

Portable MRI Magnets and Spinning Micro-Detectors

D. Sakellariou¹, C. Hugon¹, A. Wong¹, P. Aguiar¹, G. Aubert², and J-F. Jacquinot³

¹DSM/IRAMIS/LSDRM/SIS2M, CEA - Saclay, Gif-sur-Yvette, Essone, France, ²DSM / IRFU / Neurospin, CEA - Saclay, ³DSM / IRAMIS / SPEC, CEA - Saclay

Introduction

Development of mobile NMR and MRI has been pursued since the pioneering work on well-logging, in order to reach the performance of high-resolution systems. Permanent magnets are the key to such mobile systems and the development of rare earth NdFeB and SmCo materials allows the generation of high strength magnets. However, most systems currently used are based on bar magnets or Halbach designs and produce fields with poor homogeneity compared with high-field superconducting magnets. Sensitivity in MR microscopy has been alleviated with the use of micro-coils. Recent results showed that rotating micro-coils can be used to analyze metabolites in micro-biopsies [1], with ultra high-sensitivity and resolution under slow-spinning and conventional hardware.

Methods

We present an approach to magnet design based on symmetry considerations and an analytical theory of 3D magnetostatics that allows the design of arbitrary magnetic fields inside (in-situ) and outside (ex-situ) permanent magnets [2]. These magnetic fields can be optimized to achieve the required field homogeneity inside the sweet spot. The control of the field profiles can be mastered at any order, which leads to large regions of interest and deep object-penetration distances.

For MR microscopy, we introduce the concept of rotating micro-coils, as a means to achieve ultra high-resolution 2D and 3D images of microscopic objects, without the need for pulsed field gradients. The stray-field gradient of superconducting magnets can be used to encode for all three spatial dimensions by magic angle and application of synchronized pulses [3]. The use of inductively coupled micro-detectors allows for magic angle sample spinning, which also averages susceptibility related effects [4].

Results

We will present the first high-uniformity, linear-gradient, ex-situ (one-sided) permanent magnet system, which was conceived using our theoretical framework. Measurements show that the magnitude of the field is 0.33 T and its profile is linear up to 5 ppm inside a 10 mm diameter spherical volume, positioned 20 mm from the surface of the magnet. The field can penetrate up to 5 cm inside an object with a uniformity of 3%, sufficient for diffusion measurements using the natural gradient of the magnet of 3.3T/m.

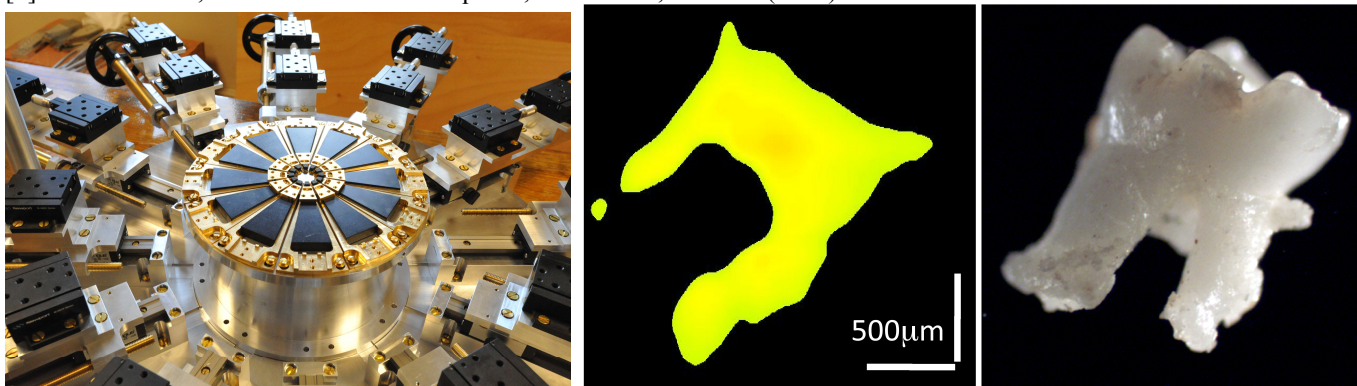
We will also present images obtained using magic angle coil spinning of water phantoms, silicon carbide samples as well as mouse bone (tibia) and tooth, in the presence of stray field gradients ranging from 0.1 to 5 T/m. Spatial resolutions as low as 9 μm by 35 μm were achieved.

Conclusions

The analytical theory we describe is a powerful tool for designing portable MRI magnets using permanent rare earth materials. Such devices can be easily miniaturized and adapted for organ-specific studies. Additionally, the introduction of solid-state methodology in MR microscopy shows that high-resolution images can be obtained without the need of pulsed field gradients. Both approaches could in principle be combined, by magnetic field rotation. This is certainly a difficult task, but possibly attainable through the use of permanent magnet technology. This work is currently underway in our Laboratory and some preliminary ideas will be presented.

References

- [1] A. Wong, P. Aguiar and D. Sakellariou, *Magn. Reson. Med.* (2009), in press.
- [2] C. Hugon, P. Aguiar, G. Aubert and D. Sakellariou, *C. R. Chimie*, (2009), in press, (doi:10.1016/j.crci.2009.09.009).
- [3] J. Baltisberger, S. Hediger and L. Emsley, *J. Magn. Reson.* **172**, 79-84 (2005).
- [4] D. Sakellariou, G. Le Goff and J-F Jacquinot, *Nature* **447**, 694-697 (2007).



Figures (Left) One-sided permanent magnet system producing a uniform linear gradient above its surface. (Middle) 2D projection image of a mouse tooth obtained using a rotating micro-coil in the presence of a stray magnetic field gradient under magic angle spinning conditions (Right) Photo of the mouse tooth.