Practical Guidance for Occupational Low Frequency Exposure Assessment

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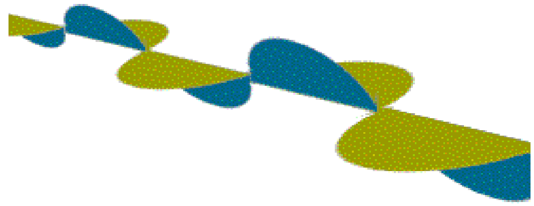
Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace. Coordination Action 8. Policy Support and Anticipating Scientific and Technological Needs

Industry or the workplace in general is a very vast domain of low frequency fields (LF's) electromagnetic fields (EMF's) from which the extreme low frequency (ELF: 30 – 300 Hz) field sources are important representatives. Since there is still no clear definition about the borderlines of the frequency ranges within the non-ionising frequency spectrum the LF's where this guidance is dealing with range from 0 Hz up to 20 kHz. Since every electrical device, apparatus or machine is in fact an ELF EMF source, there are so many sources that it is impossible to consider them all. Hence, the guidance is only based on our experience with the exposure assessment of the most important industrial high exposure LF sources:

- electrical installation for electrolysis (0 Hz)
- electrical arc furnace (50 Hz)
- induction ovens (300 Hz – 10 kHz)
- arc welding (DC, AC, DC-ripple)
- resistance or spot welding (50 Hz – 20 kHz)

What is an Electromagnetic field?

The **electromagnetic field** (EMF) is a combination of an electric and magnetic field propagating in a wavelike manner..



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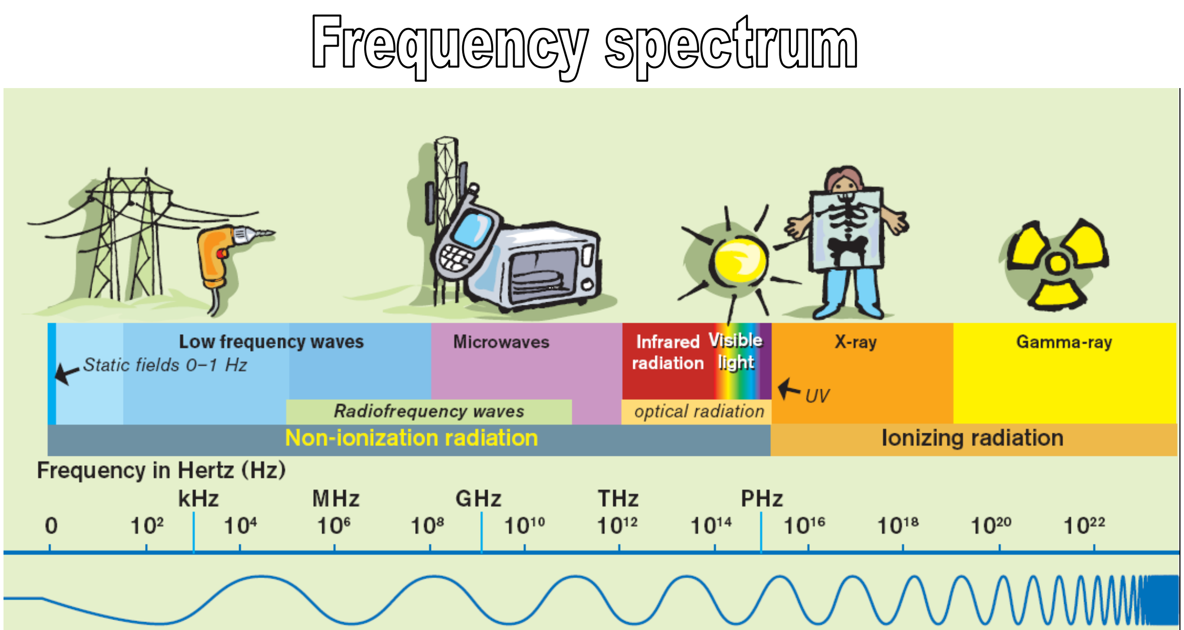
It is characterised by wave length, frequency and quantum energy The lower the frequency, the lower the quantum energy, the longer the wave length and the longer the penetration depth.

LF classification in the electromagnetic frequency spectrum?

EMF's are classified in a electromagnetic frequency spectrum divided in the spectrum for non-ionising radiation (0 Hz – 3 PHz, E < 12.4 eV) and ionising radiation (*f* > 3 PHz and E > 12.4 eV). Notice that the energy of non-ionising radiation and certainly the LF's is much to weak to ionise matter.



(source RF-guidance 2008)

After the electromagnetic frequency spectrum the LF EMF's are defined as being fields up to about 100 kHz. At this frequency the wavelength [$\lambda = c/f$ (c = *velocity of light* = 3.10^8 *m/s in vacuum*)] is 3 km. When we calculate the wave length for our exposure assessment applications we find ∞ at 0 Hz, 6000 km at 50 Hz, 1000 km at 300 Hz, 30 km at 10 kHz and 15 km at 20 kHz. In this frequency range workers are always exposed in near-field

conditions where, in contradiction to the far-field exposure, the ratio of the electric (E) and the magnetic (H) is different from the 377 ohms (Ω) which is characteristic impedance in free space. Hence the amplitudes of E and H may not be at their maximum at the same time so that in the LF-range E and H have to be measured and evaluated separately..
Since E-field strength depends on the voltage and the distance it is measured in volts per meter (V/m). The strength of the magnetic field which is current dependent is measured in amperes per meter (A/m). When taking into account the magnetic properties (magnetic permeability μ) of the propagation medium the magnetic field (H) is defined as the magnetic induction field (B = μH) and measured in tesla (SI units) or a subunit such as the microtesla (μT) or millitesla (mT).

Exposure guidelines

Though many safety and product standards for protecting workers and the general public against EMF have been published over the past decades the present guidance summarises only the ICNIRP guidelines and statement for the static and time varying EMF's on the one hand and the European directive 2004/40/EC for workers on the other hand.

- **ICNIRP (1994) guideline.**

Deals with the protection against static magnetic fields. It is the fundament of the Directive 2004/40/EC for the occupational action value of the magnetic induction field (B-field) for frequencies below 1 Hz. Note that the action values of the directive are the same as the reference levels used by ICNIRP. The reference levels used for testing the compliance of the measured static B-field are:

⇒ 200 mT working day averaged whole body exposure. The current density by moving in this field is estimated between 10 – 100 mA/m²

⇒ 2 T instantaneous whole body limit

⇒ 5 T instantaneous limit for limbs

Notice that the natural static magnetic field generated by the dynamo effect of earth varies between 30 and 70 μT.

- **ICNIRP (1998) guideline**

Deals with the protection of the general public and workers against time varying EMF's up to 300 GHz. A distinction is made between basic restrictions and reference levels.

- **Basic restrictions for LF EMF's**

Are based on the current density (***J***) induced in the body.. J is a calculation metric which is based on an established heath effect.

In the ELF range 100 mA m^{-2} is considered as the threshold current density limit for acute changes in the central nervous system excitability and other acute effects such as reversal of the visually evoked potential. . Based on the precautionary principle a safety factor of 10 is used so that occupational fields up to 1 kHz should be limited to fields that induce a ***J*** less than 10 mA m^{-2}.

Basic restrictions for frequencies between < 1 Hz and 100 kHz	
Frequency range	Current density for head and trunk J (mA m^{-2}) (rms)
Up to 1 Hz	40
1 – 4 Hz	40/f
4 – 1000 Hz	10
1 kHz – 100 kHz	f/100 (f in Hz)

- **Reference levels**

Are measurements metrics which are provided for comparison with measured values for compliance testing. If reference levels are exceeded the body induced current density has to be calculated and compared with the basic restriction limits. If the reference values are exceeded it doesn't necessarily mean that the basic restriction is exceeded.

Reference levels for frequencies between 0 Hz and 65 kHz			
Frequency range	E-field (V/m)	H-field (A/m)	B-field (μT)
0 – 1 Hz		$1.63\ 10^5$	$2\ 10^5$
1 – 8 Hz	20 000	$1.63\ 10^5/f^2$	$2\ 10^5/f^2$
8 – 25 Hz	20 000	$2\ 10^4/f$	$2.5\ 10^4/f^2$
0,025 – 0,82 kHz	500/f	20/f	25/f
0,82 – 2,5 kHz	610	24.4	30.7
2,5 – 65 kHz	610	24.4	30.7

ICNIRP statement (2003)

In the frequency range up to 100 kHz there are a number of EMF-sources (EAS, metal detectors, demagnetizers, welding equipment) with complex non-sinusoidal magnetic field wave forms which exceed the ICNIRP (1998) limits. ICNIRP clarified this problem by providing guidance values and cut-off frequencies related to the basic restrictions for the current density and the electric and magnetic induction fields respectively.

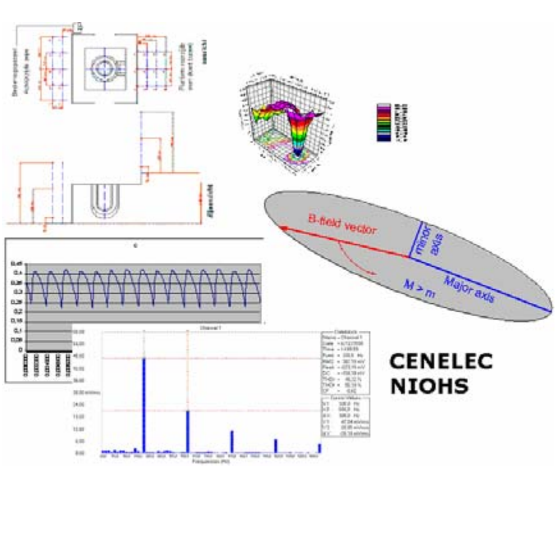
- **Directive 2004/40/EC**

This directive deals with the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields). The directive only concerns workplace exposures and uses the same limit values as the ICNIRP guidelines. However, the basic restrictions of ICNIRP correspond to the exposure limit values of the directive and the reference levels of ICNIRP correspond to the action values of the directive. The implementation of the directive by the different member states of the EC is postponed till 2012.

Good measurement practice

There are a lot of static and ELF EMF sources situated in different workplace situations. They have different dimensions varying from small magnetic reactivators up to very big arc oven installations for metal melding. Moreover, the wave form, the frequency, the harmonic content, the polarisation and the general electrical parameters of the sources may be quite different. Very important in the exposure assessment is the characterization of the:

- Source: electrical parameters, dimension, positioning
- Field: magnitude, frequency, harmonics, waveform, polarization
- Waveform: sinusoidal fields or not, transient, time rate of change of B (dB/dt))
- Uncertainty & variability



Good EMF measurement practice is a multi-step concept. It starts by mastering the basic physics for field characterisation and should be based on a balanced experimental design related to approved CENELEC standards and NIOHS manuals. Moreover it will have to take into account variability and uncertainty caused by a panoply of factors.
An obvious and important aspect in GMP is the consult with the safety staff about the exposure problem, the measurement objectives and the job content of the workers in terms of exposure position and duration. In order to define the complexity of the measurement situation, GMP requires a careful inspection of the working environment. A list of the relevant sources, their EMF characteristics and their orientation with respect to the workers or adjacent offices is indispensable. If the waveform and the harmonic content are unknown they have to be defined by oscilloscopic and spectrum analyses respectively. Compliance of unperturbed single frequency fields without substantial harmonics can be measured by broadband equipment and be tested regarding to the ICNIRP (1998) formulas for single frequencies. However, if one is faced to several sources emitting different frequency fields or to a single source emitting a substantial amount of harmonics selective measurements have to be performed and hence compliance testing is based on multi-frequency exposure approach. GMP becomes still more complex if complex pulsed non-sinusoidal waveforms are part of the exposure game. In such cases advanced oscilloscopic techniques and spectrum analyses have to be combined. A crucial point of such a combination is that the oscilloscopic harmonic content doesn't always fit with the one observed by spectrometry. Anyway, reasons have to be found, repeated measurements have to be performed for exposure reality and compliance testing with standards or guidelines for complex exposure situation. By performing GMP one always has to keep in mind that variability and uncertainty are a part of each measurement scenario. Though variability is a property of nature related to value heterogeneity over time, space and subjects and uncertainty is a lack of knowledge about the true value of exposure due to measurement errors or other factors, repeated measurement for defining the degree of reproducibility can bring some insight in both variables.

Measurement equipment

As shown in the next figure, there are different instruments needed for performing EMF measurements in the low frequency range.

Measurement equipment often used in occupational exposure assessment

The commercial instruments shown in the figure cover the frequency range from 0 Hz – 400 kHz. They also make it possible to measure the wave form as well as the harmonic content of the field under test. Since the electric and magnetic fields have to be measured and evaluated separately some meters are equipped with exchangeable probes for E and H fields while in others both sensors are integrated in the same probe. Moreover, low frequency spectrometer blocks contain selectable E- and H-spans covering a frequency range from 5 Hz up to 100 kHz. Other instruments contain a weighted frequency response so that the magnetic induction field can be displayed as a wide band value or as a percentage of the reference level of a selected exposure limit guideline. More specifications about these instruments can be found on the website of the instrument dealers.

Industrial High LF Exposure sources

The EMF sources this chapter is dealing with range from 0 Hz up to 20 kHz. Strictly speaking, they consist of a mixture of static, ELF and IF field sources and are therefore better defined as low frequency than as ELF sources. The following sources are discussed:

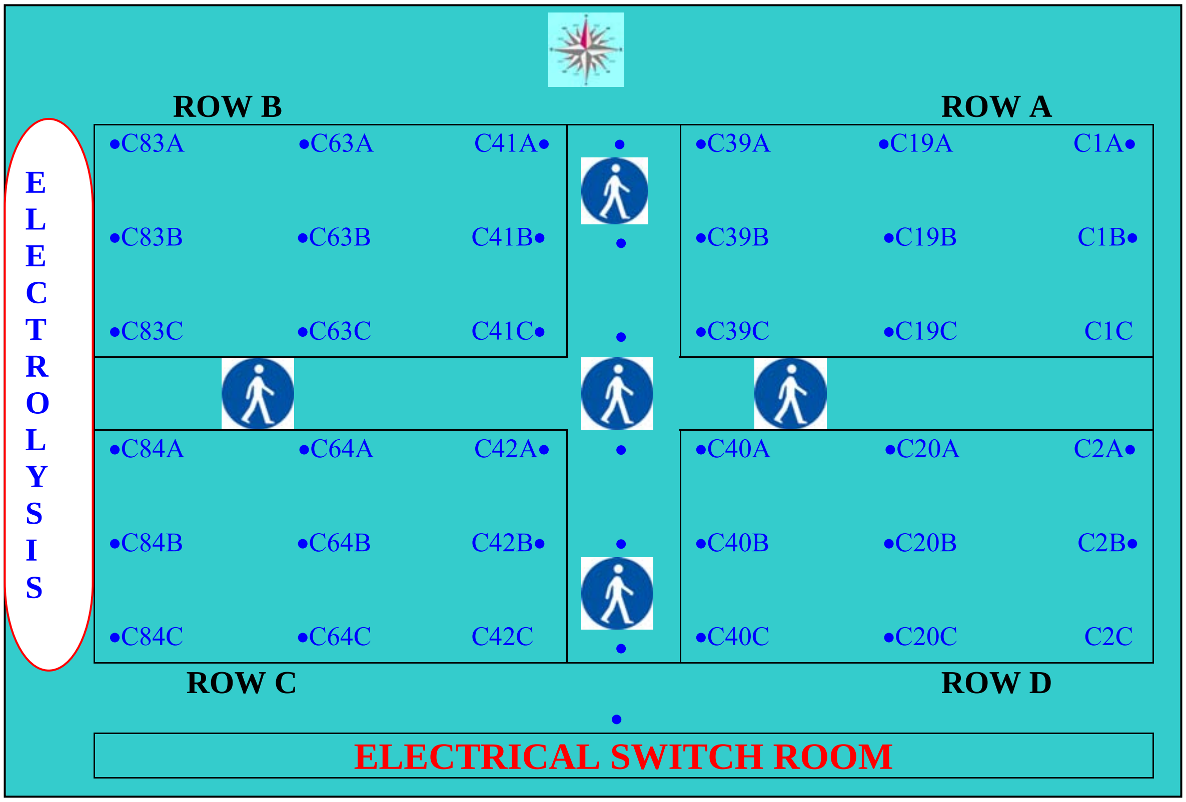
- Electrical electrolysis (0 Hz)
- Arc oven (50 Hz)
- Induction ovens (300 Hz – 10 kHz)
- Arc welding (DC, AC, DC-rippel)
- Spot welding (50 Hz – 20 kHz

Sample of occupational LF sources

Electrical installation for electrolysis

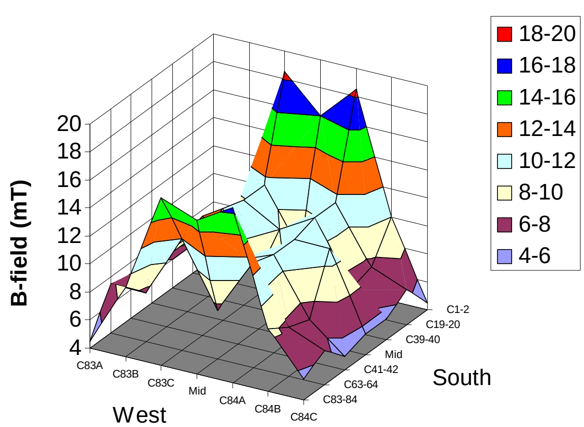
When an electrical DC current is passing a liquid solution electrolysis by which chemically bonded elements or compounds are separated occurs.

In manufactures this process is used in big installations which may cover a relatively big area.



Ground plan of an electrolysis area with one measurement point per electrolysis cell

Since industrial electrolysis requires high DC currents (up to about 130 kA), workers might be exposed to a relatively strong static magnetic induction field which can vary from one electrolysis cell to the other with a facto 5.



Static B-field (mT) distribution over the electrolysis area

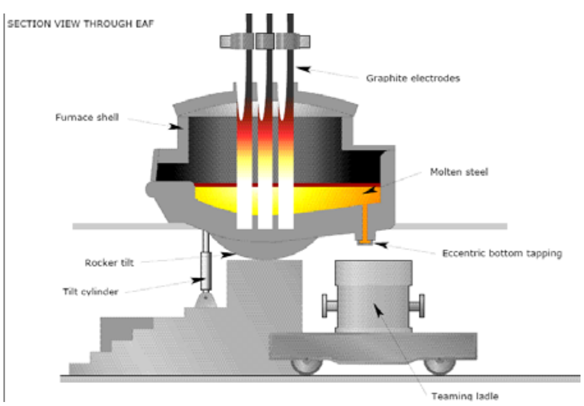
Operators of the electrolysis unit may be exposed to a DC B-field gradient varying from 4 to 20 mT. If the induced current density by moving in a DC B-field of 200 mT is estimated to be 10 – 100 mA/m², a simple calculation tells us then that the induced current in the operator's moving in 20 mT (worst case exposure) electrolysis unit varies from 1 to 10 mA/m². It is compliant with the 40 mA/m² basis restriction limit for head and trunk of ICNIRP (1998) and the exposure limit values of the directive 2004/40/EC. On the basis of the interpretation of these exposure limits no direct health effect is to be expected for workers of electrolysis installations. However, this statement has to be interpreted with precaution because there still is a lack on representative measurement data which can be used as input data for performing reliable dosimetrical calculations about induced current density by workers of industrial electrolysis installation..

As for the possible indirect effect which may occur at a 5 mT threshold level, it is recommended that carriers of pacemakers and other electronic devices know that levels of 0.425 mT and average levels of 0.352 mT may be encountered.

Notice that this paragraph only deals with the static field exposure of industrial electrical electrolysis installations and not with medical (e.g. MRI), pharmaceutical/biochemical (NMR-spectroscopy) or other occupational static field applications.

Electric arc furnaces

Most modern electrical arc furnaces (EAF) convert solid raw materials to liquid crude steel and refine it further in subsequent secondary steelmaking processes.
The EMF exposure assessment of the EAF we are dealing with is an ultra high power (AC) 96 MW furnace operating at 50 Hz for the production of liquid steel. The two following pictures illustrate show the heart and the outside (switch room side) of an EAF from which the EMF's were also measured.

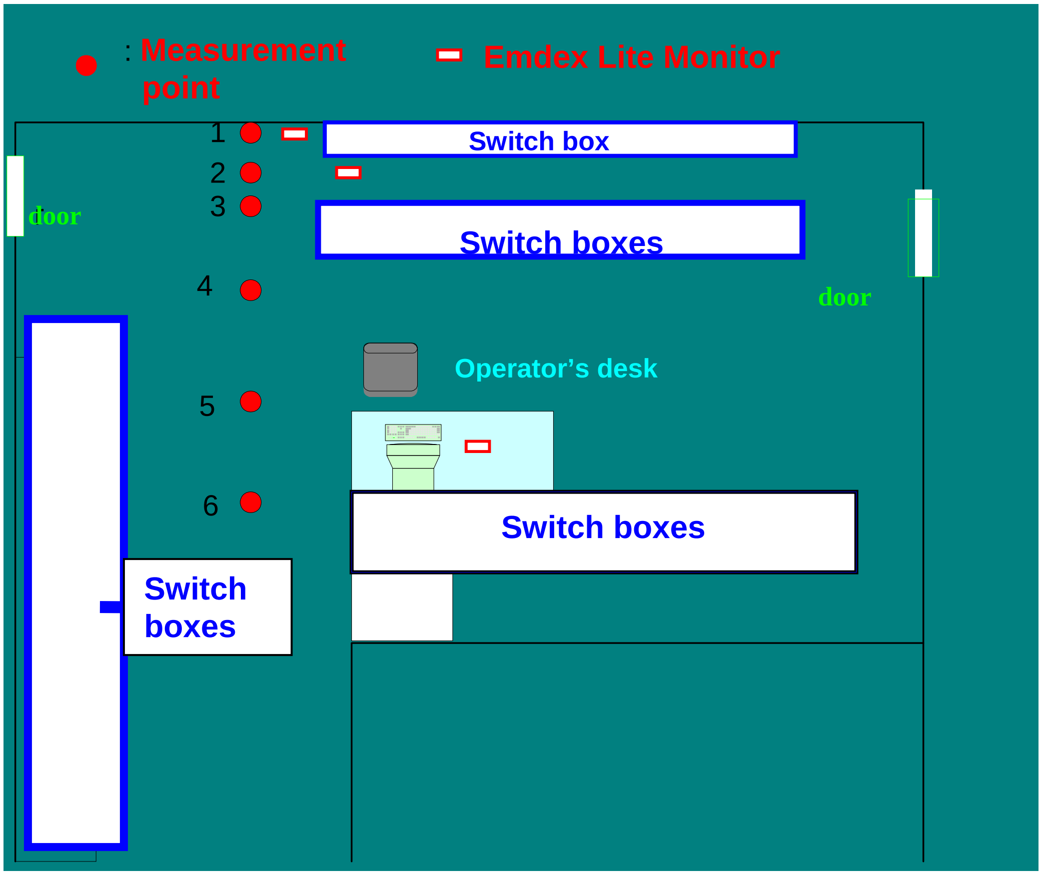


Heart of arc furnace

Switch room side of a arc furnace

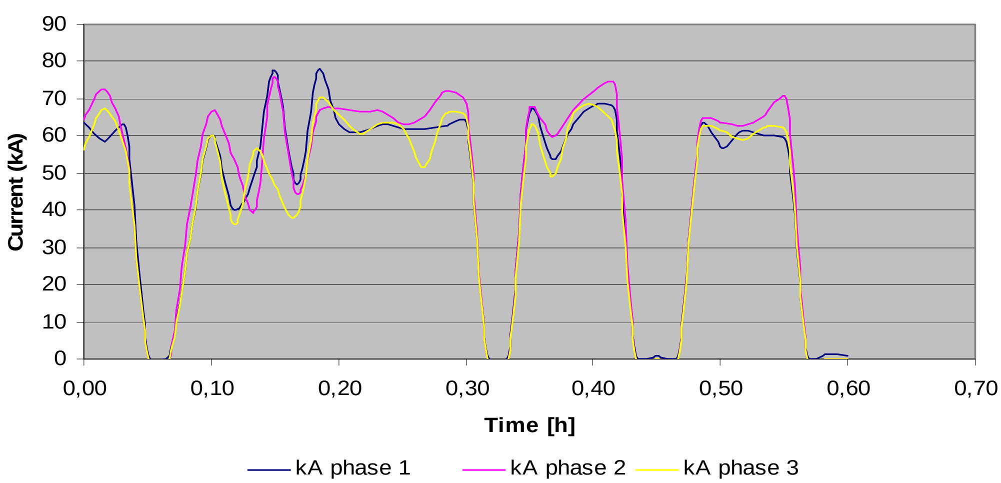
The exposure assessment of the B-field from big installations requires a good planning, prospection and measurement design by which instantaneous point measurements and field registration over a certain time can be performed respectively.

The next figure illustrates the ground plan and the measurement design of a switch room besides the arc furnace.



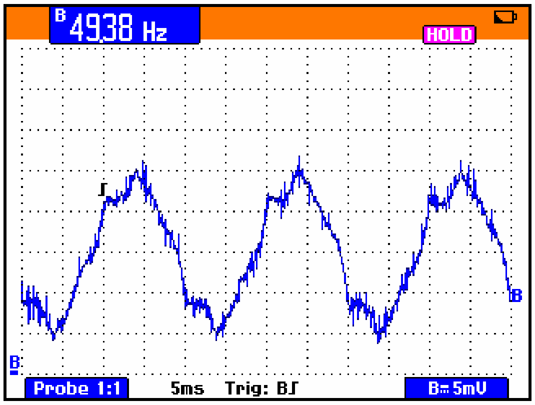
Ground plan of a switch room and measurement design

The next figure illistrates the current load of the installatioon per phase .

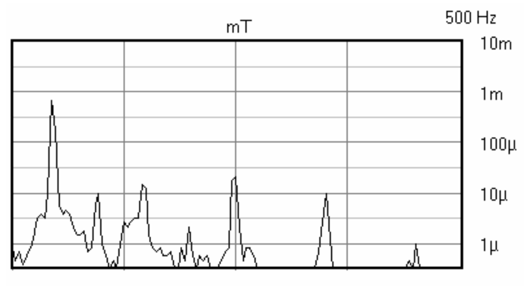


Current load versus time

Then the wave form and the harmonic content have to be checked

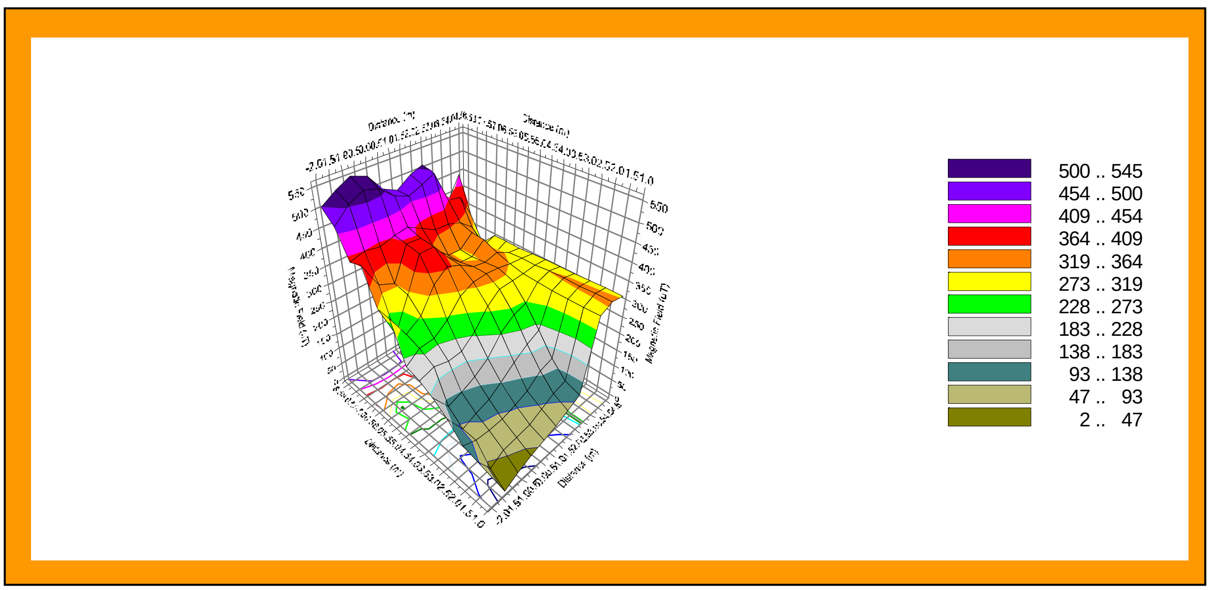


Wave form



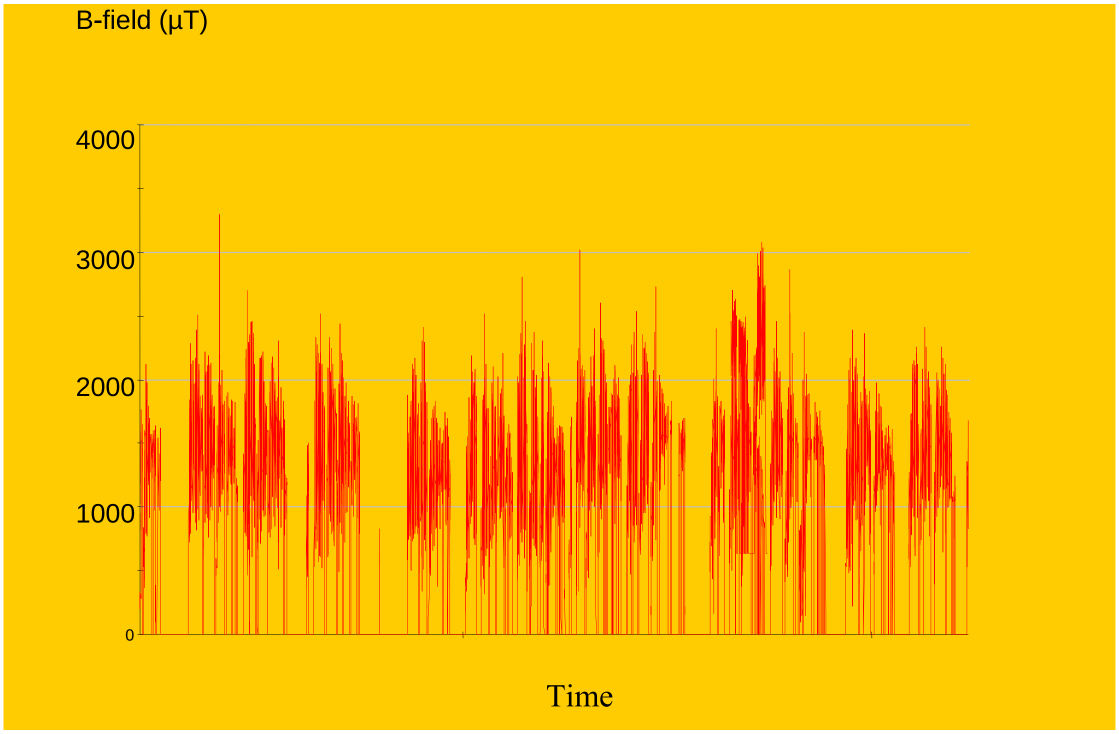
Harmonic content

Since the wave form is sinusoidal and no harmonics above 1000 Hz are present a first view of the 3 D exposure of the installation can be obtained by means of the EMDEX II meter fixed on a linear data acquisition (LINDA) wheel (Enertech Ltd).

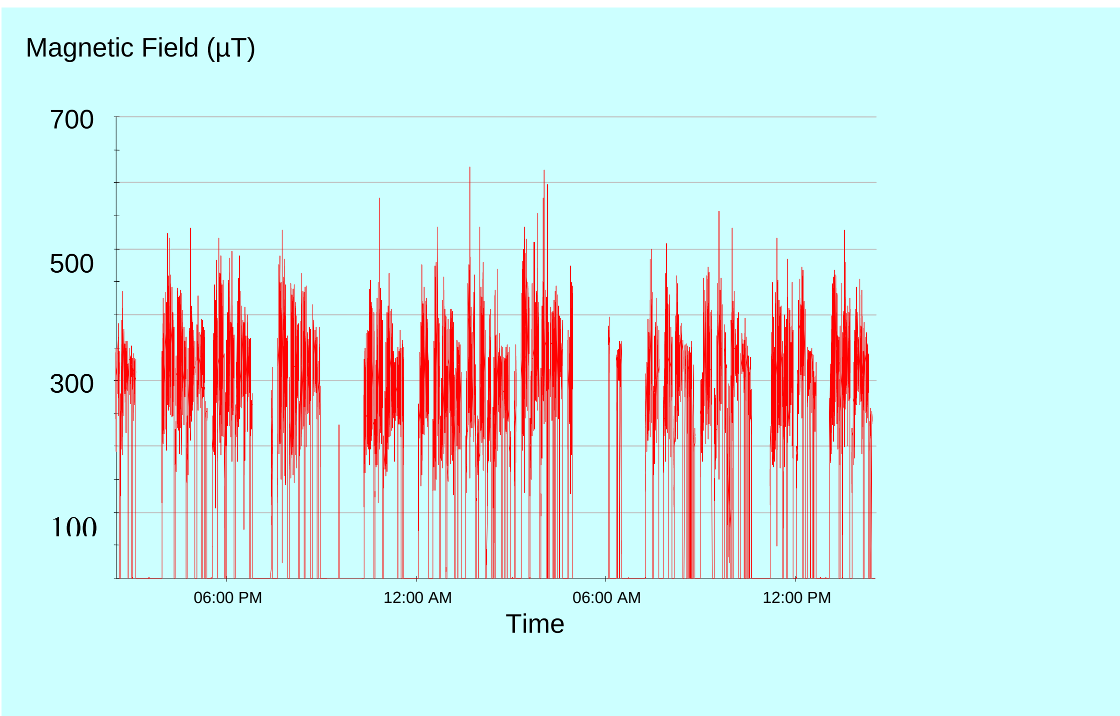


3 D map of B-field (µT) of arc oven installation

In order to get insight in the real B-field strength in space and time on the one hand and in the real exposure of the operators on the other hand place dependent and personal dependent field registration can be performed respectively.

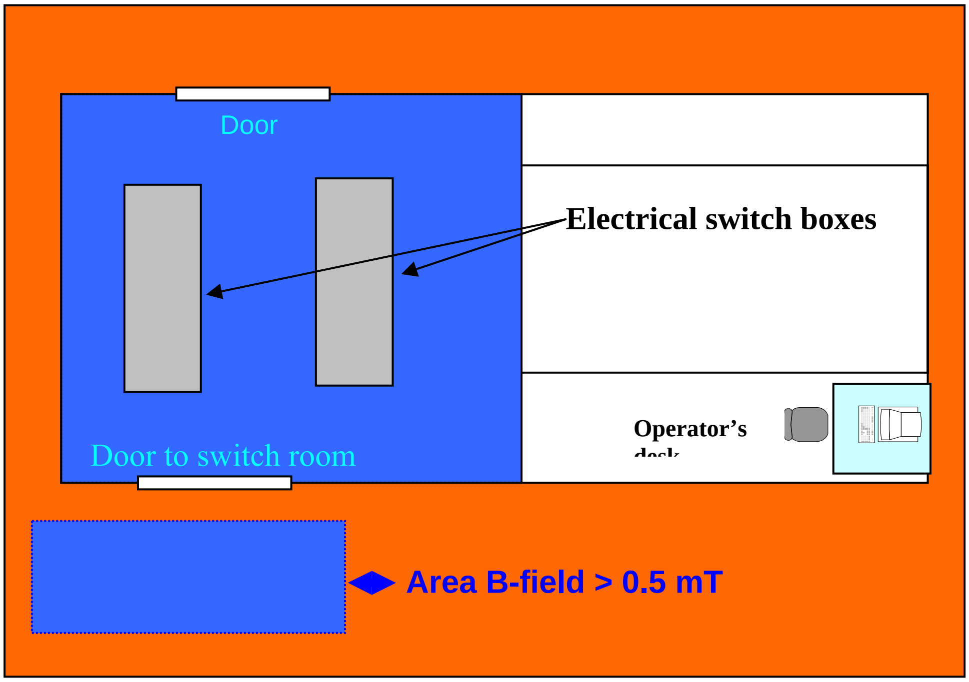


Example of B-field versus time in a point in space of the switch room



Personal exposimetry of the operator at the desk near the switch box

As shown in the next picture we have to check carefully the areas where important exposure levels can occur such as in the switch rooms of the understations of the arc furnaces. The next figure illustrates the area in a switch room near the furnace where the B-field level exceeds the 0.5 mT reference level/action value. Hence compliance with the basic restrictions /exposure limit values have to be verified by comparing the calculated B-field induced current density with the limit value of 10 mA/m² in head and trunk.



B-field in switch room of arc oven

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The maximum B-field we observed in the arc furnace installation was about 5 mT.

On the MT-2 workshop on calculation in Kielce (2007) it was concluded that the results obtained by the simplified ICNIRP (1998) formula (***J = πRfσB)*** were not substantially different from those calculated by means of complex dosimetrical models. Therefore we used this simplified approach to verify if a 50 Hz B-field of 5 mT induced a ***J*** that is compliant with the 10 mA/m² limit value.

Worst case exposure

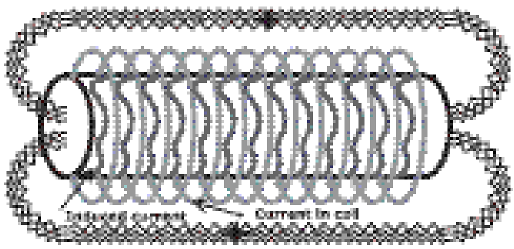
As shown in the illustration the calculation was made in the worst case situation assuming a homogeneous 50 Hz B-field incidence of 5 mT in horizontal plan, a current loop circumference in the trunk of 1 m and a conductivity σ = 0.2 S/m

Under this worst condition a maximum current density of 2.5 mA/m² was induced in the trunk and strictly speaking no (expensive) protection measures (passive or active mitigation) have to be taken by the managing safety staff of the arc furnace installation. However as long as we have no solid quantified statistical data about the goodness or lack of fit between the results of sophisticated dosimetrical models and simplified formulas the uncertainty pertains that we made the wrong decision by rejecting protection rules though this hypothesis had to be accepted or vice versa.

Notice that you can find many more approaches and details about calculation and dosimetrical techniques in the WP12 guidance made by P. Rossi. & R. Falsaperla. However, the arc furnace case gave the opportunity to illustrate the whole multi-step exposure assessment methodology that starts with an optimal experimental design and ends with calculations/models leading to decision rules about the worker's protection. The application of these rules might or might not be expensive: expensive if an older furnace installation has to be replaced by a new one because neither the active nor passive mitigation can be performed.

Induction ovens for metal melding

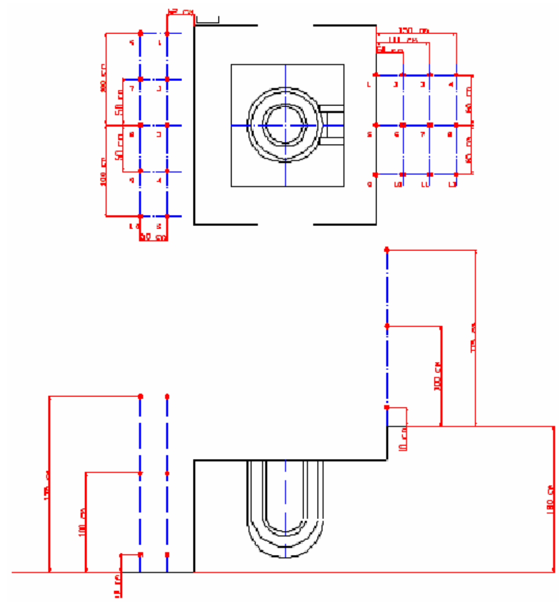
The basic components of an induction oven are the power supply, the induction coils (usually made of copper) and the working unit which contains the load/material to be treated. When an alternating current is sent from the power supply to the induction coils a magnetic field inducing Eddy currents into the load is produced.



Due to the resistive reaction forces of the load against the electrical flow localized heat is produced in the load to be treated. Low frequency applications mostly use rectified power supplies. Mid- to high-frequency applications convert the AC to DC and then to higher frequencies. The frequency used depends on the material to be heated and the depth of penetration necessary for heating. Low frequencies are usually used for thicker materials and deep penetration. Higher frequencies are used for small parts or shallow penetration.

Exposure assessment

Induction ovens (often called induction heaters) are used for a great diversity of purposes. Anyway those on which the guidance is based are used for melting of Silver (S), Gold (G), Waste (W) and Steel (S). Their nominal power ranges from 200 to 2600 W and the operating frequency was 300 Hz (S), 3 kHz (G), 9 kHz (G), 1 kHz (W), 500 Hz (S) and 1 kHz (S). A detailed ground plan of the oven and it's installation area is indispensable for efficient and reliable EMF exposure assessment of the operator and adjacent working offices.



Ground plan of an induction oven with measurement grid around the oven

In order to have an idea of the average total body exposure we recommend to measure the B-field at different heights (0.1, 1.0 and 1.75 m) in each point of the grid.

The following pictures illustrate the way the operators work at the induction ovens and how they can be exposed

Operator working at open metal induction heater

Operator working at a small closed gold melting oven

As for eventual passive mitigation purposes it is especially for small sized ovens important to know the field polarisation (X, Y, Z-vectors): which part of the body is strongest exposed and can passive mitigation be applied without losing working comfort/efficiency and/or oven performance

The next tables summarise the most important electrical oven parameters and exposure variables that have to be taken into account for the exposure assessment of induction ovens

Electrical parameters of induction ovens

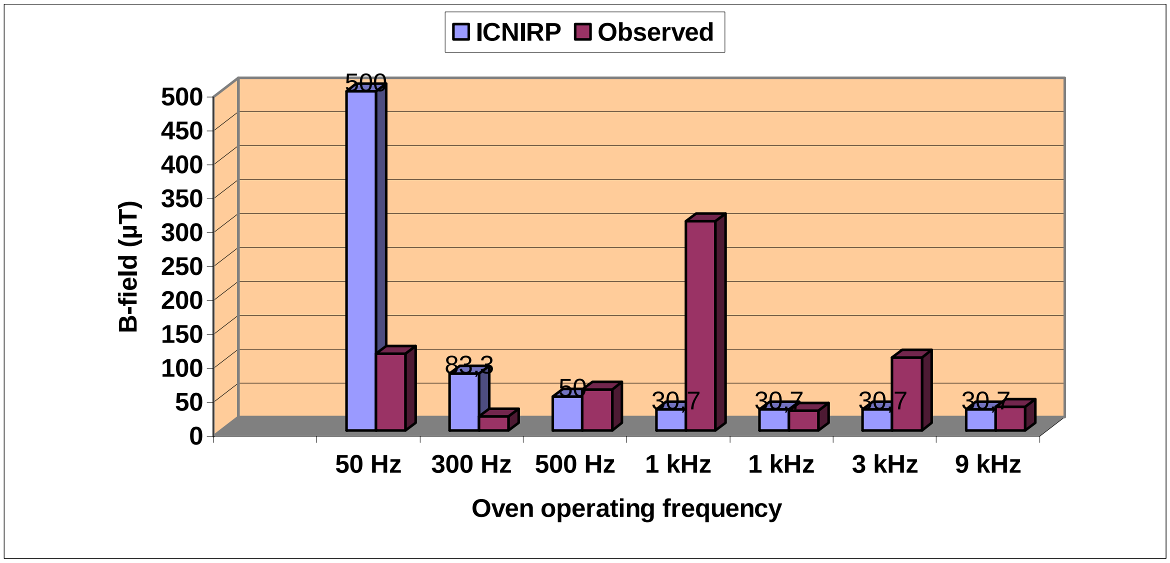
Oven	Power		Frequency		
ID	Nominal	Operating	Nominal	Operating	Application
1	450	60%	300 Hz	300 Hz	Silver melting
2	800	90%	3 to 3,3 kHz	3 kHz	Gold melting
3	800	60%	3 to 10 kHz	9 kHz	Gold melting
4	200	90%	1 kHz	1 kHz	Waste melting
5	2600	?	500 Hz	500 Hz	Steel melting
6	1800	?	1 kHz	1 kHz	Steel melting

This next table shows that most induction ovens operate irregularly, that the daily exposure duration varies from three quarters of an hour to 1 hour and that the distance between the oven and the operator strongly varies from 10 to 150 cm. By measuring the polarisation fields (X and Y- are the horizontal and Z is the vertical field vector) we can deduct in which plane the operator of the induction oven is predominantly exposed if the polarisation is not circular.

Exposure variables

Oven ID	Melting Frequency	Operator's concern		B-field (µT) and polarization			
		Exposure time (min)	Distance from oven (cm)	RMS	X%	Y%	Z%
1	Irregular	60	30	20	6	85	9
2	Irregular	60	30	107	7	51	43
3	Irregular	60	20	35	4	47	49
4	Irregular	45	10	309	44	39	17
5	Continue	45	150	60	20	70	10
6	Continue	60	60	29	8	87	5

Since the Y-vector represents the exposure in the horizontal plane between the oven and the operator the chest and abdomen are more exposed than the head and the hips. When the operator is going farther away from the oven the polarization becomes more circular and the exposure becomes the same in the horizontal and vertical plane. The next figure shows the comparison between the observed B-field and the frequency corresponding the ICNIRP reference levels at operator's working distance.



Observed B-fields at operator distance versus ICNIRP (199) reference levels

At an operating frequency of 50 Hz the B-field strength starts to exceed the ICNIRP(1998) reference level. It shows on the one hand that interference about compliance is frequency dependant and for ovens with a frequency of 500 Hz the induced current density for compliance testing with basic restrictions has to be calculated. By extrapolating the calculation protocol of the arc furnace to the induction ovens we found a 10 mA/m² induced current at operator distance by an induction oven operating at a frequency of 757 Hz and generating a B-field of 1360 µT. On base of these findings and since the induction oven was an of older type one it was decided that it should be replaced by a new oven fitting the compliance requirements. Follow-up measurements performed by an independent body will verify this hypothesis.

The summarised results have shown that the B-field at normal operator position:

- often exceeds the reference levels/action values
- might exceed the basic restrictions/exposure limit values

Hence the induction ovens require a follow up on base of a good exposure design

Arc and Spot Welding

Arc welding machine

Though welding dates back to the bronze age where it was more an art than a technology nowadays it has become an important engineering science and business covering almost all industrial applications. It is a process of fusing two materials together using high current loads, heat, pressure and/fillers. The reason why this document dealing with the exposure assessment of the EMF's of welding equipment is that welding demands high current loads which are

Spot welding machine

associated with high magnetic induction fields (B-fields) welders and adjacent workers might be exposed to.

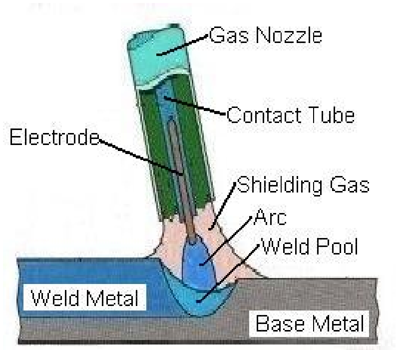
Though there are many welding processes the two welding types that are predominantly applied are Arc welding and Gas Arc welding for what about electrical arc welding and different frequency depending processes for what spot welding is concerned. The exposure assessment treated in the present guidance is therefore based on the most important arc and spot welding processes respectively. The next table summarizes the welding processes which are used in the present guidance for the EMF exposure assessment of welders.

Widely used industrial welding processes

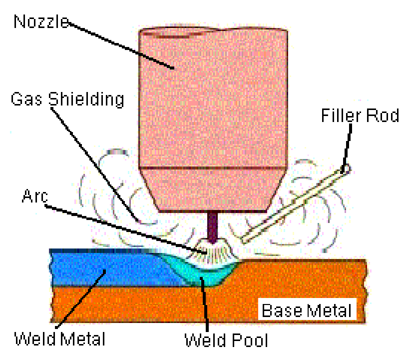
Welding processes	Current type		
	AC	DC	DC puls
Gas Metal Arc Welding (GMAW) also called MIG/MAG	-	++	+
Shielded metal arc welding (SMAW)	+	++	-
Gas Tungsten Arc Welding (GTAW) also called TIG	+	+	+
Submerged Welding (SAW)	+	++	-
Resistance Spot Welding	++	+	-
++: mostly used; + : less or equally used; - : not used			

(source Belgian EMF welding report 2008)

Gas Metal Arc Welding (GMAW) is frequently referred to as MIG welding. MIG welding is a commonly used high deposition rate welding process. Wire is continuously fed from a spool. MIG welding is therefore referred to as a semiautomatic welding process. (source AMC)



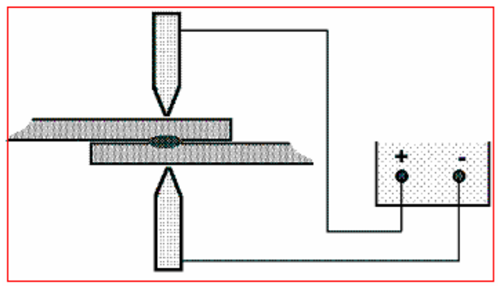
Gas Tungsten Arc Welding (GTAW) is frequently referred to as TIG welding. TIG welding is a commonly used high quality welding process. TIG welding has become a popular choice of welding processes when high quality, precision welding is required.



Submerged arc welding (SAW) is a process in which the welding actually occurs while submerged under a layer of flux. The flux prevents oxygen from entering the weld and thus prevents porosity in the weld.

Shielded metal arc welding (SMAW), is a manual arc welding that uses a consumable electrode coated in flux to lay the weld. An alternating or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined.

Resistance Spot Welding (RSW), Resistance Seam Welding (RSEW), and Projection Welding (PW) are commonly used resistance welding processes. Resistance welding uses the application of electric current and mechanical pressure to create a weld between two pieces of metal. Weld electrodes conduct the electric current to the two pieces of metal as they are forged together.



Welding Process Statistics

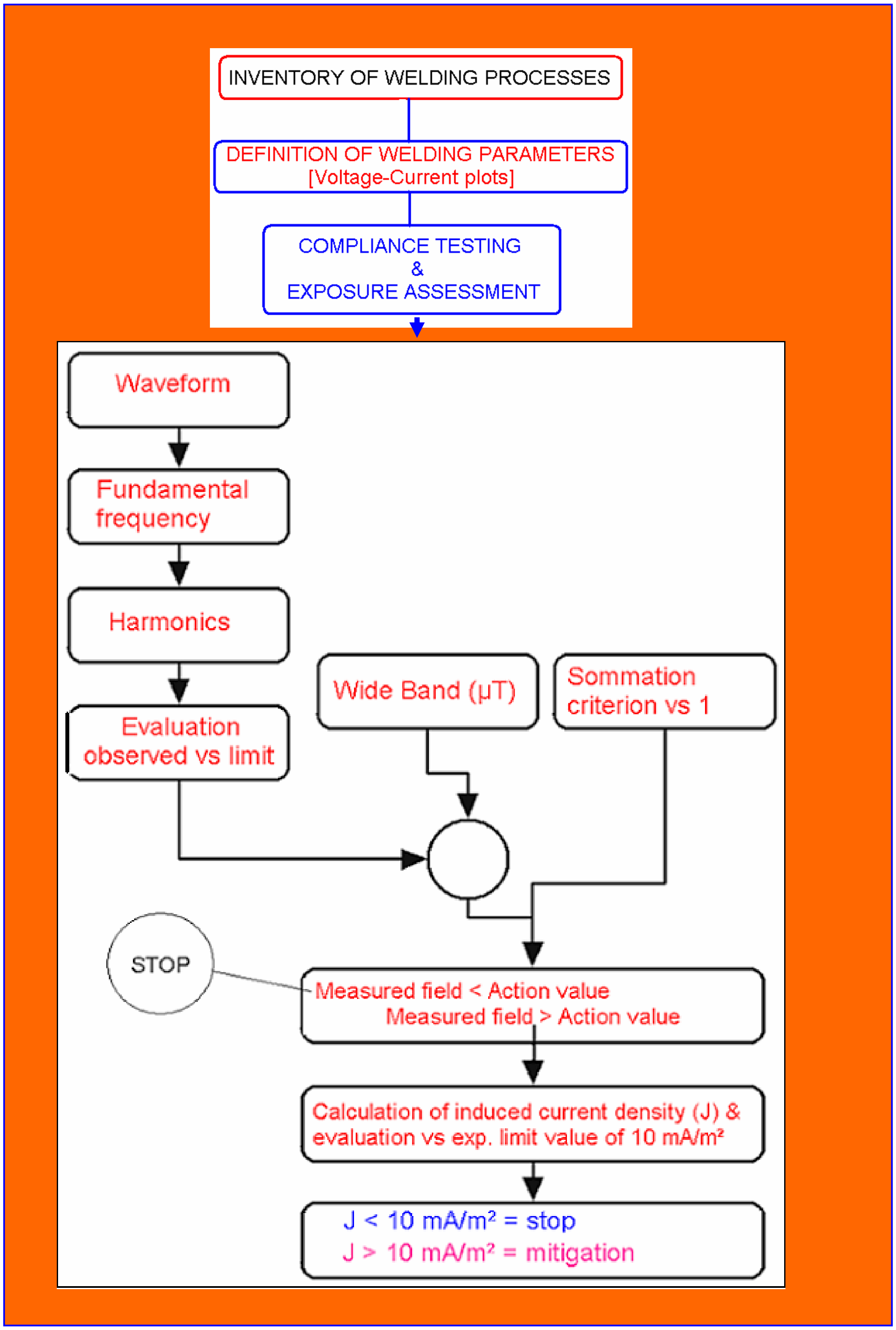
In order to get statistics on industrial welding processes an inventory about this issue is indispensable. It is the fundament of an optimal measurement design. Next table summarises the results of such an inventory for arc welding processes made in big Belgian enterprises.

Welding process	ABT **(%)**	Current Type	Mean % of use	Current load [A]	Mean % of use
Gas Metal Arc Welding (GMAW) Solid wire	25	DC+	60	150 – 250	47
		Pulse	40	250 – 350	43
				> 350	10
(GMAW) Flux cord arc welding (FCAW)	30	DC+	88	< 150	10
		DC-	12	150 250	57
				250 – 350	33
				> 350	1
Shielded Metal Arc Welding (SMAW)	20	DC+	71	50 – 100	25
		DC-	28	100 – 150	37
		AC	1	150 – 200	24
				> 200	13
Gas Tungsten Arc Welding (GTAW) or TIG	25	DC-	99	< 50	5
		AC	1	50 – 100	30
				100 – 150	50
				150 – 200	14
				> 200	1

[a] Arc burning time: average burning time in percentage of the whole welding time
(source: Belgian EMF welding report 2008)

Welding measurement processing

The next flow chart shows the different steps that have to be followed for performing exposure assessment and compliance testing related to welding.



Arc welding

An electric arc is an electrical breakdown of a gas which produces an ongoing plasma discharge, resulting from a current flowing through normally nonconductive media such as air.

Arc discharge with ribbon like plasma of tesla coil from breakdown (Wikipedia)

- **How can we define the current waveform?**

A shunt is fixed at the current path of the welding machine.

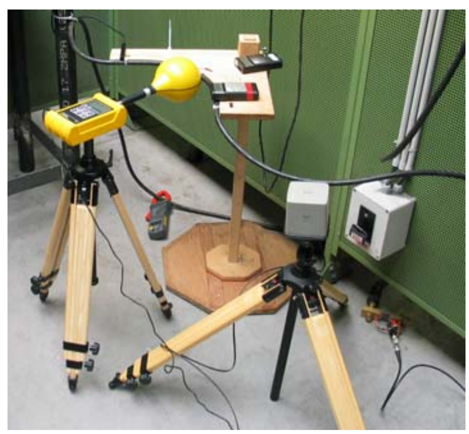
Welding machine with shunt and current clamps

After the current clamps are fixed on the cable the waveform can be measured by means of special current designed oscilloscopes (ALX and HKS).

Scopes for measuring the voltage- current waveform

- **How can we do compliance testing and exposure assessment**

By compliance testing we think in terms of the EMF emission of the welding equipment (control panel, cable, torch) at a certain point in space. By exposure assessment we think in terms of the field strength received by the worker’s body and the possible risks.
As for the EMF compliance testing of arc welding attention will only be paid to measurements of the welding cable. In this respect it is advised to measure the magnetic induction field (B-field) according to the protocol of the CENELEC standards prEN 50444 and 50445 of September 2006. Despite this advise, the big gap in terms of exposure assessment is that the only point of investigation (POI) for testing compliance is at a distance of 20 cm between the probe tip and the the bent cable and that the contact between cable and the worker’s body has not been taken into account. Anyway this doesn’t exclude that the magnitude of the B-field can be measured at other POI’s for evaluating the possible associated risks.



Setup for measuring the B-field of the cable

Moreover, one should also be interested in the B-field level at 10 cm from the cable.
The next figure illustrates how the B-field strength generated by the cable can be measured at body level by means of point measurements covering a frequency up to 400 kHz. Notice that if the frequency and the harmonic contents of the generated field fit with the measurement requirements of the personal monitor (sinusoidal wave form and frequency within 40 Hz – 1000 Hz) those measurements also can be made by personal exposimetry.

B-field measurement on the welder's body

- **Waveform and harmonics of the magnetic field**

  Since many different arc welding processes exist the waveform, frequency and harmonic components may be quite different so that it is essential to define these parameters. This is required for selecting the adequate exposure guideline/standard to which the measured B-field should be compared for decision about compliance and health risks respectively. In summary, the waveforms that may be observed in the welding practice are:

  - Sinusoidal/triangular which may be continuous or pulsed fields: they are characterized by their frequency
  - Non-sinusoidal waveforms where the frequency range exceeds the nominal frequency. In this case the rise and decay time, pulse duration, and repetition rate are best defined
  - Transients which may contain substantial amounts of energy can be observed too.

The waveform and harmonics can be measured by means of the ELT 400 meter connected to a FLUKE-scope.

	
ELT 400	FLUKE-scope

Result processing

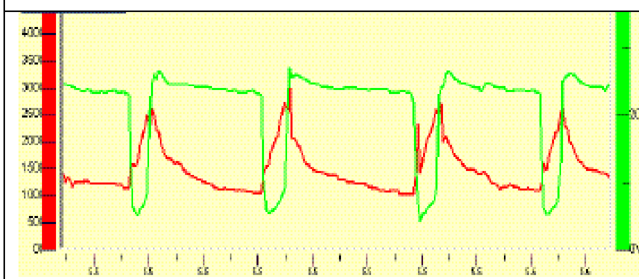
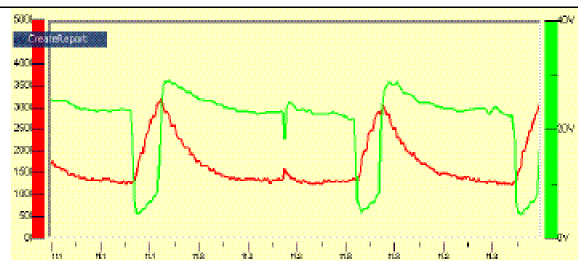
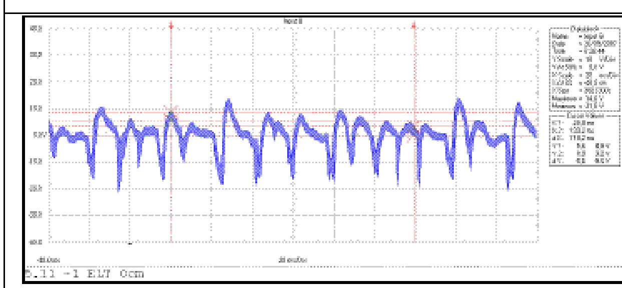
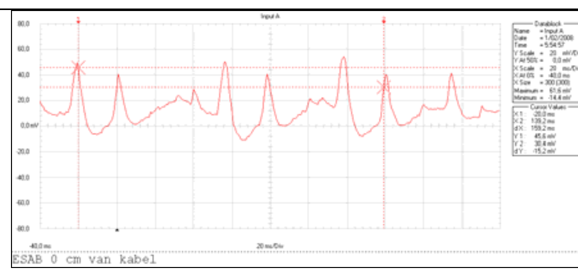
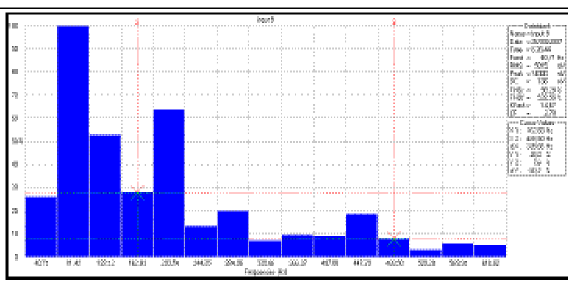
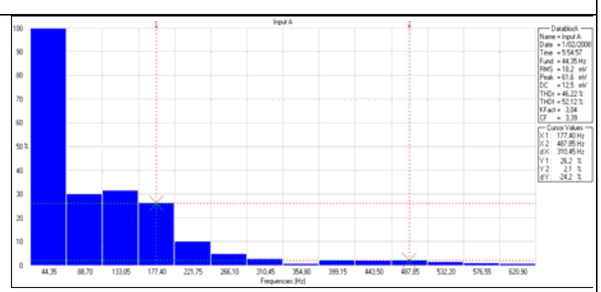
This chapter will give some relevant examples to illustrate the complexity behind the interpretation of the welding parameters, the compliance testing and exposure assessment of welding equipment and welders respectively

Waveform and Harmonics

➢ **MIG semi-automatic short-cut welding**

The figures 1 to 6 show the waveforms and the harmonics from short cut welding obtained with two different welding machines. The frequency of the voltage, current and magnetic fields is determined by the number of short-cuts that occur per second. By each short-cut a voltage drop and a current rice simultaneously occur (figures 1 and 4)

.

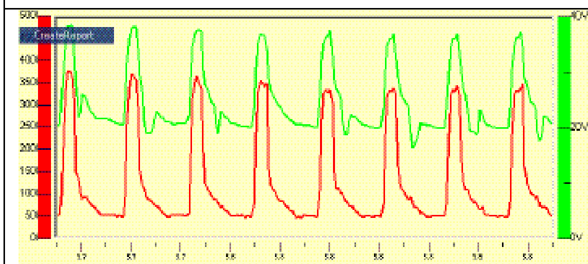
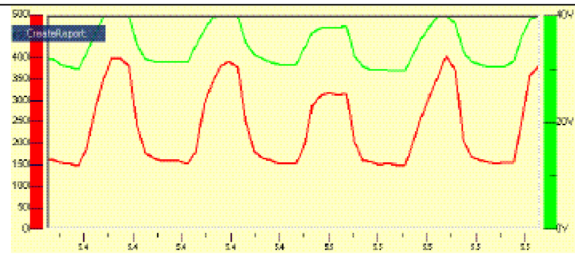
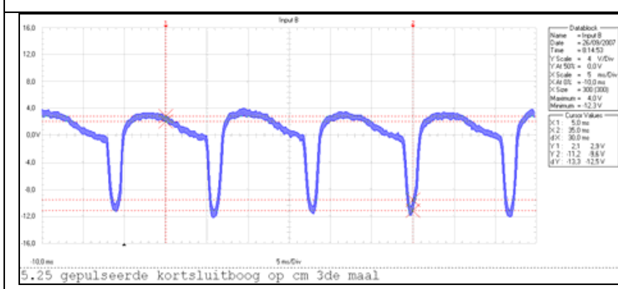
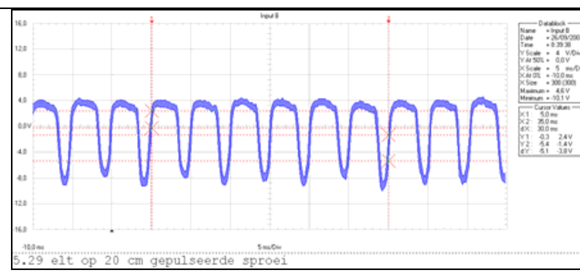
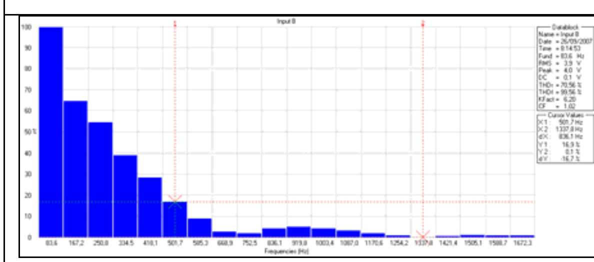
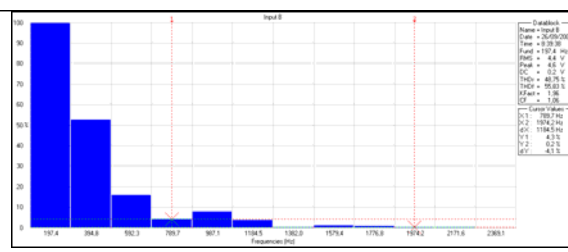
KEMPPI PRO 4200 welding machine	ESAB LUT (450W) welding machine
 Figure 1: Voltage (green) and current (red) waveform	 Figure 4: Voltage (green) and current (red) waveform
 Figure 2:Waveform of magnetic field	 Figure 5:Waveform of magnetic field
 Figure 3:Harmonics with fundamental frequency of 81.42 Hz	 Figure 6: Harmonics with fundamental frequency of 44.35 Hz

(source Belgium EMF welding report 2008)

This series of figures shows that though both welding machines generate similar waveform shapes, the fundamental frequency obtained with the Kemppi machine (81.42 Hz) is nearly double the one obtained with the ESAB (44.35 Hz). Moreover the harmonic content from the Kemppi is quite different from the ESAB. These differences may imply that though wide band B-field measured at both machines may be the same with respect to the action value, the result of the summation formula based on the harmonics may lead to contradictory conclusions about compliance. This point will be further clarified in the section about measured fields.

- **Pulsed short cut welding with low and high current parameters**

The figures 7 to 9 show the waveforms and the harmonics obtained by the low current pulse welding process. The figures 10 to 12 show the voltage-current waveform and the waveform of the magnetic field and its harmonic content obtained by high current pulse welding process. The shape of the waveforms is similar but the frequency and the harmonic contents are quite different for the two processes.

Low current pulsed welding	**High current pulsed welding**
 Figure 7: Voltage (green) and current (red) waveform	 Figure 10: Voltage (green) and current (red) waveform
 Figure 8: Waveform of magnetic field	 Figure 11: Waveform of magnetic field
 Figure 9: Harmonics with fundamental frequency of 83.6 Hz	 Figure 12: Harmonics with fundamental frequency of 197.4 Hz

(source Belgium EMF welding report 2008)

- **AC shielded metal arc welding (SMAW) and DC Gas Tungsten Arc Welding (GTAW or TIG)**

The figures 13 to 15 show the waveforms and the harmonics from the AC SMAW welding process. The wave form of the B-field is block shaped with a fundamental frequency of 60.1 Hz. The figures 16-18 show the waveforms and harmonic of the DC TIG process where a quasi sinusoidal waveform with a fundamental frequency of 156.3 Hz was found.

AC-SMAW welding

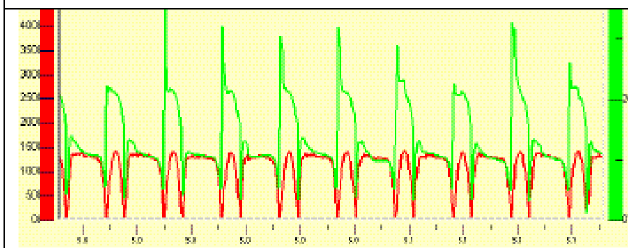


Figure 13: Voltage (green) and current (red) waveform

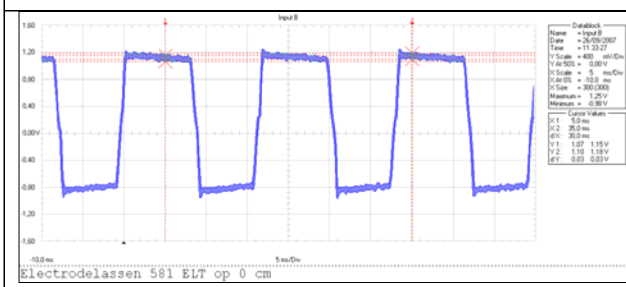


Figure 14: Waveform of magnetic field

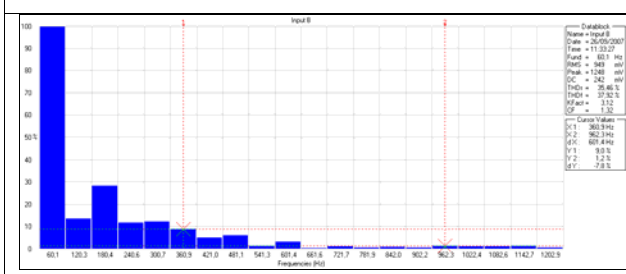


Figure 15: Harmonics with fundamental frequency of 60.1 Hz

DC TIG welding

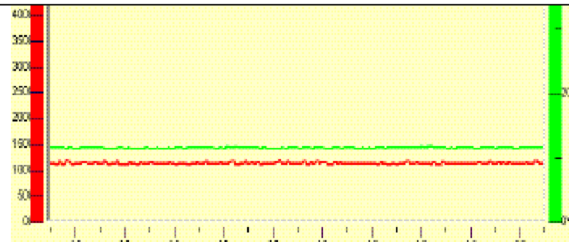


Figure 16: Voltage (green) and current (red) waveform

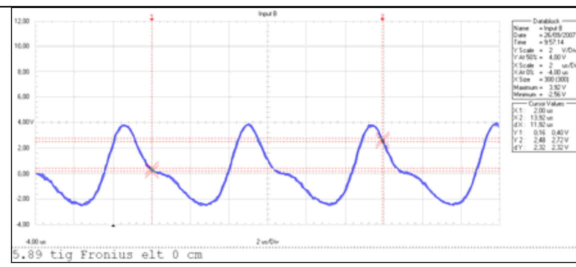


Figure 17: Waveform of magnetic field

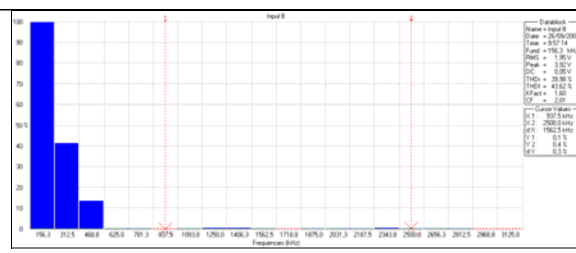


Figure 18: Harmonics with fundamental frequency of 156.3 Hz

(source Belgium EMF welding report 2008)

The aim of showing this series of waveforms and harmonics in the framework of this guidance is to illustrate that almost every welding process is characterized with its typical current and field parameters which might substantially vary according to different welding processes and even within the same processes when different equipment is used. This chapter clearly shows that compliance testing and exposure assessment of arc welding is a multi-complex process where a lot of attention has to be paid to all the steps associated with the measurement event.

Measured fields

On the basis of the next table (extract of the Belgian EMF welding report) we will illustrate the complexity that may arise by comparing the measured B-field strengths with the action values/reference level for interferences about compliance testing and exposure assessment. Next table shows only the measurement results made round the cable in agreement with the CENELEC protocol. Notice that the B-field was measured with the ELT 400 in the wide band mode and in the percentage of the action value (AV) mode. Both measurements were made in exactly the same welding and measurement conditions. The bold red italic values in the table indicate no compliance with the action values or reference levels.

Welding machine	Current type	Process	Fund. freq.. & Action Value	Distance to cable [cm]	B-field measured in the mode of : Wide band [µT]	B-field measured in the mode of : % of AV
Kemppi pro 4200	DC+	Short cut	81 Hz (AV 309)	0	172	***1150***
				10	106	***653***
				20	60	***427***
		Low current pulsed short cut	84 Hz (AV 298)	0	***310***	***895***
				10	161	***501***
				20	108	***343***
		High current pulsed short cut	198 (AV 126)	0	***350***	**913**
				10	196	**475**
				20	125	**307**
ESAB LUD 450W	DC+	Short cut	45 Hz (AV 555)	0	171	**521**
				10	90	**206**
				20	60	**169**
		Low current pulsed	83 Hz (AV 301)	0	***561***	***1315***
				10	285	***620***
				20	199	***169***

(source Belgian EMF welding report 2008)

What do the results tell us about recommendations?

Inspection of the table shows three phenomena which are important in the framework of this guidance:

1. at 20 cm from the cable (CENELEC distance) there is never an agreement about compliance between the data measured in the wide band and in the percentage to AV mode: when the wide band measured B-field is compared with the corresponding action value there is always compliance whereas compliance is never found when the measurement are made in the percentage of the AV mode.
2. when other distances from the cable than 20 cm are considered the data of the two measurement modes agree only in 1 on 5 cases when the measurements are performed on the cable (d = 0) and in none of the 15 cases at 10 cm from the cable
3. the B-field measured on the cable (d = 0) is always between 2 and 3 times stronger than the one at the 20 cm distance recommended by CENELEC.

By these contradictions the following questions arise:

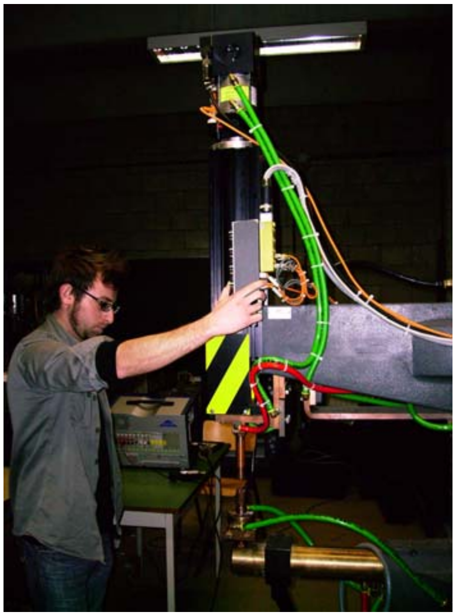
- which of both measurement methods leads to reality or in other words is the body responding to the wide band exposure or to the sum of the harmonics which form the base of the percentage to AV mode or the summation formula.
- what's the rationality behind the recommendation to test compliance at 20 cm from the cable and not on the cable while certain parts of the body are predominantly in contact with the cable.

Hence, the following recommendations are justified in the framework of this guidance for arc welders:

- look for a best available welding technique for avoising contact between the cable and the body: the best adviser in this case is the experience of the welder
- in the framework of the precautionary principle the discussion about the distance from the cable for compliance testing has to be re-opened in terms of the cable/body contact which is perhaps difficult to avoid without loss of welding comfort and/or efficiency
- the problem about the contradiction in measurement readings leading to different conclusions about compliance has to be solved. Anyway, as long as the results of both methods do not agree we cannot decide whether the B-fields generated by arc welding processes are compliant with the action values or not.

Spot welding

It is a type of resistance welding used to weld various sheet metals typically of about 0.5-3.0 mm thick. The process uses two shaped copper alloy electrodes to concentrate welding current and force between the materials to be welded. The result is a small "spot" that is quickly heated to the melting point, this forms a nugget of welded metal after the current is removed. The amount of heat released in the spot is determined by the amplitude and duration of the current. The current and duration are chosen to match the material, the sheet thickness and type of electrodes.



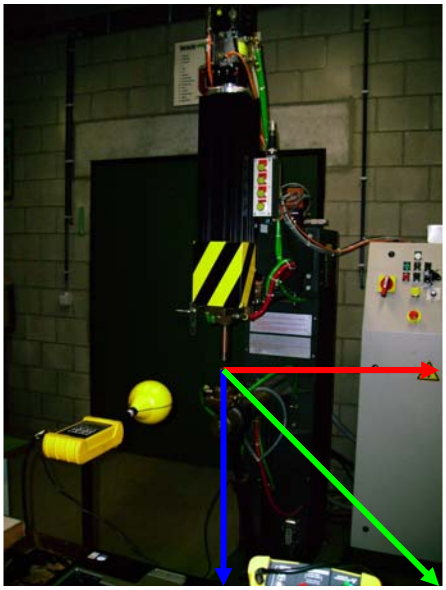
Normal operator position during spot welding

How to measure the magnetic field?

The spot welding machines we experienced with are an/a:

- AWL 65 kVA 50 Hz machine
- ARO 180 kVA MFDC 1 kHz machine
- Matuschek 32 kVA HFDC 20 kHz table model

It is advised that the B-field is measured in a 3 axis plane white the position of the probe in a angle of 0°, 45°, 90° with respect to the electrode of the machine. The 0° is the reference axis which is the axis in front of the electrode. In each axis the B-field is measured on a height of 0.20, 1.00 and 0.75 m. Moreover each axis is divided in a doubling radial distance starting from 5 cm from the electrode up to 1 m. In each point the measurements were performed in the wide band and the percentage of the action value mode of the ELF400.



3 axis probe position (0° blue, 45° green, 90° red)

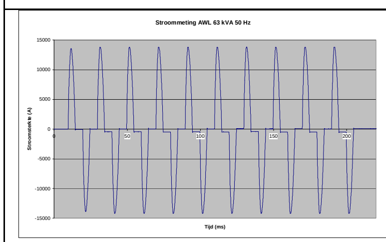
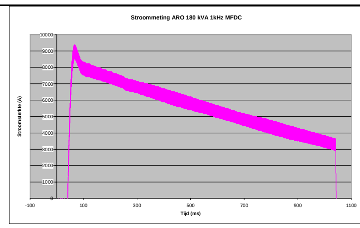
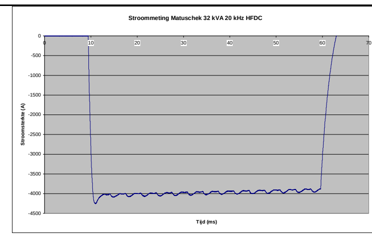
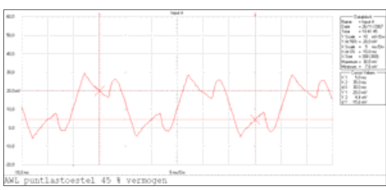
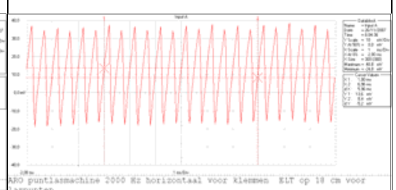
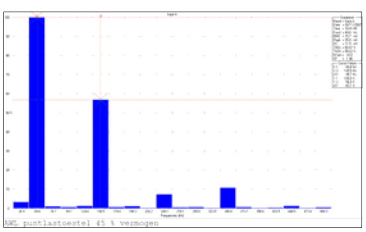
The measurement equipment that may be advised is a/an:

- DEWETRON scope for defining the current parameters of the machine
- ELT 400 for measuring the B-field
- FLUKE scope for defining the waveform and the harmonics of the B-field

Result processing

Waveforms and harmonics

The figures 1 to 7 show how waveforms and harmonics of three different spot welding machines look like. For the AWL and ARO machine the measured fundamental frequency agreed with the nominal. The waveform of the Matuschek was too unstable for taking the waveform and the harmonics of the field. Therefore the nominal 20 kHz frequency will be used for calculating the action value for comparing the measured fields.

AWL 65 kVA	ARO 180 kVA MFDC 1kHz	Matuschek 32 kVA HFDC 20 kHz
 Figure 1: Current waveform	 Figure 4: Current plot	 Figure 7: Current plot
 Figure 2: Waveform of B-field	 Figure 5: Waveform of B-field	Waveform too unstable to take picture
 Figure 3: Harmonics	 Figure 6: Harmonics	Waveform too unstable to take picture

(source Belgium EMF welding report 2008)

Measured fields

In the next two tables an example is given of the results measured on different heights and different radial distances from the electrode of a 50 Hz spot welding machine (P = 45% and I = 7.9 kA). The tables summarises the results made at the 3 heights in the 3 axis plane (0°, 45°, 90°)

The measurement height of 109 cm corresponds to the vertical position of the electrode of the machine.

Table 1: Measurements made in the percentage of the action value mode

Distance to electrode [cm	Measurement Position	Percentage of action value				
	Angle of measurement axe [°]→	0			45	90
	Measurement height [cm] →	20	109	175	109	109
5		0,69	***1766***	***110***	***overload***	***overload***
10		0,6	***670***	91	***overload***	***1867***
20		0,44	***192***	58	***1197***	***544***
40		0,32	82	38	***341***	***222***
60		/	44	/	***145***	/
80		/	27	/	79	/

(source Belgian EMF welding report 2008)

Table 2: Measurements made in the wide band mode

Distance to electrode [cm]	Measurement Position	Wide band B-field [µT]				
	Angle of measurement axe [°]→	0°			45°	90°
	Measurement height [cm] →	20	109	175	109	109
5	Action value is 500 µT	42	***2371***	/	overload	overload
10		39	***1211***	58	***1827***	***3151***
20		33	450	50	***785***	***1277***
40		24	119	33	237	331
60		17	49	22	111	126
80		/	25	/	48	/
100		/	15	/	/	/

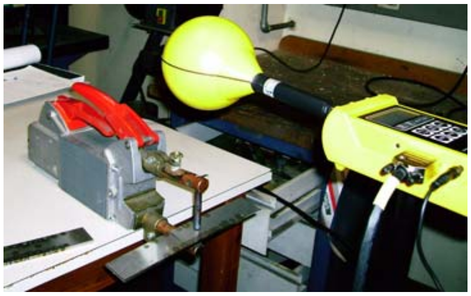
(source Belgian EMF welding report 2008)

The results of the tables show that the B-field strength is different at different heights and axes respectively. Therefore it is recommended to perform the measurements at different heights and in different axes.

If we consider the percentage of the action value mode (table 1) at a height of 109 cm of the 45° axis we see that the B-field strength is not compliant within a distance of 60 cm from the electrode. However if we consider the same measurement in the wide band mode this distance corresponds only to 20 cm. This agrees with the contradiction between both measurement modes we already observed with arc welding. In this respect the recommendations for the spot welding are the same of these made for arc welding.

Portable spot welding

Portable spot welding (PSW) is a type of resistance welding where high currents are used and consequently strong magnetic fields may be produced. PSW is mainly used in SME's and in a less extend in big industries for welding metal sheets.



PSW and ELT 4000

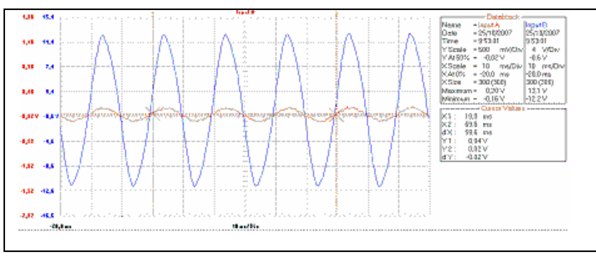
Measurement methods

The measurements the guidance is dealing with were made on a TECNA model (max 11 kVA and 7.4 kA) with a welding duration of 1.3 seconds.

It is recommended to measure the waveform, the harmonics and the B-field for PSW with the same equipment as done for the spot welding machines discussed in the chapter above. Moreover it is also advised to measure the B-field in a three axis' plan and since it is a portable system also on the body of the operator.

Result processing

The PSW generates a pure 50 Hz sinusoidal field without harmonics so that the measured wide band B-field can simply be compared with the action value for compliance testing.



The next table shows the results where the approach was focused on reproducibility of the results within the same PSW-device. Notice that for the present guidance we only are interested to know the measurement variability within one PSW device but that we don't want to know variability within and between different PSW devices for interferences and decisions about the B-field of the PSW population.

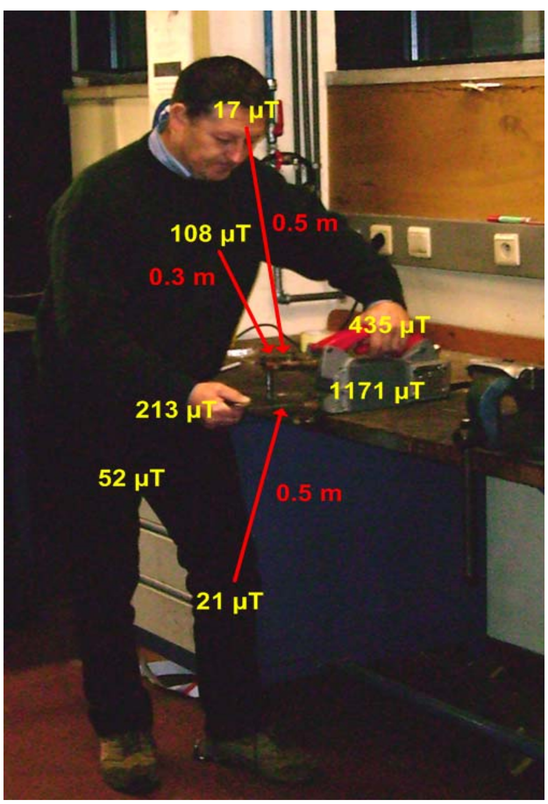
Distance to electrode (cm)	M1			M2			M3		
	Mean B-field (µT)	Stdev	N	Mean B-field (µT)	Stdev	N	Mean B-field (µT)	Stdev	N
1	1045	54	6	921	61	6	1531	43	6
10	216	6	6	213	13	6	230	21	6
20	66	5	6	73	3	6	74	2	6
30	31	1	6	31	1	6	32	1	6
40	16	0	6	16	0	6	16	0	6
50	10	0,3	6	10	0,4	6	9	0,5	6

- M1: measurement in horizontal direction in front of contact point during spot welding
- M2: measurement in vertical direction above contact point during spot welding
- M3: measurement in vertical direction under contact point during spot welding

It shows that for testing reproducibility N repetitive measurements have to be made per measurement point in M planes. The results show that one has to be very close to the electrode to exceed the action value of 500 µT. However the most interesting and most important observation from the table is that the closer to the electrode the measurements are made the bigger the variability in terms of standard deviations from the mean B-fields. Though uncertainty is different from variability this observation implies that the uncertainty about a single point measurement made near to the electrode is much bigger than the one made at a point farther away from the electrode. Hence it is advised that compliance should not be tested on base of a single point measurement but that it should be based on representative location and dispersion statistic.

What can we tell about the B-field distribution on the body?

Since the next figure shows that the B-field on the different parts of the body agrees with the action value of 500 µT it is advised that operators of PSW devices choose the best welding position available by respecting more or less the distances indicated in the picture.



Distribution of the B-field over the body of the PSW operator

As for avoiding a possible indirect effect by interference with pacemakers and/or other electronic implants it is recommended that carriers of such implants do not use PSW devices since at a distance of 30 cm from the chest the 100 µT threshold for interference with old pacemakers is exceeded.

What can we recommend about welding in general?

Throughout the data we've shown that EMF compliance testing and exposure assessment of arc welding as well as spot welding are complex tasks. Therefore it is first of all recommended that an experienced staff is involved in the job. The staff must at least consist of :

- a welding engineer, knowing the great diversity of welding processes and related electrical welding parameters
- an EMF expert, knowing the physics, the measurement and exposure assessment techniques and the interpretation of guidelines and standards in terms of reproducibility, uncertainty and variability
- last but not least, an experienced technical staff with a perfect know how of the measurement equipment and how to deal with measurement artefacts or aberrations

Good communication between all members of the crew in every step of the measurement and reporting process is indispensable in order to get a qualitative and reliable final product. Although there is a tendency to put exposure assessment or compliance testing into the plants' own safety staff's hands we have to be aware that the complexity of this task is that great that the results delivered by an un-experienced person or group will be unreliable and has to be repeated by an experienced staff.

Because the measurements showed that welders are exposed to magnetic induction fields which exceed the action value by cable contact during arc welding and at operator's distance during spot welding on the one hand and the lack of modelling data and data on protection possibilities in the welding sector on the other hand it is recommended that:

1. reliable calculations/models for checking compliance of the body induced current with the exposure limit value/basic restriction will be applied to or developed for the welding sector
2. advanced research on active and passive mitigation possibilities which have certainly to be efficient for arc welding has

to be stimulated. Since the Biot-Savart rule for field attenuation with distance is hard if not possible to apply for arc welding developing LF magnetic field reducing protective clothing (that doesn't limit working comfort or welding efficiency) is perhaps the best solution here.

3. operators of spot welding machines could enlarge their distance to the electrode to at least 60 cm therefore research on efficient remote control systems for starting the spot welding machine measurement should be encouraged.

As for sensitive groups such as carriers of pacemakers and/or other electronic implants, pregnant women and youngsters in welding education we have the following advice.

Because of the risk on interference, carriers of pacemakers and/or other electronic implants do not weld with any system.

Since more and more women start to work as a welder in the industry or weld in art schools it is recommended on base of the precautionary principle that they don't weld when they are pregnant.

As for youngsters between 14 and 18 year who are in their welding education we roughly calculated that a youngster who is welding about 18 h a week receives the same amount of B-field in 12 days than a child that is permanently exposed to 0.4 µT by living under a power line. If there is an epidemiological relation between the 0.4 µT exposure by power lines for children between 0 and 15 years old and childhood leukaemia why should we not be prudent with youngsters who are, though not continuously, exposed to far higher B-field strengths when they are welding.

References

Belgian EMF welding report 2008: Broeckx K; Decat G., Deckx L., Meynen G., Casteels M., Van Rymenant P., Mild K.H. Meten en evalueren van de blootstelling van lassers aan elektromagnetische velden in het kader van de nieuwe Europese EMF-richtlijn 2004/40/EC [[Evaluation of the EMF exposure of welders in the framewoke of the directive 2004/40/EC]. BIL/VITO 29/02/2008

CENELEC prEN 50444, September 2006. Basic standard for the evaluation of human exposure to EMF from equipment for arc welding and allied processes.

CENELEC prEN 50445 September 2006. Product family standard to demonstrate compliance of equipment for resistance welding, arc welding and allied processes with the basic restrictions related to human exposure to electromagnetic fields (0 Hz – 300 GHz).

CENELEC prEN 50505 September 2006. Basic standard for the evaluation of human exposure to EMF from equipment for arc welding and allied processes.

CENELEC EN 50499. 2006. Determination of workers exposure to electromagnetic fields.

CENELEC EN 50392: 2004-01: Generic standard to demonstrate the compliance of electronic and electrical apparatus with the basis restrictions related to human exposure to electromagnetic fields (0 Hz – 300 GHz).

CENELEC 2006. Basic standard on measurement and calculation procedures for human exposure to electric and magnetic and electromagnetic fields (0 Hz – 300 GHz). Draft pr EN 50413.

Decat G., Decks L., Meynen G., Wilczek D. Is the use of simplified current density formulas reliable for testing compliance with exposure limit values? Proceedings: XIV Congress of the Polish Radiation Research Society memorial to Maria Skłodowska-Curie. September 24-26, 2007. Kielce, Poland.

Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), O.J. nr L-184 of 24 May 2004.

ICNIRP (1994) Guidelines on Limits on Exposure to Static Magnetic Fields. Health Physics, vol. 66, No. 1, 100-106; 1994.

ICNIRP (1998) Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz), Health Physics, vol. 74, No. 4 (April), 494-522; 1998.

ICNIRP (2003) Statement Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines. Health Physics 84(3): 383-387; 2003.

ICNIRP 13/2003, Exposure to Static and Low Frequency Electromagnetic Fields, Biological Effects and Health Consequences (0 – 100 kHz). Int. Commission on Non-Ionizing Radiation Protection 2003.

NIOSH Manual for measuring occupational electric and magnetic field exposure. U.S. Department of Health and Human Services. Public Health Service. Centres for Disease Control and Prevention. National Institute for Occupational Safety and Health. DHHS (NIOSH) Publication No. 98-154.

NIOSH/WHO Occupational EMF document. Evaluation and managing occupational exposure to EMF. A Joint Publication of the World Health Organization International EMF Project and the U.S. Centres for Disease Control and Prevention, National Institute for Occupational Safety and Health. In preparation.

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