Numerical Dosimetry in A Model of The Human Body Exposed to Extremely Low Frequency Magnetic Field in Train Car

Yukihisa Suzuki1, Masateru Ikehata2, Tetsuya, Nagai1, Kazuki Nakamura2, Yoshihito Kato2, Masao Taki1
1 Tokyo Metropolitan University, Tokyo, Japan,
2 Railway Technical Research Institute, Tokyo, Japan

Abstract

In our environment, various types (e.g. frequency, field strength) of electric and magnetic fields (EMFs) exist and their distributions are complex. Therefore, it is necessary to study the method of safety evaluation for such complex field. For safety evaluation, measurement of EMFs distribution and determine the dose of exposure in human body is one of the essential step.

In this report, we focused on the estimation of dosimetry in human body that exposed to extremely low frequency magnetic field in train car. Two voxel of whole human-bodies were used for numerical analysis of induced current as “dosimetry”. In addition, compliance of the guideline of International Commission of Non-Ionizing Radiation Protection (ICNIRP) was also examined under a case condition in this study.

Introduction

Public concerns over the health effects of electric and magnetic fields (EMFs) are keep growing due to introduction of new technology such as cellular phone, Induction heater cooker, RFID, MRI, etc. The world health organization conducts the International EMF project that reviewed scientific data of biological effects of EMF to revise their Environmental Heath Criteria. In the research agenda of the international EMF project, electrified transportation systems are one category of the sources of electric and magnetic field and the needs of research to estimate its biological effects has been stated.

In our environment, various types (e.g. frequency, field strength) of electric and magnetic fields (EMFs) exist and their distributions are complex. However, there are few reports on biological effects of such complex EMFs exposure. At this point, our project aims to construct a strategy for the safety evaluation by exposure to complex EMFs.

For plausible safety evaluation of complex EMFs will include; 1. Clarification of EMFs that are generated in our environment and estimation of the induced current using the numerical model of human whole body. 2. Development of exposure devices that can generate complex EMFs. 3. Estimation of the biological effects by exposure to complex EMFs. 4. Estimation of the indirect effects of EMFs on biological experiments.

In this report, we focused on the numerical dosimetry in human body that exposed to extremely low frequency magnetic field in train car. 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.

Materials and Methods

Numerical Analysis of Induced Current

Two types of numerical human model are used to construct model condition in an electric train car. One model is heterogeneous whole-body voxel models of Japanese adult male (Taro) and female (Hanako) that developed by National Institute of Information and Communications Technology (NiCT) [1]. Figure 1 shows cross section of Taro and Hanako. These detailed human models have 2mm resolutions, and are composed of over 50 tissues and organs. The other is homogeneous numerical human model Quete (OGIS-RI, Japan). This model is able to have arbitrary position.
These models are set up as shown in Fig. 2. One position is standing in the train car and the other is seating position on the seat of train car. Two types of magnetic field source were examined. One is the magnetic field by line current that considered a power cable under the floor. The other is the magnetic field by magnetic dipole that considered the equipments such as a reactor. Distributions of the magnetic field from each source are shown in Fig. 3. Frequency of incident magnetic field was 60 Hz because frequency of power source for the equipments on the train car is 50/60 Hz in Japan.

The quasi-static approximation method can be used to obtain induced current distribution, since wavelength of electromagnetic field is extremely larger than the human model size [3]. We have attempted to calculate induced current density distribution with impedance method (IM) which is one of the quasi-static approximation methods [4]. Analysis objects, which are human models, are turned into discrete voxel representation in IM. Closed loop currents are assumed on each surface of voxel, and Kirchhoff voltage equations are written for each loop current. Simultaneous equations are obtained for all over the object. Here, successive over relaxation (SOR) method is used to solve simultaneous equation to obtain loop currents on the surface of voxel. In this study, if the value of norm of residual vector $\epsilon$ is smaller than $10^{-5}$, the solution derived from SOR method is considered to be converged.

Electric conductivities at 60 Hz are provided for each tissue by use of the parameter model in Taro and Hanako [2]. A typical conductivity of soft, high water content tissues at low frequencies is approximately 0.14 S/m [5]. In this study, we use 0.2 S/m as the conductivity in the Quete model to evaluate worst condition in induced current.

Calculation results are required post processing, because in ICNIRP guidelines [6], it is stated that, "Current densities should be perpendicular to the current direction." There cross-section of 1cm$^2$ to relax the influence of

The compliance of "reference level" of ICNIRP guideline for these magnetic fields was evaluated. Maximum or mean magnetic field density to expose human body was normalized to the "reference level" and calculated the induced current in head and trunk. These data compared with basic restriction (2 mA/m$^2$) of ICNIRP guidelines.
Results and Discussion

Numerical analysis was performed at standing and seated position in Quete model. In each position, induced current concentrated at bending regions such as ankle, knee, crotch, armpit. On the other hand, strong induced current was observed in organs that contained high water content such as cerebral fluid and blood within bladder in the inhomogeneous model Taro and Hanako. However, the density of induced current in the inhomogeneous model is lower than the homogeneous model Quete. Highest density of induced current was observed in the magnetic field by the line current because attenuation of the magnetic field lower than that of the magnetic dipole. Maximum induced current density by two magnetic field sources in human voxel models are shown in Fig. 4 (heterogeneous model, standing position) and Fig. 5 (homogeneous model, seating position).

In addition, the compliance with “basic restriction” of ICNIRP guideline in this case study was evaluated by two methods. One method uses the normalizing “maximum” incident magnetic flux density to the reference level for analysis of induced current density. The other method uses the normalizing “mean” incident magnetic flux density over the human body to the reference level. Table 1 shows the maximum induced current density in homogeneous model by the “maximum” method. As the result, maximum induced current density derived by the “maximum” method is approx. $10^{-1}$ mA/m² and approx. 1 mA/m² that derived by the “mean” method in head and trunk. These results suggest that induced current may not exceed the level of basic restriction of ICNIRP guideline although magnetic flux density generated by typical equipment on board is the same level as the reference level in this case study.
Conclusion

Numerical dosimetries on induced current density are performed with IM by using calculated magnetic flux density that simulated train equipments as a case study. Two voxel models of the average Japanese adult male and female are applied to these analyses. These results described the character of dosimetry in a train car that has the source of EMFs under the floor. Moreover, induced current densities estimated by numerical method in this case study may not exceed basic restrictions for general public exposure given by ICNIRP. It is possible to establish the simple method to evaluate safety of environmental magnetic field such as the train car to archive dosimetries of various case studies with referring the data of biological effects of magnetic fields.

Acknowledgement

This work was supported in part by the Research Program from the Japan Railway Construction, Transport and Technology Agency.

Reference


Table 1 Maximum induced current density in homogeneous model by normalizing “maximum” incident magnetic flux density to the reference level of ICNIRP guideline

<table>
<thead>
<tr>
<th>Position</th>
<th>Gender</th>
<th>magnetic field source</th>
<th>$J_{mx}$ (head) ($\mu A/m^2$)</th>
<th>$J_{mx}$ (trunk) ($\mu A/m^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>standing</td>
<td>male</td>
<td>magnetic dipole</td>
<td>3.37</td>
<td>0.01</td>
</tr>
<tr>
<td>standing</td>
<td>female</td>
<td>line current</td>
<td>45.48</td>
<td>0.04</td>
</tr>
<tr>
<td>seating</td>
<td>male</td>
<td>magnetic dipole</td>
<td>3.47</td>
<td>0.01</td>
</tr>
<tr>
<td>seating</td>
<td>female</td>
<td>line current</td>
<td>45.48</td>
<td>0.05</td>
</tr>
<tr>
<td>seating</td>
<td>male</td>
<td>magnetic dipole</td>
<td>4.37</td>
<td>0.03</td>
</tr>
<tr>
<td>seating</td>
<td>female</td>
<td>line current</td>
<td>46.75</td>
<td>0.17</td>
</tr>
<tr>
<td>seating</td>
<td>male</td>
<td>magnetic dipole</td>
<td>4.50</td>
<td>0.06</td>
</tr>
<tr>
<td>seating</td>
<td>female</td>
<td>line current</td>
<td>40.55</td>
<td>0.15</td>
</tr>
</tbody>
</table>