Passive Shimming for a Cylindrical Brain-Sample Container

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Introduction

In our group we have been studying the various sources of contrast in T_2^* weighted and phase imaging. As part of these investigations we are imaging brain samples to allow for more detailed imaging and correlation with histology afterwards. The samples of several centimeters in size are placed in closed cylindrical containers to completely immerse them in fluid. These cylinders are placed horizontally in the magnet, i.e. with the cylinder axis along the Y-axis (vertical) of the MR system. This arrangement allows for the placement of surface coils on the top and bottom face of the cylinder and for easy rotation with respect to the main field, which is important for the study of susceptibility effects.

The design however also results in a significant field inhomogeneity due to the susceptibility induced field of (water filled) the cylinder itself. The poor shimming quality results in signal drop outs and complicates the extraction of small susceptibility effects from the tissue itself. To improve the B_0 homogeneity we designed a set passive shims made out of shaped plastic blocks that can be placed next to the sample holder while leaving space for the receive coil arrays on the top, the bottom and two sides of the container.

Methods

The magnetization of a cylinder perpendicular to the main magnetic field is equivalent to the field of surface currents on the cyclinder wall in the direction of the cylinder axis (Y) with a sin(φ) amplitude (φis angle with Z-axis), plus the connecting currents in the X direction on the two faces of the cylinder. This results in a homogeneous field for a long cylinder, at some distance from the end caps, but it results in an inhomogeneous field for a short cylinder, see Fig. 1. The sample holders are 158mm inside diameter, 166mm outside with PVC rim, and 28mm inside thickness with 12.5mm polycarbonate discs as covers.

PVC was used as shimming material as its volume susceptibility is close to water (depending on the density of the material used) and it is easily machined. To homogenize the field we optimized the placement of PVC pieces, with the restriction that they could not be any thicker than the sample holder. This to ensure there still is a flat surface to place the RF coils. Second we want to have some space for one of more coils on the side (in the X-direction). For ease of fabrication a stack of identically shaped 12.5mm thick slabs was chosen. The shape was optimized in simulations using the Fourier method from Salomir et al. (Concepts in Magnetic Resonance, 2003, **19B**, 26-34), fabricated and then tested using a multi gradient echo imaging sequence on a 7T GE scanner to measure the phase as a function of echo time. The phase difference between two echoes then served to estimate the field map. The images were acquired with a 256x192 resolution over a 240x180mm FOV, 2mm slices, 3.2ms echo spacing, with a only positive readout gradients (and a fast negative 'fly back' in between) to circumvent phase differences from the changes in gradient sign.

Results

Fig. 1 shows the measured and simulated field of the bare container. Fig. 2 is a photo of the sample holder and the shimming pieces, Fig. 3 shows simulated pieces and the resulting field with shims. Fig. 4 shows the measured field for this configuration. The field homogeneity is substantially improved over the original map in Fig.1, but not quite as homogeneous as the simulation in Fig. 3.

Two attempts were made to improve on the first design. One was tested in the magnet and comprised of adding two shim pieces in the gaps, as shown in Fig. 5. This creates a more continuous susceptibility, however, it does occupy the space we like to use to add coils on the sides of the container. The second improvement was only tested in simulation, shown in Fig. 6. This modification was aimed at avoiding the sharp corners in the original design which resulted in local hot spots in the field map (Fig. 3 and 4) and also aims to compensate some of the X^2 gradient visable in the measured data (Fig. 4).

Conclusion

The field homogeneity can be substantially improved by adding the PVC shimming material. The simulated results resemble the measurements, but are not (yet) identical, likely because the simulated dimensions of the shimming pieces and the container are not exact and the susceptibility of the used PVC was somewhat different than assumed (it depends on the density, which was unknown for this sample). That the field with side blocks (Fig. 5) is homogeneous is expected, as a slab of uniform susceptibility should be homogeneous far from the edges.

From the simulations and from the measurements it appears it should be possible to create a gap for coils on the side and still make a homogeneous field in the sample, however more accurate simulations and some adjustment of the shimming pieces are still required.

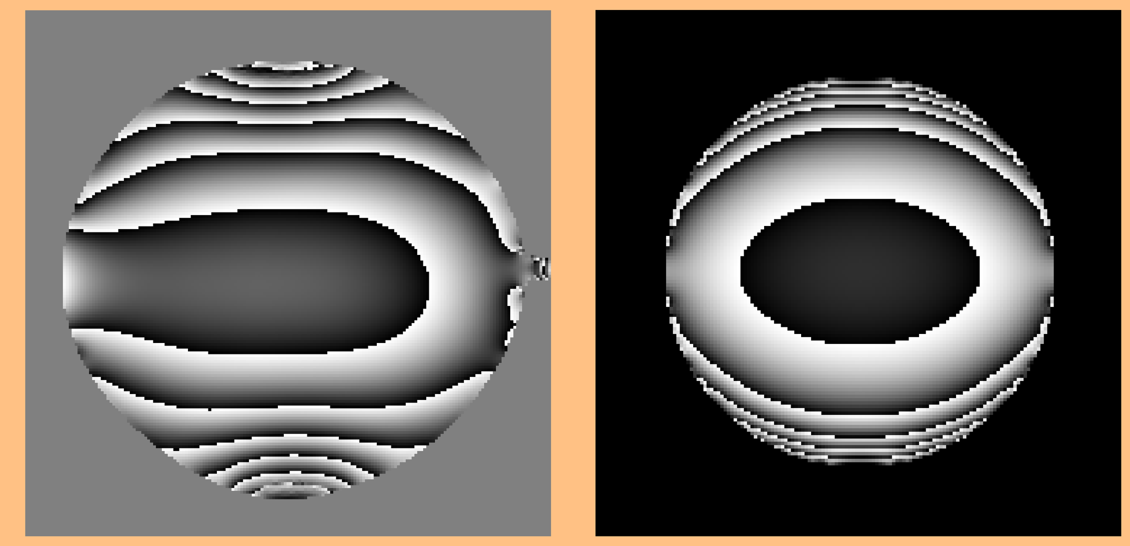

Figure 1.
Field of a bare cylinder, left is a measured phase, on the right a simulated phase map, including 2π wraps for comparison to the measured phase.

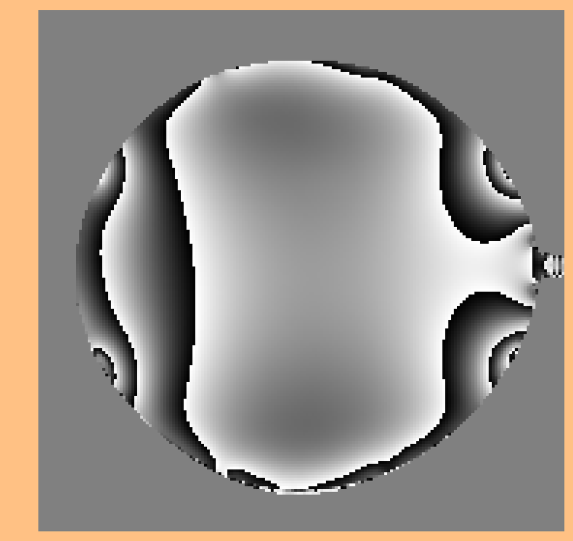

Figure 4.
Phase map with the shimming pieces in place, using the same scaling a Fig.1

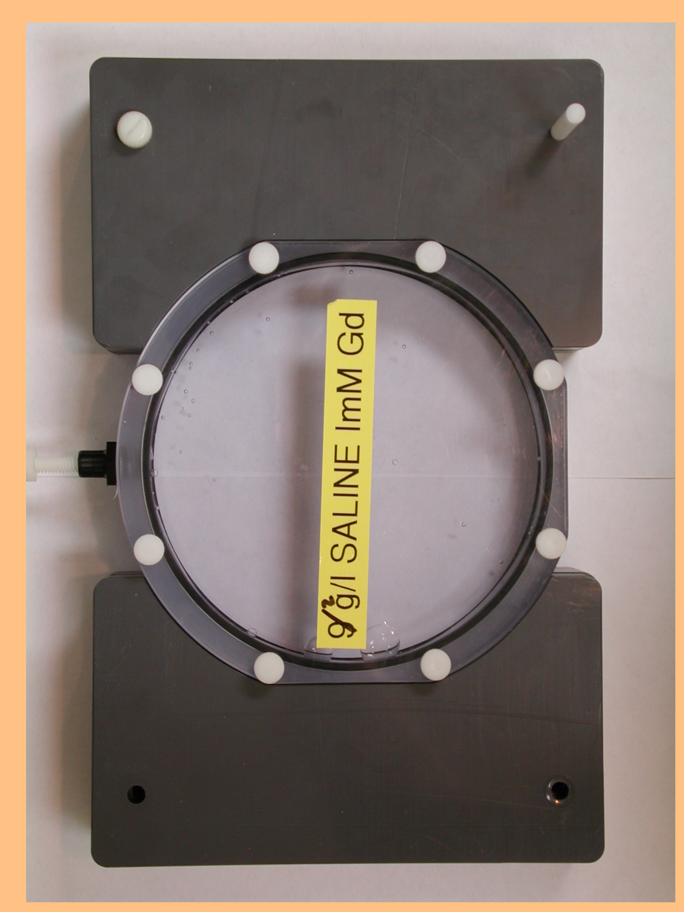

Figure 2.
Photograph of the sample holder with the PVC shimming pieces. The main magnetic field would be oriented vertical in this picture.

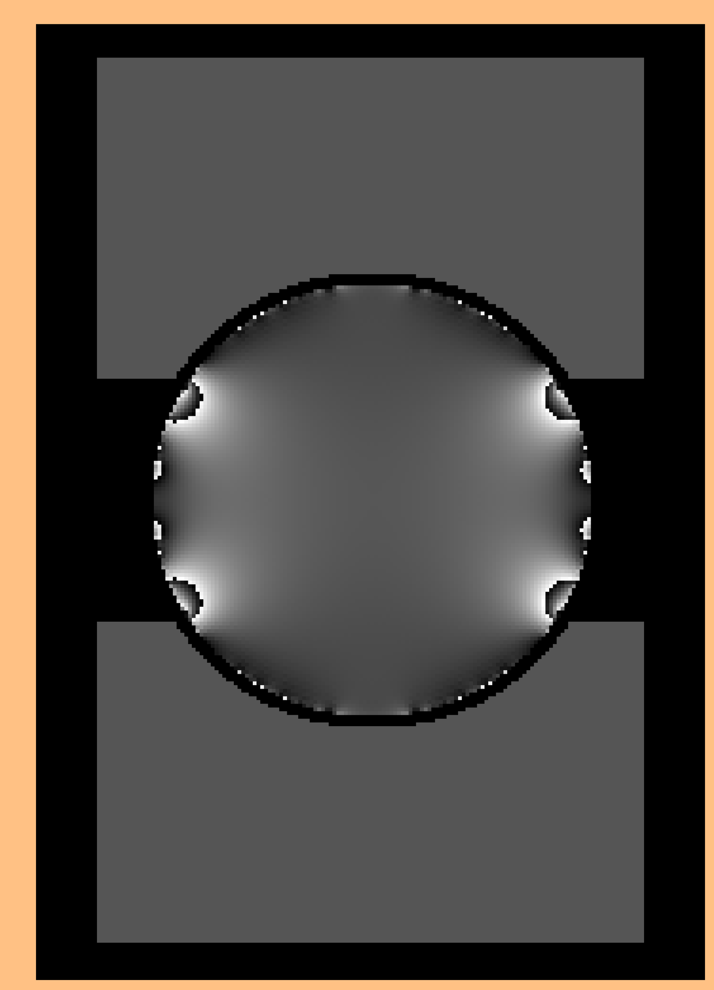

Figure 3.
Simulated field with the shims present, using the same scaling as in Figure 1.

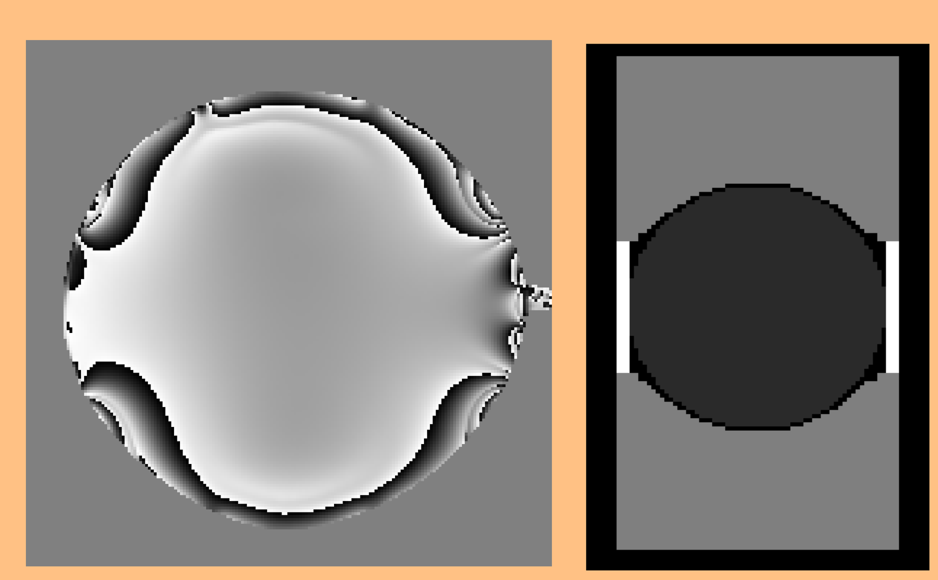

Figure 5.
Phase map (left image) with the shimming pieces in place plus two additional blocks on the side, shown in diagram on the right.

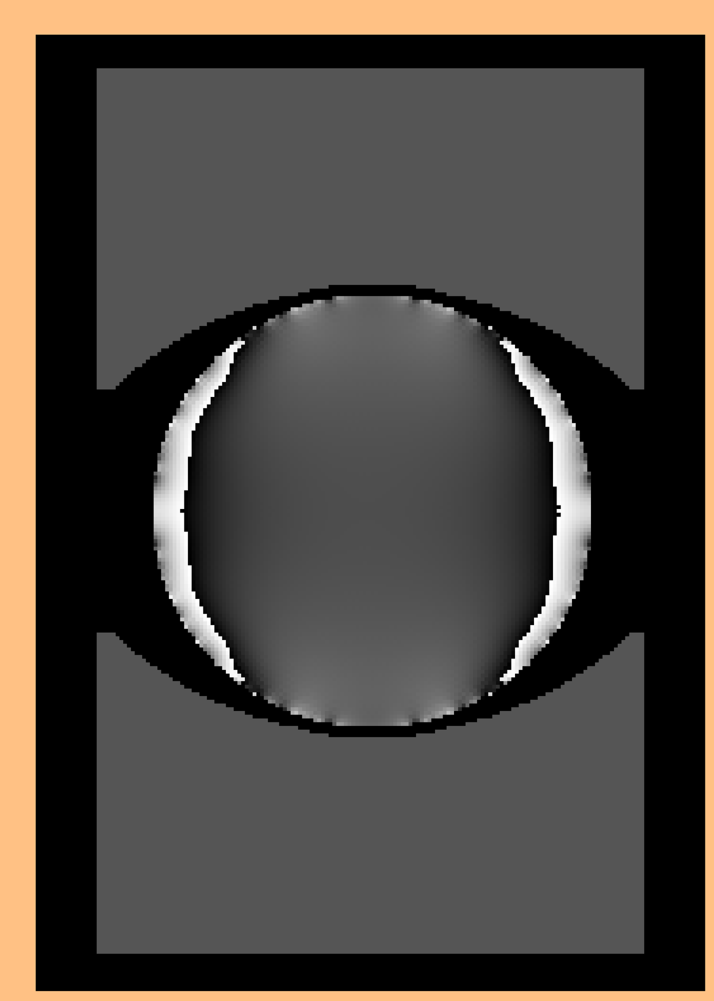

Figure 6.
Simulated field with the modified shims present, which could compensate some of the X^2 field shape observed in Fig. 4 and avoids the 'hot spots' from the corners visible in Fig. 3 and 4.