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ORIGINAL ARTICLE

Single-Axis and Three-Axis Probe Magnetic Field Meters in an Occupational Hygiene Study: A Comparative View

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ABSTRACT

One type of electromagnetic fields, based on frequency range, is Extremely Low Frequency (ELF) fields. There are lots of reports about measuring ELF-magnetic field (MF) in substations, power plants, cities and etc. This study aimed to compare the difference between measurement of three-axis and single-axis probe MF meters. ELF-MF was measured by TES-1394 MF tester (three-axis probe) and HI-3604 ELF survey meter (single-axis probe) in selected power plant and the resultant of three MF components (X, Y, and Z) was calculated based on equation. Field measurement was based on IEEE std 644-1994. In the generator building, minimum, maximum, and mean values of the magnetic flux density measured by the three-axis device were greater than those measured by the other two methods. Besides, the maximum value of the resultant method was greater compared to the measurements related to the other two methods, but the means of magnetic flux density by the three-axis device was greater than the resultant and maximum axis value. However, a significant difference was found between the maximum axis value and the results of the three-axis device (P=0.022). The best and most reliable way to measure MF is using a device with a three-axis probe and measuring the maximum MF by the singe-axis device cannot be reliable. Moreover, in the absence of a device with a three-axis probe, if there is a single-axis probe, the best we can do is obtaining the resultant from the three directions of the field.

KEYWORDS: *Magnetic field measurement, Three-axis device, Single-axis device*

INTRODUCTION

In today's world, need for electric current is increasing day by day. Meeting this need would require supplying the instruments to generate this force and the systems that could inadvertently expose employees who are working there to various adverse factors that have an impact on health. One of these harmful physical factors is magnetic field (MF) defined as a force caused by an electric charge [1]. Extremely Low Frequency (ELF) is the terminal portion of the electromagnetic spectrum with the frequency of 30-300 Hz [2].

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Extremely Low Frequency Magnetic Fields (ELF-MF) are often expressed by two quantities, namely magnetic flux density (B) with Tesla unit (SI) or Gauss (CGS) and magnetic field intensity (H) with units of amperes per meter (SI) or Oersted (CGS) [1]. Mean values exposures with magnetic field in electrical occupations is higher than other occupations such as clerical work [3]. There are lots of reports about measuring ELF-MF in substations [4-5], power plants [6], cities [7-8], near high voltage power lines [9], and various types of urban transport systems [10-11]. Ghorbani et al. after measurement of ELF-MF in high voltage substations at Hamadan City reported maximum value at zero distance (50.42 mG) from the converter transformer and minimum value at 1-meter distance from the house battery (1.53 mG) [12]. Renew et al. in England reported maximum value of ELF-MF and near the 400 (10 µT) and 11 kV (1.6 µT) high voltage fence substations, respectively [13].

In addition, various studies have reported adverse effects, such as increased incidence of suicide [14], psychiatric disorders [15], depression, paranoid disorder, obsessive disorder, sensitivity to social and personal relationships, anxiety, aggression [16], sleep disorders [17], myeloid leukemia [18], damage to DNA [19], leukemia, and cancer [20-21] in the individuals exposed to these fields. What was mentioned above shows the need for accurate measurement of MFs. Therefore, tools and methods have been presented for measuring these fields [22-24]. According to IEEE std 644-1994, the resultant of the three vertical directions of the field is calculated by the equation 1 and 2:

$$B_R = \sqrt{B_x^2 + B_y^2 + B_z^2} \qquad \textit{(Equation 1)}$$

Where B_x, B_y, and B_z were the RMS values of the three vertical components of the magnetic:

$$B_R = \sqrt{B_{max}^2 + B_{min}^2} \qquad \textit{(Equation 2)}$$

Where B_{max} and B_{min} were the RMS values of the semi major and semi minor axes of the MF ellipse, respectively. A three-axis MF Meter (TAMFM) simultaneously measures the RMS values of the three orthogonal field components and combines them according to equation 1 to indicate the resultant MF [23].

Because of widely exposure and health effect of ELF-MF, accurate measurement of field is important. So understand the differences between the measured and the actual value of the MF in fields work with instruments is important. Besides, this question is if the difference value of single-axis and three-axis probe magnetic field meters are significant, can be with measurement of MF in x, y and z direction by single-axis probe magnetic field meter and calculation of resultant (based on equation 1), this difference be compensated.

According to above discussion, this study aimed to compare the difference between measurement of TAMFM and Single-Axis MF Meter (SAMFM). The resultant of the field will be calculated by measuring the three components of the MF (x, y, and z) using SAMFM and Equation 1 and will be compared to the values of TAMFM. It is noteworthy that the objective of this study was to examine whether the resultants of the measured values of the three components of the MF by SAMFM could provide reliable values in comparison to TAMFM.

MATERIALS AND METHODS

This cross-sectional study was performed in a thermal power plant. This plant is located on a land size of 500 × 800 m in Southeast of Tehran and has three generators with nominal power of 82.5 MW working with gas and oil. ELF-MF was measured using TES-1394 MF tester (three-axis probe) and HI-3604 ELF survey meter (single-axis probe). Despite calibration certificate, the devices were calibrated again to ensure the measurements, determining the calibration factor 1 with the help of Iran's Atomic Energy Organization. Field measurement was based on IEEE std 644-1994. In order to measure ELF-MF, device or the probe should be one meter above the ground. Another point is that during the measurement, the operator can have the device on one's hand because the weak magnetic nature of human body does not cause MF perturbations and has no impact on its amount [23].

Due to the rapid changes in MFs, more stations was intended to increase measurement accuracy. The measurement stations were located inside the generator building, in the vicinity of the transformers, the 63 and 230 kV substation areas, control room building, and below and around the 63 kV power lines. At each point, field measurement was performed as follows:

1. Measurement of the maximum amount of ELF-MF by HI-3604 ELF survey meter
2. Measurement of the three components (x, y, and z) of ELF-MF by HI-3604 ELF survey meter
3. Measurement of ELF-MF by TES-1394

To measure the maximum of ELF-MF by SAMFM, according to the standard recommendations, the device was rotated in different directions, so that the maximum amount of magnetic flux density field was displayed by the device. In the same direction, this measurement amount was recorded for 3 times and average calculated. Then, x, y, and z components of the MF were measured (by rotating SAMFM) at the same point. Here, the reading operation was done 3 times for each component and then, the resultant of these measures was recorded with the help of Equation 1. Finally, the amount of MF (in fact, this number is the resultant of the three directions that is shown as a number of on-screen display of the three-axis device) was measured by TES-1394 at the same point for three times and the average was recorded.

Data were analyzed using the SPSS 20 (Chicago, IL, USA). All the measurements were performed from 9 A.M. to 3 P.M. at 32°C and smooth air condition.

RESULTS

Minimum, maximum, mean, and standard deviation of magnetic flux density of various sources of ELF-MF measured by single- and three-axis devices are presented in Table 1.

Table 1. Minimum, maximum, mean, and standard deviation of magnetic flux density of various sources by the devices (μT)

	single-axis instrument								Three-axis instrument			
	Maximum of single-axis				Resultant of X,Y and Z				Resultant of three-axis			
	Min	Max	Mean(SD)	n	Min	Max	Mean(SD)	n	Min	Max	Mean(SD)	n
Generator's building	5.47	13.10	8.72(3.22)	15	7.10	17.50	11.12(4.25)	45	8.43	17.60	12.9(3.60)	15
Transformers	0.18	5.07	2.98(1.60)	24	0.22	7.41	3.69(2.17)	72	2.56	8.53	4.76(2.10)	24
63kv Substation	0.20	12.00	3.12(1.90)	48	0.23	12.24	4.06(3.00)	144	3.00	14.40	5.01(2.75)	48
230 kv Substation	1.39	6.64	1.34(0.89)	27	1.72	7.80	3.77(2.38)	81	2.50	9.42	4.81(2.70)	27
Control room building	0.33	2.12	0.82(0.59)	36	0.38	2.95	1.02(0.75)	108	0.33	2.96	1.2(0.81)	36
63 kv Power lines	0.78	1.33	1.08(0.19)	39	0.94	1.87	1.36(0.36)	117	1.03	2.11	1.54(0.35)	39

In the generator building, the minimum, maximum, and mean values of the magnetic flux density measured by the three-axis device were greater than those measured by the other two methods. Besides, a significant difference was found among SAMFM, three-axis resultant, and three-axis device regarding the minimum, maximum, and mean values. At the station in the vicinity of the transformers, the value of the three-axis device was higher compared to the others although the values were close to each other. However, the values of the maximum axis were less than those of the resultant and the three-axis device.

At the 63 kV substations, the maximum of single-axis, resultant of three axes, and the three-axis device values of ELF-MF were partly close to each other. However, the value of the three-axis device was greater than that of the other two methods. Moreover, the mean of the maximum axis was considerably different from that of the three-axis device.

At the 230 kV substation, the measured values at the maximum axis were quite lower than those of the resultant of the three axis and the three-axis device.

In the control room building, the measured values of the three methods were close to each other. Furthermore, the results of measurement of the MFs under the power line showed that although the measured values of the three methods were different, the difference was not significant. Minimum, maximum, and mean values of the measurements in the recent cases (control room building and power lines) showed that the values of the three methods at low flux density were close to each other.

The minimum, maximum, mean, and standard deviation of the magnetic flux density irrespective of the production resource and only based on the measurement methods are presented in Table 2. The results of this table indicate a more real perspective of the difference among the MF measurements by the three methods, because in comparison to the report of statistical descriptions for each source (that the number of measurements was limited to that source), a greater number of samples (the data related to all the sources for each measurement method) has been considered in obtaining the statistical descriptions.

Table 2. Minimum, maximum, mean, standard deviation, and number of measurement points of magnetic flux density (μT)

	Min	Max	Mean	SD	n
Maximum of single-axis	0.18	13.17	2.77	2.8	189
Resultant of X,Y and Z	0.22	17.50	3.40	3.41	567
Three-axis instrument result	0.33	17.60	4.14	3.73	189

According to Table 2, although the maximum value of the resultant method was greater than those of single- and three-axis devices, the mean of magnetic flux density by the three-axis device was greater compared to the resultant and maximum axis.

Comparison of the means of magnetic flux density at the maximum axis, resultant of the measured three axes by the single-axis device, and the results of the three-axis device is shown in Table 3.

Table 3. Compression of magnetic flux measurements by the three methods

	Mean difference	Std. error	P-value	95% Confidence interval	
				Lower bound	Lower bound
Maximum of single-axis Resultant of X,Y and Z	-0.63012	0.59517	0.291	-1.8043	0.5440
Maximum of one-axis Three-axis instrument	-1.37132*	0.59517	0.022	-2.5455	-0.1972
Resultant of X,Y and Z Three-axis instrument	-0.74121	0.59517	0.215	-1.9154	0.4329

The results of one-way ANOVA (post hoc-LSD) revealed a significant difference between the maximum axis value and the results of the three-axis device (*P*=0.022). However, no significant difference was found between the resultant of the three axis of x, y, and z and the maximum axis (*P*=0.29) and three-axis device (*P*=0.21). This implies that although the resultant of the three axis can help show a more real value of the MF, the results are still unreliable.

DISCUSSION

In this study, magnetic flux density was measured in the vicinity of power plant sources of ELF-MF. The measurements were performed by HI-3604 (as a device with a single-axis probe) and TES-1394 (as a device with a three-axis probe).

As ACGIH has mentioned in its guideline of TLVs and BELs threshold, there is insufficient information on human responses and possible health effects on MFs in frequency range of 1 Hz to 30 KHz to permit the establishment of a TLV for time-weighted average exposure [2].

The results (Tables 1 and 2) showed that the TES-1394 device had a higher maximum value compared to the HI-3604 device both as the resultant of three axes and in the maximum axis. This indicates the reliability of this device compared to the single-axis devices. With an overview of Table 2, we can also find that it was true even for the minimum and mean values.

The results (Tables 1 and 2) also indicated that the maximum and mean values of the resultant of three axes (max=17.5; mean=3.40±3.41), were greater than the maximum axis (max=13.17; mean=2.77±2.8). Hosseini et al. calculated the maximum resultant of the MF by measurement of x, y, and z components (x, y, and z axes measured with HI-3604 and the resultant calculated with Equation 1) and compered that to the maximum value (in fact, the maximum axis value) of the MF. The results showed that in all cases, the maximum resultant of the MF was higher than the maximum axis value [25]. Moreover, Nasiri et al. conducted a study using the HI-3604 device and used Equation 2 to calculate the resultant value [26].

Based on Table 3, the results of TES-1394 were significantly different from the maximum axis value of HI-3604 (P=0.022), but not from the resultant of the three directions.

Furthermore, the resultant value had no significant difference from the maximum axis value of HI-3604 and the results of TES-1394. This indicated that the resultant value was close to each of these two values and represented the average of the two. However, we should note that the best results were related to TES-1394, because it has a three-axis probe. Thus, we can claim that the maximum axis value of HI-3604 did not give us a comprehensive assessment of the field. The study by Nasiri et al. also indicated that assessment of one direction was no comprehensive MF assessment in the work environments [26]. Similarly, although environmental assessment of MFs by single-axis probe devices could be relatively useful, using three-axis probe devices was recommended for long-term, more comprehensive measurements of MF [27]. As seen in the discussion, these are few such studies (Single-axis probe magnetic field meter vs three-axis probe magnetic field meter) and may be this is reason of frequent use of single-axis probe magnetic field meter without consideration of significant difference of MF value compered to three-axis probe magnetic field meter. Therefore, the emphasis on this point can help in considering the differences value in laboratory and fields studies.

CONCLUSION

The best and most reliable way to measure MF is using a device with a three-axis probe and measuring the maximum MF by the singe-axis device cannot be reliable. Moreover, in the absence of a device with a three-axis probe, if there is a single-axis probe, the best we can do is obtaining the resultant from the three directions of the field. Finally, the more number of measurement stations and implication of studies like this in environment with smooth MF can be helpful in understanding of most reliable instruments.

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