Experimental MRI evidence of the lift-off effect in the case of a small High Temperature Superconducting coil.

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Context and objectives:

The major noise sources usually involved in MRI experiments with surface coils, are the internal noise of the coil (R_CT_C) and the magnetically-coupled sample noise (R_ST_S) [1]. When the sample induced noise is dominant, the lift-off effect [2] indicates that the Signal-to-Noise Ratio (SNR) could be maximized by placing the sample at an optimal distance from the surface coil, but this has not been yet validated by MRI. In this work, we investigate on the optimization of the SNR in the case of a small High Temperature Superconducting (HTS) surface coil dedicated to local micro imaging at 1.5T [3]. This investigation is carried out as a function of the distance between the sample and the coil in three complementary ways: theoretical analysis, inductive measurements on the bench, and MRI experiments at 1.5 T.

Material and methods:

This study was conducted using a 6 mm radius HTS surface coil [1] based on the multi-turn transmission line resonator principle. A small cylindrical phantom (phantom a) of radius and height both equal to the HTS coil mean radius, *a,* and a larger phantom (phantom 3a) with radius and height both equal to 3*a* were used. Both phantoms were filled with NaCl solution diluted so as to obtain a homogenous conductivity of 0.5 S.m^{-1}, close to that of biological tissues [4]. For both the theoretical analysis and the inductive measurements, the SNR variation as a function of the distance between the sample and the coil was evaluated through the determination of the sensitivity factor of the coil expressed as: $S_{RF} \propto (B_1/I)\big/\sqrt{4k_B(R_ST_S + R_CT_C)}$ [5], where k_B is the Boltzmann constant, R_C, T_C are the internal resistance and the temperature of the coil respectively, R_S is the equivalent sample resistance inductively coupled in the coil and T_S is the sample temperature..

The theoretical variation of B_1/I as a function of the distance along the coil axis was computed using Biot-Savart's law. The sample induced resistance was calculated by integration of the dissipated power over the sample volume. In order to account for the internal noise of the HTS coil in the SNR limitation and due to the complexity of theoretical evaluation of superconducting losses in the radiofrequency range, we used the experimental R_C value of the HTS coil, 62 mΩ at 77 K, corresponding to its unloaded Q (13700) in a 1.5 T static magnetic field [6]. The theoretical analysis was also conducted in the case of a small copper coil, of the same size and geometry than the HTS coil, operating at 300 K and 77 K with respective unloaded Q factors of 120 and 300.

Inductive measurements were performed with an HP4195 network analyzer.The induction coefficient of the coil, B_1/I, was measured along the coil axis using the single-loop probe methods [7]. The sample induced resistance and the internal resistance of the coil were extracted from measurements of loaded and unloaded Q factors using a dual-loop probe coupling technique [8].

Imaging was performed on a 1.5 T whole body NMR scanner (Signa, GE Medical System). 2D multi-slice spin-echo images were acquired with TE/TR= 12/500 ms, FOV =30x30mm2, Matrix : 256x128, T_{ACQ}=1min12sec., and a 4.5 mm slice thickness. Sets of images were performed as a function of the coil-sample distance with a minimum displacement step of 0.5 mm. The SNR of phantom images was measured at close proximity to the surface inside the phantom. When using very low noise HTS coil, the noise added by the preamplifier of the MRI unit is no longer negligible. Therefore, S_{RF} values computed from the theoretical analysis and the electrical measurements were corrected accounting for the equivalent noise of the preamplifier and the acquisition channel (RT=2,88 Ω.K) as detailed elsewhere [6].

Results:

Relative SNR variations as a function of the distance from the phantom to the coil are displayed on figure 1 for phantom a and on figure 2 for phantom 3a. Displayed data were normalized to the maximum SNR obtained with the HTS coil. As it can be observed, for the small phantom the optimal distance between the HTS coil and the phantom is larger (3mm) than that with the larger phantom (2,4mm). For the copper coil at 300 K, the theoretical SNR is maximum at zero distance and no lift-off effect is observed.

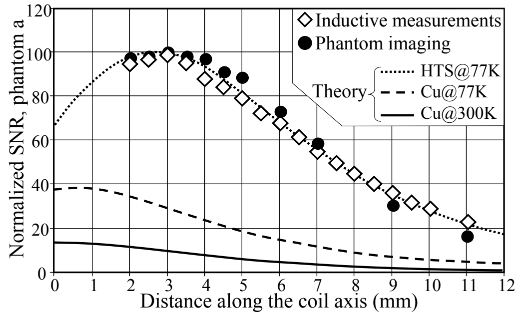

Fig. 1 : relative SNR variation as a function of the distance from the phantom to the coil for the phantom a

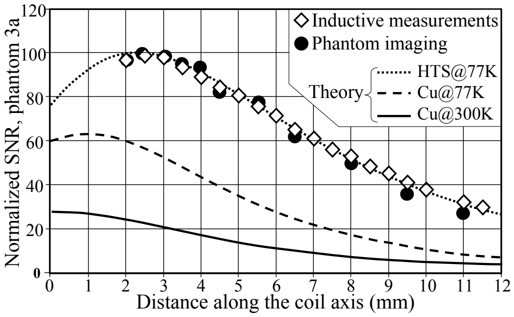

Fig. 2 : relative SNR variation as a function of the distance from the phantom to the coil for the phantom 3a

As an example, images obtained with the larger phantom (3a) are displayed on figure 3. For display, images were cropped by a factor of two in all directions.

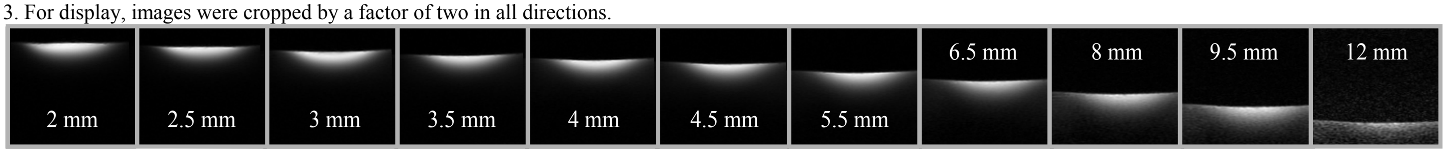

Fig. 3 : MR images performed at 1.5 T with the HTS coil and the phantom 3a as a function of the distance from the phantom to the coil.

Conclusion:

We demonstrated using MRI experiments at 1.5 T the existence of an optimal distance between the sample and the coil for which the SNR is maximum in the case of a small HTS surface coil. Experimental SNR measured on phantom images are in good agreement with both the theoretical analysis and the electrical characterization. This work will allow us to optimize the achievable SNR with the HTS coil regarding the loading configuration. It also denotes that when the sample induced noise is dominant, the spare room imposed by the thermal insulation when using of cryogenic surface coils can be accommodated with optimal coil-sample distance. While this work was restricted to the case of phantoms with size comparable to that of the coil, it indicates that optimizing the coil-sample distance can bring larger SNR gain in the case of very small samples. It also points out that the lift off effect could not be observed with a copper coil of identical geometrical than the HTS coil, even operating at 77 K. A fine analysis of the SNR variation as function of the coil and phantom size and as a function of the coil and sample-induced noise will be conducted to fully determine their complex influence on the optimal distance and on the achievable SNR.

References: [1] Ginefri J-C. et al.,. Methods, vol. 43 (1) : 54-67, 2007. [2] Suits B.H. et al., J. Magn. Reson. vol. 135 : 373–379, 1998. [3] Ginefri J-C. et al., Magn. Reson. Imaging, vol. 23: 239–243, 2005. [4]. Gabriel C. et al., Phys. Med. Biol. vol. 41 : 2231-2249, 1996. [5] Hoult DI. Et al., J Magn Reson. vol. 34 : 425-433, 1979. [6] Poirier-Quinot M. et al., Magn. Reson. Med. vol. 60 : 917 – 927, 2008. [7] Ginefri J-C. et al., Rev. Sci. Instr. vol. 70 : 4730-4731, 1999. [8] Darrasse L. et al., Rev. Sci. Instr. vol. 64 : 1841-1844, 1993.