INDUCED CURRENT INSIDE OF THE HUMAN HEAD IN THE VICINITY OF AN ELECTRIC SHAVER

Yoshitsugu Kamimura¹ Tomohiro Akutsu¹ Yoshifumi Yamada¹ Kanako Wake²

1 Faculty of Engineering, Utsunomiya University 2 Communications Research Laboratory E-mail: gami@ieee.org

Abstract: There are some electric appliances generating a high magnetic flux density in our daily life. Especially, it is reported that the value of the magnetic flux density of a AC drive electric shaver is locally more than 10 mT (100 gausses). It is necessary to evaluate the induced current in the inside of human body generated by the magnetic flux density leaking from the appliance as accurately as possible.

In this study, the harmonic component of leakage field from an AC drive electric shaver has been analyzed. As a result, it is found that its distorted wave consists of the fundamental harmonic, the third harmonic and the fifth harmonic. Moreover, the induced current density caused by the equivalent magnetic dipole to an electric shaver has been calculated using scalar potential finite deference method in the human head model of three kinds of resolution. Consequently, in the case of the trimmer mode, the induced current densities in some tissues might exceed 10 mA/m² of the basic restriction for occupational exposure of International Commission of Non-Ionizing Radiation Protection.

Key words: ELF, magnetic field, magnetic dipole, SPFD method, anatomical model

1. Introduction

Since Wertheimer and Leeper[1] suggested that magnetic field generated by electric power line related to the risk of child leukemia in 1979, we have been concerned about the health effects given by extremely low frequency (ELF) magnetic field. However, the health effects of long-term and chronic exposure suggested by epidemiology are not confirmed in the animal study. At present, the effects on the nerve tissues in induced current are clarified, and we can reproduce the health effects in ELF magnetic field exposure.

According to the guideline of International Commission of Non-Ionizing Radiation Protection (ICNIRP)[2], the basic restriction of current density for general public in the frequency from 4 Hz to 1 kHz is less than 2 mA/m². The flux density which can actually generate induced current density of 2 mA/m² is about 1 mT or less under uniform exposure. There are, however, some electric appliances

generating the flux density of several millitesla locally. It is reported that the flux densities of an AC drive electric shaver and the hair drier are especially high, compared with other electric appliances. These electric appliances are used near the human head. Therefore, the dose to the human head by magnetic field generated by them must be clarified. Tofani et al.[3] have reported on the hair dryer. They calculated the induced current density using impedance method. it is suggested that the max value is about 2.5 mA/m². On the other hand, the authors[4] have estimated the position of equivalent magnetic dipole to an AC drive electric shaver by sampled pattern matching (SPM) method, and have calculated the induced current density in planar model, spherical model and six-layered spherical model.

The electric shaver we investigated is a type to move electromagnet by AC current, and the frequency component of the leakage magnetic field is almost occupied by fundamental harmonic. However, because the induced current increases in proportion to the frequency, the higher harmonic cannot be ignored. In this study, we analyze the harmonic of leakage field from an AC drive electric shaver, and estimate the peak ratio of the distorted wave to sine wave in the induced current density. Moreover, we calculate the induced current densities in anatomical models of human head in the vicinity of an electric shaver using scalar potential finite deference (SPFD) method[5]. The results are compared with the results of a spherical model and a six-layered spherical model.

2. Harmonic analysis of leakage field

2.1 Distorted wave measurement

Fig.1 shows an AC drive electric shaver which we investigated. The mechanism of this shaver is a method to vibrate an inner blade by AC current like a buzzer, and to shave the beard. There is a pole piece of the electromagnet in the center of the case, and the magnetic field is generated here[4].

In the shaver driven by the power supply, the distorted wave was measured with a three-axis probe of the gauss meter (F.W BELL-Model 9640). The probe was placed at the position in which the highest

4B3-2

magnetic field strength was indicated on the surface of the electric shaver. The waveform was recorded with a digital oscilloscope (GOULD-Classic 6000).



Fig.1 An AC drive electric shaver

Fig.2(a) shows the output waveform of gauss meter which we observed. According to this figure, it is found that this is a distorted wave with the period of 20 msec, that is, the fundamental frequency of 50 Hz.

Fig.2(b) shows the power spectrum of the observed waveform. It is found that the distorted wave is consisted of fundamental harmonic (50 Hz), the second harmonic (150 Hz) and the third harmonic (250 Hz). Table 1 shows the power distribution of these harmonics.

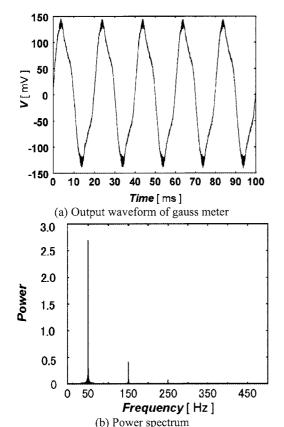


Fig.2 Waveform of leakage field and its power spectrum

Table 1. Power distribution and contribution rate to current

	50 Hz	150 Hz	250 Hz
Power distribution [%]	85.6	12.4	2.0
Contribution rate to current	0.925	1.057	0.709

2.2 Induced current density in distorted wave

For instance, the third harmonic component element is about 1/7 of the fundamental harmonics. However, the effects of the harmonic cannot be ignored because the induced current density is proportional to the frequency. On the other hand, the perceptual threshold to the current is flat up to about 1 kHz. Therefore, the reduction effect at high frequency cannot be expected. The contribution rate to the induced current of each harmonic when based on the case of the fundamental component only is shown in Table 1.

If the peak value of the current density in the worst case (J_{peak}) is obtained to the additive, it is about 2.7 times the value of only the fundamental component (J_0) . On the other hand, if the equivalent amplitude of the current density (J_{rms}) is obtained in the rootmean-square value, it is about 1.57 times J_0 . An actual induced current density will take the value between them.

3. Induced current density in anatomical model

When the electric shaver is used in trimming mode of sideburns or eyebrow, the magnetic flux density of about 10 mT (100 gausses) is locally generated on the surface of the cheek or eye. This value is much larger than the reference level for occupational exposure of the guideline of ICNIRP. Therefore, we have evaluated the induced current density in human head is in these cases.

3.1 Configuration of electric shaver and head

Fig.3(a) shows the trimming mode of sideburns when the shaver is placed near the cheek. In this case, a magnetic dipole is in the distance of 1.5 cm from a right cheek, and its direction turns to back and forth.

On the other hand, Fig.3(b) shows the trimming mode of eyebrows. A shaver is placed in front of the right eye, so it seems to be the worst-case for eye exposure. In this case, a magnetic dipole is in the distance of 1.5 cm from an eye, and its direction turns to the right and left.

3.2 Calculation condition

At first, we obtain internal electric field because induced current density in human head can be obtained the internal electric field and conductivity of the tissue. Internal electric field E in human head is calculated by SPFD method[5]. The magnetic current moment $I_m I$ is 1.15×10^{-4} Wb m s[4].

We use the human head models of three kinds of resolution (1 mm, 2 mm, 3 mm) developed in Brooks Air Force Base (Fig.3).

Brooks model of the head has 25 kinds of tissues. Each of conductivity is obtained referring to the data in Gabriel's report[6] (Table 2).



(a) Trimming mode of sideburns



(b) Trimming mode of eyebrows Fig.3 Configuration of electric shaver and head

Table 2 Conductivity of tissues

Table 2 Conductivity of tissues						
Tissue	σ (S/m)	Tissue	σ (S/m)			
Muscle	0.35	Skin/Dermis	0.1			
Ligaments	0.27	Fat	0.04			
Blood	0.7	Brain(cerebellum)	0.1			
Blood vessel	0.26	Brain(gray	0.1			
		matter)				
Body fluid	1.5	Brain(white	0.06			
		matter)				
C.S.F.	2.0	Nerve(spine)	0.03			
Eye(aqueous	1.5	Cartilage	0.18			
humor)						
Eye(retina)	0.5	Born(cancellous)	0.07			
Eye(sclera/wall)	0.5	Born(marrow)	0.05			
Eye(cornea)	0.4	Born(cortical)	0.02			
Eye(lens)	0.25	Tooth	0.02			
Glands	0.52	Mucous	0.0004			
		membrane				
Lymph	0.5					

3.3 Calculation results

Fig.4 shows the distribution of induced current density (J_{peak}) in Brooks model with voxel size of 1 mm for cheek exposure in the trimming mode of sideburns. The values in some regions among Brooks models exceed the basic restriction for general public exposure (2 mA/m²) of ICNIRP. The maximum

value of induced current density (J_{peak}) is detected in Glands and it is 13.94 mA/m². This value is comparable to the basic restriction for occupational exposure (10 mA/m^2) of ICNIRP guideline.



Fig. 4 Distribution of induced current density (J_{peak}) in 1 mm Brooks model for cheek exposure

Fig.5 shows the distribution of induced current density (J_{peak}) in 1 mm Brooks model for eye exposure in the trimming mode of eyebrows. The maximum induced current density is 42.99 mA/m². This value is detected in muscle in the vicinity of eye.

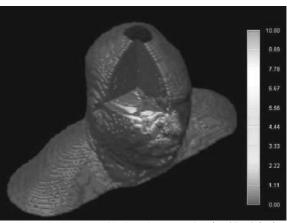


Fig. 5 Distribution of induced current density (J_{peak}) in 1 mm Brooks model for eye exposure

Fig.6 shows the induced current density (J_{peak}) of each tissue in Brooks head models of three kinds of voxel sizes for eye exposure. Red grid bars are the values of 1 mm voxel model, blue stripes are of 2 mm voxel model and white bars are of 3 mm voxel model. According to this figure, it is found that the voxel size of 2 mm seems to be insufficient. The basic restriction for occupational exposure (10 mA/m²) is exceeded in many of tissues. However, it is delicate whether to actually stimulate the retina. Table 3 shows the maximum induced current densities in the Brooks head model of each mode and each voxel size. The induced current density in the homogeneous spherical model and the six-layered spherical model is put on the list for the comparison.

4B3-2

The homogeneous spherical model is comparable with the cheek exposure of the Brooks model, and the six-layered spherical model is compared than the eye exposure of that.

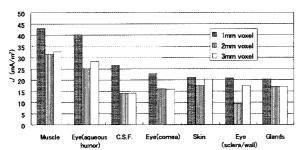


Fig. 6 Peak value of induced current density (J_{peak}) of each tissue in Brooks head models of three kinds of voxel sizes for eye exposure

Table 3 Maximum values of induced current densities in human head models

Model (position)	$J_{ m rms}$	$J_{ m peak}$
Spherical	6.51	11.19
Six-layered	18.74	32.65
3 mm (cheek)	3.88	6.63
2 mm (cheek)	8.80	15.06
1 mm (cheek)	8.15	13.94
3 mm (eye)	19.08	32.63
2 mm (eye)	18.41	31.49
1 mm (eye)	25.14	42.99

4. Conclusion

We investigated harmonic in an AC drive electric shaver to obtain more accurate and reliable value of the induced current density. As a result, the real induced current density is 1.57 times or 2.7 times the value in only fundamental harmonic. The induced current density distributions are calculated for two kinds of exposure in the anatomical human head models of three kinds of resolution.

In the trimmer mode, the induced current densities locally exceed the basic restriction for general public

exposure (2 mA/m²) of ICNIRP guideline. Especially in trimming case of the eyebrow, the peak values of induced current density (J_{peak}) in many tissues exceed for occupational exposure (10 mA/m²) of ICNIRP guideline. However, we have never observed the magnet phosphene by this shaver. Though 30 mA/m² is exceeded on eyes (aqueous humor) and the nearby muscles, it is delicate whether the retina is actually stimulated.

For comparing our result strictly with ICNIRP guideline, the current densities should be averaged over a cross-section of 1 cm² perpendicular to the current direction. In the shaver of rechargeable or battery drive type, the magnetic field is only 1/20 times or less than the value of AC drive type. However, it will be necessary to investigate them in the future because they generate the leakage field of higher frequency.

References

- [1] N. Wertheimer and E. Leeper, "Electrical wiring configurations and childhood cancer," American Journal of Epidemiology, 109, pp.273-284, 1979.
- [2] R. Matthes, J.H. Bernhardt, A.F. McKinlay (ed.). "Guidelines on limiting exposure to non-ionizing radiation," ICNIRP, 1999.
- [3] S. Tofani, P. Ossola, G. d'Amore, and O.P. Gandhi, "Electric field and current density distributions induced in an anatomically-based model of the human head by magnetic fields from a hair dryer," Health Phys., Vol.68, No.1, pp.71-79, 1995.
- [4] Y. Kamimura, M. Kojima, and Y. Yamada, "Induced Current Inside a Spherical Model of a Human Head Due to Magnetic Current Sources of AC Drive Electric Shaver," IEICE vol. J85-B No.5, pp.706-714, 2002.
- [5] T.W. Dawson, J.D. Moerloose and M.A. Stuchly, "Comparison of magnetically induced ELF fields in humans computed by FDTD and scalar potential FD codes," ACES Journal, 11(3), pp.63-71, 1996.
- [6] C. Gabriel, "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies," Brooks Air Force Base, Report No.AL/OE-TR-1996-0037, 1996.