RF and gradient coils for an elliptical surface NMR device

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Introduction. Mobile unilateral magnets have been developed in the past ten years to investigate samples that cannot be moved or do not fit within the bore of traditional MRI scanners [1]. We have designed a novel device (see fig. 1) based on an elliptical magnet with a large free space at the centre of the magnet to host the entire coil system and, eventually, other sensor for multimodal studies. The magnet generates a magnetic field parallel to its surface (directed along the major axis) and has been optimized to have a highly homogeneous B_0 along the ellipse major axis to allow 1D imaging along such direction [2]. Homogeneity is about 1500 ppm along strips of 12×2 mm^2 parallel to the surface of magnet, at distances between 7 and 10 mm from the magnet surface. Moving from the ellipse centre, orthogonally to the magnet surface, the maximum field intensity B_0=124 mT is reached at 7 mm. We present a complete coils system for signal transmission [3], detection and gradient generation along the ellipse major axis.

The Receiver coil.

The RF coils are realized on an elliptical support that can be moved in and out the free central space, parallel to the magnet surface. They both generate a field orthogonal to the ellipse major axis even if with two different geometries (fig. 2). The non monotonic behaviour of B_0 at different penetration depths (z axis) forces to discard the simple loop-like solution for the RX coil: it would mix signals from depths larger and smaller respect to the 7 mm maximum. To obtain a planar but depth selective coil we decided to consider a figure of eight coil [4]. For the first prototype we designed a RX coil with maximum sensitivity at a smaller depth (4 mm) compared to the target imaging region (fig. 4b). This has been done to gain SNR (approx. a factor of 3) and thus simplify the device fine tuning. Such coil can be used with our magnet just fixing the RF coils support 3 mm away from the magnet surface so to have the maximum sensitivity at the right depth (7 mm) at the price of reduced penetration depth inside the sample. The coil has been numerically simulated. They have been tuned at frequency of 5.28 MHz and the field measured with a small pick-up coil (2 mm diameter, 2 turns). Measured field for RX coil is reported in fig. 4 together with simulated values. Small deviations from simulated values are due to the presence of the capacitors for the matching/tuning circuit and the presence of the motor for the movement of the magnet (not included in the simulations).

Gradient coil

Gradient coil is hosted inside the free space in the centre of the magnet and produces a field gradient along the x-axis. The coil adds 1D capabilities while full 2D images (in planes parallel to the magnet surface) can be reconstructed from several 1D projections rotating the magnet itself [5]. The simulations indicated that the best performance could be achieved with D-shaped coils. We realized a two wrappings coil (see fig. 5) with 60 turns of 0.7 mm diameter copper wire on each side.
In the fig. 1 we show our system. At the bottom you can see the rf coil located in the free space of magnet, whether the gradient coil is not visible because it is over the rf coils. We have measured the gradient field, along the x direction, at several distances from the surface to test the entire target region of the device (fig. 5). The deviation from linearity inside the region of interest is at % level and we get a gradient strength of about 0.04 mT/mm for a current of 1 A in the coil.

Conclusions.

We have designed and tested the RF and gradient coil system of a unilateral elliptical NMR device. The actual configuration has a satisfactory gradient linearity and can reveal signals up to 4 mm inside the sample. Small changes of the receive coil can improve the potentialities up to the targeted 7-10 mm range (work in progress).To image inside the target region the gradient field should be high enough to overcome the non monotonic behaviour of B_0 field along the x direction. We showed that this could be obtained with a 0.04 mT/mm gradient [2], so a gradient current of the order of few Amperes is enough to encode spatial positions.

[1] Blumich B. et al., 2008, J. Prog. Nucl. Magn. Reson. Spectrosc., doi:10.1016/j.pnmrs.2007.10.002; [2] Ciarrocchi et al. Measurement Science and Technology, In press, 2008; [3] Galante A. et al. ESMRMB 2008; [4] Alfonsetti M et al., Magn. Reson. Mater. Phys. (2004) 18 69; [5] Bray CL et al., J. Magn. Reson. (2007) 188 151;

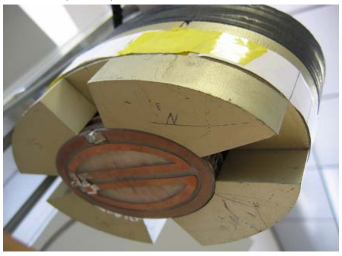

Fig. 1 The magnet has a central free space that hosts the RF coils without reducing the effective penetration depth

Fig. 2 Geometry of transmitter (brown strip) and receiver (green strip) RF coils.

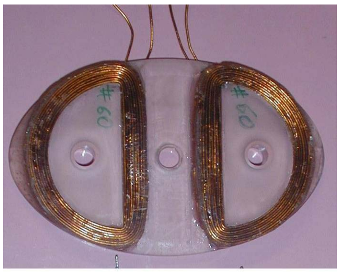

Fig. 3 Gradient coil: radius of the wrapping is 35 mm and the gap between them is 16 mm.

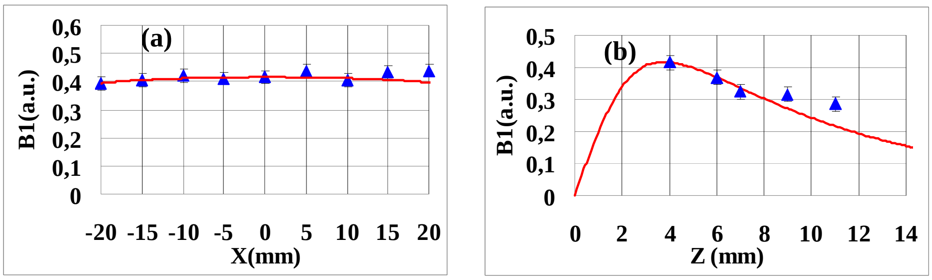

Fig. 4 (a) Simulated and measured B1 field values along the major axis of the ellipse (x-axis) at 7 mm from the coil surface, (b) The field B1 as a function of the distance z from the coil surface.

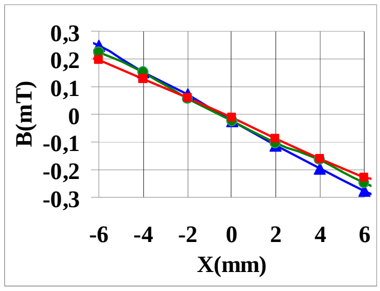

Fig. 5 Behaviour of the gradient field for a current of I =1A at distances of z= 7mm (blue), z= 9 mm (green) and z=10 mm (red).