Safety Considerations for a PatLoc Gradient Insert Coil for Human Head Imaging

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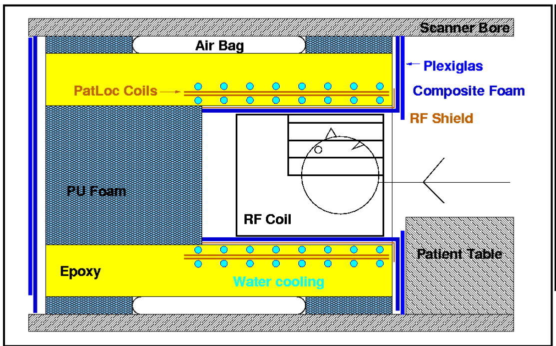
Introduction: We present the design considerations and evaluation measurements for the safety of a PatLoc (Parallel Acquisition Technique using Localised Gradients [1]) gradient insert coil designed for human head imaging on a 3T MRI system [2]. This novel concept has the potential to allow higher gradient switching rates while not exceeding the Peripheral Nerve Stimulation (PNS) limits.

Construction: (See Fig.1)

Mechanical Stability: The 2 cylindrical layers of coil elements are mounted on a 12.5mm thick GRP (glass fibre reinforced plastic) former, wrapped with a spiral of water cooling plastic tubing, and everything cast under vacuum in transparent epoxy resin (48mm thick top resin layer). Inside the scanner, the coil is supported by rubber-mounted wheels on the patient table rails and 3 inflatable airbags fixate it. A 7mm thick Plexiglas shield is installed between the front of the coil and the volunteer's shoulders. Electrical & Acoustic Insulation: A liner of 7.5mm thick composite foam-vinyl (E-A-R Barrier Composites, type E-0-10-25) separates the RF shield and the RF coil/volunteer. The space between the coil and the bore is sealed by 2 rings of 37.5mm thick / 275mm wide PU foam (Polyform, ES PF366, UL94 approved). The coil's former is sealed at the back with a 400mm long PU foam plug. A Plexiglas cover lined with composite foam-vinyl is installed at the back (also covers the electrical power connectors). An additional inflatable airbag is placed under the coil: its pressure can be adjusted to modify mechanical resonances by lifting the coil off the rails. Cooling: Provided by 2 layers of water cooling tubing (4mm diameter) spiral, 10 parallel circuits/layer, 7.5mm spiral step, 8.6m length per circuit. One cooling layer is between the gradient coils and the volunteer. Temperature sensors (7 x NTC) are built in likely hotspots (high wiring density) and monitored during operation.



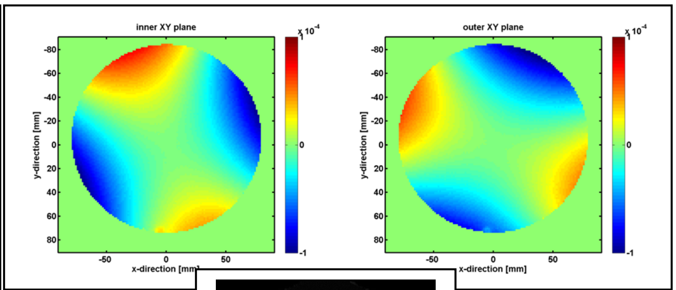


Fig.1 [Top Left]: Cross section, side view (color figure).
Fig.2 [Top Right]: Measured non-linear PatLoc coil magnetic fields [T/A], for the inner and the outer layers/channels (color figure).
Fig.3 [Bottom Right]: Preliminary image of a biological sample.

Experiments and Results:

Mechanical Stability: We simulated the internal/external forces/torque using Vector Fields Opera 3D modelling software: for the standard multi-polar PatLoc configuration (Fig.2),[2] placed inside a Siemens Tim Trio 3T magnet, the overall (external) force/torque are negligible. Sound Pressure Level (SPL): Using a Brüel & Kjær 3560-L ADC and calibrated Type 2671 microphone in the bore, we identified vibration resonances from the peaks of a frequency sweep protocol. We measured Leq (human ear corrected SPL) for various levels of sinusoidal current I at these resonant frequencies: regulatory acceptable SPL (<= 129dBA, i.e. <= 99dBA with earplugs) is not exceeded at any frequency for I=25A, and except 480-650Hz for I=50A. With a standard FLASH protocol (max BW 700 Hz/pixel), we measured Leq=95dBA (no earplugs). Lifting the coil by inflating the underside airbag made it slightly louder at higher frequencies, but quieter at lower ones. Cooling performance: Evaluated by applying test trapezoidal pulses on both channels with known current (I) and duty cycle (DuCy) while monitoring the temperature inside (NTC-s) and on the surface (infrared camera). For I=80A & DuCy=55%, the PatLoc coil reached 55°C internally / 32°C at the RF shield, and was thermally stable in this regime (tested for > 40min). Peripheral Nerve Stimulation (PNS): We plotted the multi-polar Patloc fields outside the magnet with a robotic arm Hall probe over a 30cm sphere (24 planes, 20 points per plane, using a 'lock-in' method for better accuracy); we also measured the fields with a cylindrical liquid-filled phantom (160mm diameter) and a multi-echo gradient echo sequence (delta TE = 3ms; constant current through the coil) (Fig.2). The measured real fields were very close to the simulations ([2] and Opera 3D modelling). Additionally, we measured dB/dt using a pickup coil: 10 turns of Cu wire on a 31mm diameter former, connected to an oscilloscope. We drove the PatLoc coil with a test trapezoidal pulse of 50A and 120us rise time (i.e. close to the experimentally determined max slew rate achievable with Siemens Tim Trio electronics), the 2 layers both in sync and in opposite polarity. We measured locations (inside the head RF coil) with high B strength according to the simulated and mapped B fields: dB/dt was up to 53 T/s (simulations for 1 channel: about 50 T/s). We also evaluated a standard EPI sequence (echo spacing 510us, BW 2232 Hz/pixel, base res 64^2, FOV 192mm) driving the standard linear/body gradients. With the pickup coil in various orientations around where the middle torso of the volunteer would be, bottom-centre of the bore (spine position) and bottom-side (elbows), we measured a dB/dt up to 106/120 T/s in Y/X direction. Compared to the standard body gradient coil, the PatLoc head insert produces highly localized magnetic fields: they decay steeply in the shoulder/torso region of a volunteer, where PNS effects are usually noticed with the standard gradients. Moreover, the spatial extent of the PatLoc coil's fields is significantly smaller than the extent of the body coil's fields, thus the induced voltages in the volunteer are expected to be lower. A volunteer study is in preparation to evaluate the switching rates attainable without noticeable PNS effects.

Conclusion: We consider imaging human volunteers with this system to be safe, and we are preparing an application for IRB approval.

References: [1] Hennig J. et al., MAGMA 21(1-2):5-14 (2008). [2] Welz A. et al, ESMRMB 2009 #316.
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