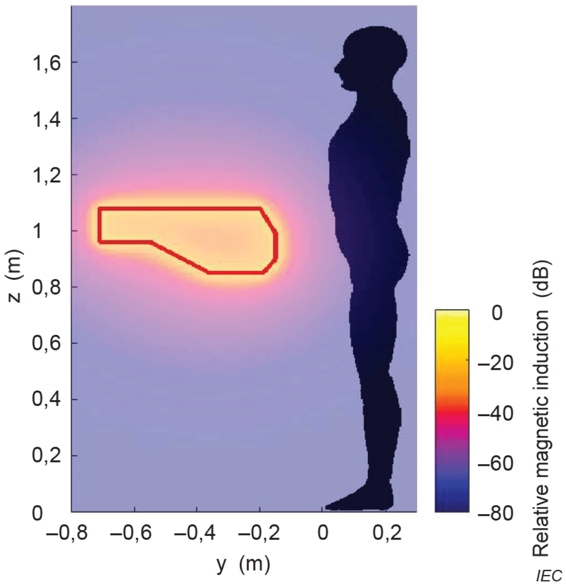


Figure E.2 – Magnetic field distribution around the exposed body

The model of the welder positioned in the magnetic field makes it possible to determine by simulation the electric fields induced in the body as illustrated in Figure E.3 and Figure E.4. Yellow indicates the highest electric fields, red represents the medium fields and dark blue shows the weakest fields. Figure E.3 results are used to determine the maximum induced electric fields in the trunk and the head. It can be seen that the field is maximum in front of the gun at the level of the belly and the upper part of the operator's legs.

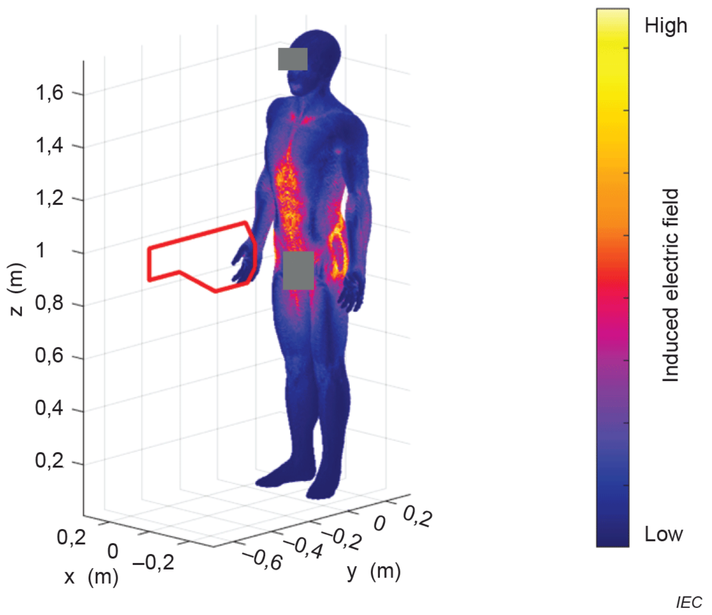


Figure E.3 – Configuration and electric field distribution on the exposed body (for 1 kA at f = 50 Hz)

Figure E.4 results give the maximum induced electric fields in the hands. One hand is horizontal and the other is vertical and this allows to consider their worst-case exposure regardless of orientation.

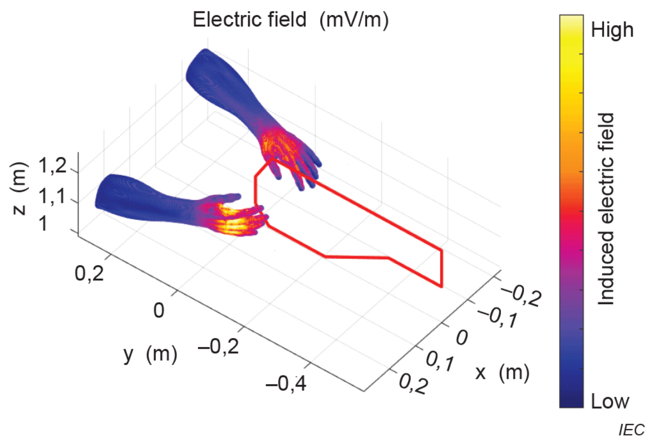


Figure E.4 – Electric field distribution on hands (for 1 kA at f = 50 Hz)

E.4 Main simulation parameters and results

E.4.1 Main simulation parameters

The main simulation parameters are

- human model: ALVAR (see 7.3);
- tissue conductivities: based on Gabriel's values at 50 Hz [22] with update [23];
- mesh resolution: 1 mm^3 cubic;
- method: SPFD (see Annex F);
- data extraction: maximum average electric field on (2 × 2 × 2) mm^3 (Annex E) of relevant tissues (see 7.4).

E.4.2 Simulation results

Results of the right hand are presented, as the induced electric field is higher than the electric field of the left hand due to a larger section crossed by the magnetic flux.

Coupling coefficients of the magnetic field (CC_{BI}) and coupling coefficients of the electric field obtained by simulation on the human model ($CC_{\text{EI/HM}}$) are presented in Table E.1.

Table E.1 – Coupling coefficients for the magnetic field and on human model

Body region	Max magnetic field (CC_{BI})	Max average electric field (50 Hz)	$CC_{\text{EI/HM}}$
Trunk	$0{,}214\,\frac{\text{mT}}{\text{kA}}$	$4{,}80\,\frac{\text{mV/m}}{\text{kA}}$	$0{,}0153\,\frac{\text{mV/m}}{\text{kA}\cdot\text{Hz}}$
Hand	$3{,}26\,\frac{\text{mT}}{\text{kA}}$	$17{,}3\,\frac{\text{mV/m}}{\text{kA}}$	$0{,}0551\,\frac{\text{mV/m}}{\text{kA}\cdot\text{Hz}}$
Head	$0{,}030\,\frac{\text{mT}}{\text{kA}}$	$0{,}620\,\frac{\text{mV/m}}{\text{kA}}$ (CNS)	$0{,}0020\,\frac{\text{mV/m}}{\text{kA}\cdot\text{Hz}}$ (CNS)

E.5 Exposure assessments

E.5.1 General

Values, their origin tables and units (if there are any) are set in Table E.2 to Table E.5.

E.5.2 Method based on magnetic field calculation

The method based on magnetic field calculation is described in 5.2.3. Exposure indices are established on the magnetic field repartition (CC_{BI}), welding current (I) and on the action levels (low, high and limb action levels). Formula (4) is applied with values from Table E.1 and Table A.2.

Table E.2 – Results based on magnetic field calculation

Health effects (trunk)	
CC_{BI} (Table E.1)	$0{,}214\,\frac{\text{mT}}{\text{kA}}$
CEI_{HighAL} (Table A.2)	$4{,}113\,\frac{\text{kA}}{\text{mT}}$
EI_{HighAL} (4)	**0,880**

Health effects (hand)	
CC_{BI} (Table E.1)	$3{,}26\,\frac{\text{mT}}{\text{kA}}$
CEI_{LimbAL} (Table A.2)	$1{,}47\,\frac{\text{kA}}{\text{mT}}$
EI_{LimbAL} (4)	**4,79**

Sensory effects (head)	
CC_{BI} (Table E.1)	$0{,}030\,\frac{\text{mT}}{\text{kA}}$
CEI_{LowAL} (Table A.2)	$13{,}4\,\frac{\text{kA}}{\text{mT}}$
EI_{LowAL} (4)	**0,402**

E.5.3 Method based on coupling coefficients

The method based on coupling coefficients is described in 5.3.2. Exposure indices are established on the coupling coefficients (CC_{BI} and $CC_{\text{EB/2D}}$), welding current (I) and on exposure limit values (or basic restrictions). Formula (8) is applied with values from Table C.2, Table E.1 and Table A.1.

Table E.3 – Results based on coupling coefficients

Health effects (trunk)		Health effects (hand)		Sensory effects (head)	
$CC_{EB/2D}$ (Table C.2)	$0{,}15\ \frac{mV/m}{mT \cdot Hz}$	$CC_{EB/2D}$ (Table C.2)	$0{,}0375\ \frac{mV/m}{mT \cdot Hz}$	$CC_{EB/2D}$ (Table C.2)	$0{,}15\ \frac{mV/m}{mT \cdot Hz}$
CC_{BI} (Table E.1)	$0{,}214\ \frac{mT}{kA}$	CC_{BI} (Table E.1)	$3{,}262\ \frac{mT}{kA}$	CC_{BI} (Table E.1)	$0{,}030\ \frac{mT}{kA}$
CEI_{ELV_H} (Table A.1)	$10{,}7\ \frac{kA \cdot Hz}{mV/m}$	CEI_{ELV_H} (Table A.1)	$10{,}7\ \frac{kA \cdot Hz}{mV/m}$	CEI_{ELV_S} (Table A.1)	$40{,}5\ \frac{kA \cdot Hz}{mV/m}$
EI_{ELV_H} (8)	**0,342**	EI_{ELV_H} (8)	**1,31**	EI_{ELV_S} (8)	**0,182**

E.5.4 Method based on the correction factor

The method based on the correction factor is described in 5.3.3. Exposure indices are established on the exposure indices according to action levels and on the correction factor k_E. Formula (10) is applied with values from Table E.2 and the values obtained from Clause D.4.

Table E.4 – Results based on the correction factor

Health effects (trunk)		Health effects (hand)		Sensory effects (head)	
EI_{HighAL} (Table E.2)	0,880	EI_{LimbAL} (Table E.2)	4,80	EI_{LowAL} (Table E.2)	0,402
k_E (Clause D.4)	0,35	k_E (Clause D.4)	0,35	k_E (Clause D.4)	0,35
EI_{ELV_H} (10)	**0,308**	EI_{ELV_H} (10)	**1,680**	EI_{ELV_S} (10)	**0,141**

E.5.5 Method based on the human model

The method based on the human model is described in 5.3.4. For the last method, exposure indices are established on the coupling coefficient $CC_{EI/HM}$, welding current (I) and on exposure limit values (ELV_Sensory and ELV_Health). Formula (13) is applied with values from Table E.1 and Table A.1.

Table E.5 – Results based on human model

Health effects (trunk)		Health effects (hand)		Sensory effects (head)	
$CC_{EI/HM}$ (Table E.1)	$0{,}0153\ \frac{mV/m}{kA \cdot Hz}$	$CC_{EI/HM}$ (Table E.1)	$0{,}0551\ \frac{mV/m}{kA \cdot Hz}$	$CC_{EI/HM}$ (Table E.1)	$0{,}0020\ \frac{mV/m}{kA \cdot Hz}$
CEI_{ELV_H} (Table A.1)	$10{,}7\ \frac{kA \cdot Hz}{mV/m}$	CEI_{ELV_H} (Table A.1)	$10{,}7\ \frac{kA \cdot Hz}{mV/m}$	CEI_{ELV_S} (Table A.1)	$10{,}7\ \frac{kA \cdot Hz}{mV/m}$
EI_{ELV_H} (13)	**0,164**	EI_{ELV_H} (13)	**0,590**	EI_{ELV_S} (13)	**0,081**

E.6 Conclusion

The more realistic method (based on induced electric fields obtained with a human model in working position compared with exposure limit values (or basic restrictions)) gives the more realistic and more precise exposure levels. An assessment against the action levels (or reference levels) overestimates most of the exposure as it considers the uniform magnetic field. The simplified assessment against exposure limit values using the coupling coefficient or correction factor is intermediate.

Whatever the method for this use case, the exposure is compliant with [9].

Annex F[2]
(informative)

Computational methods

F.1 General

Different calculation methods can be used for the determination of induced quantities in the human body by an external magnetic field emitted from resistance welding equipment. Annex F provides an overview of different calculation methods for low frequencies. Magnetic field data is applied as the incident field in the computational methods such as IM or SPFD.

As the information given in Annex F is not sufficient for application, the source materials referred to should be reviewed.

All these methods are based on the resolution of the macroscopic Maxwell's formula. The choice of a precise method for the resolution is based on various criteria including calculation time.

F.2 SPFD method

The scalar potential finite difference (SPFD) method sets the branch current instead of the loop current. Defining scalar potentials (unknowns) at each node of a voxel, a branch current flowing from one node to a neighbouring one along the side of the voxels is derived, which includes a vector potential due to the applied magnetic fields and impedance between the nodes. By applying Kirchhoff's current law at all nodes, simultaneous formulae are then set. The potential is then solved iteratively. The electric field along the side of the voxel is obtained by dividing the difference of the potentials between the nodes of the voxel by the distance across the nodes and adding the vector potential [25], [26].

$$\sum_{n=1}^{6} S_n \varnothing_n - \left(\sum_{n=1}^{6} S_n \right) \varnothing_0 = j\omega \sum_{n=1}^{6} (-1)^n S_n l_n A_{0n} \tag{F.1}$$

where S_n, $\varnothing_n$, l_n, ω, and A_{0n} denote the edge conductance derived from the tissue conductivity, scalar potential, length between nodes, angular frequency and magnetic vector potential, respectively. The matrix formulae for SPFD were solved iteratively by an iterative matrix solver. An algebraic or geometric multigrid method can be also combined into the method to accelerate the computation [15], [16].

F.3 Quasi-static – Finite element method

The finite element method (FEM) with cubic elements may be used to assess exposures from resistance welding equipment. Under the quasi-static assumption and simply-connected domains, the electric field in the body can be represented as

$$\boldsymbol{E} = -\nabla \varnothing - \frac{\partial \boldsymbol{A}_0}{\partial t} \tag{F.2}$$

where $\varnothing$ is the electric scalar potential and $\boldsymbol{A}_0$ is the vector potential of the incident magnetic field.

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2 Annex F is taken from IEC PAS 63184:2021, Annex F [27].

Due to the continuity condition, the electric scalar potential in the body satisfies the following elliptic partial differential formula:

$$\nabla \cdot \sigma \nabla \varnothing = -\nabla \cdot \sigma \frac{\partial}{\partial t} A_0 \tag{F.3}$$

with the boundary condition

$$n \cdot \sigma \left(\nabla \varnothing + \frac{\partial}{\partial t} A_0 \right) = \frac{\partial}{\partial t} Q_S \tag{F.4}$$

where σ is the conductivity and Q_S is the surface charge induced by the incident electric field.

For modelling the exposure to a magnetic field, Q_S was set to zero and $\boldsymbol{A}_0$ was calculated analytically. The exposure to the external electric field was modelled in two steps. First, the external electric potential in air was determined assuming that the body is a perfect electric conductor by solving the following formula and boundary conditions:

$$\nabla \cdot \varepsilon_0 \nabla \varnothing_{\text{ext}} = 0 \tag{F.5}$$

$$n \cdot \nabla \varnothing_{\text{ext}} = -n \cdot E_0 \quad \text{on outer boundary} \tag{F.6}$$

$$\nabla \varnothing_{\text{ext}} = 0 \quad \text{on body surface}$$

where $\boldsymbol{E}_0$ is the incident electric field and ε_0 is the permittivity of air. In Formula (F.6), it is assumed that the outer boundary is at a sufficient distance so that the perturbation in the incident field due to the body is negligible at the boundary.

The induced charge Q_S in each voxel on the body surface is calculated from the normal component of the external electric flux density, and the internal potential was determined by solving Formula (F.3) and Formula (F.4).

The electric scalar potential Formula (F.3) and Formula (F.5) are discretized using Galerkin FEM with piecewise linear basis functions. The elements were cubical, and the degrees of freedom were the values of the electric potential at the corners of each cube. This resulted in a sparse matrix equation for the unknown scalar potential values. The matrix equation may be combined with the geometric multigrid method and solved iteratively.

F.4 Impedance method

The impedance method (IM) models an inhomogeneous human body as a three-dimensional impedance network [17], [18]. Each voxel is associated with dielectric constants corresponding to the location in the human body model. Since the impedance is assigned at each edge of the voxel, the impedances are determined by an average of the dielectric constants of four adjacent voxels, for example for an impedance along the x-direction:

$$Z_x |_{i,j,k} = \frac{1}{j\omega\varepsilon_0 \dot{\varepsilon}_a |_{i,j,k}} \cdot \frac{l_x}{l_y l_z} \tag{F.7}$$

where ω and ε_0 are the angular frequency and free-space permittivity, respectively. l_x, l_y, and l_z are the edge lengths in the x-, y-, and z-directions, respectively. $\dot{\varepsilon}_a$ denotes the average complex relative permittivity, i.e. for the x-direction,

$$\dot{\varepsilon}_a |_{i,j,k} = \frac{\dot{\varepsilon} |_{i,j,k} + \dot{\varepsilon} |_{i,j+1,k} + \dot{\varepsilon} |_{i,j,k+1} + \dot{\varepsilon} |_{i,j+1,k+1}}{4}, \quad \dot{\varepsilon} |_{i,j,k} = \varepsilon_r |_{i,j,k} + \frac{\sigma |_{i,j,k}}{j\omega\varepsilon_0} \tag{F.8}$$

$\varepsilon_r |_{i,j,k}|$ and $\sigma |_{i,j,k}$ are the relative permittivity and conductivity, respectively, associated with the voxel at the location indexes i, j, and k. Once the impedance network has been constructed, the induced loop currents at each voxel face are then determined by applying an electromotive force due to Faraday's law and solving the system of equations with the successive overrelaxation (SOR) method. After the loop currents are obtained, the line currents along the edges of each voxel can be calculated from four loop currents surrounding each edge, and the current at the centre of each voxel is determined by averaging the four-line currents in each direction. Finally, the internal electric field is then computed using the following formula, for example for the z-component electric field,

$$E_z^{in} |_{i,j,k} = \frac{I_z^c |_{i,j,k}}{\sigma |_{i,j,k} + j\omega\varepsilon_0\varepsilon_r |_{i,j,k}} \cdot \frac{1}{l_x l_y} \tag{F.9}$$

where $I_z^c |_{i,j,k}$ is the z-component current at the centre of the voxel at the location indexes i, j, and k.

F.5 Hybrid technique of FEM and SPFD method

In this hybrid technique [19], the external magnetic induction field B is solved using any finite element method (FEM) approach [20], [21], while the internal electric field E is evaluated with the SPFD described in Clause F.3. Specifically, the values of the welding current are needed to calculate the magnetic field behaviour. The resulting magnetic field is then exported with a fixed grid resolution and imported in any low-frequency (LF) magneto-quasi-static (MQS) solver based on the SPFD method, which has shown to work up to about 10 MHz [24]. In this method, the electric field is obtained starting from the knowledge of the magnetic vector potential $\boldsymbol{A}$.

F.6 Computation of the magnetic vector potential

Measured magnetic field data may be directly applied as a source in IM. However, since SPFD uses vector potentials as a source to calculate the internal electric field, the reconstruction of vector potentials from the measured magnetic field (H) or the magnetic flux density (B) is required. A finite number of samples of B from simulations can be used for field reconstruction. Otherwise, a finite number of sample measurements can be collected through *ad-hoc* field meters (monitor points).

In this case the spatial coordinate of the collected measurement samples is also needed.

The procedure to reconstruct the B-field distribution *in silico* is described in [14]. The magnetic flux density is assumed to be $\boldsymbol{B} = u_x \boldsymbol{B}_x + u_y \boldsymbol{B}_y + u_z \boldsymbol{B}_z$, which satisfies $\nabla \cdot \boldsymbol{B} = 0$, where $u_{x,y,z}$ are unit vectors.

Hence it can be represented using a vector potential $\boldsymbol{A}$, so that $\nabla \times \boldsymbol{A} = \boldsymbol{B}$; a vector potential is given by the following formulae:

$$A_x = -\int_0^y \left[\frac{1}{3} B_z(x, y', z) + \frac{1}{6} B_z(x, y', 0) \right] dy' + \int_0^z \left[\frac{1}{3} B_y(x, y, z') + \frac{1}{6} B_y(x, 0, z') \right] dz' \quad \text{(F.10)}$$

$$A_y = -\int_0^z \left[\frac{1}{3} B_x(x, y, z') + \frac{1}{6} B_x(0, y, z') \right] dz' + \int_0^x \left[\frac{1}{3} B_z(x', y, z) + \frac{1}{6} B_z(x', y, 0) \right] dx' \quad \text{(F.11)}$$

$$A_z = -\int_0^x \left[\frac{1}{3} B_y(x', y, z) + \frac{1}{6} B_y(x', 0, z) \right] dx' + \int_0^y \left[\frac{1}{3} B_x(x, y', z) + \frac{1}{6} B_x(0, y', z) \right] dy' \quad \text{(F.12)}$$

Formula (F.10), Formula (F.11), and Formula (F.12) do not depend on electric or magnetic properties, therefore they are valid for any arbitrary inhomogeneous, anisotropic or nonlinear media.

Annex G[3]
(informative)

Averaging algorithms

G.1 Current density averaging over an area

G.1.1 General

The averaged current density J_{avg} according to [2] is calculated on a circular surface with an area A_0. The tissues of the anatomical models in which J_{avg} is calculated should distinguish the following groups:

– central nervous system tissue;
– peripheral nervous system tissue;
– other tissues.

The anatomical models are meshed using either Cartesian voxels or tetrahedra. Each voxel or tetrahedron is assigned a single tissue belonging to one of the three groups. Each tissue has one particular electric conductivity value. For the calculation of J_{avg} in an anatomical model, its tissues should be selected from one or more of the groups listed above. Voxels or tetrahedra with unselected tissues should be disregarded by the averaging algorithm.

For the calculation of J_{avg}, the current density vector should be determined for each voxel (G.1.2) or tetrahedron (G.1.3) and then averaged over one or more voxels or tetrahedra (G.1.4). The maximum J_{avg} of all voxels or tetrahedra should be reported.

G.1.2 Calculation of the current density in a Cartesian voxel

For Cartesian computational meshes or voxel based meshes, a current density vector is calculated for each voxel. The twelve E-field components are calculated by linear interpolation of the vector components on the E-fields on the voxel edges (Figure G.1) into the voxel centre using Formula (G.1), Formula (G.2) and Formula (G.3).

$$E_x = \frac{1}{4}(E_{1x} + E_{2x} + E_{3x} + E_{4x}) \quad \text{(G.1)}$$

$$E_y = \frac{1}{4}(E_{1y} + E_{2y} + E_{3y} + E_{4y}) \quad \text{(G.2)}$$

$$E_z = \frac{1}{4}(E_{1z} + E_{2z} + E_{3z} + E_{4z}) \quad \text{(G.3)}$$

The current density vector is calculated by multiplying the interpolated E-field vector by the electrical conductivity assigned to the voxel.

[3] Annex G is taken from IEC PAS 63184:2021, Annex G [27].

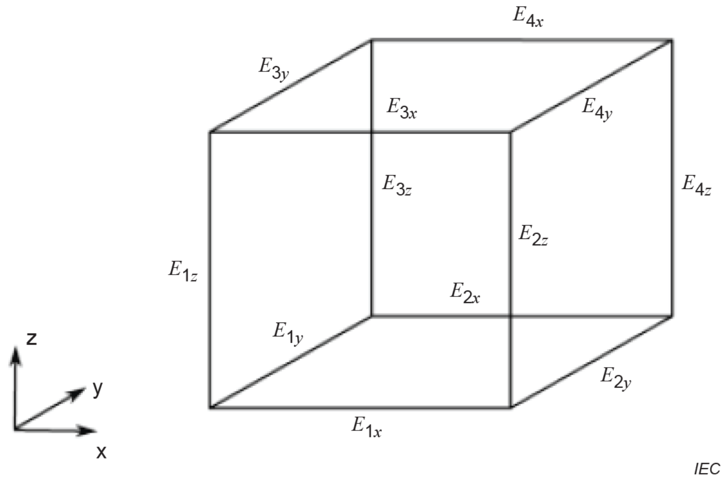

Figure G.1 – Field components on voxel edges

G.1.3 Calculation of the current density in a tetrahedron

For the calculation of the current density in the tetrahedra, the electric field vector should be calculated in the gravitational centre of each tetrahedron by evaluation of the respective finite elements. It should then be multiplied by the conductivity assigned to the respective tetrahedron.

G.1.4 Calculation of J_{avg}

J_{avg} should be evaluated for all points sampled on a rectilinear grid at a step width of sqrt(A_0) / 10 or alternatively for each voxel or tetrahedron according to the following steps:

a) Determine the direction of the current density vector $\boldsymbol{j}_v$ at point v or in the centre of the current voxel v or tetrahedron v in terms of the normalized vector $\mathbf{n}_v$.

b) Determine a circle with the area A_0 and the direction of the current density of the normal vector.

c) Triangulate the circle with a maximum edge length of sqrt(A_0) / 10.

d) Initialize two variables I_v and A_v to zero. These variables contain the current and the area contributing to J_{avg} of the current voxel v or tetrahedron v.

e) Calculate the contribution of each triangle t in the circle to the averaged current density J_{av}:

1) Determine the current passing through each triangle It by multiplying the current density vector calculated in its centre by the normalized vector $\mathbf{n}_v$ and the dimensions of the respective triangle.

NOTE 1 The current through the triangle t can be very different from the current of the voxel v or tetrahedron v for which J_{avg} is evaluated. Only the part of the current that is parallel to the current of the voxel v or tetrahedron v is considered.

2) If It is positive, add it to I_v and add the area of the current triangle t to A_v.

3) After iterating over all triangles of the circle, calculate J_{avg} by dividing I_v by A_v.

NOTE 2 This algorithm automatically adapts the size of the averaging area to structures or current paths of the cross sections which are thinner than the area of the averaging circle (e.g. peripheral nerve cords) and reduces the dimensions of the averaging area at tissue-air interfaces. As a result, excessive overestimation due to a reduced averaging area is prevented.

G.2 E-field averaging in a cubical volume

The averaged E-field E_{avg} in a selected tissue group within cubical volumes [3] should be evaluated using the following algorithm in case of anatomical voxel models:

a) The magnitude of the local E-field should be interpolated at the centre points of each voxel.

b) For each centre point, a cube C_{avg} with initial edge length d_1 = 2 mm should be constructed.

c) For each voxel which belongs to the selected tissue group, its volume inside C_{avg} should be added up to V_{avg}.

d) While V_{avg} is smaller than 8 mm^3, the edge length d_1 should be increased to approximate V_{avg} = 8 mm^3, but only as long as $d_1 < d_{1,max}$ = 4 mm.

   NOTE With this limitation, in the case of a voxel model with a thin nerve of 0,5 mm diameter, the E-field in this nerve would be averaged over a length of 4 mm, i.e. 8 voxels, instead of 32 mm with 64 voxels. A larger $d_{1,max}$ of e.g. 8 mm could also be used.

e) The final V_{avg} should not exceed 8 mm^3 by more than 0,1 %, the smallest V_{avg} and its d_1 and its centre point should be reported.

f) For the final V_{avg} all local E-field magnitudes should be multiplied by their voxel's partial volume inside C_{avg} and summed up. The sum should be divided by V_{avg}. The resulting E_{avg} should be assigned to the centre voxel.

In case of anatomical surface models, the above algorithm should be used assuming virtual voxels around the sampling points of an equidistant rectilinear grid. In this case, each virtual voxel belongs to the tissue found at its centre.

G.3 E-field averaging along an averaging distance

G.3.1 General

The averaged E-field along an average distance [5], [6], [7], [8] should be evaluated by calculating the voltage difference ΔV on two points in a tissue or a group of tissues and dividing it by the averaging distance d_a. It is assumed that quasi-static conditions are met (see G.1.3) such that the E-field integral over the distance d_a can be regarded as independent from the actual integration path. For exposure to fields higher frequencies or to magnetic sources, the E-field integral can no longer be assumed to be independent of the integration path. The E-field averaging algorithm needs to consider this by finding a path that maximizes the integral of the E-field vector along this path. For typical mesh resolutions in anatomical models, the computational effort for rigorous search of the path that maximizes the E-field integral can be assumed to significantly exceed available resources.

Hence, the integration path of the E-field is constructed following the direction of the E-field vector through the tissue groups that are evaluated. For the quasi-static case, this method will identify the path that correctly calculates the voltage difference ΔV if the mesh resolution is sufficiently fine. For the general case, this method is expected to yield convergent results if the mesh resolution is refined.

If the E-field in the domain of interest is assumed to depend on the phase of the field source, the maximization should be carried out by integrating the real part of the E-field vector for seven different phase steps of 45° of the field source.

The tissues of the anatomical models in which E_{avg} is calculated should distinguish the following groups:

– central nervous system tissue;
– peripheral nervous system tissue;
– other tissues.

Depending on the algorithm to calculate the induced fields, the anatomical models are meshed using elements, i.e. either Cartesian voxels or tetrahedra. Each element is assigned a single tissue which belongs to one of the three groups. For the calculation of E_{avg} in an anatomical model, its tissues should be selected from one or more of the groups listed above. Elements with unselected tissues should be disregarded by the averaging algorithm.

To improve the accuracy, for example in case of large tetrahedra of higher finite element order, virtual voxels can be used as elements in the following algorithm. These should be created by sampling the volume with a constant sampling step $d_0 < d_a/5$.

G.3.2 Algorithm to construct the integration path

The integration of the E-field vector along a path with the length of the averaging distance d_a should be carried out based on the following assumptions:

- Each element that belongs to the selected group of the three tissue groups listed in G.3.1 should be used as a starting point for the integration path.
- For each element, the E-field vector should be linearly interpolated into or evaluated in its gravitational centre. The reference location for each element should be assumed to be in the gravitational centre as well.

The integration path should be determined in the following steps:

a) Define two variables arrays that store the dot product of the E-field vector and its direction and the location of the gravitational centre of the element.
b) At the starting element, determine the direction of the E-field vector and the dot product of the E field vector and its direction. Store the result and the location of the vector in their respective variable arrays.
c) Identify the face of the voxel or tetrahedron through which the current direction vector passes. If the direction vector passes through an edge or vertex, all faces adjacent to this edge or vertex should be considered in the next steps.
d) For the faces identified in step c), identify the elements that share these edges.
e) If no elements can be identified in step d), disregard the current starting voxel and proceed to the next one.
f) For all elements identified in step d), determine the one with the maximum $|E|$. Store this $|E|$ and its location as part of the path for the current starting element.
g) Calculate the distance covered by the path. If the distance is less than d_a, return to step c) and add the next element.
h) Calculate the sum of the stored $|E|$ and scale it to the target distance d_a. Assign it to the current starting element.
i) Proceed to the next starting element and return to step b).

Report the overall maximum of all elements. If no maximum can be determined (see step e)) over the entire computational domain, report an error message.

Annex H
(informative)

Correspondence table between time domain and frequency domain

In theory, the calculation can be carried out indifferently in the time domain and in the frequency domain. Transcription from the first domain to the second consists in processing the frequency components (amplitude and phase). This involves replacing the convolution product (*) with an arithmetic multiplication. The symbols are expanded on in 3.4 (see Table H.1).

The frequency domain seems easier to understand but it is more complex to implement (designing a filter once is easier than implementing a Fourier transform on each waveform).

Table H.1 – Transcription of formulae

Formula	Time domain (any waveform signal)	Frequency domain (single frequency signal)
(2)	$EI_{\mathrm{RL}} = \max\left\|W_{\mathrm{RL}}(t) * B(t)\right\|$	$EI_{\mathrm{RL}} = \frac{\max[B(f)]}{B_{\mathrm{RL}}(f)}$
	$W_{\mathrm{RL}}(t) = \mathcal{F}^{-1}\left(W_{\mathrm{RL}}(f)\right)$	$W_{\mathrm{RL}}(f) = \frac{1}{B_{\mathrm{RL}}(f)}$
(3)	$B(t) = CC_{\mathrm{BI}} \cdot I(t)$	$B = CC_{\mathrm{BI}} \cdot I(f)$
(4)	$EI_{\mathrm{RL}} = CC_{\mathrm{BI}} \cdot \max\left\|W_{\mathrm{RL}}(t) * I(t)\right\|$	$EI_{\mathrm{RL}} = \max(CC_{\mathrm{BI}}) \cdot \frac{I(f)}{B_{\mathrm{RL}}(f)}$
(5)	$E_i(t) = \frac{R}{2} \cdot \frac{dB(t)}{dt}$	$E_i(f) = R \cdot \pi \cdot f \cdot B(f)$
(6)	$E_i(t) = CC_{\mathrm{EB/2D}} \cdot \frac{dB(t)}{dt}$	$E_i(f) = CC_{\mathrm{EB/2D}} \cdot 2 \cdot \pi \cdot f \cdot B(f)$
(7)	$E_i(t) = CC_{\mathrm{EB/2D}} \cdot CC_{\mathrm{BI/2D}} \frac{dI(t)}{dt}$	$E_i(f) = CC_{\mathrm{EB/2D}} \cdot CC_{\mathrm{BI/2D}} \cdot 2 \cdot \pi \cdot f \cdot I(f)$
(8)	$EI_{\mathrm{BR}} = CC_{\mathrm{EB/2D}} \cdot CC_{\mathrm{BI/2D}} \cdot \max\left\|W_{\mathrm{BR}}(t) * \frac{dI(t)}{dt}\right\|$	$EI_{\mathrm{BR}} = CC_{\mathrm{EI}} \cdot \max(CC_{\mathrm{BI/2D}}) \cdot \frac{2 \cdot \pi \cdot f \cdot I(f)}{E_{\mathrm{BR}}(f)}$
	$W_{\mathrm{BR}}(t) = \mathcal{F}^{-1}\left(W_{\mathrm{BR}}(f)\right)$	$W_{\mathrm{BR}}(f) = \frac{1}{E_{\mathrm{RL}}(f)}$
(9)	$k_{\mathrm{E}} = \frac{EI_{\mathrm{BR}}}{EI_{\mathrm{RL}}}$	$k_E = \frac{Ei_{\mathrm{HM}}(f)}{E_{\mathrm{BR}}(f)} \cdot \frac{B_{\mathrm{RL}}(f)}{B(f)}$
(10)	$EI_{\mathrm{BR}} = k_{\mathrm{E}} \cdot EI_{\mathrm{RL}}$	$EI_{\mathrm{BR}} = k_{\mathrm{E}} \cdot \frac{B(f)}{B_{\mathrm{RL}}(f)}$
(11)	$CC_{\mathrm{EI/HM}} = \frac{\max E_{i,\mathrm{avg}}}{2 \cdot \pi \cdot f}$	$CC_{\mathrm{EI/HM}} = \frac{\max E_{i,\mathrm{avg}}}{2 \cdot \pi \cdot f}$

Formula	Time domain (any waveform signal)	Frequency domain (single frequency signal)
(12)	$CEI_{\text{BR}} = \max\left\lvert W_{\text{BR}}(t) * I(t)\right\rvert$	$CEI_{\text{BR}} = \dfrac{I(f)}{B_{\text{RL}}(f)}$
(13)	$EI_{\text{BR}} = CC_{\text{EI/HM}} \cdot CEI_{\text{BR}}$	$EI_{\text{BR}} = CC_{\text{EI/HM}} \cdot CEI_{\text{BR}}$
NOTE Values are peak in the time domain and RMS in the frequency domain. The RMS values are equal to the peak values divided by √2 for sinusoidal quantities.		

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[4] A reference update will be necessary before the document becomes an IS.

(Continued from second cover)

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 62822-1 : 2016 Electric welding equipment — Assessment of restrictions related to human exposure to electromagnetic fields (0Hz to 300 GHz) — Part 1: Product family standard	IS 18483 (Part 1) : 2024/ IEC 62822-1 : 2016 Electric welding equipment — Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz): Part 1 Product family standard	Identical

The Committee has reviewed the provisions of the following international standards referred in this adopted standard and decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60050-851 : 2008	International Electrotechnical Vocabulary (IEV) — Part 851: Electric welding (available at: http://www.electropedia.org)
IEC 61786-1	Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings — Part 1: Requirements for measuring instruments
IEC 61786-2 : 2014	Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings — Part 2: Basic standard for measurements

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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