Research on low frequency electromagnetic environment of electric vehicle and human health

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Abstract. In order to study the influence of electromagnetic environment produced by low frequency current in power cables of electric vehicle on driver’s and co-driver’s tissues, especially in the central nervous system (CNS). The distribution of the magnetic induction intensity and the induction electric field intensity in human trunk and CNS of the driver’s and co-driver’s are calculated and analysed. The results are compared with the related standards of International Committee on Non-ionizing Radiation Protection (ICNIRP). The study shows that the induced fields in human trunk and CNS are much smaller than the occupational and public exposure limits defined by ICNIRP. Therefore, the low frequency current would be safe for human health to some extent.

1. Introduction
With the deterioration of global ecological environment and the worsening problem of energy and resource exhaustion, it has become a new competition focus in the automotive industry to vigorously promote the related technology research of electric vehicles. By 2020, Some organizations predict that, global sales of electric vehicles will reach more than 34.0 million, including 31% in Europe, 28% in China, 18% in the United States and 15% in Japan [1]. However, unlike traditional fuel-fired vehicles, the power system of electric vehicles usually requires hundreds of kilowatts of power [2]. The cabinet space of electric vehicles is relatively compact, and passengers are very close to electric power components such as high-power motors, inverters and high-voltage power cables. During the driving, passengers are inevitably exposed to the electromagnetic environment generated by these high-power electric equipments. If exposed to the electromagnetic environment for a long time, the human body may be discomfort, such as headache, dry skin and so on. Besides, it may also increase the probability of inducing diseases of nervous system and immune system [3].

In recent years, some researchers have measured and calculated the distribution of electromagnetic field in different electric vehicle compartments and obtain some conclusions about the characteristics of field distribution [4-6]. Especially, in the [7], the distribution of spatial field in different positions of ten electric car compartments which are popular in the Chinese market is measured, and the safety of electromagnetic exposure for child passengers is studied. Others have carried out relevant research on electromagnetic radiation of electric vehicle wireless charging system to human body [8,9]. However, there is few researches on human exposure to the low-frequency electromagnetic environment of power cables in electric vehicle.

When human body is exposed to electromagnetic field, it is impossible to obtain the distribution of physical quantities such as magnetic induction intensity and induction electric field intensity in various
tissues by external equipment. For the kind of problem, the general method is based on the principle of electromagnetic dosimetry, using the numerical calculation method to quantitatively analyze the distribution of electromagnetic field in human tissues [10]. The paper is based on the finite element method, the electromagnetic simulation software is used to model the electric vehicle body, power cables and passengers. The simulation model of electromagnetic environment of the electric vehicle power cables is established. The distribution of different induction fields in the trunk and CNS of driver's and co-driver's are calculated, and the results are compared with the standards [11] defined by International Committee on Non-ionizing Radiation Protection (ICNIRP), and evaluate the safety of electromagnetic exposure in the low-frequency electromagnetic environment. It has positive significance to enrich the research on electromagnetic radiation of electric vehicles and to eliminate the fear of electromagnetic exposure and occupational diseases.

2. Calculating model and dielectric parameters of human body

For the most electric vehicles, the power battery pack is usually located directly below or behind the car body. The power battery pack is connected with other electrical systems such as motors, inverters and other electric equipments by power cables. The general picture of typical electric vehicles is shown in figure 1.

![Figure 1. Overview of electric vehicles.](image)

2.1. Calculating model

Using the Comsol Multiphysics as simulation platform, a simplified low-frequency electromagnetic environment model is established. As shown in figure 2, the simplified electromagnetic environment model includes car compartment, driver, co-driver, power cable, windows and so on.

![Figure 2. The model of the simple car with human body and electromagnetic power cable.](image)

The human body model refers to the international standing posture of 1.75 m adult male and establishes the human sitting posture model in proportion, as shown in figure 3. For human head
model, we also adopt a simple three-layer head model, which is commonly used in the related scientific research. In this model, the radius of scalp is 92 mm, the radius of skull is 85 mm, and the radius of brain is 80 mm [12].

![Image of human model and head dimensions]

**Figure 3.** The sitting posture of human model and head dimensions.

### 2.2. Human dielectric parameters

The frequency-dependent tissue conductivity can be extracted from the internet database of Italian National Research Council [13,14]. For a simple human model, it is assumed that the human tissues is uniformity. The electrical conductivity and relative permittivity of the brain are taken as the average values of cerebrospinal fluid, white matter and gray matter; the electrical conductivity and relative permittivity of the trunk are taken as the average values of muscle, blood and bone. Thus, the approximate values of electrical conductivity and relative permittivity of the main tissues of the human body at 500 Hz are shown in table 1.

| Biological tissues | Relative permittivity | Conductivity(S/m) |
|-------------------|-----------------------|-------------------|
| Scalp             | 34116.0               | 0.0006            |
| Skull             | 22295.0               | 0.0813            |
| Brain             | 153926.3              | 0.7192            |
| Trunk             | 371684.8              | 0.3637            |

### 3. Calculating results

In the study, the AC/DC magnetic field module is used in Comsol Multiphysics software to calculate and analyze the magnetic induction intensity ($|B|$) and induced electric field intensity ($|E|$) in the trunk and CNS of driver's and co-driver's, when the current in the power cables of electric vehicles is 30 A in amplitude and 500 Hz in frequency. During the calculation, we use the platform of Sugon high performance cluster with 64 G memory and the calculating time is 3-4 hours. The results are as follows.

#### 3.1. Distribution of human magnetic induction intensity

The distribution of magnetic induction intensity in the driver's trunk is shown in figure 4. The maximum magnetic induction intensity in the driver's trunk is 21.3 μT, in the area of the foot and
ankle the magnetic induction intensity is larger, the magnetic induction intensity is relatively uniform in other parts of the trunk, and the value is much lower than that in the foot area. The magnetic induction intensity of human trunk in this position is much lower than the basic restriction of 1000 μT [11] of occupational exposure defined by ICNIRP.

Similarly, the distribution of magnetic induction intensity in co-driver's trunk is shown in figure 5. The maximum magnetic induction intensity in the co-driver's trunk is 0.388 μT, and the strongest area appears in the foot and the lateral area of the leg, which is directly related to the distance from the power cable. The magnetic induction intensity of human trunk in this position is also far lower than the basic restriction of 200 μT [11] of public exposure defined by ICNIRP.

The brain is the core of the CNS. Therefore, ICNIRP specifically defines the limits of electromagnetic field exposure in the head. The vertical section magnetic induction intensity of the
driver's and co-driver's head is shown in figures 6 and 7, respectively. The maximum magnetic induction intensity of the driver's and the co-driver's head is 0.0968 μT and 0.079 μT, respectively. The closer the human head to the power cable, the greater the magnetic induction intensity. The magnetic induction intensity in the driver's and co-driver's head is much lower than the basic restriction of occupational exposure and public exposure defined by ICNIRP [11].

3.2. Distribution of human induced electric field intensity

According to the theory of electromagnetic field, the variable current produces a variable magnetic field, and the variable magnetic field would induce electric field. As shown in figure 8, the maximum induced electric field intensity in the driver's trunk is 16.7 mV/m, and the maximum induced electric field intensity is much lower than the basic restriction of 800 mV/m of the induced electric field intensity of occupational exposure defined by ICNIRP [11].

The induced electric field intensity in co-driver's trunk is shown in figure 9. The co-driver is much far from the power cable than the driver, so the value of induced electric field intensity in co-driver's trunk is much small. The maximum value of induced electric field intensity in the co-driver's trunk is 0.552 mV/m. The value is also far below the basic restriction of 400 mV/m of the induced electric field intensity for public exposure defined by ICNIRP [11]. From the figures 8 and 9, it can also be seen that the closer to the power cable, the greater the induced electric field intensity; conversely, the farther the distance, the smaller the induced electric field intensity.

For the induced electric field intensity in the CNS, the vertical sections of the head models of driver's and co-driver's are shown in figures 10 and 11 respectively. The maximum induced electric field intensity of driver's head is 1.78 mV/m, which is higher in skull and brain tissues, and the lowest in scalp area. The induced electric field intensity is lower than the basic restriction of 360 mV/m of occupational CNS exposure defined by ICNIRP [11] in driver's head. Similarly, the maximum induced electric field intensity in the co-driver's head is 0.0537 mV/m, which is concentrated on the side of the head near the power cable, and mainly concentrate in the skull and brain tissue. The maximum value is much lower than the basic restriction of 720 mV/m of public CNS exposure defined by ICNIRP [11].

Figure 8. Distribution of induced electric field intensity in driver's trunk.  
Figure 9. Distribution of induced electric field intensity in co-driver's trunk.
4. Discussion
For study the electromagnetic exposure of human body in low-frequency electromagnetic environment of power cables in electric vehicles, the distribution of induced electromagnetic fields in human tissues, especially in the CNS of driver's and co-driver's is calculated. By establishing an equivalent electromagnetic environment in Comsol Multiphysics, the power cable with the current of 500 Hz in frequency and 30A in amplitude is modelled.

The numerical results show that under the action of the low frequency current, the magnitude and distribution characteristics of the magnetic induction intensity and the induced electric field intensity in different tissues of human body are directly related to the distance of the power cable. The closer the distance, the larger the values. The maximum values of magnetic induction intensity and induced electric field intensity in the trunk of driver's and co-driver's are much lower than the basic restriction of occupational exposure and public exposure defined by ICNIRP. Similarly, the induction fields in the CNS of driver's and co-driver's are also far below the basic restriction of occupational and public CNS exposure limits. Taking the values of magnetic induction intensity and induced electric field intensity as examples, the maximum magnetic induction intensity in driver's trunk reaches 2.13% of ICNIRP limits, and the corresponding value in co-driver's could only reach 0.19% of ICNIRP limits. The maximum induced electric field in the driver's CNS is only 0.49% of the ICNIRP limits, and the corresponding value in the co-driver's is only 0.07% of the ICNIRP limits.

Therefore, the electromagnetic environment in the cabinet of electrical vehicle would not damage the human tissues in a short time, and the study is similar to the electromagnetic wave emitted from the mobile phone and base station, the values are far below the ICNIRP limits. In fact, the result doesn't fully support the viewpoint that the radiation is not harmful to human health for long term exposure. It also needs to be validated by epidemiological methods for long-term follow-up of specific populations.

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