Design and Construction of a Permanent Magnet System for a Free Radical Imaging

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Abstract

The aim of this work was to design and build a permanent magnet system with uniform magnetic fields for a free radical imaging system. The magnet system was composed of 50 small permanent magnet cubes. The dimension of a magnet cube is 40 mm x 40 mm x 40 mm. Each magnet piece was separated by a space 3 cm and placed on two steel plates with dimension of 0.9 cm x 60 cm x 75 cm. The plates were placed in parallel to each other with distance 40 cm. From experimental results, by measuring at the center between two plates, the measured magnetic field was 42 mT, given a field inhomogeneity of 0.038 ppm, useful for a main magnet in our free radical imaging system.

Keywords: Permanent magnet: Resistive magnet: FC-PEDRI: FC-DNP

Introduction

Proton-electron double-resonance imaging (PEDRI) is a technique for imaging free radicals in biological samples or animals, which has been developed by irradiating both electron (EPR) and proton (NMR) in a sample. This technique, also called Dynamic Nuclear Polarization Imaging (DNPI) or Overhauser Imaging (OI), utilizes the Overhauser effect [1], involving the observation of the NMR signal of a solvent while irradiating the EPR resonance of a free radical solute: the free radical's unpaired electrons are irradiated by applying irradiation (radiowave or microwave) at the EPR frequency, and the NMR signal is obtained in the usual way by applying pulses of a radiowave at NMR frequency. If there is good magnetic coupling between the unpaired electrons and the water hydrogen nuclei, the EPR irradiation can cause a transfer of polarization from the electrons to the nuclear spins or the solvent nuclei under study, resulting in a large increase in amplitude of observed NMR signal.

Field-Cycled PEDRI or FC-PEDRI has been developed to reduce the problem of high RF power deposition in the sample from the EPR irradiation, without reducing the image signal-to-noise ratio (SNR) [2]. The main magnet for this technique is composed of two magnets: a resistive magnet and a permanent magnet, which their fields are aligned in the direction opposite each other. During the EPR irradiation, the applied field is switched to a low value, correspondingly low frequency (typically 50-150 MHz) with correspondingly low absorbed RF power levels [3]. The field is then increased to the field from the permanent magnet so that the NMR signals can be detected with good SNR. Field-Cycled Dynamic Nuclear Polarization (FC-DNP) has been also developed to allow the positions and amplitudes of EPR spectral lines [4]. Many experiments have been studied in low magnetic field [5-9].

The aim of this work is to build a permanent magnet system for free radical imaging in FC-PEDRI and FC-DNP. The work focuses on a lower field at

42 mT, used to cancel a magnetic field in opposite direction from a resistive magnet. The permanent magnet has been also designed to obtain a less field inhomogeneity at the center of the magnet.

Materials and Methods

In order to build a permanent magnet system, a magnetic field in the z direction from permanent magnet cubes with different thickness was measured. The magnetic field from two permanent magnets with different thickness separated by a space 40 cm was also measured between two pieces in the z direction. In Set up for measuring the magnetic field from 25 small permanent magnet cubes with each dimension 40 mm x 40 mm x 40 mm (Figure 1), placed on a steel plate with dimension 0.9 cm x 60 cm x 75 cm, is shown in Figure 2. In this set up, the magnetic field was measured in the z direction. In this work, the permanent magnet system was set up by using two steel plates separated by a space 40 cm, as shown in Figure 3. In this set up, the magnetic field was also measured at between two plates in XZ and YZ and XY planes.

Figure 1 A small permanent magnet cube with dimension 40 mm x 40 mm x 40 mm.

Figure 2 Set up for measuring a magnetic field from a plate of 25 small permanent magnet cubes.

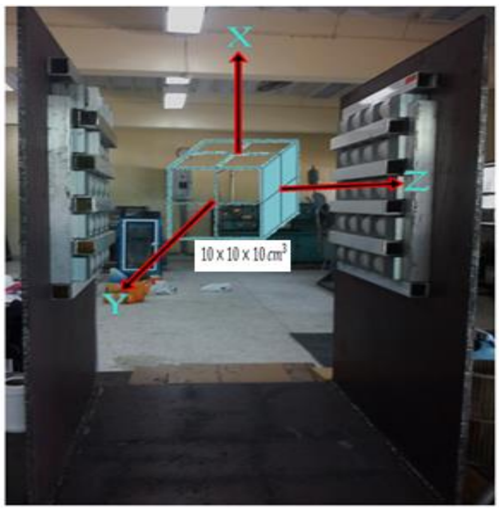

Figure 3 A permanent magnet system with directions for measuring magnetic fields.

Results and Discussion

The plot of a magnetic field in the z direction (Bz) from a permanent magnet cube is shown in Figure 4. From the figure, the magnetic field is given a maximum at the surface of the permanent magnet cube. The magnetic field then reduces exponentially to zero at distance (z) from 15-20 cm. In addition, the differences between any two magnetic fields from their different thickness (t = 1 cm, 2 cm, 3 cm and 4 cm) at distance (z) from 0-2.5 cm are quite large. The thicker of the permanent magnet cube, the greater the measured magnetic field.

The plot of a magnetic field in the z direction (Bz) from two permanent magnet cubes separated by a space 40 cm is shown in Figure 5. From the figure, the differences between any two magnetic fields of their different thickness (t = 1 cm, 2 cm, 3 cm and 4 cm) are quite close to each other at distance (z) from -10 cm to 10 cm. This range was given a lower field and a field inhomogeneity.

Figure 6 shows the plot of a magnetic field in the z direction (Bz) on XZ plane from the permanent magnet system at distance (z) from -5 cm to 5 cm. This shows the lower field of 42 mT at the center of the magnet.

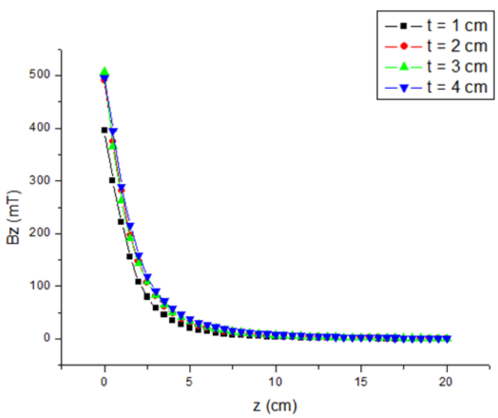

Figure 4 Plot of a magnetic field in the z direction (Bz) from a permanent magnet cube with different thickness (t = 1 cm, 2 cm, 3 cm and 4 cm).

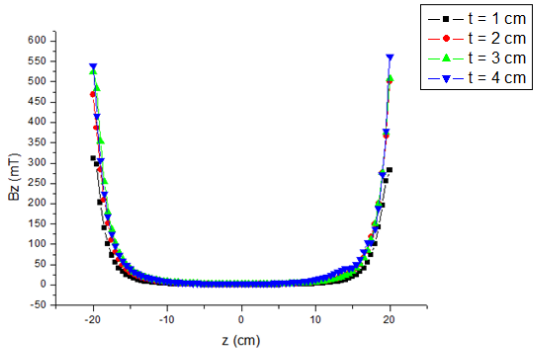

Figure 5 Plot of a magnetic field in the z direction (Bz) from two permanent magnet cubes with different thickness (t = 1 cm, 2 cm, 3 cm and 4 cm) separated by a space 40 cm.

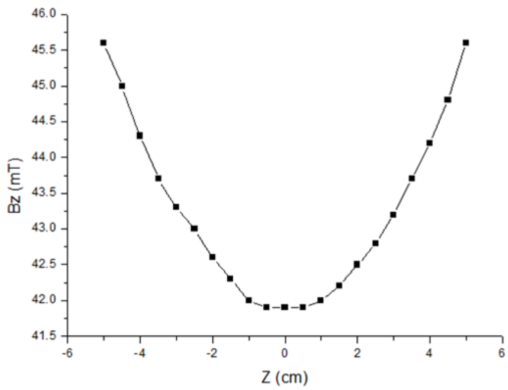

Figure 6 Plot of a magnetic field in the z direction (Bz) from the permanent magnet at distance (z) from -5 cm to 5 cm.

Figure 7 shows 3D plot for the magnetic field in the z direction (Bz) on YZ plane from the permanent magnet at distance (z) from -15 cm to 15 cm. The measured magnetic field at the center was also 42 mT, given a field inhomogeneity of 0.038 ppm. These data was also plotted in contour of the magnetic field on YZ plane at distance (z) from -15 cm to 15 cm, as shown in Figure 8.

Contours of a magnetic field in XZ, YZ and XY planes are shown in Figures 9, 10 and 11. These figures show the cross section area of a magnetic field of the permanent magnet at distance (z) from -5 cm to 5 cm. In XZ plane, the lower field in the ranges Z from -1.5 cm to 1.5 cm and X from -3.8 cm to 2.2 cm. In XZ plane, the lower field in the ranges Z from -1.7 cm to 2.3 cm and Y from -1.5 cm to 1 cm. In XY plane, the lower field in the ranges X from -3.0 cm to 2.0 cm and Y from -2.2 cm to 1.8 cm. The fields from these figures are also given the field inhomogeneity of 0.038 ppm, which is useful for a free radical in the FC-PEDRI technique.

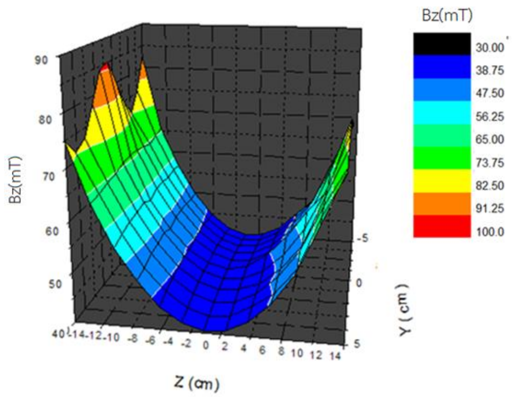

Figure 7 3D Plot of a magnetic field in the z direction (Bz) on YZ plane from the permanent magnet at distance (z) from -15 cm to 15 cm.

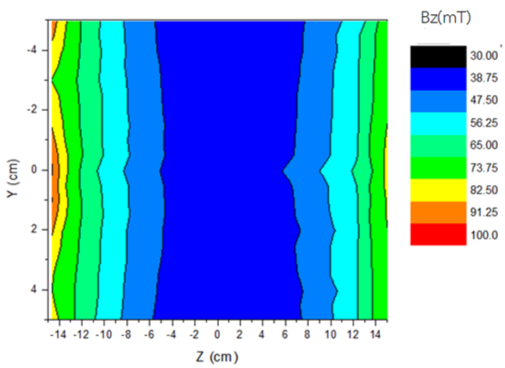

Figure 8 Contours of the magnetic field on YZ plane at distance (z) from -15 cm to 15 cm.

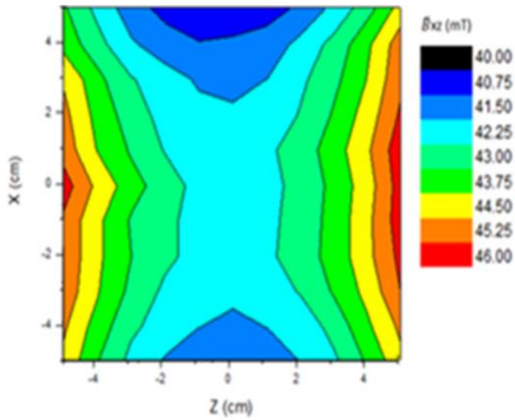

Figure 9 Contours of the magnetic field on XZ plane at distance (z) from -5 cm to 5 cm.

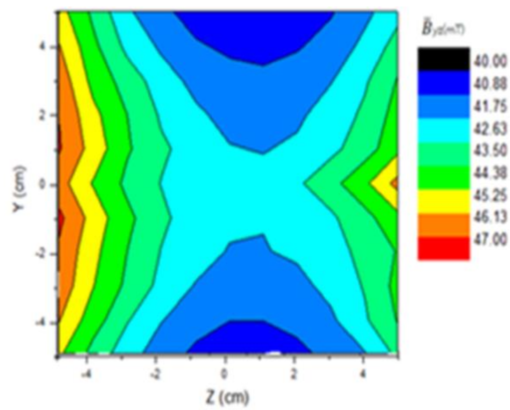

Figure 10 Contours of the magnetic field on YZ plane at distance (z) from -5 cm to 5 cm.

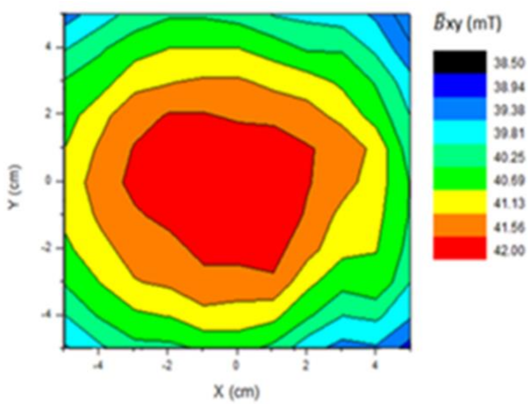

Figure 11 Contours of the magnetic field on XY plane at distance (z) from -5 cm to 5 cm.

Conclusions

The permanent magnet system can be built and given a magnetic field of 42 mT at the center of the magnet. This field is a field inhomogeneity enough to use with a free radical imaging in FC-PEDRI technique.

Acknowledgments

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