Design Simulations of an Open-Access Permanent Low-Field Magnet for Hyper-polarised Gas Imaging

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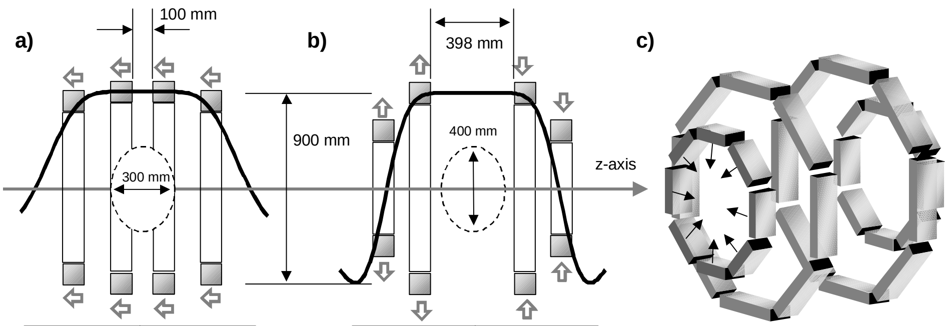
Introduction

Hyperpolarised (HP) gases such as Helium-3 can give rise to large MR signals, without the need for a polarising magnetic field, making it is possible to image at ultra low field [1]. An alternative design for a permanent magnet is proposed. It uses permanent rings of neodymium-iron-boron (NdFeB) with the magnetic dipoles ***orientated towards the central z-axis***. To our knowledge such geometries have not been exploited for MRI purposes, but are now being utilised in the field of nuclear physics [2,3]. The design is advantageous as a low field magnet since it affords a large open access volume, and could allow imaging of a human subject in the either the ***vertical or supine*** positions.

Simulations

The permanent elements of each magnet were treated as equivalent Amperean surface currents, and the corresponding magnetic fields were computed using the Biot-Savart law (coded in Matlab). No non-linearity was considered due to the low field requirement. The aim was to find configurations that maximised the field-strength to weight ratio (i.e. cost); and minimised the field deviation across a 300 x 400 x 400 mm^3 ellipsoid. Parameters such as ring radius, thickness and position were optimised using Nelder-Mead simplex least-squares minimisation of the field deviation within the region-of-interest.



501 gauss	859 Kg
0.58 gauss kg^{-1}	1820 ppm

856 gauss	659 Kg
1.30 gauss kg^{-1}	750 ppm

Fig 1. Two magnet designs are presented. Thick black line is the Bz field profile. a) Rings are magnetised in the conventional way b) Magnetic domains are polarised radially towards z-axis. c) 3D scale schematic of 1b

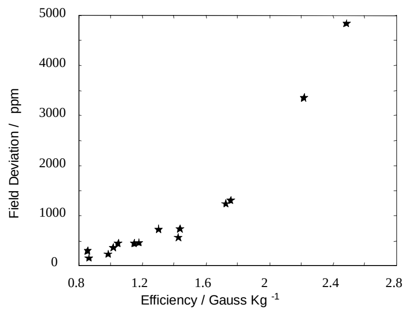


Fig 2: Field homogeneity in 300x400x400 mm^3 ellipsoid plotted against field-to-weight ratio

Results

Figure 1. compares two open magnets with four rings. In Fig. 1a the rings are polarised in the conventional way. In Fig 1b the ring are polarised radially outwards/inwards according to our design. Both magnets have the same cross-sectional area. However, design 1b gives a better homogeneity and, crucially, more access: 398 mm gap compared to 100 mm gap. In addition, design 1b produces more field per kilogram of material. Figure 1c. depicts the radially-polarised magnet in 3D, which comprises eight subsections for each ring. A variety of designs were analysed using rings with variable thickness. The results are summarised in Figure 2. where the best field homogeneity across a 300 x 400 x 400 mm^3 ellipsoid (for an unshimmed magnet) is plotted against the overall efficiency of the design, i.e. the ratio of field strength to magnet weight.

Discussion

Using permanent elements with the dipoles orientated towards the z-axis yields homogenous fields with a high degree of “open-access”. A challenge with such a magnet lies in the engineering, since the overall homogeneity is greatly dependent on the placement of each element to sub-millimetre precision. In addition, producing a permanent magnet with the dipoles orientated towards the z-axis requires each ring to be formed from multiple elements, which can lead to high-order gradient terms that may be difficult to shim. It should be possible to build much smaller versions of these magnets, which could yield higher field strengths (> 0.2 T) with relatively good, unshimmed, homogeneities (< 500 ppm) making them suitable for low-field animal experiments, or as an alignment field for production of the HP gas. Crucially, with this radial design there is a trade-off between (unshimmed) homogeneity and field strength.

References

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