Optimized Litz Coil Design for Prepolarized Extremity MRI

T. Grafendorfer[1,2], S. M. Conolly[1,2], N. I. Matter[2], J. Pauly[2], G. Scott[2]
[1]Bioengineering, UC Berkeley, Berkeley, CA, United States, [2]Electrical Engineering, Stanford University, Stanford, CA, United States

Introduction: There are a number of applications for low field MRI, including hyperpolarized gas MRI, hyperpolarized ^{13}C or PHIP, and prepolarized MRI. Unlike conventional MRI, there is no SNR advantage to increased field strength above the so-called body noise dominance threshold [1, 2]. It is critical to choose the most sensitive RF coil for low field MRI. It is well known that litz wire is more sensitive than solid copper up to 1 MHz [3]. Here we investigate litz wire for resonant frequencies up to 10 MHz.

Theory: Litz wire is a bundle of multiple insulated strands, twisted or woven together in such a way that the current gets evenly distributed among the separated strands, which results in reduced eddy current losses. Litz wire theory [4, 5] shows that both the strand wire gauge and the number of strands determine the total AC resistance. To minimize the total coil noise, we must minimize the AC resistance. As an example, Figure 1 shows the simulated AC resistance of two gauges of 2 mm diameter litz wire. Also plotted is the optimal number of strands, found by differentiating the coil resistance expression from Ref. [5]. The low frequency plateau is due to physical size limits. Figure 1 shows that optimal AWG 52 strand size litz wire should have 50% less resistance than solid copper at 8 MHz.

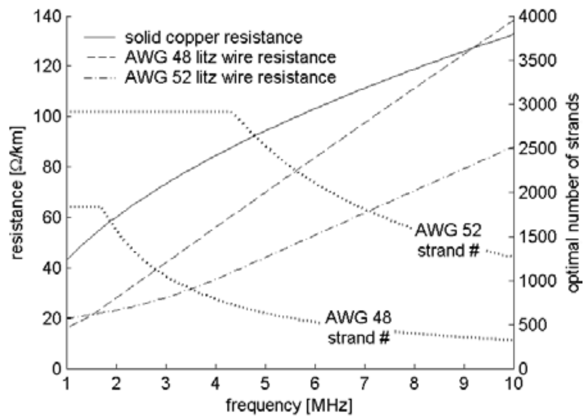

Figure 1: AC resistance simulation of 2 mm diameter AWG 48 and AWG 52 strand size litz wire provided that the number of strands is optimally chosen for each frequency. Compared with solid copper, AWG 48 litz wire performs substantially better up to 4 MHz and AWG 52 litz wire is advantageous up to 10 MHz.

Methods: To test this theory we designed, constructed, and tested a litz wire wrist-sized receiver coil suitable for 4.3 MHz operation, consisting of AWG 48 wire gauge strands. First a magnetic field simulator was written to calculate eddy current losses (both skin effect and proximity losses) as a function of frequency and number of strands. The number of strands was optimized by minimizing the eddy current losses at 4.3 MHz. The software found a minimum at 6,900 total strands for a 3.5 inch diameter saddle coil. Figure 2 shows our coil with twenty bundles of 345 strands (total strands = 6,900). The bundles were distributed as uniformly as possible, (similar to [6], where copper sheet was used instead of litz wire) and the spacing between layers was optimized. The coil was constructed with AWG 48 litz wire and high Q Cornell Dubilier surface mount mica capacitors (Q > 2,000). The RF shield shifted the coil's resonant frequency up to 5.7 MHz. Human wrist images were obtained on a 0.4 T/5.7 MHz prepolarized MRI scanner [7].

Results: The 4.3 MHz coil had a measured unloaded Q factor of 1040. A comparable copper coil had a measured Q factor of 500. This translates to an SNR boost of 1.4, if coil noise dominates. The loaded Q factor of the 4.3 MHz litz coil drops down to 500 which indicates that 50% of the noise comes from the sample. A Faraday shield had no effect, indicating that dielectric losses were insignificant. A normal volunteer wrist image obtained with this coil is shown in Figure 2.

Discussion: Achieving body noise dominance [1, 2] at low frequency and small sample sizes is enabling for low field MRI with prepolarization or hyperpolarization, since it allows for inexpensive resistive magnets. Our 0.2 T homogeneous knee-sized magnet cost just $12,000 (Stangenes Industries). Low field applications like prepolarized MRI, hyperpolarized gas or PHIP could greatly benefit from optimized litz wire construction.

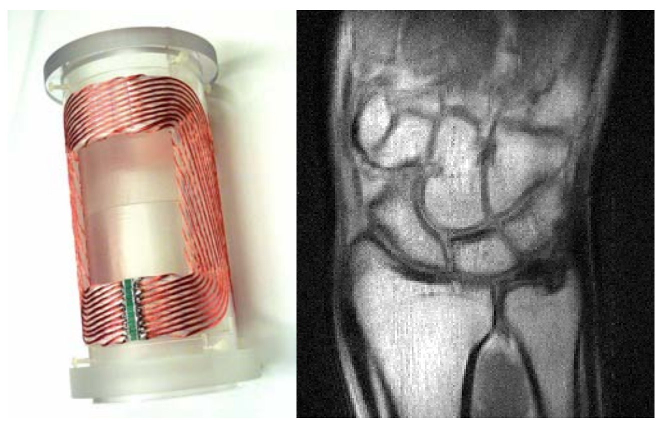

Figure 2: Litz wire saddle coil used for a PMRI human wrist image. At 4.3 MHz the unshielded Q factor is 1040, which is double the Q of a comparable copper sheet coil. The loaded Q factor (human wrist) drops down to 500, indicating onset body noise dominance. Inside a 5 inch diameter shield the resonant frequency shifts to 5.7 MHz, where the 3D wrist image was made. Scan time: 7 min (20 slices), Resolution: $(0.42\ mm)^2$ x (3 mm)

References:

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