Development of a 2.0 Tesla permanent magnetic circuit for NMR/MRI

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Abstract

We have developed the 2.0T permanent magnetic circuit for NMR/MRI (figure1). In the previous study, the maximum field strength of permanent magnets for MRI was 1.0T [1, 3]. With using NdFeB magnetic materials and a special magnetic circuit design, it has been achieved that the magnetic field strength of 2.03 Tesla, ^{1}H center frequency of 86.3MHz, air gap of 60 mm, 10 ppm-homogeneous volume of 30 mm DSV (diameter spherical volume), outer size of 80 cm× 63 cm× 84 cm. NMR/MRI experiments were performed with using a compact NMR/MRI console [2] and RF solenoid coil. High resolution 3D MR microscopy images (100um res.) of a human finger *in vivo* were acquired in several minutes (figure 2). Three chemical-sift lines in Ethanol spectrum (figure 3, CH_3OH_2OH, 4 cc) were clearly measured with current shimming of higher orders. These result promises the stability and wide-use of the maintenance-free 2.0T permanent magnets.

Introduction

Figure 4 shows an example of permanent magnetic circuits which is used for usual medical MRI systems. Currently NdFeB materials have a maximum energy-product in magnetic materials. Almost of all 0.2T-0.4T whole body MRI system employ the typical magnetic circuit and NdFeB materials. This magnetic circuit is consisted of three major parts; yolks, magnetic-materials, and pole-pieces. The magnetic circuit has a advantage of its simple mechanical-structure, however the iron yolk cause a trouble of heavy weight more and more as increasing its air-gap or magnetic field-strength.

On the other hand we had developed a 4.4T permanent magnetic circuit [4] (figure 5, 50 kg, ID: 6 mm, Halbach type) for a polarizing lens for an instrument of linear accelerators. Unfortunately the 4.4T magnet did not have enough field homogeneity for NMR/MRI at its 6 mm diameter. Figure 6 shows a magnetic circuit design modified from Halbach type especially for NMR/MRI applications. In the previous study [1, 3] a 1.0T magnetic circuit (44 MHz, 10 ppm@ 20 mmDSV, 60 mm gap, 200 kg) was developed.

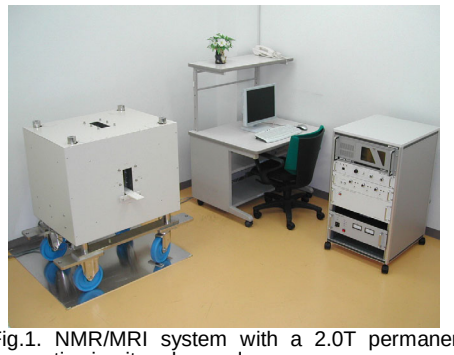

Fig.1. NMR/MRI system with a 2.0T permanent magnetic circuit and console.

Materials and imaging experiment

The 2.0T magnet with NdFeB shown in figure 1 (left), has achieved that the field strength of 2.03 T, ^{1}H center frequency of 86.3MHz, air gap of 60 mm, 10 ppm-homogeneous volume of 30 mm DSV, outer size of 80 cm× 63 cm× 84 cm. The 2.0T magnet has double bores of vertical& horizontal crossing at the homogeneous volume and NMR/MRI samples are easily placed at the iso-center. The whole magnetic circuit is covered with thermal insulators, so that the resonance frequency changing caused by temperature drifts is reduced within 1kHz with using a PID control of heaters attached to the magnet.

NMR/MRI experiments for the 2.0T magnet were performed with using a compact NMR/MRI console [2] and RF solenoid coil. A NMR spectrum of Ethanol (CH_3OH_2OH, 4cc) was measured with using higher order shim coils. A human finger in vivo was imaged using a conventional 3D spin echo sequence; TR/TE = 200/16 ms, matrix = 256×128×32, T_{acq} = 8min, voxcel size 100 um× 200 um× 800 um.

Fig.2. MRM image of a human finger *in vivo*; 3D-SE, 256x128x32, TR/TE=100/16, NEX=1, 100umx200umx800um, Tacq=8min

Result and discussions

The ^{1}H spectrum of Ethanol in a tube is shown in figure 3. As a result of the achievement for a few ppm of the field homogeneity with the shim coils, chemical sifts of three different intensities representing CH3, CH2, and OH ware acquired. The MR microscope images of a human finger are shown in figure 2. The anatomical details *in vivo* are clearly observed in this image.

One of the advantages for NMR/MRI systems with permanent magnets is that we can use RF solenoid coils for signal detections. In theory the SNR for solenoid RF coil is twice as much as the SNR for a quadrature birdcage coil in the same diameter of its coil dimension. According to the above estimation, a combination of the 2.0T and solenoid rivals a super-conducting 4.0T system at SNR.

Conclusion

The first trial of development for a 2.0T permanent magnet for NMR/MRI was successfully done. The combination of the 2.0T and solenoid rivals 4.0T systems at SNR. The NMR/MRI experiments were performed with using a compact NMR/MRI console and RF solenoid coil. This result promises the stability and wide-use of the maintenance-free 2.0T magnet.

References

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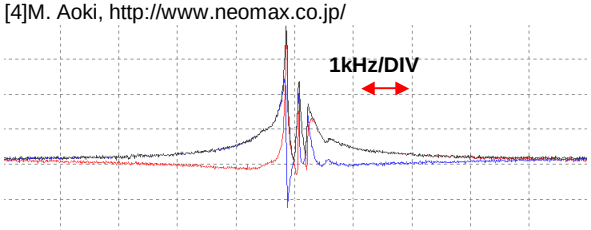

Fig.3. ^{1}H spectrum of Ethanol acquired with the 2.0Tmagnet

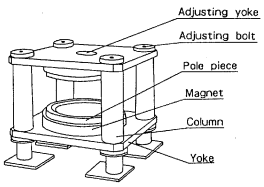

Fig.4. Column type circuit

Fig.5. Halbach circuit (4.4T)

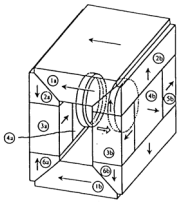

Fig.6. Yolkless circuit