Initial measurements with an Ambulatory Static and Gradient Magnetic Field Dosimeter for Workers in MR Environments

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Introduction: There is growing concern for the health and safety of occupational workers who are frequently exposed to magnetic fields present when moving through a spatially non-uniform static magnetic field or during gradient-pulsed magnetic fields outside of the scanner or a combination of the two. Such magnetic field gradients induce electric fields and currents in tissue that depending on the position of the subject relative to source can exceed the relevant EU, ICNIRP and IEEE standards [1]. Furthermore, repeated exposure to strong static magnetic fields should also be treated with caution by adhering to the guidelines in place that limit the time-weighted exposure during an 8-hour working day.

This study details the design and construction of an ambulatory magnetic field dosimeter [2] that measures tri-axial cumulative and instantaneous magnetic fields and magnetic field gradients that occupational workers experience in modern magnetic resonance imaging (MRI) environments. The aim of the study was to measure isotropic gradient-pulsed magnetic field exposures with an ambulatory device at positions shown by Crozier *et al* [1] to induce large current densities and electric fields.

Method: A schematic diagram of the dosimeter is shown in Figure 1, a combination of Hall sensors and sensing coils allow high sensitivity measurements over a large dynamic range of magnetic fields otherwise unattainable by use of a Hall sensor alone. The three axis system allows isotropic measurements over a $1cm^3$ volume during simultaneous gradient coil switching. The device was used to measure gradient field exposure at z = 70cm, r = 0cm and r = 30cm, positions where workers are predicted to be exposed to the largest induced current densities and electric fields [1].

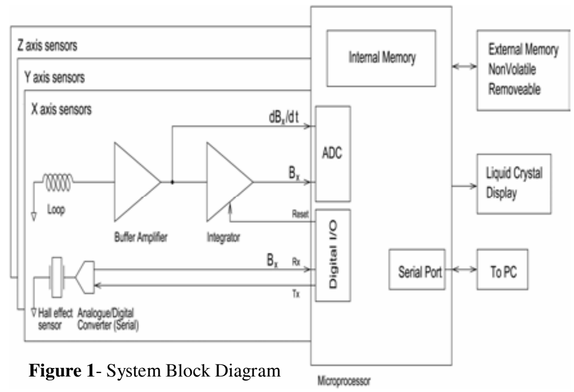

Figure 1- System Block Diagram

A 2T MR system with actively shielded whole-body symmetric gradient coils with an axial length of 1.4 metres and 30mT/m field strength was used. At each radial position, a positioning pilot scan switched the three gradients independently and simultaneously with rise times of 450µsec, progressively increasing gradient field strengths up to 24 mT/m to invoke the worst case induction scenario. A 4-segment EPI scan with 100µsec gradient rise times was also performed to record a typical worst case exposure in a daily working routine for an MR worker.

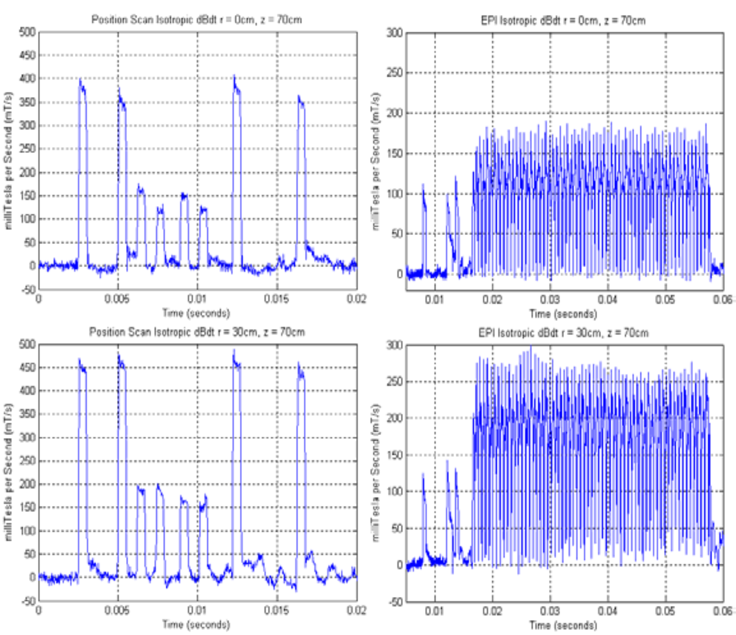

Figure 2 – Isotropic Magnetic Gradient Field Measurements during 1 TR period

Results and Discussions: Switching a single gradient coil whilst the instrument is aligned with B_z inside the DSV region produces negligible activity in the other two Cartesian directions demonstrating that there is little cross-talk between the measurement axes and that the gradient coils produce well defined fields in the imaging region. When the sensors are placed at the ends of the gradient coils during individual gradient coil switching, magnetic field gradients in the three axes are measured, indicating the divergent fields produced by the gradient coils at these positions and the need for isotropic measurements to calculate total gradient field exposure. When placed inside the DSV the device measured average maximum field gradients of 12.26 T/s during the position scan, switching the z gradients at 80% scale and 18.11 T/s during the EPI sequence.

Figure 2 illustrates the isotropic magnetic gradient field measurements at z = 70cm during simultaneous gradient switching and during the EPI sequence at the two radial positions. The device experienced higher levels of exposure at r = 30cm which is significant as it is a position where workers will most commonly attend to patients during imaging. At this position the average peak magnetic field gradients were 475 mT/s and 254 mT/s for simultaneous gradient switching and the EPI sequence respectively whilst at r = 0cm the average peak gradient fields were 389 mT/s and 167 mT/s respectively. The static magnetic field at these positions were found to be B_z = 740 mT, B_y = 117mT, and B_x = 42.3mT at r = 0cm and B_z = 742mT, B_y = 116.4mT, and B_x = 43.7mT at r = 30cm.

Conclusion: This study presents pilot data of measured dB/dt exposures to health care workers near the end of gradient coils. The dosimeter described measures both static and dynamic magnetic fields which are in agreement with prior modelling. It is lightweight and engineered to be worn throughout a working shift. It is envisaged that the dosimeter will assist in determining the true peak and time-averaged exposures of workers in MR environments.

References

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[2] A Magnetic Field Dosimeter - PCT/AU2005/001495.

Acknowledgments

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