

# Measuring Exposed Magnetic Fields of Welders in Working Time

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**Abstract:** The assessment of the occupational electromagnetic field exposure of welders is of great importance, especially in shielded-arc welding, which uses relatively high electric currents of up to several hundred amperes. In the present study, we measured the magnetic field exposure level of welders in the course of working. A 3-axis Hall magnetometer was attached to a subject's wrist in order to place the sensor probe at the closest position to the magnetic source (a cable from the current source). Data was acquired every 5 s from the beginning of the work time. The maximum exposed field was 0.35–3.35 mT (Mean  $\pm$  SD: 1.55  $\pm$  0.93 mT, N=17) and the average value per day was 0.04–0.12 mT (Mean  $\pm$  SD: 0.07  $\pm$  0.02 mT, N=17). We also conducted a finite element method-based analysis of human hand tissue for the electromagnetic field dosimetry. In addition, the magnetic field associated with grinders, an air hammer, and a drill using electromagnetic anchorage were measured; however, the magnetic fields were much lower than those generated in the welding process. These results agreed well with the results of the electromagnetic field dosimetry (1.49 mT at the wrist position), and the calculated eddy current (4.28 mA/m<sup>2</sup>) was much lower than the well-known guideline thresholds for electrical nerve or muscular stimulation.

**Key words:** Welding, Magnetic fields, Electromagnetic field dosimetry, Eddy current, Welding current

## Introduction

Approximately 220,000 people are engaged in welding operations in Japan. However, the possible adverse effects of electromagnetic fields (EMFs) generated in welding processes are of great importance because welding uses relatively high electric currents of up to several hundred amperes<sup>1–3</sup>.

The coupling of low-frequency magnetic fields and the absorption of energy from EMF is a basic mechanism through which time-varying electric and magnetic fields interact directly with living matter<sup>4–7</sup>. In the physical interaction of a time-varying magnetic field with a human body, electric fields and circulating elec-

tric currents are induced inside the body. The magnitudes of the induced field strength and current density are proportional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change in the magnitude of the magnetic flux density<sup>7, 8</sup>. These currents can stimulate nerves. Exposure to an EMF at a frequency greater than ~100 kHz can cause a considerable absorption of energy and a temperature increase. Because the biological effects of EMF depend on the field properties, characterization of the frequencies and the magnetic field strength is essential. The field properties in welding depend on the process (e.g., shielded-arc welding, tungsten inert gas (TIG) welding, metal inert gas (MIG) welding, etc.) and the capability of the power source (DC, sinusoidal AC, rectangular wave, etc.)<sup>1, 3</sup>. In typical welds, low-frequency components that are lower than 1 kHz are dominant, although some-

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times high frequencies between several kilo to mega Hz exist due to the ripple currents generated by the welding power source<sup>1)</sup>.

So far, a number of reports and guidelines on EMFs have been published<sup>7, 9)</sup>. The exposure guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)<sup>7)</sup> and the threshold limit values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH)<sup>9)</sup> are widely accepted in Japan. There have been several reports containing the measurements of magnetic fields for arc welding<sup>1, 10)</sup>. A review of the literature indicates that the ICNIRP reference levels for magnetic fields may be exceeded in both arc and resistance welding<sup>1, 3)</sup>. One report shows that for most arc welding processes, the ICNIRP reference levels are not exceeded unless the measurement is taken close to the welding cable, i.e., 10 cm, but for manual welding the reference level would be exceeded at the welder's hand<sup>1)</sup>.

Considering the results of this previous report<sup>1)</sup>, the present study focused on the local exposure to the magnetic field at a welder's hand to investigate the actual exposure level at the position closest to the magnetic source, which in this study was the cable from the current source. Electromagnetic field dosimetry was performed to compare the results of the magnetic fields in the workplace and to calculate the eddy currents induced in a subject's wrist by the welding processes.

## Material and Methods

### Measurement of welding currents

The welding currents were obtained by a current probe (PR430: LEM, Measuring range  $\pm 60$  A and  $\pm 600$  A, frequency range: DC to 20 kHz) and a data logger (8807: HIOKI, sampling rate: 8–400 kHz). Fast Fourier Transform (FFT) analysis was performed to show frequency components of welding current.

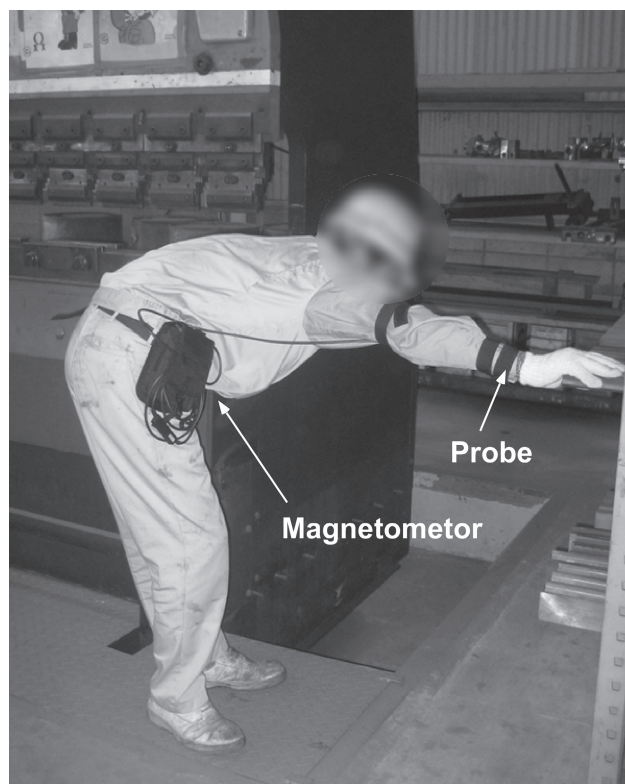
### Electromagnetic field dosimetry

We used a finite element method (FEM) –based analysis for the electromagnetic field dosimetry<sup>11)</sup>. A two-dimensional human wrist model consisting of five tissues with different conductivities was developed. The conductivities of the tissues were obtained from the database of electric properties developed by Gabriel *et al.*<sup>12, 13)</sup> (skin dry:  $2.000 \times 10^{-4}$  S/m, muscle:  $3.001 \times 10^{-1}$  S/m, bone:  $2.008 \times 10^{-2}$  S/m, blood vessel:  $3.005 \times 10^{-1}$  S/m, and nerve:  $2.829 \times 10^{-2}$  S/m). It was assumed that the relative magnetic permeabilities of all the tissues were 1.0. The model was constructed with a resolution of 2 mm and the number of elements was 37,500. The wire was placed at 6–20 mm from the

wrist model. The results were obtained using a computer program (PHOTO-Series: PHOTON Co., Ltd.). The electric current applied to the wire had an intensity of 15 A, 300 Hz, which resulted in a magnetic field intensity of 2.71 mT at the wire element.

### Measurement of magnetic field at the workplace

To measure the actual workplace, 22 subjects (welders: 17 people and office workers: 5 people) were selected from five industrial companies and two research institutes in Japan. Magnetic field data was acquired every 5 s by the 3-axis Hall magnetometer (THM1176: Metrolab, measuring range: 8.0 mT, frequency range: DC~1 kHz) at a 2.048 kHz sampling rate. The sensor probe was attached to the subject's right wrist (Fig. 1) and measurements were taken throughout the working time (approximately 8 h except for lunch time). Welders (17 people) were mainly engaged in welding operation, however, other work contents (cutting, polishing, hole-drilling, and crane operation) were also included. These electromagnetic field sources (drill, grinder and air hammer) were also recorded individually using the same protocol. Office workers were mainly engaged in clerical works using personal computer operation (PC operation). The background magnetic field (MF) level



**Fig. 1. Measurement of magnetic field at the workplace.**

Magnetic field data was acquired by the 3-axis Hall magnetometer and the sensor probe was attached to the subject's right wrist.

was measured for 5 min before starting operation at each working place and data was averaged.

## Results

### *Electromagnetic field dosimetry*

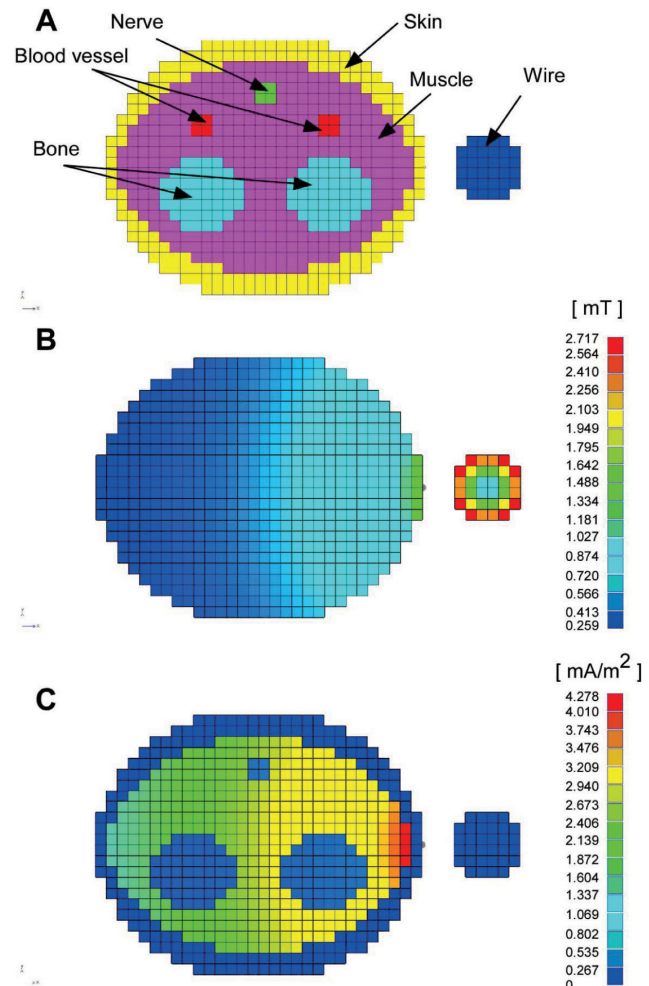
Figure 2 shows the results of the electromagnetic field dosimetry. The maximum magnetic flux density in the model was 1.49 mT. The maximum induced eddy currents were 4.28 mA/m<sup>2</sup> and each value was observed in the muscle in the model (Table 1).

### *Measurement of magnetic field at the workplace*

Each subject's belongings, work contents, maximum and average exposed magnetic fields, and other electromagnetic field (EMF) sources (drill, grinder and air hammer) are shown in Table 2. The maximum exposed field throughout the working time varied between 0.35–3.35 mT (Mean  $\pm$  SD: 1.55  $\pm$  0.93 mT, N=17), and the 1-day average exposed field was 0.04–0.12 mT (Mean  $\pm$  SD: 0.07  $\pm$  0.02 mT). The average of back ground level was 0.05 mT. Welders were exposed higher magnetic fields than those of office workers (Maximum exposed field: 0.07–0.09 mT, Table 2). Since welders were also engaged in other work contents (cutting, polishing, hole-drilling, and crane operation), these other electromagnetic field sources (drill, grinder and air hammer) were recorded individually to compare the strength of MF to that of welding. However, these magnetic fields were much lower than those of the welding process (Table 3). Figure 3 shows a typical welding current observed in the current study. Time-varying (AC) component with static (DC) bias and several irregular peaks were observed. FFT analysis of typical welding current showed an obvious peak at DC and a small peak at 300 Hz due to DC bias in the original source (Fig. 4A). Then DC filtration was performed in order to evaluate AC components of the source. Visible peak was observed at 300 Hz and harmonics were shown up to 2 kHz in DC-filtered source (Fig. 4B).

## Discussion

In the present study, we performed the measurement of the local MF exposure at welders hand position to investigate the actual exposure level at the position closest to the magnetic source, which in this study was the cable from the current source. We used 3-axis Hall magnetometer which has a acquisition capability in DC-1 KHz because low-frequency components that are lower than 1 kHz are dominant in the typical welds. Relatively high transient MF exposure was observed throughout the working time of welders (0.35–3.35 mT,



**Fig. 2. Electromagnetic field dosimetry.**

A: Numerical model with 2 mm section. B: Induced magnetic field density in a model. C: Induced eddy current in a model.

**Table 1. Electromagnetic field dosimetry by FEM analysis showing the maximum induced eddy currents in the model**

Distance from the wire	Maximum induced eddy current [mA/m <sup>2</sup> ]	
	Whole model	Tissue name
6 mm	4.28	Muscle
10 mm	3.80	Muscle
20 mm	3.17	Muscle

Mean  $\pm$  SD: 1.55  $\pm$  0.93 mT, N=17), however, the one-day average (0.04–0.12 mT, Mean  $\pm$  SD: 0.07  $\pm$  0.02 mT, N=17) was mostly same to the background level (0.05 mT).

Since the transient high (-mT) MF exposure may induce the electrical stimulation in low frequencies (<100 kHz), electromagnetic field dosimetry was performed to calculate the magnetically-induced eddy current inside the tissue. The electrical condition was

**Table 2. Measurement of magnetic field at the workplace**

Subject No	Company	Work contents	Max exposed field (mT)*	Average exposed field (mT)**	Other EMF sources***
1	A	Shielded-arc welding	2.79	0.05	Grinder
2	A	Shielded-arc welding	3.35	0.08	Grinder Drill#
3	A	Shielded-arc welding	1.44	0.05	Grinder
4	A	Shielded-arc welding	1.67	0.07	Grinder Drill#
5	A	Shielded-arc welding	0.99	0.07	Grinder
6	A	Shielded-arc welding	2.42	0.07	Grinder Drill#
7	B	TIG welding / Rectangular wave	0.6	0.04	Grinder
8	B	TIG welding / Rectangular wave	0.35	0.05	Grinder
9	C	Shielded-arc welding	0.59	0.12	Air hammer
10	D	Shielded-arc welding	0.81	0.07	Grinder Drill#
11	D	Shielded-arc welding	1.00	0.07	Grinder Drill#
12	D	Shielded-arc welding	0.85	0.06	Grinder Drill#
13	D	Shielded-arc welding	3.05	0.08	Grinder Drill#
14	E	Shielded-arc welding	1.70	0.10	Grinder
15	E	Shielded-arc welding	2.18	0.05	Grinder
16	E	Shielded-arc welding	0.74	0.05	Grinder
17	E	Shielded-arc welding	1.77	0.07	Grinder
18	F	PC operation##	0.07	0.06	PC
19	F	PC operation##	0.09	0.06	PC
20	F	PC operation##	0.07	0.06	PC
21	F	PC operation##	0.09	0.05	PC
22	F	PC operation##	0.08	0.06	PC
23	-	Background level	0.06	0.05	-

\*The highest value of exposed field throughout the measurement, \*\*Average of exposed fields throughout the measurement, \*\*\*EMF source except for welding process, #A drill using electromagnetic anchorage, ##Personal computer (PC) operation.

**Table 3. EMF sources in the work place**

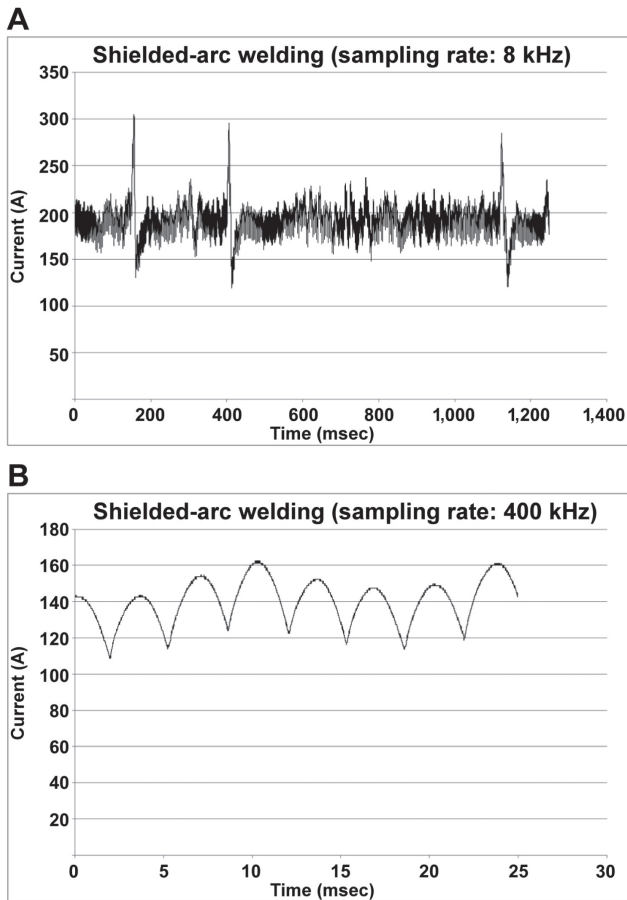
Max exposed field (mT)	
Welding	8.69
Grinder	1.01
Drill*	1.70
Air hammer	1.68

\*A drill using electromagnetic anchorage.

set as 300 Hz, 15A based on the FFT analysis of the welding current (Figs. 3 and 4). The results (1.49 mT at the wrist position, Fig. 2) agreed well with the results of those of the workplace (Table 2), and the calculated eddy current (4.28 mA/m<sup>2</sup>, Table 1).

The thresholds of neuronal stimulation lower than 100 mA/m<sup>2</sup> were derived from other studies of the visual and mental functions in human subjects. Changes in the response latency for complex reasoning tests were

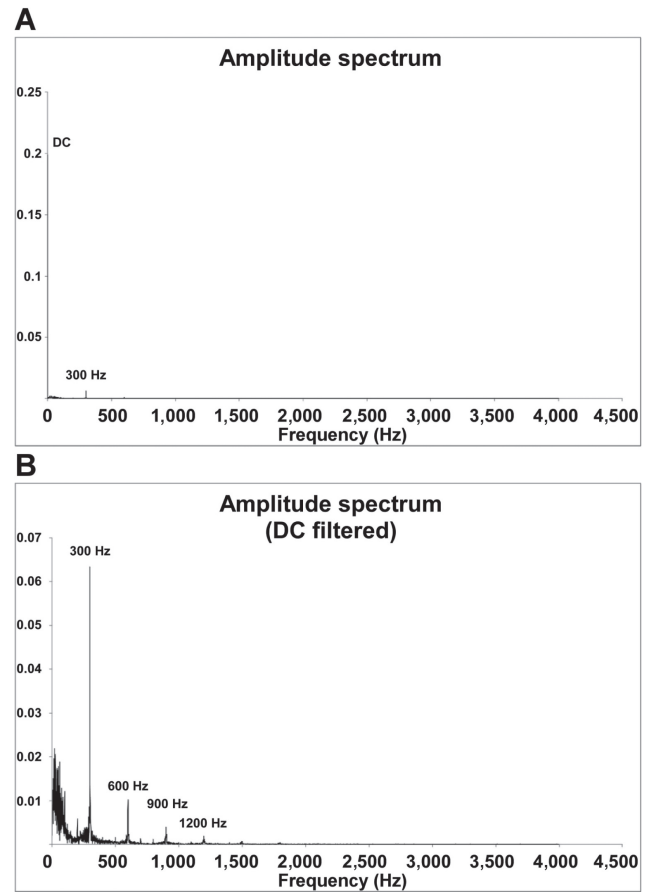
reported in individuals subjected to weak power-frequency electric currents passed through electrodes attached to the head and shoulders, for which the current densities were estimated to be between 10 and 40 mA/m<sup>2</sup> (14, 15). Also, many studies have reported that subjects experienced faint flickering visual sensations, known as magnetic phosphenes, during exposure to extremely low frequency (ELF) magnetic fields above 3–5 mT<sup>16</sup>. At 20 Hz, current densities of approximately 10 mA/m<sup>2</sup> in the retina have been estimated as the threshold for the induction of phosphenes; this level is above the typical endogenous current densities in electrically excitable tissues. Higher thresholds have been observed for both lower and higher frequencies<sup>17, 18</sup>. However, the maximum induced eddy currents in the present study were shown to be 4.28 mA/m<sup>2</sup> (4.28 × 10<sup>-4</sup> mA/cm<sup>2</sup>) (Table 1). Therefore, these results indicate that magnetically induced eddy currents in the present study are lower



**Fig. 3.** Typical waveforms of welding currents of the present study. A: Welding current of shielded-arc welding (sampling rate: 8 kHz). B: Welding current of shielded-arc welding (sampling rate: 400 kHz). AC component with DC bias and several irregular peaks were observed.

than the guideline thresholds for neuronal and muscular stimulation. And this value did not exceed the basic restriction of ICNIRP guideline (300 Hz, 10 mA/m<sup>2</sup>). Cardiovascular systems were also considered to be sensitive to electric stimulation. However, experimental studies of both short-term and long-term exposure indicate that, while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with low frequency fields are unlikely to occur at exposure levels commonly encountered environmentally or occupationally<sup>4</sup>).

Evaluation of the EMF exposure level based on frequency components was essential since the exposure guidelines published by ICNIRP<sup>7</sup>) or ACGIH<sup>9</sup>) give the reference levels or TLVs for the magnetic field according to the frequencies. As both ICNIRP and ACGIH provide separate guidelines for static (DC) and time-varying (AC) magnetic fields, the DC and AC components of the data must be assessed individually if the acquired data contains the overlapping DC/AC signal



**Fig. 4.** Fast Fourier Transform (FFT) analysis of the welding current.

A: FFT analysis of the original source. B: FFT analysis of DC-filtered source. An obvious peak at DC and a small peak at 300 Hz were shown in the original source (Fig. 4A). Visible peak was observed at 300 Hz and harmonics were shown up to 2 kHz in DC-filtered source (Fig. 4B).

(Fig. 3A). The maximum magnetic field of the DC/AC superimposed signal was 3.35 mT (Table 1) and this value was lower than the widely accepted guidelines for the static (not time-varying) magnetic field: ICNIRP guidelines (8 T, occupational)<sup>19</sup>) and ACGIH (20 T (ceiling value), limbs)<sup>20</sup>). Further analysis using exposure level tester (e.g., Narda ELT-400) is necessary to evaluate assess the compatibility evaluation for the ICNIRP and ACGIH exposure guidelines of AC component.

## Conclusion

The present study focused on the local exposed magnetic field at a welder's hand to investigate the actual exposure level at the position closest to the magnetic source, which was a cable from the current source. The maximum exposed field was 0.35–3.35 mT (Mean ± SD:

1.55 ± 0.93 mT, N=17) and the average value per day was 0.04–0.12 mT (Mean ± SD: 0.07 ± 0.02 mT, N=17). From the result of the electromagnetic field dosimetry, 1.49 mT of the magnetic field induced an eddy current of 4.28 mA/m<sup>2</sup> at the wrist, and this value was much lower than the well-known thresholds for electrical stimulation of a nerve or a muscle reported in the guidelines.

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