Workplace assessment of EMF in welding environment

APPLICATION NOTE

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Application Note
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1. INTRODUCTION

Occupational EMF guidelines, such as the 2013/35/EU directive [1] require employers to ensure that workers are not overexposed to electromagnetic field. This requirement could have an impact on the welding industry and companies using welding processes, where the welding currents are high and welding operators may be significantly close to the equipment.

In welding applications, the main sources of EMF (depending on the welding processes) are usually the welding cables, electrode jaws, transformers, inverters and other power sources or any component that carries current.

As the voltages are relatively low and the welding current is high, the most significant field to be assessed is magnetic field. Measurement of magnetic flux density is relatively straightforward; however, it is important to note that welding waveforms are rarely sinusoidal, and the fields are non-uniform, hence the weighted peak method is the recommended method of assessment.

In this application note, occupational EMF exposure assessments are shown for different typical welding processes to illustrate the normative procedures. Magnetic fields have been measured and compared to the 2010 ICNIRP [2] occupational reference level, which corresponds to the European Directive 2013/35/EU low action level (Low AL), as seen in figure 1. Another very popular limit used is the IEEE C95-1 2019 [3] exposure reference levels for restricted environment.

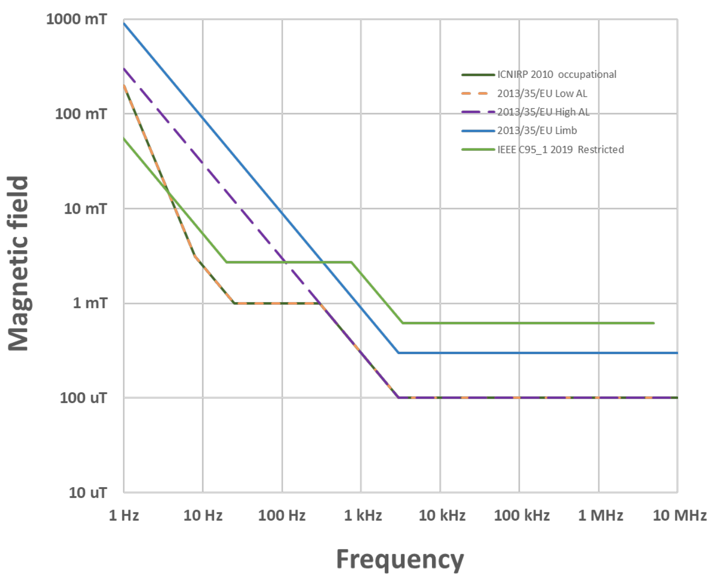

Figure 1. Comparison of EMF limits commonly used

Assessment is done in accordance with the following standards [4 – 7]:

- **IEC/EN 62822-1: 2016** – *Electric welding equipment - Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) - Part 1: Product family standard.*
- **IEC/EN 62822-2: 2016** – *Electric welding equipment - Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) - Part 2: Arc welding equipment.*
- **IEC/EN 62822-3: 2017** – *Electric welding equipment - Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 Hz) - Part 3: Resistance welding equipment.*
- **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 50445: 2008** – *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).*

2. Welding Processes (Manual vs Automatic welding)

There are numerous welding processes which can be categorized into two types: manual and automatic welding. Arc and resistance welding are typically classified under manual welding. However, some resistance welding machines like medium frequency resistance welding can be automated especially when used for production lines. Other welding processes such as laser welding, electron beam welding, friction welding and so on, are mostly fully automated due to safety and operational reasons.

2.1 Manual welding processes

This type of welding processes requires an operator standing or sitting next to the equipment. So, it is important to assess sensitive areas of the body for EMF exposure, for example the head, trunk (also referred to as torso) and limb (see figure 2). The position of the worker (or operator) is an important factor when assessing each welding process.

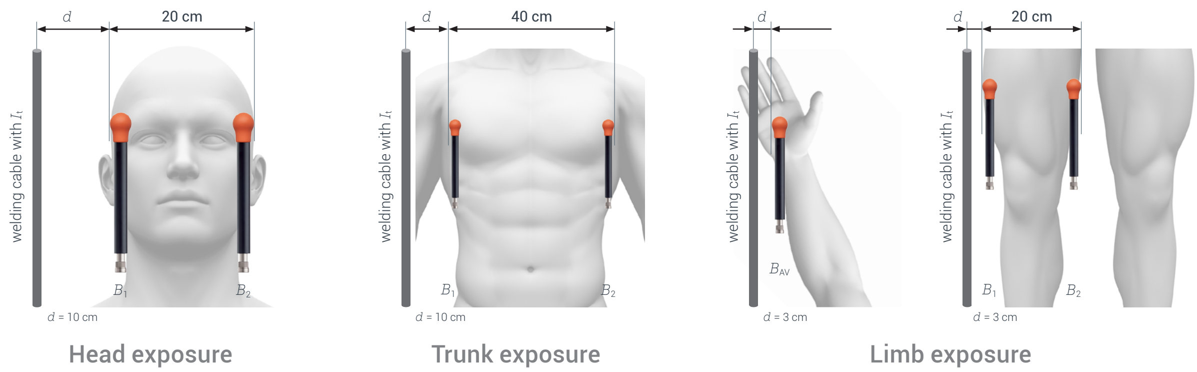

Figure 2. Areas for measuring EMF exposure in manual welding processes

2.2 Automatic welding processes

These welding processes typically do not require an operator and as a result, assessment does not need to be done taking an operator into account. Here, an exclusion zone is made to assess the areas accessible to workers and to individuals classified as "general public" including workers at particular risk (workers who wear active or passive implanted medical devices, such as cardiac pacemakers, workers with medical devices worn on the body, such as insulin pumps, and pregnant workers).During active welding operations, the exclusion areas marked must be respected.

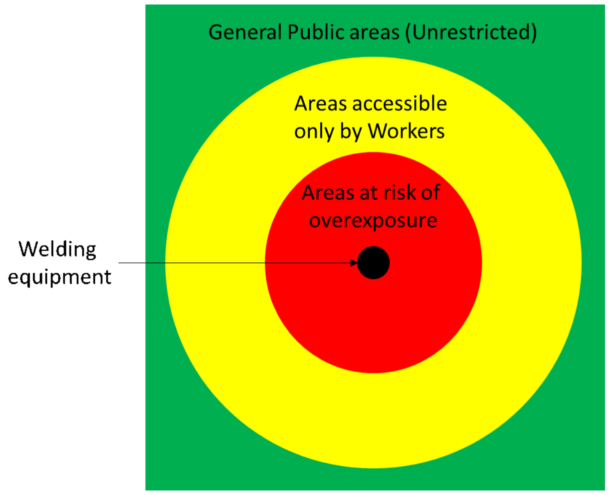

Figure 3. **Exclusion zones**

3. Measurement equipment

According to IEC 61786-1, a measurement instrument must be capable of measuring magnetic fields up to 100 kHz for non-thermal effects. However, welding processes (specified in IEC 62822) generate fields at frequencies up to 10 MHz. Moreover, international standards like ICNIRP 2010, the EU directive and others require EMF assessment for non-thermal effects up to 10 MHz. Therefore, the measurement instrument must be capable of measuring up to 10 MHz to meet these requirements.

The instrument should implement the Weighted Peak Method (WPM) for exposure assessment as this is the best method (recommended by the standards) to assess non-sinusoidal fields which occur very commonly in welding processes. The peak value of the field must be measured.

To facilitate compliance to the normative, it is important that the meter has the relevant limits, embedded in them. For assessment according to the EU directive, the meter should have all three action levels (the Low AL, High AL and Limb AL).

With the new SMP3 from Wavecontrol, LF measurement up to 10 MHz can be achieved to completely cover the complete welding and international EMF standards frequency requirements on non-thermal effects. This meter also allows performing WPM up to 10 MHz to correctly assess the fields correctly within the complete frequency range in welding applications and defined by the EU 2013 directive.

The instrument should also comply with the requirements set by local and international standards (such as IEC 62822, IEC 61786-1 [8] and other relevant national standards like BS EN 50444 and BS EN 50445). These requirements are as follows:

- The instrument should allow for isotopic (triaxial) measurement.

- It should allow for data logging for further evaluation and have an internal battery.
- It should be calibrated for the applied frequency range.
- Operating temperature and humidity range around -10 to 45 ºC and 5% to 95% respectively.
- According to the IEC standard, the probe used for welding applications should have a sensor area of 3 ± 0.6 cm^2. Some standards also accept the probe with a 100 cm^2 sensor area (for example, BSI standard UK).

The SMP series meter and its probes (WP400/WP400-3 or WP10M probes) meet these requirements for EMF assessment in the welding workplace environment, incorporates limits from any region and is delivered with a globally accepted ISO 17025 accredited calibration.

Figure 4. **SMP series EMF meter + WP400-3 or WP10M probe from Wavecontrol**

4. Measurement procedures

To carry out assessment of EMF exposure of workers to welding equipment, it is important to know the characteristics of these equipment and their operation conditions. Therefore, some standard procedures must be followed:

- Gather sufficient information on assessment, for example make a list of all equipment present in building or room to be assessed. Then, identify all EMF emitting sources, which includes areas with welding cables, motors, conductors, or any component that carries current.

- Preassessment of the welding equipment geometry and location of current loop sources to note the relevant measurement points around the equipment. If the equipment has multiple operating modes, assessment should be done for all modes.

- Observe the work environment to monitor the usage and operation of the welding equipment. This should also be done by performing a complete welding operation from start to end. This can be used to determine the typical position, heights distances and movements of both standing and sitting operators during normal welding operation.

- The heights, distances of the head, trunk, groin and hands of the operator from the current loop should be measured. In the present application, the measurement positions used were based on the male average height in the UK of 175 cm and summarized in **table 1**.

Table 1 - Measurement positions and heights used in present study

Measurement position	Condition	Height (in cm) from ground
Head	Standing	170
Head	Sitting	125
Trunk	Sitting	95
Groin	Sitting	55
Hand	Both Standing and sitting	Based on the equipment

Measurement positions are adjusted to accurately perform assessment based on each welding process. In this application, the maximum measured values for each measurement position were taken as the final values. In addition to the assessment of the welding operator, measurements were also taken around straight welding cables to assess the potential exposure of other employees near the welding equipment.

Using the SMP series meter, measurement is done in the following steps:

- Connect the probe and set FIELD to H (Magnetic field measurement)
- To implement the Weighted Peak Method, select the LIMIT depending on the country where measurement is done (In this present example, EU 2013 Directive was used).

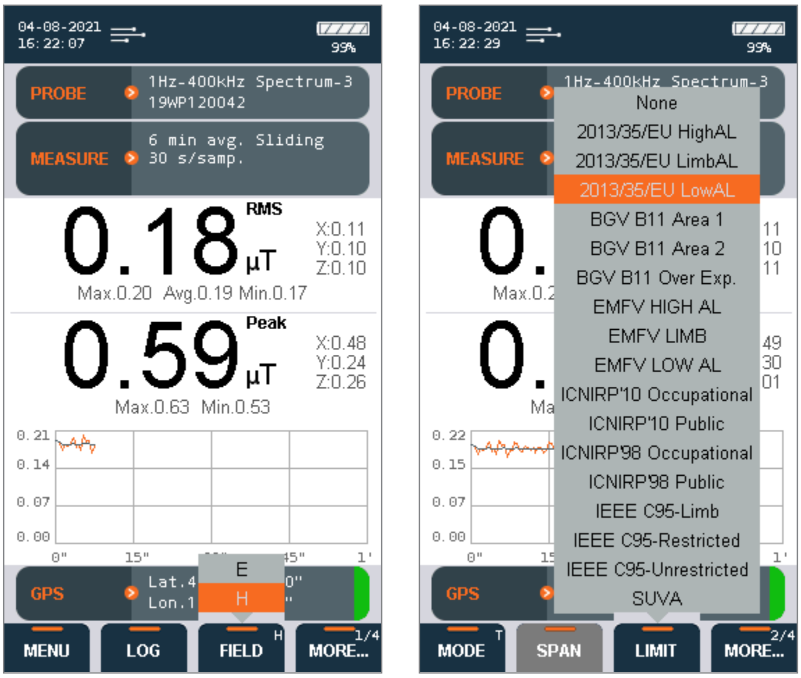

Figure 5. **SMP series meter Menu Selection (a) H field (b) 2013 EU Low ALs**

- In the SMP series meter there are two modes which could be used for welding measurements, TIME mode (temporal information) and FFT mode (frequency information).

- **For FFT mode**
  - Set MODE to FFT.
  - Set HOLD to Max Hold (to keep the maximum Peak, RMS, FFT values).
  - Set SPAN according to frequency range of the welding equipment. Using the WP400 series or WP10M probes, there are four SPAN selections.

Figure 6. SMP series meter Menu Selection (a) FFT mode (b) SPAN (c) HOLD to Max

- **For TIME mode**
  - Set MODE to Time.
  - Set RANGE to Autoincrease (to emulate the Max Hold function in FFT mode).

Figure 7. **SMP series meter Menu Selection (a) Time mode (b) RANGE to Autoincrease**

- Once device settings are ready, ensure that all non-essential metallic items are removed from the measurement area, which might interfere with the magnetic field during measurement. Then, place the SMP series meter at the measurement points as described earlier in the section (Measurement procedures) with the aid of a non-metallic tripod or any other suitable non-metallic stand.

- Take measurement during a normal welding operation by pressing the LOG button to record and save measurement. All measurement results should be document in an assessment report.

NOTE: *In FFT mode, wait till the maximum is no longer increasing before saving the measurement. Also, if the lower action level is exceeded, then assessment should be done with respect to the high action levels.*

4.1 Measurement Uncertainty

Assessment reports usually contain information on the measurement uncertainty. The uncertainty should be calculated taking into account all the potential sources of uncertainty. For more information on uncertainty calculation, please refer to Wavecontrol application note [9].

If the expanded uncertainty is higher than the permissible uncertainty values specified in table

1 of the IEC 62822-1, the method to calculate uncertainty penalties for the applicable limits must be applied [4, 10].

The typical expanded measurement uncertainty of the SMP series meter+WP400 probes for magnetic field is 0.6 dB (or 7.16 %), which is much less than the permissible uncertainty. Therefore, no extra action needs to be taken.

5. Real Measurement Results and Recommendation

5.1 Results

Measurements of the magnetic field for arc-welding processes are carried out with the welding parameters set to the highest pulsed settings on the power supply to obtain the worst-case scenarios. Assessment of the head, body and limb was done for DC, AC and pulsed metal inert gas (MIG) and Tungsten inert gas (TIG) processes.

Measurements were also taken for typical resistance welding processes, for example single phase AC resistance spot welding and medium frequency resistance welding, under the highest possible welding settings. Measurements were taken at different distances to determine best possible work practices for EMF safety during active welding processes. The measurements are given in % with respect to the low action levels. Results below 100% means the assessment test is a PASS ✓ and above 100% is a FAIL ✗.

The measurement results are summarized for both arc welding and resistance welding processes in tables 2 – 5.

5.1.1 Arc Welding

The low action levels were not exceeded for conventional arc welding processes operating in DC mode, for example TIG, MIG and MMA. The maximum exposure measured was 80 % with respect to the low ALs for operator's trunk in sitting position during pulsed TIG welding operation as shown in **table 2**.

Table 2: Magnetic field exposure in % low ALs during arc welding process such as DC Electrode Positive MIG (200 A), pulsed MIG (210 A), AC TIG (150 A) and pulsed DC TIG (150 A) with centre of the current loop at 80 cm height.

Measurement point	Horizontal distance from current loop (cm)	Magnetic field exposure % low AL			
		DC-EP MIG	Pulsed MIG	AC TIG	Pulsed DC TIG
Minimum Head (Standing)	10	2 % ✓	7 % ✓	5 % ✓	15 % ✓
Maximum Trunk (Sitting)	20	35 % ✓	42 % ✓	50 % ✓	80 % ✗

Magnetic field exposure was also assessed around both straight and bent cable during different welding processes. It is seen from table 3 that if there is sufficient distance (for example, 20 cm), the exposure should not exceed the low ALs. However, measurements close to a bent welding or return cable could exceed the ALs with poor cable placements.

Table 3: Magnetic field exposure in % low ALs at 20 cm around welding return cables for pulsed MIG (420 A), AC TIG (150 A) and pulsed DC TIG (150 A) welding processes.

Welding Processes	Field strength as % with respect to EU low ALs at 20 cm			
	Straight return cable		Bent return cable	
Pulsed MIG (420 A)	40 %	✓	72 %	✓
AC TIG	70 %	✓	110 %	✗
Pulsed DC TIG	54 %	✓	60 %	✓

5.1.2 Resistance welding

In single-phase AC resistance welding operations, the body of the operator can be exposed to fields close to or slightly exceeding the Low ALs depending on the operator's position (up to 118%). Hence, it is recommended that welding operations are done in front of the welding equipment as the magnetic field measurements are higher on the sides than in front of the electrodes. The results for magnetic field exposure of an operator, in front or on the side of a single-phase AC spot resistance welding machine at 10 kA with centre of the current loop at 100 cm height, are summarized in table 4.

Figure 8: Reference measurement of a single-phase resistance welding equipment using the SMP series meter

Table 4: Magnetic field exposure in % low ALs during arc welding process such as DC Electrode Positive MIG (200 A), pulsed MIG (210 A), AC TIG (150 A) and pulsed DC TIG (150 A) with centre of the current loop at 100 cm height.

Measurement point	Horizontal distance from current loop (cm)	Magnetic field exposure % low AL	
		FRONT	SIDE
Minimum Head (Standing)	15	14 % ✓	21 % ✓
Maximum Trunk (Sitting)	30	73 % ✓	118 % ✗

Medium frequency resistance welding equipment are very important in automated production lines and can have welding currents as high as 30 kA. Due to the wide range of movement, measurement had to be taken with reference to the position around the current loop, rather than the operator's height. The positions (corner, middle and electrode) from the front and side were measured following the geometry in figure 9B. The maximum values were recorded as seen in **table 5**.

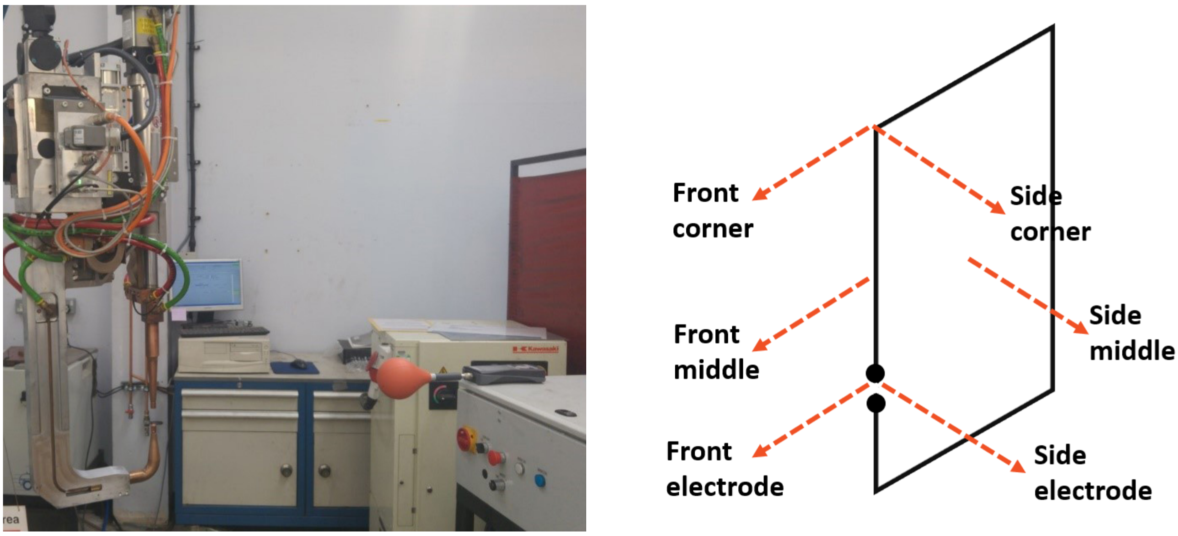

Figure 9: (a) Medium frequency resistance welding machine (b) Measurement positions of the welding machine

Table 5: Magnetic field exposure (% low ALs) around a medium frequency resistance welding machine at 30 kA at 20 cm and 50cm from the current loop.

Measurement point	Magnetic field exposure % low AL	
	20 cm	50 cm
Minimum (Front Electrode)	210 % ✗	80 % ✓
Maximum (Side Electrode)	426 % ✗	115 % ✗

Similarly, it is seen that the measurement results for medium frequency resistance welding are also higher on the side (>400 %) than in front of the electrode (>200 %), see figure 10. The exposure is less than the low ALs with further distance (50 cm) from the welding electrode.

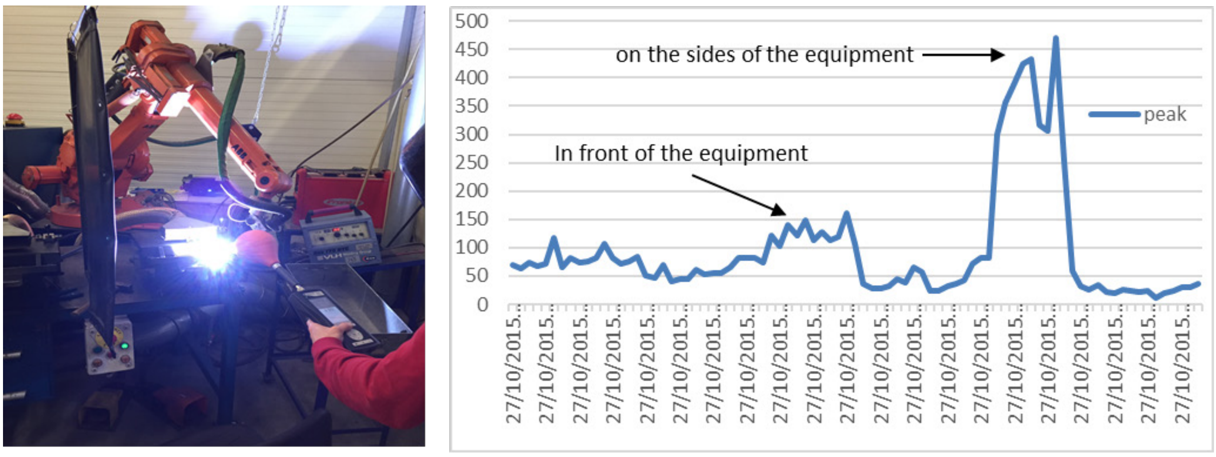

Figure 10: (a) Measurement of an ongoing welding operation (b) Comparison of measurement results in front of the equipment and on the sides of the equipment

5.2 Recommendations

- Measurements are done for the Head, Trunk and Arms/Legs. Initial measurements should be done against the Low ALs and if exceeded (>100% = FAIL), the High ALs must be used to check for compliance. For the arms and legs, the Limb action levels must be used. In case of employees at particular risk, e.g., pregnant workers, or medical devices bearers, the General Public Reference Levels should be used to perform measurement. It is important to use an instrument that implements limits for whole body and limb tissues, such as the SMP series meter.

- An action plan must be taken by the employer in case occupational EMF levels are exceeded (> 100%) in the workplace. For example, marking restricted areas as seen in figure 3. Other actions such as providing proper training and safe working practices to workers near the welding equipment must be provided by the employer as required by, for example, the European Directive.

- Exposure to resistance welding processes is likely to exceed the action levels, however, this can be solved by simply moving away from the electrodes. In arc welding, to minimize the risk of overexposure, the operators should follow certain recommended practices, such as:

  - Operators should not stand within a current loop, with a return cable on the opposite side of the body to the welding cable.
  - No cables (welding or return) should be wrapped around the body of the operators and should be kept at a distance of at least 30 cm away from the operator. Overall, there should be sufficient distance between the operator, power sources and welding equipment.

References

[1] **Directive 2013/35/EU of the European Parliament and Council** on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields).

[2] **ICNIRP 2010 Guidelines** for limiting exposure to time varying Electric and Magnetic fields (1 Hz – 100 kHz), **HEALTH PHYSICS 99(6):818-836; 2010**.

[3] **IEEE C95-1 2019 – IEEE Standard** for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.

[4] **IEC/EN 62822-1: 2016** Electric welding equipment – Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) – Part 1: Product family standard.

[5] **IEC/EN 62822-2:2016** Electric welding equipment – Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) – Part 2: Arc welding equipment.

[6] **IEC/EN 62822-3:2017** Electric welding equipment – Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 Hz) – Part 3: Resistance welding equipment.

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

[8] **IEC 61786-1:2013** Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments.

[9] **Wavecontrol Application Note** on Calculation of the total measurement uncertainty of a field strength meter.

[10] **Wavecontrol Application Note** on EMF Assessment of Welding Equipment.

Acknowledgement

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