STUDY AND EVALUATION OF INDUCED CURRENTS IN HUMAN BODY FROM EXPOSURE TO ELECTROMAGNETIC FIELDS AT LOW FREQUENCIES

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ABSTRACT
Extremely Low Frequency (ELF) Electromagnetic Fields due to low and medium voltages are normally low. But with the wide spread and increase in the use of electrical energy, the potential for exposure has increased considerably. The recent research has focused on potential health effects of magnetic fields because some epidemiological studies have suggested an increased cancer risk associated with estimated time of magnetic field exposure. Since the wavelength of ELF electric and magnetic field is sufficiently greater than the dimensions of the biological object, so the electric and magnetic fields can be independently treated. Our main topic in this research is to investigate the effect of magnetic field at power frequency and analyse of the interaction between these fields and the living organisms. We used the measured results and the applied the three techniques of simulating the induced currents in the human body by using a Matlab program. The obtained results can demonstrate the degree of danger due to the induced currents from both magnetic and electric fields. Comparing these results by the values given by International Committee on Non-Ionizing Radiation Protection (ICNIRP) guidelines can tell the degree of danger.

INTRODUCTION
Many methods have been developed to calculate the induced current densities due to the magnetic and electric fields in the vicinity of the human body. The paper will present three calculation methods:
1- The first method uses the ellipsoidal model to calculated the induced current densities from the exposure to the electromagnetic fields. This method studied proposed ellipsoidal model as shown in Fig. 1. This model is placed at the origin of the rectangular coordinate system. The size and shape of ellipsoid are determined by the parameters of a, b and c. The ellipsoid is expressed as:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1
\]

Where the parameters a, b and c are the axes of the ellipsoid with a>b>c.

The internal electric fields vectors in x, y and z-axis resulting from three orientations of the sinusoidal magnetic field are expressed as:

\[
\vec{E}_x = \frac{\omega}{c} c_b \left( c^2 z \vec{y} - c^2 y \vec{z} \right) B_x e^{j(\omega t - \phi_x)}
\]

\[
\vec{E}_y = \frac{\omega}{c} c_b \left( a^2 x \vec{z} - c^2 z \vec{x} \right) B_y e^{j(\omega t - \phi_y)}
\]

\[
\vec{E}_z = \frac{\omega}{c} c_b \left( b^2 y \vec{x} - b^2 x \vec{y} \right) B_z e^{j(\omega t - \phi_z)}
\]

Where

\( E_{Bx} \): electric field around x-axis induced by magnetic field component \( B_x \),

\( E_{By} \): electric field around y-axis induced by \( B_y \),

\( E_{Bz} \): electric field around z-axis induced by \( B_z \),

\( \omega \): angular frequency =2\( \pi \)f, \( f \)=50 Hz and \( \phi \): phase angles of \( B_x \), \( B_y \), and \( B_z \).

The total induced electric field in this model can be expressed as:

\[
\vec{E} = \vec{E}_{Bx} + \vec{E}_{By} + \vec{E}_{Bz}
\]

The total current density induced by magnetic fields is obtained from

\[
J = \sigma \vec{E}
\]

Where \( \sigma \) is the conductivity of biological object.

Adopting the above technique for a person sitting in front of a point source, taking the vertical ellipse at \( z=0 \) and neglecting the angle \( \phi \) in this case.

The parameters were taken as:
\( 2a=0.9m, 2b=0.6m \) and \( 2c=0.3m \) for an ordinary human configurations. It is assumed that the model is filled with a homogenous biological tissue and the exterior medium is air. The human body conductivity is assumed to be 0.1 S/m,[2] and the circulating currents due to the measured magnetic fields are computed accordingly.
The results of, induced electric fields and induced currents at different values of $y$ and $z$ considering $x=0$ from magnetic fields shown in Figs 3-5[2].

Since the spheroid model is nonmagnetic (human body), $H_m=H_0$

$A_a$ and $A_b$ are the depolarization factors given by:

$$A_a = 1 - \frac{1}{2}$$

$$A_b = \frac{1}{2}$$

And the relative complex permittivity $\varepsilon^*_r$:

$$\varepsilon^*_r = \varepsilon^* - j\frac{\sigma}{\omega\varepsilon_0}$$

Since $\varepsilon^*_r = 8.85 \times 10^{-12}$ F/m, then $\varepsilon^*_r = 1.2 \times 10^7 \angle 88.8$

The induced electric field, $E_{in}$ induced by the external magnetic field:

$$E_{in} = -j\omega\mu_s H_{ax} \left[ y\bar{z} - \frac{b}{a} z\bar{y} \right]$$

$$1 + \frac{b}{a}$$

$$E_{m2} = -j\omega\mu_s H_{ax} \left[ \frac{b}{a} \bar{x} - x \bar{z} \right]$$

$$1 + \frac{b}{a}$$

$$E_{m3} = -j\omega\mu_s H_{ax} \left[ \frac{b}{a} \bar{z} - x \bar{z} \right]$$

The internal magnetic field $\vec{H}_m$ by external electric field:

$$H_{e1} = -j\omega\mu_s E_{ex} \left[ y\bar{z} - \frac{b}{a} z\bar{y} \right]$$

$$1 + \frac{b}{a}$$

$$H_{e2} = -j\omega\mu_s E_{ex} \left[ \frac{b}{a} \bar{z} - x \bar{z} \right]$$

$$1 + \frac{b}{a}$$

$$H_{e3} = -j\omega\mu_s E_{ex} \left[ \frac{b}{a} \bar{z} - x \bar{z} \right]$$

Adopting this technique for a person sitting in front of a point source taking the vertical ellipse at $x=0$. The results of the induced magnetic fields, induced electric fields and induced current densities at different values of $y$ and $z$ considering $x=0$ from electromagnetic fields are shown in Figs 6-8. The induced current densities from electric field exposure only is shown in Fig 9. The induced current densities from magnetic field exposure only is shown in Fig 10. These figures indicate that the
induced current densities due to the electric fields are insignificant to be considered in calculations. These results are consistent with other researcher's findings [3].
The Third Method

This method considered the living organism as an electrically homogeneous cylinder, which is electrically isolated from its surroundings by dry air. An axially oriented and spatially uniform magnetic field \( H \) will induce an electric field in the exposed body, according to Faraday's law, the electric field \( E_i [4] \):

\[
E_i = -j \frac{\partial B}{\partial t} \left( \frac{\sqrt{3}}{2} \right) \tag{25}
\]

Where:
- \( r \): radial distance from the centre of the cylinder to the point where \( E_i \) is evaluated and
- \( E_i \): vector lies in a plane perpendicular to \( B \) and is oriented tangentially to circles of radius \( r \).

\[
E_i = j \omega B / \left( \frac{\sqrt{3}}{2} \right) \tag{26}
\]

\[
J = \pi r f \sigma B \tag{27}
\]

Applying this method on a person with head radius = 0.1m and body radius = 0.3m the results for induced currents are given in Figs 11.

![Image](image.png)

**Fig.11 The induced currents from magnetic field for human body**

**RESULTS AND DISCUSSIONS**

Time–varying magnetic fields induce currents within the body. It was noticed from the first method that the maximum measured magnitude of magnetic field was found at \( z = -0.2m \). The induced electric field and corresponding currents are higher at the upper part of the body than at the lower part of it. The maximum induced electric field is \( 2.186 \times 10^7 \text{V/m} \) and the maximum induced current density is \( 2.186 \times 10^7 \text{A/m}^2 \) at the upper part.

In the second method, we calculated the total induced current from external magnetic field and external electric field and the contribution of each. The following results were predicted. The magnetically induced electric field strength and the corresponding current density are greatest at the periphery of the body. The induced magnetic field values in the first method are less than the induced magnetic field in this case because here we use the electromagnetic field. The induced electric fields in this case due to electromagnetic fields nearly have the same shape but differ in values with the induced electric fields due to magnetic fields as in first method. Where the induced electric field is less than the first method by approximately 20\%, which means that the induced electric fields due to magnetic field decreases the total induced electric fields because it's direction is opposite to the induced electric field from external electric field. This method indicates that the induced currents due to the electric fields are insignificant to be considered in calculations.

The third method, we calculated the magnetically induced electric field and corresponding current density at the surface of human head and body. The calculated induced current densities at human head was \( 1.35 \times 10^{-7} \text{A/m}^2 \), and that at the human body was \( 3.96 \times 10^{-7} \text{A/m}^2 \). The average induced current was \( 2.65 \times 10^{-7} \text{A/m}^2 \) which is near to the calculated value using method one. From these methods it is recommended to use the first method for accurate and precise calculations these results are in quite agreement with the practical measured values.

**CONCLUSIONS**

It is clear that the first technique express the values with great accuracy compared to the second technique. For that the first method will be adopted instead of the second method for measurements which have 3 coordinates and takes longer time. The third simplified and quick method could be used instead of the first for calculating the induced electric field and corresponding induced current density for the average measurements and for measurements without the three components which is more easy and simple. The magnitude of induced magnetic field from the applied magnetic field is virtually the same outside the body as inside it. Unlike The electric field for which the internal field strength is many orders of magnitude less than that of external field. This indicates the danger of magnetic field.

It is noticed that the maximum calculated induced current densities was \( 3.96 \times 10^{-7} \text{A/m}^2 \) which is so small when compared to the ICNIRP standard (10mA/m²) that may produce any significant biological effects. But it has to be noticed that these induced current densities from short–term exposure (few hours) that it may cause minor transient effects on health. Long term exposures may cause dangerous effects [5].

**REFERENCES**


