Assessment of Current Density Induced within Human Body in the Proximity of Induction Heat Hob by Numerical Simulation

Yukihisa Suzuki(1), Kanako Wake(2), Masao Taki(1), Soichi Watanabe(2)
(1)*Department of Electrical & Electronic Engineering, Faculty of Urban Liberal Arts, Tokyo Metropolitan University, 1-1 Minamiosawa, Hachiojim, Tokyo 192-0397, Japan.*
suzuki@eei.metro-u.ac.jp

(2)*National Institute of Information and Communications Technology, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan*

ABSTRACT

Numerical dosimetry on induced current density inside human body exposed to magnetic fields in the vicinity of induction heat (IH) hob is performed by the impedance method (IM). Two detailed voxel models of the average Japanese adult male and female, which are developed by National Institute of Information and Communications Technology (NICT) in Japan, are used. Results of these analyses indicate that the maximum values of current density in trunk are 8.8 mA/m^2 in the male model and 5.3 mA/m^2 in the female model. These are obtained by the 23kHz actually measured incident magnetic field. Assessment of simultaneous exposure to multiple frequency magnetic fields is investigated. Calculated values according to the definition of ICNIRP basic restriction are 0.01 for the male model and 0.008 for the female model in this condition.

INTRODUCTION

Induced heat (IH) hobs what is called IH cooker, which use 20 kHz-60kHz time varying magnetic fields for heating frequency, increase in its number for general use because of their convenience for cooking in Japan. IH hobs are used in the proximity of a human body. These situation stimulate public concern on possible health effects of exposures to electromagnetic fields.

The time varying magnetic field used by IH hob is classified intermediate frequency by WHO, and it induces electric field or current in the human body. Basic restrictions are provided on electric current density to prevent effects on nervous system functions by ICNIRP[1] as the guideline for intermediate frequency magnetic field. So, it warrants estimating induced current quantitatively in the human body to compare basic restrictions.

The purpose of this study is to examine numerical dosimetry for induced current densities within the human body caused by magnetic field in the proximately of IH hobs with the impedance method (IM)[2], and to compare results of induced current density calculation with the current density values given in basic restrictions. We discuss the relation between induced current and incident magnetic field on human body to compare the relation between basic restrictions and reference levels given in guidelines. Furthermore, simultaneous exposure to multiple frequency magnetic fields, which is higher harmonics generated by IH hob, is discussed.

NUMERICAL DOSIMETRY OF INDUCED CURRENT DENSITY

We have attempted to calculate induced current density distribution with IM. To calculate induced current under the realistic condition, actual magnetic field distribution is required. Distribution of magnetic flux density was measured with 5cm intervals by the 3-axis magnetic field probe in the proximity of IH hob under the following operating conditions. Water is filled in the cooking vessel with 160mm diameter and heated by the 3kW heating coil. During measurement of magnetic field distribution, it keeps maximum input power. Figure 1 shows magnetic flux distribution we have measured. Magnetic flux is highly localized in the proximity of IH hob.

Two voxel models, which is developed by National Institute of Information and Communications Technology (NICT)[3], of whole human-bodies based on the average Japanese adult male and female data are used to construct realistic cooking condition. These detailed human models have 2 mm resolutions, and are composed of over 50 tissues and organs. In this study, electric conductivities at 23 kHz are provided for each tissue by use of parameter model[4].

The calculation condition is as follows. The top of the IH cooker is located at 800 mm position from the floor, and the front edge of IH cooker is placed 50 mm away from the nearest surface of the human model. That is the nearest position where human can approach to an IH hob.

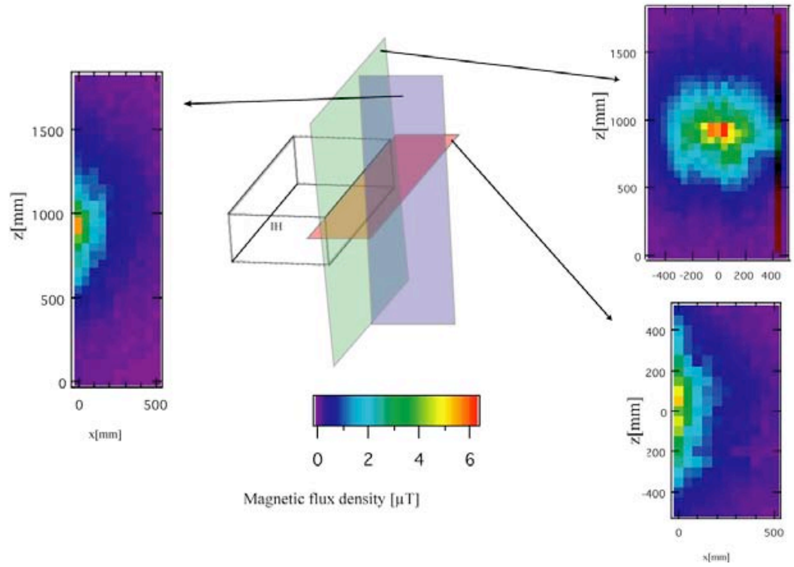

Fig. 1. 3D distribution of magnetic flux density in the proximity of IH hob.

RESULT

Results of numerical calculation are shown in Fig.2. Induced current densities are averaged over a cross-section of 1cm^2 perpendicular to the current direction in these figures. Higher values of induced current density tend to be appeared at the tissue of muscle, where a few cm inside from the skin in both models. Because muscle has relatively higher conductivity (0.34 S/m at 23 kHz) than surrounding tissues for example fat (0.02 S/m at 23kHz). Therefore induced currents are concentrated into muscle.

The maximum values of current density obtained in trunk are 8.8 mA/m^2 in the male model and 5.3 mA/m^2 in the female model, respectively. The basic restriction of induced current for general public exposure given by ICNIRP is 46 mA/m^2 at 23 kHz. Induced current values are not exceeded the basic restriction in both models under this calculation condition.

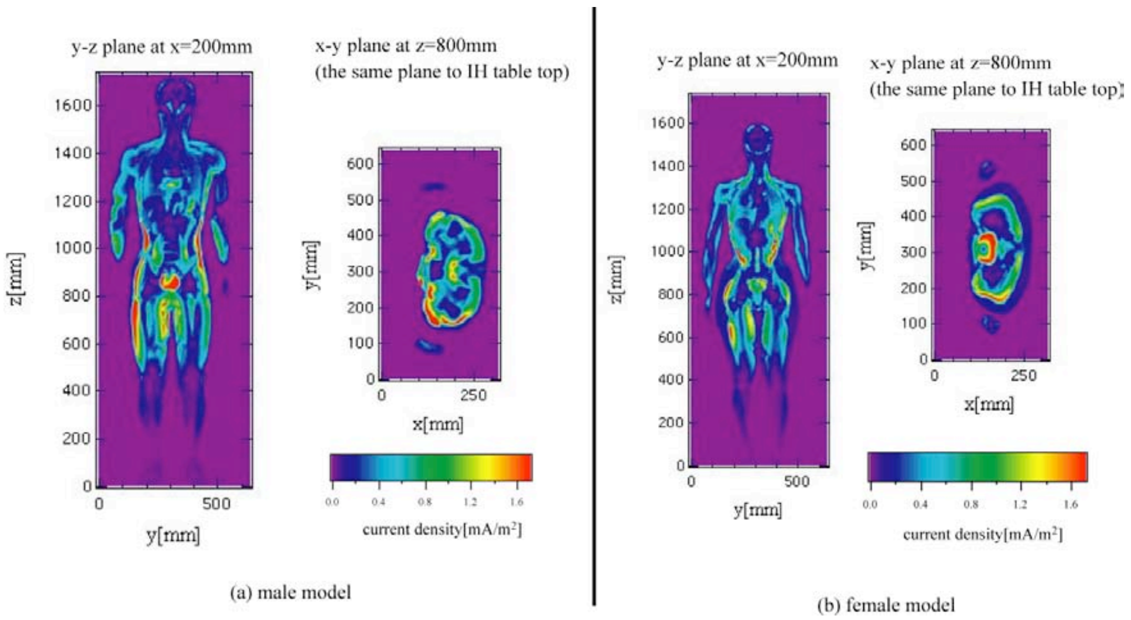

Fig. 2. Result of induced current analysis by Impedance Method.
(a) Result of male model. (b) Result of female model.

DISCUSSION

Comparison with Reference Revel

We discuss the relation between induced current value and incident magnetic field value to evaluate the consistency with guidelines. The maximum incident magnetic field values on the human body are 2.3μT at male model and 2.5μT at female model. When these magnetic field values are normalized to 6.25μT, which is given in ICNIRP reference level for general public exposure, maximum values of induced current density are 25 mA/m^2 for male model and 13mA/m^2 for female model. If the maximum value of incident magnetic field is smaller than reference level, values of maximum current density do not exceed basic restriction for general public exposure, in this case of localized exposure due to IH hob.

Consideration of Multiple Frequencies

Figure 3 shows spectrum of time varying magnetic field measured in the proximity of IH hob. In this case, fundamental heating frequency is approximately 23kHz. Second and third higher harmonic component is observed at 46 kHz and 96 kHz, respectively. Magnetic flux density strength at second higher harmonic is 0.8% of fundamental frequency, and at third higher harmonic is 7% of fundamental frequency. These relatively small components of higher harmonics induce electrical current. Therefore, contribution rate of these harmonics to total induced current density should be investigated. In this paper, we try to estimate induced current densities caused by higher harmonics.

To compare induced currents with basic restriction under the consideration of multiple frequencies, followings are postulate. (i)Flux density (B) distributions of higher harmonics are same with that of fundamental frequency, because B field source is heating coil. (ii)Tissue conductivities at 46kHz and 96kHz are almost equal to that of fundamental frequency. (iii)According to measurement data, amplitude of second higher harmonic is 0.8% of fundamental frequency, and third higher harmonic is 7% of fundamental frequency, respectively. Maximum values of induced current density caused by each higher harmonic component under these postulations are shown in Table 1. J_i and $J_{Br,i}$ indicate maximum current density in the trunk at frequency i and the value of basic restriction for general public exposure at frequency i, respectively. As shown in Table 1, Induced current value caused by higher harmonics is smaller than 2% of basic restriction for each frequency.

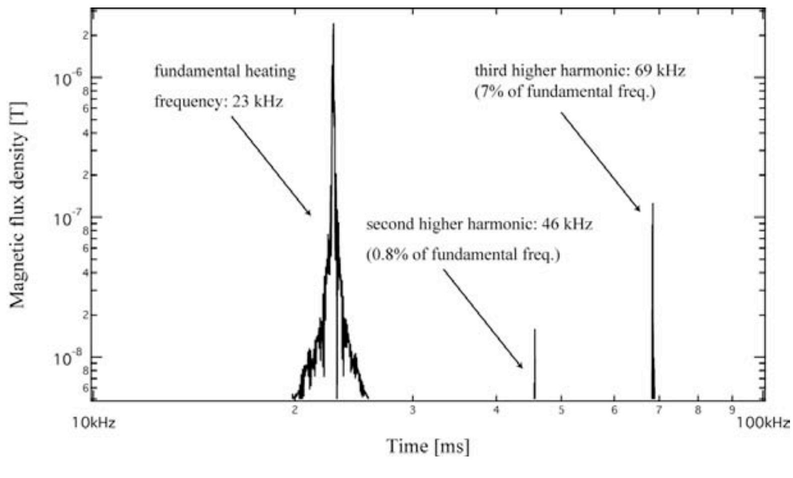

Fig. 3. Spectrum of flux density measured in the proximity of IH hob.

Table 1. Estimation of maximum induced current density at each higher harmonic component.

	23kHz		46kHz		69kHz	
	J_i mA/m^2	$J_{Br,i}$ mA/m^2	J_i mA/m^2	$J_{Br,i}$ mA/m^2	J_i mA/m^2	$J_{Br,i}$ mA/m^2
male	8.8	46	0.14	92	1.8	138
female	5.3		0.085		1.1	

Evaluation of simultaneous exposure to multiple frequency are performed with estimated values provided in Table 1, according to the formula (1) provided by ICNIRP[3].

$$R_B = (R_f + R_h) = \sum_{i=1Hz}^{10MHz} \frac{J_i}{J_{Br,i}} \leq 1 \qquad (1)$$

Here, R_B is total value. R_f and R_h indicate contribution of fundamental frequency and contribution of higher harmonics to the total value. Table 2 shows result of the evaluation. R_B is satisfied the basic restriction in both male model and fmale model cases. The contributions of higher harmonics to the total values are 5 % for male model and 7 % for female model. As shown in this result, it is found that effect of higher harmonics is relatively small in this evaluate condition.

Table 2. Evaluation result of simultaneous exposure to multiple frequency magnetic fields.

	R_B	R_f	R_h
male model	0.21	0.2	0.01
female model	0.12	0.112	0.008

SUMMARY

Numerical dosimetry on induced current density inside human body exposed to magnetic fields due to induction heat hob is performed. Maximum induced currents do not exceed the basic restriction provided by ICNIRP. Simultaneous exposure to multiple frequency B fields is evaluated with our calculation model. It is found that the contribution of higher harmonics is relatively small. Calculations performed in this study are one of the cases of localized exposure to time varying magnetic field. To understand this, further investigation to clear the relationship between incident magnetic field and induced current in the human body is required.

ACKNOWREDGEMENT

The authors are most grateful to Dr. K. Yamazaki of Central Research Institute of Electric Power Industry for lending us magnetic probe he has developed.

REFERENCES

[1] International Commission on Non-Ionizing Radiation Protection, ”Guidelines for Limiting Exposure to Time Varying Electric, Magnetic, and Electromagnetic Fields (up to 300GHz)”, Health Phys., 74, pp. 494-522, (1998).
[2] N. Orcutt and O. P. Gandhi, “A 3-D Impedance Method to Calculate Power Deposition in Biological Bodies Subjected to Time Varying Magnetic Field”, IEEE Trans. Biomed. Eng., Vol.35, pp.577-583, 1988.
[3] T. Nagaoka, S. Watanabe, K. Sakurai, E. Kunieda, S. Watanabe, M. Taki and Y. Yamanaka, ”Development of realistic high-resolution whole body voxel models of Japanese adult and females of average height and weight, and application of models to radio-frequency electromagnetic-field dosimetry”, Phys. Med. Biol., 49, pp. 1-15 (2004).
[4] S. Gabriel, R. W. Lau and C. Gabriel, ”The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues”, Phys, Med, Biol., pp.41, 2271-2293, (1996).