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Occupational Exposure to Sub-Radiofrequency Electric and Magnetic Fields

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Reported by C. Eugene Moss and Dino Mattorano

Introduction

The National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation concerning possible employee exposures to electromagnetic fields (EMFs) at a major manufacturer of power transmission products. The company produced steel engineering drives and conveying chains for use in such applications as mining, construction, paper and sugar mills, amusement parks, and the automobile industry. During the manufacturing process, electrical equipment was used that produced high levels of EMF.

Background

The evaluation of occupational exposure to EMFs was limited to areas of the facility using electric resistance heaters (ERHs) and induction heaters (INHs). There were four Cheston ERHs in operation at the facility on the days of evaluation. The units are rated at 480 V, single phase, and 400 A. The ERH can be visualized as an automated, heavy-duty step-down transformer. Figures 1 through 3 show additional details about the nature of the work and the position in which workers stand to perform their work tasks. The insertion of a workpiece directly into the secondary circuit of the transformer that carries a high current causes the workpiece to heat up rapidly. The manufacturer of the ERH informed NIOSH that the frequency of the magnetic field is dominant 60 hertz (Hz). The ERHs have a silicon-controlled rectifier phase controller with a frequency of 9 kHz, which helps regulate the voltage applied to the primary.

FIGURE 1. Frontal view of ERH device. Note the storage of carbon electrodes.

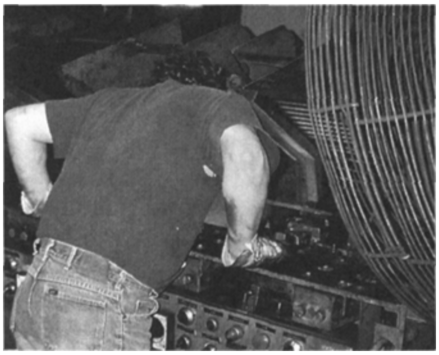

FIGURE 2. ERH worker location during heating cycle.

The carbon workpieces are delivered to the ERH electrodes for approximately 30 seconds of heating. At the end of a two-stage heat cycle, shown in Figure 4, the electrodes retract and the heated workpiece is conveyed to a forge where it is shaped into a single chain link. The largest link takes 30 seconds to heat, while the smallest link takes about 16 seconds.

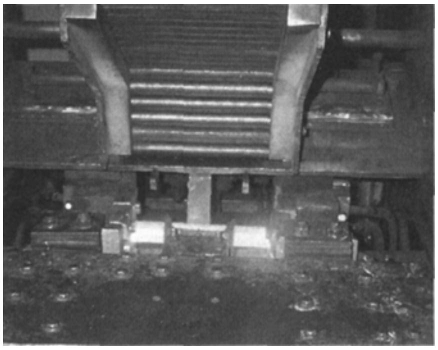

FIGURE 3. Carbon electrode being heated in an EHR.

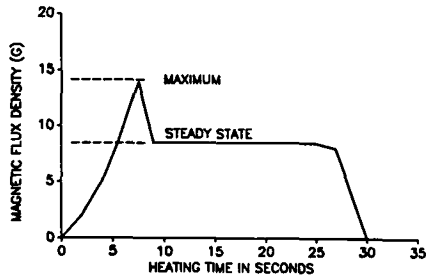

FIGURE 4. Typical heat curve for resistance heaters showing the magnetic field produced at the edge of the heater (worker waist position) as a function of time.

The four units have been at the facility for 8 years and have the potential to produce about 2000 chain links per shift. There are two workers per shift and two shifts per day. All service work on the ERHs is performed by plant workers. Potential occupational EMF exposure to workers will occur when the worker stands next to the heaters (either for adjustment purposes or for unjamming heated workpieces going to the forge). Occupational exposure can be considered continuous since the four ERHs operate simultaneously.

INHs are used to heat electrically conducting material used to join the chain links together. The material is placed in an alternating current magnetic field produced by unshielded coils of various sizes and designs. High power levels are then delivered to the workpiece in order to heat it. As a result of the high power levels that must be used, as well as the lack of coil shielding, INH operators can be exposed to high levels of EMF, which may increase the potential for health effects.

All of the INHs measured at the facility were manufactured by Tocco, Inc. These units produced power levels ranging from 35,000 to 70,000 W at frequencies ranging from 7 to 10 kHz. Two of these units are shown in Figures 5 and 6.

FIGURE 5. INH worker handling workpieces by hand during the heating cycle.

Since INH operators tend to handle the workpiece with tongs or by hand, arm/hand/wrist locations are the more prominent sites of worker exposure.

Evaluation Design and Methods

Emphasis was placed in this evaluation on documenting occupational levels of sub-radiofrequency (RF) electric and magnetic fields (SRE/MF). The evaluation was designed to survey actual worker exposures to SRE/MF during work tasks. The limited number of measurements taken in and around the facility were not intended to represent an in-depth evaluation of the SRE/MF radiation fields at the site, but were rather intended to approximate occupational exposure levels on the days of measurement.

The following equipment was used to document levels of EMF:

- A Holaday Industries, Inc. model HI-3602 ELF sensor, connected to an HI-3600 survey meter, was used to document both the magnitude of SRE/MF and the electrical frequency (as well as the waveforms) produced by such fields. The sub-RF electric fields (SREFs) can be measured either in volts per meter or kilovolts per meter. The sub-RF magnetic fields (SRMFs) can be expressed in units of gauss (G) or milligauss (mG). One G equals 1000 mG.
- SRMF measurements were made with the EMDEX II exposure system, developed by Enertech Consultants, under project sponsorship of the Electric Power Research Institute, Inc. The EMDEX II is a programmable data acquisition meter which measures the orthogonal vector components of the magnetic field through its internal sensors. Measurements can be made in the instantaneous read or storage mode. The system was designed to measure, record, and analyze power frequency magnetic fields in units of milligauss in the frequency range from 30 to 3000 Hz. Measurements were made in both the walk-around and personal dosimetry modes.
- Holaday Industries, Inc. models HI-3600-01 and HI-3600-02 survey meters were used to document the electric and magnetic fields in the very low frequency (VLF; 1 to 30 kHz) and extremely low frequency (ELF; 0.1 to 1000 Hz) bands. The SREF can be measured either in volts per meter or kilovolts per meter, while the SRMF can be expressed in units of milligauss. These instruments also provided the ability to record the frequencies, as well as the waveforms, produced by such fields. Frequency measurements were made at locations where personnel worked during the day.
- Holaday Industries, Inc. model 3637 three-axis VLF was used to make isotropic measurements of the magnetic field in and around the INH. The magnetic field is measured over the frequency region from 2 to 400 kHz and the dynamic range of the instrument is from 6 to 400,000 mG with special probe adapters.
- Holaday Industries, Inc. model HI-3627 three-axis ELF magnetic field meter was used to make isotropic measurements of the magnetic field in and around different heaters. The magnetic field is measured over the frequency region from 30 to 2000 Hz, and the dynamic range of the instrument is from 0.2 mG to 20 G.

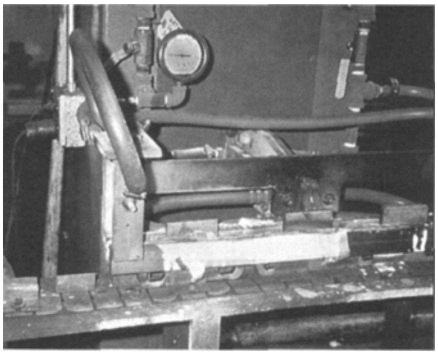

FIGURE 6. Unshielded workpieces moving in a coil of the INH.

All measurements were taken during daylight hours and at positions considered to be typical of occupational exposure (1 m away from the source and 1 m from the floor). Where possible, at least two readings were taken at each measurement site with the equipment and the average reading was recorded. All equipment used to document exposure to SRE/MF had been calibrated within 6 months' use either by NIOSH or by their respective manufacturers.

Evaluation Criteria

Sub-RF Electric and Magnetic Fields

At the present time, there are no Occupational Safety and Health Administration or NIOSH exposure criteria for sub-RF fields covering the frequency region from 0.1 to 30,000 Hz. However, the American Conference of Governmental Industrial Hygienists (ACGIH) has published threshold limit values (TLVs) for SRE/MF in this frequency region.[1] The TLV for SRMF states "routine occupational exposure should not exceed:

$$\text{SRMF (in mT)} = 60/f \qquad (1)$$

where f is the frequency in hertz."

One millitesla (mT) equals 10 G. Conversely, the SREF TLV states "occupational exposures should not exceed a field strength of 25 kV/m from 0 to 100 Hz. For frequencies in the range of 100 Hz to 4000 Hz (or 4 kHz), the SREF TLV is given by:

$$\text{SREF (in V/m)} = 2.5 \times 10^6/f \qquad (2)$$

where f is the frequency in hertz. A value of 625 V/m is the exposure limit for frequencies from 4 kHz to 30 kHz."

This means, for example, that at 60 Hz, which is classified as ELF, the SREF TLV is 25,000 V/m and the SRMF TLV is 1 mT or 10,000 mG. At 10 kHz, the SREF TLV is 625 V/m and the SRMF TLV is 60 mG. The basis of the ELF SREF TLV is to minimize occupational hazards arising from spark discharge and contact current situations. The SRMF TLV addresses induction of magnetophosphenes in the visual system and production of induced currents in the body. Prevention of cancer is not a basis for this TLV because exposure has not been conclusively linked to cancer.

The ACGIH has recently proposed

new TLVs for the SRE/MF region that will alter the above levels. The proposed TLV for SRMF recommends the use of the same magnetic field equation TLV, but has adopted a ceiling value of 10 G from 1 to 300 Hz and a ceiling value of 2 G from 300 to 30,000 Hz.

Many of the observed biological effects of exposure to what is known as microwave (MW) and RF radiation can be attributed to a rise in body temperature. The heating effect of MW/RF radiation depends on the amount of energy absorbed by the body. The rate of absorption, denoted the specific absorption rate (SAR), is measured in watts per kilogram for the whole body or parts of the body. The SAR depends on many factors, such as the frequency and intensity of the radiation, size and shape of the exposed worker, and the worker's orientation in the radiation field.

Another standard for occupational exposure to MW/RF radiation is the Institute of Electrical and Electronics Engineers (IEEE) standard published under the auspices of the American National Standards Institute and known as IEEE C95.1-1991.[(2)] The IEEE scientific committee concluded that an SAR of 4 W/kg represents the threshold absorption level above which adverse health effects may arise as body temperature increases. A safety factor of 10 was then added to give an SAR of 0.4 W/kg as the maximum permissible exposure limit, averaged over the entire body. This standard uses dosimetry measurements of MW/RF radiation to calculate the power density limit necessary to achieve an SAR of 0.4 W/kg. Under the IEEE standard for a frequency of 10 kHz, the magnetic field power density limit is 1,000,000 mW/cm^2. This is equivalent to a magnetic field strength of 2.01 G. The basis of the IEEE standard is to minimize adverse biological effects due to excessive heating of internal body tissues. The human body absorbs maximally in the frequency region from 30 to 300 MHz. Outside this region, such as 10 kHz, much less energy is absorbed by the body from the radiation field.

TABLE 1. Maximum and Steady-State ELF and VLF Magnetic Field Levels at Waist Level Near the ERH

Heater Number	Maximum Levels (G)	Steady-State Levels (G)	Maximum VLF (mG)
1	12.3	7	50
2	13.6	6	50
3	13	7	50
4	13.9	8	30

Results and Discussion

Electric Resistance Heaters

Table 1 indicates that workers can be exposed to SRMF levels as high as 13.9 G at waist locations for long periods of time. If the workers were to perform any type of maintenance or service work while the units were activated, the levels of SRMF, in the 30 to 3000 Hz frequency region, would be much higher since the workers would need to lean over the heaters and be located closer to the radiated fields. An example of a higher exposure scenario is shown in Figure 2.

SRMF levels associated with ERHs ranged from 0.1 to 13.9 G in the 30 to 2000 Hz region, while SREF levels ranged from 0.1 to 30 V/m over the 30 to 1000 Hz region. While time-weighted ELF levels of SRMF were not documented in this evaluation, it is noted that these levels would probably be well below the levels shown in Table 1 since the workers do move about the area during the conduct of their jobs. However, the NIOSH investigators did observe ERH workers staying in the close vicinity of these heaters for relatively long periods of time (i.e., 1 to 2 hours) and they would therefore be exposed to SRMF ceiling levels above the new proposed ACGIH TLVs. Finally, the maximum measured VLF level shown in Table 1 was 50 mG, which is below both the ACGIH TLV and IEEE exposure limit for a 9-kHz source.

Induction Heaters

All magnetic field measurements of INHs were corrected for the work cycle duration before comparison with occupational exposure criteria. This was accomplished by multiplying the estimated duty cycle factor (df) by the measured exposure level. The df is defined as the ratio of the magnetic field on-time in seconds to the sum of the time on and time off during any 6 minutes of operation, and it is expressed as a fraction.

Table 2 shows df-corrected data on occupational SRMF maximum levels for INHs as a function of process, power, and measurement location at the worker site. The shaded zones in Table 2 indicate levels that exceed the TLV. The levels shown in Table 2 were averaged over two trials. Notice that hand exposures to the 10-kHz INH gave the highest occupational exposure. Table 2 shows that 75 percent of the body measurements were below the IEEE limits, while 67 percent of the hand measurements were above the IEEE limits. Moreover, the hand measurements were much higher in intensity than the body levels.

Very few measurements on INHs have been reported in the literature, but those results that do exist suggest that INH operators are exposed to SRMF levels which are high relative to recommended exposure limits.[(3,4)] The review of the

TABLE 2. INH Duty-Factor Corrected SRMF Levels

Process	Applied Power (kW)	Operating Frequency (kHz)	Estimated Duty Factor (df)	Maximum df-Corrected Exposures (G)		Current TLV (mG)	IEEE MPE (G)	ELF Exposure Level (mG)
				Hand	Body			
Hot bender 50 kW	35	10	0.6	24	0.96	60	2.0	460
Hot bender 100 kW	70	10	0.6	NM	0.24	60	2.0	NM
Hot header	70	7	0.75	7.5	3	86	2.0	200
Induction hardener	60	10	0.6	0.24	0.03	60	2.0	10

NM = not measured.

FIGURE 7. Sparks and fire on top of the ERH, probably due to heating of oil residuals.

limited literature suggests that the hands were the most exposed parts of the body and, in most cases, the total body exposure was low. During this evaluation, several INH workers were asked if they ever perceived any effects of exposure to such fields. No effects were reported by any of the workers. It is noted that while metal objects can be heated to high temperatures in short periods of time, exposure to the hands did not produce the same effects. Power absorption is directly proportional to the conductivity of the object. At 10 kHz there is a factor of 10^8 difference between conductivity of the hands and metals.

Fire and Fume Issues

During the evaluation for EMFs, it was noted that lubricating oil on the top surface of the ERH would occasionally flame, causing fire and fume problems (see Figure 7). One explanation was that lubricating oil was used to inhibit corrosion and to assist in delivering the workpieces to the ERH electrodes. This practice needs to be fully investigated by safety personnel due to potential fire concerns and occupational exposure to toxic vapors.

Summary

SREF measurements of ERHs in the 30 to 1000 Hz region ranged from 0.1 to 30 V/m. SRMF levels associated with the ERHs ranged from 0.1 to 13.9 G in the 40 to 2000 Hz region. These SRMF levels from ERHs exceeded the ACGIH TLV of 10 G. The maximum SRMF levels associated with INHs operating near 10 kHz was 40 G, which exceeded both the ACGIH TLV value of 60 mG and the IEEE maximum permissible exposure level of 2 G.

Based on the data collected in this evaluation, NIOSH investigators concluded that exposure to SRMF levels, in the frequency regions from 0.1 to 2000 Hz and at 10 kHz, exceeded the appropriate occupational guideline limits on the days of measurement.

Recommendations

The following recommendations were offered to reduce potentially significant occupational exposures and safety risks at the facility:

1. The company should consider purchasing appropriate static magnetic and SRE/MF monitoring instruments to monitor levels of electric and magnetic field produced on the plant property.
2. Management needs to investigate the possibility of either requiring INH operators to work at distances farther away from the units or developing control measures, such as automated systems or shielding, that will eliminate excessive hand/body exposures.
3. Operators should be positioned farther from the ERH when work does not demand being close to units. In addition, automation of some elements of the INH processes could reduce occupational exposure levels which are above the exposure limit.
4. Company safety personnel need to investigate the practice of using flammable oils on the hot surfaces of ERHs.

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EDITORIAL NOTE: C. Eugene Moss and Dino Mattorano are with the Hazard Evaluations and Technical Assistance Branch of NIOSH. More detailed information on this evaluation is contained in the Health Hazard Evaluation Report No. 92-0306-2465 available through NIOSH, Hazard Evaluations and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, OH 45226, or by telephoning 1-800-35-NIOSH.