

Electromagnetic Fields (EMF) in the welding environment

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The Electromagnetic fields (EMF) Directive (2013/35/EU) was adopted in June 2013. Member States are required to bring into force any laws, regulations and or administrative provisions necessary to comply with the Directive by July 1st, 2016. This research report considers various types of welding and the requirements of the Directive.

The report provides:

- A review of available literature using the TWI 'Weldasearch'" database and other sources
- Measurements of the EMF emissions welders may be exposed to during the welding processes
- Understanding where welding fits in with the requirements of the EMF Directive
- A proposal for an EMF emission risk assessment procedure
- Guidance on compliance for the welding industry

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Executive Summary

Background

The new European Physical Agents Electromagnetic fields (EMF) Directive (2013/35/EU), was published in June 2013 and will come into effect on 1 July 2016. It requires employers to limit workers' exposure to EMFs in the workplace. The Directive contains technical Annexes, which provide action levels (ALs) and exposure limit values (ELVs). Meeting these values can be used as one way to demonstrate compliance with the Directive. Action levels can be measured directly with an appropriate meter but most ELVs require computer modelling or calculations to make the assessment.

Concerns have been raised that this Directive may have an impact on companies using welding processes. In particular, the major impact may be on those using arc and resistance welding, where the welding currents are high and the operator may be close to the equipment. Other processes, in the welding industry, which may also lead to relatively high exposures, are induction heating, stud welding and magnetic particle inspection. Mechanised variants of the above processes should not in general expose the welder to significant EMFs.

Overview

The report provides:

- A review of available literature using the TWI "Weldasearch" database and other sources.
- Measurements of the EMF emissions welders may be exposed to during the welding processes.
- An understanding of the impact that the EMF Directive may have on welding.
- A proposal for an EMF emission risk assessment procedure.
- Guidance on compliance for the welding industry.

Approach to Measurement

Measurements of the magnetic field in positions where a worker is likely to stand were carried out for the following processes.

- Pulsed MIG/MAG welding.
- AC square wave TIG welding.
- Single-phase AC resistance welding.
- Medium frequency resistance welding.
- Magnetic particle inspection (MPI).
- Stud welding.
- Induction heating.

Measurements were made using a NARDA ELT-400 instrument, which measures the magnetic field over a frequency range of 1Hz to 400kHz. This instrument displays the field in absolute units (tesla, T) and as a percentage of the low AL. For comparison with the high and limb ALs the waveform was passed through a digital filter, based on the weighted peak method of assessment. Welding parameters were chosen as being typical of those used with the equipment for a range of applications.

Results

For arc welding processes operating in DC mode the low ALs were not exceeded even in situations where the workers were in very close proximity to the magnetic field. However, for AC and pulsed arc processes higher magnetic fields were measured. Although the limb AL was not exceeded for hand held torches, close to a bent welding cable the field to which the welder may be exposed, was found to approach the low AL.

Due to the much higher welding current used for resistance welding processes, the fields to which welders may be exposed were found to be much higher than for arc processes and exposure is very dependent on welder position. For equipment operating at mains frequency, it is possible the low AL could be exceeded and if the welder is holding components close to the electrodes hand exposure may also exceed the limb AL depending on welding parameters. For medium frequency equipment (typically 2kHz), the magnetic field at positions up to 500mm from the electrodes, is likely to exceed the low AL when using typical operating parameters. Closer to the electrodes, the high AL and limb AL are also likely to be exceeded.

There are many variants of the stud welding process, but for the capacitive discharge variant tested, the field was found to significantly exceed the low AL at positions normally occupied by the welder.

Magnetic particle Inspection (MPI) is a widely used technique for detecting cracks in welds. For standard equipment, the external magnetic field was found to be low, but techniques for inspecting large components may result in the inspector being exposed to fields above the low AL.

Induction heating is used for brazing and pre-heating components before welding. Typically, for brazing the field was found to be below the low AL, but for pre-heating large components the ALs may be exceeded. The field is very dependent on position and the geometry of the component.

Conclusions

The work carried out in this project has shown many of the commonly used welding processes should not expose welders and operators to magnetic fields in excess of the action levels (ALs). Some process options may lead to the action levels (ALs) being exceeded.

If the low ALs are exceeded, it is difficult to assess against the high ALs and the limb ALs because direct reading instruments are not commercially available. Furthermore, compliance to the ELVs can only be demonstrated by calculation or modelling which requires a suitable expensive software package.

This work has shown that the resistance welding processes are most likely to be above the ALs. However, many exposures may be borderline or just exceed the ALs and simple measures may reduce workers exposure. Simply moving further away from the electrodes can solve the problem, so moving a foot switch, providing a guard or changing the operator's position may be sufficient. However in some cases, more elaborate measures may be required such as holding components in a fixture, rather than by hand or using a robot to hold components whilst welding takes place.

Whilst the use of robot welding lines reduces operator's exposure to EMF, companies need to ensure they carry out an assessment for all potential exposure scenarios, such as maintenance operations, training and operation of repair stations.

However, it is worth noting that showing EMF exposure is below the action levels is only one way to demonstrate compliance to the Directive.

The measurements, information and risk assessment procedures outlined in this report could be used by employers who undertake welding activities, to help them with their risk assessments and work towards compliance.

1 Introduction

The new European Physical Agents (Electromagnetic fields (EMF)) Directive (2013/35/EU), which was published in June 2013, will require employers to limit workers exposure to EMF in the workplace. It is believed that this may have a significant impact on companies using welding processes. In particular, those using arc and resistance welding, where the welding currents are high and the operator may be close to the equipment.

However, previous work on which these conclusions are based, almost exclusively compared electromagnetic fields with the limits in the previous Directive 2004/40/EC. The new Directive introduces new limit values which will require a reassessment of the situation.

The new Directive contains Annexes which provide exposure limit values (ELVs) and action levels (ALs) which may be used to demonstrate compliance with the Directive. Action levels can be measured directly with an appropriate meter but ELV require computer modelling or calculations to make the assessment.

TWI recognised the need to provide information on EMF exposure from welding processes, to their member companies, so initiated a preliminary study of EMF. HSE also had a requirement to understand how the new Directive would affect companies in the fabrication industry and decided to contribute to funding this project.

In this report, a survey has been carried out on a range of typical welding processes, in which magnetic fields have been measured and compared to the ALs.

It is important to note that while the Directive, which sets out the limits and the basic requirements of employers has been published, the document is not comprehensive. References are made within the Directive to a "Practical Guide", which will be published in 2015 and will describe how assessments will be made and other areas not described in the Directive. This report has been written, taking into account, what is expected to be within that practical guide.

2 Action Levels

An assessment against ALs can be carried out by direct measurement of the magnetic flux density (tesla) in the vicinity of the operator and demonstrating compliance with these values may appear to be straight forward.

Action Levels have changed considerably between the Action Values (AVs) of the original EMF Directive (2004/40/EC) and the ALs of the new Directive (2013/35/EU), see Figure 1.

The new ALs have increased from the original action values (AVs) in the previous Directive and in particular the low AL between 25Hz and 300Hz is now constant at 1000 μ T. This may have a significant effect for compliance of welding processes operating at power frequencies (50Hz).

Also, the new Directive introduces ALs for limbs. These levels are higher than for the body, because coupling is lower due to the smaller cross section of limbs compared to the body, but hands may be much closer to the source of EMF due to the operator holding a welding torch (welding cable) or holding a component close to the electrodes of a spot welder. An assessment is therefore also now required for hands and other limbs that may be close to the source of EMF.

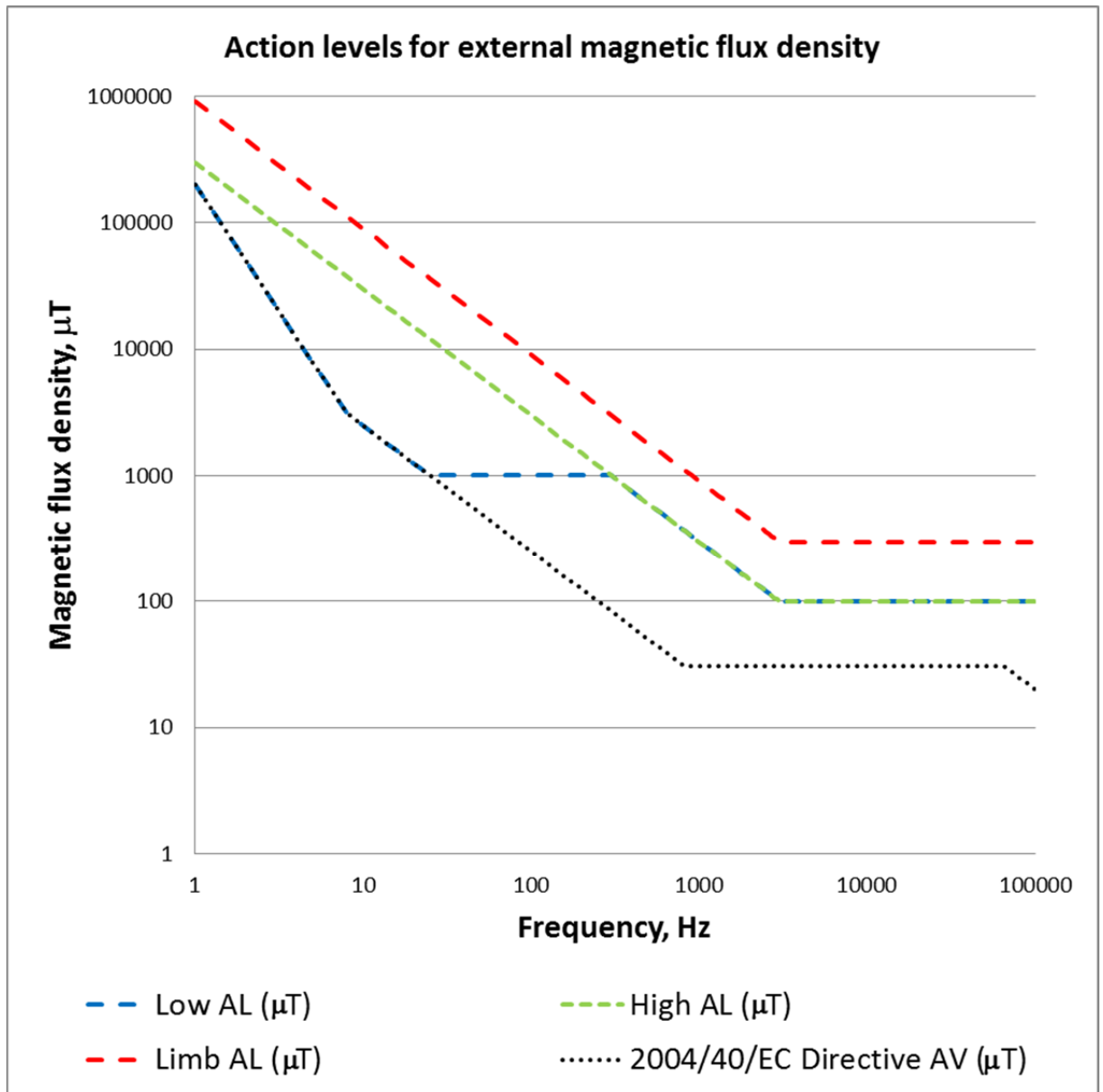


Figure 1 Comparison between ALs of 2013/35/EU and AVs of 2004/40/EC.

Although measurement of magnetic flux density is relatively straight forward with the correct instrumentation, it should be noted that welding waveforms are rarely sinusoidal so the weighted peak method of measurement is recommended. Also, the field is non-uniform, so spatial averaging over the operator's body should be considered.

Whilst detail of these measurement methods should be included in the Practical Guide, this will not be available until 2015.

3 Welding Processes

There are many welding processes and TWI estimates about 130 process variants. These include the process groups of:

- Arc welding.
- Resistance welding.
- Laser welding.
- Electron beam welding.

- Friction and friction stir welding.
- Explosive welding.
- Magnetically impelled arc butt welding.
- Flash butt welding.

However, due to safety or operational reasons most of these processes are performed with mechanised equipment and the operator is not in the local vicinity.

Arc welding is the most common welding process and is usually performed manually, with the welder holding a welding torch in the hand. Even when mechanised, the operator may stand close to the process. There are many variants of arc welding including:

- Manual metal arc (MMA).
- Metal inert/active gas (MIG/MAG).
- Flux cored arc (FCA).
- Tungsten inert gas (TIG).
- Plasma.
- Submerged arc welding (SAW).

Of these processes, SAW is the only one that is not generally used manually.

For resistance welding there are also a number of process variants and terms:

- Spot.
- Seam.
- Stud.
- Projection.

The resistance welding gun can be held by hand (often known as portable spot welders) or the operator stands by a pedestal machine, often holding the component.

Traditionally, arc and resistance welding is performed using equipment based on (50Hz) power transformers, so the welding current and hence magnetic field contains a fundamental frequency of 50Hz and harmonics (eg 150 and 300Hz). Modern equipment is inverter based. Inverters are more energy efficient, lighter and provide greater control of the process. For arc welding, inverters running up to 100kHz are available but for resistance welding lower frequencies (medium frequency at 1kHz) are the norm.

In arc welding the welding current may be AC or DC and also pulsed current is sometimes used. For resistance welding the equipment may be single phase AC, three phase DC or inverter based DC, see Figure 2. For arc welding pulsed MIG/MAG and square wave AC TIG are believed to generate the highest magnetic fields, with welding currents up to about 600A. For resistance welding the current is much higher and may be in excess of 30,000A.

In arc welding, pulsed current is used to improve quality and increase productivity of the MIG/MAG and TIG processes. Also for TIG welding of aluminium alloys, AC current is used to disrupt the surface oxide. Square wave AC is preferred to sine wave AC for process stability.

A recent survey carried out as part of the EMFWELD European collaborative project, showed that industry believes MIG/MAG, TIG and resistance welding to produce the highest EMF.

There have also been concerns expressed about magnetic particle inspection (MPI), stud welding and induction heating, so these processes are also included in this study. However, there are many process variants, so not all exposure scenarios have been assessed. In MPI the component is magnetised, either completely or in localised areas and a dye is applied which will identify any cracks in the weld. Stud welding is used to weld studs onto metal plates for attaching other panels, electrical connections etc. Induction heating is used

to heat metals for brazing and also to preheat and post heat treat welds to reduce cracking and distortion.

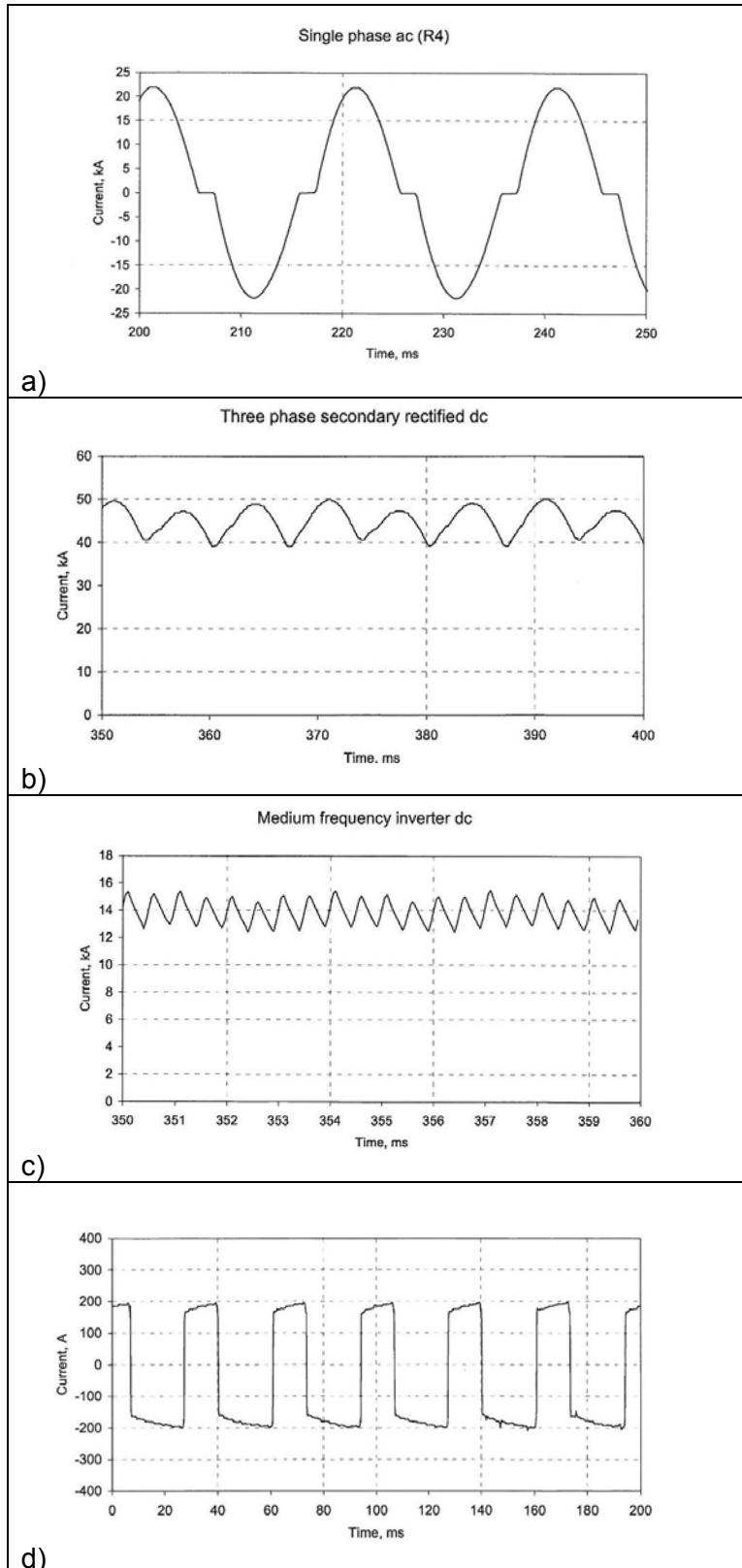


Figure 2 Current waveforms:
a) Single phase resistance welding;
b) Three phase rectified resistance welding;
c) Medium frequency inverter;
d) AC TIG.

It was therefore decided to assess the following welding processes:

- Pulsed MIG/MAG welding.
- AC square wave TIG welding.
- Single phase AC resistance welding.
- Medium frequency resistance welding.
- Magnetic particle inspection (MPI).
- Stud welding.
- Induction heating.

The most widely used process is MIG/MAG together with the derivative FCA welding which together account for over 50% of all arc welding performed. MMA accounts for about 20% and the remainder is taken up by the other processes.

It is difficult to assess the percentage use of resistance welding. Much of the equipment still in use today is over 30 years old. TWI estimates that about two to three times the number of companies used arc welding processes compared to resistance welding. It is used extensively in most industries, and applications include shipbuilding, power stations, off-road vehicles, bridges and aircraft engines.

Resistance welding is predominantly carried out on thin sheet steels particularly in the automotive and white goods industries, but the process is also used in a diverse range of applications from aerospace to office furniture.

4 Number of Welding Operators

It is difficult to estimate the number of workers exposed to magnetic fields from welding processes. Welding is used in most manufacturing factories. A figure of between 50,000 and 70,000 is often quoted for welders in the UK. TWI believes that the lower end of the range is more realistic. However, these are qualified (coded) arc welders and the number of welding operators will be much higher. For resistance welding, the operators are generally unqualified and resistance welding is considered as a general manufacturing process. Resistance welding is most widely used in the automotive and white goods industries. However, even a small pedestal welder used for welding electrical sensors may produce a significant exposure.

The Office of National Statistics 2011 reports 56,000 people in the welding trades and 107,000 in metal forming, welding and related trades.

Also, arc welding is used extensively in many industries, eg car repair and, although skilled, these welders will not be coded.

5 Literature Review

Recent literature on electromagnetic fields from welding processes was reviewed and a summary is given in Appendix A. Conclusions are based on 2004/40/EC and ICNIRP 1998 requirements, so are difficult to interpret for compliance with the new Directive 2013/35/EU.

6 Measuring Equipment

For welding processes, the welding current is high but voltages are relatively low, so the magnetic field is of most importance. There are a number of instruments available for measuring magnetic fields. It is important to choose an instrument with sufficient bandwidth. For non-thermal effects the instrument must be capable of measuring frequencies up to 100kHz. Some instruments have a much lower frequency range. Although the fundamental frequency of power frequency equipment is only 50Hz, inverter technology works at much higher frequencies and harmonic components need to be taken into account for measurement.

It is also important that the measuring instrument has a fast response because many resistance and stud welds are of short duration, ie less than one second.

Action levels are frequency dependent, so for non-sinusoidal fields (as usually occurs for welding processes), the weighted peak method should be used for assessing exposure. This is difficult to calculate for field strength measurements because the values of the field at all the harmonic frequencies need to be assessed against the action levels. Also, it is important to measure the peak of the field and not the rms value. It is suspected that many people are misled into measuring the rms value of the field, because this is specified in the Tables in the Directive and the correct procedure is only explained further in the notes.

Electromagnetic field meters with built in filters are a considerable aid to measuring action levels. Until recently, only instruments with the ICNIRP 1998 filter were available. However, now the latest meters are equipped with the ICNIRP 2010 filter, which is the same as the low Action level (low AL) for the magnetic flux density in the new Directive. One such instrument, the NARDA ELT-400, was used for the measurements in this work.

Demonstrating compliance with the upper ALs and those for limbs is difficult, because meters do not exist with the filters built in for these limits. Also, there are limitations in terms of measurement positions with some probes (eg closest approach).

To make an assessment for magnetic field exposure of an operator's hands, when holding a welding torch or a component close to the electrodes of a resistance welder, TWI developed its own filter to process captured waveforms. This filter was validated by injecting sine waves of known frequency and amplitude and comparing the results against the ALs for limbs.

During measurements the ELT400 was placed either on a custom built stand to align the three-axes sensors in the X, Y and Z direction or attached to a tripod. The percentage of the low ALs was read directly from the instrument. Also, an analogue output signal proportional to the magnetic flux density was recorded on a digital oscilloscope and process by the TWI filter.

7 Assessment Procedure

7.1 General

To assess the magnetic field to which operators may be exposed, the following assessment procedure was followed:

- Geometry of the welding equipment and its current loop was observed, and the height of the centre of the current loop recorded, in order to provide reference of data to other welding equipment locations.
- Operation of the equipment was observed, from loading components, through welding, to unloading components in order to determine typical operator positions and movements for both a sitting and standing operator.
- The distance of the operator's head, trunk and groin from the current loop were recorded.
- The magnetic probe was placed in positions corresponding to the operator's head, trunk and groin, for sitting and standing positions. An assessment was made in these positions against the Directive 2013/35/EU low ALs. If the magnetic flux density was lower than the ALs, no further assessment was deemed necessary and the horizontal distance of the assessment from the current loop was recorded.
- If the magnetic flux density exceeded the low action levels, a further assessment was made, recording the magnetic flux density at different distances from the current loop.

7.2 Measurement positions

Measurement positions were based on the UK male average height of 175cm, and measurements were taken at positions of head, trunk, groin, floor and hand. The nominal measurement heights are given in Table 1. This height is in approximate agreement with 'Duke' the male anatomical model, often used for calculating the induced field.

Table 1 Nominal height of measurement positions

Measurement position	Height from ground (cm)
Standing head	170
Sitting head ~ Standing trunk	125
Sitting trunk ~ Standing groin	95
Sitting groin	55
Floor	20
Hand	Selected based on equipment

Each welding process was examined during operation and if necessary, the measurement positions altered to more accurately assess the magnetic field at the operator's position. This is most often occurred for the MPI inspection processes, where the operator is typically looking very closely at the magnetised sample. The positions corresponding to the head and torso can be used to produce a spatial average value for the body exposure as described in several European Standards as a method of assessing the level of the magnetic flux density against the limit, but the validity of this approach should be clarified in the Practical Guide.

Measurements were also taken around straight welding cables, in isolation from the welding operation, to enable a standardised assessment of exposure and to assess the exposure of other employees, not necessarily the operator of the welding equipment.

7.2.1 Measurement procedure

Measurements were taken by placing the ELT-400 in ICNIRP (2010) mode, equivalent to the low ALs and recording the magnetic flux density whilst welding was performed. The process determined when the measurement was taken. For prolonged welding procedures such as metal inert gas (MIG) and tungsten inert gas (TIG) welding, the weld was initiated and then the ELT-400 was placed in 'Max Hold', and left for five seconds. For short-term welding operations, such as resistance welding, the ELT-400 was placed in 'Max Hold' before the process was initiated, and the reading examined when the welding process was complete. The 'Max Hold' setting kept a recording of the highest magnetic flux density at the probe's position.

7.2.2 Low action levels and limb action levels

The majority of the assessments, ie those for the head and torso, were made against the low action levels, as compliance with these levels implies compliance with the higher action levels and exposure limit values.

The hand exposures were assessed against the low ALs and if the recorded measurement did not exceed these levels, no further assessment was made. If exposure exceeded the low ALs, an assessment was made against the limb action levels.

Hand assessments could not be made directly with the ELT-400 because there is no filter for the limb AL built into the instrument, so a different assessment method was used. The waveform was recorded, scaled and run through a simulated high pass filter circuit, such that a weighting function was applied to the frequencies inherent in the waveform. This weighting function corresponded to the limb action levels as described in the Directive, such that the output of the filter was a waveform similar to that of the ELT400 in 'ICNIRP mode', with a value of $\pm 1V$ corresponding to 100% of the limb action level. ('Method for assessing magnetic fields from welding against the coming EU directive', Y. Hamnerius et al, BioEM2013, June 2013, Greece.) This is the method described in the ICNIRP guidelines as 'the weighted peak method'. This method was validated by using both simulated multiple harmonic compound sine waves and recorded magnetic field waveforms to test whether the output was accurate.

8 Measurements

Details of the measurements are given in Appendix B.

9 Summary of Results

9.1 Arc welding processes

For conventional arc welding processes operating in DC mode (TIG, MIG and MMA), the low ALs were not exceeded even when “bad practice” such as draping the cables over the shoulder, which increases exposure to the magnetic field, was adopted. The maximum magnetic field measured was about 50% of the lower AL.

- For pulsed MIG, higher magnetic fields were measured and for hands holding a welding torch, the magnetic field approached the lower ALs, however this is significantly below the ALs for limbs.
- For AC TIG, hand exposures were also quite high but negligible when assessed against the limb AL. However, measurement close to a bent welding cable showed that the lower ALs may be exceeded with certain cable placements, eg with the cable lying over the shoulder.
- Pulsed TIG produced high exposures and in the sitting position the exposure at the operators groin was close to the lower AL (80%).

9.2 Resistance welding processes

9.2.1 Single phase AC resistance welding

- The operator’s body can be exposed to fields close to or exceeding the lower ALs, depending on position (66 to 118%).
- If the operator holds a small component close to the electrodes the limb ALs could also be exceeded (94%).
- The magnetic field is higher to the side than in front of the electrodes, so both body and limb exposures are very dependent on operator position.

9.2.2 Medium frequency resistance welding

- The operator is likely to be exposed to magnetic fields exceeding the lower AL at distances of up to 500mm from the electrodes. Some very high exposures (over 500%) were measured suggesting the upper AL could also be exceeded.
- If the operator holds a component close to the electrodes, or with a large gun actually holds the arms, hand exposures above the limb AL are likely to occur (200%).
- The magnetic field is higher to the side than in front of the electrodes, so both body and limb exposures are very dependent on operator position.

9.3 Stud welding

- Although the current is only flowing for a very short period of time, the magnetic field is high and depending on cable and operator position can exceed the lower ALs (175%)
- Equipment manufacturers recommend that the operator stands between the two current return cables, normally supplied, so that the current is balanced to give a good weld. However, this results in maximum exposure to the magnetic field. It is recommended where possible, that the return cables are diverted away from the welder to the other side of the work piece to reduce the field to below the lower action levels.

9.4 Magnetic particle inspection (MPI)

- Although a process that deliberately generates a magnetic field would be expected to give a high exposure, in practice all measured fields were below the lower ALs, for the types of standard equipment examined (60%). However, it is known that MPI is also carried out by magnetising very large components and in which case, the magnetic field can be appreciably higher.

9.5 Induction heating

- Close to a small induction heating coil, which is typical of that used for brazing, the field was quite high (62%) although the lower AL was not exceeded.
- For a large induction heating coil, as used for preheating components prior to welding, the low action level is likely to be exceeded in operator positions.

10 Implications for Risk Assessments

Based on the measurements carried out on standard welding equipment, it is possible to group the DC arc welding processes together and consider them not to exceed the lower action levels, providing certain considerations are given to best practice set up and use:

- Welders should not stand within a current loop, with a return cable on the opposite side of the body to the welding cable.
- Welders should not wrap or drape any cables around their body, but should route them away from their body. A minimum of 30 cm distance between the welder and the cable (apart from the hand and the feet) should be maintained, which may require special attention where cables are hung from the ceiling and passed by the head.

For AC and pulsed arc welding processes, particularly TIG welding, the lower and limb ALs may be exceeded under certain operating conditions and an EMF exposure assessment may be required.

For stud welding, as long as a distance of 40cm is maintained between the welder and the welding and return cables (except in hand), and the welder is not standing in a current loop, the lower action levels should not be exceeded.

For magnetic particle inspection, using standard equipment, the low action levels should not be exceeded. However, if components are magnetised by wrapping cables around them and applying currents in excess of about 500A an EMF exposure assessment may be required.

Resistance welding equipment, configurations and parameters vary considerably so a general assessment is not possible. An EMF exposure assessment may be required.

Induction heating is also a highly individual process and whilst small coils may generate fields below the low action level, an EMF exposure assessment may be required, particularly for preheating of large components

11 Guidance to Industry

The work carried out in this project has shown whilst many of the commonly used welding processes should not expose welders and operators to high magnetic fields in excess of the action levels (ALs), some process options may lead to the action levels (ALs) being exceeded. Demonstrating that EMF exposure is below the action levels is only one way to demonstrate compliance to the Directive.

A step by step procedure to provide guidance for performing EMF assessments is provided in Appendix C.

Compliance to the low ALs is relatively easy to demonstrate with the right measuring equipment. Typically, an instrument will display a percentage of the low ALs, so the results are easy to interpret. However, if the low ALs are exceeded, it is difficult to assess against the high ALs and the limb ALs because direct reading instruments are not commercially available. Furthermore, compliance to the ELVs can only be demonstrated by calculation or modelling which requires a suitable expensive software package.

Some companies may take the view that it is easier to reduce the magnetic field to which the welder is exposed below the ALs. This work has shown that that the resistance welding

processes are most likely to fall into this category. Many exposures may be border line or just exceed the ALs and simple measures may reduce workers exposure. Simply moving further away from the electrodes can solve the problem, so moving a foot switch, providing a guard or changing the operator's position may be sufficient. However in some cases, more elaborate measures may be required such as holding components in a fixture, rather than by hand or using a robot to hold components whilst welding takes place.

Whilst the use of robot welding lines reduces operator's exposure to EMF, companies need to carry out an assessment for all potential exposure scenarios, such as maintenance operations, training and operation of repair stations.

Appendix A

Literature review

A.1 Background

A literature survey was performed using the TWI "Weldasearch" database, which collates abstracts and keywords from all welding related journals (including those not published in English, which demonstrated in this case that there is some international interest in the EMF around welding, particularly in Poland) and other sources. Any papers published before approximately 2000 were discounted, as they could not be considered in light of either the 2013 or the 2004 Directive.

Almost without exception the literature that has been reviewed has based measurement and conclusions on the ICNIRP 1998 reference levels. These levels are significantly lower than the ICNIRP 2010 and new Directive levels, in the power frequency range.

TWI carried out a series of measurements for the HSE in 2005 as reported in 'Measurement and analysis of magnetic fields from welding processes'. This work showed that the ICNIRP 1998 levels are likely to be exceeded for some welding processes. These conclusions were based on the 2004 version of the Directive, and as such need to be re-examined in light of the 2013 version.

A.2 EMF Characteristics of Electric Welding

Mair (2008) provides an overview of EMF standardisation up to 300GHz. For welding processes, the vast majority of this range is not relevant. The justifications for frequency range limits are given in EN 50444 and EN 50505. Typically, the thermal effects above 100kHz are justifiably discounted. The electric field component around welding is low, due to the low welding voltage. Only the magnetic field needs be considered (except for the manufacturer, who should demonstrate that the electric field is negligible).

Mair claimed, the magnetic fields around welding processes consistently exceed the action values given in the standards. This necessitates a more involved assessment, including current density calculation or simulation.

The welding cable is frequently the main source of exposure, with the field around cables less at the operator's position than fields from other equipment at relevant distances. This means it may be possible to base EMF assessment on the welding current. This was also suggested by Doebbelin et al (2010).

There is a highly non-uniform field around certain welding operations, such as spot welding. This means that the actual field may deviate heavily from the uniform field distribution used to derive action values. It may be possible to use methods based on coupling factors, such as in EN 50505 to avoid overly conservative results. The coupling factors are presumably accounted for in the computational model.

The ICNIRP guidelines provide some information on non-sinusoidal fields, but assessment is complex. EN 50444, EN 50445 and EN 50505 contain specific procedures for welding, but further work is needed.

A.3 Types of Assessment

Mair (2006) briefly discusses the different types of assessment method. There is the conservative summation in the frequency domain, where each frequency component is converted to a percentage of the reference level at that frequency and directly summed. This is generally considered too conservative for welding because it does not take account of phase information.

There is the phase adjusted summation of the frequency domain. Here, the phase of coherent frequency components is taken into account. This is less conservative.

Finally, there is the time domain assessment, which is dependent on how the magnetic field behaves with time, without performing spectral analysis. This method is discussed in EN 50505 and BGV B11. These methods may include subjective approximation or separation steps for different parts of the

signal', such that the different components, eg power source and pulse ripples may not be easy to assess via computational methods.

The preferred method to demonstrate compliance with the limits (based on a calculation performed by Mair) is phase summation of induced current densities by numerical modelling using an anatomical body model. This is a more accurate method, compared with the summation of magnetic flux densities.

A.4 Opinions on the EMF Directive (2004/40/EC)

A number of authors have expressed opinions on the EMF Directive, prior to publication of 2013/35/EU.

Mair, (2008) stated that the Directive is aimed at employers, but 'employers express their expectation to obtain declarations of conformity with all requirements'. It appears that it is going to be necessary to convince employers that they need to perform this testing, or shift responsibility onto manufacturers, which would require a separate legal framework. There is also possibly some confusion over the meaning of the various levels.

Winkler et al., (2007) claims the "reference limits are uplifted greatly by the use of safety factors, which can reach two orders of magnitude, referencing to the 2003 ICNIRP guidelines for compliance". Mair claims that this may result in the banning of resistance welding, but hopes that more accurate modelling of the human body will allow the reduction of these safety factors. Also, these conclusions were based on the action levels of the 2004 version of the Directive. These have now been raised in the 2013 Directive.

The ICNIRP reference levels were derived using basic human models. Recent studies showed that more accurate models allow the reference levels to be roughly three times higher. A better study of non-uniform fields may also allow the reference levels to be raised, without altering the basic restrictions.

Mair believes that the spatial resolution stated in the Directive (2004/40/EC) is too large, not allowing accurate study of the CNS. This appears to have changed since the paper was written. The situation is covered in EN 50444, and has been changed in the updated ICNIRP guidelines.

Doebbelin et al, (2010) examined the various legislative documents regarding the measurement and exposure limits of EMF around welding sources, and offered conclusions and opinions of the current statutory regulations, and their suggestions for alternatives.

They examined the pre-existing standards, EN 50444, EN 50445 and EN 50505. They consider them to be based on obsolete information, due to the long development time of standards and EU directives, and especially believe that EN 50505 is inaccurate for central nervous system (CNS) data. They consider the standards to be overly conservative, especially in relation to resistance welding, due to the 'obsolete' human models used to calculate the reference levels. They say that in contrast EN 50499 and EN 50413 may be very important in future.

Germany has its own legislation, BGV B11, which contains information on the assessment methods of pulsed EMF, which is equivalent to a BS EN, and BGR B11, which puts legislation in place, equivalent to a directive. They believe the BGV B11 contains much more accurate measurement methods for pulsed square wave fields, compared to ICNIRP which compares them to sinusoidal fields. They argue that the limit values should be altered due to their dependence on the waveform, beyond simple frequency dependence.

In response to the standards already in existence, which they felt were restrictive, the Safety in Electromagnetic Fields International Research Association (SEMFIRA) was established. This is a collection of SMEs and research groups, who are arguing for a change in assessment and calculation methods. They may have produced (unclear) an alternative assessment and calculation method, detailed in Forschungs bericht 400-E (available in English).

Winkler et al, (2007) again refer to the German guideline, BGV B11, which is 'different from the ICNIRP guidelines, and seen as an improvement'. They state that the highly inhomogeneous fields around resistance welding equipment mean that the action values could be raised by a factor of 20 compared to the action values for the body without exceeding the basic restrictions. (Currently, the limb AL is 3x the high body AL.) They also state that parts of BGV B11 were included in EN 50505 as an annex, so a comparative study of the two will be necessary.

Levchenko and Levchuk (2008) considered the situation in the Ukraine, and considered in particular the problems that the Directive would introduce for resistance welding processes. They suggested that the most suitable solution to problems associated with resistance welding is a technological one, and considered that manufacturers should provide guidelines with equipment that state which equipment settings are likely to exceed the limits.

A.5 Relative Limits in the Various Legislation

The main guidance on EMF exposure, is that developed by ICNIRP and the IEEE. At the time of writing, Mair, (2008) showed that the reference levels varied between the two standards, with IEEE generally being more lenient. However, ICNIRP refer to values spatially averaged across the whole body, while the IEEE standards refer to spatial maximum. The latest ICNIRP guidelines were used as the basis for the EU Directive. The Directive does not contain assessment methods, so further standards are required, to demonstrate compliance.

Doebbelin et al, (2010) performed magnetic field measurements around a resistance welding machine, and studied the results using both the ICNIRP guidelines and the suggested German method. A fast Fourier transform was performed and study of the frequency spectrum found that the 2kHz harmonic of a 1kHz inverter power supply was the only frequency to exceed the reference levels at a short distance from the machine. They measured the magnetic field at various points from the machine, and calculated minimum safe distance from the machine using the various standards.

It was found that using the straight summation method described in the ICNIRP guidelines produced a safe minimum distance approximately five times greater than that produced when only considering the 2kHz component. They believe this to be overly conservative, though did concede that the guidelines were less conservative when they included the weighting factor for harmonics, also described in the ICNIRP guidelines. In all cases, using the German assessment method provided a minimum safe distance smaller than that of the ICNIRP guidelines using only the 2kHz component.

A.6 Measurement Guidelines

Some guidelines for reproducible, accurate measurements have been specified in the literature, (Boyer, 2006):

- Use a high quality apparatus with 3-dimensional probe.
- Check the probe's calibration regularly.
- Place the equipment being measured as far away as possible from any other potential sources of magnetic fields.
- Carefully define operating conditions of equipment being measured.
- If possible, move away from the measuring area during measurements.
- For mapping magnetic fields around a given piece of equipment, a grid map is recommended to allow easy reproducibility.
- Size of probe must be appropriate. For measurements close to the surface, use a small probe.
- The welding machine's emission time (welding time) must exceed or at least equal the integration time required by the measurement device. The integration time may well be longer than typical welding times.

A.7 Simulation of Magnetic Fields Generated By Welding

Mair, (2006) briefly discussed simulations. For anatomical human models, a knowledge of the frequency spectrum is necessary to study how the body is likely to respond to each frequency component, as the anatomical response is frequency dependent. Models based solely on the magnetic field would need to demonstrate compliance with the reference levels (ICNIRP), which translate to the lower ALs (2013/35/EU). The use of an anatomical model to calculate exposure, will allow the ALs to be exceeded as long as the basic restrictions are not exceeded.

Yamane et al, (2012) performed simulations to study the effect that the presence of a large metal sheet has on the magnetic field around a welding cable. They discussed the fact that EN 50444 does not consider this, but looks at a cable in isolation. The presence of a large metal sheet alters the magnetic field and increase its intensity around the welding cable in certain areas.

Three types of welding cable arrangement were considered, as shown in Figure 1. These were based on a welding cable positioned horizontally, with a 5mm thick I-shaped metal plate either absent, or positioned such that the cable was within either 300 or 100mm of the legs of the L, with one leg of the L on the floor, and the other pointing vertically. A welding current of 100A were passed through the cable, with a square wave pulse, frequency 60Hz, peak current 400A.

This setup was simulated, and the predicted magnetic field is also shown in Figure 1. The results showed that when the cable was positioned at 300mm from the legs of the plate, there was no significant change in the magnetic field around the cable. When the cable was positioned 100mm from the legs of the plate, the magnetic field was significantly altered, and increased.

Desideri et al (2012) studied the current waveform produced by a pulsed MAG set, creating a virtual power source current waveform in MATLAB, and studied multiple variants of current types. They then calculated the harmonic components of these waveforms and calculated the magnetic field that the power source would generate using the Biot-Savart relationship. They then calculated the induced body currents by estimating the torso to a disc with radius 0.2m, calculating the induced body currents both taking account and not taking account of the phase relationship of the harmonics, as described in the various EMF standards (eg EN 50445) and the ICNIRP guidelines.

They then studied the effects that altering the pulse waveform has on the induced body currents seen in the body. Increasing the peak current increased the exposure, and increasing the pulse frequency had no effect when harmonic phase relation was taken into account.

In general, their work will allow an assessment of the induced body currents to be made, but it will always be more conservative than that done by full modelling.

A.8 Measurements Made of Magnetic Fields Generated by Welding

Boyer, (2006) measured the magnetic field along three orthogonal axes around a portable resistance welding device and estimated the induced current density in the body by using a model containing a coupling factor, based on the dependence of magnetic field on distance from the welding device. This resulted in higher magnetic field limits, but still in some cases resulted in the limits being exceeded.

Yamane et al, (2012) measured the magnetic field around a welding cable to validate their simulation. They used the ELT-400 sensor from Narda. They used the instrument with a high-pass filter of 30Hz to avoid geomagnetic effects. They took measurements in a square grid around the welding cable, with separation distances of 100mm (Figures A1, A2 and A3).

The spectra were measured and FFT processed according to EN 50444.

The magnetic field measurements were in good agreement with the simulation. The measurements demonstrated that the magnetic field is greatly increased when the L plate is at 100mm from the cable compared to when the cable is at 300mm from the L plate. With the metal plate present, the reference levels were exceeded up to 300mm from the cable's position, showing welder position and posture is

going to be an important factor in whether equipment passes the test or not. They stated that the central nervous system is not likely to be within 300mm, and so there's not likely to be a problem.

This was based on base and peak currents of 100 and 400A respectively. Increasing the current variation will increase the hazard distance.

As part of an overview of the radiation hazards associated with welding, Marzec (2012) presented some measurements he had made on MAG and TIG welding systems, focusing mainly on electric fields, but with some consideration given to magnetic fields and came to the same conclusions as TWI, with MAG and DC TIG proving safe and pulsed TIG potentially posing a problem in terms of exposure.

Single phase AC resistance spot welding and capacitor discharge welding was briefly studied by Levchenko and Levchuk (2012) who made use of the assessment method described in several of the standards, using a fast Fourier transform to produce a frequency spectrum that can be assessed against the action levels using the non-phase relation harmonic summation method. They found that both processes resulted in exposure to magnetic field strengths greater than the action levels. However, this is the most conservative method of assessment, and shows the importance of an agreed assessment method.

A.9 Health Risks Associated with EMF Generated by Welding

Health risks associated with EMF in general have been mentioned by several different authors, including Beaufils (2000) and McKeown (2007), but typically these have been relatively brief descriptions of the fact that there may be cause for concern and do not contribute in any significant manner to the debate, often simply stating that there is a public debate currently ongoing.

There are several papers that have been produced studying the effect of low-frequency magnetic fields on biological systems, though these have not focused particularly on the field generated around welding, looking primarily at 50Hz, this being the one of greatest public concerns.

The papers produced specifically about welders, by Dasdag et al (2002), Dominici et al (2011) and Hakansson et al (2005) looked at the effects of the magnetic fields on a range of different body systems. They looked at both short and long term effects, by the use of direct observation and review of self-reported data. No strong conclusions were drawn, with the studies typically having very small sample groups (as small as 15 for the Dasdag study), which has introduced uncertainty into the results.

Hakansson et al (2005) studied the relationship between low-frequency electromagnetic fields and cancer, with a particular focus on endocrine cancer. They studied both arc-welding and resistance welding, based on the reported processes the individuals performed. They found a roughly doubling of the rates of endocrine cancer in those who had performed welding relative to those who had not. They could attribute the increase in risk for arc welding, but not for resistance welding, which ran counter to expectations if the cancer is caused by electromagnetic fields, because they are much greater around resistance welding processes. However, it is possible that operators of resistance welding equipment may self-report as operators, but may be standing well away for the field, whereas arc welders are typically close to the current carrying cables. The authors also reported that they had a small sample group, which may have confounded the results. It is also important to consider that while the increase in cancer risk could be stated as not being due to the use of chemical solvents, it could not be separated from other environmental risk factors, such as welding fume.

The Dasdag study looked at the effect of EMF on hematological and immunological systems, and could identify no differences between the welders and the control group that were clinically significant. Their conclusions were that the data suggested that the magnetic fields do not affect these systems.

The Dominici study compared 21 welders to 21 controls, and studied the genotoxic effect of magnetic fields. They performed the study by measuring the magnetic field the welders were exposed to with a personal dosimeter, though it should be noted this would not take account the frequency components of the field, merely the strength. The results showed that there was no alteration to the replication

mechanics of the exposed welders, but did show minor variations in the lymphocytes. However, the small sample size meant the authors believed a larger scale study should be performed.

Marzec (2012) attempted to provide a system for defining a dose of EMF, determined by calculating the product of the square of the field strength and the exposure time. This is based on the Polish system of zoning different regions of magnetic field, in a similar manner to the limb, high and low action levels, with a maximum permissible dose being roughly equivalent to the square of the high action level over an eight hour period. No consideration was given to the frequency components of the magnetic field, though it would be reasonable to make use of the field strength that correlated to the frequency component of the spectrum experienced that had the lowest limit. He also provided a broad overview of the radiation hazards associated with welding, and described the difficulty in making an assessment of the effect of EMF relative to the much easier results of UV or optical radiation exposure, describing the experiments performed to assess the effect, such as the observation of calcium ions in brain tissues.

A.10 Recommendations to Minimise Exposure

The following recommendations are drawn from the literature;

- Maximise distance between welder, power source and welding equipment.
- In electric arc welding, route electrode/torch and current return cables together.
- Do not allow the electrode/torch cable or any electric cable to be wrapped or draped around the body.
- Do not allow the worker's body to be between the electrode cable/torch and any other electric cable. Keep all cables together on one side or the other. (Costa, 2009).

A.11 Standards

There are many European Standards that cover aspects of EMF assessment and the main ones are listed below:

BS EN 50413:2008+A1:2013. Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz).

BS EN 50444:2008. Basic standard for the evaluation of human exposure to electromagnetic fields from equipment for arc welding and allied processes.

BS EN 50499:2008. Procedure for the assessment of the exposure of workers to electromagnetic fields.

BS EN 50505:2008. Basic standard for the evaluation of human exposure to electromagnetic fields from equipment for resistance welding and allied processes.

BS EN 62226-2-1:2005. Exposure to electric or magnetic fields in the low and intermediate frequency range. Methods for calculating the current density and internal electric field induced in the human body. Exposure to magnetic fields.

BS EN 62226-1:2005. Exposure to electric or magnetic fields in the low and intermediate frequency range. Methods for calculating the current density and internal electric field induced in the human body. General.

BS EN 62226-3-1:2007. Exposure to electric or magnetic fields in the low and intermediate frequency range. Methods for calculating the current density and internal electric field induced in the human body. Exposure to electric fields. Analytical and 2D numerical models.

BS EN 62311:2008. Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz - 300 GHz).

These other publications are also relevant;

ICNIRP Guidelines for limiting exposure to time varying electric and magnetic fields (1Hz-100kHz), Health Physics 99(6), pp 818-836, 2010.

IEEE C95.3.1-2010, IEEE Recommended Practice for Measurement and Computations of Electric, magnetic and Electromagnetic Fields with Respect to human exposure to Such Fields, 0Hz to 100kHz.

IEEE C95.6-2002, IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3kHz.

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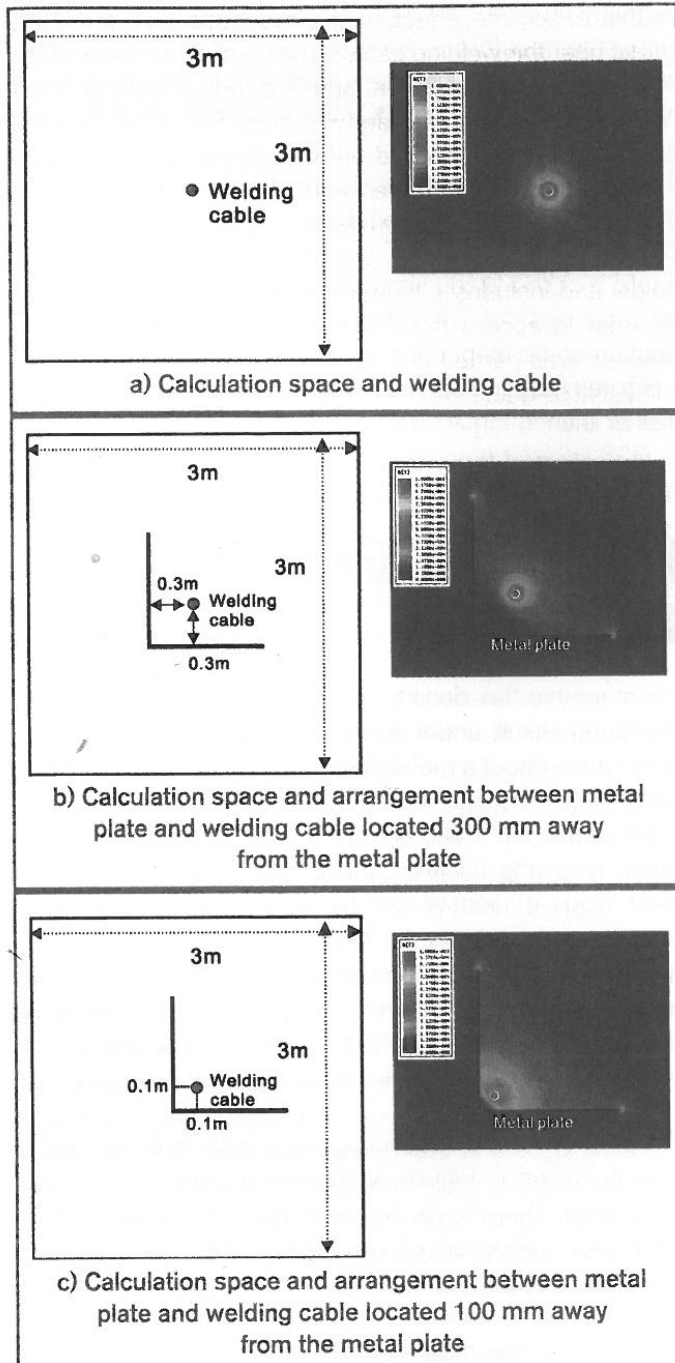


Figure A1 Equipment setup and simulation results (Yamane, et al., 2012).

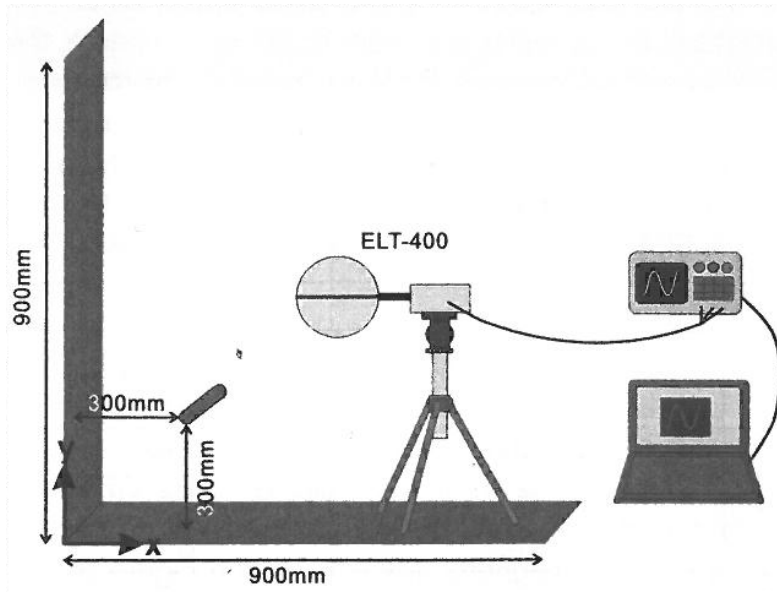


Figure A2 Experimental setup (Yamane, et al., 2012).

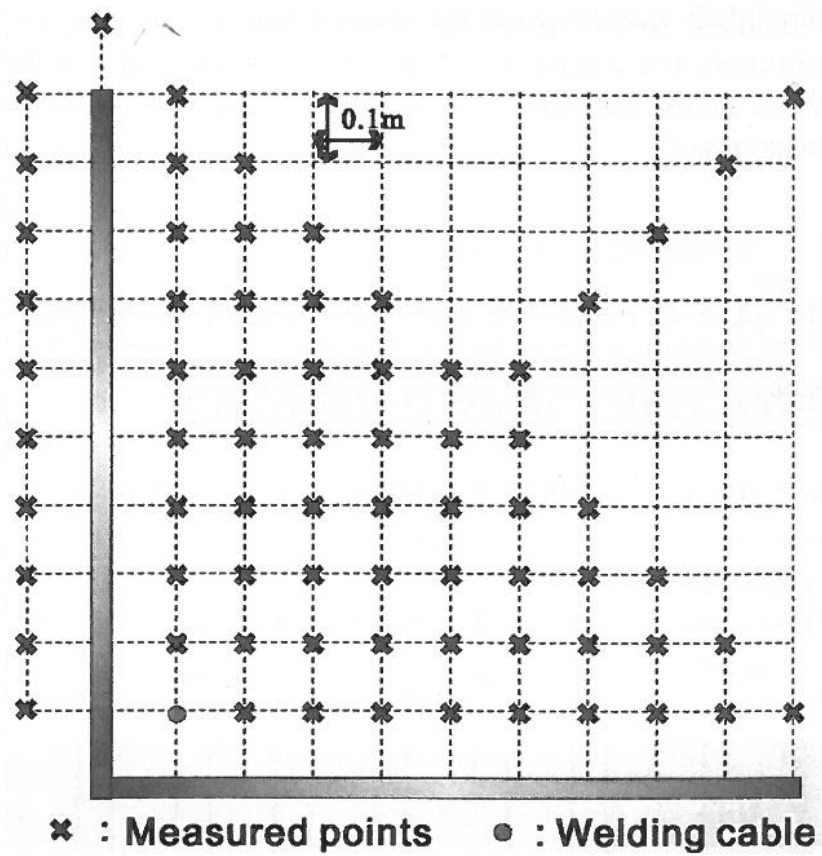


Figure A3 Measurement positions (Yamane, et al., 2012).

Appendix B

Measurements

B.1 Processes

B.1.1 Arc-welding processes

Measurements of the magnetic field were carried out considering the worst case scenario, with a welder standing or sitting at a welding table, with a welding torch in one hand, and the return cable clamped to the work piece next to his other hand. This leaves the welder in a current loop and leads to a typically higher exposure than would be seen during good welding practice.

Welding parameters were chosen by taking the worst case pulsed settings on the power supply (largest variation in current and fast rise time). This was presumed to give a reasonable assessment of a high exposure. The precise welding parameters are given in Table B1.

An assessment was also made relative to the low action levels for AC and pulsed DC TIG based on welding cables slung over the shoulder, which is common but not recommended welding practice. Measurements were made with the welding cable bent at 90 degrees, to simulate bending over a shoulder, and an assessment of the exposure relative to the low action levels was made within the curve, at distances of 10 and 20cm, based on EN 50444. This provided an assessment of the exposure within the head, which has the lowest allowable exposure level.

A typical measurement set up is shown in Figure B1.

B.1.2 Single phase AC resistance spot welding

For a pedestal type spot welder the operator sits or stands in front of the machine holding the material to be welded. However, operator positions around the welding equipment were measured at both the front and the side. This is because the magnetic field experienced at the side of the current loop is rather greater than that in front and occasionally the component geometry and size may require the operator to change position to enable the weld to be located.

Measurements were made on the highest possible welding settings, which corresponded to an RMS current of 10kA. For this particular equipment, this was a transformer 'Tap' of 8 and a 'Phase control' of 100%. However, even at this setting, harmonics were observed in the output. This equipment is shown in Figure B2.

B.1.3 Medium frequency resistance welder

Medium frequency (1 to 4kHz) resistance welding equipment typically has a high output and is used in robotic production lines. Typical welding currents can be as high as 30kA, which is often required to weld aluminium alloys and this is the rated maximum current of the welding equipment examined. Results given here are for using the equipment with an rms current of 30kA.

With such a high welding current the ALs are exceeded much further away from the welding equipment. The exposure relative to the low ALs was therefore assessed at 20 and 50cm from the current loop in order to assess an 'operational window', within which an operator should not be positioned.

This type of equipment is generally used for robotic welding, but EMF exposure may occur at a repair station when the equipment is used manually and during maintenance operations.

In this case, the equipment assessed was mounted on a robot and as such had a wide range of movement. Absolute measurement heights based on the human position were not appropriate, due to the fact that the operator could effectively take a wide variety of positions around the current loop. Measurements are therefore given relative to the current loop. The geometry of the current loop is shown in Figure B3 and the equipment is shown in Figure B4.

B.1.4 Stud welding

The manufacturer of the equipment recommends that optimum welds are produced by welding the stud equidistantly between two ground cables. This results in the operator being placed within a current loop. This scenario was measured, as was the alternative position, where an operator stands outside of the current loop by welding from the opposite side to the ground cables.

Welding was performed using 1600A peak current and a 4ms pulse.

B.1.5 Magnetic particle inspection (MPI)

In this process, conducting samples are magnetized, either by being placed within a magnetic field, or by having a current induced or passed through them. Magnetic field sensitive dyes are then introduced, and the surface of the sample is studied. Often, the operator studies the surface at short distances, so this was taken into account when choosing measurement positions. Three different types of equipment were examined, but the process is also used by wrapping a cable around a component on an individual basis.

B.1.5.1 Toroidal MPI coil

In this process, an alternating current of 600A is passed through a large steel coil at 50Hz, in order to induce a field in a conducting sample placed within the coil. The sample is frequently held within the coil, and so measurement positions were based on this assumption. The equipment is shown in Figure B5. Measurements were made at distances radially out from the coil and along the axis of the coil.

B.1.5.2 Magnetized MPI clamps

Here the sample to be magnetized is clamped in place between two current coils. Either the coils are magnetized to induce a magnetic field in the sample (magnetic flow mode), or a current is passed through the sample to magnetize the sample (current flow mode). The current flow mode consistently generated higher magnetic fields than magnetic flow mode, so measurements were made on that. Typically, the current passing through the sample was approximately 500A. The equipment is shown in Figure B6.

B.1.5.3 Handheld MPI device

This device induces a highly localised magnetic field in a metallic sample by passing current between two prongs. This results in a very localised magnetic field. The measurements were made on the basis of an operator bending close to observe the sample between the prongs to get a realistic assessment of magnetic flux density in the operator's position. The equipment is shown in Figure B7.

B.1.6 Induction heating (brazing)

This process involves a current being induced in a conducting sample, by placing it within a current carrying coil. An AC current at a particular frequency, dependent on the coil geometry and sample, is used. Induction heating is used for brazing and heating components. Two geometries were examined.

The small coil shown in Figure B8 carried a current of 442A alternating at 350kHz. Measurements were made at hand and body positions based on the worst case scenario of an operator holding a brazing rod close to the sample being heated.

Measurements were also made close to a large heating coil wrapped around a pipe section, with a pipe diameter of 600mm and coil wrapped around 350mm along the length of the pipe. A schematic of this is shown in Figure B9. During the steady state operation of the equipment, the power source operated at 9.7kW with an alternating current frequency of 10.5kHz.

B.2 Results

B.2.1 Arc welding processes

The full results for MIG and TIG are given in Tables B2 – B5, but typically, the low action levels are only exceeded in a minority of cases. When the magnetic probe was moved outside of the current

loop, the low action levels were not exceeded. In no cases were the low action levels exceeded during manual metal arc (MMA) welding at a typical current of 150A. A summary of the magnetic field strength around welding cables is given in Tables B6 and B7,

B.3 Resistance Welding Processes

B.3.1 Single phase AC resistance welding

Results of measurement for positions of an operator in front of the welding machine are found in Table B8. For an operator at the side of the machine, results are in Table B9. For these results, the 'hand' measurements are based on a two handed hold either side of the electrodes. So for the operator sitting in front of the machine, the hands are actually either side of the electrodes. For an operator working at the side of the machine, the hands are in front and behind the electrode (relative to the machine geometry).

B.3.2 Medium frequency resistance welding

The window of operation, below the low AL was found to be approximately 50cm in all directions around the current loop. Measurements for each position are given in Table B10.

Hand positions of 10cm had an exposure relative to the limb action levels of 200%.

B.4 Stud Welding

The stud welding process was shown to generate relatively high magnetic fields. The position of the operator was found to have a major impact, with an operator being stood within a current loop experiencing considerably higher magnetic fields than an operator stood outside of the current loop. Despite the positioning of a return cable either side of the welding cable being good welding practice; it is a setup that produces much higher magnetic fields. The full results can be seen in Tables B11 and B12.

B.5 Magnetic Particle Inspection

The magnetic particle inspection process typically involved the operator's head getting very close to the magnetic field generating equipment in order to carefully study the behaviour of magnetic dye. This would be expected to result in the low action levels being exceeded. However, all MPI processes observed were shown to have magnetic field strengths that complied with the low action levels at all positions around them. The magnetic fields were also very localised. A summary of the magnetic field strength around MPI equipment is given in Tables B13 – B16.

B.6 Induction Heating

The smaller induction heating coil possessed a very localised field that did not exceed the low action levels. The factor limiting how close an operator would get to the coil was the temperature generated rather than the magnetic field. A summary of the magnetic field strength around this induction heating equipment is given in Table B17.

The larger coil generated much higher fields, and exceeded both the low and limb action levels. A summary of the magnetic field strength is given in Tables B18 and B19.

Table B1 Experimental setup for studying the magnetic field around arc-welding processes

Process	Process parameters
DCEP MIG	200A welding current, 28V arc voltage
Pulsed MIG	Wire feed speed 13m/min and a 210A welding current
AC TIG	150A peak current, 75% -ve, 120Hz frequency
DC TIG	150A peak current, 75% pulse time, 15A background current, 100Hz pulse frequency.

Table B2 Magnetic field during DC Electrode Positive MIG at 200A welding current, 28V arc voltage, with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	2
Sitting head ~ standing trunk	10	12
Sitting trunk ~ standing groin	20	35
Sitting groin	20	5
Floor	20	2
Hand	10	40 – low AL
Spatial average		16.3

Table B3 Magnetic Field during pulsed MIG at 210A welding current, 13m/min wire feed speed with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	7
Sitting head ~ standing trunk	10	10
Sitting trunk ~ standing groin	20	42
Sitting groin	20	15
Floor	20	5
Hand	10	90 – low AL
Spatial average		19.7

Table B4 Magnetic Field during AC TIG – 150A peak current, 75% -ve, 120Hz switching frequency with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	5
Sitting head ~ standing trunk	10	15
Sitting trunk ~ standing groin	20	50
Sitting groin	20	20
Floor	20	5
Hand	10	16 – limb AL
Spatial average		23.3

Table B5 Magnetic field during pulsed DC TIG - 150A peak current, 75% pulse time, 15A background current, 100Hz pulse frequency with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	15
Sitting head ~ standing trunk	10	30
Sitting trunk ~ standing groin	20	80
	30	50
Sitting groin	20	30
Floor	20	10
Hand	10	90 – low AL
Spatial average		41.7

Table B6 Magnetic field around a straight return cable for various welding processes

Process	Field strength, % low AL at 20cm	Field strength, % low AL at 10cm
MMA, 150A, 4mm electrode	10	30
DCEP MIG – 200A, 28V	20	40
Pulsed MIG – 420A peak current, 1.8ms pulse, 80A background current, 200Hz	40	65
AC TIG – 150A, 75% -ve, 120Hz	70	90
DC Pulsed TIG – 150A peak current, 75% pulse time, 15A background current, 100 HZ	54	80
Stud Welding ~ 1600A, 4ms pulse	180 (77 at 40cm)	-

Table B7 Magnetic field around a bent return cable for various welding processes

Process	Field strength, % low AL at 20cm	Field strength, % low AL at 10cm
MMA 150A, 4mm electrode	20	40
DCEP MIG – 200A, 28V	40	60
Pulsed MIG – 420A peak current, 1.8ms pulse, 80A background current, 200Hz	72	105
AC TIG – 150A, 75% -ve, 120Hz	110	200
DC Pulsed TIG – 150A peak current, 75% pulse time, 15A background current, 100 HZ	60	90

Table B8 Magnetic field experienced by an operator sitting in front of a single phase AC spot welder at 10kA, with centre of current loop at height of 100cm

Measurement position	Horizontal distance from current loop, cm	Field strength, % low AL
Standing head	15	14
Sitting head ~ standing trunk	30	73
	40	40
Sitting trunk ~ standing groin	30	66
Sitting groin	30	14
Floor	30	2
Hand	10	94 – limb AL
Spatial average		51

Table B9 Magnetic field experienced by an operator sitting to the side of a single phase AC spot welder at 10kA. with centre of current loop at height of 100cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	15	21
Sitting head ~ standing trunk	30	118
	40	80
Sitting trunk ~ standing groin	30	98
Sitting groin	30	24
Floor	30	2
Hand	10	94 – limb AL
Spatial average		79

Table B10 Magnetic field strength around a medium frequency resistance welding machine at 30kA

Position	Distance from current loop, cm	Field strength, relative to low action levels, %
Front Corner	20	162
	50	32
Front Middle	20	170
	50	45
Front Electrode	20	210
	50	80
Side Corner	20	217
	50	73
Side Middle	20	525
	50	128
	55	90
Side Electrode	20	426
	50	115
	55	86
	10	200 – limb AL
	20	80 – limb AL

Table B11 Magnetic field strength experienced by a stud welding operator stood inside a current loop with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	0	31
Sitting head ~ standing trunk	20	44
Sitting trunk ~ standing groin	20	175
	40	80
Sitting groin	20	80
Floor	20	20
Hand	10	40 – limb AL
Spatial average		83.3

Table B12 Magnetic field strength experienced by a stud welding operator stood outside a current loop with centre of current loop at height of 80cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	0	20
Sitting head ~ standing trunk	20	30
Sitting trunk ~ standing groin	20	57
Sitting groin	20	30
Floor	20	5
Hand	10	40 – limb AL
Spatial average		35.7

Table B13 Magnetic field strength at radial positions from a toroidal coil with centre of current loop at height of 110 cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	25
Sitting head ~ standing trunk	20	52
Sitting trunk ~ standing groin	20	33
Sitting groin	20	2
Floor	20	0
Hand	5	74 – low AL
Spatial average		36.7

Table B14 Magnetic field strength at positions along the coil axis of a toroidal coil with centre of current loop at height of 110cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	14
Sitting head ~ standing trunk	20	35
Sitting trunk ~ standing groin	20	17
Sitting groin	20	10
Floor	20	2
Hand	5	74 – low AL
Spatial average		22

Table B15 Magnetic field strength around a magnetised clamp magnetic particle inspection system with centre of current loop at height of 110cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	43
Sitting head ~ standing trunk	20	15
Sitting trunk ~ standing groin	20	5
Sitting groin	20	0
Floor	20	0
Hand	10	70 – low AL
Spatial average		21

Table B16 Magnetic field strength around a handheld MPI device with centre of current loop at height of 110cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	10	60
Sitting head ~ standing trunk	20	30
Sitting trunk ~ standing groin	20	15
Sitting groin	20	1
Floor	20	0
Hand	10	29 – low AL
Spatial average		35

Table B17 Magnetic field strength around an induction heating current carrying coil with centre of current loop at height of 110cm

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	0	46
Sitting head ~ standing trunk	20	62
Sitting trunk ~ standing groin	20	16
Sitting groin	20	5
Floor	20	0
Hand	5	90 – low AL
Spatial average		41.3

Table B18 Magnetic field strength at radial positions from an induction heating coil

Measurement position	Horizontal distance from current loop, cm	Field strength relative to low action levels, %
Standing head	20	93
Sitting head ~ standing trunk	30	50
Sitting trunk ~ standing groin	30	50
Sitting groin	30	50
Floor		
Hand		
Spatial average		

Table B19 Magnetic field strength at positions along the coil axis of an induction heating coil

Measurement position	Vertical distance from current loop, cm	Field strength relative to low action levels, %
Standing head	20	350
Sitting head ~ standing trunk		
Sitting trunk ~ standing groin		
Sitting groin		
Floor		
Hand	5	137 – limb AL
Spatial average		

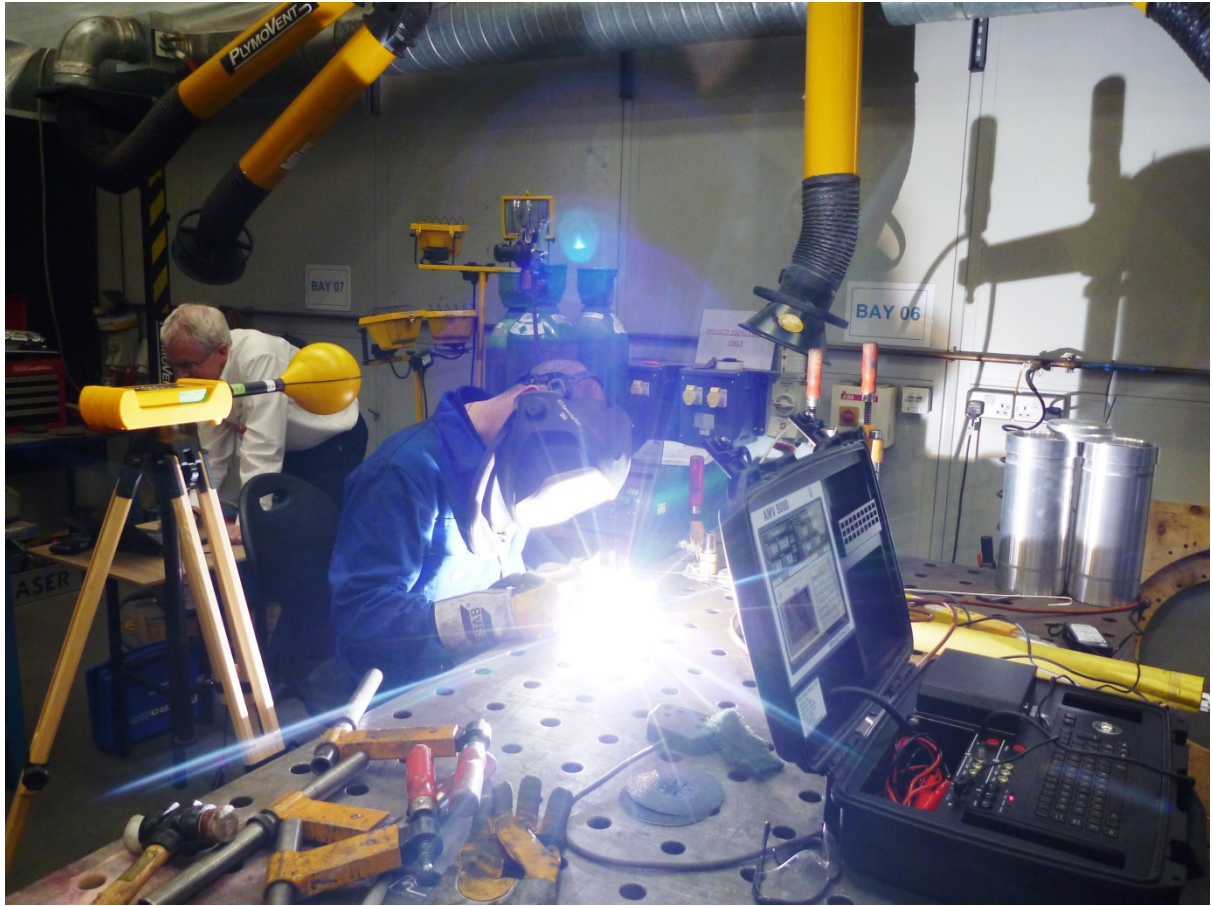


Figure B1 Measurement of magnetic field around arc welding processes.

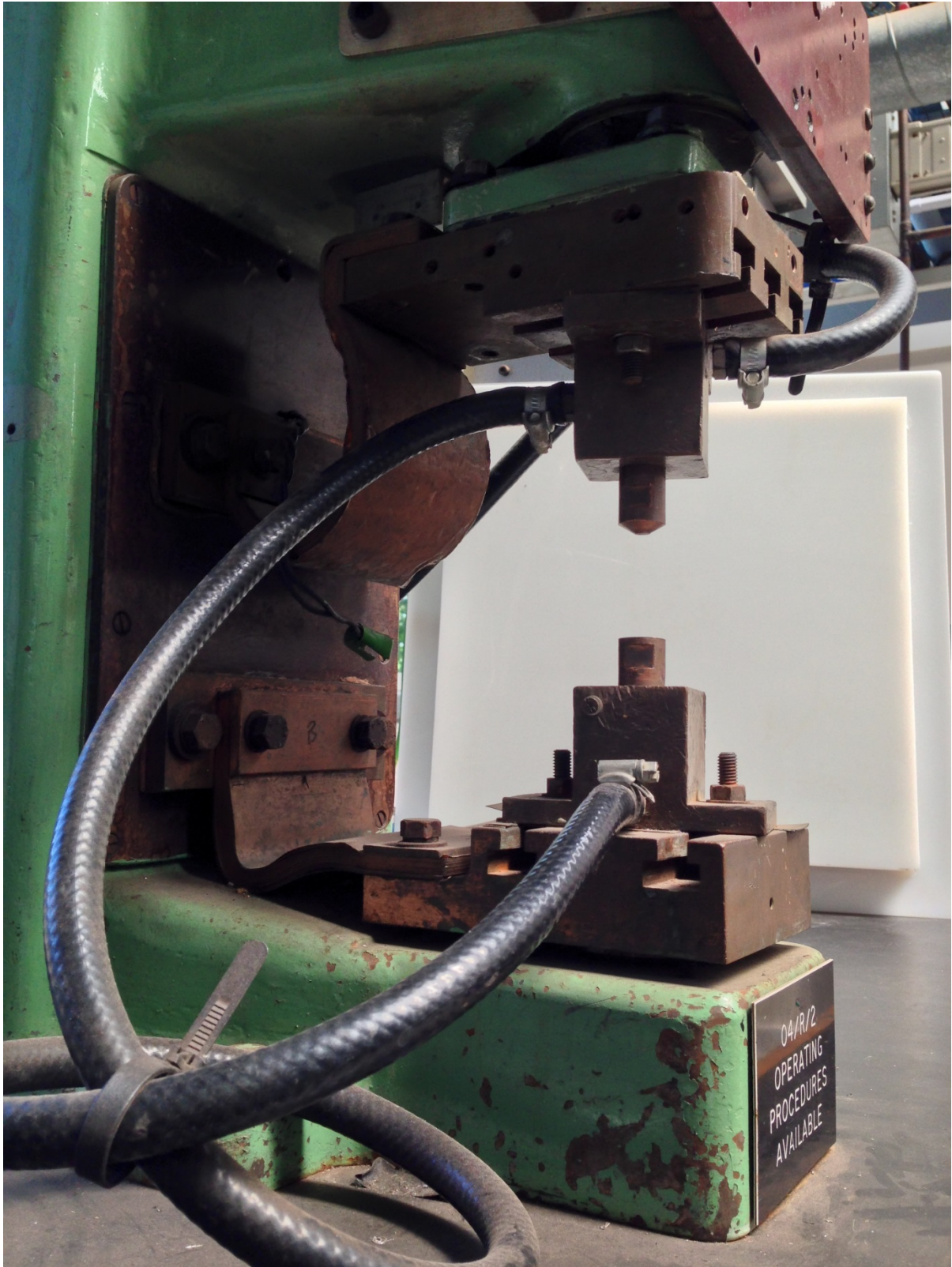


Figure B2 Single phase AC resistance welding machine.

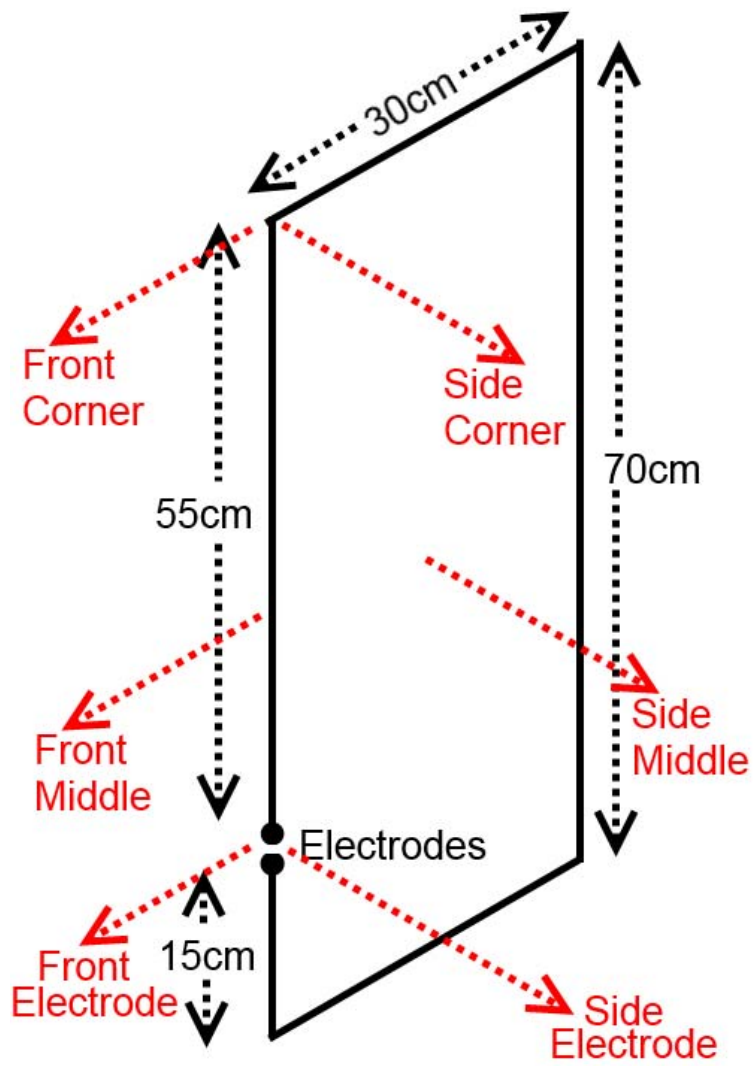


Figure B3 Geometry of medium frequency resistance welding machine.

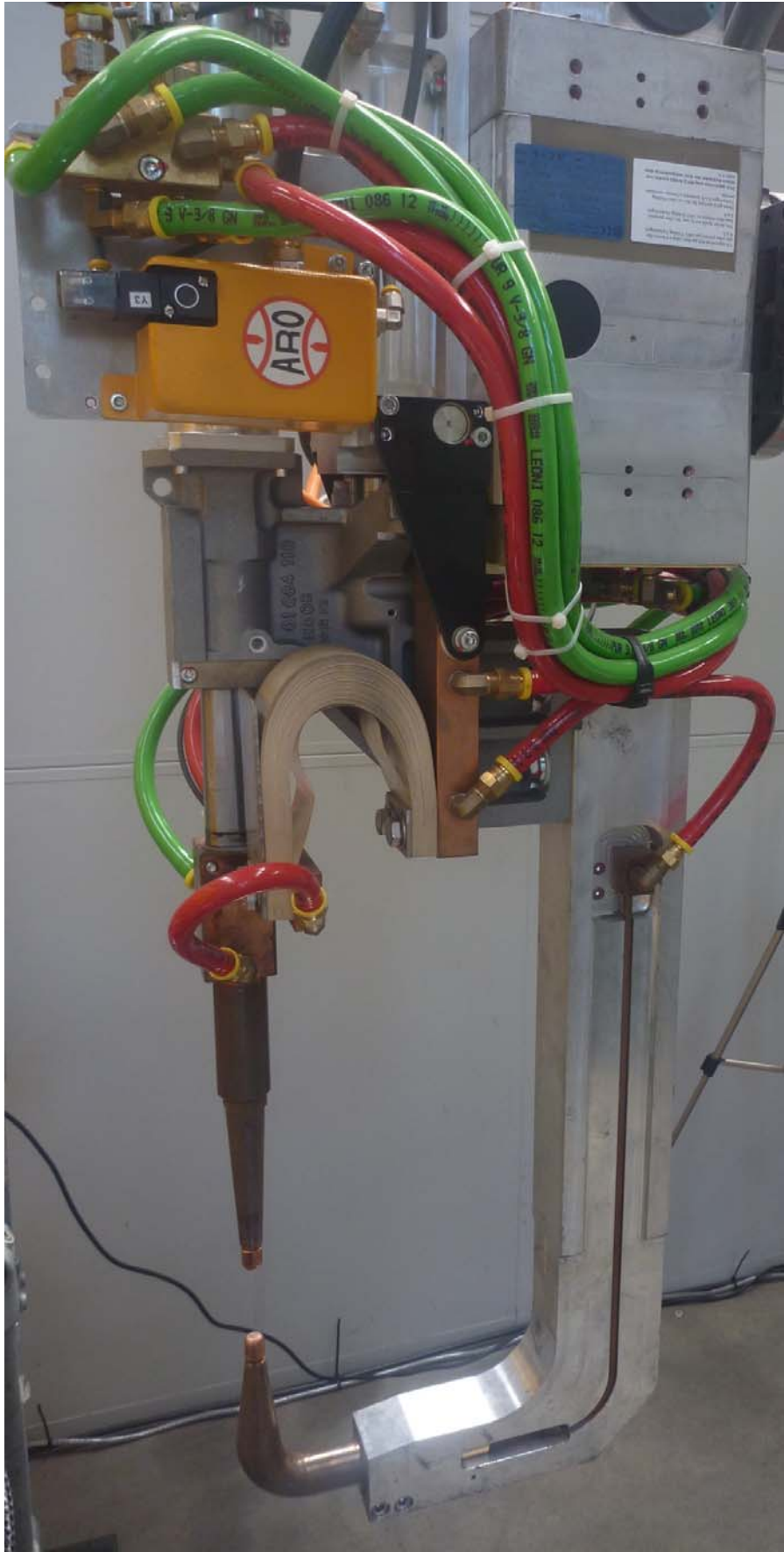


Figure B4 Medium frequency resistance welding machine.



Figure B5 Magnetic particle inspection equipment.

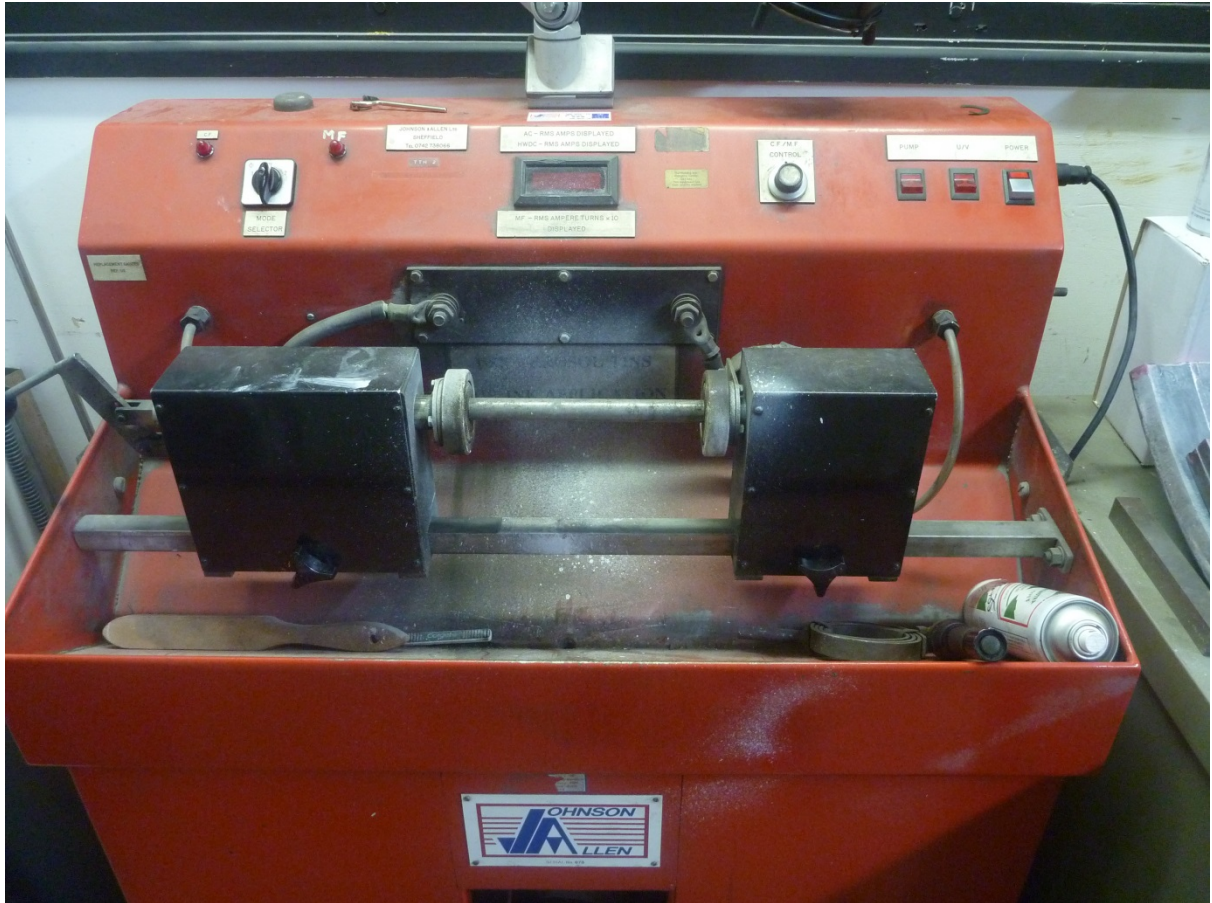


Figure B6 Magnetic particle inspection equipment.



Figure B7 Magnetic particle inspection equipment.

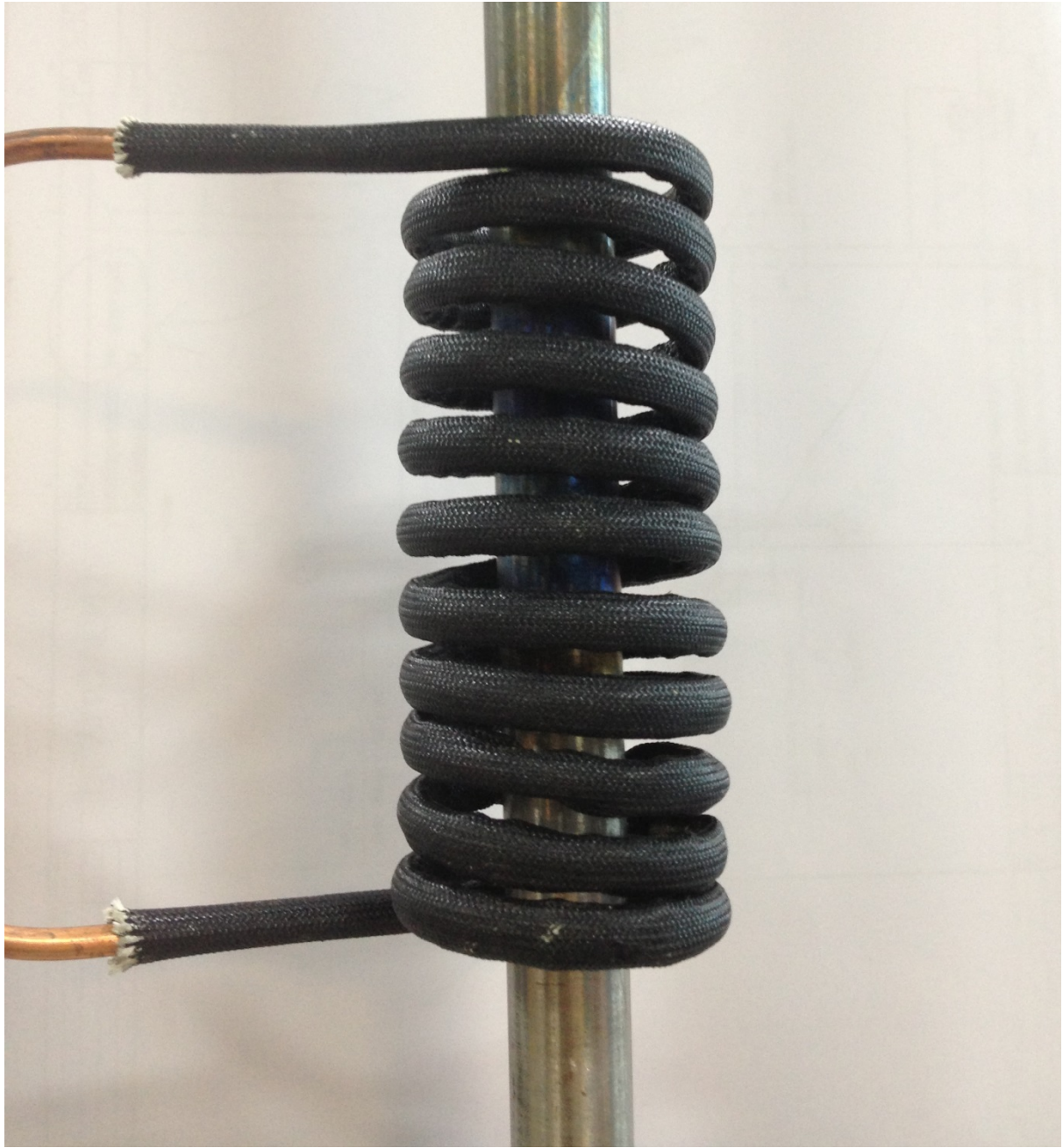


Figure B8 Induction heating coil.

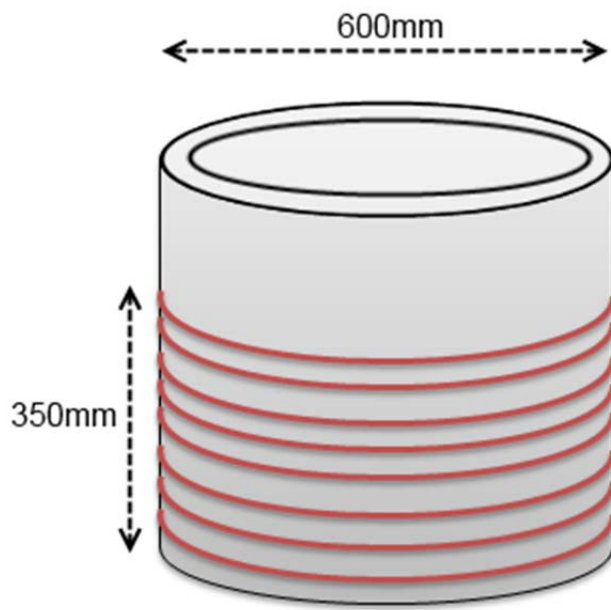


Figure B9 Schematic of current carrying coil used for induction heating.

Appendix C

EMF emission risk assessment procedure

Proposal for an EMF Emission Risk Assessment Procedure

Information

1. Record the relevant administrative information in the assessment sheet.

Process Equipment

2. Identify likely sources of EMF emission from the equipment. Any component that carries current is a possible emitter, such as cables, electrode jaws or transformers/inverters/power sources.
3. Record the geometry of the equipment, or obtain technical drawings to allow easy assessment of the field at positions around the equipment. Take particular note of the position of the current loop.
4. Assemble a grid of measurement points around the equipment in both the horizontal and vertical plane. Where possible, use symmetry to minimise the number of necessary measurement points.
5. Record the output characteristics of the equipment:
 - a. What process is being used?
 - b. What is the maximum current setting/recorded?
 - c. What type of power source, eg power frequency 50 Hz or inverter frequency?

Operation

6. Set up the equipment to generate the highest EMF emission likely to be achieved. This may either be the maximum possible settings of the equipment, or the setting at which the equipment is always used. The assessment will not be valid for operation above these conditions. To obtain the maximum emission, consider the following:
 - a. Difference between peak and background current – maximum
 - b. Pulse rise time – minimum
 - c. Waveshape – as square-like as possible.

Often these parameters will be pre-programmed

7. Perform a simulated or actual welding operation, from start to end.
8. Observe the operator's position during standard operation. Determine the position(s) of the operator's head, trunk and hands during operation.
9. Record the distance of operator's head, trunk and hands from equipment surfaces, and mark these positions on the technical drawings. For equipment with multiple operators, it is recommended to record the position of all operators and use the shortest distance observed.
10. Record the height of the operator's head, trunk and groin during operation. For multiple operators, it is recommended to select nominal heights corresponding to head, trunk and groin, for standing and sitting operators. Heights based on the UK average are given in Table C1. These heights can be deviated from if the true position varies by more than 15cm, eg in magnetic particle inspection, where it is necessary to closely observe the sample surface. In all cases, the height chosen must be recorded.

Measurement Equipment

11. Use a calibrated broadband three-axis probe with frequency response up to 100kHz (for non-thermal effects) and preferably with dependent filtering in time-domain, in order to assess the magnetic field using the weighted peak method described in the Directive against the lower action levels. Append the calibration certificate of the probe to the report where necessary.

12. The probe dimensions must be suitable for the position being measured. The minimum distance from the source of EMF to the centre of the probe is twice the diameter of the probe.

Pre-measurement Checks

13. Set the probe to its least sensitive mode and take exploratory measurements from a distance, changing probe sensitivity and distance to the source. Compare the magnetic field strength to the damage level of the probe to ensure that no damage will occur to the probe. Also perform an initial assessment to ensure that the assessor will not be overexposed to the magnetic field.

Measurement

14. Remove all non-essential metallic items from the measurement area that might interfere with the magnetic field during measurement. Do not stand between the probe and the source of the EMF emission.

15. Place the probe in position corresponding to the operator's head, trunk or groin.

16. The probe must be held stationary in position by a tripod or other suitable stand, which must essentially be non-metallic.

17. Align the probe such that the probe axes align with the magnetic field axes based on the geometry of the current loop.

18. Assess whether it is a short (less than 1 second) or long (greater than 1 second) welding process. For a short process, place the probe in "Max Hold" mode before initiating welding. For a long process, place the probe in "Max Hold" mode once the process has begun.

19. Perform the welding operation.

20. Record the magnetic field strength relative to the lower action levels as shown on the display.

21. Perform the assessment at all points corresponding to operator position.

22. If the lower action levels are exceeded, further assessment is necessary.

Further Assessment Method 1 - Field of operation assessment

23. Perform measurements of the magnetic field strength against the low action levels at positions a specified distance from the source of the emission, using the grid of measurement points established around the equipment. Locate positions at which the magnetic flux density relative to the low action level is 100%. This defines a conservative "field of operation" outside of which an operator will be exposed to a magnetic field below the low action level.

Further Assessment Method 2 – Waveform analysis

24. Use a magnetic probe that records directly the magnetic field strength. Collect the output of this probe with a digital waveform collector, such as an oscilloscope.

25. To assess the exposure against the high and limb action levels, the magnetic field strength, recorded in uT, must be scaled and processed using a simulated filter circuit. Full details on how to do this are included below.

Uncertainty

26. An assessment should be made of the uncertainty of the measurement. There are four major contributors to uncertainty:

- a. Probe position
- b. Probe calibration
- c. Display reading uncertainty

d. Repeatability

27. Guidance should be sought from the probe manufacturer and relevant standards.

28. The uncertainty is considered reasonable provided that it is less than 30% (BSEN 50444). If the uncertainty is greater than 30%, the reason for the higher value must be justified in the assessment report.

Results

29. Report the magnetic field strength relative to the low action levels at either the operator positions or at defined positions around the equipment, specifying a field of operation.

30. Determine whether the recorded magnetic field strength is below the lower action level.

31. The equipment can be described as either:

- a. The magnetic field strength does not exceed the low action level in the operator position.
- b. The magnetic field strength exceeds the low action level in some operator positions. Specific operator training and further, more detailed assessments against the high and limb action levels may be required to ensure workers' exposures are adequately managed (refer to the Directive and Practical Guide).
- c. The magnetic field strength greatly exceeds the low action level, and does so for some distance (greater than 1 metre) from the equipment. Signage and automation may be necessary (refer to the Directive and Practical Guide). A more detailed assessment against high and limb action levels or a direct assessment against ELVs will be required. Work may be allowed to continue subject to certain restrictions (see Article 3(3) of the Directive and the Practical Guide)

32. Example assessment templates are given below.

Table C1 Nominal measurement heights

Measurement Position	Height from ground (cm)
Standing Head	170
Sitting Head ~ Standing Trunk	125
Sitting Trunk ~ Standing Groin	95
Sitting Groin	55
Floor	20
Hand	Selected based on equipment

Assessment of magnetic field against high and limb action levels

To assess the field against high and limb action levels, the magnetic field waveform must be processed through a high pass filter. While this filter could be based on hardware, it is easier to collect the waveform as a digital waveform, eg using an oscilloscope.

The waveform can then be fed through a simulated filter, using digital circuit simulation software.

Filters to process these waveforms to get the assessment relative to the limb and high action levels are shown in Figures 1 and 2. ('Method for assessing magnetic fields from welding against the coming EU directive', Y. Hamnerius et al, BioEM2013, June 2013, Greece.)

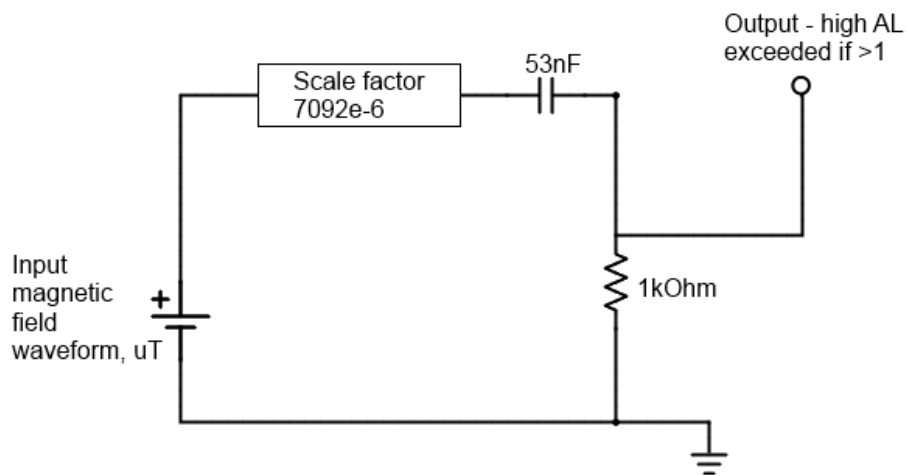


Figure C1 Filter to assess waveform against high action levels.

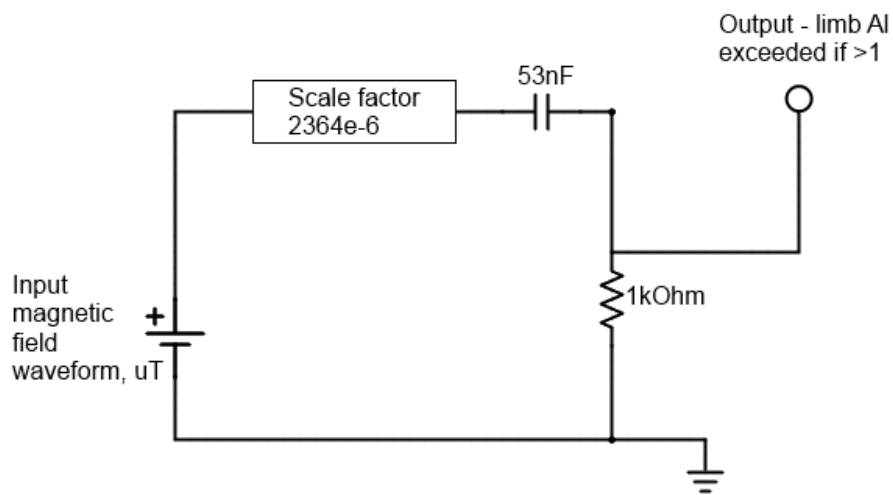
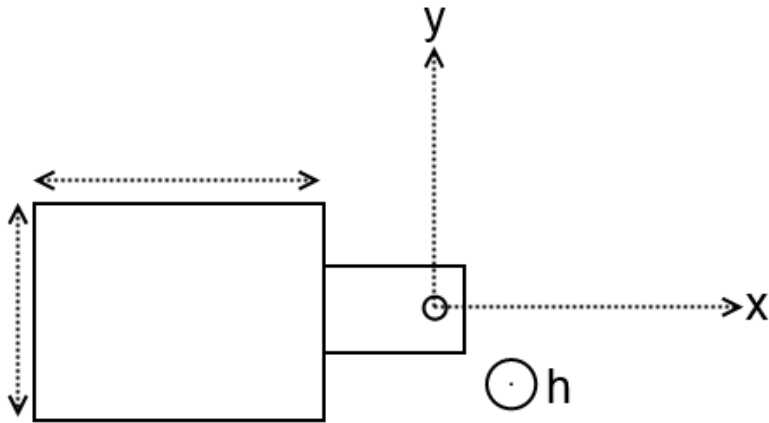


Figure C2 Filter to assess waveform against limb action levels.

Example risk assessment template		
Date		
Organisation		
Site Address		
Operator Name		
Welding Equipment Manufacturer		
Welding Equipment Type		
Model	Serial number	
Rated output of the equipment and frequency		
Process type (eg resistance)		
Procedure		
Maximum Current		
Mapping document number		
Measurement equipment manufacturer		
Model	Serial Number	Date of Calibration
Assessor's organisation		
Levels exceeded?		
Recommendations		
Assessor	Signature	Page ___ of ___



Position (x,y,h) (cm)	Process Parameters	Probe mode	Result (% AL)	Comment
20, 0, 170	10kA, Full wave	Low action level	73%	Operator head

Electromagnetic Fields (EMF) in the welding environment

The Electromagnetic fields (EMF) Directive (2013/35/EU) was adopted in June 2013. Member States are required to bring into force any laws, regulations and or administrative provisions necessary to comply with the Directive by July 1st, 2016. This research report considers various types of welding and the requirements of the Directive.

The report provides:

- A review of available literature using the TWI ‘Weldasearch’ database and other sources
- Measurements of the EMF emissions welders may be exposed to during the welding processes
- Understanding where welding fits in with the requirements of the EMF Directive
- A proposal for an EMF emission risk assessment procedure
- Guidance on compliance for the welding industry

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