Water-cooling in the space between RF body coil and RF shield

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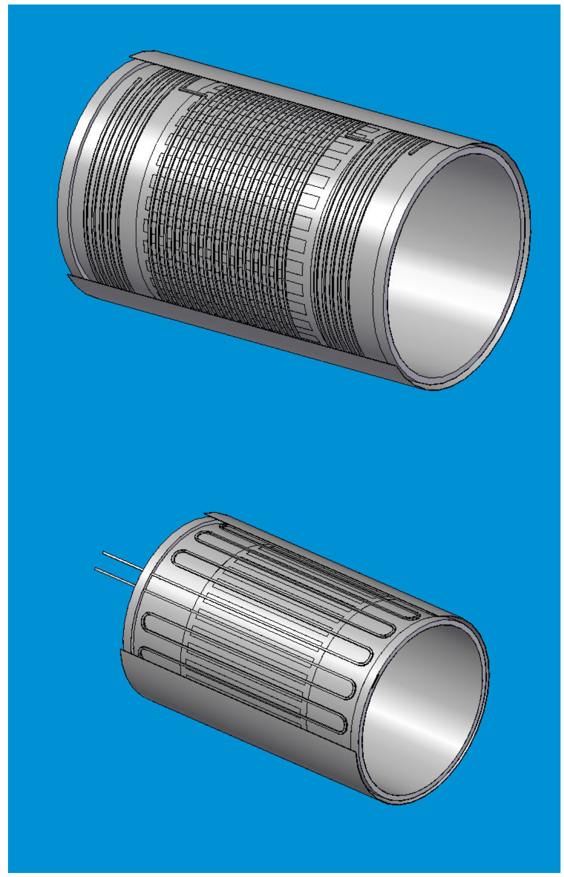
INTRODUCTION

The past decade has shown a steady increase of gradient amplitudes and slew rates. The needed current amplitudes through the gradient coils have increased, and so has the heat that is generated by the series resistance of the gradient coil. Typically, the heat is transported out of the bore via water-cooling integrated within the gradient coil assembly. Between the warm bore of the magnet, and the patient tube (the diameter of the system that the patient experiences) we place shimming, the gradient assembly, RF shield and RF Body coil. We run out of space to fit additional water-cooling lines. It is the purpose of this investigation to examine the effects of placing water-cooling lines between the RF shield and the RF Body coil. This is an area with very high RF E and B field amplitudes and is normally filled with a dielectric or air. If the water lines were to be made from plastic, then the water would produce proton MR signal that may find its way back into the image as an artifact. Most other cooling liquids also contain protons or nuclei, that are of specific interest in MR spectroscopy. Doping the water to bring down the T2 has a limited effect, since modern pulse sequences accommodate echo times in the micro-seconds. A logical solution is therefore to make cooling lines out of copper in order to shield the cooling medium. Copper has good thermal conduction, however electrical conduction will carry RF current, and may change the performance of the RF body coil.

METHOD

Birdcage resonators were created on a 610 mm OD fiberglass epoxy tube (ID = 600 mm). A 16 rung birdcage, length 610 mm, was created out of 1 inch copper strips, high pass, with an endring capacitance of 91 pF. Placed inside a phosphor bronze mesh (325 lines per inch, wire diameter 0.036 inch) RF shield, diameter 652 mm, 3 feet long, the frequency of the homogeneous mode was 65.4 MHz and Q was 240. An additional 32 rung birdcage of length 520 mm was created. The rungs were made from 40 mm wide copper strip, the endrings from 1 inch wide copper strip. With an endring capacitance of 47 pF the homogeneous mode resonated at 135.4 MHz with a Q of 330 inside the phosphor bronze mesh shield, frequency 134.6 MHz and a Q of 440 inside a solid copper (70 um) shield. ABS strips were cut with grooves for the cooling lines. With the ABS covering the entire RF coil, we made sure that the distance between the cooling lines and the RF coil was constant everywhere. The groove in the ABS accommodated a solenoidal cooling line with a pitch of 1 inch per revolution, except in the area of the birdcage endring, where the most severe coupling was expected (1). The line crossed the endring perpendicularly for a length of 3 times the endring width as was found to be the optimum in (1). The cooling line we used was a copper pipe with a rectangular cross section of 4.2 by 6.9 mm, and a wall thickness of 1.2 mm. The final set up is sketched in the top figure. In the 1.5T experiments, the distance between the RF coil and the center of the cooling line was 13 mm, in the 3T experiments it was 15 mm. The shield resides at a diameter of 652 mm, or 21 mm above the RF coil surface. After these initial experiments, we experimented with 2 and 4 solenoids in parallel with respective pitches of 2 and 4 inch per revolution. The solenoids were intertwined but shifted by 180 and 90 degrees respectively, so the 2 endring crossings would occur 180 degrees apart in the 2 solenoid version, and 90 degrees apart in the 4 solenoid version. The multiple solenoids would provide more flow and heat transport for the same size pump. The beginning and end of the cooling spiral was always chosen to be in the middle between the I and Q drive port of the RF coil to prevent isolation problems.

An alternative cooling configuration, shown in the bottom figure, was also tested using a 16 rung birdcage, 610mm in diameter and 610 mm long, having 6 cm wide rungs and 5 cm wide rings. The coil was tuned to 64MHz, having an unloaded Q of 250, by placing 156pf capacitor arrays (6 parallel capacitors) in the rings. The coil was placed inside the phosphor bronze mesh with a coil to shield spacing of 20mm. Copper tubing was then placed in parallel with the rungs of the birdcage. The tubing was 5mm in diameter and turned upon itself having a serpentine width of 48". The tubing was 2mm from the RF shield. For symmetry 16, 32 and 64 tubes were equally spaced around the RF coil.



RESULTS

The serpentine cooling resulted in a minor frequency shift, but introduced a Q reduction dependant on the number of tubes. The Q stayed constant (250) at 16, but reduced by 20% to 200 with 32 windings, and reduced by 40% to 150 with 64 windings. Since the turnaround points were well outside of the coil, the results were consistent without any connection between tubes.

As for the solenoidal cooling: The 65 MHz coil with the single spiral resulted in a slight frequency shift to 65.6 MHz, and a Q of 220. The 2 spiral model was the same frequency, but a Q of 200. When the 2 spirals were connected at 1 end with a U turn, so as to provide a return path for the water, the Q dropped to 196. The 4 spiral version saw a significant Q drop to 150. The 2 spiral version was also tested in the MR system to check SNR and Uniformity performance. No significant changes were seen with a standard RF body coil, as long as the coil was properly centered. The 135 MHz coil was covered with the ABS as shown before. That by itself brought down the frequency and Q to 131.6 MHz and 370 due to the dielectric constant and losses of the ABS. Adding a complete solenoid without perpendicular endring crossings gave a spectrum with many modes, none seemed to be homogeneous, efficiency was very poor. By going to the perpendicular endring crossings of 3 inch length, the frequency was 134.5 MHz and the Q was 230. Uniformity was unchanged

DISCUSSION and CONCLUSION

The copper tubing wound in the form of a solenoid has minimal coupling with the RF body coil, as long as the solenoid is round, and coaxial with the RF Body coil. Coupling does occur however over the birdcage endring locations, where the solenoid has to jump across perpendicularly. The gap thus created has to be filled with a thermally conductive spacer in case cooling is required in this area. Up to 2 solenoids with water cooling can be applied in parallel as long as the pitch does not increase above 2 inch per revolution. 4 Parallel spirals gave unfavorable results due to low Q. The 4 inch pitch means that there is a large component in the Z direction that can couple to the E field associated with the rungs of the birdcage. The solenoid also has to be centered with respect to the isocenter of the magnet to prevent coupling with the Z gradient coil. Serpentine cooling can be achieved by matching the spacing of the RF birdcage, ideally placing the copper tubing between each of the rungs of the coil. In this case, no reduction in performance was found through Q data. Increased density of copper does have a negative effect however, narrowing of the rungs should minimize this effect.

REFERENCES

(1) E. Boskamp, R. A. Mallozzi, L. Blawat, W. A. Edelstein. Proc. ISMRM, 10, p816 (2002)