Influence of different materials of electric vehicle body on low frequency electromagnetic exposure for driver

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Abstract. For electric vehicles (EVs), in addition to the power system is its core technology, the use of the new body materials with stronger hardness, lighter weight and better shielding performance is also one of the important issues concerned by the EVs industry. The distribution of induction field in the trunk and the central nervous system (CNS) of the driver's is studied with the vehicle body materials are aluminum alloy, non-magnetic steel, metal X and permalloy. The results show that the maximum values of induced electric field intensity (E-field) and induced current density (J-field) in the driver's trunk only reach 2.27% and 67% of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) limits respectively, and the maximum values of E-field and J-field in the driver's CNS only reach 0.29% and 0.62% of the ICNIRP limits respectively. So, the electromagnetic exposure levels of the driver's body are within the safe range in this situation. In short, the EVs body material with the higher resistivity and relative permeability would make the electromagnetic exposure level for the driver's body in a much lower level, and it is also much safer for the driver's body from the perspective of electromagnetic dosimetry.

1. Introduction
China has become the largest automobile producer and consumer in the world. It is estimated that the number of passenger cars in China would reach 250 million by 2030. However, With the implementation of energy conservation and emission reduction, improvement of air quality and other policies, reducing energy dependence has gradually become the development trend of the international automobile industry. The Chinese government has officially listed EVs as one of the seven strategic industries [1,2]. The promotion of vehicle electrification has become an urgent problem in related industries in recent years.

For EVs, the power system mainly includes high-power power cable, inverter, power battery module and so on. During driving, the power battery system (about 5-200 kW according to the vehicle type) provides the power source for the whole vehicle, and the power cable transmits the electric energy to the power components [3,4]. Considering the size and space constraints of the vehicle itself, the passengers are likely to be very close to the high-power electrical devices. As a result, the passengers would be exposed to electromagnetic fields generated by components of the electric power system. Moreover, with more and more electric devices are deployed in the vehicle power system, it is more and more important to evaluate the electromagnetic field exposure in EVs [5]. In addition, with the development of new material technology, steel plates traditionally used for vehicle body structure are replaced by other lightweight materials, such as aluminum alloy or carbon fiber composite materials [6]. These materials have electrical and magnetic properties different from the traditional
steel plates. Therefore, with the use of these new materials, the electromagnetic environment in the EVs would be also changed.

When the human body is exposed to a complex electromagnetic environment, the induction field in tissues couldn't be measured by equipment but could only be solved by numerical calculation [7-9]. In the study, the software of Comsol Multiphysics is used to establish the low frequency electromagnetic environment of power cable of EVs. The shielding effect of different body materials to the low-frequency electromagnetic field is studied. The distribution of E-field and J-field in the driver's trunk and CNS are calculated. Finally, the influence of different vehicle body materials on the low frequency electromagnetic field is analyzed. The study would provide references for the protection measures of low-frequency electromagnetic exposure of EVs.

2. Construction of calculation model
The power battery pack with other electrical components are mainly connected by the power cable in the EVs, and provide power source for the whole vehicle. The traction current in the power cable is the main source of low frequency electromagnetic field in EVs [5]. In order to compare the influence of different body materials on the electromagnetic environment inside the EVs, the low-frequency current with amplitude of 20A and frequency of 320Hz in the power cable as the radiation source. The influence of different vehicle body materials on the driver's trunk and CNS is studied. The overview of electric vehicle body, human body and power cable are shown in figure 1.

![Figure 1. Low frequency electromagnetic environment model of EV.](image1)

2.1. Finite element model
In view of the fact that the amount of numerical calculation is closely related to the size and geometric complexity of the model, in order to solve the problems efficiently, and to avoid taking up too much computer resources for finite element calculation. In the Comsol Multiphysics, a low-frequency

![Figure 2. Finite element mesh of calculation model.](image2)
electromagnetic environment model including electric vehicle cab (2200 mm × 1540 mm × 1250 mm), driver and co-driver, power cables is established in figure 1. The finite element mesh generation is carried out as shown in figure 2, and the whole model is divided into more than 4 million tetrahedral meshes.

The sitting posture model is established by referring to a male mannequin with the height of 1.75 m [10, 11]. The overall height of the seated model is 910 mm and the shoulder width is 490 mm. The radius of the three-layer head model are as follows: 80 mm (brain), 85 mm (skull) and 92 mm (scalp).

2.2. Human dielectric parameters and vehicle body material properties

For the dielectric parameters of different tissues in the simple human body model, we take the mean values of the major components for the different tissues respectively [12]. Therefore, the approximate values of dielectric parameters of major tissues of the body at 320 Hz are shown in table 1.

| Tissues | Relative permittivity | Conductivity (S/m) |
|---------|-----------------------|--------------------|
| Scalp   | 17135.0               | 0.0004             |
| Skull   | 12620.0               | 0.0568             |
| Brain   | 99267.2               | 0.2137             |
| Trunk   | 253378.3              | 0.4233             |

In order to effectively evaluate the influence of different vehicle body materials on the electromagnetic environment in the EVs, four kinds of material are selected, and the resistivity and relative permeability are shown in table 2. Besides, the thickness of vehicle body is 1.5 mm, which is the same as the common steel structure.

| Material name | Resistivity (Ωm) | Relative permeability |
|---------------|------------------|-----------------------|
| Aluminium alloy | 2.8×10^4         | 1                     |
| Nonmagnetic steel | 1.7×10^7       | 1                     |
| Metal X[13]  | 1.7×10^7         | 500                   |
| Permalloy     | 0.7×10^7         | 35000                 |

3. Calculating results

The numerical calculation of the study is carried out in the AC-DC module of multiphysical field numerical calculation software Comsol Multiphysics. By finite element method based on maxwell equations, with the model establishment, excitation source setting, boundary conditions loading and finite element mesh generation, the distribution of the E-field (|E|) and J-field (|J|) in drive's trunk and CNS tissues are calculated.

3.1. Distribution of E-field

The influence of different vehicle body materials on the E-field in the driver's trunk are shown in figure 3–figure 6. In these figures, we could find that with the increase of the resistivity and the relative permeability, the maximum of the E-field in the trunk is gradually reduced. When the vehicle body material is permalloy, the E-field in the trunk is the minimum, and the minimum is 11.4 mV/m. When the vehicle body is aluminum alloy, the E-field in the trunk is the maximum, which is 18.2 mV/m. Besides, from the distribution of the E-field in the driver's trunk, it could be seen that the areas with strong E-field are mainly concentrated in the abdomen and below, and the distribution of the E-field above the abdomen is relatively uniform and the value is small.
**Figure 3.** Distribution of E-field in trunk (EV body material: aluminum alloy).

**Figure 4.** Distribution of E-field in trunk (EV body material: nonmagnetic steel).

**Figure 5.** Distribution of E-field in trunk (EV body material: metal X).

**Figure 6.** Distribution of E-field in trunk (EV body material: permalloy).

**Figure 7.** Distribution of E-field in CNS (EV body material: aluminum alloy).

**Figure 8.** Distribution of E-field in CNS (EV body material: nonmagnetic steel).
The distribution of E-field in the cross section of the driver's CNS are shown in figure 7 - figure 10. It could be seen from the figures that the different vehicle body materials have little influence on the distribution of induced electric field in the CNS, and the value in the CNS is just between 2.37mV/m-2.38mV/m. This is because, compared with the trunk, the head is far away from the power cable, so the value of the induced electric field in the CNS is more uniform and the value is much smaller.

3.2. Distribution of J-field

The distribution of J-field in the driver's trunk are shown in figure 11-figure 14. It could be found that the J-field in the trunk gradually decreases with the increase of the electrical resistivity and relative permeability of the vehicle body material. When the vehicle body is made of permalloy, the J-field in the trunk is the minimum, and the minimum is 4.18mA/m². When the vehicle body is made of aluminum alloy, the J-field in the trunk is the maximum, and the maximum is 6.70mA/m². Therefore, the electrical properties of different body materials would directly affect the J-field in the driver's trunk. In addition, from the distribution trend of the J-field in the driver's trunk, the value is relatively larger and concentrated in the abdomen and below, the J-field value is smaller in the area above the abdomen.
The distribution of $J$-field in the cross section of the driver’s head are shown in figure 15-figure 18. It could be seen from the figures that the resistivity and the relative permeability of different body materials have great influence on the distribution of $J$-field in the driver's CNS. When the vehicle body material is aluminum alloy, the $J$-field is the maximum, the maximum is $617 \mu A/m^2$ in the driver's CNS, when the vehicle body material is permalloy, the $J$-field is the minimum, the minimum is $397 \mu A/m^2$ in the driver's CNS, the difference between the maximum and the minimum value of the $J$-field is $220 \mu A/m^2$. In addition, we could find that the distribution of $J$-field in brain tissue is relatively uniform, and the value is the largest. However, in the skull and scalp tissues, the value of the $J$-field is much smaller than that in the brain. Therefore, in the design of vehicle body materials, we should fully consider the influence of materials on the $J$-field in passenger's CNS, and minimize the influence as much as possible.

**Figure 13.** Distribution of $J$-field in trunk (EV body material: metal X).

**Figure 14.** Distribution of $J$-field in trunk (EV body material: permalloy).

**Figure 15.** Distribution of $J$-field in CNS (EV body material: aluminum alloy).

**Figure 16.** Distribution of $J$-field in CNS (EV body material: nonmagnetic steel).
As shown in the figure 19, in order to study the different distribution of induction field in different positions of the CNS, three points A, B and C are taken, and the corresponding induced electric field values are compared, as shown in table 3. It could be seen from the table that the E-field in the CNS are small and relatively uniform, while the J-field in the CNS are quite different.

### 4. Discussion

The simplified electromagnetic environment model with low frequency of EV power cable is modeled in the Comsol Multiphysics. The distribution of E-field and J-field in the driver's trunk and CNS are studied when the electric vehicle body material are aluminum alloy, non-magnetic steel, metal X, permalloy, with the amplitude and frequency of the current in the power cable are 21A and 320Hz.

The value of induction field in the driver's trunk and CNS is small as a whole. Considering the difference of the electrical resistivity and the relative permeability of these four materials, by comparing the E-field and J-field in the driver's trunk and CNS, we could conclude that with the increase of electrical resistivity and the relative permeability, the induction field in driver's trunk and CNS would gradually decrease. In other words, the greater the resistivity and the permeability of the vehicle body material, the smaller the corresponding induction field. For example, in the driver's CNS, the maximum of J-field is 617 μA/m² with the body material of aluminum alloy, while the minimum value is just 397 μA/m² with the body material of permalloy.

### Table 3. Comparison of induced field values at different points on the cross section of the CNS (|E|:mV/m, |J|:μA/m²)

| Position | Material 1 | Material 2 | Material 3 | Material 4 |
|----------|------------|------------|------------|------------|
| A | | | |
| | 0.51 | 0.47 | 0.52 | 0.53 |
| | 387 | 335 | 351 | 262 |
| B | | | |
| | 0.53 | 0.45 | 0.49 | 0.48 |
| | 368 | 296 | 307 | 212 |
| C | | | |
| | 0.49 | 0.50 | 0.47 | 0.51 |
| | 507 | 476 | 423 | 348 |

*Material 1, 2, 3 and 4 indicate that the EV body material are: aluminum alloy, nonmagnetic steel, metal X, permalloy.*
With the influence of different vehicle body materials, the maximum of E-field and J-field in the driver's trunk only reach 2.27% and 67% of the ICNIRP [14,15] limits respectively, and the maximum of E-field and J-field in the driver's CNS only reach 0.29% and 0.62% of the ICNIRP [11,12] limits respectively. So, the electromagnetic exposure levels of the driver's body under different vehicle body materials are within the safe range in this situation.

However, from the perspective of epidemiology, considering the cumulative effect of low-frequency electromagnetic exposure for human body, for the safety of low-frequency electromagnetic exposure in EVs, we need to collect sample population, and judge the safety level of electromagnetic exposure by long-term observation of physiological indicators of sample population. In generally, the better shielding performance of the vehicle body material could make the electromagnetic exposure level much lower, and it is also much safer for the driver and passenger.

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