

Exposure Measurements on MR-Workers at the Stray Field of 1.5T, 3T, and 7T MR Systems

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Introduction

The new EU directive limits electromagnetic exposure due to movement in strong static magnetic fields to a value of 200 mT / s [1]. Several magnetic field measurements have been performed, however, to the field strength never exceeded 4T and measurement area was restricted to the waist [2, 3]. This work presents a new probe for field measurements on healthcare workers that is mounted near the head, and which can operate at field strengths of up to 7 Tesla.

Materials and Methods

The magnetic field probe was constructed from 3 orthogonal Hall sensors and 3 orthogonal induction coils to measure the magnetic flux density B_0 and time-varying fields dB/dt simultaneously (Fig. 1). Coils (200 windings of 0.1 mm coated copper wire) and Hall sensors were connected to separate voltage amplifiers, and an active low-pass filter (cut-off frequency: 10 Hz) was used to suppress high-frequency noise. The amplifiers were connected to a PC to record absolute values of B_0 and dB/dt. The Hall sensors were calibrated with a 20T-Hall-probe (Three-axis Hall Magnetometer THM1176, Metrolab Instruments SA, Plan-les-Ouates, Switzerland).

For calibration the dB/dt probe was placed at iso-center height onto the patient table of a 1.5T-MR system (Magnetom Avanto 1.5T, Siemens, Erlangen, Germany). The patient table was moved over the strongest gradient ($dB/dz = 2.56 \text{ T/m}$ at $z = 823 \text{ mm}$ distance from isocenter) into the bore and back again. While moving, dB/dt and table velocity $v(z)$ were acquired. Using the relation $dB/dt = v(z) \cdot dB/dz$, measured dB/dt values were converted into dB/dz, which were then compared to a known B_0 -field mapping (Fig. 2).

With the probe measurements were performed with 2 healthcare workers and 8 MR physicists. The probe was fixed at the forehead to acquire dB/dt not only while walking through the magnet room but also during head movements (e.g. head shaking, bending into the bore). The volunteers were asked to wear the probe during normal operating procedures (e.g., coil placement, patient preparation) on whole body MR-systems with three different field strengths (Magnetom Avanto 1.5T, Magnetom TIM Trio 3T, Magnetom 7T, all Siemens, Erlangen, Germany). Five exposure parameters were determined: the overall cumulative exposure in [Ts], the time-weighted average (TWA) of B_0 [mT] and dB/dt [mT/s] per procedure, peak fields of B_0 [T] and dB/dt [T/s].

Results and Discussion

Table 1 summarizes the measurements of all volunteers. ICNIRP limits were exceeded for all peak dB/dt values. Maximum peak dB/dt value ($dB/dt > 5T/s$) was detected at 7T during phantom placement. The maximum peak B_0 value of 2.39 T was reached during coil plugging at 7T (Fig. 3). Also the TWA of dB/dt exceeds the limits at procedure 2, 5, 7 and 9, whereas the volunteer in procedure 2 placed a phantom at the 1.5T MR system.

The cumulative exposure depends mostly on the overall duration of stay. Due to the long magnet bore for the 7T MR system (320 cm, for comparison: 3T: 213 cm, 1.5T = 150 cm) the field strength at the end of the magnet is comparable to the other systems. The new probe provides a simple and reliable tool for magnetic field exposure measurements. By measuring the exposure at the forehead, fast head movements can be detected which can lead to vertigo, dizziness, or metallic taste. In the future the probe will be used to acquire the exposition data in ultra-high magnetic fields during standard operation procedures.

References

- [1] EU Directive 40/EC (2004)
- [2] F. deVocht, et al., JMRI 30 (2009)
- [3] M.A. Fuentes, et al. IEEE T Bio-Med Eng 55 (2008)

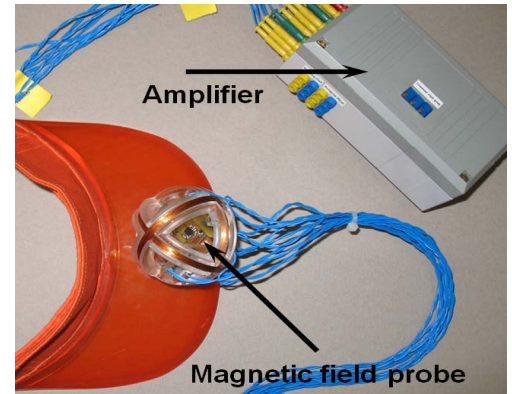


Fig.1: probe fixed on a cap to measure magnetic fields at the head of a volunteer.

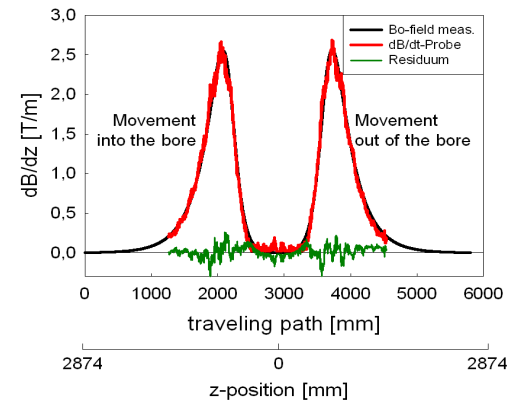


Fig.2: Black curve: local gradient of the Avanto 1.5T along the traveling path. Red curve: measurement of dB/dz with velocity $v(z)$. Green curve: Residuum.

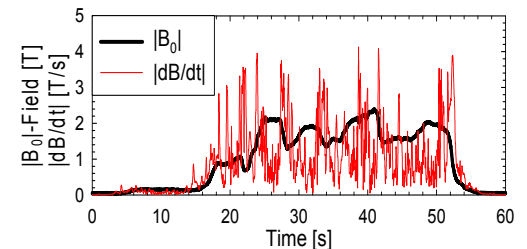


Fig.3: Exposure during coil plugging and phantom placement at 7T (cf. #10 in Tab. 1).

	B_0 [T]	total time [s]	cumulative exposure [Ts]	TWA of B_0 [mT]	TWA of dB/dt [mT/s]	Peak B_0 [T]	Peak dB/dt [T/s]
1	1.5	329	8,87	27,02	54,62	0,27	1,86
2	1.5	152	19,63	128,95	311,87	1,09	2,25
3	3	451	25,43	56,37	89,03	0,63	3,88
4	3	161	34,86	34,86	99,71	0,29	2,00
5	7	107	39,88	371,68	220,08	1,30	3,73
6	7	185	49,31	267,07	197,10	1,65	4,61
7	7	67	19,56	292,59	449,09	1,21	5,25
8	7	81	11,97	168,68	128,91	0,84	5,42
9	7	46	12,69	277,83	390,03	1,03	5,76
10	7	61	59,78	981,07	410,49	2,39	4,08

Tab.1: Exposure data at the different MR-systems