IIW 2007 in Dubrovnik, Croatia
Doc. III-1449-07

Joint Workshop on "Health, Safety and Quality in Welding"
by C-III, C-VIII and C-XII

Exposure Electromagnetic Fields During Resistance Welding Operations

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IIW Commision III

Reprint from the document of Sheet Metal Conference XII

Exposure to Electromagnetic Fields During Resistance Welding Operations

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Abstract

The dramatic increase of electrical appliances in occupational environment as well as at home during the last half century has urged the health authorities to anticipate measures in order to prevent hazards which might result from exposure to electromagnetic fields (EMF) generated by electrical currents.

In that respect, the World Health Organisation (WHO) formed a working group called International Commission for Non Ionizing Radiation Protection (ICNIRP) with objectives to evaluate the health risks and develop recommendations for protecting the workers against EMF exposure and their consequences.

ICNIRP made it clear that the evidence for any long-term health effects from exposure to EMF is very weak but short-term effects linked to electric current induced in the body were clearly established and thresholds were set up.

Based upon ICNIRP guidelines, the European Council has issued a Directive which targets to keep occupational exposure below limit values. This Directive will take effect in the European Union in April 2008. At that time, all working stations whether new or old will have to comply with the Directive guidelines.

Due to rather high currents involved during resistance welding process, this technology and related equipment is candidate for further investigations especially when welders are manually operated, whether portable or pedestal, given the worker is standing next to the equipment.

The main objective of this publication is to provide guidelines for the design of resistance welding equipment as well as for the layout of the working stations in order to bring workers' exposure below limits.

Summary of the publication:

- Overview of physical laws in order to better understand how physical quantities like current density, frequency, distances etc. are influencing the magnetic flux density
- Explaining through simple formulas the coupling mechanisms between fields and body and the related biological effects
- Showing the limit values as expressed in the European Directive and explaining how they were established
- Displaying and interpreting measurements performed in the vicinity of resistance welding tools
    - Magnetic fields were measured on both 60 Hz and medium-frequency direct current (MFDC) manual welders

  - Mapping of the gun surrounding area was built up and boundaries corresponding to limit values were drawn
  - Further models were developed for better evaluation of induced currents by taking into account the non continuous nature of the field against distance to the welder
- Results and suggested guidelines for product design and process monitoring, as well as for working station engineering in order to comply with the Directive's thresholds include:
  - Influence of phase shift angle
  - Influence of shielding devices
  - Influence of switching frequency (for MFDC equipment)
  - Influence of gun ergonomy and workers' body movements

Terminology and Elementary Physics

Electrical Fields

Symbol: $\vec{E}$

Unit: Volts per meter (V/m)

Definition: The presence of an electrical field in a region in space is detected by the force that it exercises on an electrically charged particle, whether fixed or mobile, located at a point within this space (vacuum, air or within a solid, liquid, or gaseous). This influence is determined by the following equation:

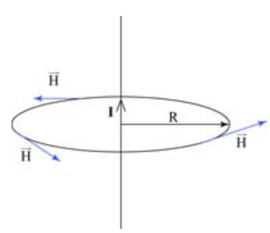
$$\vec{F} = q\vec{E}$$ $\vec{F}$ in Newton (N), q in Coulomb (C), $\vec{E}$ in (V/m)

In our resistance welding applications where voltage levels are low even on the power supply side (generally < 500 V), compared with those present in high or very high voltage power lines, electrical fields do not represent a predominant risk factor. Any further analysis of it will therefore be restricted in the remainder of this document to a few general points.

Magnetic Field/Magnetic Flux Density

Symbols and units: Magnetic field intensity $\vec{H}$ (A/m), magnetic flux density $\vec{B}$ (Tesla)

Definition: A conductor carrying an electrical current expressed in amperes will develop, tangentially to the circumference of a perpendicular winding, a field of magnetic vectors $\vec{H}$ where the module H is the intensity of the magnetic field expressed in amperes per meter (A/m).



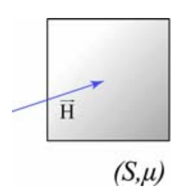


Figure 1. Definition of Magnetic Field

This field of magnetic vectors $\vec{H}$ with a module of H, perpendicularly exercises through a flat area (S) through a medium of permeabilityμ, a magnetic flux with a density expressed in Tesla (T). The relation that links the magnetic induction $\vec{B}$ and the intensity of the magnetic field $\vec{H}$ is:

$\vec{B} = \mu \, . \, \vec{H}$ ($\mu 0 \, . \, \vec{H}$ in a vacuum)

μ = magnetic permeability of the environment

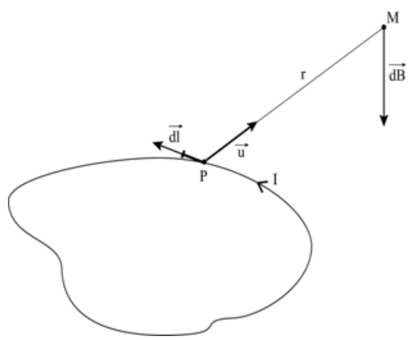
μ (air) $\cong \mu 0$ (vacuum) = $4\Pi \ 10^{-7}$ $H.m^{-1}$

For the remainder of this presentation, we will only retain the concept of a magnetic flux density $\vec{B}$ expressed in Tesla. The reference medium for studying the fields generated by welding materials always being ambient air.

As the unit used to calculate the amplitude of field $\vec{H}$ is Amperes per meter (A/m), it is easy to understand the predominant influence of the intensity of the electrical current, hence its importance in terms of resistance welding equipment where the current levels can reach very high values (10 to 100 kA).

We shall also see that a Tesla is a relatively large unit and that for expressing the fields encountered in our industrial environments, we will rather be using milli-Tesla (mT) or micro-Tesla (μT).

Derivation of Magnetic Field Generated by a Conductor Carrying an Electrical Current



$$\vec{B} = \frac{\mu_0}{4\pi} \oint_{(c)} \frac{I \, \overrightarrow{dl} \, \Lambda \, \overrightarrow{u}}{r^2}$$

Figure 2. Biot and Savart Formula [The intensity of the magnetic flux can be computed in any position of space thanks to the Biot and Savart formula. Assumptions: B: magnetic flux density (in Tesla), I: intensity of the electrical current in the closed loop (C) (in amperes), R: distance of M to the circuit (in meters), μ_0: magnetic permeability of the vacuum ($4\Pi 10^{-7}$).]

Special case where a straight conductor wire carries a current:

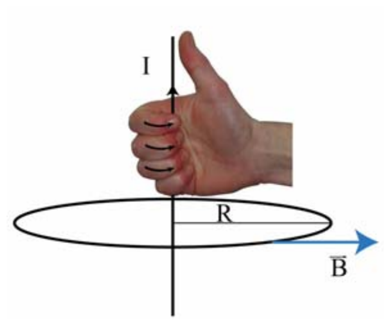


Figure 3. Direction of Magnetic Field (The intensity of the field $\vec{B}$ generated at a distance R is given by the simplified formula: $B = \frac{\mu_0 I}{2\pi R}$.)

B is constant in intensity all along a circle with a radius of R and with a plane that is perpendicular to I. Its axis is tangential to the circle and its direction is given by the four fingers of the right hand with the thumb directed according to I.

Special case of a straight conductor with a radius of r carrying a current with an intensity of I:

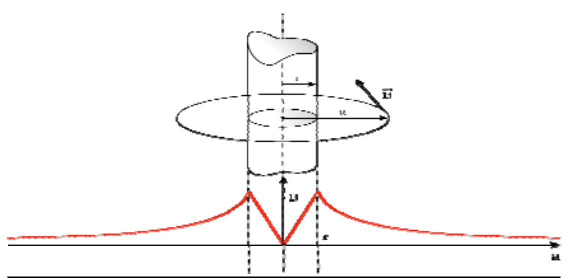


Figure 4. Magnetic Field Generated by a Conductor ($\vec{B}$ outside the conductor results from the following formula: $B = \frac{\mu_0 I}{2\pi R}$. Axis and direction as above.)

Special case of a two parallel conductors carrying opposite electrical currents:

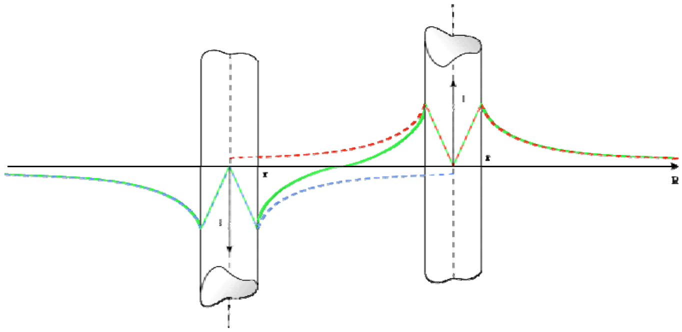


Figure 5. Magnetic Field Generated by Two Conductors (Assuming electrical currents are flowing in opposite directions in the conductors, magnetic fields are in opposite directions as well so they get neutralized between the conductors.)

Electromagnetic Waves

An electromagnetic wave corresponds to an energy transfer in the form of an electrical field coupled with a magnetic field (light is a very high-frequency electromagnetic wave).

With the exception of static fields which may exist independently (e.g., a magnetic field created by a magnet or an electrical field between the two plates of a charged capacitor), fields $\vec{E}$ and $\vec{B}$ resulting from the circulation of electrical currents will always coexist when these currents vary over time (frequency > 0).

Both fields propagate in space along a wave pattern, perpendicularly to each other in a plane that is itself perpendicular to the direction of propagation.

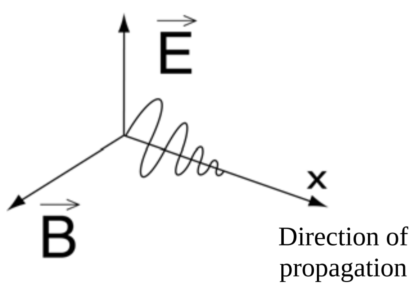


Figure 6. Electromagnetic Wave [The power density ($W.m^{-2}$) of an electromagnetic wave is characterized by Poynting vector: $\vec{S} = (\frac{\vec{E} \wedge \vec{B}}{\mu 0})$.]

When an electromagnetic wave passes through matter (e.g., biological tissue) all or part of its energy is transformed into heat.

The specific absorption rate (SAR) expressed in W/kg quantifies the power absorbed by the tissues.

The SAR depends on:

- The conductivity of the tissues (σ)
- The amplitude of the electrical or magnetic field, and these two values are linked by the relationship E/B=c
  c: light velocity in free space (300,000 km/s)
- The tissue mass density (ρ)

$$\text{SAR} = \frac{\sigma E^2}{\rho} = \frac{\sigma c^2 B^2}{\rho}$$

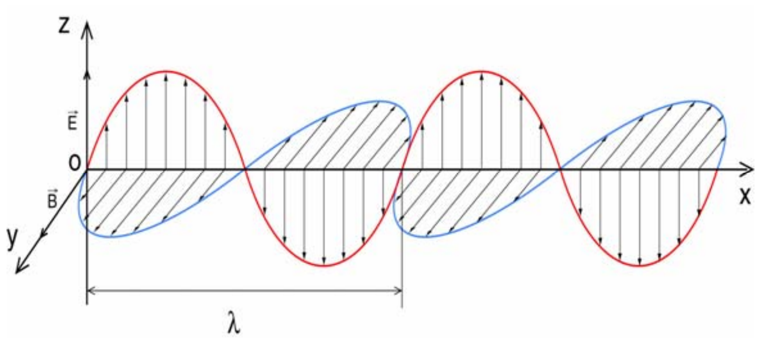


Figure 7. Electromagnetic Wave Propagation [λ = wave length (in meters), f = frequency (in hertz): the number of oscillations per second at a given point in space (x axis). The wave length λ and the frequency f will characterize the electromagnetic wave. Its propagation speed depends on the medium it passes through. These two values are linked together by the following physics formula: $\lambda = c/f$.]

Consequence/Application to 50-Hz Welding Equipment

The device to person distances are of course incomparably less, leading to consider that in relation to the source, we are in the area referred to as the "near field", in which case the energy transfer laws relating to the $(\vec{E},\vec{B})$ coupling do not apply and the $\vec{E}$ and $\vec{B}$ fields interact separately with the biological systems. As we have seen in our applications, only the $\vec{B}$ field is significant and we will therefore study its effects only, the currents that it induces in tissues.

EMF and Wave Classification

According International Classification, frequencies below 3000 Hz belong to the extremely low frequency (ELF) range of the whole spectrum.

<u>Electromagnetic Induction</u>

The remainder of this presentation will show that electrical and especially magnetic fields can be hazardous, less by their direct effects (attracting magnetized particles or deviating electrically charged particles from their path in a magnetic field) than by their ability to cause so-called induced current in conductive circuits. This property is called electromagnetic induction and it was evidenced for the first time in the early nineteenth century by two physicians, Henry in the U.S. and Faraday in England.

Faraday's Induction Law

A coil with a surface area of S exposed to a magnetic field $\vec{B}$ is subject to a magnetic flux $Ø_B$ that matches the general formula.

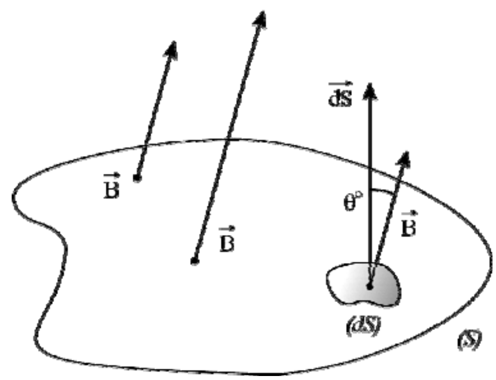


Figure 8. Faraday's Induction Law [$dØ_B = \vec{B}.\overrightarrow{dS}$ = B.dS. cos θ, $Ø_B = \int_{(s)} B.dS.\cos\theta$, $\overrightarrow{dS}$: normal vector to the incremental surface element dS, θ : angle formed by $\overrightarrow{dS}$ and $\vec{B}$, If $\vec{B}$ is homogenous and perpendicular to the surface area (S), Ø = B × S.]

This flux induces an electromotive force (EMF) and therefore an induced current, with a value that is dependent on its derivative (variation of Ø over time).

$$e = -\frac{dØ}{dt} = -\frac{d(B \times S)}{dt}$$

To generate an induced current, field $\vec{B}$ must vary over time (if it is generated by a 50-Hz AC source, for example), or the surface or the axis of the surface vary over time, which happens if the circuit is moved within the field or if its shape is changed.

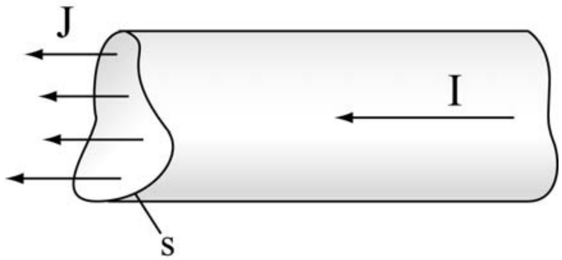
Special case: a field created by a sine wave source with a pulsation of ω = 2 πF:

B = Bm cos ωt
dB/dt =-ω Bm cos ωt
$e = -\frac{dØ}{dt} = -\frac{d(B.S)}{dt} = -S\frac{dB}{dt}$ (if S does not vary)
e = ω S Bm cosωt
e = 2πfS Bm cos ωt

Clearly, the induced electromotive force is directly proportional to the frequency, which explains why the limit values for exposure to magnetic fields will be all the lower if the frequency of the current that generates it is higher.

<u>Current Density, J</u>

When a current I is regularly spread over a surface with a section of S, the current density through this surface is symbolized by the letter J and it is expressed in A/m^2 or mA/m^2 and is deduced using the formula:



$$J = I/S$$

Figure 9. Current Density Inside a Conductor

When analyzing the biological effects of induced currents, it is the density value of current J that will be the determining factor that is setting exposure limits.

Biological Effects of EMF

<u>Coupling Process Between Magnetic Field and Human Body</u>

The human body is made up of tissue of known electrical conductivity which varies from one organ to another. When exposed to an outside magnetic field, conductor tissues may represent closed circuits (rings) within which induced currents may appear in compliance with the electromagnetic induction laws defined in the last section.

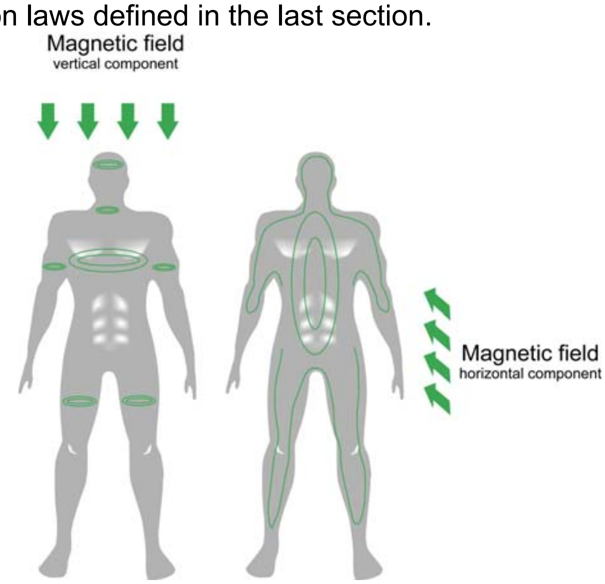


Figure 10. Induced Current in Human Body Exposed to Magnetic Radiations

The evaluation of the induced current levels caused by an exposure to a magnetic field source is extremely complex, due especially to the:

- Complexity of the magnetic field in which the body or exposed part of the body is located. The field may vary strongly in intensity and orientation within an interval of only a few centimeters.
- Non-isotropic nature of the human body or exposed part of the body due to its make up of tissues with highly different levels of electrical conductivity. The actual orientation of the tissues themselves (veins, muscles, bones) may also encourage current induction in certain directions.
- Dimension (radius) of the equivalent ring within which an induced current may appear is also an important parameter with a value that may be affected.

Researchers have built three dimensional models which, thanks to calculations using finite element numerical methods have allowed an approach to the maximum current density values generated within the tissues.

Physical models (ghosts) have been used to check these values using measurements.

Thanks to all this, far simpler 2 D models have been developed in order to perform checks in relation to the possible basic restrictions by companies affected by these problems.

Theoretical Approach*:* Currents Induced within a Homogeneous Disk Exposed to a Uniform Magnetic Field:

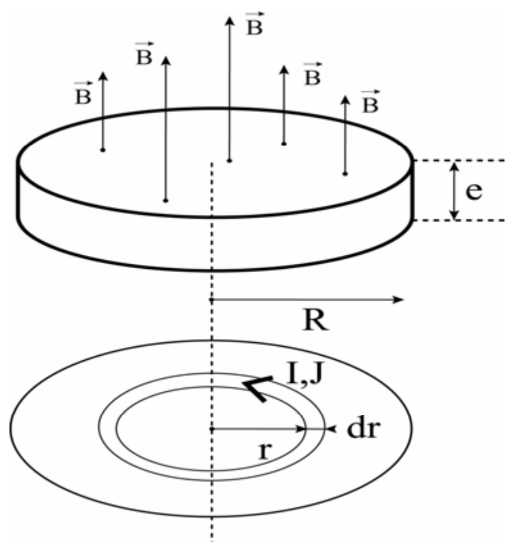


Figure 11. Induced Currents in a Homogeneous Disk [Assume an homogeneous disk of matter of conductivity σ, radius R and thickness e exposed to a uniform field $\vec{B}$ that is perpendicular to its surface. with a radius r. Assume a ring of that disk of radius r, width dr, thickness e and section ds = e × dr. The magnetic field B induces within this disk: (1) a flux Ø = B x S = B x π r^2 and (2) an EMF = - $d\phi / dt = \varpi B \times \pi r^2 = 2\pi$ f × B × πr^2 (if B is a sine wave, e.g., 50 Hz) (1) an induced current I = $\frac{\sigma ds}{2\pi r} . 2\pi f . B . \pi r^2$ and (2) a current density $J = I / ds$ $J = \sigma \pi fBr$ in A.m^{-2}.]

The maximum current density will be found in the peripheral area with r = R

$$J_{max} = \sigma \pi f B R$$

Example:

The disk (or portion of the human body) was chosen with a radius of 100 mm and an electric conductivity level of 0.2 Siemens/meter (SI unit).

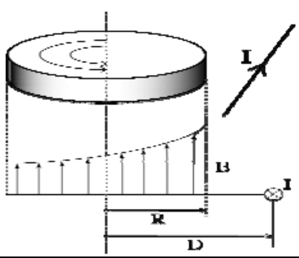
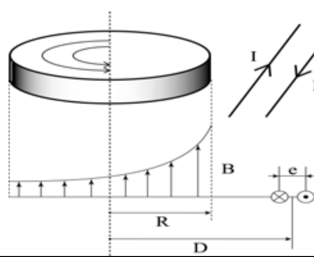
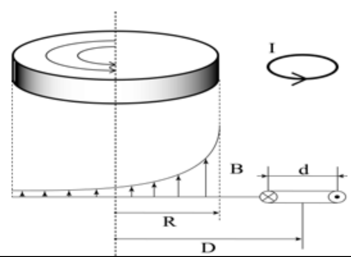
If it is exposed to a 50-Hz magnetic field of 10 mT, the induced current density level will therefore be:

$J = 0.2 \times 3.14 \times 50 \times 10.10^{-3} \times 0.1 = 31$ mA/m^2 to be compared with the limits stated in the following section.

<u>Practical General Approach</u>

In reality, the field is not homogeneous and using the disk from the above example, depending on the type of source for field $\vec{B}$ and the distance to the source, three models have been defined, corresponding to three characteristic field sources.

Table 1. Variation of B-Field vs. Distance from the Source

A: Field created by a straight alone conductor	B: Field created by two conductors side by side carrying reverse currents	C: Field created by a circular ring
		
B = f (1/D) Single conductor carrying a current (this conductor lays far away from the second conductor that handles the return current)	**B = f (1/D²)** A two or three phases wires supplying a machine or an electrical device e << R, D	**B = f (1/D³)** Rotating machine coils, motors, alternators, etc. transformers d << R, D

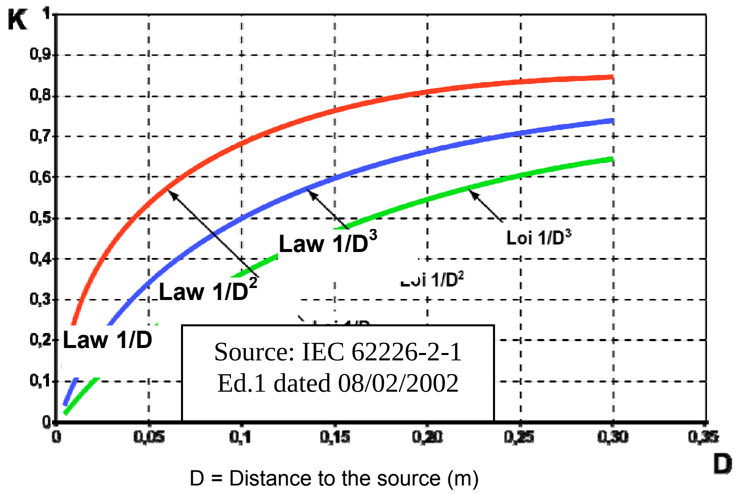


Figure 12. Coupling Factor = f (D) [This graph determines a moderating factor K which helps to take into consideration the decreasing nature of the B-Field against the distance from the source (e.g., from the electrical conductor). The function K vs. D is also depending upon the decreasing law of the B-Field which is itself related to the proximity and shape of the electrical conductors.]

- The faster the field's down slope, the lower the induced currents within a disk of conductive material exposed to this field.
- The "moderating" factor K called the "coupling factor" is less influencing when getting away from the source.

The formula described above and used to compute the intensity of the induced current level becomes:

$$J = K.\sigma\pi f BR$$

The numerical example developed above yields, for a distance D of 0.025 m and assuming a ($1/D^2$) law to consider a coupling factor K equal to 0.025.

The new computed value of current density amounts J = 8 mA/m^2 to be compared with the 31 mA/m^2 level calculated without taking into consideration any coupling factor.

<u>Practical Specific Approach - Secondary Circuits of Portable Welders</u>

The secondary circuits of spot welding machines and especially of portable welders take the form of closed circuits that are more or less of a rectangular form.

In order to investigate a coupling factor which would take the specific nature of the welders' secondary circuits into consideration, a mathematical model (rectangular antenna) was developed and induced currents were computed by finite-element analysis (FEA).

The graph shows which value can be considered for the Coupling Factor K depending upon the distance to the secondary circuit of the welder.

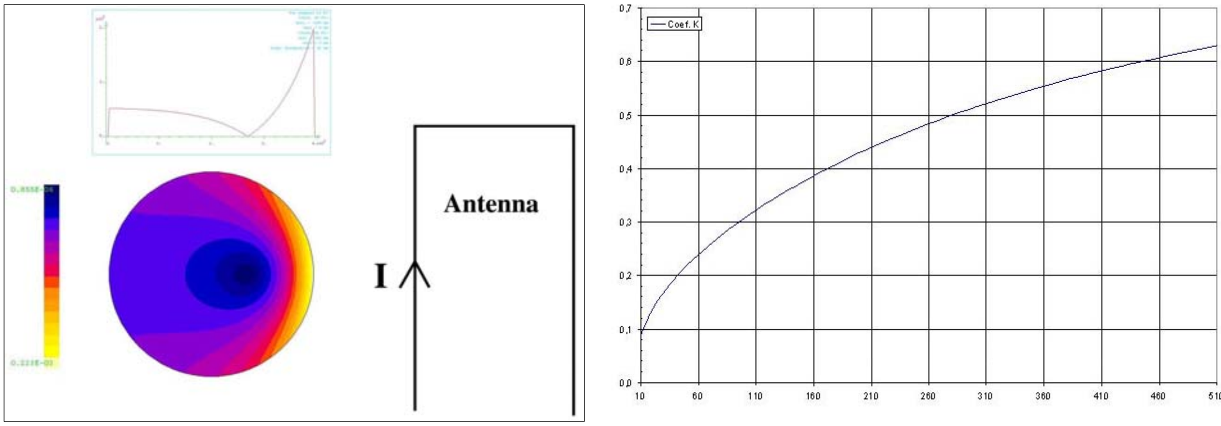


Figure 13. Determination of Coupling Factor by FEA

Limits Values and Reference Levels

<u>Known Effects of EMF on Persons</u>

EMF may interact in different ways with biological systems. Two types of possible effects are regularly considered:

- The short-term effects are immediate ones linked to exposure to intense fields. The levels at which they appear are the subject of international scientific consensus.
  - o *It is the short-term effects that are used to draw up the regulations and recommendations referred to below.*
- The long-term effects of exposure to EMF are the subject of long running scientific debate. The matter is far from closed and is based on many hundreds of studies built up of many tens of years of research.
  - o *So far, there is no conclusive scientific evidence establishing a causal relationship between carcinogenic effects and exposure to time varying electric, magnetic and EMF.*

Consequently, it is necessary to distinguish between what relates to scientific study, especially through epidemiological studies (in the research field) and what relates to effects observed and that can be reproduced, and from which actual exposure limits are developed (in actual practice).

This scientific uncertainty can lead to a fear factor, one that is often irrational.

The process of interaction between EMF and the human body is strongly dependent on the frequency of these fields.

- Static magnetic fields (f = 0) penetrate the human body but no notable physio-pathological effect has been recorded below 2.5 Tesla (a very high value).
- ELF fields (<1000 Hz) cause induced currents in the human body based on the coupling process described in the previous section. It is these currents rather than the magnetic field itself that may cause irritation and at the extreme electrocution.

The table below describes the main effects observed in relation to the intensity levels of the currents induced within the organism (source: World Health Organization).

Table 2. Hazardous Effects Against Current Density

Current density[(1)] at 50 Hz	Effect observed
1 to 10 mA/m^2	Minor transient biological effects
10 to 100 mA/m^2	Effects on sight (magneto-phosphenes) and the nervous system
100 to 1000 mA/m^2	Stimulation of excitable tissue is observed
>1000 mA/m^2	Extra-systoles and ventricular fibrillation: major health risks

The 10 mA/m2 value has now been widely adopted as the basic restriction for the head and the trunk regarding the exposure to ELF EMF.

Basic Restrictions and Reference Levels

Although the measurement of magnetic flux density all around the body is easy, it is on the other hand practically impossible to measure the induced currents inside the human body. Yet it is only the knowledge of this current density value that allows determining the hazard represented by a given exposure level.

Given the paradox stated above, two different concepts will therefore be introduced:

- Basic restrictions or limit values
- Reference levels or values for action

Basic Restrictions or Limit Values:

These thresholds are based on observed effects on health and biological considerations. They are dependent on the field frequency.

In the case of extreme low frequencies (<1000 Hz) the basic restriction is the maximum current density level that must not be exceeded.

10 mA/m^2 for occupational exposure

If it can be scientifically proven that these values are not exceeded, the magnetic field that is their source cannot be considered as hazardous.

Reference Levels or Action Values

Given induced currents cannot be measured and computing them is complex, magnetic field thresholds have been defined based on a scientific certainty that they will not generate current levels that exceed the limit values. There is therefore a certain safety margin.

In a specific situation, measured or calculated values of the B-field may be compared with the appropriated reference level. Complying with the reference level will guarantee compliance with the basic restriction.

If the measured value exceeds the reference level, this does not necessarily mean that the basic restriction limit is exceeded.

Under these circumstances, two options can be considered:

- Improving the Man-Machine system in order to bring the B-Field below the reference levels
- Performing further calculations (using finite element analysis) in order to evaluate the induced current and determine whether it does not exceed the limit values

European Directive 2004/40/EC

Purpose

- Defining minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (EMF).

Status

- This Directive was voted by the European Parliament of March 30, 2004 and approved by Council decision of April 7, 2004.
- The Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive no later than May 2008.
- At that time any equipment in use inside the European Union whether new or old will have to comply with the Directive guidelines.

Definitions (Article 2)

Exposure Limit Values

- Limits on exposure to EMF which are based directly on established health effects and biological considerations. Compliance with these limits will ensure that workers exposed to EMF are protected against all known adverse health effects.

Compliance with these limits is mandatory.

Action Values (were Named Reference Levels in the Former Text)

The magnitude of directly measurable parameters provided in terms of electric field (E), magnetic field strength (H), magnetic flux density (B), and power density (S), at which one or more of the specified measures in this Directive must be undertaken.

Compliance with these values will ensure compliance with the relevant exposure limit values.

If these values are exceeded, the employer shall demonstrate that the exposure limit values are not exceeded and that safety risks can be excludes**.**

Table 3. Limit Values vs. Frequency

Frequency Range	Current Density for Head and Trunk J (mA/m^2) (rms)	Whole Body Average SAR (W/kg)	Localized SAR (Head and Trunk) (W/kg)	Localized SAR (Limbs) (W/kg)	Power Density S (W/m^2)
Up to 1 Hz	40	–	–	–	–
1-4 Hz	40/f	–	–	–	–
4-1000 Hz	10	–	–	–	–
1000 Hz-100 kHz	f/100	–	–	–	–
100 kHz-10 MHz	f/100	0,4	10	20	–
10 MHz-10 GHz	–	0,4	10	20	–
10-300 GHz	–	–	–	–	50

Table 4. Action Values vs Frequency

Frequency Range	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Magnetic Flux Density, B (μT)	Equivalent Plane Wave Power Density, S_{eq} (W/m^2)	Contact Current, I_C (mA)	Limb Induced Current, I_L (mA)
0-1 Hz	–	1.63×10^5	2×10^5	–	1.0	–
1-8 Hz	20,000	$1.63\times10^5/f^2$	$2\times10^5/f^2$	–	1.0	–
8-25 Hz	20,000	$2\times10^4/f$	$2.5\times10^4/f$	–	1.0	–
0.025-0.82 kHz	500/f	20/f	25/f	–	1.0	–
0.82-2.5 kHz	610	24.4	30.7	–	1.0	–
2.5-65 kHz	610	24.4	30.7	–	0.4 f	–
65-100 kHz	610	1600/f	2000/f	–	0.4 f	–
0.1-1 MHz	610	1.6/f	2/f	–	40	–
1-10 MHz	610/f	1.6/f	2/f	–	40	–
10-110 MHz	61	0.16	0.2	10	40	100
110-400 MHz	61	0.16	0.2	10	–	–
400-2000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	f/40	–	–
2-300 GHz	137	0.36	0.45	50	–	–

Measurements in the Vicinity of Portable Welders

Measuring Magnetic Fields

The publication of new regulations related to public and workers' exposure to EMF has urged manufacturers to develop measuring devices that are more suitable, easier to use and that offer improved performance in order to guarantee fast and reliable evaluations. These devices are commonly known as field analyzers as they generally have the ability to measure both electric and magnetic fields. They are also named Gaussmeters in reference to the unit used formerly to measure magnetic induction: the Gauss (G) used in the CGS system.

$$1 \text{ Gauss} = 10^{-4} \text{ Tesla}$$

Single Measurement Coil

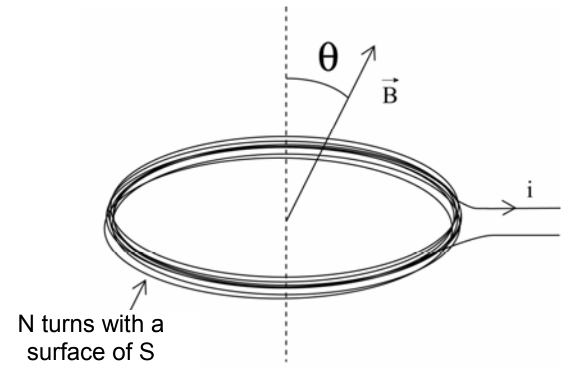


Figure 14. Toroid for B-Field Measurement [This coil includes n turns, Ø = n. $\vec{B}.\vec{S}$ = n B.S cos θ, EMF = - $\frac{d\phi}{dt}$ = -n S cos θ $\frac{dB}{dt}$, (EMF) = 2Πf n S B. If the wire is perpendicular to field $\vec{B}$.]

Applies Faraday's electromagnetic induction principle as described in the first section.

Generally, the measurement coil has a diameter of 3 cm or a surface area of 100 cm^2 which means that the measurement represents an integrated value of the field over the entire surface ($\phi = \iint_s \vec{B}.\overrightarrow{dS}$).

Advantages: Robust and virtually insensitive to the ambient temperature.

Drawbacks: Bulky, require longer integration times. Assuming, in most of the cases the direction of the Magnetic vector isn't known, the operator has to proceed tentatively in order to catch the maximum value of the B-Field or he must perform three measurements along orthogonal axis in order to compute the true value of the B-Field.

Three-Directional Sensors

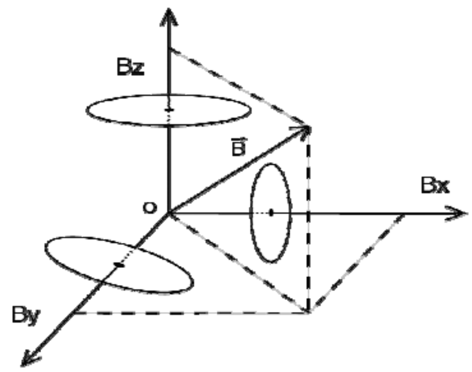


Figure 15. 3-Dimensions B-Field Analyzer [Whatever the direction of the sensor in relation to field $\vec{B}$, i.e., whatever the values of the respective components Bx, By, and Bz, the calculation will always provide the true intensity of field $\vec{B}$ (the vector's module).]

$$B = \sqrt{Bx^2 + By^2 + Bz^2}$$

Measurement Guidelines

Measuring magnetic fields is a time consuming and extremely delicate operation when aiming to obtain consistent results that can be reproduced over time.

- Choose a high-quality apparatus with a three-directional measurement probe.
- Check its calibration regularly.
- Place the equipment whose magnetic field radiations are to be measured in a place that is as far away as possible from other potential sources of magnetic fields that could interfere with the measurements (any operating machine or electrical appliance or power distribution line).
- Make sure that the operating conditions of the equipment to be measured are clearly defined.
- The respective positions of the operator and the sensor may also influence the results (this is especially true for electrical fields). If possible, move away from the measuring area during measurements.
- For mapping magnetic fields in the vicinity of a given equipment, it is suggested to prepare a grid map of the area in order to be able to reproduce the measurement a number of times in the same location.
- The size of the probe (100 cm^2 or ϕ 3 cm is standard) must be suited to the proximity in relation to the source. The $\vec{B}$ field decreases very rapidly when moving away from a current carrying conductor. To determine the field value close to its surface, a small probe is required (3 cm).
- The welding machine's emission time (welding time) must exceed or at least equal the integration time required by the measurement device in order to obtain the true value of the magnetic field. This length of time (1.5 s for a Wandel Goltermann device) far exceeds normal welding conditions (<0.5 s as a general rule).

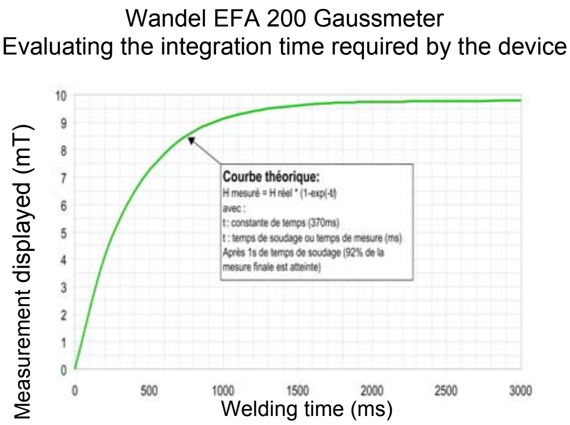


Figure 16. Theoretical Response Curve {H measured = H real × [1- exp(-t/T)], with: T: time constant (370 ms), t: welding time or measurement time (ms). After a 1-s welding time (92% of the final measurement value is reached).}

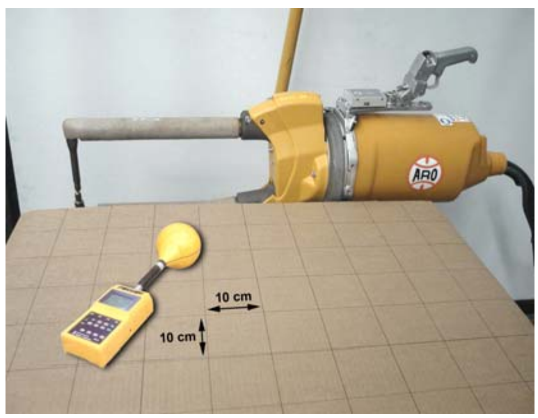


Figure 17. Measuring the B-Field in the Vicinity of a Portable Welder [It is suggested to setup a measuring network (grid) in order to ease measurements replication.]

Magnetic Fields Generated by Portable Welders Operating from a 1000-Hz Supply (MFDC)

Principal

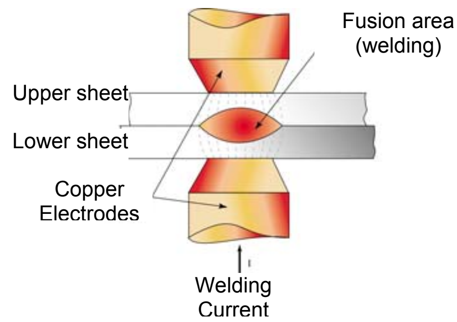


Figure 18. Resistance Welding Principle [Resistance welding is used for assembling metal sheets by running a high-intensity electric current through them in order to cause local melting in a very short time. More than 80% of applications are related to thin steel panels (with a thickness of 0.5 to 3 mm), requiring currents of 10 to 20 kA for periods of time that are generally less than a half second. Bringing the current to the electrodes as well as the need to apply a significant amount of pressure between the sheets leads designers to develop more ore less complex large-scale power circuits that may generate fairly significant magnetic fields in their near vicinity.]

Typical Morphology of Portable Welders used for Resistance Welding operations

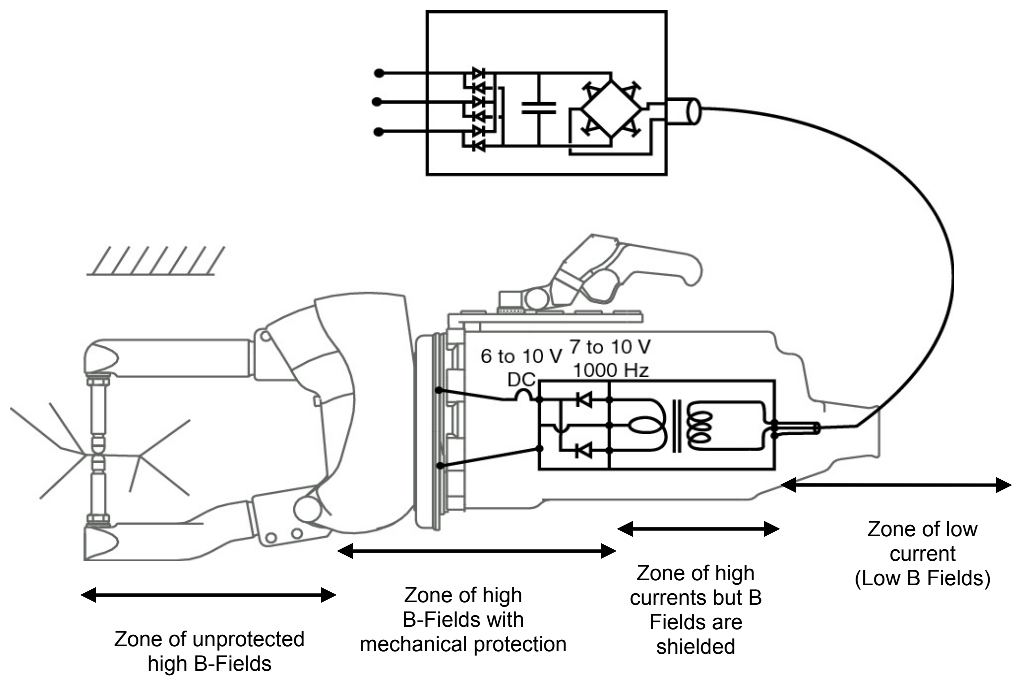


Figure 19. Morphology of Portable MFDC Welder

Measuring Method

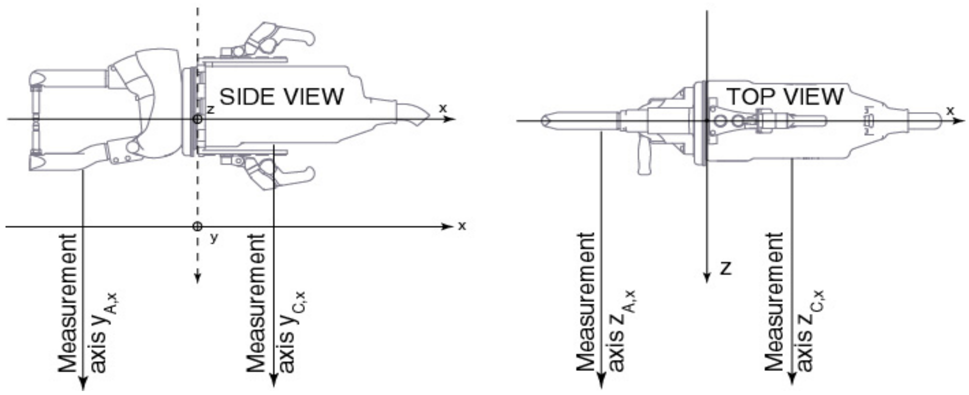


Figure 20. Measuring Method for Portable Welder

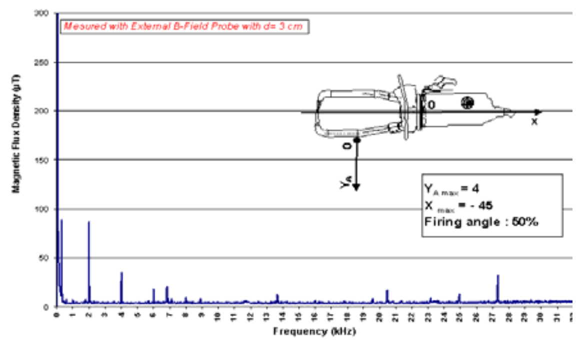


Figure 21. B-Field Measurements in the Vicinity of Welders' Arms (Spectral analysis shows that 2000-Hz frequency is predominant. At this frequency: Reference level is 30,7 µT and limit value is 20 mA.)

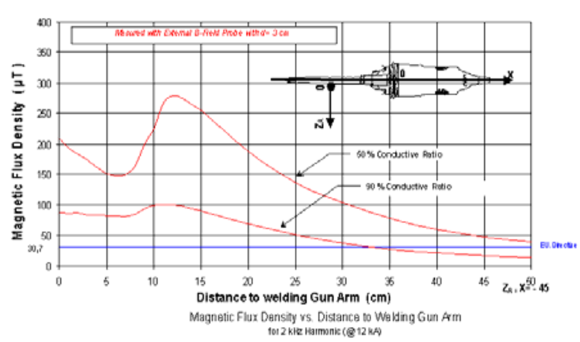


Figure 22. B-Field Measurements in the Vicinity of Welders' Arms [Further measurements along Z axis perpendicular to the arms show a peak value of B-Field at 250 µT far above reference value. This peak value is substantially reduced if the welder works near its maximum capacity (90% shift angle), or worker must stand 50 cm away from the arms.]

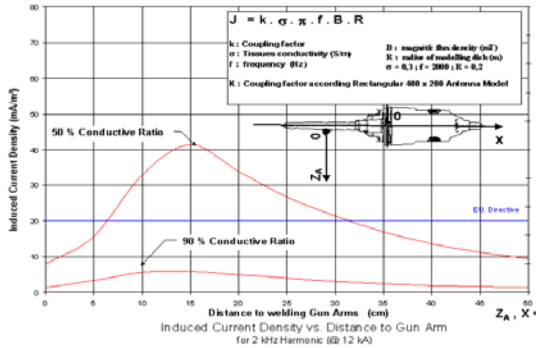


Figure 23. J-Density Estimation in the Vicinity of Welders' Arms [Using the model developed previously and applying a coupling factor of 0.3 (related to the non-continuous nature of the B-Field) leads to a max current density of 42 mA which is above the limit value. In order to comply with the EU Directive, the workers' body and head must stand 35-cm away from the welders' arms.]

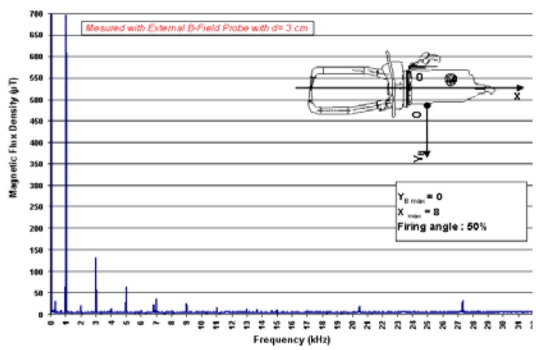


Figure 24. B-Field Measurements in the Vicinity of Welders' Body (Downward) (Spectral analysis shows that 1000-Hz frequency is predominant. This is due to the proximity of the rectifier. At this frequency: reference level is 30.7 µT, limit value is 10 mA.)

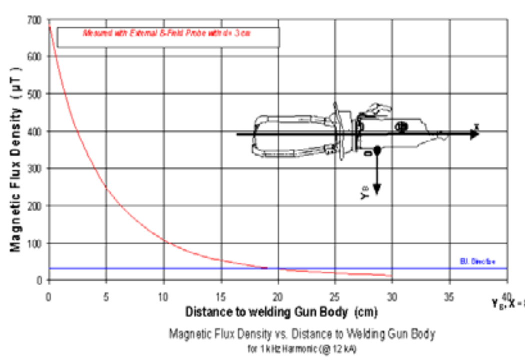


Figure 25. B-Field measurements in the Vicinity of Welders' Body (Downward) (Further measurements along Y axis perpendicular to the body show a peak value of B-Field at 700 µT far above reference value. The worker must stand 20-cm away from the welders' body in order to stay below the reference levels.)

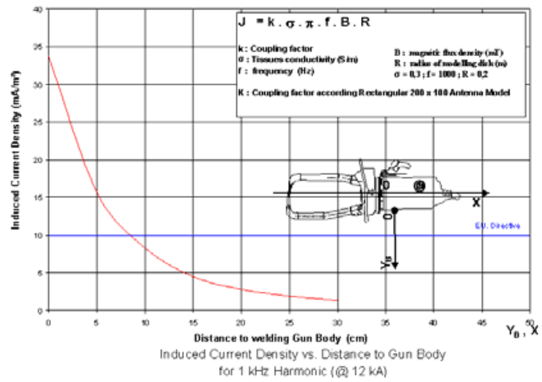


Figure 26. J-Density Estimation in the Vicinity of Welders' Body (Downward) [Using the model developed earlier and applying a coupling factor of 0.3 (related to the non-continuous nature of the B-Field) leads to a max current density of 33 mA which is above the limit value. In order to comply with the EU Directive, the workers' body and head must stand 10-cm away from this side of the welders' body.]

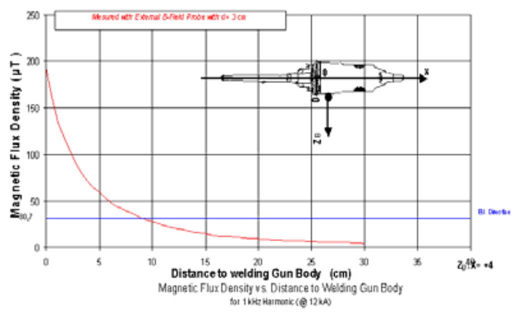


Figure 27. B-Field Measurements in the Vicinity of Welders' Body (Sideward) (Further measurements along Z axis perpendicular to the body show a peak value of B-Field at 200 µT far above referenced value. The worker must stand 10-cm away from the side of welders' body in order to stay below the reference levels.)

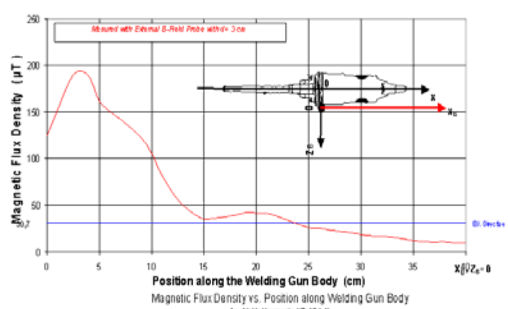


Figure 28. B-Field Measurements in the Vicinity of Welders' Body (Sideward) (Further measurements along X axis parallel to the body show a peak value of B-Field at 200 µT far above reference value. The worker must stand 10-cm away from the front side of welders' body or move to the rear side of the welders' body.)

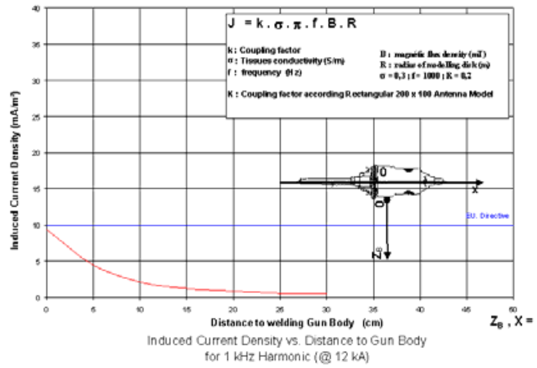


Figure 29. J-Density Estimation in the Vicinity of Welders' Body (Sideward) [Using the model developed above and applying a coupling factor of 0.3 (related to the non-continuous nature of the B-Field) leads to a max current density of 9 mA which is below the limit value in any position along the welders' body.]

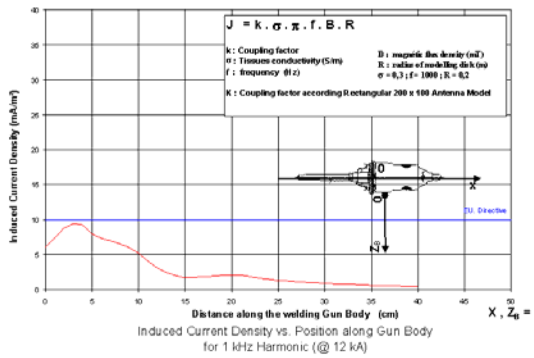


Figure 30. J-Density Estimation in the Vicinity of Welders' Body (Sideward) [Using the model developed above and applying a coupling factor of 0.3 (related to the non-continuous nature of the B-Field) leads to a max current density of 9 mA wherever the Operator stands along the welders' body.]

Guidelines for Reducing Workers' Exposure to Electromagnetic Fields

Figure 31. Improving Welders Ergonomy

Welders must be well balanced of reasonable weight.

- The more painful to handle, the closer to his body the worker shall keep the welder

Welders must be equipped with suitable handling devices.

- Easy to catch in all positions
- Convenient for gun manipulations
- Keep worker away from high magnetic fields area and especially avoid using welders' arms as manipulating levers

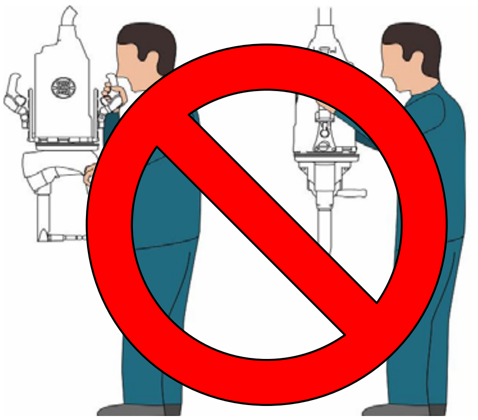


Figure 32. Improving Working Stations (Working stations must be designed in such a way that the worker is not obliged to bring the welders' arms nearby his head or trunk. In some circumstances, turning jigs must be preferred.)

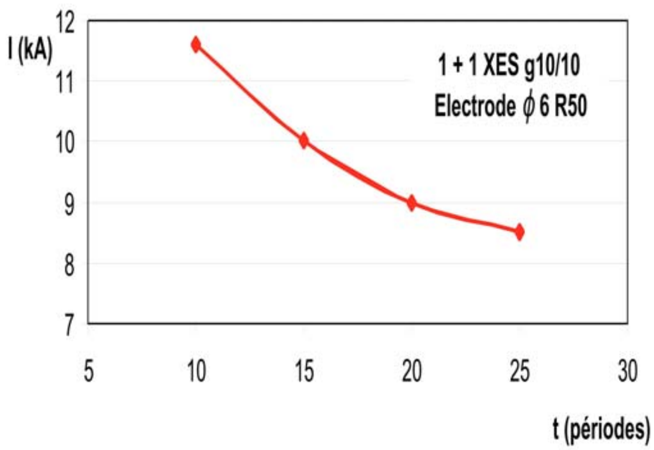


Figure 5.3 Decrease the Welding Intensity when Possible (To encourage the setting of longer welding time/lower current intensity for manual welding operations. The magnetic field intensity will be reduced proportionally to the current density. Increasing the welding time from 100 to 200 ms provides a 20% reduction of the magnetic field.)

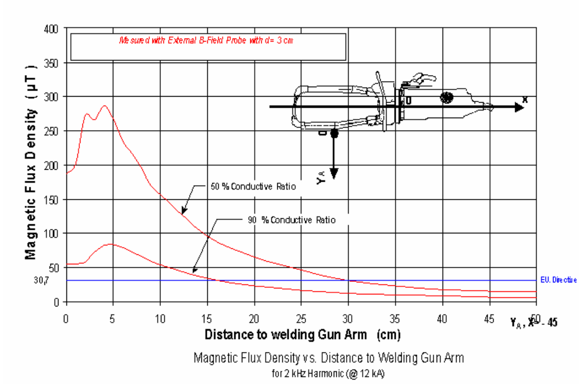


Figure 34. Improving Welding Process (Adjust welding parameters and welder dimensioning in such a way that the welders shouldn't work below 80% of its maximum power. **This could lead to finer welding transformer range or innovative power controllers allowing power adjustment without phase-shift angle.)**

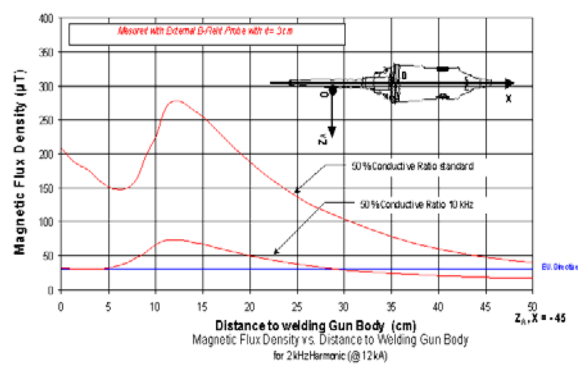


Figure 35. Improving Welding Controllers (Very preliminary investigations have showed that the B-Field can be reduced substantially if the triggering frequency of the transistors is increased to 10 kHz. This could lead to finer welding transformer range or innovative power controllers allowing power adjustment without phase-shift angle.)

Figure 36. Shielding the Radiative Areas of the Welder (Very preliminary investigations have showed that the B-Field can be reduced substantially by placing a simple metallic screen in front of the rectifier.)

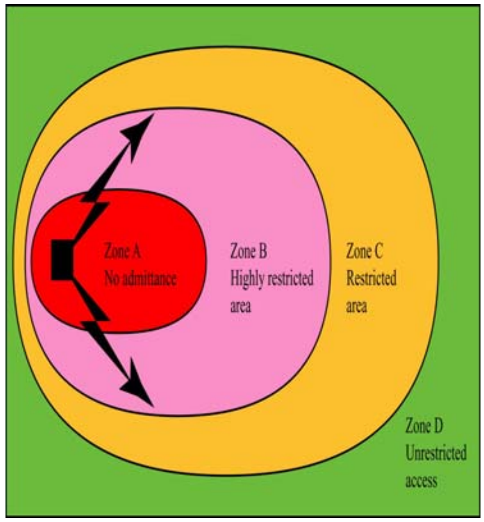


Figure 37. Defining the Exposure Zones (The exposure zones as related to an installation or a work station are volumes split into four categories A, B, C, and D as defined below. Zone A: no admittance zone - except under special circumstances. Zone B: highly restricted access. The exposure levels are those allowed for workers after taking into account local values and average spatial or temporal values. Zone C: restricted area. The exposure limits are those allowed for workers. Zone D: unrestricted access. Authorized for Public as well.)

Protection of occasional users like maintenance/quality control operators:

- Classifying plant areas as A, B, C, or D.
- Releasing a simplified information brochure.
- Training/providing explanations to exposed personnel (approximately 2 hours required).
- Certifying personnel who have received this training.
- Developing tools so that there is no need to be less than 30-cm away from the welding gun when it is operating. e.g., clamps for holding samples a fair distance away during welding trials.
- Identifying and indicating high risk areas

Table 5. Definition of Pictograms Related to EMF

Sign Posting	Definition	Exposure Areas			
		A	B	C	D
	Magnetic field hazard	X	X	X	
	No entry to persons with pacemakers	X	X	X	
	No entry to unauthorized persons	X	X		
	An area where fields are stronger than those applicable to workers. No presence allowed except when specifically stated.	X			

Conclusions and Scope for Improvement

Resistance welding using manually operated welding units has been used for more than 50 years now, especially in the automotive industry and no causal links have ever been clearly established proving that this activity generates occupational illnesses linked to the exposure to magnetic fields.

The fact that this technique is applied within an industry where workers have the benefit of medical screening and good levels of healthcare provision further increases the credibility of the above comment.

ARO has already greatly contributed to reducing the exposure of workers to magnetic fields, especially through:

- Promoting, for over 50 years, the use of welding guns with built-in transformers, reducing the exposure of an operator's body or even their head, to magnetic fields by a factor of 20 compared with welding guns that use separate transformer (or cable supplied welding guns).
- An on-going process of improvements to worker comfort, which especially thanks to easier welding gun handling, means that it is not necessary to handle the welding gun arms or the beam itself in order to complete movements and thanks to integral encasing, avoiding where ever possible, any direct contact with the secondary conductors, which have surfaces where high level magnetic fields appear.

This observation must not, however, keep us for seeking to still further improve the protection and comfort of our users.

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