CENELEC standards on human exposure to the magnetic fields generated by arc welding equipment: a critical survey based on interventions in real situations

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Contents

Introduction 3

The methods defined in standard EN 50444 4

Methods for the determination of the magnetic field exposure indices starting from measurements at fixed points 4

Modelling of the welding circuit 5

Procedure for the computation of the clearance distance 6

Determination of $i_n(t)$ 7

Determination of IE_{max} 7

Determination of the spatial distribution function f(d) 7

Procedure for the determination of the indices referred to the dosimetric quantities 9

Application of the described procedures to the results of the measurement campaign 9

The measured waveforms 10

The clearance distances 12

Computation of the exposure indices referred to radiometric and dosimetric quantities for the welding operator 13

Conclusions 17

References 17

Introduction

CENELEC is the official electrotechnical standardisation body at European level; its standards, as far as the assessment of human exposure to electromagnetic fields (EMF) is concerned, carry considerable legal weight, being explicitly cited in European Directive 2004/40, in turn reproduced verbatim by Legislative Decree No. 81 of 9 April 2008, the "Consolidated act on health and safety at work". The latter, in Chapter IV, Art. 209, paragraph 1, indeed prescribes that "assessment, measurement and calculation must be carried out in accordance with the standardised European standards of the European Committee for Electrotechnical Standardization (CENELEC)".

The field of EMF exposure caused by arc welding equipment appears particularly fortunate in this sense, since it can rely on a fairly complete regulatory context, consisting of a specific basic standard (EN 50444, [1]) and a product standard (EN 50445, [2]), both published in 2008.

However, the application of these standards is not free of problems. Indeed, while on the one hand they contain useful indications concerning the standardisation of the exposure scenario and of the measurement procedure, on the other they propose in some cases exposure assessment metrics which, besides presenting intrinsically controversial aspects, appear as an arbitrary extension of the ICNIRP guidelines [3][4][5].

An assessment procedure for the magnetic field generated by welding equipment that does not amount to a mere bureaucratic formality should aim to (1) clearly indicate whether the reference levels for the magnetic field are exceeded and, if so, at which distances from the source; (2) where the reference levels are exceeded and it is not possible to reduce the exposure, compute by means of dosimetric techniques whether or not the basic restrictions for the dosimetric quantities are complied with.

Standard EN 50445, and even more so standard EN 50444, propose procedures that address the various aspects of exposure assessment individually, but do not provide an organic framework in which all the elements at play are considered. For example, the methods for assessing the effect of complex waveforms are defined with reference to measurements performed at fixed points. Separately, indications are given on possible models, more or less simplified, that make it possible to determine the spatial distribution of the field, without however illustrating how the results they provide can be related to those that take into account the particular waveforms encountered. Finally, also as regards the dosimetric aspects, although a reference cable configuration is defined in [1], the standards do not elaborate on its possible use, but refer to the scientific literature for this purpose.

In this work, starting from a quick description of the main methods described in the technical standards, a possible procedure is defined for the determination of the exposure indices and of the clearance distances referred to the radiometric quantities, and of the exposure indices referred to the dosimetric quantities. The procedure will then be applied to the data collected during a recent measurement campaign organised within a joint project between ASL7 and CNR-IFAC for the development of the electromagnetic fields section of the PAF, the Physical Agents Portal (www.portaleagentifisici.org).

The methods defined in standard EN 50444

Of the two CENELEC standards cited, it is certainly the basic standard EN 50444 that is richer in concrete indications, while the product standard EN 50445 mostly provides indications of a general nature; for this reason, in the following, we shall mainly consider the former.

In this work we shall refer to the indications that the standard proposes in order to prevent stimulation effects, and we shall neglect those referring to thermal effects, which are generally of secondary importance for this type of sources.

We shall then concentrate on the case of pulsed or in any case non-sinusoidal waveforms, which is the one actually encountered during the measurement campaign that will be reported below.

Methods for the determination of the magnetic field exposure indices starting from measurements at fixed points

In the presence of complex waveforms, the ICNIRP guidelines provide that one may operate either in the frequency domain or in the time domain. The basic method (standard, or STD in the following) operates in the frequency domain and does not take into account the phases of the spectral components, generating in some cases (for example in the presence of noise) patently over-precautionary results.

However, methods that take phases into account are also defined, by means of which more reasonable results are obtained. These methods (called WP — from weighted-peak — in the following) can be applied either in the frequency domain or in the time domain, whichever is more convenient.

A more detailed presentation of the methods defined by the ICNIRP guidelines for fields with complex waveform is reported in [5]; from it the expressions of the exposure indices reported below are derived. In this case, a generic magnetic flux density field linearly polarised along the unit vector $\hat{i}_p$ is considered, expressed mathematically by (1), where f_0 is the spectral resolution, B_f is the amplitude of the generic spectral component at frequency f and θ_f its phase:

$$\vec{B}\,(t) = \hat{i}_p \cdot \sum_{f=f_0}^{n\cdot f_0} \left[B_f \cos(2\pi f t + \theta_f)\right] \tag{1}$$

The index I_{STD} expressed by (2) does not take into account the phases of the field and consists of the linear sum of the ratios between the amplitude B_f of each spectral component and the IC-NIRP limit at the same frequency $B_{L,f}$, the latter multiplied by the term $\sqrt{2}$ to convert it from an RMS value to a peak value:

$$I_{\mathrm{STD}} = \sum_f \frac{B_f}{\sqrt{2} \cdot B_{L,f}} \quad (2)$$

The WP index, which in (3) is expressed in the frequency domain, takes into account the phases θ_f of the spectral components and moreover introduces additional phase terms φ_f, for whose explanation reference is again made to [5]:

$$I_{\mathrm{WP}} = \max_t \left\{ |\sum_f \frac{B_f}{\sqrt{2} B_{L,f}} \cos(2\pi f t + \theta_f + \phi_f)| \right\} \quad (3)$$

Standard EN 50444, while referring to the expressions of the ICNIRP indices reported above, adds the important prescription of excluding from the summations all spectral components with amplitude lower than 3% of the fundamental. This prescription introduces a threshold that is in some ways arbitrary and appears sensible only to mitigate the over-precautionariness of the I_{STD} index, especially in the presence of noisy signals. On the other hand, the exclusion of the less intense contributions from the expression of the I_{WP} index, which takes phases into account, appears at odds with the basic principle of the methodology, which precisely by means of the phases aims to minimise the effect of noise [5].

Modelling of the welding circuit

To take into account the spatial distribution of the magnetic flux density, reference was made to two models that standard EN 50444 indicates as usable both for the assessment of compliance with the reference levels and for the dosimetric verification of the basic restrictions.

The simplest model is the one referring to an infinitely long current-carrying wire, and hence to the Biot–Savart law. The standard introduces a multiplicative factor (Geometry Factor, GF in the following) to take into account the possible curvatures of the cable: GF equals 1.25 in case the model is used for the verification of the reference levels, and 1.8 in case it is used for dosimetric assessments.

The second model that we shall use in this work is the one described in Figure 1, taken from standard EN 50444, to which we shall return below.

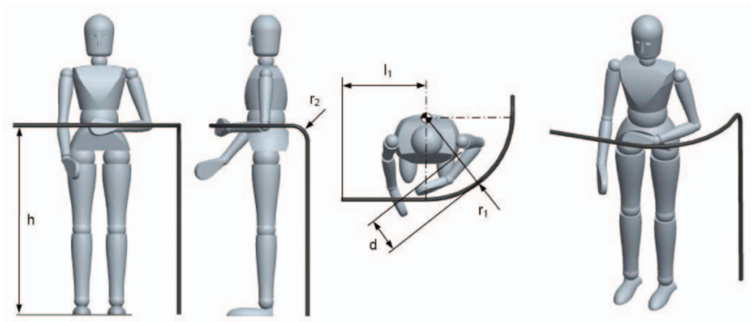

Figure 1. *Modelling of the welding circuit according to standard EN 50444.*

Procedure for the computation of the clearance distance

There are two fundamental aspects to consider when dealing with magnetic field sources such as welding machines: (1) the waveform of the magnetic field, in relation to the fact that the reference levels defined by the regulations vary with frequency; (2) the spatial distribution of the field.

These two aspects can be separated thanks to the particular characteristics of the low-frequency magnetic flux density **B**(t, Q) produced at a generic point Q by a current-carrying circuit. One can write:

$$\vec{B}(t,Q) = \frac{I(t)}{I_0} \cdot \vec{B}_n(Q) = i_n(t) \cdot \frac{I_{\max}}{I_0} \cdot \vec{B}_n(Q)$$
$$\text{with } I_0 = 1 \text{ A and } i_n(t) = \frac{I(t)}{I_{\max}} \tag{4}$$

In expression (4), **B**_n(Q) is the magnetic flux density — which in the following we shall call "normalised" — generated at point Q when the source circuit carries a direct current I_0 = 1 A. It is a vector term whose direction identifies the polarisation of the field, which in this case is always linear whatever the time behaviour of the current. The term I(t) represents the current in the circuit itself, and in particular I_{max} is its maximum. Consequently, $i_n(t)$ is the dimensionless waveform (wf in the following) of the current with its maximum normalised to 1.0; it is this waveform that we shall examine below for the analysis of the time variation of the field.

Returning to welding machines, the term $I_{max} \cdot i_n(t)$ depends fundamentally on the welding technology employed, while the term **B**_n(Q) depends on how the cables of the welding circuit are arranged and on the particular characteristics of the generator used (if one is in its immediate vicinity).

Having made these premises, it is possible to describe a procedure for the computation of the "clearance distance", defined as the distance from the source beyond which a particular regulatory limit is complied with.

1. The function f(d) = |**B**_n(Q − P_0)| with d = |Q − P_0| is determined; it is the function describing how the magnitude of the normalised magnetic flux density varies with the distance d of the calculation point Q from a reference point P_0 on the source, modelled with one of the methods described in standard EN 50444 and assumed to carry — we recall — a unit current. The f(d) is derived by moving the point Q along a reference directrix.
2. The techniques in the time domain or in the frequency domain described in standards EN 50444 or EN 50445 are applied to the wf $i_n(t)$, so as to derive a time-varying exposure index IE(t) that takes into account the limits set for the magnetic flux density; the maximum value IE_{max} of this index must be lower than 1 for the regulations to be complied with. When these methods are applied to a dimensionless wf such as $i_n(t)$, which has a maximum normalised to 1.0, the results are not significant from the point of view of the exposure to the magnetic field: they will be so only after the combination with the part that takes into account the spatial distribution of the magnetic flux density, i.e. after the next step.

3. Once the peak current I_{max} is fixed, the clearance distance d_R is determined by imposing that:

$$f(d_R) \cdot \frac{I_{\max}}{I_0} \cdot IE_{\max} = 1.0 \quad (5)$$

More generally, the exposure index reached at the generic distance d from the source is given by the product $(I_{max}/I_0) \cdot f(d) \cdot IE_{max}$.

In the rest of the work, the field generated by the cables of the welding circuit is considered, rather than the one dispersed by the generator. This does not constitute a loss of generality as long as it can be assumed that the polarisation of the field remains linear and that it is possible to separate, as described above, the time-dependence term from the one that takes into account the spatial distribution of the magnetic flux density. The dependence on space may possibly follow laws different from those valid for the cables, but the procedure will remain valid nonetheless.

Determination of $i_n(t)$

As mentioned, IE_{max} is the value obtained by applying the algorithm for the determination of the exposure index (I_{STD} or I_{WP}) to the wf $i_n(t)$. The most direct way to determine $i_n(t)$ is the one involving the use of instrumentation suited to the measurement of the current in the time domain. This also makes it possible to relate the peak value of the measured current to the one shown on the display with which welding devices are often equipped. It should be noted that standard EN 50444 itself clearly indicates that the exposure assessment process can start from current measurements. Failing that, it is in any case possible to derive the waveform starting from measurements of the magnetic flux density in the time domain, exploiting expression (4). Indeed, after verifying that the polarisation of the field is actually linear, it is sufficient to choose one of the Cartesian components of the field (for example the most intense one) and normalise its waveform to 1.0.

Determination of IE_{max}

Once the wf $i_n(t)$ is known, IE_{max} is determined by applying the techniques presented in the previous section and discussed in more detail in [5]. In this context we shall apply to the examples only the weighted-peak index (see eq. (3)), both for reasons of space and because the application of the standard method (eq. (2)) leads to identifying unreasonably large clearance distances.

Determination of the spatial distribution function f(d)

As regards the function f(d) that takes into account the spatial distribution of the field, besides the Biot–Savart law referring to the case of the straight, indefinitely long wire (to which, as mentioned, a suitable Geometry Factor GF is applied), the model represented in Figure 1 is also considered. The circuit being three-dimensional and presenting no particular symmetries, it is necessary to choose some reference directrices along which to proceed to determine the f(d); these directrices are represented in Figure 2.

Figure 3 shows the behaviours of the f(d) derived using the straight, indefinitely long wire model of the welding circuit and three different values of GF; the distance from the cable is measured proceeding orthogonally to it in a straight line. In addition, the f(d) derived with the model taken from standard EN 50444 are reported, along the internal and external directrices of Figure 2. The f(d) relating to the three-dimensional model are derived as the envelope of the profiles obtained along the considered directrices. As can be noted, a GF value of 1.25 applied to the Biot–Savart model is able to overestimate the profile relating to the 'external' directrices only, while a value of 1.8 also overestimates the one derived along the internal directrices.

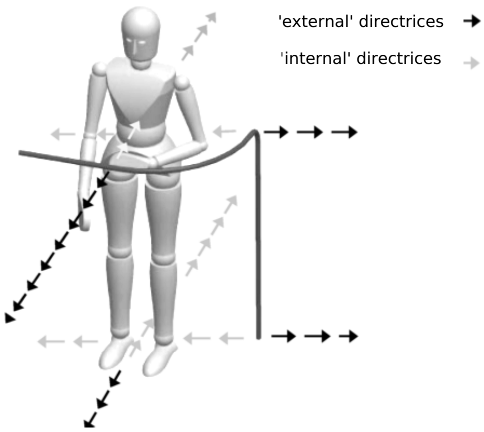

Figure 2. *Directrices for the computation of f(d).*

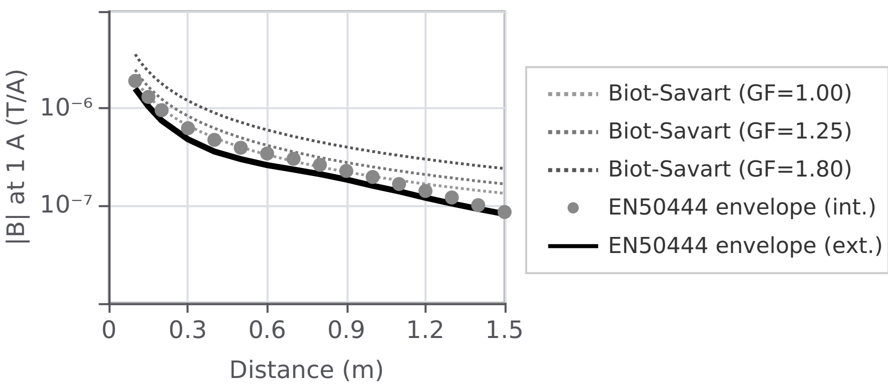

Figure 3. *Comparison among f(d).*

Procedure for the determination of the indices referred to the dosimetric quantities

At low frequency, the basic dosimetric quantities induced inside a biological organism exposed to an impressed field having the characteristics described at the beginning of the previous section can be expressed in a way similar to (4). Expression (6) describes the current density induced at a generic point Q inside the organism of the exposed subject. In this expression, the term $\mathbf{J}_{n,f_0}$(Q) represents the peak induced current density when a sinusoidal current at frequency f_0 with peak amplitude equal to 1 A flows in the source circuit.[1] The current density is therefore proportional at every instant to the time derivative of i_n(t), and this is due to the fact that the coupling between the low-frequency magnetic field and the organism is governed by Faraday's law (the variation of the dielectric characteristics of the tissues with frequency is neglected here).

$$\begin{aligned} \vec{J}(t,Q) &= \frac{\mathrm{d}I(t)}{\mathrm{d}t} \cdot \frac{1}{2\pi f_0} \cdot \frac{\vec{J}_{n,f_0}(Q)}{I_0} \\ &= \frac{I_{\max}}{I_0} \cdot \frac{\mathrm{d}i_n(t)}{\mathrm{d}t} \cdot \frac{1}{2\pi f_0} \cdot \vec{J}_{n,f_0}(Q) \\ &\text{with } I_0 = 1\ \mathrm{A} \end{aligned} \tag{6}$$

The induced current density is the reference dosimetric quantity for the 1998 ICNIRP guidelines. An analogous expression can also be written for the in-situ electric field, which is the quantity considered instead by the 2010 ICNIRP guidelines.

To obtain exposure indices that take into account both the geometry of the problem and the considered waveforms, the term $\mathbf{J}_{n,f_0}$(Q) (which also depends on the physical characteristics of the exposed subject) must therefore be computed. Moreover, it is necessary to process the i_n(t), and in particular to take its derivative and apply to it the weighting algorithms that take into account the frequency behaviour of the pertinent basic restrictions. A more detailed description of a similar procedure (although referred to homogeneous fields with non-linear polarisation) and of the related approximations is reported in [6].

Application of the described procedures to the results of the measurement campaign

The measurements were performed at the operational site of the company DBi FAU S.r.l. near Asciano (SI) and involved five different arc welding devices, indicated in the following by the labels S1, ..., S5. As can be noted in Table 1, welding machines S1 and S3 were of the same model; even though used for different jobs (S1 was part of an apparatus in which the electrodes

1. $\mathbf{J}_{n,f_0}$(Q) is a vector that does not depend explicitly on the considered waveform. The reference to the frequency f_0 is however necessary because the distribution of the basic quantities inside the exposed organism depends on the dielectric characteristics of the tissues, which are known as a function of frequency. The frequency f_0 is therefore the one at which the conductivity of the tissues is determined, and it is chosen with criteria that depend on the waveform of interest [6].

are held by a robotic arm, while S2 [sic] was used in a traditional welding station), they turned out to produce very similar waveforms. For this reason, in the following, a distinction is made among four types of devices, giving rise to as many types of waveforms.

Table 1. *Devices involved in the measurement campaign.*

Label	Model	Job
S1	Kempo Weld 5500W (KEMPPI)	Iron – robotic
S2	Kempo Weld 4200 (KEMPPI)	Iron
S3	Kempo Weld 5500W (KEMPPI)	Iron
S4	Sinvert 302 (SINCOSALD)	Steel
S5	Kempo Weld 4000 (KEMPPI)	Aluminium

The measurement chain used, described in detail in [6], is based on the use of the Narda ELT-400 probe in 'Field Strength' mode, i.e. with a flat frequency response; it also includes an acquisition board able to simultaneously sample and store to file the three analog outputs of the ELT-400, which are instantaneously proportional to the Cartesian components of the magnetic flux density.

The measured waveforms

For each device, measurements were performed at several points: at the head, trunk and limbs of the welding operator, near one of the cables, and at the generator. Figures 4 to 7 report the results measured at four points (one per welding machine model), where the graph of the components refers to the whole measurement interval (5 s at 200 kS/s), while the one of the magnitude is a close-up near the measured maximum. It should be noted that the intensities of the measured fields are not directly comparable, because they refer to different waveforms and to different distances from the devices. The measurements were performed taking care that the operator started welding after the start of the measurement, so that the field corresponding to the striking of the arc was acquired as well. As can be observed from the figures, the maximum of the field always occurred precisely during the striking; the same holds for the WP-type indices (expression (3)). It should be noted that the examples reported in Annex B of standard EN 50444 always refer to periodic wfs and do not consider in any way the striking event, which instead turned out to be significant in all the cases addressed here.

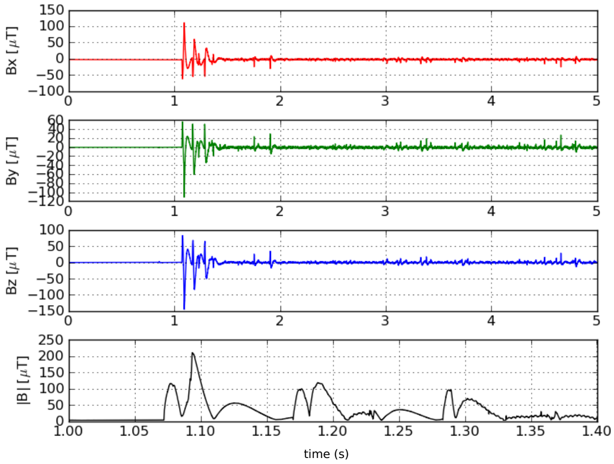

Figure 4. *Wf S1-S3 (measurement at the inspection window).*

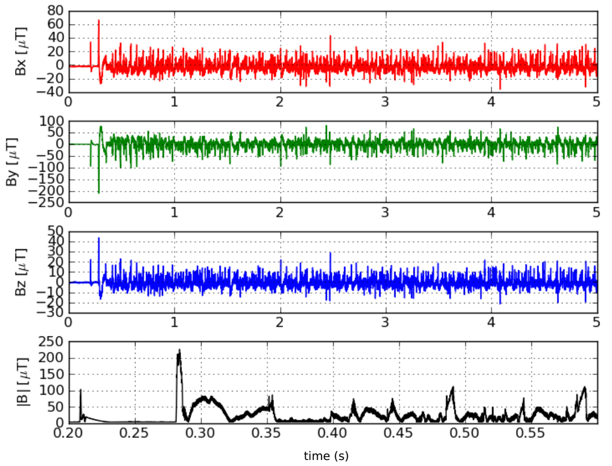

Figure 5. *Wf S2 (measurement at 20 cm from the cable).*

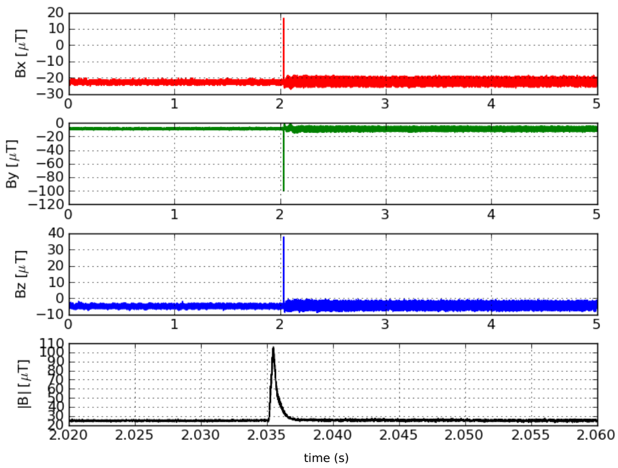

Figure 6. *Wf S4 (measurement at 20 cm from the cable).*

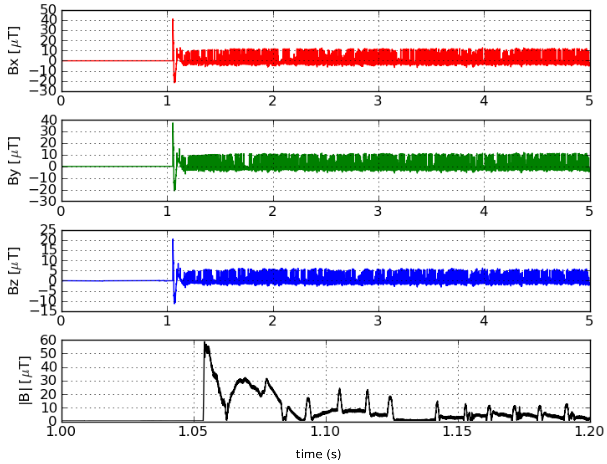

Figure 7. *Wf S5 (measurement at 1 m from the generator).*

Table 2. *IE_{max} indices for the normalised waveforms.*

Welding machine	comp.	crest factor	IE_{max} 1998 work	IE_{max} 2010 work	IE_{max} 1998 pub	IE_{max} 2010 pub
S1-S3	X	14.4	3232.2	779.2	16097.9	3389.0
S2	Y	5.1	13413.6	2536.3	66593.9	9458.6
S4	Z	7.5	11763.1	2701.5	58514.7	10684.2
S5	X	9.3	9684.9	1539.4	48231.9	6239.4

The clearance distances

Table 2 reports the exposure indices referred to the normalised waveforms and to the reference levels for workers (work) and general public (pub), both for the 1998 ICNIRP guidelines and for the 2010 ones. The table also identifies the Cartesian component of the magnetic flux density chosen for the determination of the normalised waveform, and the crest factor of the normalised wf itself. It should be noted that the criterion for choosing the waveform (among all those relating to the same device) for which the IE_{max} index is computed consists mainly in the search for the best signal-to-noise ratio.

Resorting to expression (5) and using the IE_{max} indices of Table 2 and the f(d) represented in Figure 3, it is possible to determine the clearance distances as a function of the peak current circulating in the welding circuit. These distances are reported (for welding machine S2 only, taken from here on as the typical case) in Table 3 and Table 4, considering respectively the straight, indefinitely long wire cable model with GF = 1.25 and the one represented in Figure 2.

Table 3. *Clearance distances in metres for S2 (Biot–Savart, GF = 1.25).*

I_{max} (A)	100	200	300	400	500	600	700	800	900	1000
1998 workers	0.35	0.7	1.05	1.35	1.7	2.05	2.35	2.7	3.05	3.4
1998 general public	1.7	3.35	5	6.7	8.35	10	11.7	13.35	15	16.65
2010 workers	0.1	0.15	0.2	0.3	0.35	0.4	0.45	0.55	0.6	0.65
2010 general public	0.25	0.5	0.75	0.95	1.2	1.45	1.7	1.9	2.15	2.4

Table 4. *Clearance distances in metres for S2 (cable as per standard EN 50444, external directrices).*

I_{max} (A)	100	200	300	400	500	600	700	800	900	1000
1998 workers	0.3	0.65	0.95	1.15	1.25	1.35	1.45	1.5	1.6	1.65
1998 general public	1.25	1.65	1.9	2.25	2.5	2.75	2.95	3.15	3.3	3.45
2010 workers	0.1	0.1	0.15	0.25	0.3	0.35	0.4	0.5	0.55	0.65
2010 general public	0.2	0.45	0.7	0.9	1.05	1.15	1.25	1.3	1.4	1.45

Computation of the exposure indices referred to radiometric and dosimetric quantities for the welding operator

The indications on the clearance distances contained in the previous section can be considered significant for the assessment of the exposure of the workers who linger around the welding station, or of other persons possibly present in the working environment; however, they do not provide sufficient information for the risk assessment of the welding operator. As can be noted from Figure 8, some parts of the body are a few centimetres from the cable, and hence within the distances reported in the previous tables even for relatively low currents.

In the rest of the work, the aim is therefore to characterise more precisely the exposure of the welding operator, and in particular the objectives listed below are pursued.

- To assess the occupational exposure indices for the magnetic flux density to which the different parts of the worker's body are subjected, distinguishing in particular the head from the rest of the body.
- To assess the exposure indices for workers referred to the basic dosimetric quantities: induced current density (1998 ICNIRP guidelines) and in-situ electric field (ICNIRP 2010).

Moreover, we asked ourselves how sensitive the above results were to modifications with respect to the welding circuit model proposed by standard EN 50444. Therefore the computations were repeated both with the model proposed by the standard, characterised by a distance d between trunk and cable equal to 20 cm (Figure 9), and with a slightly modified model, in which the distance d was reduced to 5 cm and the vertical section was brought forward, aligning it with the leg of the organism model (Figure 10). To do this, it was necessary to eliminate the small arc (with radius r_2) that in the complete model joins the vertical section and the horizontal one.

The organism model used has a relatively low resolution (cubic cells with a 5 mm side) and, moreover, is not articulated in a realistic posture, which should have included the bending of the arms to grip the electrode-applicator and the slightly stooped position: these elements may be taken into consideration in possible follow-up studies.

Figure 8. *Welding operator.*

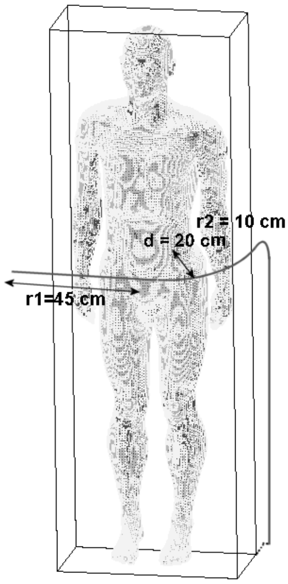

Figure 9. *Cable model, d = 20 cm.*

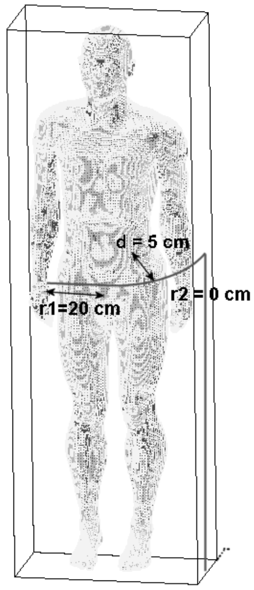

Figure 10. *Cable model, d = 5 cm.*

Tables 5 and 6 report the exposure indices relating to the reference levels for the magnetic flux density defined in the 1998 and 2010 ICNIRP guidelines for workers. In particular, Table 5 refers to the model represented in Figure 9 (d = 20 cm) while Table 6 refers to the one in Figure 10 (d = 5 cm).

Table 5. *Exposure indices referred to the magnetic flux density for S2, cable d = 20 cm (columns: peak current I_{max} (A)).*

Index	Tissues	100	200	300	400	500	600	700	800	900	1000
1998 work.	Head	0.33	0.66	0.99	1.32	1.65	1.98	2.31	2.64	2.97	3.30
	Other districts	2.00	4.01	6.01	8.02	10.02	12.03	14.03	16.04	18.04	20.05
2010 work.	Head	0.06	0.12	0.19	0.25	0.31	0.37	0.44	0.50	0.56	0.62
	Other districts	0.38	0.76	1.14	1.52	1.90	2.27	2.65	3.03	3.41	3.79

Since the cable is closer to the body, the indices of Table 6 for the districts other than the head are higher than those reported in Table 5.

Table 6. *Exposure indices referred to the magnetic flux density for S2, cable d = 5 cm (columns: peak current I_{max} (A)).*

Index	Tissues	100	200	300	400	500	600	700	800	900	1000
1998 work.	Head	0.17	0.35	0.52	0.69	0.86	1.04	1.21	1.38	1.55	1.73
	Other districts	6.82	13.64	20.46	27.28	34.10	40.92	47.74	54.56	61.38	68.20
2010 work.	Head	0.03	0.07	0.10	0.13	0.16	0.20	0.23	0.26	0.29	0.33
	Other districts	1.29	2.58	3.87	5.16	6.45	7.74	9.03	10.32	11.61	12.89

However, the exposure of the head turns out to be lower, for the same current, when the cable is closer to the leg. This can be ascribed to the fact that the horizontal section of the cable model with d = 5 cm is shorter, and to the fact that the vertical section has less influence precisely because the head is closer to its prolongation (the field generated by a current-carrying segment at a point lying on its prolongation is zero).

Finally, Tables 7 and 8 report the results of the dosimetric investigations referred to the two cable models considered. The WPJ index (relating to the induced current density and hence to the 1998 ICNIRP guidelines) is significant in the tissues of the central nervous system (CNS) only, and is exceeded only for relatively high current intensities. The WPE index, which refers to the in-situ electric field and to the 2010 guidelines, is instead differentiated for the central nervous system tissues of the head alone and for all the other tissues of the head and body (PNS). In this case, as can be observed in the tables, while the WPE indices are always below unity in the tissues of the head, exceedances can occur in the other tissues; these appear at lower currents when the cable is closer (cf. 400 A, Table 8 vs. 600 A, Table 7).

Table 7. *Exposure indices referred to the dosimetric quantities for S2, cable d = 20 cm (columns: peak current I_{max} (A)).*

Index	Tissues	100	200	300	400	500	600	700	800	900	1000
WPJ	Head CNS + spinal cord	0.17	0.33	0.50	0.67	0.84	1.00	1.17	1.34	1.50	1.67
WPE CNS	Head CNS	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.11
WPE PNS	Other tissues of head and body	0.18	0.37	0.55	0.73	0.91	1.10	1.28	1.46	1.65	1.83

Table 8. *Exposure indices referred to the dosimetric quantities for S2, cable d = 5 cm (columns: peak current I_{max} (A)).*

Index	Tissues	100	200	300	400	500	600	700	800	900	1000
WPJ	Head CNS + spinal cord	0.12	0.25	0.37	0.49	0.62	0.74	0.86	0.99	1.11	1.23
WPE CNS	Head CNS	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05
WPE PNS	Other tissues of head and body	0.33	0.66	0.99	1.32	1.65	1.98	2.31	2.64	2.97	3.30

Conclusions

What was initially meant to be a critical review of the technical standards took on, along the way, a more concrete connotation, aiming to provide indications useful for a risk assessment concerning the exposure to the magnetic fields generated by arc welding machines. This was certainly also inspired by the context in which the work was carried out, namely the development of the PAF, which was created precisely as a resource targeted (and legally recognised) for that purpose. Indeed, procedures were proposed — and applied to concrete examples — that make it possible to address in its full complexity the problem of the assessment of human exposure in the situation in question.

References

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