Numerical Calculation of Induced Current Densities in the Human Body due to Intermediate Frequency Magnetic Fields

Yukihisa SUZUKI[†], Kanako WAKE[‡], Sumiko WATANABE[†], Masao TAKI[†], Soichi WATANABE[‡], and Yukio YAMANAKA[‡] [†]Graduate School of Engineering, Tokyo Metropolitan University [‡]Communications Research Laboratory

E-mail: suzuki@eei.metro-u.ac.jp

Abstract: Numerical dosimetry on induced current density inside human body exposed to magnetic fields due to induction heat (IH) hob is performed by the impedance method (IM). Magnetic flux density distribution which is obtained by measurement with magnetic probe is used for incident magnetic field in IM. Current density distributions induced within two voxel models of the average Japanese adult male and female are obtained. These results indicate that hot spots of induced current density are observed at a few [cm] inside from the surface of two models because of inhomogeneous conductivity of tissues. The maximum value of current density inside the male model is larger than that inside the female model.

Key words: intermediate frequency, inhomogeneous magnetic field, induced current, induction heat cooker, anatomical human model, impedance method, dosimetry

1. Introduction

A variety of equipments using electric power have come into common use in our living environment. These equipments, which have possibility to be time varying magnetic field sources, are used in the vicinity of human body, and a dosimetry should be performed as to magnetic fields from these equipments.

For example, time varying magnetic fields from 50[Hz] to 100[kHz] are observed in the vicinity of induction heat (IH) equipments, because inverter circuits based on power semiconductor devices as IGBT (Insulated Gate Bipolar Transistor) are used in these equipments. Electromagnetic fields (EMF) from 300[Hz] to [10MHz] are classified intermediate frequency in International EMF Project by WHO[1] and International Commission on Non-Ionizing Radiation Protection (ICNIRP). IH hobs, which use 20[kHz] magnetic field for heating frequency, increase in its number for general use because of their convenience for cooking. Therefore, an interest on interactions between an intermediate frequency magnetic field and biological bodies is increasing.

It is thought that, as the electromagnetic field (EMF) effect on the biological tissues, the induced current

density is dominant from 1[Hz] to 10[MHz]. Basic restrictions are provided on current density to prevent effects on nervous system functions[2]. It warrants estimating induced current in the human body to compare basic restrictions provided by ICNIRP.

The purpose of this study is to examine numerical dosimetry of induced current inside of the human body caused by magnetic field from IH cookers with the impedance method (IM)[3], and to obtain the detailed distribution of induced current density in a realistic human model.

2. Properties of magnetic field due to IH hob

We have measured magnetic field by a measurement system as shown in Fig.1. Measurement region is 500[mm](x-direction) \times 1000[mm](y-direction) \times 1800[mm](z-direction) in front of an IH hob. Magnetic field from the IH cooker is measured by the magnetic field probe which can measure the three components of magnetic field (B_x, B_y, B_z) in the frequency region from 25Hz to 100kHz. Magnetic field data are measured 50mm intervals in the measurement region. An example of measurement result in the time domain is shown in Fig.2 (a). Time dependent waveform indicate that magnetic field of fundamental heating frequency (20[kHz]) is modulated by 100[Hz] ELF



Fig. 1: Schematic view of a measurement system for magnetic field distribution in the vicinity of an IH hob.

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component due to full wave rectification. A power spectrum by FFT analysis is shown in Fig.2 (b). In this case of measurement, fundamental heating frequency is about 23[kHz], and very small second and third higher harmonic are observed. Therefore, only fundamental heating frequency is considered in this induced current analysis.



Fig. 2: A measurement result by magnetic probe: (a) wave form in the time domain (b) power spectrum in the frequency domain by FFT analysis.

3. Numerical calculation of induced currents

In this study, IM[3] is used to estimate induced current in human bodies, because it is assumed that inducing frequency is sufficiently low (quasi-static) that the human body is much smaller than the free-space wavelength.

Two voxel models[4] 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] resolution, and are composed of over 50 tissues and organs. In this case, electric conductivities at 23[kHz] are provided for each tissue by use of parameter model[5].

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.

4. Results

The detailed distribution of induced current density is shown in Fig.3 and Fig.4. These figures indicate that hot spots of induced current density are observed at a few [cm] inside from the surface of two models because of inhomogeneous conductivity of tissues. The maximum value of current density for trunk is $21[mA/m^2]$ in the male model and $11[mA/m^2]$ in the female model, respectively. Tissues in which maximum current density observed are small-intestine (σ =0.57[S/m]) in the male model and muscle (σ =0.34[S/m]) in the female model. Both tissues are surrounded by fat (σ =0.02[S/m]) or air (σ =0[S/m]) which have smaller conductivity. The basic restriction of induced current for general public exposure given by ICNIRP is 46[mA/m^2] at 23[kHz], and induced current values are smaller than the basic restriction in the case of this study.

5. Conclusions

Magnetic flux density distribution in the vicinity of an IH hob is measured by the magnetic probe. As a case study, numerical dosimetry on induced current density inside human body exposed to magnetic fields due to induction heat (IH) hob is performed by IM with measurement data. Two voxel models of the average Japanese adult male and female are applied to this analysis. It is found that hot spots of induced current density are observed at a few [cm] inside from human skin. The maximum value of current density inside the male model is larger than that of the female model.

Acknowledgment

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.

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Fig. 3: induced current distribution within the average Japanese adult male model.

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Fig. 4: induced current distribution within the average Japanese adult female model.