LOW FREQUENCY MAGNETIC FIELDS INDUCED BY CAR TIRE MAGNETIZATION

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Abstract—**Alternating magnetic fields have been measured in a variety of different cars, the dominant contribution being from magnetized tires. Magnetic field strengths have been measured as a function of frequency directly at the tires and at different positions in rolling cars. Measurements at the tires showed field strengths up to 100 microtesla (μT). In the interior of rolling cars, close to the wheels at foot regions and at the back seat, field strengths of several μT were obtained in the 10–200 hertz (Hz) frequency domain. In some cases measured field values were considerably higher than those found in previous studies. Purposely magnetizing single tires made it possible to study the influence of various parameters. Degaussed tires retained low field values over prolonged time under conditions of normal use.**

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INTRODUCTION

In the present study, low frequency magnetic fields were measured at different positions in the interior of various vehicles at rest and when rolling at defined speeds. The main magnetic field contribution could be traced to the steel-belted tires: fields are highest at measuring spots close to the wheels, and spectral peaks of the alternating field correlate with the wheel spinning frequency, independent of using aluminum or steel rims. These findings correlate with those reported by other groups (Vedholm 1996; Jacobs et al. 1998‡; Milham et al. 1999). Milham et al. (1999) had demonstrated tire magnetization by cutting tires and using iron filings on a paper put on the sections. In the present study, magnetic fields were measured by approaching a field sensor very close to the surface of tires spinning on a balancing machine.

Tire magnetization varies considerably among individual specimens. Therefore, a broad range of samples has been investigated, using a variety of different tires and cars. In addition, tire magnetization and demagnetization were induced deliberately in order to get defined measuring conditions. A degaussing method has been developed and it was checked whether degaussing remained sustainable.

MATERIALS AND METHODS

Magnetic fields were measured using a NARDA EFA200 Electromagnetic Field Analyzer together with a BN2245/90.10 field probe (Telemeter Electronic, Ellighausen, Germany). The instrument uses three measuring coils at right angles to each other to intercept fields of arbitrary direction. Spectral analysis of root mean square (rms) signals was performed in Fast Fourier Transform (FFT) mode at 1 hertz (Hz) spectral resolution in the 5 to 2000 Hz range.

In the present study, magnetic fields are characterized using two different parameters of the FFT spectrum: the highest value in the rms spectrum ("maximum-peak value") and the sum of all peak values in the rms spectrum between 5 and 200 Hz ("sum of peaks").

Magnetic fields in the interior of a car were determined at the following locations (Fig. 1):

1. Driver's pelvis region;
2. Driver's head region;
3. Driver's or co-driver's foot region;
4. Back seat (pelvis region of person in back seat).

Measurements were done in vehicles at rest and when rolling at defined speed on public roads. The following vehicles were used in the survey: BMW 318i, Ford Focus 1.8, Ford Mondeo Trend 2.0, Opel Astra 1.6, Opel Corsa 1.2, Opel Zafira 2.2, Volvo V70 D5, Volvo

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‡ Jacobs WL, Dietrich FM, Feero WE, Brecher A. Assessment of magnetic fields produced by spinning steel belted radial tires. Poster at EPRI/DOE Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity, Tucson, AZ; 1998.

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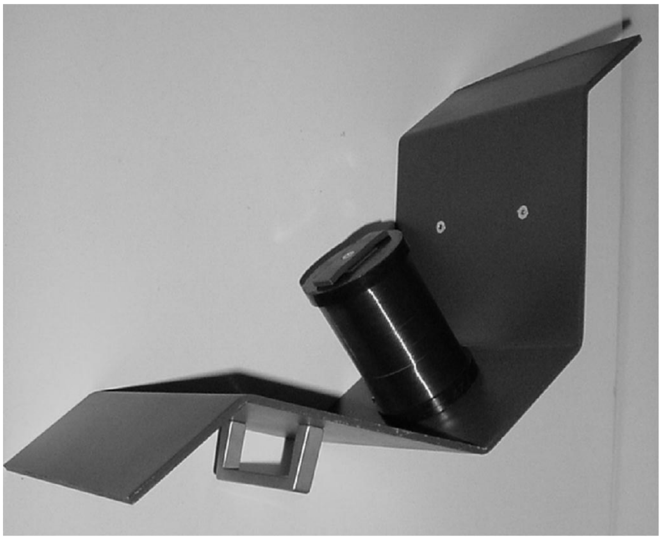

Fig. 1. The degaussing coil, also used for purposely magnetizing tires.

V40 T4, VW Golf, VW Polo, Toyota Yaris 1.4i, Peugeot 106 1.1i, and Renault Express. Vehicles used for experiments with defined magnetization also included Toyota Carina, Fiat Punto, and Daewoo Matiz. Some of these vehicles were made available by friends and never entered the laboratories, thereby excluding any influence of some unknown field source within the labs themselves.

Wheel rotation frequencies at given speed were calculated from the known geometries of rims and tires.

Direct measurements at tire surface were performed with the NARDA instrument close to the surface of tires mounted on a balancing machine and spinning at defined speeds between 240 and 360 rpm. “Close distance” refers to the gap between the surface of the instrument’s measuring bulb and the surface of the tire. Since the bulb has a radius of 5.5 cm and the steel inlay of the tires lies some millimeters beneath the profile, a surface-to-surface distance of 1 cm corresponds to the 7 cm distance between the center of the measuring coil and the steel inlay of the tire. The latter value has been used when analyzing distance dependencies. Investigated tires were from the following brands: Good Year, Dunlop, Pirelli, Michelin, Firestone, Semperit, and Nokian.

Tires were degaussed by using a self-made instrument consisting of a coil of 1,200 windings with iron core, with metal wings 80 mm × 160 mm (Fig. 1). Applying a 50 Hz AC current, it was slowly removed by hand from the tire spinning on a balancing machine. Tires were intentionally magnetized by bringing the “degaussing coil” attached to a 12 V battery near to the surface of the tires. Magnetic field values obtained close to the surface of magnetized tires were 50–75 microtesla (μT) with a single application of the DC coil and 75–150 μT with two applications at opposite parts of the wheel.

In order to investigate the influence of tire magnetization on the magnetic fields in a car, all tires of a given car were thoroughly demagnetized. One particular tire was then purposely magnetized and the magnetic field strength was measured at close distance from the tire spinning on a balancing machine. The magnetized tire was then mounted in the car and the field strength measured when rolling at 80 km h^{-1}, at the measuring location closest to the magnetized tire.

RESULTS

Magnetic fields in cars

Measurements of magnetic fields at different locations in the interior of cars at rest and rolling on public roads are summarized in Table 1. Values obtained at position 1 (driver’s pelvis) in the vehicle at rest with the engine stopped were close to instrumental noise, typically well below 0.1 μT maximum peak.

Values obtained in idle mode, with the car stopped and the motor running, were measurable but remained low, typically in the range 0.1–0.3 μT, at frequencies slightly above 30 Hz. Magnetic fields measured in rolling cars, analyzed according to FFT, yielded spectral peaks coinciding with the spinning frequency of the wheels of 10–12 Hz at 80 km h^{-1}, and harmonics of it. Fig. 2 shows a typical FFT reading.

Relatively high field values of up to 9.5 μT were obtained in the driver’s or co-driver’s foot regions and at the back seat in a large number of cases. Table 2 gives an overview of the maximum-peak values and sum-of-peaks results for these two positions for 12 different cars. Fig. 3 gives the corresponding distribution. Foot region and

Table 1. Maximum peak values in μT measured in the interior of 12 cars with untreated tires in different measuring positions (1 = pelvis, 2 = head, 3 = co-driver’s foot, 4 = back seat). Rolling speed 80 km h^{-1}.

Peak field in car	Position 1 at rest	Position 1 at 80 km h^{-1}	Position 2 at 80 km h^{-1}	Position 3 at 80 km h^{-1}	Position 4 at 80 km h^{-1}
Mean	0.08	0.29	0.21	3.22	3.28
Standard deviation	0.04	0.18	0.10	2.53	2.55
Maximum value	0.18	0.73	0.45	8.89	9.51
Minimum value	0.03	0.12	0.10	0.76	0.65

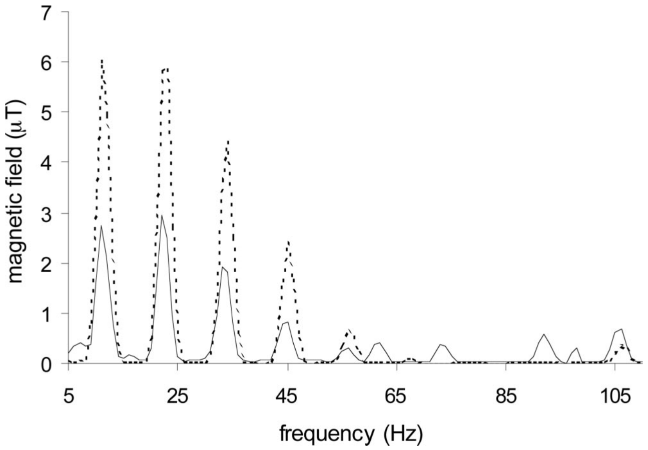

Fig. 2. Typical FFT spectrum of magnetic field intensity B measured in a rolling vehicle, BMW 318i at 80 km h^{-1}. Broken line: measurement at co-driver's foot region; full line: back seat region.

back seat results being very similar, they have been pooled for this analysis in order to have a sufficient sample number, $n = 24$, and improve the statistics. In two thirds of cars, maximum-peak values were above 2 μT. In 25% they exceeded 6 μT in at least one measuring position. If the analysis is not limited to the value of the maximum peak in the spectrum, but all harmonic peaks are summed up, 50% of the studied cars yielded values above 10 μT, and in 2 out of 12 cars values exceeded 20 μT in at least one measuring position.

The influence of speed was tested in the range of 40 km h^{-1} to 120 km h^{-1}. Peak frequencies remained strictly correlated to the calculated wheel revolution frequencies. Maximum field strengths remained virtually unchanged, independent of speed (e.g., Peugeot 106, co-driver's foot: 10.2 μT at 8 Hz for 50 km h^{-1}, 10.6 μT at 20 Hz for 120 km h^{-1}).

Magnetic fields of tires

Direct measurement of magnetic fields on commercial tires, performed at close distance from the surface of tires mounted on a balancing machine, yielded magnetic field spectral peaks at the spinning frequency and harmonics of it. Analysis of maximum-peak values for 32 tire samples of different brands and types, some used, some new, and mounted on steel or aluminum rims, is given in Table 3. It shows a very broad distribution of maximum-peak values ranging from 0.8 to 97 μT, the overall mean being at about 25 μT. No significant differences have been found among different sample groups. However, the distribution for old tires appears to be broader than for new ones.

Demagnetization and magnetization of tires

In order to better study the influence of tire magnetization on the magnetic fields in cars, tires were demagnetized and magnetized in a controlled way. Demagnetization of the tires has been performed by a degaussing coil with metal wings. Peak values dropped below 5 μT at close distance from the belt. Demagnetization was stable over months. Demagnetized tires being used on a car under normal conditions were checked from time to time and field strengths remained low in repeated measurements (Table 4).

Magnetic fields in cars have been measured after mounting intentionally demagnetized or magnetized tires. Using demagnetized tires, fields in the vehicle's interior were correspondingly reduced. If the right front wheel was magnetized, field values increased maximally at the co-driver's foot region. If the rear wheel was magnetized, fields were most important at the back seat. For example, magnetizing a rear tire of a Toyota Carina with a 79 μT maximum peak at close distance on the balancing machine gave rise to the strongest fields at the back seat of 2.9 μT maximum peak (10.6 μT sum of peaks). Degaussing the same tire to the residual field strength of 1.2 μT at close distance reduced the fields at the back seat in the rolling car to 0.56 μT (1.5 μT sum of peaks).

Influence of distance from the wheel and car body on magnetic fields in cars

Increasing the distance between a tire and the field probe, the field strengths decreased markedly. Log-log plots of magnetic field vs. distance between the steel inlay of the belt and the center of the field probe could be fitted by straight lines with a slope of 2 (2.1 ± 0.25 based on 5 measurements).

The question thus arose whether the field in the interior of cars was essentially dependent on the distance from the rotating wheel or whether there was a damping effect of the car body. This question can be answered by comparing measurements in the rolling car with measurements obtained at the balancing machine at the same distance from the wheel. Though the rotation frequencies are different in the car and at the balancing machine, the results can be compared because the maximum field intensities are found to be independent of car speed and therefore of rotation frequency.

As an example, all tires of a Toyota Carina were degaussed and afterwards one tire was magnetized. The tire was mounted at the right front position, and the field measured in the rolling car at 80 km h^{-1} at the co-driver's foot position was 2.4 μT. The tire was also measured at the balancing machine at close distance (71.7 μT) and at a distance of 18 cm, the distance between the measuring

Table 2. Sampling of 12 cars with untreated tires: maximum peak magnetic fields and summed harmonic peaks, in μT, at the most strongly affected measuring positions (3 = co-driver's foot, 4 = back seat).

Max. peak field/summed peaks	Position 3 at 80 km h^{-1}		Position 4 at 80 km h^{-1}	
	Max. peak	Sum peaks	Max. peak	Sum peaks
Mean	3.22	8.44	3.28	8.02
Standard deviation	2.53	5.52	2.55	5.25
Maximum value	8.89	21.83	9.51	20.21
Minimum value	0.76	2.78	0.65	1.22
Upper quartile	4.05	10.73	4.38	10.73
Lower quartile	1.25	3.45	1.45	4.50
Mean of upper 50%	6.61	15.12	6.90	14.84
Mean of lower 50%	1.33	4.37	2.34	4.09

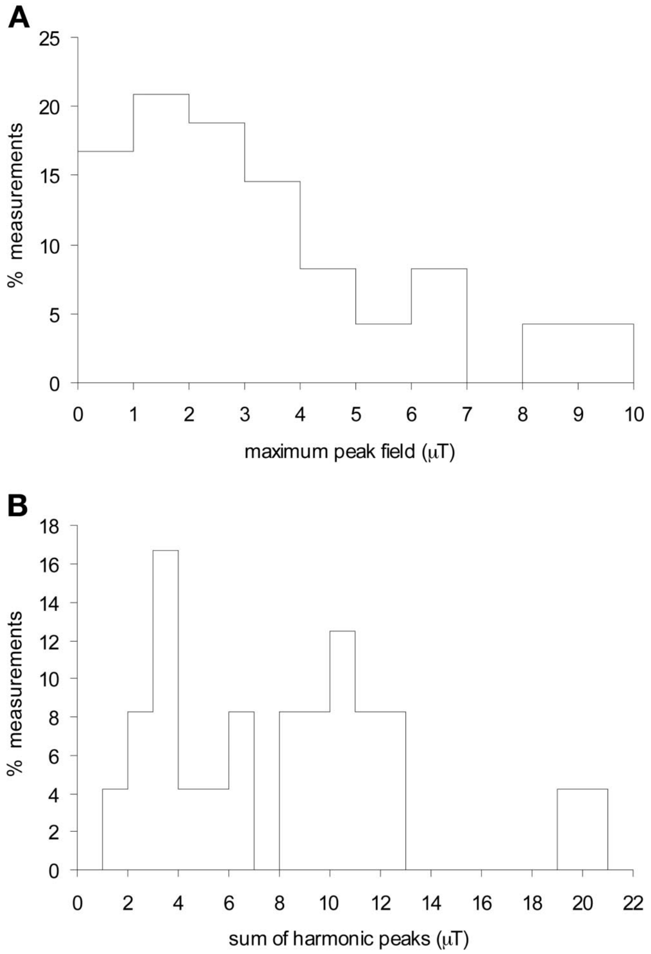

Fig. 3. Statistical distribution of maximum-peak values (A) and of summed peaks of harmonics (B) by magnetic field for a pooled sample of measurements at foot and back seat locations. Total number of data points is 24, obtained in 12 different cars.

position in the car and the Carina front wheel tread, yielding 14.3 μT. This experiment shows that distance dependence is not sufficient to explain field intensity in the interior of the car. The additional six-fold reduction must be due to the influence of the car body. The same experiment was repeated at the back seat with a magnetized rear tire. Similar experiments were also performed on a Fiat Punto and a Daewoo Matiz. Reduction factors produced by distance and by the car body are listed in Table 5. They show that car body damping can differ by at least a factor of 2 in different cars.

DISCUSSION

Experiments on various tires and vehicles confirm previously published conclusions that tires can be a source of non-negligible low frequency magnetic fields in cars. Examining a number of tires, used tires had a larger variance than new ones, presumably reflecting a larger variety of production conditions as compared to the new samples. Alternatively, the larger variance could also reflect changes of magnetization during usage. The results obtained in the present study rather argue against this last possibility, because the high fields required to produce the observed magnetization (close to 100 μT) are unlikely to appear in normal usage car environment, and also because degaussed tires did not show any sign of spontaneous magnetization effects in the present study. This, however, is in contrast with observations by Milham et al. (1999).

Previous experiments had shown large differences in the magnetic field strengths detected in individual cars (Vedholm 1996; Jacobs et al. 1998[‡]; Milham et al. 1999). In this study, 12 arbitrarily chosen vehicles have been tested. Magnetic fields encountered in this study reached values noticeably higher than previously reported. A possible reason could be the fact that smaller and lighter vehicles have been included as compared to previous studies (Vedholm 1996; Milham et al. 1999). Analysis of distance dependence from the wheel and comparing measurements at the balancing machine and in rolling cars in fact showed differences in the damping effect by the car's body (see Table 5).

Field intensity strongly decreases with distance from the tread. In order to get precisely reproducible values of the measured fields, the position of the measuring instrument should therefore be precisely defined. Changing its

Table 3. Statistics of maximum peak values of the magnetic field intensity of tires, in μT, measured at the balancing machine at close distance from the tire surface.

Peak field of tires	all (n = 32)	new (n = 13)	used (n = 19)	alu rim (n = 25)	steel rim (n = 7)
Mean	25.2	22.4	29.2	21.5	38.1
Standard deviation	22.3	7.8	34.0	18.8	29.9
Maximum value	97.0	33.9	97.0	97.0	71.9
Minimum value	0.8	10.1	0.8	0.8	6.4
Upper quartile	30.8	28.4	68.4	29.5	68.4
Lower quartile	11.6	18.4	2.4	11.0	11.6

Table 4. Maximum peak magnetic fields of tires before and after degaussing, in μT (Renault Express, standard use during control time).

Peak field/tire	Front left	Front right	Rear left	Rear right
Before degaussing	15.0	13.6	9.4	8.7
After degaussing	2.3	0.2	3.4	0.1
Control after 1 month	2.4	0.3	1.0	0.6
Control after 5 months	3.6	0.5	1.0	0.5

Table 5. Field reduction by distance and by car body damping, (3) = co-driver's foot, (4) = back seat. Due to tolerances in distances, car body damping values have ± 0.5 uncertainty.

	Reduction factor by distance	Damping factor by car body	Overall damping factor
Toyota Carina (3)	6	5	30
Toyota Carina (4)	13–14	1.2–1.5	19
Daewoo Matiz (3)	12	2.5	29
Daewoo Matiz (4)	25	1	25
Fiat Punto (3)	7	2	14
Fiat Punto (4)	15	1–1.5	18

position in the car by about 1 cm changes the measured field by 5–6%. In this study, it has not been attempted to define the measuring positions more exactly than that. In fact, interest is in assessing exposure of people whose sitting position is of course subject to variation. In addition, distance to the wheel is also subject to changes as a function of spring compression.

The field values in the interior of cars given in this study therefore have an uncertainty of 10%. This figure combines 6% of positioning uncertainty with 4% statistical standard deviation of the measurements, the latter being determined by six-fold repetition under equal conditions.

Distances at the balancing machine were adjusted to ±1 mm precision. At the close distance to the tire, this corresponds to 2–3% uncertainty. Together with the statistical standard variation, this yields 7% uncertainty for tire measurements at the balancing machine.

A particular problem is the appearance of harmonics, apparently due to multiple magnetization spots on the tires. The harmonics contribute to the overall field exposure, but tend to be neglected when the analysis is limited to the single maximum-peak value of the rms spectrum, as in previous publications (Vedholm 1996; Milham et al. 1999). Whereas the maximum-peak value is a valuable figure for characterizing the degree of magnetization of a tire and for comparing with other publications, in the present report the sum of harmonic peaks is also evaluated in order to better characterize the overall exposure. Direct summation is in line with the multiple frequency rule applicable at low frequencies where the field amplitude is the relevant parameter, in contrast to quadratic summation at frequencies above 100 kHz where energy absorption dominates (ICNIRP 1998, 2003).

In order to compare the measured magnetic fields with the internationally recommended limits for the general public, peak values at different frequencies have been weighted and summed up according to the recommendations of ICNIRP (1998). The sum was truncated at 100 Hz. Though some harmonic peaks at higher frequencies are lost in this way, truncation at 100 Hz avoids blowing up of small peaks near noise level by the fact that ICNIRP weighting factors increase with frequency. The following results were obtained in percent of the ICNIRP tolerance threshold for the general public. At the co-driver's foot region: mean 4.6%, standard deviation 3.8%, maximum value 14.3%. At the back seat: mean 4.0%, standard deviation 2.7%, maximum value 6.9%. These values are given for a car speed of 80 km h^{-1}. Field intensities remain unchanged with increasing speed, but ICNIRP limits decrease with frequency as $5/f$ (μT, f in kHz) in the relevant frequency domain. Therefore, weighted sums increase proportional to speed, e.g., 14% at 80 km h^{-1} would correspond to 21% at 120 km h^{-1}.

CONCLUSION

Magnetic fields in cars in the μT domain have been found to be produced by magnetized tires. In rolling cars, they give rise to low frequency field exposure. Field values measured in the present study are higher than previously reported. Taking into account the higher frequency harmonics, summed-up peaks reach values of up to 20 μT. Although the measured fields in cars remain well below the general limit for public exposure as defined by ICNIRP (1998) standards, they are relatively high compared to other exposures in daily life, especially for children seated in the rear seat, as field strengths are comparatively high there and children are a sensitive part of the population.

In the given situation, it appears rewarding to concentrate on cheap means for eliminating tire magnetization. The degaussing procedure performed in this study led to significant decrease of exposure that remained stable over months of normal use. In the mean time, the degaussing coil has been attached to a balancing machine and efficient and reproducible degaussing demonstrated under routine conditions. As a precautionary measure, degaussing could thus be offered as a service supplement when buying or balancing tires, or could be routinely performed by producers or vendors.

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