Litz Wire Radiofrequency Coils for Hyperpolarized Noble Gas Imaging of Rodent Lungs at 74 mT

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Introduction

Hyperpolarized noble gases, ^{3}He and ^{129}Xe, have become a promising tool for lung MR imaging. With hyperpolarization, the available magnetization is independent of the magnetic field strength. Furthermore, above a cut-off Larmor frequency when the sample (i.e. body) noise dominates the RF coil noise, the signal-to-noise ratio (SNR) is expected to decrease with field due to a reduction in the transverse relaxation time, T_2* [1]. The optimum field strength for clinical lung imaging has been predicted to correspond to low field strengths (0.05-0.2 T) [1] and will depend on the sample/coil size and geometry and field-dependence of the lung properties (i.e. relaxation times, susceptibility effects). For small animal imaging, coil noise dominates over a large range of frequencies and SNR improvements are expected by reducing coil noise by minimizing electrical resistance especially at low frequencies [2]. It has been shown that the resistance of conventional copper coils can be reduced by cooling with liquid nitrogen [3]. However, in practice it is difficult to build cryogenic coils which maintain sensitivity while ensuring the sample (ie. animal) does not also become cooled. An alternate approach is to use multi-strand conductors at room temperature (eg. Litz wire) which have been shown to reduce resistance compared to conventional (ie. solid) copper conductors below 1 MHz [2] and possibly up to 10MHz.

The objective of this work was to compare coils built with conventional copper wire at room temperature versus three different Litz wire types. Quality factors (Q) and SNR measurements for each coil were compared. The comparison was conducted at 866 kHz and 2.385 MHz corresponding to ^{129}Xe and ^{3}He frequencies at 74 mT

Methods

The experiments were performed using a broadband, variable field (0.01 – 0.15 T) MR imaging system for rodents [4]. Hyperpolarized natural abundance xenon gas (26.4% ^{129}Xe) was produced by spin exchange optical pumping using a home-built, continuous-flow polarization system delivering 5mL/s gas mixture with polarizations up to 15%. The polarizer used a 60W diode array laser (λ=794.8 nm, Coherent, Santa Clara, USA). Hyperpolarized ^{3}He was produced by a turn-key polarizer (GE Helispin, GE Healthcare) providing polarizations up to 40 %.

The system used a Transmit Only/Receive Only (TORO) coil configuration. For this work the same transmit coil and similar receive coil geometries were used. Receiver coils were constructed of the following wire types: (a) conventional AWG18 copper wire, (b) Litz AWG 24 Type 1 (100 strands of AWG 46), (c) Litz AWG 18 type 1 (660 strands of AWG 46) and (d) Litz AWG 8 Type 2 (4200 strands of AWG 44). To quantify the proximity effects between windings, three sets of half saddle receiver coils were built for each wire type with an inner diameter of 3.5". The coils were built on identical plastic formers milled with grooves to accommodate the different wire types and making sure the center of the wires were placed in the same position. The first set of coils had only 1 turn (Fig. 1). The second set was designed with 2 turns, all with the same spacing of 3.3 mm, which was the diameter of the thickest wire (i.e. Litz AWG 8). For the third set of coils, the conventional copper wire was spaced 1.1mm (ie. 1 wire diameter) apart, while the Litz wire had no spacing. To quantify the effect of increasing the number of turns, a 5-turn full saddle configuration was built with each wire type spaced by 3.3mm. .

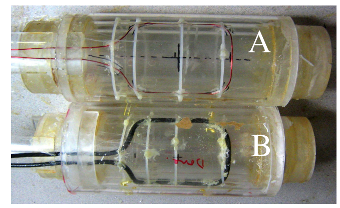

Figure 1. Examples of 3.5" RF coils built. (a) Copper wire coil. (b) Litz wire type 2 coil (4200 strands)

All the coils were separately tuned using appropriate choices of tuning capacitance to both 866 kHz and 2.385 MHz corresponding to ^{129}Xe and ^{3}He Larmor frequencies at 74 mT. The quality factor (Q) of each coil was measured using a vector impedance analyzer (Bravo MRI II, AEA Wireless, Inc., Vista CA, USA). The SNR was estimated from ^{1}H gradient echo images (TR/TE = 30/7 ms 64 x 64 pixels and 5cm FOV) acquired with a 6cm diameter sphere, filled with saline solution doped with gadolinium (Gadoteridol 0.5mg/mL, Squibb Diagnostics, Montreal, Canada), by changing the magnetic field strength to 20.35 mT and 56 mT respectively. The SNR values were estimated using the mean value of the image signal divided by the standard deviation of the noise in the background. ^{129}Xe and ^{3}He images were also obtained from the 5-turn full saddle coils in Sprague Dawley rats ventilated with a custom ventilation system using a University-approved animal care protocol.

Results and Discussion

Table 1 shows the Q values and SNR estimated for each coil at 2.385 MHz, and for the 5-turn coils at 866 kHz. Due to the very small inductance of the 1- and 2-turn coils, tuning and matching at 866 kHz wasn't possible. The Q values of the copper coil were better at the higher frequency as expected, however in the case of the Litz wire, performance was better at 866 kHz because the size of the strands were optimized for this frequency. Nevertheless, in all cases, the Litz wires with AWG 8 and AWG 18 performed better than the conventional copper, particularly the AWG 8 at 866 kHz. The Litz wire AWG 8 has strands of 44 AWG, which are designed to work up to 850 kHz. Differences in SNR between frequencies are expected due the different field strengths. The Litz AWG 24 did not perform as well as the conventional copper presumably because the diameter of the Litz conductor is much smaller than the effective diameter of the conventional copper even accounting for skin depth effects. As expected, the SNR increased linearly with the number of turns and the Q values of the coils. By comparing the 2-turn coils, in the case of minimum spacing, the Q values and SNR increased because the effective area of the inner turns is larger, and for Litz which were wound with no spacing, the Q also increased which demonstrates that proximity effects are negligible. This is another advantage of Litz wire, for a giving size of coil, twice the number of turns can be used for the same wire AWG, compared to copper, since no spacing between windings is needed. This doubles the sensitivity of the coil and, as shown in Table 1, no losses are introduced by proximity effects as occurs with the conventional copper wire. ^{3}He images of *in vivo* rat lungs obtained with the 5-turn copper (a) and Litz type II (b) coils are shown in Fig. 2 with SNR of 26 and 34 respectively.

Preliminary Q value results of increasing the number of turns to 10 using Litz AWG 18 wire confirms that further increases in SNR (of factor two or more) are attainable. This will be studied in more detail in future.

	2.385 MHz								866 kHz	
	1 turn		2 Turns max. spacing		2 Turns min. spacing		5 Turns		5 Turns	
Coil	**Q**	**SNR**	**Q**	**SNR**	**Q**	**SNR**	**Q**	**SNR**	**Q**	**SNR**
Copper (AWG 18)	64	18	87	26	99	29	121	102	79	19
Type I Litz (AWG 24)	53	15	69	20	77.5	22	92	87	102	25
Type I Litz (AWG 18)	77	20	104	31	120	39	146	126	215	57
Type II Litz (AWG 8)	77	20	105	32	115	37	145	127	200	51

Table 1. SNR and Q factor measured in water phantoms for each coil at the frequencies of interest.

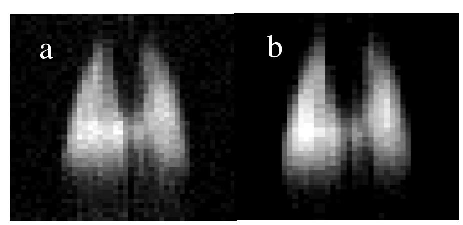

Figure 2. Hyperpolarized ^{3}He images of *in-vivo* rat lungs acquired with two 5 turns coils. copper (a) Litz type 2 (b).

Conclusions

In conclusion, construction of low field RF coils for hyperpolarized gas imaging of rodents benefits from the use of Litz wire, particularly with increased number of turns where an SNR improvement of approximately 200% is possible compared to copper wire at 866kHz. This improvement is comparable or better than that achieved using cooled conventional copper wire as presented by Berger *et al* [3]. Further improvements from Litz are expected using wire optimized for the specific low frequency of interest.

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References

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