Calculation and Measurement of Induced Current Density Inside Human Body Under 60 Hz ELF Magnetic Fields

Suk Won Min[#1], Eung Sik Kim[*2], Sung Ho Myung[**3]

[#]*Electrical and Communication Department, Soonchunhyang University*
Asan Chungnam, 336-745, Korea
[1]swonmin@sch.ac.kr

[*]*Safety and Health Department, Hoseo University*
Asan Chungnam, 336-795, Korea
[2]eskim@hoseo.edu

[**]*Electrical Power Research Laboratory, korea Electrotechnology Research Institute*
Sungju-dong, Changwon, Kyongnam, 641-120, Korea
[3]shmyung@keri.re.kr

***Abstract*— This paper calculated and measured the characteristics of current density induced inside human body under 60 Hz extremely low frequency magnetic fields. Human model was composed of several organs and other parts, whose shapes were expressed by spheroids or cylinders. Organs such as the brain, heart, lungs, liver and intestines were taken into account. Applying the boundary element method to the human model, we estimated effects on the induced current distribution due to differences of the organ conductivity and shape.**

Key words: induced current density, extremely low frequency magnetic field, human model, organ conductivity

I. INTRODUCTION

Though a large number of epidemiological studies have been carried out to assess possible links between exposure to ELF fields and cancer risk [1]-[3], there are concern on possible health effects from exposure to electric and magnetic fields because research results are somewhat inconsistent. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set international guidelines for limiting the exposure in 1998 [4].

Exposure to time varying electric and magnetic fields result in induction of internal body current, and the known adverse effects are associated with nerve excitation. ICNIRP's basic limit is set at 2 mA/m^2 (rms, averaged over a cross-section of 1 cm^2 perpendicular to the current direction) for general public exposure, a value not to be exceeded at any time.

To investigate current densities inside human body under 60 Hz ELF magnetic fields, we applied the boundary element method to calculate current densities induced in organs and measured them by the use of a phantom experiment.

II. CALCULATION

A. Method

Basic equations related with a magnetic fields induction current analysis are as follows.

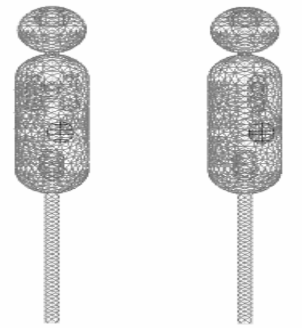
$$\nabla \times B = j\omega \quad (1)$$

$$\nabla \cdot J = 0 \quad (2)$$

$$J = \sigma E \quad (3)$$

Where E: induced electric field, B: magnetic flux density, ω: angular frequency, σ: conductivity, J: induction current density, and time differential is transformed into $j\omega$.

It is known we can solve these equations using various numerical methods such as impedance method [5], finite differential time domain method [6], finite element method [7], boundary element method [8], etc. In this paper we use a "Faraday 3D" program of 3 dimensional boundary element method which is made by IES (Integrated Engineering Software) in Canada because this is easy to make input data and calculation time is short. Human 170 (cm) tall is modeled in the brain, heart, lungs, liver, intestines, and other parts as Fig. 1 whose shapes are spheroids or cylinders as in [9] and organ conductivity is assigned to human model as shown in Tab. 1 [8].



a) Front view b) Side view

Fig. 1 Surface meshes of human model

TABLE I

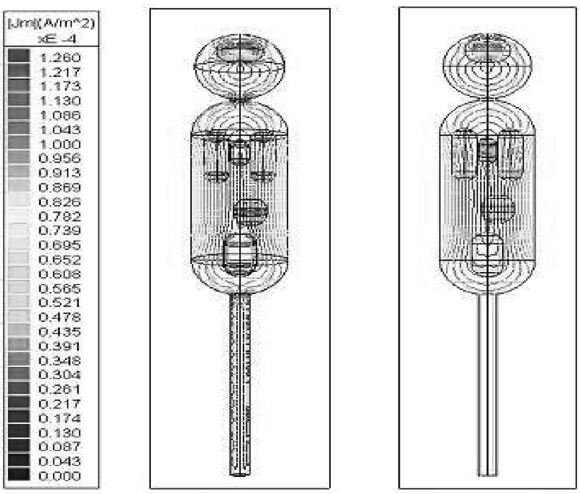
ORGAN CONDUCTIVITY ASSIGNED TO HUMAN MODEL.

Organ	Conductivity (S/m)
Brain	0.75
Heart	0.70
Lungs	0.10
Liver	0.10
Intestines	0.03
Other parts	0.11

B. Results

Uniform magnetic fields were applied in the direction of 3 orthogonal axis(x axis; a direction from the abdomen to the back, y axis; the lateral direction, z axis; a direction from the head to the leg), respectively. Magnitude and frequency of magnetic fields density was 10 μT and 60 Hz.

Fig. 2 shows the distribution of current density induced at a cross section (y-z plane) of brain (x=0 cm) and heart (x=4.5 cm) when magnetic fields entered from the abdomen. The maximum current density of 0.126 mA/m^2 was induced in a brain because conductivity of brain was highest. Meanwhile, 0.056 mA/m^2 was in lungs because conductivity and radius of lungs was smaller than a brain.



a) x=0 cm b) x=4.5 cm

Fig. 2 Distribution of current density induced at a cross section of brain and lungs when magnetic fields were incident from the abdomen

Fig. 3 shows the distribution of current density induced at a cross section (z-x plane) of brain (y=0 cm) when magnetic fields entered from the lateral direction. The maximum current density of 0.164 mA/m^2 was induced in a heart because conductivity and radius of heart was high.

Fig. 4 shows the distribution of current density induced at a cross section (x-y plane) of brain (z=125 cm) when magnetic fields entered from the head. The maximum current density of 0.120 mA/m^2 was induced in a heart and vector fields were concentrated in a heart because conductivity of heart was higher than the other circumferential organ.

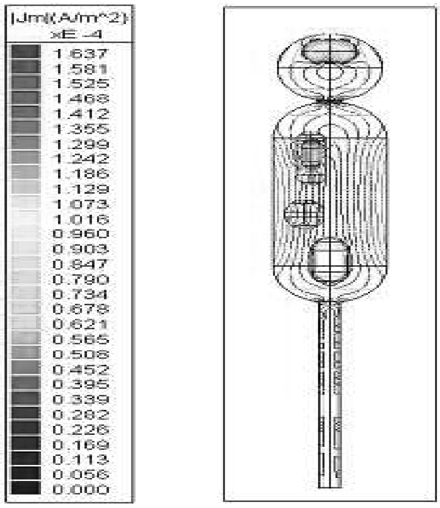
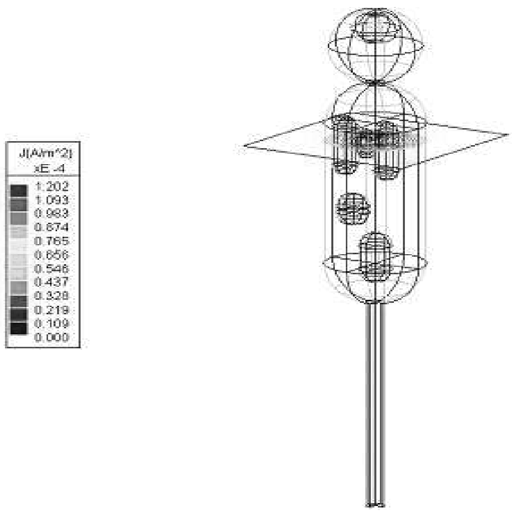
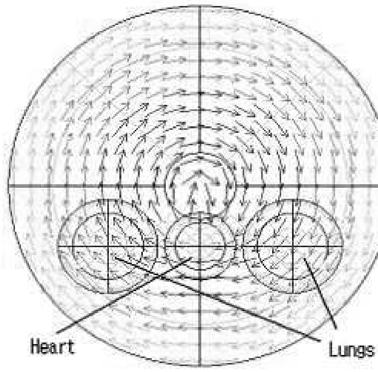


Fig. 3 Distribution of current density induced at a cross section of brain when magnetic fields were incident from the lateral direction



a) contour map



b) Vector fields

Fig. 4 Distribution of current density induced at a cross section of heart and lungs when magnetic fields were incident from the head

III. MEASUREMENT

A. Method

To measure the induced currents in human body magnetic fields generation apparatus is designed as in Fig.5. 4 groups of coils are positioned to make uniform vertical fields varying from 100~300 μT. A Schematic view of the measurement system is shown in Fig. 6.

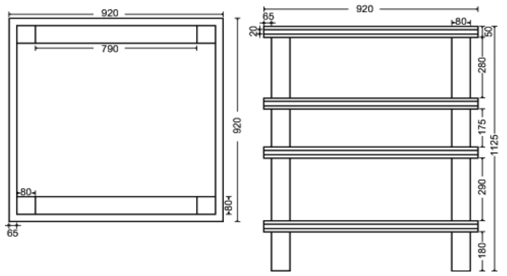


Fig. 5 Apparatus for uniform field generation

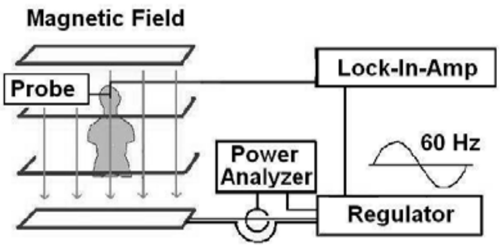


Fig. 6 Schematic of the measurement system

The human body is mocked up with a silicon frame and the molds of other organs are made as in Fig. 7. As a result the mock-up can be filled with Agar having different conductivities.

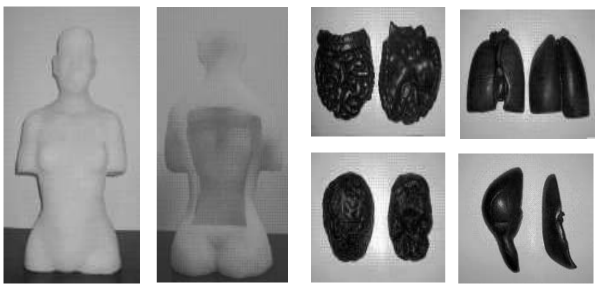


Fig. 7 The mock-up of human body and organs

B. Results

• Homogeneous brain model

Fig.8 shows current densities measured in the head having homogeneous conductivity (0.2 S/m) with different measuring points according to depth (6cm, 8cm) when exposed to 100, 200 and 300μT. The magnitude is slightly higher at 8cm depth than at 6cm depth and the magnitude at back of head is also higher than that of the front.

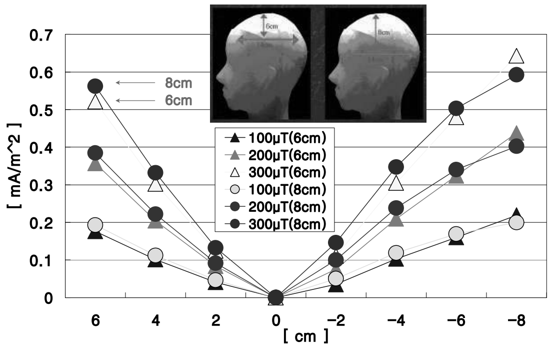


Fig.8 Current densities measured at different depth in homogeneous head model

• Inhomogeneous brain model

Fig. 9 shows the brain model which has 2 conductivities as shown in Table 1 (0.75 S/m for brain and 0.11 S/m for the surrounding). The measuring points were distributed along the sagittal and coronal plane at the 2 different depth level from the top of the head (6cm, 8cm).

The induced current densities were measured along the midfrontal and sagittal plane at 6 and 8cm depth when exposed to 100, 200 and 300 μT as in Fig. 9, 10.

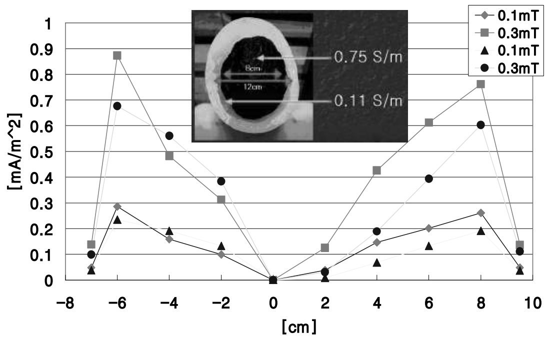


Fig. 9 Current density along the sagittal plane

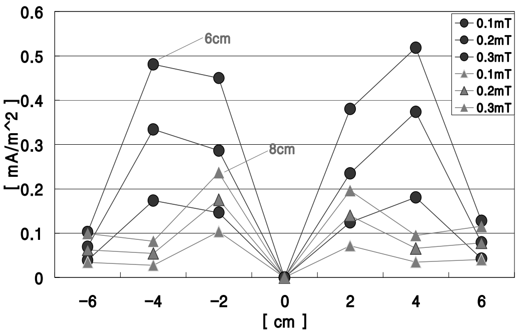


Fig. 10 Current density along the midfrontal plane

• Inhomogeneous abdomen model

Fig. 11 shows the abdomen model which has 2 conductivities as shown in Table 1 (0.03 S/m for intestines and 0.11 S/m for the surrounding). The measuring points were distributed along the sagittal and coronal plane at 5cm, 8cm depth level from the plane 5cm above navel position.

The magnitude is slightly higher at 8cm depth than at 5cm depth and the magnitude of front is higher than that of rear as in Fig. 11..

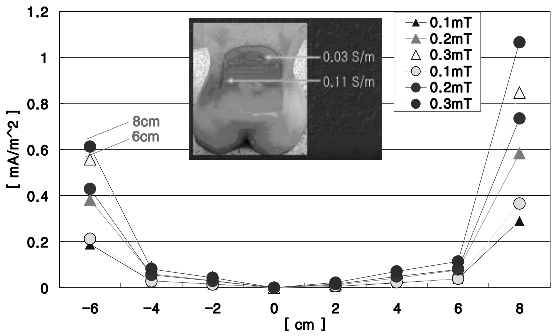


Fig. 11 Current density along the sagittal plane at different depth

- Inhomogeneous chest model

Fig. 12 shows the chest model which has 2 conductivities as shown in Table 1 (0.7 S/m for heart and 0.11 S/m for the surrounding). The measuring points were distributed along the sagittal and coronal plane at 10 and 15cm depth level from the collarbone position.

The induced currents were measured along the midfrontal plane at 15 cm depth. The current density at heart is relatively higher than that of surrounding due to the high conductivity.

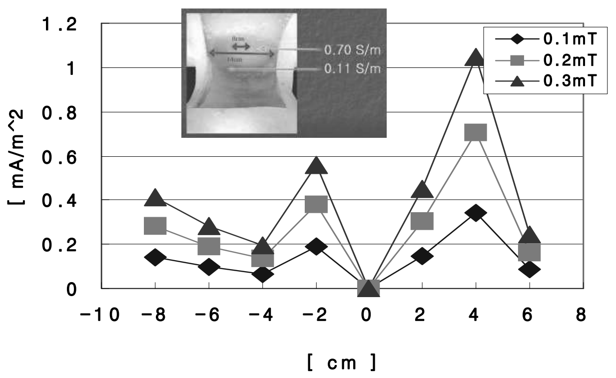


Fig. 12 Current density along the midfrontal plane at 15 cm depth

IV. CONCLUSION

This paper calculated and measured the characteristics of current density induced inside human body under 60 Hz extremely low frequency magnetic fields.

As results of study, we found the maximum current density of 1.3 mA/m^2 was calculated in a brain surface when magnetic field of 83.3 μT entered from the abdomen, which was ICNIRP's guideline for 60 Hz magnetic fields. This could satisfy the ICNIRP's basic limit of 2 mA/m^2. In homogeneous mock-up human model current density at the larger area of cross section is higher than that of smaller one. The maximum densities are 0.8 and 1.7 mA/m^2 respectively in head and abdomen when exposed to 300 μT. In inhomogeneous model current density are dependent on conductivity. The current density at area of higher conductivity is larger than that of lower conductivity. Conductivity and area of cross section are the important factors in making the field distribution. But the position and difference of conductivity of neighboring material are also important. To estimate the precise field value in much more complex human body correct conductivity and position of each part should be known.

REFERENCES

[1] A. Ahlbom et al., "A pooled analysis of magnetic fields and childhood leukemia," Br J Cancer, vol. 83, no. 5, pp. 692-698, May 2000.

[2] S. Greenland et al., "A pooled analysis of magnetic fields, wire codes, and childhood leukemia," Epidemiology, vol. 11, no. 6, pp. 624-634, June 2000.

[3] MS Linet et al., "Residential exposure to magnetic fields and acute lymphoblastic leukemia in children," New Engl J Med, vol . 337, pp. 1-7, 1997.

[4] International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300GHz)," Health Phys., vol. 74, pp. 494-522, April 1998.

[5] P. J. Dimbylow, "Induced current densities from low-frequency magnetic fields in a 2 mm resolution, anatomically realistic model of body," Phys. Med. Biol., vol. 43, pp. 221-230, 1998.

[6] C. M. Furse, O. P. Gandhi, "Calculation of electric fields and currents induced in a millimeter resolution human model at 60 Hz using the FDTD method," Bioelectromagnetics, vol. 19, pp. 293-299, 1998.

[7] P. Baraton, J. Cahouet, B. Hutzler, "Three dimensional computation of the electric fields induced in a human body by magnetic fields," in Proc. of 8th Intern. Symposium on High Voltage Engineering 1993, pp. 517-520.

[8] O. Bottauscio, R. Conti, "Magnetically and electrically induced currents in human body models by ELF electromagnetic fields," in Proc. of 10th Intern. Symposium on High Voltage Engineering 1997, 5-8.

[9] K. Yamazaki, T. Kawamoto, H. Fujinami, T. Shigemitsu, "Investigation of ELF magnetically induced current inside human body development of estimation tools and effect of organ conductivity," Trans. IEE Japan, vol. 120-A, pp. 81-87, Jan. 2000.