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MEASUREMENT OF ELECTRIC AND MAGNETIC FIELD STRENGTHS FROM INDUSTRIAL RADIOFREQUENCY (15-40.68 MHz) POWER SOURCES

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ABSTRACT

This paper describes the performance characteristics of radiofrequency (RF) electric and magnetic-field-strength monitors and the results of RF (15-40.68 MHz) power source measurements made with these monitors. The monitors were constructed and calibrated for near-field exposure measurements for NIOSH by NBS. Near-field measurements must be made at locations within fractions of a free space wavelength to RF power sources. These measurements are necessary because personnel operating RF power sources receive near-field exposures. Results from a limited preliminary survey indicated that at least 80% of the sources emitted electric and magnetic-field strengths that exceeded the field-strength guides (200 V/m and 0.5 A/m, respectively) specified in the ANSI C95.1-1974 Personnel Exposure Standard for RF radiation. The degree of personnel exposure can only be ascertained reliably by electric and magnetic-field-strength measurements with monitors such as those described in this paper. The use of commercial far-field power density monitors (with dipole antenna elements) for near-field RF (15 to 40.68 MHz) exposure measurements neglects the magnetic-field-induced power absorption which predominates under near-field conditions. Problems regarding the application of totally incorrect RF exposure monitoring techniques and instrumentation may partially result from the absence of any Federal personnel exposure standard which specifies field-strength measurements for RF (10-300 MHz) sources. In an effort to provide this mandatory monitoring data for a Federal RF personnel exposure standard, research is in progress to investigate factors influencing industrial personnel electric and magnetic-field-strength exposures.

INTRODUCTION

Current OSHA Regulations include occupational exposure limits for Radiofrequency/Microwave radiation for the frequency range 10 MHz to 100 GHz. However, only one commercial instrument is available which can be validly used for radiofrequency (RF) radiation measurements below 300 MHz (1). Consequently little usable personnel exposure data has been obtained within the RF radiation band (10 to 300 MHz). Within the FCC regulated Industrial-Scientific-Medical (ISM) bands at 13.56, 27.12, and 40.68 MHz, the power output of RF sources is unlimited and their industrial applications are rapidly increasing. For these reasons, surveys of the magnetic and electric-field-strength levels emitted by industrial RF power sources were made to obtain actual industrial exposure data for RF bioeffects studies.

Commerical power density monitors (with dipole antenna elements) give no indication of magnetic-field-strength exposure. Consequently, the vast majority of commercial power density monitors do not indicate magnetic-field-strength exposure. However, Guy *et al*. (2) have shown that magnetic-field-induced power absorption predominated in a 70-kg spherical model of man for dominant magnetic-field exposures from 3 to 30 MHz. Dominant magnetic-field exposures can occur in close proximity (less than one meter) to radiofrequency (15 to 40.68 MHz) power sources where operators are located. Guy *et al*. (2) concluded that magnetic fields must be measured to obtain any estimate of hazards due to RF exposure.

Virtually every commercial RF/Microwave exposure monitor is calibrated for power density in terms of milliwatts per square centimeter (mW/cm^2). One exception is a useful magnetic-field-strength monitor developed by Aslan (1) which recently became commercially available. Guy *et al*. (3) cautioned that the use of power density monitors which respond only to the electric-field vector but are calibrated in terms of power density (mW/cm^2) can result in completely erroneous and possibly dangerous assumptions at RF (10 - 300 MHz) frequencies.

Almost all RF personnel exposure measurements must be performed in the reactive near-field region within one meter of the RF source where the operators are located. Bowman (4) demonstrated that the power density (e.g. in mW/cm^2) of reactive near-fields can be *zero* while these near-fields can be *quite strong* and contribute significantly to personnel exposure. Bowman (5) concluded that for frequencies below 1,000 MHz both the electric and magnetic-field strengths should be measured.

Electric and magnetic-field-strength quantities are defined for *all* near-field and far-field condtions and can be measured accurately with exposure monitoring instrumentation recently developed for NIOSH (6, 7). For these and other reasons, Guy *et al*. (3) recommended that RF personnel exposure standards be written in terms of maximum allowable electric and magnetic-field strengths.

The American National Standards Institute (ANSI) has recognized the inherent difficulties associated with power density personnel exposure standards from 10 to 300 MHz. It was previously assumed that the guides derived for the 1,000 to 3,000 MHz frequency range were usable from 10 to 1,000 MHz. The recent RF bioeffects data of Gandhi (8,9) indicated that personnel exposures from 25 to 26 MHz are more potentially hazardous than microwave (1,000 to 3,000 MHz) personnel exposures. The latest ANSI standard (ANSI C95.1-1974) specifies electric-field strength (200 V/m) and magnetic-field strength (0.5 A/m) guides. The OSHA RF/Microwave Personnel Exposure Standard was adopted from the inadequate previous ANSI C95.1-1966 power density standard. Modification of this OSHA standard is currently under consideration. The field-strength monitoring techniques and data presented in this publication should prove useful for modification of the OSHA standard within the radiofrequency range 10 to 30 MHz. This paper describes the performance characteristics of RF electric and magnetic-field-strength monitors, the field-strength monitoring techniques, and the results of RF (15 to 40.68 MHz) field-strength measurements performed on the near-field exposures generated by industrial power sources.

MATERIALS AND METHODS

The details of the design, construction and calibration of the electric-field-strength exposure monitor developed under contract for NIOSH by NBS (6) have been reported. The electric-field-strength exposure monitor (EDM-2) employs a set of three orthogonal dipoles to obtain an essentially isotropic response. For additional versatility, each orthogonal axis signal may be read independently. The dipoles are connected to the meter electronics by special high resistance conductors which have minimal interaction with the RF field. The meter displays electric energy density from 0.003 to 30 microjoules per cubic meter ($\mu J/m^3$) which corresponds to electric field strengths from approximately 26 to 2600 volts per meter (V/m). The exposure monitor was calibrated by NBS from 10 to 500 MHz with specific calibration points within the Federal Communication (FCC) Industrial-Scientific-Medical (ISM) frequency bands at 13.56, 27.12 and 40.68 MHz. The EDM-2 exposure monitor accuracy specifications have been published previously by NIOSH (6). NBS specified that the total inaccuracy of the EDM-2 monitor was ± 1.5 dB from 10 to 40.68 MHz. The monitor has the capability to display peak or average readings. Variable response times (0.1 to 10 seconds) are available to give a controllable averaging of varying signals.

The description of the NIOSH magnetic-field-strength probes and the associated electronic equipment has been published by NIOSH (7). Two portable (HFM-2) magnetic-field-strength probes were developed that consist of small, single-turn, balanced loop antennas 10 cm and 3.16 cm in diameter. The 10 cm loop antenna was designed for a measuring range of 0.5 to 5.0 A/m and the 3.16 cm loop antenna was designed to measure from 5.0 to 50 A/m. A type 1N4148 silicon-junction, semi-conductor diode was connected internally across a gap in each loop to rectify the induced RF voltage. For the above mentioned range of magnetic field strengths, the d-c output of each probe is approximately 1 to 10 volts. A newly developed non-metallic, high-resistance, transmission line is used to transmit the d-c voltage to an electrometer voltmeter. The loop probes were swivel mounted at the end of a 36-inch-long tubular figer-glass handle. The probes were tripod mounted while performing magnetic-field-strength measurements. The angle between the pricipal axes of the loop and the probe handle can be set for 54.74 degrees to enable orthogonal measurements to be taken. The HFM-2 probes, like the EDM-2 monitor, have been specifically calibrated by NBS for use within the ISM bands at 13.56, 27.12, and 40.68 MHz but can be used at any frequency from 10 to 40.68 MHz. The HFM-2 exposure monitor accuracy specifications have been given in a prior NIOSH publication (7). NBS specified that the total inaccuracy of the HFM-2 monitor was ± 1.5 dB of the monitor reading from 10 to 40.68 MHz. These ISM band calibration points were chose because the great majority of high power industrial RF power sources operate within one of these bands.

A total of ten radiofrequency power sources with nominal power outputs ranging from 0.7 to 20 kW were surveyed. There were two synthetic fiber dryers used in the textile industry, one edge gluer from the lumber industry and seven heat sealers utilized in the plastics industry. These are typical industrial RF applications. Each power source had a single dial power control which was commonly set close to the maximum power for optimum production speed. The variable RF application time control incorporated in each source was usually positioned so that the RF source was activated for 1 to 3 seconds. The measured fundmental frequencies of the power sources ranged from 15.00 to 40.68 MHz. The two synthetic fiber drying sources had a fixed ISM band frequency of 40.68 MHz and the one lumber industry power source had a fixed ISM band frequency of 27.12 MHz as did two plastic industry sources. The remaining five plastic industry sources had frequencies which varied depending on the application conditions at the time of measurement. Each source used continuous wave (CW) modulation.

Measurements were performed in areas occupied by personnel operating the RF power sources. These personnel were located within one meter of the RF power sources. Operators were observed for several repetitions of their work cycles to establish normal work patterns prior to making the measurements. Operators were then instructed to maintain these normal work patterms during the measurements. All field-strength measurements were taken using the operator's anatomy as a reference framework. Measurements were taken at the eyes, waist, and hands positions of most operators. Each operator was in a stationary position during the time of measurement (commonly 1 to 3 seconds). The probe, meter electronics and the interconnecting cable as well as the surveyor were stationary during all measurements. The highest field strength reading observed during RF power source operation was recorded in each case. Unfortunately, available time, personnel and monitoring equipment allowed only one repetition of each measurement. All possible efforts were made to insure reproducibility of exposure conditions during these measurements. Additional work is planned to investigate the possible influence of selected factors on RF exposure to personnel.

The EDM-2 exposure monitor was used to make the electric-field-strength measurements. The monitor was operated in the isotropic response mode (x, y, z channels activated) and the average readings were displayed. The meter needle was zeroed before each measurement. The response time constant switch was set to the 0.1 seconds. The range switch was adjusted so that the displayed readings were maintained between 20 and 80 % of full scale. The EDM-2 monitor readings were converted to electric-field-strength levels (V/m) using the information given in a NIOSH report (6). The monitor readings can always be validly converted to root mean square (RMS) electric-field-strength values but not to far-field power density (mW/cm^2) values.

The HFM-2 exposure monitor was utilized to perform all magnetic-field-strength measurements. The probe with the appropriate magnetic-field-strength sensitivity was mounted on a tripod support. The principal axes of the loop antenna were oriented at 54.74 degrees relative to the probe handle (to insure orthogonal measurements) and secured in that position for the duration of these measurements. The loop probe was connected to the electrometer voltmeter with the special high-resistance line. The voltmeter feedback switch was set at the normal feedback position and the range switch was placed in the 10^{-10} Amperes position. The meter zero was verified prior to all readings. The multiplier switch was set at 10 so that a full scale meter needle deflection would represent 10 volts directly. The HFM-2 monitor voltage readings were converted to RMS magnetic-field-strength (A/m) levels based on the data published by NIOSH (7).

RESULTS AND DISCUSSION

RF field-strength measurements made in the textile, lumber and plastics industries are listed in Table 1. Measurements performed on the two RF power sources utilized for synthetic fiber drying did not have a linear dependence on the source power output. A two-fold increase in power output resulted in less than a factor of two enhancement of the electric-field-strength exposure. The magnetic-field-strength values exhibited a supralinear (factor of 6.6 increase) behavior with the two-fold increase in power output. Both RF power sources were virtually identical in all aspects except for power output. The measurement location was reproduced for each power source. In addition, the measurement data on the plastic heat sealers demonstrated that an increase in power output was not necessarily accompanied by an enhancement of the electric or magnetic-field-strength exposure. For example, the plastic heat sealer with a 2 kW power output emitted a magnetic-field-strength level at the eyes position which was more than five times that generated at the same location by the plastic heat sealer with an output power of 10 kW. A further illustration of this point is that the electric-field-strength exposure generated by the 2 kW plastic heat sealer at the waist location was more than 10 times that emitted at the same location by the 4 kW heat sealer immediately below it in Table 1.

The highest electric-field-strength measured was almost five times the 200 V/m radiation protection guide recommended by the ANSI C95.1-1974 RF/Microwave Personnel Exposure Standard. The largest magnetic-field-strength was more than twenty-five times the 0.5 A/m guide set by the same standard. The tabulated data reveals that 90% of the sources emitted electric-field-strengths greater than 200 V/m and 80% of the sources produced magnetic-field-strengths in excess of 0.5 A/m.

CONCLUSIONS

Measurements of RF (15 to 40.68 MHz) electric and magnetic-field-strength exposures generated by power sources having application in the textile, lumber, and plastics industries are presented. Measurements were taken for near-field conditions (at distances less than one meter from the sources) where operating personnel were located. The measured electric and magnetic-field-strength exposures showed no clear dependence on the RF power output. The field-strength exposures were compared to the ANSI C95.1-1974 RF/Microwave Personnel Exposure Standard radiation exposure guides. This comparison revealed that 90% of the sources measured exceeded the electric-field-strength guide of 200 V/m and 80% of the sources exceeded the magnetic-field-strength guide of 0.5 A/m. These guides were exceeded by factors as high as five for the electric field and by as high as twenty-five for the magnetic field. Based on the information contained in the ANSI C95.1-1974 standard at least 80% of these RF power sources represent a potential personnel exposure hazard.

The degree of personnel exposure hazard relative to existing standards can only be ascertained reliably by the measurement of electric <u>and</u> magnetic-field-strengths with monitors such as those described in this publication. These measurements have demonstrated that a very significant magnetic-field-strength personnel exposure can be completely neglected if commercial far-field power density monitors (with dipole antenna elements) which respond only to the electric-field component of an RF field are used. It is important not to neglect the magnetic-field-strength component of the RF field because magnetic-field-induced power absorption (in biological phantom models of man) predominates for near-field exposure conditions.

Little, if any, emphasis has been placed on the need for monitoring electric and magnetic-field-strength exposures under near-field conditions partially because no Federal standard has been written in terms of field-strength exposure for the frequency range 15 to 40.68 MHz. In an effort to develop useful monitoring techniques and instrumentation for a Federal RF personnel exposure standard, additional research is being done to investigate factors influencing industrial personnel electric and magnetic-field-strength exposures to RF radiation. Because of the large number of RF power sources utilized in industrial applications, the rapid increase in the types of RF applications, the unlimited power output of sources operating within the ISM bands at 13.56, 27.12 and 40.68 MHz, and the high-level RF industrial exposures documented in this paper, greater emphasis should be placed on the collection of RF bioeffects and personnel exposure data with the proper monitoring techniques and instrumentation described in this publication.

Table 1

Electric and Magnetic-Field-Strength Measurement Results

POWER OUTPUT (kW)	FREQUENCY (MHz)	MEASUREMENT LOCATION	ELECTRIC FIELD STRENGTH (V/m)	MAGNETIC FIELD STRENGTH (A/m)
Textile Industry-Synthetic Fiber Dryers				
20	40.68	Waist	305, 333	13.8, 12.6
10	40.68	Waist	179, 189	1.9, 2.1
Lumber Industry-Edge Gluer				
20	27.12	Waist	211, 231	1.05, 0.95
Plastic Industry-Heat Sealers				
0.7	27.12	Eyes	318, 298	0.4, 0.4
		Waist	21, 23	0.02, 0.02
1.25	27.12	Eyes	293, 323	0.04, 0.04
		Waist	220, 236	0.04, 0.04
1.5	38.00	Eyes	330, 342	0.58, 0.62
		Waist	468, 482	0.67, 0.73
2.0	22.00	Eyes	482, 504	7.5, 7.9
		Waist	481, 499	- - - - -
		Hands	506, 480	12.6, 11.6
4.0	30.00	Eyes	958, 982	0.72, 0.68
		Waist	44, 48	0.48, 0.52
4.0	30.0	Eyes	948, 998	0.41, 0.39
		Waist	196, 206	0.67, 0.73
10.0	15.0	Eyes	649, 671	1.34, 1.46
		Waist	811, 851	0.51, 0.49

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