

## EMF ASSESSMENT RESULTS AND PROTECTION MEASURES AT WORKPLACES UTILIZING ELECTRIC WELDING PROCESSES

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### ABSTRACT

*The 30<sup>th</sup> of April 2008, deadline for national implementation of Directive 2004/40/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electro-magnetic fields – EMF), is getting closer. Employers, responsible for taking the required actions for the protection of their employees, as well as manufacturers of electric equipment, committed to provide reliable and useful EMF data for their customers (the employers), are struggling with the possible consequences of the resulting legal and contractual obligations and are exploring ways to deal with this new challenge. This paper gives attention to aspects like interpretation of the Directive, practicable procedures for exposure evaluation, examples for assessment results and measures that can be taken.*

### 1 INTRODUCTION

Directive 2004/40/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electro-magnetic fields) [1][2] was published in April 2004 with a transition period of 4 years. It adopted the basic restrictions and reference levels of guidelines published by ICNIRP <sup>2</sup>, the International Commission on Non-Ionizing Radiation Protection and therefore transformed these non-binding recommendations into European legislation. As the ICNIRP guidelines are scientifically based and were derived using conservative assumptions, their application can lead to problems in specific areas like electric welding, induction heating, MRI and other complex professional exposure scenarios which differ from the conservative exposure scenarios used for derivation of the practically detectable Action Values of the Directive (ICNIRP reference levels). These complications become more and more apparent, EU-committees, scientific organizations and standardizing bodies are working on solutions for some of those specific areas.

Fortunately members of the welding community anticipated some of the upcoming issues and already initiated work on EMF standards and scientific studies some years ago. CLC <sup>3</sup> committees prepared standards for assessment of electric welding equipment, which can primarily be used to determine the amount of EMF originating from electric welding equipment and the welding circuit with respect to the principal safety requirements of the Low Voltage Directive [3][4][5][6], which include risks due to radiation.

However, the results of such an equipment assessment can be used by employers as a basis for EMF workplace evaluation, considering the layout of the respective workplace and EMF data from other

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<sup>2</sup> <http://www.icnirp.de/>

<sup>3</sup> <http://www.cenelec.org/Cenelec/Homepage.htm>

electric equipment used there. The basic document describing the procedures to be applied for workplace assessment is currently drafted by CLC TC 106X [7], it includes the use of comprehensive EMF data provided by equipment manufacturers to avoid the need for complex and costly assessment procedures for each workplace.

More information on basic principles of EMF protection guidelines, physical and biological background and standardization may be found in earlier publications [10][11][12].

The examples of assessment results given in the following sections are based on the standardized topologies and measurement or calculation procedures given in the CLC draft standards referenced above. These standards are expected to be published in the OJ <sup>4</sup> by the end of 2007 and will then be suitable as a basis for the assumption of conformity with EU New Approach directives for product certification and to derive EMF data to be provided for employers.

## 2 INTERPRETATIONS OF THE EMF WORKPLACE DIRECTIVE

Directive 2004/40/EC is, as mentioned above, based on the EMF limits recommended by ICNIRP. However, it contains requirements beyond the element of determination of exposure and assessment of risks (Article 4). There is also the legal obligation to consider elements like provisions aimed at avoiding or reducing risks (Article 5), worker information and training (Article 6), consultation and participation of workers (Article 7) and health surveillance (Article 8). Based on this and the fact that the Directive is addressed to employers, it is quite obvious that it is incorrect to expect that equipment itself can comply with all provisions of Directive 2004/40/EC, i.e the inclusion of a general statement of compliance with Directive 2004/40/EC in any manufacturers declaration of conformity, e.g. for CE marking. After harmonizing the relevant CLC EMF standards [4][5][6], the confirmation of compliance with the Low Voltage Directive [3] will include the prevention of risks due to EMF, based on respecting the applicable exposure limits when the equipment is used according to the manufacturers recommendations.

Another item liable to misinterpretation is the distinction of Action Values and Exposure Limits. Action Values provide, as they were conservatively derived and are given in measurable quantities, a practical way to show that the Exposure Limits are not exceeded. In the case of electric welding, typically the magnetic flux density is the relevant metric. When the Action Values are exceeded, it does not necessarily mean that the Exposure Limits are exceeded. The only binding consequence of exceeding the Action Values is the necessity to determine whether the Exposure Limits, in the case of electric welding primarily the induced current density in the central nervous system, is exceeded. Only if this is detected, which may be done numerical simulation, overexposure is demonstrated.

Figure 1 is a quote from a welding equipment manufacturers publication. The author is not aware of the scientific basis for that statement, it is assumed that it is referring to field strength measurements and therefore to exceeding the Action Values. If this assumption is correct, this statement is a clear

**Accused of emitting a high magnetic field that can have very serious effects on health, all resistance spot welders currently in use in the 25 countries of the European Union must be definitively switched off by April 30, 2008 at the latest.**

misinterpretation of the contents of the EMF Directive, as compliance with the Action Values is not a requirement of Directive 2004/40/EC and therefore non-compliance with them is no legal reason to switch off equipment by April 30<sup>th</sup> 2008. The examples given in the following sections show that for many typical electric welding scenarios, by applying numerical simulation methods, compliance with the Exposure Limits can eventually be shown for situations where the Action Values are clearly exceeded.

Figure 1 Excerpt of manufacturers publication

One of the consequences of the above principle is that, as long as the Action Values are respected, field measurements are a simple way to show compliance with the limits of Directive 2004/40/EC. On the other hand there might be significant difficulties to substantiate non-compliance at specific sites without performing numerical simulations, which requires the knowledge of the EMF relevant properties of all field sources existing at the respective workplace.

<sup>4</sup> <http://europa.eu.int/eur-lex/en/oj/index.html>

### 3 ASSESMENT EXAMPLES

#### 3.1 Exposure quotients

The Action Values and Exposure Limits given in Directive 2004/40/EC are frequency dependent. Therefore the evaluation of non-sinusoidal signals can be based on spectral analysis of the measured or calculated curves, weighing of the frequency components with respect to the relevant limit values and summation of all weighted components. The result may be expressed as a fraction or percentage of the permissible value, the exposure quotient  $EQ$ . If not stated otherwise, fractions are used in this paper, a exposure quotient of e.g. 0,5 means that the assessed exposure is 50 % of the permissible value. Fractions higher than 1 represent exceeding the Action Values or the Exposure Limits.

#### 3.2 General principles of field measurements

As discussed in the previous section, direct measurement of the field properties at the workplace are a straightforward way to show compliance with the limits of the EMF workplace directive, as long as the Action values are respected. ICNIRP has stated that the Reference Levels (Action Values) are intended to be spatially averaged values over the entire body of the exposed individual. However, when dealing with non-uniform fields at low and medium frequencies, this might lead to significant underestimation of exposure and therefore to exceeding the current density restrictions. Based on the typically highly non-uniform field distribution at workplaces utilizing electric welding, averaging of measured field values before comparison with the Action Values with respect to stimulation effects is not permissible and is precluded in the CLC draft standards for electric welding.

All measurements in the following examples were made with isotropic field probes based on coils, which pick up time varying field components only. The frequency range of the probes was 1 Hz to 400 kHz, the relevant frequency components were summed according to the procedures given in prEN 50444 and prEN 50505. Static fields or d.c. components of time varying fields emerging during electric welding are typically far below the permissible values and are therefore not further discussed in the given examples.

#### 3.3 Field measurements around welding equipment

These measurements are a requirement of the referenced EMF product standards and were included to provide additional information on the exposure of the welder due to stray fields from the power source as well as the exposure of persons not directly involved in the welding process, e.g. passers by or co-workers in the vicinity of the welding power source in use. Measurements at 50 cm, 1 m and 2 m distance are specified in the arc welding basic standard, the examples below refer to 50 cm measurements only. Figure 2 shows typical measurement scenarios for arc and resistance welding equipment.



Figure 2 Typical measurement scenarios for electric welding equipment, sources: ARC, AUVA, FRONIUS, [8]

Table 1 includes examples for minimum and maximum  $EQ$  values measured at grids in vertical planes, positioned at a distance of 50 cm from the left and right sides of MIG and TIG welding power sources.

Scenario	Parameters	$EQ_{MIN}$	$EQ_{MAX}$
left side, d=50 cm	Pulsed MIG, 320 A $PEAK$	0,040	0,538
right side, d=50 cm	Pulsed MIG, 320 A $PEAK$	0,030	0,112
left side, d=50 cm	TIG AC, 200 A	0,030	0,041
right side, d=50 cm	TIG AC, 200 A	0,030	0,037

Table 1 Measured EQs in vertical grids at 50 cm distance to welding equipment, sources: AUVA, ARCS, FRONIUS

The measured values show large variations regarding positions, from left to right and also between the various points within the measurement grid. This is partly due to the internal construction of the power sources (placing of inductive components with concentrated stray field) and partly due to the exit points of the welding circuit, which generates the highest local field strengths.

### 3.4 Field measurements at operator position

Welders have to be close to the welding circuit, therefore they are exposed to high local field levels. When doing measurements these should reflect the typical position of the relevant parts of a welders body with respect to the welding cable. The draft standard prEN 50444 defines a measurement point (point of investigation POI) at the centre of a quarter circle with a radius  $r = 20$  cm. Additionally measurements were made in a vertical grid placed in the area of the welders head and trunk, with the welding cable and torch fixed by non-conducting material in a position representing a real welding scenario, see Figure 3.

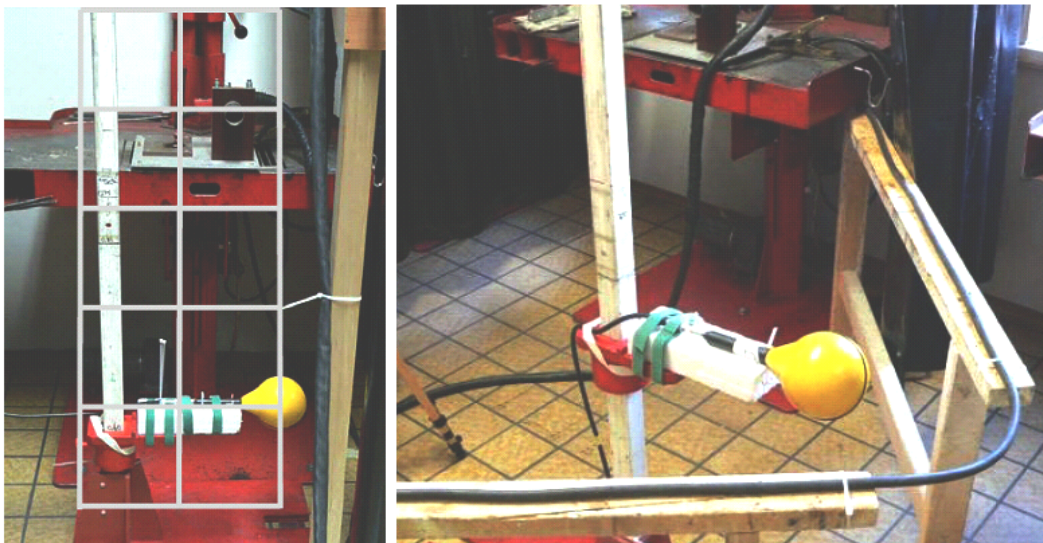


Figure 3 Points of investigation to measure EMF at operator positions, sources: AUVA, ARCS, FRONIUS

Table 2 includes examples for minimum and maximum  $EQ$  values measured within the shown grid in the vertical plane and the point of investigation defined in the arc welding basic standard using MIG and TIG welding power sources.

Scenario	Parameters	$EQ_{MIN}$	$EQ_{MAX}$
vertical grid	Pulsed MIG, 320 A $PEAK$	0,072	8,256
vertical grid	TIG AC, 200 A	0,048	2,760
inside quarter circle	TIG AC, 200 A	—	1,600

Table 2 Measured EQs at operators positions, source: AUVA, ARCS, FRONIUS

The measured values are exceeding the Action Values and, again, show large variations between the various points of investigation. This is due to major variations of the distance to the torch cable, some points within the vertical grid are very close to this conductor. The consequence of these results is that further steps to assess intra corporal current densities have to be taken, see 3.5.

Figure 4 shows some results of a numerical calculation of the field distribution around a single welding cable at elbow position. The concentration of the localized field maxima around the cable and the distinctive partial body exposure are clearly visible.

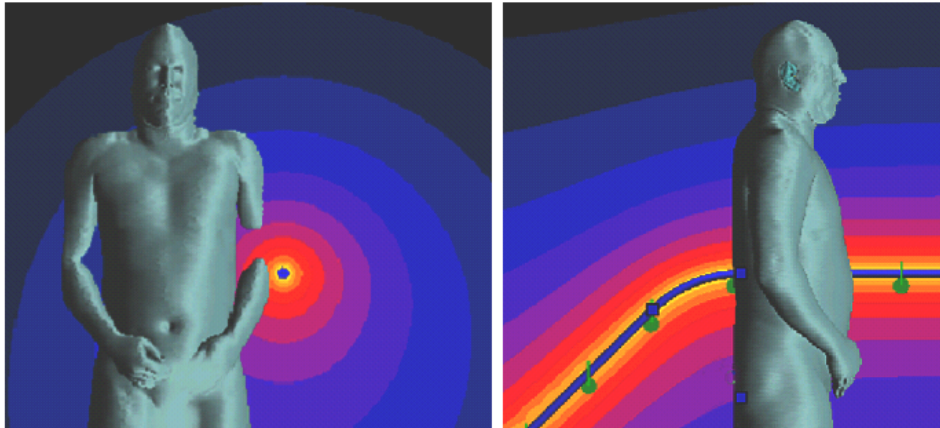


Figure 4 Field distribution around a single welding cable, source: [13]

Figure 5 shows some results of a numerical calculation of the field distribution around a resistance welding cable-gun at shoulder position, where the welding current is flowing both in the connection cable to the gun and the welding clamp. The concentration of the localized field maxima around the cable, the expanded distribution area at the clamp window and the distinctive partial body exposure are clearly visible.



Figure 5 Field distribution around a resistance welding cable-gun, source: [13]

When measuring fields at realistic distances to resistance welding guns for manual use, the Action Values will typically be exceeded. Therefore also in these cases calculations based on simplified models or numerical simulations are necessary to assess the levels of intra corporal induced current densities, see 3.5.

### 3.5 Induced current density assessment at operator position

#### 3.5.1 Simulation procedure and uncertainties

In order to determine the intra corporal effects occurring in the welders body as precisely as possible, based on the current scientific knowledge, complex numerical simulation methods have to be applied. The relevant metric for electric welding applications is the induced current density in the central nervous system of the welder, which can be derived by using anatomical high resolution models to

simulate the welders body and realistic replications of the structures generating the magnetic field close to the body, which are welding cables, torches and welding guns. The current flowing in the welding circuit, together with the modelled system allow the calculation of amplitude and waveform of the induced current densities, which are assessed against the Exposure Limits. In line with the considerations in 3.1, the result can be expressed as an exposure quotient  $EQ$ .

For arc welding several cable topologies and positions were simulated, the results given in 3.5.2 were obtained by using a straight vertical cable carrying the respective welding current to represent the field source. This topology results in worst case coupling to the body model and allows a simple variation of the distance to the body, a range of 0 cm (cable is touching the torso) to 2 m was used. The principle of these simulations is given in Figure 6.

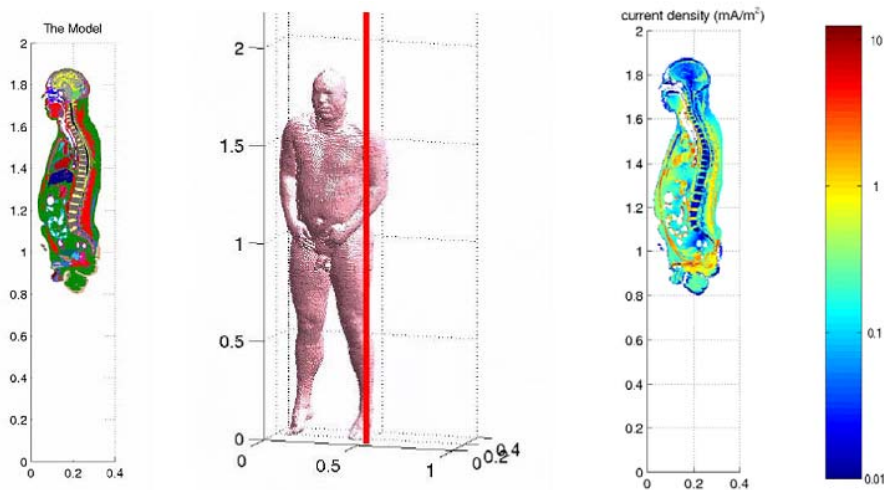


Figure 6 Basic principles of numerical current density simulation for arc welding, source: [9]

The situation is more complex for resistance welding with handheld welding guns, several positions of the gun in relation to the workers body have to be considered in addition to the complex topology of the welding current path and effects of isolated metallic parts of the welding gun. Currently two positions of a specific welding gun at elbow and shoulder height were simulated, the simulations with the gun at shoulder level resulted in considerably higher results and these are therefore used for the examples. Figure 7 shows the simulation scenario with the welding gun at a horizontal distance of 10 cm from the armpit, calculations were executed in a range of distances from 0 cm (above the armpit) to 1 m.

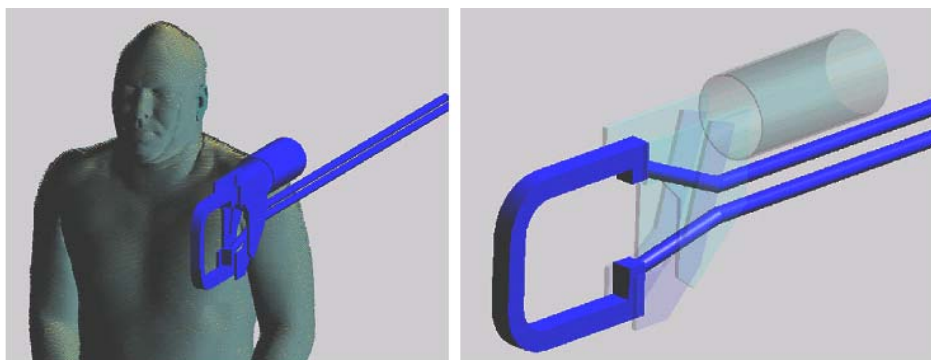


Figure 7 Topology example for numerical current density simulation for resistance welding, source: [13]

Another issue to be considered for simulating resistance welding guns is the structure of the cable to the welding clamp and the construction of the gun. For cable guns the current in the connection cables is identical to the welding current, the field distribution around the cable is depending on the geometrical properties of the cable used. A conservative scenario, representing a parallel run of a pair of cables at the maximum potential distance between the conductors and the worst case pair orientation was used. The case of a transformer gun, where the connection cable carries the primary current of the transformer integrated in the gun, is not considered in the example given in 3.5.3.

For any kind of exposure evaluation, both measurements and calculations, assessment uncertainties have to be considered. Models used for simulations include a comparatively larger amount of uncertainty factors than measurements, e.g. the parameters used for electrical conductivities of human tissues, the voxel size of the human model, current density averaging algorithms and other components. In order to get a better picture of the reliability of such simulations, the scenario for arc welding was simulated by two independent research institutes<sup>5 6</sup>, using exactly the same topology but applying different calculation methods.

Figure 8 shows the comparison of results for these simulations at different frequencies. The bars show the relative results expanded by the uncertainties specified by the research institutes. It can be seen that, considering the uncertainty ranges, the simulation results show a fairly good consistency with a tendency for slightly higher results at all frequencies from one institute.

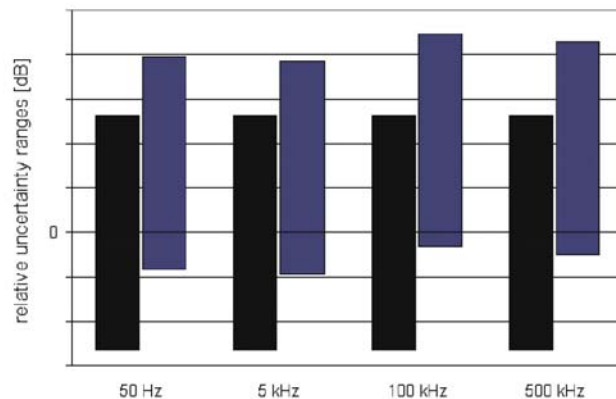


Figure 8 Comparison of simulation results for identical scenarios including uncertainties, sources: [9] [13]

As, according to the current standardization situation, a limited amount of uncertainty is permissible without penalties on the limit values, the results for the *EQ* gradients over distance given in 3.5.2 and 3.5.3 and the statistics presented in 4.3 already include correction factors considering the specified values of uncertainty.

### 3.5.2 Results for a arc welding scenario

Figure 9 shows the simulation results for a selected pulsed MIG welding process. The blue curve in the left diagram represents the welding current waveform, the red curve is the phase summation of the maximum induced current density spectral components in central nervous system tissues for a cable distance of 20 cm, weighted with the corresponding limits and therefore representing the course of the exposure quotient *EQ*. The relation between the occurring changes in the welding current and the induced effects is clearly visible.

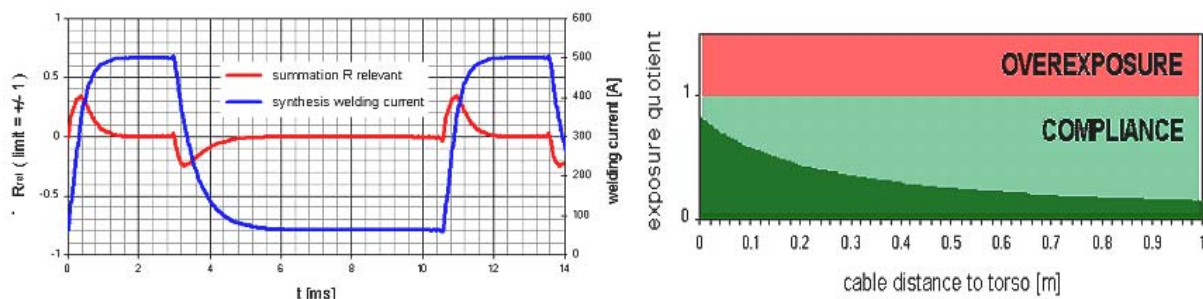


Figure 9 Simulation results for a selected pulsed MIG welding process

The right diagram in Figure 9 is the gradient of  $EQ_{MAX}$  over distances from 0 cm to 1 m to the torso, signifying that the Exposure Limits are respected even when the welding cable is touching the torso.

<sup>5</sup> [http://www.smart-systems.at/products/products\\_mobile\\_communications\\_impact\\_en.html](http://www.smart-systems.at/products/products_mobile_communications_impact_en.html)

<sup>6</sup> <http://www.elmagn.chalmers.se/MPgroup/>

### 3.5.3 Results for a resistance welding scenario

Figure 10 shows the simulation results for the most critical phase during a 7 kA d.c. spot weld using a 1 kHz inverter power source and a cable welding gun. The blue curve in the left diagram represents the welding current waveform, the red curve is the phase summation of the maximum induced current density spectral components in central nervous system tissues for a position of the connection cable at the shoulder of the welder (with a horizontal distance of 0 cm to the armpit), weighted with the corresponding limits and therefore representing the course of the exposure quotient  $EQ$ . The relation between the occurring changes in the welding current and the induced effects is clearly visible.

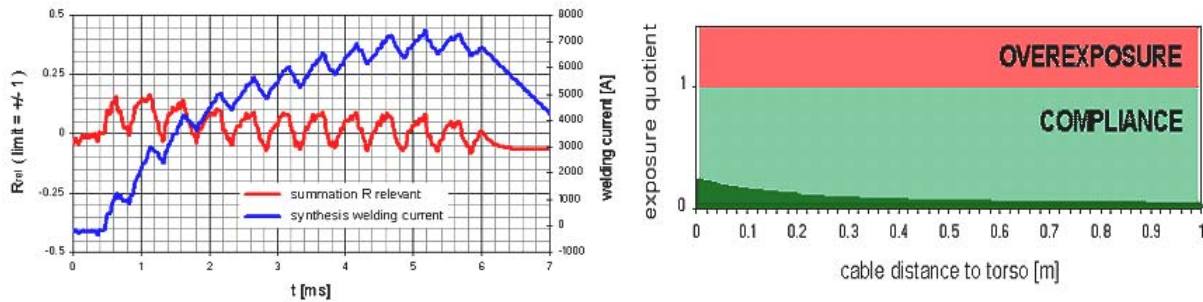


Figure 10 Simulation results for a resistance welding cable gun during the rising slope of a d.c. spot weld with 7 kA

The right diagram in Figure 10 is the gradient of  $EQ_{MAX}$  over horizontal distances from 0 cm to 1 m to the armpit, signifying that the Exposure Limits are clearly respected when the welding cable is placed on the shoulder of the welder. It might be assumed that even a more adverse cable position would not lead to exceeding the Exposure Limit at this current setting, however, as no simulations were made at positions closer to the neck and head of the welder this assumption is currently not justifiable.

## 4 CONSIDERATION OF VARYING CURRENT WAVEFORMS

### 4.1 Power setting and current waveform

The waveform of the welding current is different for different power settings. This is valid for all electric welding processes and technologies used, e.g. inverters, phase angle controlled and pulsed current power sources. This waveform variability leads to different exposure quotients, whereby higher peak or r.m.s. values of the welding current do not necessarily result in higher exposure values. Figure 11 shows the current waveforms for two different pulsed MIG programs at various settings.

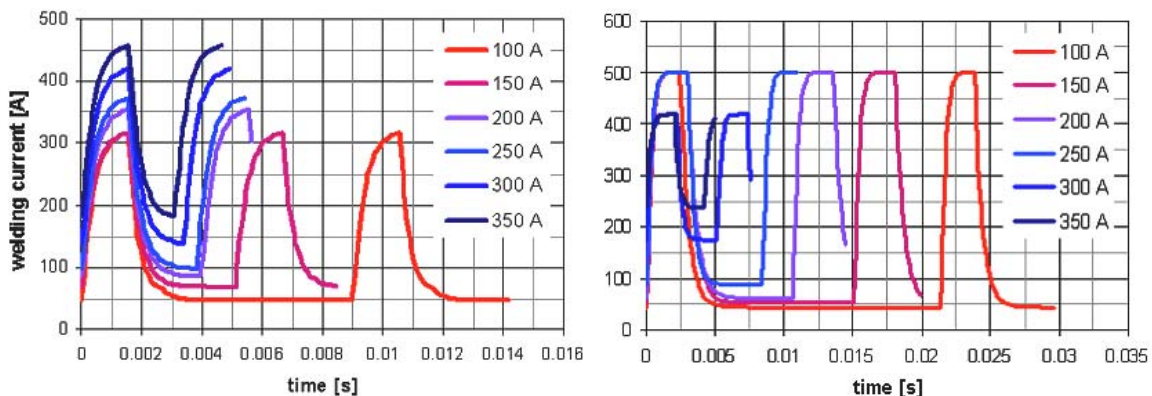


Figure 11 Welding current waveforms for two examples of pulsed MIG programs at different power settings

The example in the left diagram shows that, although the peak values of the welding current change with the setting, the  $di/dt$  values, crucial for the induction of currents inside the welders body, remain nearly unchanged. This is not the case for the example in the right diagram, where the peak currents and the differences between the pulse- and the background current decrease for higher settings. The repetition frequency and pulse duration of the pulses may also change, to a different degree for different welding programs.

**4.2 Power setting and EQ for pulsed MIG**

Based on the above the resulting EQ values for a range of pulsed MIG welding programs and settings were calculated and analysed. Figure 12 shows the relative changes of the EQ for selected programs in a welding current range from 100 A to 350 A, normalized to the values at 100 A. It is quite remarkable to see that for the majority of the analysed pulsed MIG programs, the EQ values are approximately constant or decrease with increasing current amplitude.

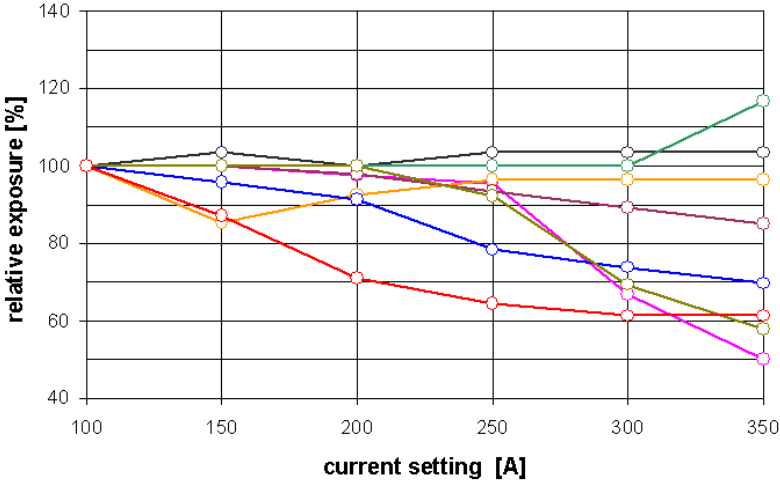


Figure 12 Relative EQ variation for selected pulsed MIG programs at different power settings

Thus different settings have to be carefully considered separately when doing detailed EMF exposure assessment, the highest peak or r.m.s. welding current amplitude cannot be deemed to be the worst case. However, this is not generally valid for other processes, detailed investigations are required when doing EMF assessment of various types of welding equipment.

**4.3 EQ and minimum distance statistics for pulsed MIG processes**

To get an overview of typical exposure data for pulsed MIG processes, 740 welding current waveforms from the FRONIUS database were analysed and the respective EQs, given in %, at 20 cm distance to the torso and the required minimum distances to the torso were calculated. It is self evident that these results are valid for the investigated set of welding current waveforms only and that no general conclusions may be drawn from these values.

Figure 13 shows the statistic EQ distribution, displaying the percentages of current waveforms belonging to EQ categories, separated by 5 % steps. The majority of waveforms results in EQs below 30 %, no waveform resulted in an EQ of more than 65 % at 20 cm distance.

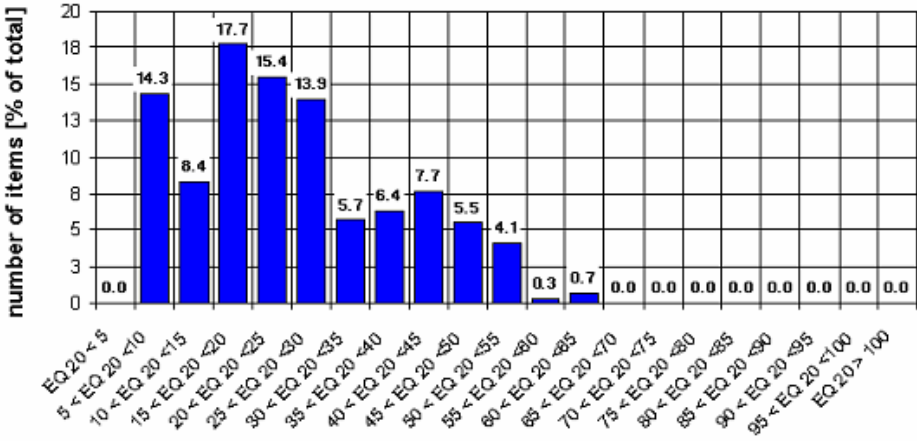


Figure 13 Statistic EQ distribution at 20 cm distance to the torso for 740 pulsed MIG current waveforms

Figure 14 shows the statistic distribution of the minimum distances, displaying the percentages of current waveforms belonging to distance categories, separated by 1 cm steps. The vast majority (96,2 %) of waveforms does not require a minimum distance to the torso (i.e. the welding cable may touch the torso without exceeding the Exposure Limit), no waveform resulted in a required minimum distance of more than 4 cm to the torso of the welder.

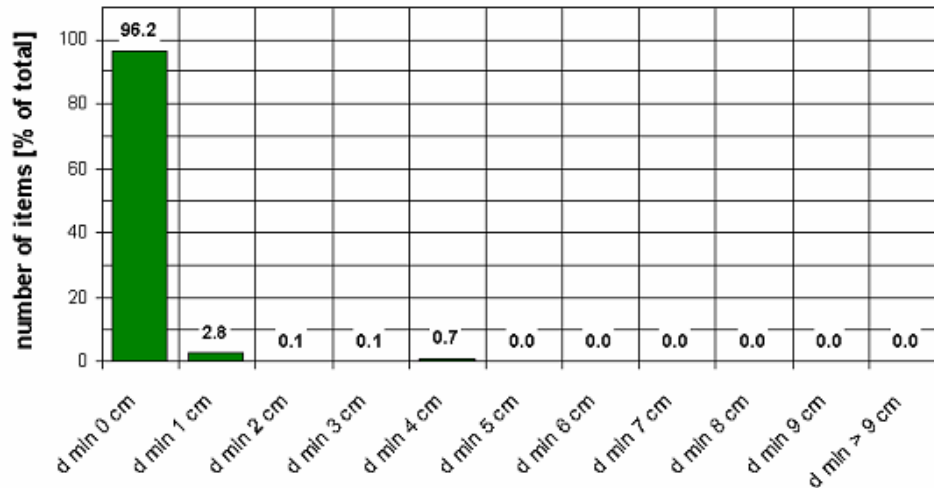


Figure 14 Statistic distribution of minimum distances to the torso for 740 pulsed MIG current waveforms

Additional simulations with vertical cables at close distances (some cm) to the head and spinal cord were made, the results show increased induced current densities exceeding the Exposure Limits for some waveforms. Based on these results and on the precautionary principle, a minimum safety distance of 15 cm from the welding cables to the head and the back of the torso (the spinal cord) is generally recommended, which is in line with existing national EMF guidelines on electric welding.

## 5 WORKPLACES WITH MULTIPLE SOURCES

### 5.1 General approach

For the EMF evaluation of specific workplaces all relevant field sources have to be considered. If the EQs related to the EMF workplace directive for all sources are available, e.g. when they were provided by the manufacturers of the equipment in use, the procedure may be as simple as adding all EQs in order to get the total exposure quotient *TEQ* for this workplace, without performing measurements or complex exposure calculations. As long as this *TEQ* is below 1 (or 100 %), the workplace is compliant with the limits given in Directive 2004/40/EC. However, some specific items have to be considered, which are discussed in the following paragraphs.

### 5.2 Stimulation and heating effects

The frequency range of the Directive covers areas with different biological effects, which are not additive in their nature. Low and medium frequencies (up to 10 MHz) may create stimulation of nervous cells, these effects are quantified by the induced current density. High frequencies (above 100 kHz) create heating effects in human tissues. Care must be taken not to add EQs for equipment operating only in the high frequency range (e.g. mobile phones or microwave heating) to EQs derived for low and medium frequency apparatus or systems (e.g. electric welding, electric tools like grinding machines or electric power distribution systems). Some types of field sources create relevant EMF in the intermediate frequency range between 100 kHz and 10 MHz, where both effects have to be considered. EQs for such equipment have to be added to the *TEQs* for both stimulation and thermal effects. If the respective frequency range for which EQs were provided is unknown, there is the possibility to consider this EQ for the whole frequency range (which is a worst case approach), or to obtain additional information. This may be done by simple orientation measurements to determine the frequency range of operation for a specific type of equipment, or by requests to the equipment manufacturer.

### 5.3 Effective distances

As shown in examples 3.5.2 and 3.5.3 *EQs* are typically distance dependent. Therefore the respective *EQs* valid for particular distances to relevant field sources valid for the workplace to be evaluated have to be considered. Using single *EQ* values, derived for short distances when equipment is being used by the worker himself, also for the evaluation of fellow employees workplaces at larger distances will lead to overestimation of exposure.

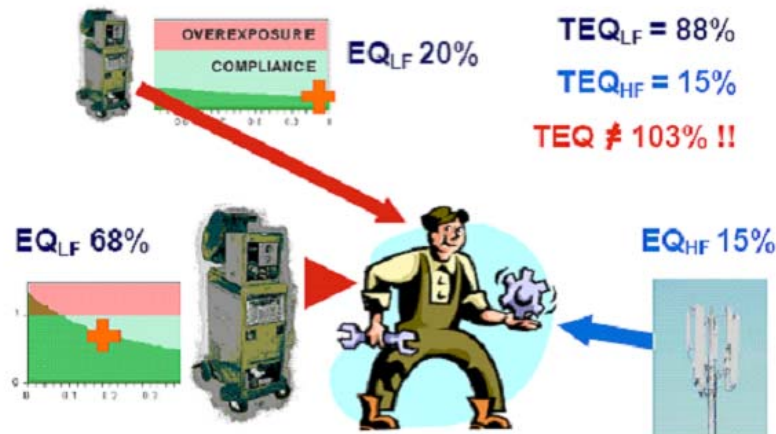


Figure 15 Principles for consideration of different EQ values, source: [11]

Figure 15 gives an example for the application of the principles discussed above. At the simplified model workplace described three different field sources are present. A electric welding machine used by the worker itself, resulting in a *EQ* of 68 % in the low frequency range, another welding machine used by a co-worker at some distance, resulting in a *EQ* of 20 % in the same frequency range and the radio-frequency field from a base station, resulting in a *EQ* of 15 %. If the maximum *EQ* for both welding machines, valid for a distance of 20 cm would be used for calculation of the *TEQ*, this would result in a value of 136 %, misleadingly indicating overexposure. The same would occur if the correctly calculated *EQ* for both welding machines (88 %), corresponding to stimulation effects, would be added to the *EQ* resulting from the radio-frequency exposure due to the base station, corresponding to thermal effects.

## 6 MEASURES

### 6.1 Training of welders

Awareness of welders regarding the possibly arising EMF risks when using electric welding equipment is the first step to avoiding those risks. Even though the exposure due to electric welding systems will in many cases not exceed the permissible values, welders have to be trained to avoid adverse application practices. One such practice, which is quite common among welders, is draping welding cables around the neck or other parts of the body in order to keep the weight of the cable from the arm operating the torch. Of course this information has to be accompanied by the development of alternative routines and possibly the supply of auxiliary means to achieve the same goals without increasing the exposure to EMF.

EMF fields may interfere with some medical implants, e.g. pacemakers, therefore these workers have to be informed and protective measures for persons wearing medical implants have to be taken. This may be achieved by e.g. access restrictions for passers-by or individual risk-evaluations for welders.

The EMF draft standards include some procedures in order to minimize exposure to EMF fields from equipment and the welding circuit, e.g. for optimising the layout of welding cables or to avoid carrying portable equipment whilst welding, which shall be both known and applied by all welders. These procedures have to be included in the instruction manual of welding equipment, which will be checked as a part of the product certification in accordance with the Low Voltage Directive as soon as the EMF product standards are harmonized and used by manufacturers.

## 6.2 Equipment design

The magnetic field around conductors carrying electric current is defined by physical principles. The magnitudes of EMF arising during welding processes can basically be influenced by varying the shape and position of these structures and the properties of the welding current itself.

The field around the welding power sources may be minimised by optimising the internal design, e.g. the positioning and construction of inductors or the topology of internal electric circuits. However, the EMF reduction potential of such measures is limited due to the dominating fields around single conductors like welding cables and the technologies available. Moreover, direct power source emissions are typically well below the permissible values.

Relevant fields are mainly generated by parts of the welding circuit close to the welder, which are typically the torch and return cable for arc welding and the connecting cable to and parts of the welding gun for resistance welding. Whereas there are no realistic possibilities to reduce the magnetic field around single conductors (mainly used for arc welding) by design, some techniques to reduce the field around multiple conductor cables are available, which can primarily be applied to resistance welding guns.

Figure 16 illustrates the results of a study on the application of multi-conductor cables to connect a resistance welding cable-gun to its power source. Field measurements were made at the points indicated in the left figure, first with a ordinary connection cable assembly using a simple pair of wires and then with a so called "field reduced" cable consisting of multiple pairs of conductors which are arranged in a way allowing the individual fields around the single conductors to (nearly) compensate each other. The diagram shows the relative field reduction achieved with the multi-conductor cable in relation to the values measured with the cable pair.

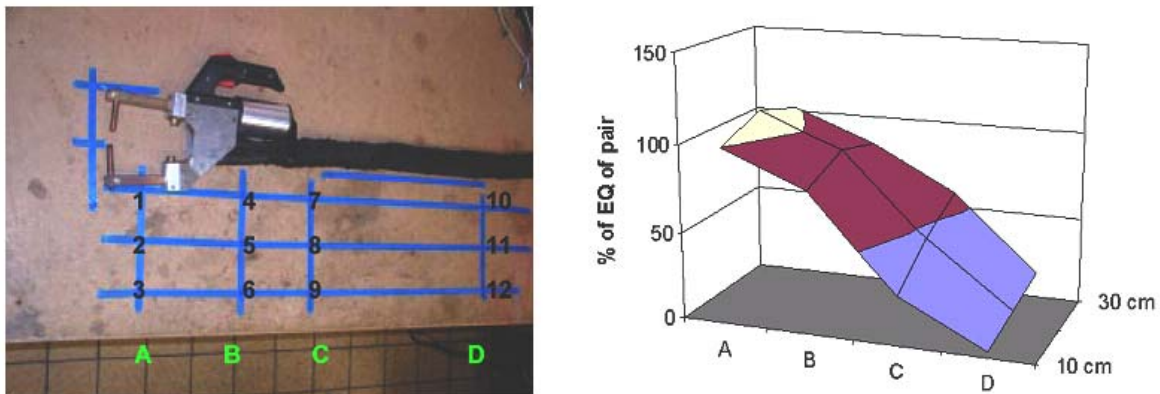


Figure 16 Field reduction effect of a multi-conductor cable compared to a simple pair of wires with a cable-gun

It can be seen that the reduction at positions remote to the welding clamp reaches considerable values up to approximately 90 % (only 10 % of the stray field remains), whereas the field close to the welding window may even slightly increase for the same power setting, which is based on the decrease of the cable inductance and the resulting increased welding current.

Resistance welding guns with integrated medium frequency transformer, where the connection cables to the power source carry the primary current of the transformer (with a comparatively low amplitude but higher frequency) can be used to decrease the absolute values of the magnetic field around the welding cable if needed, but don not change the field distribution at the welding window itself.

Further exposure reductions may be achieved by software measures like slew rate control of the welding current with modern switched mode power supplies incorporating microprocessor controls. However, there are limitations to that method based on the waveforms needed to comply with the requirements of the sophisticated welding processes needed for joining new materials and to implement the demands of advanced serial production in the industries relying heavily on various electric welding processes.

### 6.3 Shielding and active compensation

Shielding methods are based on keeping the magnetic field away from the welders body, e.g. by shunting the magnetic flux using high permeability materials. Studies are currently in progress in several research institutes in order to explore the practicability of these methods and to investigate the properties of new shielding materials. Currently no material useful for effective and affordable protective clothing is commercially available for low frequency magnetic fields. From a practical point of view the application of shielding will in many cases be confined to stationary welding applications. The same applies to active compensation techniques, where the magnetic field is reduced, or ideally cancelled, by superposing an additional inverse field. The principle of compensation, which is widely used in acoustic applications like headphones, only works for a confined area, in wide range electromagnetic applications the added field might even lead to increased EMF levels due to constructive superposition outside the controlled zone.

### 6.4 Reduction of exposure time

Stimulation effects due to low and medium frequency electromagnetic fields are considered to be instantaneous by ICNIRP. Therefore the reduction of exposure time has no effect on the occurring exposure levels and is no permissible measure to deal with potential overexposure. Some national EMF regulations and standards include provisions for short time exposure also for the low and medium frequency range, however these considerations claim to be based on biological sub-threshold effects in human cells, which still have to be verified and implemented in European legislation.

The effective exposure time compared to the duration of a whole working day, resulting in averaging the individual peak exposure values, can be used for the assessment of high frequency exposure causing thermal effects, however these phenomena are in general no issue for electric welding processes.

## 7 CONCLUSIONS

The EMF Directive 2004/40/EC is undoubtedly a additional burden and challenge for both the European employers and the manufacturers of electrical equipment in general and electric welding equipment in the special, which will have to initiate comprehensive activities to show compliance of their products and provide data for their costumers or, in some cases, to apply measures to reduce EMF exposure. On the other hand, if applied with responsibility, it represents the chance to further improve safety at work and raise the awareness for odourless, inaudible and impalpable and therefore often incomprehensible phenomena present in daily life. There are definitely some remaining questions to be answered by authorities and the scientific community and some homework to be done by the industry, however this should not be used as a justification for commercial exploitation of this topic, playing on some currently existing uncertainties.

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