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Sample Description	LVT Flooring (Film Color 7404-1) Flooring underlayment
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1. Purpose

The purpose of this phase of the project is to quantitatively assess magnetic field strengths of a magnetic flooring system. The assessment was carried out on one flooring type, LVT.

2. Background

2.1. The Hall Effect

In the 19th century Edwin Hall attached a wire to each side of a rectangular piece of gold foil, passed an electrical current through the length of the foil, and measured the voltage across the width of the foil. Hall discovered that the voltage, now called the *Hall voltage*, V_H, is directly proportional to the number of flux lines passing through the foil, the angle at which they pass through it, and the amount of current used. He also found that the polarity of the voltage reverses when the direction of the flux travel reverses.

Because of the extremely low voltage produced by the foil, the *Hall effect* remained a laboratory curiosity until the development of certain semiconductor compounds such as gallium arsenide (GaAs) and indium arsenide (InAs). These materials produce relatively large Hall voltages and led to the widespread use of the Hall effect in science and industry.

A modern Hall effect device, commonly called a *Hall generator*, consists of a thin square or rectangular plate or film of GaAs or InAs to which four electrical contacts are made. The plate or film is often affixed to a ceramic substrate that provides mechanical support, thermal stability, and wiring nodes. Other devices are wire bonded to a nonmagnetic lead frame and encapsulated in a dielectric material.

The output of a Hall device is greatest when the flux lines are perpendicular to the surface of the material. When the angle is held constant, and a constant current is provided through the material, the Hall voltage is directly proportional to flux density. Conversely, holding the flux density and current constant allows the device to respond to the angle of the flux lines. One particularly useful aspect of a Hall generator is its ability to sense the direction of flux travel, allowing it to detect both static (DC) and alternating (AC) fields.

The active area, the area of greatest magnetic sensitivity, is considered to be located in the center of the plate or film and is the largest circular area that can fit within the boundary of the connection points. Present manufacturing methods have produced active areas as small as 0.13 mm in dia. Some devices are only 0.25 mm thick, allowing their use in very tight spaces.

The ideal Hall generator produces zero voltage in the absence of a magnetic field, but actual devices are subject to variations in materials and construction. Most Hall generators therefore produce some initial output in a zero field. This signal, known as the Hall offset voltage, V_m, can be cancelled with external analog circuitry, arithmetically cancelled by a computer, or removed by abrasive or laser trimming. The offset voltage is affected by temperature and can change in either the positive or negative direction. V_m is usually specified as a maximum ±μV/ºC change.

The ideal Hall generator has a constant sensitivity over a range of flux density, but actual devices are seldom linear. Typical accuracy ranges from ±0.1% to ±2% of reading. The sensitivity is also temperature dependent and always decreases as temperature increases for both GaAs and InAs. Typical values range from 0.04%/ºC to 0.2%/ºC.

A Hall generator produces a positive voltage for flux lines traveling in one direction and a negative voltage in the opposite direction. Ideally, for equal fields of opposite polarity a Hall device will generate equal voltages of opposite polarity. In reality there is a phenomenon called a reversibility error that causes these voltages to be slightly different in magnitude. This is caused, in part, by inconsistencies in the material's composition and by the locations and sizes of the electrical connections to the edges of the Hall plate. The error is usually stated in terms of percent of reading and can be as high as 1%.

2.2. The Hall Effect Gaussmeter and Probe

A modern Hall generator may produce signals as low as 5 nV/μT (500 nV/G) or as high as 2 μV/μT (200 μV/G). Hall effect gaussmeters (or teslameters) are designed to amplify and condition these low-level signals and provide a result that is calibrated in terms of gauss and/or tesla. These instruments range from small handheld meters to more sophisticated bench-type units. The instruments generally provide multiple range settings that allow the user to measure flux density as low as 0.1 nT (1 μG) and as high as 100 T (1 MG). Some meters measure only static and DC fields while others are capable of both DC and AC measurements. Some instruments accept input from several Hall generators simultaneously, allowing for 2- and 3-axis vector measurements. In addition to front-panel readouts, some gaussmeters provide analog signals that can be used in control loops or for analysis of pulsed or alternating magnetic field waveforms. High-end gaussmeters usually offer some form of communications, typically RS-232, IEEE-488 (GPIB), or stream data live via a USB connector, allowing the instrument to be used in automated data acquisition and control systems.

Often the Hall generator is mounted inside a protective tube, or stem, made of aluminum, fiberglass, perspex or other non-magnetic material. The wires are connected internally to a flexible cable and the cable is terminated with a multi-pin connector. This assembly, known as a *Hall probe*, is generally available in two configurations. *Transverse* probes are usually thin and flat; *axial* probes are cylindrical. The primary difference is the axis in which flux lines are sensed. Transverse probes are often used to make measurements between two poles of a magnet such as those found in audio speakers, electric motors, or MRI machines. Axial probes can be used to measure the fields generated by coils or solenoids. Either type can be used where there are few physical constraints. Some probes contain several Hall generators arranged orthogonally to allow simultaneous measurements in different axes.

The Hall effect is generally considered as having a maximum resolution of 100 nT (1 mG). Below this level, electrical noise and thermal effects swamp the usable signal. Some gaussmeters use heavy filtering, modulation techniques, and sophisticated averaging in an attempt to provide better resolution. Placing the Hall sensor near one or two pieces of iron or other ferrous material can enhance the signal. These pieces, called concentrators, bend the local flux pattern so that more lines pass through the sensor. Because of the local flux distortion and the size of the concentrators, this type of probe is normally used to make volumetric measurements such as in geomagnetic surveys, electrical interference studies, or preflight package inspections.

2.3. Using a Gaussmeter in Practice

Gaussmeters are relatively straight-forward to use, but there are several sources of errors that can affect accuracy if the operator is not familiar with the Hall effect or magnetic fields. "Zeroing" or "nulling" the Hall probe and meter is one of the most important steps toward obtaining accurate flux density measurements. As stated earlier, most Hall devices produce an offset signal in the absence of a magnetic field. Second, the internal circuitry of the meter itself is likely to produce a small offset signal even in the absence of an input signal. Finally, local flux from the Earth (i.e., the geomagnetic field) or nearby magnetic sources will affect the Hall sensor. The process of zeroing eliminates these errors. The probe is frequently placed in an assembly called a *zero flux chamber* to shield the Hall device from all local flux. In other situations, it may be desirable to zero the probe without the chamber so that all future readings are relative to the local flux condition.

Another common source of error is due to the angle of the Hall generator relative to the flux being measured. The highest output is generated when the flux lines are perpendicular to the Hall sensor. This is the way each Hall probe is calibrated and specified. It is often incorrectly assumed that the plane of the Hall generator is exactly the same as the axis of the probe's stem, but because of variations in material and manufacturing this alignment is not a certainty. The user should always peak the probe, a process in which the probe is rotated and tilted in several planes to obtain the highest possible output for a given field. At that point the probe should be fixed in place.

Hall effect measurement of permanent magnets can lead to confusing results. Flux density decreases as the distance from the pole face increases. The Hall generator will always be some finite distance from the pole face because there will always be material (the stem and air) between it and the magnet. Flux lines are seldom distributed evenly across the pole face of a magnet. Interior flaws such as cracks or bubbles, or an inconsistent mix of materials, can result in flux density variations. The Hall device will respond to this if it is much smaller than the face of the magnet. Finally, problems can arise from ferrous materials in the area where the test is being conducted. A steel workbench can redirect the flux lines from a magnet and cause erroneous results.

Temperature effects, linearity errors, and reversibility errors should be taken into consideration when making Hall effect measurements. Modern gaussmeters can compensate for these problems, but the user should always refer to the specifications and take advantage of additional performance data if the manufacturer offers them.

Many gaussmeter manufacturers also offer a variety of permanent reference magnets and reference coils that can be used to verify the basic operation of the equipment. Verifying overall accuracy often requires a huge investment in magnetic standards and specialized equipment, so certification and calibration are often left to the original manufacturer or a third-party calibration laboratory. Most manufacturers recommend a one-year calibration cycle.

Hall effect gaussmeters provide an economical and relatively easy way to measure flux density. They are used in research, product design, education, and materials inspection. However, it is important that the operator have a proper understanding of magnetic fields and the Hall effect to most effectively use such instruments.

3. Test Item Description

Samples of LVT Flooring (referred to in this report as "overlay") and Flooring Underlayment (referred to in this report as "underlay") were delivered to *airmid healthgroup* on the 11th of January and the 10th of February 2017, respectively. Figure 3.1 shows the overlay (a) and underlay (b) laid in the environmental test chamber.

(a) (b)

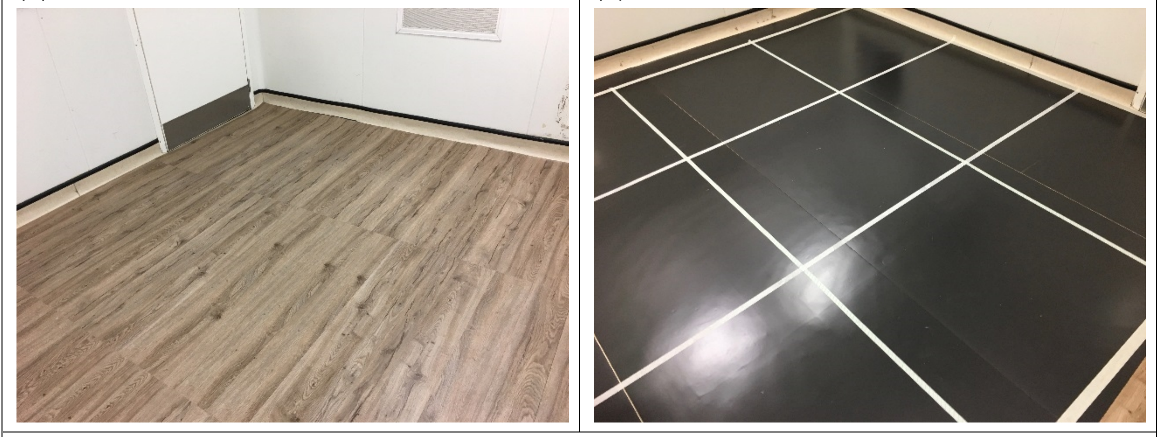

Figure 3.1. (a) Overlay – unmarked. (b) Underlay marked into sections

4. Materials and Methods

4.1. Instrumentation Used

The state-of-the-art type-GM07 Gaussmeter used in the present study was supplied by Hirst Magnetic Instruments Ltd., UK – a company with a distinguished history in this field. It is designed for inspection and measurement of magnetic flux density and magnetic field strength of magnets and magnetic assemblies in quality assurance environments such as factory settings, research laboratory environments, and on-site locations.

The GM07 gaussmeter is equipped with a robust transverse Hall effect probe mounted at the end of a flexible 1.5 m long cable. The sensitive gallium arsenide Hall element within the probe has a thickness of 1.0 mm and an active area of 0.2 mm × 0.2 mm. The accuracy of measurement at 20°C is ±1%, traceable to National Physical Laboratory (NPL), UK standards, with a reproducibility of better than 0.5% and a temperature coefficient of ±0.1% of reading per °C including probe.

The GM07 is multi-ranging, being designed to operate in any one of four distinct flux density ranges namely, 0 – 3 T; 0 – 299.9 mT; 0 – 29.99 mT; and 0 – 2.999 mT (see Table 4.1), the latter two being the most sensitive. It can be set to switch automatically between ranges as the flux density demands. The GM07 comes supplied with its own zero flux chamber, which enables the operator to “null” the instrument and Hall probe in advance of conducting a set of sensitive recordings, as discussed above.

Table 4.1. GM07 instrumental flux density range and resolution
(GM07 Serial No: 0704; Transverse Probe Serial No: PT/6310)

Magnetic flux density range	Resolution
Range 1: 0 – 3 T	1 mT
Range 2: 0 – 299.9 mT	100 μT
Range 3: 0 – 29.99 mT	10 μT
Range 4: 0 – 2.999 mT	2 μT

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4.2. Procedure

Preparatory tests conducted within *airmid healthgroup*'s large test chamber of the magnetic flux density at various points on the surface and heights above the supplied sample of magnetized underlay informed the detailed suite of measurements that followed.

Specifically, it was evident that (i) the magnetic flux density as recorded just above the underlay was noticeably non-uniform, even allowing for the practical constraints on positioning the Hall element (area: 0.2 mm × 0.2 mm) with reproducible precision (see Table 5.2), and (ii) the flux density diminished rapidly with increasing height above the surface, being virtually indistinguishable from the background flux within the chamber (dominated by the Earth's geomagnetic field) at heights > 1,000 mm (see Table 5.7).

Nine square metres of supplied underlay were assembled face-up on the horizontal floor of the test chamber (temperature set at 17.6°C) and divided uniformly into nine square zones (each of area 1 m^2) using marking tape (Figure 3.1, b). Within each zone a sub-set of 10 magnetic flux density measurements were recorded (above randomly selected points) at heights of 0.5 mm, 1.0 mm, 10 mm, 100 mm and 1,000 mm above the underlay. The individual data sets are given in Tables 5.2 – 5.6, inclusive.

For completeness, a 1m^2 sample of underlay was placed face down, i.e., inverted, on the floor and a set of twenty flux density measurements were recorded, again at randomly selected points, at heights of 0.5 mm, 1.0 mm, 10 mm, and 100 mm above the inverted underlay. These data are given in Tables 5.8 – 5.11, inclusive.

Finally, an identical procedure was replicated when the overlay (9 m^2) was placed upon the underlay in the test chamber and flux measurements were recorded above the combination at the same heights as for the underlay (Tables 5.13 – 5.17, inclusive).

5. Results

5.1. Measurement of Background Geomagnetic Field

The GM07 Gaussmeter was deployed to measure the strength of the geomagnetic field at airmid healthgroup's outdoor environment in central Dublin. It recorded readings within the flux density range 43 – 48 μT (Table 5.1), as expected, and fully consistent with data published by widely recognized national and international bodies (AGNIR, 2008; NGDC, 2006). Obviously, this speaks to the accurate (absolute) calibration of the instrument.

Table 5.1 **Geomagnetic field flux density measurements, outdoor environment, Dublin**
(Dublin latitude, longitude: *53.3501°N, 6.2662°W*)
Temperature at which geomagnetic field measurements were undertaken: 14°C

Recording #	Positive polarity reading (μT)	Negative polarity reading (μT)	Mean reading (μT)
1	50	46	48
2	47	44	46
3	48	43	46
4	44	41	43
5	49	45	47
			Mean (±1σ): 46 ± 1.9

5.2. Magnetic Flux Density Measurements on Magnetized Underlay ('face-up' case)

Table 5.2. Magnetic flux density (gross) measurements by zone at 0.5 mm (nominal) above surface of magnetized underlay (area of sample: 9 m^2) – 'face-up' case. Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (µT) per zone**
1	18750, 12350, 17360, 6800, 10290, 23560, 8990, 25390, 26460, 17000
2	13440, 16660, 29230, 28700, 17600, 19620, 19100, 21500, 30400, 35800
3	25100, 18500, 21200, 25300, 30700, 28400, 11300, 5800, **4500**, 23500
4	18600, 25900, 22500, 28400, 33600, 17900, 25800, 24700, 29600, 28900
5	28400, 29600, 10600, 14800, 21000, 9600, 27100, 22400, 33300, 20400
6	21700, 11300, 27800, 16000, 28700, 29100, 31700, 15000, 37100, 7500
7	8400, 31800, 24300, 31600, 6800, 12700, 11300, 28900, 28100, 27200
8	21000, 34400, 17400, 50800, 4500, 27900, 12200, 41900, 9400, 4900
9	17100, 23900, 37600, **60000**, 20300, 23500, 25600, 7100, 34800, 33100

Table 5.3. Magnetic flux density (gross) measurements by zone at 1.0 mm (nominal) above surface of magnetized underlay (area of sample: 9 m^2) – 'face-up' case. Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (µT) per zone**
1	3360, 6100, 7520, 1600, 2800, 1900, 2500, 2600, 4500, 1200
2	2300, 4800, 6500, 2100, 2700, 10600, 9100, 8800, 1300, 1300
3	1900, **1020**, 1240, 2890, 3780, 1020, 1710, 1520, 1350, 2700
4	1560, 2680, 2970, 9410, 7660, 2920, 9900, 6550, 4400, 8240
5	5530, 10480, 2330, 1220, 8610, 2320, 4370, 3340, 2980, 3700
6	1630, 4400, 2400, 6090, 2430, 4910, 9370, 3220, **10990**, 8850
7	2350, 3740, 6170, 1370, 2630, 1090, 3850, 6900, 2930, 7950
8	6610, 10790, 6530, 5910, 9800, 9130, 3360, 7040, 2200, 7300
9	1900, 4520, 4360, 3300, 9150, 2710, 8760, 3060, 10600, 9950

Table 5.4. Magnetic flux density (gross) measurements by zone at 10 mm above surface of magnetized underlay (area of sample: 9 m^2) – 'face-up' case. Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (µT) per zone**
1	100, 106, 124, 131, 144, 127, 141, 122, 114, 136
2	090, 107, 170, 099, 127, 151, **197**, 102, 085, 112
3	112, 100, 095, 129, 075, 082, 147, 131, 088, 158
4	139, 126, 122, 102, 103, 092, 163, 144, 124, 186
5	**070**, 105, 095, 132, 123, 094, 109, 150, 136, 142
6	120, 104, 139, 142, 115, 146, 130, 125, 155, 127
7	123, 105, 116, 111, 084, 164, 116, 123, 146, 116
8	082, 139, 111, 136, 187, 110, 155, 164, 140, 145
9	103, 158, 156, 080, 119, 139, 123, 135, 119, 194

Table 5.5. Magnetic flux density (gross) measurements by zone at 100 mm above surface of magnetized underlay (area of sample: 9 m^2) – ‘face-up’ case. Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (μT) per zone**
1	95, 103, 86, 71, **70**, 72, 125, 100, 79, 74
2	112, 105, 100, 81, 95, 92, 110, 82, 81, 87
3	85, 82, 80, 83, 79, 94, 79, 80, 81, 83
4	91, 88, 89, 90, 73, 84, 100, 90, 89, 85
5	125, 103, 93, 84, 80, 101, 88, 85, 85, 83
6	91, 105, 88, 86, 87, 89, 98, 102, **131**, 110
7	83, 82, 93, 88, 85, 81, 80, 79, 86, 88
8	89, 88, 91, 87, 123, 106, 116, 101, 90, 102
9	98, 95, 96, 91, 89, 87, 103, 111, 104, 107

Table 5.6. Magnetic flux density (gross) measurements by zone at 1000 mm above surface of magnetized underlay (area of sample: 9 m^2) – ‘face-up’ case. Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (μT) per zone**
1	89, 86, 91, 88, 90, 89, 86, 90, 91, 87
2	83, 85, 86, 83, 89, 92, 87, 85, 88, 90
3	88, 91, 89, 86, 86, 91, 85, 84, 88, 87
4	87, 86, 91, 92, 93, 92, 93, 88, 93, 94
5	84, 85, 89, 88, 93, 94, 85, 84, 90, 90
6	89, 91, 86, 87, 90, 85, 82, 83, **79**, 90
7	95, 97, 95, 102, 100, 98, 105, 103, 98, 99
8	96, 100, 103, 96, 95, 102, 102, **109**, 108, 97
9	86, 95, 102, 83, 90, 100, 85, 94, 99, 99

At the nominal separation of 0.5 mm the resulting flux densities (net of background flux as measured in the horizontal plane) were determined to lie in the range 4,420 - 59,920 μT (Table 5.2), with a mean of 22,260 μT (Table 5.7). At the nominal separation of 1.0 mm, flux densities were very considerably reduced, being in the range 940 - 10,910 μT (Table 5.3), with a mean of 4,630 μT (Table 5.7), while at 10 mm separation, the measured range was further reduced at 0 - 117 μT (Table 5.4), with a mean of 45 μT (Table 5.7). At the larger separation of 100 mm and above, the flux density due to the magnetized underlay (Tables 5.5 & 5.6) was barely distinguishable from the background flux in the test chamber, i.e., 80±5 μT (Table 5.7).

Table 5.7. Mean magnetic flux density (± 1σ) versus height above magnetized underlay (n = 90 for each height setting) – 'face-up case'

Height above underlay (mm)	Mean magnetic flux density (μT) – gross	Magnetic flux density C.I. (95%)	Mean magnetic flux density (μT) – net
0.5	22,340 ± 10,220	2314 – 42,370	22,260
1	4,710 ± 3020	-1,208 – 10,633	4,630
10	125 ± 27	73 – 178	45
100	92 ± 12	67 – 116	12
1,000	91 ± 6	79 – 104	11
Mean background flux:			
Hall probe horizontal	80±5 (*n* = 10)		
Hall probe vertical	49±3 (*n* = 20)		

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5.3. Magnetic flux density measurements on magnetized underlay ('face-down' case)

Note that magnetic flux density measurements conducted on the underside of the underlay (Table 5.8) showed them to be almost an order of magnitude lower than the data for the face-up side given in Table 5.2 above. Furthermore, the fall-off with distance from the upturned underside (face-down case) was similarly sharp, as the data in Table 5.12 clearly confirm.

Table 5.8. Magnetic flux density (gross) measurements at 0.5 mm above surface of magnetized underlay (area: 1m^2) – 'face-down' case.
Note: maximum and minimum values highlighted in bold

Recording #	Magnetic flux density (μT)	Recording #	Magnetic flux density (μT)
1	5450	*11*	2380
2	4750	*12*	**1170**
3	4420	*13*	2720
4	4410	*14*	2210
5	2440	*15*	3410
6	1590	*16*	2640
7	5360	*17*	**6060**
8	2500	*18*	4640
9	1710	*19*	2760
10	4130	*20*	3640

Table 5.9. Magnetic flux density (gross) measurements at 1.0 mm above surface of magnetized underlay (area: 1m^2) – 'face-down' case.
Note: maximum and minimum values highlighted in bold

Recording #	Magnetic flux density (μT)	Recording #	Magnetic flux density (μT)
1	1141	*11*	620
2	1324	*12*	510
3	1159	*13*	1126
4	701	*14*	**200**
5	1150	*15*	400
6	1160	*16*	600
7	**1615**	*17*	580
8	1210	*18*	620
9	1002	*19*	1190
10	1305	*20*	702

Table 5.10. Magnetic flux density (gross) measurements at 10 mm above surface of magnetized underlay (area: 1m^2) – 'face-down' case. Note: maximum and minimum values highlighted in bold			
Recording #	**Magnetic flux density (µT)**	**Recording #**	**Magnetic flux density (µT)**
1	140	*11*	137
2	115	*12*	146
3	**103**	*13*	152
4	117	*14*	**154**
5	150	*15*	134
6	134	*16*	125
7	131	*17*	121
8	126	*18*	145
9	135	*19*	127
10	148	*20*	123

Table 5.11. Magnetic flux density (gross) measurements at 100 mm above surface of magnetized underlay (area: 1m^2) – 'face-down' case. Note: maximum and minimum values highlighted in bold			
Recording #	**Magnetic flux density (µT)**	**Recording #**	**Magnetic flux density (µT)**
1	83	*11*	78
2	80	*12*	81
3	84	*13*	88
4	90	*14*	83
5	80	*15*	97
6	87	*16*	117
7	83	*17*	102
8	80	*18*	**120**
9	**77**	*19*	112
10	80	*20*	85

Table 5.12. Mean magnetic flux density (± 1σ) versus height above magnetized underlay (n = 20 for each height setting) – 'face-down case'			
Height above underlay (mm)	**Mean magnetic flux density (µT) – gross**	**Magnetic flux density C.I. (95%)**	**Mean magnetic flux density (µT) – net**
0.5	3,420 ± 1,410	650 – 6190	3,340
1	916 ± 375	180 – 1650	836
10	133 ± 14	106 – 160	53
100	89 ± 13	64 – 115	9
1,000	91 ± 6	79 – 104	11
Mean background flux: Hall probe horizontal Hall probe vertical	 80±5 (*n* = 10) 49±3 (*n* = 20)		

5.4. Magnetic flux density measurements on ferromagnetic overlay and magnetized underlay combined

Table 5.13. Magnetic flux density (gross) measurements by zone at 0.5 mm (nominal) above the surface of magnetized overlay and underlay combined (area of sample: 9 m^2)
Note: maximum and minimum values highlighted in bold

Zone	Magnetic flux density measurements (µT) per zone
1	1730, 1283, 1436, 458, **2223**, 1679, 1219, 1913, 742, 1607
2	206, 1290, 986, 470, 1490, 1691, 1211, 1010, 1635, 1785
3	1320, 840, 546, 1992, 1482, 1378, 263, 430, 1172, 663
4	1972, 1000, 1405, 559, 398, 847, 1530, 1804, 890, 1359
5	290, 510, 1469, 1150, 920, 567, 373, 1502, 1700, 1420
6	410, **100**, 1600, 1189, 940, 514, 711, 514, 1144, 1279
7	1180, 1605, 1401, 875, 880, 829, 1520, 750, 702, 1640
8	1995, 1340, 1688, 1730, 129, 1830, 431, 352, 1035, 1526
9	1072, 1560, 982, 410, 1845, 580, 817, 1803, 549, 301

Table 5.14. Magnetic flux density (gross) measurements by zone at 1.0 mm (nominal) above the surface of magnetized overlay and underlay combined (area of sample: 9 m^2)
Note: maximum and minimum values highlighted in bold

Zone	Magnetic flux density measurements (µT) per zone
1	110, 310, 160, 352, 349, 379, 186, 549, 247, 467
2	443, 484, 258, 402, 350, 140, 570, 231, 430, 420
3	140, 350, 327, 360, 530, 450, 320, 112, 460, 201
4	100, 150, 160, 420, 480, 180, 150, 390, 440, 400
5	400, 230, 205, 580, 610, 370, 200, 380, **050**, 270
6	409, 336, 060, 301, 300, 210, 250, 230, 400, 350
7	145, 300, 180, 200, 310, 210, 565, 220, 130, 220
8	300, 290, 530, 360, 370, 320, 130, 350, 380, 310
9	245, 180, 330, 390, 419, 542, 145, 310, **650**, 504

Table 5.15. Magnetic flux density (gross) measurements by zone at 10 mm above the surface of magnetized overlay and underlay combined (area of sample: 9 m^2)
Note: maximum and minimum values highlighted in bold

Zone	Magnetic flux density measurements (µT) per zone
1	107, 98, 99, 117, 125, 103, 125, 113, 114, 99
2	140, 149, 139, 150, 160, 117, 170, 145, 156, 148
3	148, 123, 129, 105, 117, 114, 132, 142, 132, 116
4	139, 104, 145, 120, 142, 140, 131, 138, 118, 104
5	168, 139, 123, 137, 120, 117, 116, 105, 130, 148
6	138, 135, **82**, 137, 115, 125, 106, 183, 117, 127
7	102, 132, 99, 123, 125, 150, 152, 146, 135, 94
8	95, 99, 133, 114, 90, 112, 104, 142, 123, 109
9	98, 93, 122, 142, 139, 144, 131, **190**, 95, 119

Table 5.16. Magnetic flux density (gross) measurements by zone at 100 mm above the surface of magnetized overlay and underlay combined (area of sample: 9 m^2) Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (μT) per zone**
1	107, 98, 99, 117, 125, 103, 125, 113, 114, 99
2	**96**, 107, 121, 132, 125, 132, 118, 120, 118, 115
3	108, 111, 109, 105, 103, 105, 129, 115, 107, 112
4	110, 107, 112, 98, 122, 107, 110, 107, 105, 123
5	102, 103, 107, 123, 104, 105, 115, 110, 112, 114
6	107, 109, 108, 106, 112, 127, 120, 116, 120, 106
7	99, 105, 107, 110, 107, 102, 106, 105, 112, 111
8	116, 119, 128, **137**, 117, 119, 116, 123, 120, 111
9	106, 107, 112, 107, 133, 122, 121, 120, 106, 108

Table 5.17. Magnetic flux density (gross) measurements by zone at 1000 mm above the surface of magnetized overlay and underlay combined (area of sample: 9 m^2) Note: maximum and minimum values highlighted in bold	
Zone	**Magnetic flux density measurements (μT) per zone**
1	88, 89, 90, 87, 91, 93, 94, 91, 95, 94
2	90, 93, 96, 97, 98, 96, 94, 98, 95, 98
3	101, 104, 99, 103, 98, 102, 101, 105, 106, 109
4	96, 93, 98, 94, 99, 89, 100, 94, 95, 97
5	97, 96, 95, 100, 102, 95, 96, 101, 97, 98
6	95, 101, 102, 102, 97, 96, 96, 98, 93, 100
7	107, 111, 104, 105, 111, 110, 108, 110, 106, **113**
8	100, 102, 103, 105, 95, 94, 101, 102, 103, 98
9	90, 89, **84**, 88, 94, 93, 96, 97, 88, 94

The magnetic flux density was similarly recorded for the combined overlay and underlay at separations of 0.5 mm, 1.0 mm, 10 mm, 100 mm and 1,000 mm from the overlay surface. The individual data sets are given in Tables 5.13 – 5.18, inclusive. At the nominal separation of 0.5 mm the resulting flux densities (net of background flux measured in the horizontal plane) were determined to lie in the range 20 - 2,143 μT (Table 5.13), with a mean of 1,030 μT (Table 5.18). At the nominal separation of 1.0 mm, net flux densities were very considerably reduced, being in the range 0 - 570 μT (Table 5.14), with a mean of 238 μT (Table 5.18), while at 10 mm separation, the measured flux range (net) was further reduced at 2 - 110 μT (Table 5.15), with a mean of 46 μT (Table 5.18). At 100 mm separation, the maximal flux (net) recorded was 57 μT (Table 5.16), while at 1,000 mm separation the maximal flux (net) recorded was 33 μT (Table 5.17).

Table 5.18. Mean magnetic flux density (± 1σ) versus height above magnetized overlay and underlay combined (n = 90 for each height setting)

Height above underlay (mm)	Mean magnetic flux density (μT) – gross	Magnetic flux density C.I. (95%)	Mean magnetic flux density (μT) – net
0.5	1,110 ± 530	60 – 2150	1,030
1	318 ± 136	50 – 590	238
10	**126 ± 21**	**85 – 170**	**46**
100	113 ± 9	95 – 130	33
1,000	98 ± 6	86 – 110	18
Mean background flux:			
Hall probe horizontal	80±5 (*n* = 10)		
Hall probe vertical	49±3 (*n* = 20)		

6. Discussion and Guideline Limits

From the perspective of non-ionizing radiation protection and, in particular, the safety of humans with implanted medical electronic devices, it is the 10 mm data set that is of greatest interest here. Clearly, it is inconceivable that an individual with an implanted device, such as a cardiac pacemaker or defibrillator, lying face down on the floor surface in question (for whatever purpose or reason), could contrive, however accidentally, to have his/her device exposed to a magnetic flux density (gross) in excess of 170 μT; this latter figure being the upper bound of the 95% confidence interval for the set of data (n = 90) recorded at 10 mm separation (Table 5.18). In fact, the highest figure in this data set (Table 5.15) is a mere 190 μT (gross).

Note that the International Commission on Non-ionizing Radiation Protection (ICNIRP) recommended static field limit for members of the public fitted with sensitive electronic devices of this nature is 500 μT or 0.5 mT, while the limit for continuous exposure of the public in general is 40,000 μT or 40 mT (Table 6.1). In the case of occupational exposure, a time-weighted average (working day) limit of 200,000 μT (200 mT) applies (Table 6.1).

These limits and the scientific basis for them are discussed in some detail in the report on Phase 2 of this project (ASCR092199). The Phase 2 report focuses on the recommendations and guidelines of the key organizations involved in non-ionizing radiation protection, particularly those of the ICNIRP. The report also seeks to provide the reader with an overview on presently understood safe exposure limits for both occupational engaged workers and the general public, as well as the research findings underpinning them.

Table 6.1. ICNIRP/ WHO/ EC recommended reference limits for static magnetic fields in units of milli-tesla (mT)

	Recommended Flux Density Limit	
Nature of Exposure/ Risk	**General Public (mT)**	**Occupational (mT)**
Continuous exposure	40	
Spatial peak (acute) exposure	400	
Potential adverse indirect effects	< 0.5	
Time-weighted average (working day)		200
Spatial peak (ceiling value) exposure to head and trunk		2,000
Spatial peak (ceiling value) exposure to legs		8,000
Attraction/ projectile risk near fields >100 mT	3	3

7. Conclusions

It follows from the extensive, experimentally determined magnetic flux density dataset presented above that the combination of magnetic overlay and underlay as submitted to airmid healthgroup for testing is fully compliant with the strictest of current recommendations and legislation (where it is enacted) in relation to static magnetic fields as laid down by ICNIRP, WHO, ILO, NCRP, EC, and other international and national bodies.

It is important to add, given the present state of knowledge, that there is no scientifically reliable evidence, epidemiological or other, that exposure to the extremely low-level static magnetic fields likely to be encountered by close contact with the overlay and underlay materials which are the subject of this study, i.e., levels in the range 0 – 200 μT, are in any sense harmful to humans, including those fitted with active medical implants.

Finally, for reference purposes, levels of magnetic flux density produced by some everyday electrical household appliances and electronic devices are briefly discussed om the following page.

7.1. Comparison with magnetic fields produced by some everyday electrical appliances

It is helpful to offer context by comparison with levels of selected other everyday exposures to magnetic fields. Table 7.1 shows typical values for several A.C. based electrical appliances commonly found in homes and workplaces. The measurements were taken in Germany and all the appliances operate on electricity at a frequency of 50 Hz. It should be noted that the actual exposure levels vary considerably depending on the model of appliance and distance from it.

Table 7.1. Magnetic flux density of household appliances at various distances
(Source: Federal Office for Radiation Safety, Germany, 1999; WHO, 2017a)

Appliance	3 cm distance (μT)	30 cm distance (μT)	100 cm distance (μT)
Hair dryer	**6 – 2000**	0.01 – 7	0.01 – 0.03
Electric shaver	**15 – 1500**	0.08 – 9	0.01 – 0.03
Vacuum cleaner	200 – 800	**2 – 20**	0.13 – 2
Fluorescent light	40 – 400	**0.5 – 2**	0.02 – 0.25
Microwave oven	73 – 200	**4 – 8**	0.25 – 0.6
Portable radio	16 – 56	**1**	< 0.01
Electric oven	1 – 50	**0.15 – 0.5**	0.01 – 0.04
Washing machine	0.8 – 50	**0.15 – 3**	0.01 – 0.15
Electric iron	8 – 30	**0.12 – 0.3**	0.01 – 0.03
Dishwasher	3.5 – 20	**0.6 – 3**	0.07 – 0.3
Computer	0.5 – 30	< **0.01**	
Refrigerator	0.5 – 1.7	**0.01 – 0.25**	< 0.01
Colour TV	2.5 – 50	0.04 – 2	**0.01 – 015**

Note: data for typical operating distances given in bold

Table 7.1 illustrates two main points. First, the magnetic field around all appliances rapidly decreases the further you get away from them. Secondly, most household appliances are not operated very close to the body. At a distance of 30 cm the magnetic fields surrounding most household appliances are more than 100 times lower than the ICNIRP guideline limits of 100 μT at 50 Hz (the so-called European power frequency limit) or 83 μT at 60 Hz for the general public (WHO, 2017b). These limits are not to be confused with the ICNIRP guideline limit for static magnet field of 40 mT for the general public (Table 6.1).

During the present study a small number of magnetic/ electronic devices including a mobile phone were tested for static magnetic field level with the same GM07 Gaussmeter as used to test the samples of magnetic underlay and overlay above. The resulting data for separations of 0.5 mm, 1.0 mm, 10 mm and 30 mm between (Hall) transverse probe and surface of device are given in Tables 7.2 and 7.3. It is important to stress that these are maximal values (as determined by surveying the entire surface of each device) and that the measurements were conducted within 30 mm of each device. It is salutary to compare these flux levels with those recorded above the overlay and underlay combination, bearing in mind that the devices listed in Tables 7.2 and 7.3 are all deemed to be fully compliant with current recommendations as enunciated by the ICNIRP and others.

Table 7.2. Magnetic flux density (maximum values) at or near the surface of some everyday magnetic/ electronic devices (present study)

Device type	Magnetic flux density (μT) – net of background			
	0.5 mm	1.0 mm	10 mm	30 mm
Fashion handbag magnetic clasp	50,000 – 85,000	10,000 – 50,000	11,000 – 13,000	1,000
Portable computer Apple MacBook	50,000	20,000	4,500	400
Portable landline telephone Siemens	5,100	3,200	1,700	170
Portable radio Sony Corporation	600	570	500	440

Table 7.3. Magnetic flux density recorded at or near the surface of a typical commercial mobile phone in the present study (*Example*: Samsung Galaxy SIII Mini)

Position (vertically along central axis of front face of phone)	Magnetic flux density (μT) – net of background			
	0.5 mm	1.0 mm	10 mm	30 mm
1	4,800	2,720	600	150
2	1,200	610	380	130
3	7,100	3,100	30	120
4	0	10	0	100
5	60	0	0	80
6	0	36	10	80
7	40	50	20	80
8	0	32	16	80
9	100	40	26	80
10	220	120	20	80

8. References

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End of Report