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Original Article

일부 용접공의 극저주파 자계노출평가

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Exposure Assessment of Welders to Extremely Low Frequency Magnetic Fields

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ABSTRACT

Objectives: This study was conducted to investigate the patterns of exposure of welders to strong magnetic fields for extended periods of time on the basis of their daily activities as recorded in a logbook.

Methods: Male workers whose main job is welding, specifically seven welders occupied with gas tungsten arc welding(GTAW), two performing shielded metal arc welding(SMAW), and ten engaged in gas metal arc welding(GMAW), were measured in terms of the degree to which they were exposed to extremely low frequency(ELF) magnetic fields over 24 hours by using an electromagnetic field meter(EMF meter), as well as based on a daily activity log.

Results: The welders were exposed to 1.25±4.95 μT of magnetic field per day on average. For those who spent more than half a day-735.26 minutes, or 51.1% of the day-at work, the figure averages 3.88±8.85 μT with a maximum value of 221.28 μT. The subject welders spent 338.14±154.95 minutes per day at home. During their stays at home, they were exposed to an average of 0.17±0.06 μT with a maximum value of 3.50 μT. The maximum exposure of 221.28 μT occurred when welders performed GMAW. The average exposure reached its highest at 17.71±6.96 μT when conducting SMAW. Magnetic field exposure also depends upon posture: welders who sat while welding were exposed five times more than those who stood during work, and this difference is statistically significant. As for the relationship between distance from the welding power supply and maximum magnetic field exposure, maximum magnetic field exposure decreases as the distance increases. The average magnetic field exposure, in the meantime, showed no significant difference depending on distance.

Conclusions: The following were observed through this study: 1) welders, while conducting jobs, are exposed to magnetic fields not only from the welding machine, but also from the surrounding base material due to the current flowing between the welding machine and base material, meaning that they are continuously exposed to a magnetic field; and 2) welders are more exposed to magnetic fields while they sit at a job compared to when they stand up.

Key words: daily activity, extremely low frequency, magnetic fields, welder

I. Introduction

According to the definition by American Welding Society, welding is defined to be a materials joining process which produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.

Welding processes are categorized into Arc welding(AW), Oxyfuel gas welding(OFW), Resistance welding(RW), Solid-state welding(SSW), Brazing(B),

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and Soldering(S). Depending on the application method, welding is again categorized into Manual welding(MA), Semiautomatic welding(SA), Mechanized welding(ME), Automatic welding(AU), Robotic welding(RO), and Adaptive control welding(AD).

Arc welding is most broadly used in the field to heat up and join base materials with an arc. There are two types of AW: one is to melt consumable electrodes with an arc and molten metal is transferred to arc gap; and the other is to take advantage of non-consumable electrodes. Non-consumable electrodes do not melt down with an arc; and filler metal is separately added to weld pool. There are several types of arc welding using non-consumable electrodes: Gas tungsten arc welding (GTAW), Plasma arc welding(PAW), Carbon arc welding(CAW), and Arc stud arc welding(SW). As for arc welding using consumable electrodes, the types include Shielded metal arc welding(SMAW), Gas metal arc welding(GMAW), Flux cored arc welding(FCAW), Electro gas welding(ESW), Submerged arc welding (SAW).

Arc welding, or AW, is a most commonly used joining process which heat up metals with an arc to join base materials, or to produce coalescence of metal. Current value generally required for AW is 10 to 35 V with 5 to 500 A. During making welds, electric field and magnetic field arise. Welders are occupationally exposed to the electromagnetic field as a result.

Harmful effect of electromagnetic field to welders who are occupationally exposed to it for long term has been under controversy since 1979 when an epidemiological study was conducted to find the relationship between young children reside around power lines and childhood leukemia(Wertheimer & Leeper, 1978). Studies on extremely low frequency electromagnetic field have been conducted afterwards.

According to Fact Sheet No.322 published by World Health Organization, there are established biological effects from acute exposure at high levels(above 100 µT) for the short term period: external ELF magnetic field induce electric field and current in the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system. However, there are no accepted biophysical mechanisms that would suggest that long-term low-level exposures are involved in cancer development. In addition, the evidence related to childhood leukemia and magnetic field is not strong enough to be considered causal(WHO, 2007).

Out of 10 studies conducted on electromagnetic field with extremely low frequency between 2008 and 2011, 7 of them(Chen et al., 2010; Kheifets et al, 2011) suggested that the electromagnetic field do not have biological effects on human body while 3 of them suggested otherwise(Schuz & Ahlbom, 2008; Coble et al., 2009; Cooper et al., 2009; Davanipour & Sobel 2009; Hug et al., 2009; Li P et al., 2009; Maslanyj et al., 2009; SCENIHR, 2009).

In workplaces exposed to ELF magnetic fields, the average magnetic field exposure of a female worker ranged from 0.03 to 0.68 µT and Bakers, cooks, chefs, users of sewing and spinning machines, electrical workers, and cashiers were exposed to about 0.23 µT(Deadman & Infante-Rivard, 2002).

Welders working in shipyards are exposed to magnetic fields of 7.22 µT(on average), with maximum exposures up to 27.5 µT(Skotte & Hjøllund, 1997). Stuchly & Lecuyer(1989) measured the magnetic field 10 cm away from the head, chest, wrist, gonad, arms, and legs and found that wrist exposure was 1 mT or higher, and chest exposure was several hundred µT.

Savitz et al.(1999) reported a correlation between magnetic field exposure of electrical workers(the occupational group that handles electric devices), and arrhythmia and acute myocardial infarction. Electrical workers also showed a high leukemia incidence rate(Milham, 1985; Tynes et al., 1992). Furthermore, occupational exposure to a 50 Hz magnetic field was suspected to increase the risk of female breast cancer(Kliukiene et al., 2003).

Various epidemiological studies were conducted to find the relations between exposure to electromagnetic field of extremely low frequency and cancer development for electric engineers who are occupationally exposed to the electromagnetic field, e.g., electric welder, or live-line workers. However, the studies have come up with inconsistent results, failing to address anxiety of the workers who are occupationally exposed to electromagnetic field for long term(Demers et al., 1991; Theriault et al., 1994; Savitz & Loomis, 1995).

This study is conducted for welders whose daily job exposes them to electromagnetic field with extremely low frequency for long term. To identify the characteristics of electromagnetic field exposure, exposure levels are measured for each type of welding; and individual exposure levels are also quantified based on 24 hour measurement and daily activity log to understand whether subtle environmental differences among individuals have effects on exposure levels.

Ⅱ. Subjects and Methods

According to the 2008 data of Statistics Korea (Statistics Korea, 2009), there are 64,125 welders in South Korea, which accounts for 0.81% of the total 7,959,995 workers in all occupational groups in companies with five or more employees. Welder's working hours for those who occupationally expose to electromagnetic field with extremely low frequency are 218.3 hours per month, and they work 23.6 days per month. The figure is greater than working hours of different industrial occupations of 188.7 hours per month, and 29.6 days per month.

This study is conducted for welders who make manual welds by holding a torch, welding gun or welding rod holder: 7 welders conducting GTAW of using non-consumable electrodes; 2 welders conducting SMAW and 10 welders conducting GMAW both of which utilize consumable electrodes were subject to the study. The welders are reasonably in sound condition to be part of this study, male workers whose main job is making welds(for more than 8 hours per day), and agreed to participate in this study after being explained fully about this study. GTAW is a fusion method of using an arc between tungsten electrodes and weld pool. Tungsten Inert Gas(TIG) welding to fuse nonferrous metals, like aluminum and magnesium, is also a GTAW type. SMAW is to take advantage of an arc formed between weld pool and shielded welding rod. GMAW is to take advantage of an arc formed between weld pool and filler material that is supplied continuously. CO_2 welding method falls into this category.

Measurement Equipment and Method

The measurement devices for this study, EMDEX II and EMDEX LITE, are developed by the U.S based Electric Power Research institute(EPRI). The digital devices measure electromagnetic field for all x-/y-/z-axial directions. EMDEX II can measure magnetic field between 0.01 ~ 300 μT in a range of 40 to 800 Hz; and its maximum reception is at 0.01 μ. EMDEX LITE can measure magnetic field between 0.01 ~ 70 μT in a range of 40 to 1,000 Hz; and its maximum reception is at 0.01 μT.

The measurements were performed at the heart region(on the left side of the chest), considering the interference with the activities of the subjects based on the locations of the major organs(heart, kidnev, liver, stomach et al), and according to the IEEE C95.1 standard(IEEE,1991,2006) and the ICNIRP standards on the human exposure to electromagnetic fields(ICNIRP, 1998). The welders are informed to carry the measurement devices with them all the time; and asked to write daily activity pattern by time on daily activity recording paper, and to record the voltage value of a welding machine they use.

Measurement of personal exposure

To determine the magnetic field exposure level for each of the subjects' activities, the subjects were instructed to record their specific activities and their duration, home appliances and devices they were using, and their indoor or outdoor locations. The microenvironments of the subjects were categorized as home, work, travel, in line with the behavior categorization for data collection on time use survey of

Statistics Korea(Statistics Korea, 2009). Home was subdivided into sleep and non-sleep, and work was subdivided into welding and non-welding. The subjects were instructed to note these microenvironments in the logbook. When the subjects returned their measurement instruments and logbooks after finishing the measurements, the computer was used to check the data errors and the measured magnetic field values according to the time activities to verify the accuracy of the measurements.

Ⅲ. Results

The 24 hr pattern of magnetic field exposure of the welders as a function of their daily activities is shown in Figure 1. The welding activity at work accounted for most(78%) of the total magnetic field exposure. Exposure during travel remained constant at 0.16 ~ 0.19 μT. The 24 hr magnetic field exposure in different microenvironments is shown in Table 1; the average value for all microenvironments was 1.25 ± 4.95 μT, with very large variations depending on the activity. The welders are exposed to highest level of electromagnetic field at 221.28 μT during 24 hour period when they make welds at work. Average electromagnetic field exposure level is at 3.88 ± 8.85 μT in the work place. They are exposed to the electromagnetic field for an average of 735.26 ± 180.83 min, which is more than half a day.

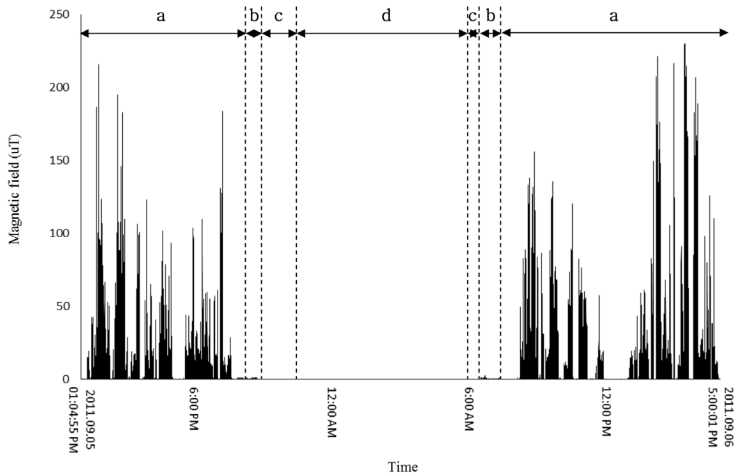

Figure 1. An example of 24 hr personal exposure to magnetic fields (a; at work, b; during travel, c; while awake at home, d; during sleep at home)

Table 1. Magnetic field exposure levels in different microenvironments

			Magnetic field(μT)			Time(min)
			AM ± SD	Max	Median	AM ± SD
N=19	24 hours		1.25 ± 4.95	221.28	0.04	1439.11 ± 291.17
	Work	All(work)	3.88 ± 8.85	221.28	0.10	735.26 ± 180.83
		Welding	4.70 ± 9.31	221.28	0.27	461.74 ± 216.17
		Non-welding	0.24 ± 0.61	13.24	0.03	273.53 ± 162.35
	Home	All(home)	0.17 ± 0.06	3.50	0.03	338.14 ± 154.95
		Sleeping	0.16 ± 0.03	3.50	0.03	469.17 ± 51.91
		Non-sleeping	0.18 ± 0.08	3.16	0.04	207.11 ± 101.88
	Travel		0.19 ± 0.12	11.16	0.05	75.0 ± 35.17

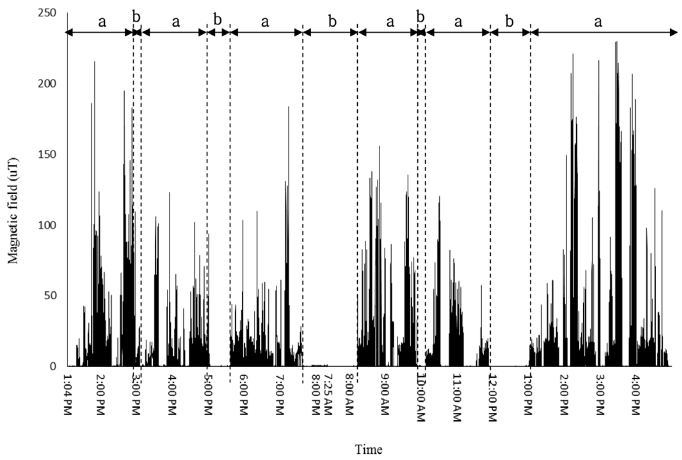

Figure 2. Magnetic field exposure at work (a; welding, b; non-welding)

Table 2. Magnetic field generation by welding

		GTAW		SMAW		GMAW	
		AM ± SD	Max	AM ± SD	Max	AM ± SD	Max
Welding rod diameter	1.2 mm	No work		No work		4.94 ± 9.06	101.56
	1.4 mm	No work		No work		4.34 ± 4.38	221.28
	3.2 mm	No work		17.71 ± 6.96	130.84	No work	
Welding position (N=1)	Standing Flat Position	No work		No work		3.08 ± 6.23	43.68
	Sitting Flat Position	No work		No work		15.42 ± 32.01	221.28
Distance (N=1)	0 m	53.49 ± 31.60	112.8	No work		No work	
	2 m	0.56 ± 0.99	53.50	No work		No work	
	4 m	0.51 ± 0.52	10.50	No work		No work	
Welding current	500 A	2.73 ± 3.42	191.50	17.71 ± 6.96	130.84	4.31 ± 7.59	221.28
	600 A	No work		No work		6.88 ± 14.40	101.56
	20 kW	No work		13.75 ± 8.03	130.84	No work	
Welding type		2.73 ± 3.42	191.50	17.71 ± 6.96	130.84	3.48 ± 7.08	221.28

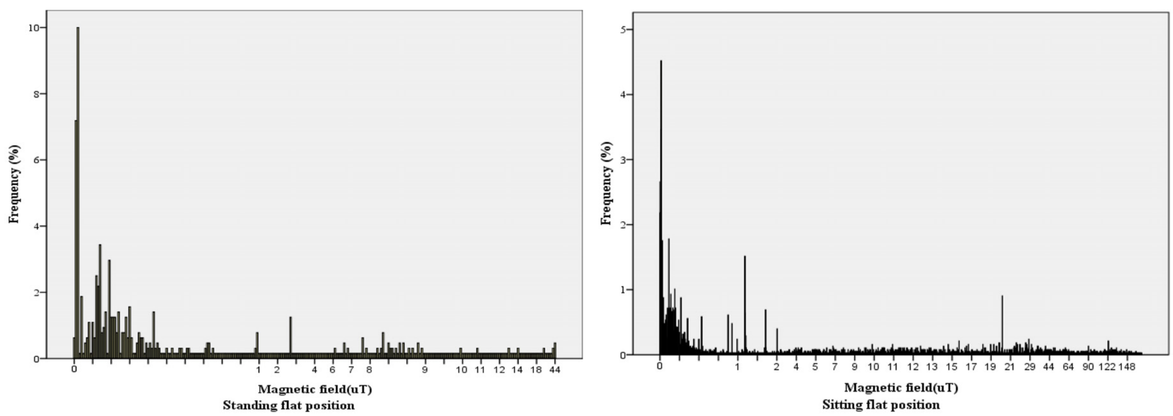

Figure 3. Standing flat position vs sitting flat position.

The exposure level at home was 0.17 ± 0.06 μT, and was similar during sleep(0.16 ± 0.03 μT) and non-sleep(0.18 ± 0.08 μT). The exposure level during travel was 0.19 ± 0.12 μT.

Electromagnetic field exposure patterns depending on activity in the workplace are described in Figure 2. Exposure levels are at maximum when welders make welds, especially during GMAW, the exposure is estimated at its highest of 221.28 μT. During a stand-by before welding, exposure is at 0.2 ~ 0.3 μT, which is about 0.13% of the maximum exposure(221.28 μT). The exposure value during a stand-by is similar to the average default electromagnetic field exposure level at 0.2 ~ 0.4 μT in the workplace.

Table 2 shows the data on magnetic field exposure during welding. We found the highest magnetic fields with 3.2 mm arc welding(17.71 ± 6.96 μT), followed by 1.2 mm CO_2 welding(4.94 ± 9.06 μT) and 1.4 mm CO_2 welding(4.34 ± 4.38 μT). but statistically significant differences($p>0.05$) are not. During an observation, welders took flat position as they make weld from upside. To understand differences in exposure depending on posture, one welder conducting GMAW was monitored both when standing up and looking down while making weld and when sitting down and looking down for the job(Figure 3).

We found that exposure in the sitting flat position(15.42 ± 32.01 μT) was approximately 5 times that in the standing flat position(3.08 ± 6.23 μT), and this difference was statistically significant($p<0.05$). To measure electromagnetic field exposure depending on distance between a welder and a welding machine's power supply, one welder conducting GMAW was observed. The welder stood up and looked down for making welds; and distance from power supply was set differently at 0 meter, 2 meter, and 4 meter to measure exposure. The average electromagnetic field exposure from power supply is measured at 53.49±31.60 μT. The figure drops to 0.56±0.99 μT when the distance is at 2 meter, and again drops to 0.51 ± 0.25 μT when the distance is at 4 meter. Maximum exposure stands at 112.8 μT when the distance is 0 meter, and cut to 53.50 μT for 2 meter, and again to 10.50 μT for 4 meter. Magnetic field exposure due to the welding current of 500 A AC during arc welding(17.71 ± 6.96 μT) was 6 times that during TIG welding(2.73 ± 3.42 μT), 4 times that during CO_2 welding(4.31 ± 8.38 μT), and 2.6 times that during CO_2 welding that used 600 A AC current(6.88 ± 14.40 μT).

Depending on the type of welding, average electromagnetic exposure is highest in an order of SMAW(17.71 ± 6.96 μT), GMAW(3.48 ± 7.08 μT), and GTAW(2.73 ± 3.42 μT). Maximum exposure is highest in an order of GMAW(222.28 μT), GTAW(191.50 μT), and SMAW(130.84 μT).

As to the differences in magnetic field by the welding type, GMAW *vs*. SMAW, and GTAW *vs*. SMAW welding showed significant differences($p<0.05$), but no significant difference was observed between GMAW and GTAW.

IV. Discussion

The maximum magnetic field exposure during welding observed in our study(221 μT) was lower than that reported by Stuchly & Lecuyer(1989) 400 μT. The difference may have been caused by different welded materials, welding devices, electrodes, or welding and measurement conditions. The maximum momentary exposure was only 22.13% of the ICNIRP's 2010 electronic system exposure guideline level, but it was higher than the exposure levels of other industrial occupational groups(SCENIHR, 2009).

Park & Min's(2008) analysis of the current density induced in the human body by the AC arc welding machines predicted 578 μT around the heart(20 cm from the cable), but the maximum value observed in our study(221 μT) was only 38% of the predicted value. This difference is likely due to the lower maximum current in our study(500–600 A *vs*. 1000 A in the Park & Min's study(2008)).

According to Song et al(1998), welding current is decided according to the thickness of base material, welding type, welding joint, root gap, welding rod's diameter and etc. When it comes to welding rod, its diameter decides required calorie for heating and melting. The bigger the diameter is, the more heat energy is required. Accordingly, welding rod with bigger diameter requires higher current, resulting in higher electromagnetic field arising. Electromagnetic field arises in similar scale for 1.2 mm diameter and for 1.4 mm diameter, with 4.94 ± 9.06 µT and 4.94 ± 9.06 µT, respectively. However, compared to 3.2 mm diameter, the figure approximately quadruples to 17.71 ± 6.96 µT. Such differences are attributable to the holder type and diameter of welding rod. The bigger the diameter is, the higher voltage and current is required, meaning higher exposure to electromagnetic field. In the meantime, electromagnetic field exposure differs, regardless of welding rod diameter, depending on the type, characteristics and thickness of base material, location of welding rod's holder, welding habits of each welder, and a welder's posture while making weld.

The welding position is determined by the location of the weld zone and the environment. As to the effect of the welding position, the exposure at the sitting flat position(15.42 ± 32.01 µT) was 5 times that of the standing flat position(3.08 ± 6.23 µT). Low weld zones generally require sitting flat position, which results in a higher magnetic field exposure because the body is bent down with the close contact between its upper and lower halves; other factors are the distance between the body and the welding machine, the degree of bending of the upper half of the body and the arms, the distance between the body and the base metal, and the welding habits of the worker.

A welding machine generally consists of a power supply, a wire-feeding device, and a welding holder. The power supply supplies power to the arc generated between the wire and the base metal, and arc discharge occurs in the welding holder due to the strong current. Electromagnetic exposure is expected to decrease significantly as a welder is more distanced from power supply of a welding machine. Average exposure shows no significant difference between distance of 2 meter and of 4 meter, at 0.56 ± 0.99 µT and 0.51 ± 0.25 µT, respectively. However, when it comes to maximum exposure, the figure dropped from 112.8 µT for distance of 0 meter, to 53.50 µT for 2 meter, and to 10.50 µT for 4 meter. Electromagnetic field arising from a welding machine is spike type, leading to dramatic drop in exposure as distance increases. Moreover, lots of currents flow from power supply to welding rod, from base material to welding machine, and from welding machine to base material, generating electromagnetic field(Cary, 2001). As a result, when the distance from power supply increases from 2 meter to 4 meter, electromagnetic field effect from power supply decreases while electromagnetic field between welding machine and base material becomes more significant.

The average magnetic field at 600 A was 1.60 times that at 500 A for GMAW, which confirmed that the magnetic field changes with the current. At 500 A, the order was SMAW, GMAW and GTAW whereas by welding type, the order was SMAW, GMAW and GTAW.

V. Conclusions

The following observations are made for the impact of electromagnetic field on welders: 1) due to current flowing between a welding machine and base materials, electromagnetic field arise not only around a welding machine, but around base material. Welders are exposed to electromagnetic field all-the-time; 2) welders who sit down and look down while making weld are exposed to higher electromagnetic field than those who stand up and look down for the job.

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