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Static Magnetic Field and Extremely Low-Frequency Magnetic Field in Hybrid and Electric Vehicles

***Abstract**. Static and extremely low-frequency (ELF) magnetic fields are exist in hybrid and electric cars. These fields are mainly due to the currents flowing through the car supply circuits, the motor circuits and the battery current. To determine the magnetic field exposure levels measurements were made in driver's seats. Our results have been compared to those presented in the literature.*

Streszczenie.** W samochodach hybrydowych i elektrycznych występują pola magnetyczne statyczne i skrajnie niskiej częstotliwości (ELF). Pola te są wynikiem oddziaływania prądów przepływających przez obwody elektryczne, obwody silnika elektrycznego i prądu akumulatora. Aby określić poziomy ekspozycji na pole magnetyczne, wykonano pomiary na siedzeniu kierowcy. Uzyskane pomiarowo wyniki zostały porównane z wynikami przedstawionymi w literaturze. **Statyczne i wolnozmienne pola magnetyczne w samochodach hybrydowych i elektrycznych

Keywords: static magnetic field, low-frequency magnetic fields, hybride vehicle, electric vehicle
Słowa kluczowe: pole magnetyczne, pole magnetyczne skrajnie niskich częstotliwości, pojazd hybrydowy, pojazd elektryczny

Introduction

Hybrid and electric vehicles (HEVs) produce stronger magnetic fields than traditional cars fitted with only petrol or diesel engines. With the growing popularity of hybrid technology and electric cars, potential users are concerned about the long-term impact of this type of vehicle on their health and safety. Are their fears justified? HEVs rely on the combination of the use of gasoline engines and electric motor. An electric motors uses batteries to power supply. The main mechanical components of a hybrid car are the power-control unit, the generator, the electric motors, the battery, and the gasoline engine. At start-up and when driving at low speeds, the vehicle is powered purely by the electric motor. As the speed increases, the system switches from an electric motor to an gasoline engine. Acceleration from cruising speed makes the electric motor to instantly supplement the gasoline engine to deliver a surge of acceleration. Modern HEVs offer efficiency-improving technologies, such as regenerative braking, which converts the vehicle's kinetic energy into electric energy recharging the batteries [7].

A crucial step in the process of the development of hybrid and electric vehicles is to understand the relationship between the magnetic field generated in the vehicle and the potential health hazards it may pose to the passengers [4, 11, 12, 18-22].

Magnetic field patterns are characterized by extremely complex combination of static and time-varying components depending on the devices that generate them and changes with operational regimes. The range of frequencies vary from the zero in the case of DC cables to the several kHz of harmonic components due to the inverter commutation [4, 9, 12, 16]. It was observed that the major components of the magnetic flux density appeared at frequencies up to 100 Hz [8]. At frequencies above a few kHz, the magnetic field is less than 100 nT and the inverter was identified as the sole source from the vehicles [16]. Therefore, we focused our assessment on static and low-frequency magnetic field.

Results in our article refer to the International Commission on Non-Ionizing Radiation Protection - (ICNIRP) reference values for the exposure of the general public. According to ICNIRP guidelines on limits of exposure to static magnetic fields (DC), acute exposure of the general public should not exceed 400 mT (any part of the body). However, because of potential indirect adverse effects and to prevent inadvertent harmful exposure of people with implanted electronic medical devices and implants containing ferromagnetic materials, and injuries due to flying ferromagnetic objects, ICNIRP implements much lower restriction levels, such as 0,5 mT [5]. The lowest ICNIRP reference level for the general exposure to magnetic field up to 400 Hz is 200 uT. The guideline for 50 Hz for implants like pacemakers or brain stimulators is about 100 uT [8,10].

In general, it is accepted that local field strengths of greater than 1 mT are sufficient to induce electromagnetic interference with implantable electronic devices [1].

Fig.1. The example of the placed probe during measurements and the example of the central display with photo-realistic images.

Material and methods

Measurements were performed in a Mercedes-Benz GLC 350 e 4MATIC with a plug-in hybrid complex AWD drive train. It comprises of a four-cylinder petrol engine with a 155 kW (211 hp) and a hybrid module with 85 kW (116 hp) of electric power. The electrical energy is stored under the trunk floor in a lithium-ion battery with an energy content of 8.7 kWh. GLC 350 e 4MATIC offers Silent Start (almost noiseless electric start), Boost (activation of the electric motor for accelerating) and Regeneration (when braking and rolling to a standstill, energy is recuperated and stored in the battery). The technical information concerning the examined vehicle was obtained from the car manufacturers' official Web pages. The magnetic field of the car was measured using a Gauss meter (Model GM2, AlphaLab, Inc, USA). The measurement of the produced electric field was not carried out since its value is nullified.

The measurements were carried out in four different driving conditions: stationary (idling) and travelling at 50 km/h (city driving), over 100 km/h (high-speed cruising), and breaking because the value of magnetic flux density changes as the car travels, following the functioning sequence of the combustion engine and the electric motor. The measurements represent typical exposure of the upper body of a front seat passenger and driver (Fig. 1) considering additionally the exposure of people with implanted electronic medical devices and implants containing ferromagnetic materials) The values presented in this article represent the percentages of the ICNIRP 2010 reference levels for the exposure of the general public [6].

Results and discussion

The results of our measurements show that the maximum values of exposure to magnetic field on-board do not exceed 8 uT. There are no significant differences between the exposure to the driver and the passengers (front and rear seats). The maximum exposure accompanies high-speed coursing and acceleration and braking. For the city driving speed and for idling the values are 70 % and 32% of the maximum permissible limits respectively. Our results agree with that of other researchers. Moreno et al. studied EMF generated by an electronic converter. The levels of magnetic field exposure assessed in simulation and measurements taken in the inverter at a distance of 20 cm, for the high current (39, 58 and 120 A, 100 Hz) which would correspond to the strong acceleration or deep regenerative braking of the car, didn't exceed 8 uT [9, 10] measured the same for two cars and the maximum values are found to be 4 uT for Opel Ampera (hybrid car) and 7 uT for Peugeot Ion (electric car) during city driving.

Another study has analyzed the magnetic field exposure in the frequency range of 5 Hz –2 kHz, for 12 different cars at the speed of 80 km/h. Average readings at the left floor level were found to be 3,22 uT and at the back seat were found to be 3,28 uT. This study also measured the magnetic field generated from the tyres at a distance 2 cm away from the wheel. Average magnetic field strength from new tyres was 22,4 uT, and from used tyres was 29,2 uT. Moreover, magnetic field level from the tyres with steel rims, such as 38,1 uT, were higher than those with alumi-nium rims [4,14]. The magnetic flux density in the range of 0-3,5 μT was found in other tests for a hybrid car [12, 15].

Tests carried out in Toyota Prius cars show that the magnetic field was consistently higher at the rear seats than at the front seats. Maximum values of magnetic field flux density occur when both the gasoline engine and electric motor were running; for example, when the car is accelerating, warming up, climbing slight hills or charging the battery (up to1 uT), [2].

Exposure values at the floor level and seat level in a hybrid car were investigated by [4]. The magnetic field level were the highest at the front and left seat (2,4 uT). The maximum levels of recorded magnetic field strength were at 12 Hz (Halgamuge et al., 2010).

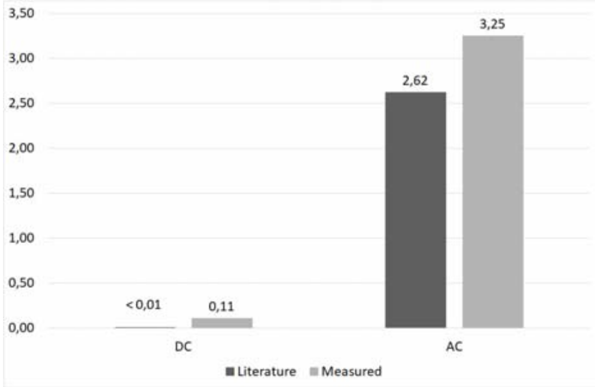

Fig.2. Magnetic field values in percentage with respect to the ICNIRP recommended limits. Levels assessed by authors in comparison of with those from literature

Karabetsos and colleagues [7] assessed 6 cars: 3 full-hybrid vehicle (FHVs) and 3 mild-hybrid vehicle (MHVs), selected as typical representatives, manufactured between 2001and 2010 by 3 different car-manufacturing companies. Measurements were carried out at velocities 20–40 km/h and a significant increase in the measured values is spotted in the foot area of the driver's seat. Values were found to be higher when both the electromotor and the gas engine were operating (at velocities of 80–120 km/h) [8].

All these reported results clearly indicate that the highest field (with exposure up to 80% of ICNRP levels) is generated during regenerative braking, decelerating or rolling on a declivitous road, while the battery was charging and maximum acceleration. Moreover, tests show that the highest values of magnetic field in all types of cars were located at the driver's seat. The measured values in all mild- hybrid-type (20%) cars are higher than those in full-hybrid-type cars (15%). Mild hybrids have far more powerful starter motors because the electric motor provides its maximum torque from zero speed, and it operates more like an electric turbocharger, providing an on-demand transient power boost. [7, 8, 13, 17].

In addition, measurements in the vicinity of the battery pack were performed during the start-up of the vehicles. The value around battery in the trunk was 0,15 mT. The static magnetic field measured on the floor and close to the surfaces of the vehicles, and the resulting values varied from 0,08 – 0,95 mT during the different driving conditions. Consequently, in all the examined cases, the dc magnetic flux density was found to be much lower than the limit value of 400 mT for the exposure of the general public [4, 7].

Conclusions

This paper briefly summarizes the current status of knowledge on electromagnetic fields related to HEVs/EVs, including the current regulations on the electromagnetic fields exposure to general public. Although several regulations have been published, there are no legislative requirements to limit low frequency electromagnetic fields exposure for the general public in electric and hybrid vehicles till date. Currently, the studies are not sufficient enough since these transportation systems are new and they have been operating only for a relatively short period of time [7, 17]. Results presented in this article show the magnetic field exposure during traveling remaining below ICNIRP reference values for all driving conditions and according to current regulations it can't be classified as health or safety hazards.

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