PROTEÇÃO CONTRA RADIAÇÕES NA COMUNIDADE DOS PAÍSES DE LÍNGUA PORTUGUESA

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Campos Magnéticos de Frequências Extremamente Baixas em Veículos Elétricos

Extremely Low Frequency Magnetic Fields Inside Electric Vehicles

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Palavras-chave: veículos elétricos, campos magnéticos de frequências extremamente baixas (ELF), limites de exposição do ICNIRP.

Resumo: Neste estudo foram efetuadas medições dos campos magnéticos (CM) em cinco viaturas de fabricantes e tipos diferentes – um automóvel turbo-diesel, um automóvel elétrico a baterias, dois automóveis híbridos com ligação à rede elétrica ("plug-in") e um mini-autocarro elétrico a baterias – para avaliar o nível de exposição dos ocupantes a estes campos. As medições foram obtidas ao nível dos pés, do assento e da cabeça em cada um dos lugares de cada veículo e realizadas para a gama de frequências entre os 30 e os 3000 Hz. Posteriormente, os resultados foram comparados com os limites recomentados pelas linhas orientadoras de 1998 da International Commission on Non-Ionizing Radiation Protection (ICNIRP). Estes resultados foram ainda comparados com alguns valores de CM obtidos em ambientes residenciais. Os dados obtidos mostram que, de um modo geral, os valores de CM são mais elevados ao nível dos pés, decrescendo em altura. Verifica-se ainda que os valores obtidos são mais elevados nos lugares da frente, variando, no entanto, com o modelo e tipo de veículo. A comparação dos resultados com os limites de 1998 da ICNIRP mostram que, em média, os valores medidos são sensivelmente 1000 vezes inferiores a estes limites, sendo que não foi contabilizado o efeito cumulativo de exposição simultânea a campos de diferentes frequências. Finalmente, os valores de CM medidos nas diferentes viaturas são muito semelhantes aos obtidos em ambiente residencial.

KEYWORDS: electric vehicles, extremely low frequency magnetic fields (ELF), ICNIRP exposure limits.

ABSTRACT: In this study, the magnetic fields (MF) were measured in five vehicles from different types and manufacturers – one diesel car, one battery electric car, two plug-in hybrid cars and one battery electric mini-bus – to assess the level of exposure to these fields. Measurements were obtained at foot level, seat level and head level in each car seat for the frequency range from 30 to 3000 Hz. Following, the results were compared with the 1998 recommended limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These results were also compared with some MF values obtained in residential environments. The data obtained show that MF values are generally higher at foot level, decreasing with height. It also show that the values are higher in the front seats, although this varies from vehicle to vehicle. Comparing the results with the 1998 ICNIRP recommended limits, the measured values are roughly 1000 times lower than these limits. However, it should be noticed that the cumulative effect to simultaneous exposure to fields of different frequencies was not taken into account. Finally, MF values obtained in the different vehicles are very similar to those obtained in residential environment.

1. INTRODUCTION

With the growth of the use of electrical and electronic devices and systems, some public concern has been arising about the human everyday exposure to electromagnetic fields, particularly after the classification of radiofrequency electromagnetic fields as possible carcinogenic to humans [IARC 2011]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has been establishing guidelines for protection of humans exposed to electric and magnetic fields in the low-frequency range of the electromagnetic spectrum for both occupational and public exposure [ICNIPR, 1998] [ICNIPR, 2010]. The European Union (EU) adopted the 1998 ICNIRP guidelines in 1999 as a Council Recommendation on the limitation of exposure to the general public [EU Council, 1999]. These exposure guidelines also apply to electric and non-electric vehicles.

Although there are some ongoing work on the assessment of magnetic fields onboard electric vehicles, data are still scarce, particularly not involving frequency sweep measurements [Hareuveny, 2015] [Tell, 2013]. The studies available so far suggest that the magnetic field (MF) is not significant above the frequency of 1 kHz [Dietrich, 1999] [Vassilev, 2015]. Some studies reveal that tire magnetization can induce alternating magnetic fields up to 2 μT in the interior of the cars, usually at frequencies below 20 Hz [Milham, 1999] [Stankowski, 2006].

In this work, the magnetic field inside conventional and electric vehicles was measured for frequencies ranging from 30 Hz to 3 kHz, at several places in the interior of the vehicles. This frequency range was chosen because it is related with the electrical drive system of electric vehicles.

2. METHODOLOGY

When measuring magnetic fields (MF) in electrical vehicles it is more important to consider the instantaneous power instead of the driving speed. Therefore, the measurements in the electric cars were performed on a very steep highway (slope of about 6%) in order to ensure a significant power consumption of about 20 kW at a safe driving speed (of about 40 km/h). This power consumption of 20 kW roughly corresponds to a horizontal driving speed of about 90-100 km/h. The diesel vehicle was driven at 60 km/h in a flat road. All data obtained near high voltage power lines were discarded.

The measurements were made at the foot, seat and head level at each passenger place, including the driver. The MF levels were measured in 4 different vehicles: one Battery Electric Vehicle (BEV), two Plug-in Hybrid Electric Vehicles (PHEV), and one Diesel vehicle, from different manufacturers.

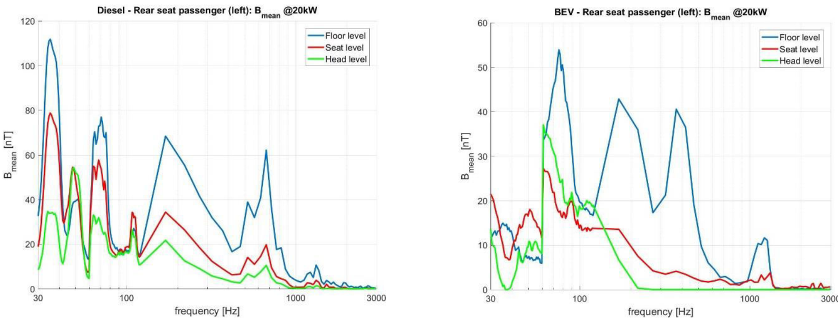
The measurements in the electric mini-bus were made during its normal round trip urban route as it belongs to a city public transportation system. The first part of the bus circuit is at an historical area of the city, ascending and descending narrow streets, where the velocities are below 20 km/h. The other part of the circuit is flat, in a larger avenue, where the velocity was up to 45 km/h. The bus has two rows of four seats each. One is at the front, behind the driver, next to the electric DC traction motor and other auxiliary motors and electronics. The other row of seats is located at the rear, over the 72 V battery pack and next to the DC-DC 12 V and 24 V converters. The measurements were made at the foot, seat and head level at the passengers' places.

All measurements were obtained along three frequency ranges: 30 to 60 Hz, 60 to 120 Hz, and 120 to 3000 Hz. The filter bandwidth (resolution bandwidth) was of 3 Hz for the first two frequency ranges, and of 100 Hz for the last one. The measurement equipment used was an Aaronia Spectran NF-5020 [Aaronia, 2013], with a measuring bandwidth from 1 Hz to 1 MHz, connected to a laptop computer for fast configuration and data logging.

3. RESULTS

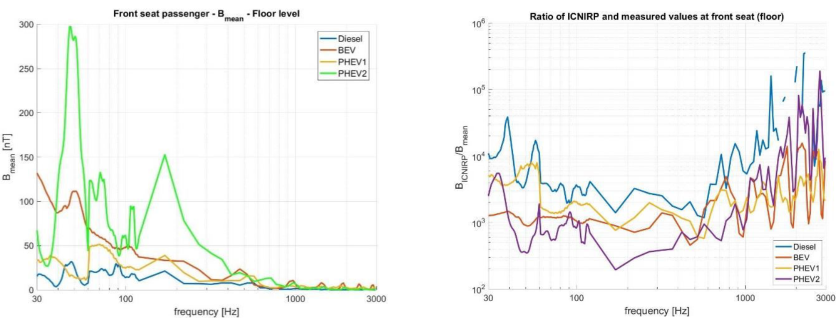
All the magnetic field (MF) intensity values presented are RMS. Mean values were obtained after several band sweep cycle readings.

In Figure 1, it is shown the mean measured MF values for the diesel vehicle and a battery electric vehicle (BEV) obtained at the left rear seat at different heights. It can be observed that MF values are significantly larger at the foot level and that they decrease with height and frequency. Figure 2a presents the MF measured at the passenger front seat at foot level for the cars considered in this study. It evinces that the MF differ from car to car, being higher for electric cars. Figure 2b shows that the MF measured are at least 1000 times lower than the maximum recommended by the 1998 ICNIRP guidelines for frequencies below 1 kHz. For higher frequencies, this ratio increases.



(a) (b)

Figure 1. Mean MF measured at the rear left passenger seat at different heights: (a) diesel vehicle; (b) battery electric vehicle.



(a) (b)

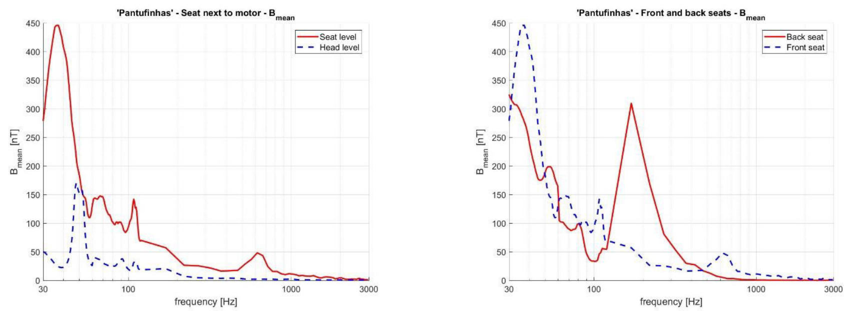
Figure 2. Mean MF measured at front seat passenger (foot level): (a) Mean measured values; (b) Ratio of ICNIRP recommended maximum values and mean measured values.

Table 1. Maximum MF values and highest mean values measured and respective frequency

	Diesel	BEV	PHEV1	Mini-bus EV
B_{max} (nT)	348 @31.2 Hz	349 @34.8 Hz	755 @34.8 Hz	1947 @81.6 Hz
B_{mean}(nT)	89 @35.4Hz	65 @30 Hz	51 @35.4 Hz	442 @37.2 Hz

The MF values vary significantly during the measuring period and in table 1, it can be observed that maximum values are significantly higher than mean values. It also shows that the maximum values in the cars are registered at frequencies around 30-35 Hz and in the mini-bus around 82 Hz.

In figure 3, it is shown the mean measured MF values for the battery electric mini-bus, obtained at the front and rear right seats, where maximum values were obtained. Figure 3a shows MF values at the front right seat, at different heights. Figure 3b shows the mean measured MF values at the right rear and front seats, at seat level. At these levels the magnetic fields were higher than at other levels. The right front seats are the closest to the electric DC traction motor and other auxiliary motors and power electronics. Just behind the rear seats are located the DC-DC 12 V and 24 V converters and electric buses.



(a) (b)

Figure 3. Mean MF measured at the electric mini-bus: (a) at the front right seat, next to motor, at different heights; (b) at the front right and rear right seats.

Table 2 shows that MF in different residential environments can also vary significantly. The measured values in the electric cars are of the same order of magnitude as those observed in modern residences. At half meter from operating microwave ovens, the measured MF values are about 600 nT which is comparable to some values registered within the PHEVs and mini-bus. Next to some high consumption home appliances (dish washer machine, electric oven, small power transformers) measured MF values can reach values from 1.3 up to 5.2 μT, which is much higher than the MF values measured in the electric vehicles.

Table 2. Maximum MF values and highest mean values measured and respective frequency at different residence environments (without high power appliances operating).

	Low MF Residence	High MF Residence
B_{max} (nT)	53 @48 Hz	389 @48 Hz
B_{mean}(nT)	30 @48 Hz	347 @48 Hz

4. CONCLUSIONS

In this work, the MF at five different vehicles – one diesel car, one battery electric car, two plug-in hybrid electric vehicles, and one battery electric mini-bus – were measured in the frequency range from 30 to 3000 Hz. In the cars, the measurements were performed under the same electric power consumption of about 20 kW, for comparison purposes. The mini-bus measurements were obtained in its normal round trip urban route.

From the obtained values, it was verified that in the cars, MF are higher at the floor level, decreasing with height. The distance from the cabling and the batteries of the vehicles, which are mainly located at the floor of the car, explains this variation. In the mini-bus, the MF are higher at the seat level because it is close to power electronics and electric motors.

Above 1 kHz, the magnetic fields are very low because electric cars are usually equipped with AC synchronous motors fed by an inverter and the mini-bus operates with a DC motor. As expected, the values obtained for the diesel vehicle are generally lower than those obtained in the electric vehicles.

Generally, MF are higher in the cars front seats, which are closer to the electric motor and inverter. Nevertheless, the MF distribution over the interior of the cars vary from model to model.

The MF values in the cars are significantly lower than those recommended by 1998 ICNIRP guidelines for general public exposure. On average, the values are about 1000 times below the recommended maximum limit values. In the mini-bus, although the MF values are higher than those in the cars, they are about 200 times below the recommended maximum limit values. These results do not take into account additive effects due to simultaneous exposure to fields of different frequencies.

Finally, MF values measured in the different cars are of the same magnitude of those measured in residential environments. Next to some high consumption home appliances, the MF are higher than those measured at electric vehicle seats.

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