An Optimised Elliptical Magnet for Deep Surface NMR Imaging

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Introduction. Unilateral NMR allows positioning of the sample on the surface of a portable measuring device and this technique has been used for MRS/MRI applications in materials science, biology, environmental science and medicine [1-7]. However, the open magnet geometry produces a magnetic field with high inhomogeneity, giving rise to reduced relaxation time T_2*. The limitation due to the strongly inhomogeneous field has been overcome in MRS applications by using specialised RF coils and pulse sequences [5-6]. MRI applications require a better field homogeneity and increased penetration depth. Unfortunately, most of the unilateral devices present in the literature do not satisfy both these requirements [1-7].

Aims. Here we report the design of a novel elliptical unilateral magnet with improved field homogeneity and penetration along one direction.

Magnet Optimization and Testing. The magnet simulation and optimization has been performed using a field simulation program (RADIA) interfaced to Mathematica. The magnet model has an elliptical shape obtained by an iron joke and 4 identical blocks of Neudymium Iron Boron (NdFeB), Fig. 1. The model is described by a set of 7 parameters including (see Fig.1): internal and external radii, eccentricity, thickness of the iron joke, height of the blocks, angular separations between the NdFeB blocks along x and y axes. In view of the envisaged applications in surface sciences, the optimization had as a target a depth from the magnet surface between 7 and 10 mm a useful strip of about 12 mm along the x direction and width about 2 mm, see Fig. 2. The elliptical shape of the magnet allows to obtain a good uniformity in a relative large volume, but constrains its maximum field strength to 1240 G. The optimization was done to allow simultaneous acquisition from a number of strips at different depth from the magnet surface. This required the development of a multichannel MRI console that allows to acquire and process the signal from a maximum of 8 strips [8]. Fig. 3 shows a prototype of the magnet and mechanical rig for sample positioning. The magnet has been constructed by Vacuumschmelze GMBH (Germany). The magnet dimensions (170×108×50 mm^3) are contained allowing the system to be portable, this being crucial for expected applications such as skin and frescoes analyses**.** The magnet is mounted on an aluminium support that permits rotation around the magnet z axis. The acquisition of the MRI signal from a number of radial strips is used to reconstruct 2D images. The magnetic field components were measured using a Gaussmeter (LPT- 141-2s Group3) equipped with a Hall Probe of sensitivity equal to 50 mG and a micrometric position rig. The magnet elliptical shape allows to extend the useful volume to a target region of 12×2×4 mm^3 with a field inhomogeneity of less than 1500 ppm at a fixed z position (see Fig. 4 and 5). Of course better field homogeneity could be achieved with narrower strips.

Conclusions. We have designed and tested a novel elliptical unilateral magnet with improved field homogeneity along narrow strips, positioned at higher depth with respect to the existing devices. The addition of a x-gradient of about 1G/cm will suffice to distinguish different x positions at a given distance from the magnet surface without mixing signals at different z values. This opens the possibility for novel stratigraphic MRI using a multi-channel receiver.

[1] Blumich B. et al, Magn Res Imag, 1998, 16, 479-484; [2] Blumich B. et al, Magn Res Imag, 2005, 23, 197-201; [3] Haken R. et al, JMR 2000, 144, 195-199; [4] Manz et al, JMR, 2006, 183, 25-31; [5] Blumich B. et al, Magn Res Eng, 2002, 15, 255-261; [6] Casanova F. et al, JMR, 2004, 166, 76-81; [7] Prado P. J. et al, JMR, 2000, 144, 200-206. [8] Ciarrocchi et al, 1st Workshop MRI in NRW, Jülich Nov. 12-13, 2007.

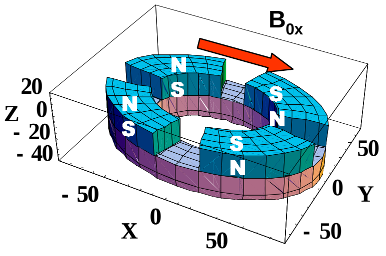

Fig. 1 Model of the magnet device.

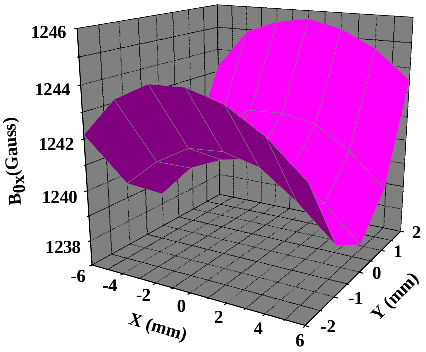

Fig. 2 The measured field B_{0x} as a function of the x and y position at a distance from the surface of z = 7 mm.

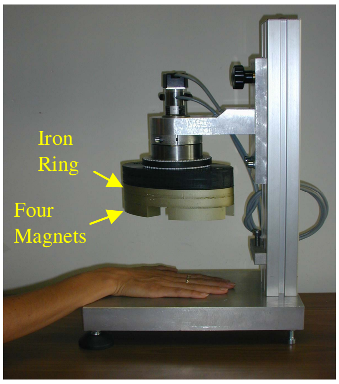

Fig. 3 Prototype of the unilateral device.

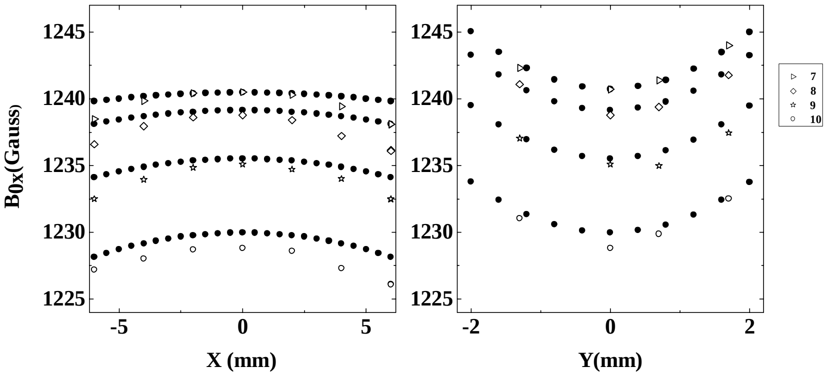

Fig. 4 The measured (open symbols) and theoretical (points) field intensity along the x (at y = 0) and y (at x = 0) directions for different distances z (in mm) from the magnet surface.

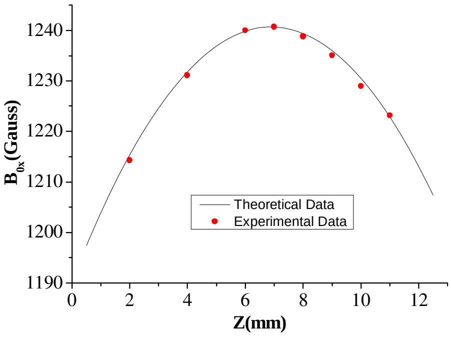

Fig. 5 The field B_{0x} as a function of the distance z from the magnet surface.