A prototype field-cycling Overhauser MRI scanner

J. Overweg[1], C. Leussler[1], P. Röschmann[1], K. Luedeke[1], D. Riekmann[1], D. Holz[1], U. Katscher[1], P.Börnert[1], J.H. Ardenkjær-Larsen[2], J.S. Petersson[2]

[1]Philips Research, Division Technical Systems Hamburg, D-22335 Hamburg, Germany, [2]Nycomed Innovation AB, S-20512 Malmö, Sweden

Introduction

We have developed a prototype imaging system for Overhauser MRI experiments on phantoms and on small animals (rats and rabbits). So far, two copies of the scanner have been built; one is operated at Philips Research in Hamburg, the other one at Nycomed Innovation in Malmö. The scanners are intended for evaluation of contrast agents for in-vivo Overhauser MRI and for the development of scanning methods.

Background

Overhauser MRI involves the use of a contrast agent containing unpaired electrons. The Electron Spin Resonance (ESR) transition of this electron spin system (γ = 28 GHz/T) is irradiated with c.w. RF power at the appropriate frequency. If this is done for a time of the order of T1 of the protons, their polarisation is enhanced by a factor of the order of 5-50. The enhancement depends, among other factors, on the RF power and on the concentration of the agent. After this enhanced proton polarisation has been built up, one profile of a more or less standard NMR imaging experiment is acquired. An identical ESR pre-polarisation block must also precede all subsequent profiles.

RF-Frequencies

The enhanced nuclear polarisation increases linearly with the ESR frequency. On the other hand, the frequency must be low enough that the ESR RF-field penetrates the object under investigation without too much spatial inhomogeneity. It was found that for animals of the size of a rat (diameter 50 mm) an ESR frequency of 230 MHz (corresponding to 8.2 mT) could be used. For rabbit-sized animals (diameter 120 mm), we had to go down to about 150 MHz (5.5 mT) to get a reasonable ESR field homogeneity. We decided to implement the field-cycling scheme proposed by Lurie et al to improve S/N; after the pre-polarisation, the field is rapidly ramped to 15 mT, corresponding to an NMR frequency of 630 kHz.

System Architecture

Where possible, the prototype scanner utilises modules from the standard whole-body Philips Gyroscan product line. The gradient coil assembly is the inner coil of a (actively shielded) mid-field scanner coil. Instead of the shield windings, the outer cylinder of this structure carries a solenoidal B_0 magnet. The coil assembly was built by Epicon Alkmaar. Each of the four coils of the magnet/gradient assembly is driven by a Copley 234 gradient amplifier. The coil constant of the B_0 magnet is 0.1 mT/A. This is about an order of magnitude more sensitive than the gradient coils and hence the (ghost) effect of ripple and drift in the current from the amplifier is much stronger. In order to limit field ripple related ghosts to an acceptable level, the stability of the B_0 amplifier channel was improved. A Danfysik 600 sensor measures the magnet current and this signal is used in a feedback loop around the Copley amplifier. The minimum field cycling time from 8 to 15 mT is 5 ms.

The RF-coil system of an Overhauser MRI system consists of transmit and receive coils for the NMR signal (which may be combined in one T/R coil) and a transmit coil for the ESR coil. All RF coils must be oriented perpendicular to the main magnetic field direction. Several RF-coil architectures were built and tested. The best choice for NMR signal-to-noise was a rather close wound solenoid, oriented perpendicular to the axis of the main field magnet. Coil losses are minimised by using thin filament Litz wire. If the ESR field were polarised in the same direction as the NMR RF-field, the two coils would couple very strongly and the NMR coil will act as a shield for the ESR field. In this case, the ESR coil must be the inner coil of the system. This, however, is unwanted because the NMR coil should be as closely coupled to the sample as possible. This coupling problem was avoided by orienting the ESR field perpendicular to the NMR field. The ESR coil can then be a saddle coil or linearly polarised birdcage located outside the NMR coil. The NMR transmit signal is generated by an ENI 150 amplifier. An ENI 5100L amplifier generates the ESR power.

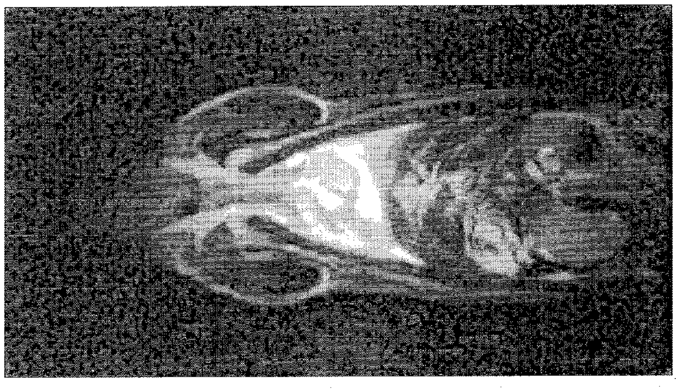
The signals from the coils are fed into a digital receiver in which the signal is directly sampled (without mixing down to a lower frequency). The receive bandwidth is only limited by the coils, which have an effective bandwidth of about 15 kHz. A further limitation is that the harmonics of the chopping frequency of the Copley amplifiers (80 kHz) must be kept outside the receive band to avoid degradation of the image quality.

Methods

The NMR scanning methods normally used on the systems are simple field-echo imaging and spin-echo imaging. The sequences do not differ significantly from those used on higher-field scanners. The two resonances (NMR and ESR) are found by adjusting the field set points. Shimming is done by adjusting the offsets in the linear gradients. The ESR RF waveform is a simple block pulse with adjustable amplitude and duration.

Results

The stability and reproducibility of the main field is better than 50 nT over the duration of a scan, which is good enough to provide ghost-free gradient-echo images with echo times up to 50 ms and scan times of up to 10 minutes. Without enhancement, the rabbit coil produces a signal to noise ratio from doped water of about 10 for a voxel size of 5 mm^3 (128 acquisitions, bandwidth per pixel 25 Hz). With Overhauser enhancement, the signal is typically one order of magnitude stronger. A phase variation over the slice could be observed, which is caused by the concomitant gradient fields, which are in the order of magnitude of the main magnetic field.



Overhauser-enhanced image of a rat

References

[1] Ardenkjær-Larsen J.H. et al., J. Magn. Reson. **133** No. 1 (1998).
[2] Lurie D.J. et al., J. Magn. Reson. **84** 431 (1989)