Temperature determination of the pre-polarising process of an earth’s magnetic field MRI system

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Abstract. Magnetic resonance imaging is a low inherent sensitivity technique with a low nuclear polarisation at thermal equilibrium. Low sensitivity is a major problem for ultralow field magnetic resonance imaging, but it can be overcome by improving the polarising process. This procedure may increase the temperature of the sample to be imaged affecting its integrity. We investigate the temperature increase generated by a pre-polarisation process for an ultralow field nuclear magnetic resonance system. We measured the pre-polarising field with a magnetic field sensor inside the system to study the possible effects on it. Temperature readings inside the system were also obtained varying the polarising time. A linear fitting was then calculated showing a low rate of 0.0086°C/s, and a total increment of 5°C for around 10 minutes. This is an important temperature increment that it should be considered when running imaging experiments of biological subjects.

1. Introduction

Ultralow-fields Nuclear Magnetic Resonance (ULF NMR) systems have been used to successfully conduct magnetic resonance imaging experiments at magnetic fields in the micro Tesla range [1]. These systems encounter the problem of insufficient magnetization of the sample. This is typically resolved by using a pre-polarisation technique applied during a short time prior to each image sequence. We can quantify the pre-polarisation pulse calculating the ratio of the NMR signal observed with and without the use of pre-polarisation by detection of the field and temperature [2]. A larger signal during the relaxation process can be obtained, but a major energy deposition over the sample is generated. This can cause heating of the object to be imaged [3]. The main goal of the current study is to investigate the local temperature increase generated by the pre-polarisation scheme of an ULF NMR system during the signal acquisition.

2. Method

The combination of field independent polarisation with multi-turn coils using the maximum allowed conductor length results in low-field MRI sensitivity increase similar to that of high-field MRI [4]. The local temperature inside of an ULF NMR system (Terranova-MRI, Magritek Limited, Wellington, NZ) was measured, while a magnetic field was produced by the polarising coil during the pre-polarised process. The polarising coil was 17 cm long and had a 17 cm diameter able to produce a polarising field of 18.8 mT at 6 A.
The solenoid coil used for the pre-polarisation process necessarily causes an increase on the temperature inside the magnet. This is particularly important when imaging animal models, because the integrity of the biological sample might be drastically affected. This can also affect the relaxation times of different tissues degrading the image quality.

![Figure 1. Experimental setup to measure the Bp along the Pre-polarising solenoid coil.](image)

The pre-polarising field, $B_p$, was measured along the pre-polarising coil length using a magnetic field sensor (PASPORT Magnetic Field Sensor - PS-2112, PASSCO, CA, USA) as shown in Fig. 1.

This imager uses the so-called brute-force approach which is performed at a higher magnetic field strength, $B_p$. The signal enhancement is directly proportional to pre-polarisation field, $B_p$, demanding a longer time. A direct consequence of the pro-polarising process is an increase on the temperature inside the MR imager. The assessment of the temperature rise will allow us to conduct MRI experiments of biological samples safeguarding them. Infrared cameras offer the tools to measure temperature remotely avoid the interaction with the electromagnetic fields produced by the MRI system. High resolution thermal images were taken using an infrared camera (FLIR E40, FLIR Systems, Wilsonville, OR, USA) for temperature readings. Thermal imaging experiments had a spatial resolution of 160×120 with 19200 total pixels, and thermal sensitivity/NETD < 0.07 °C. Due to the physical principle of acquisition, the electronic components do not interact with the pulsed magnetic fields.

The imaging experiments were acquired with the following parameters: TE/TR = 200/6000 ms, acquisition time = 400 ms, durations of the 900 and 1800 were 2.2 ms and 4 ms, respectively, NEX = 2, polarising current = 5 A, polarising time = 3000 ms. Spin Echo imaging experiments were performed for all measurements and image acquisition at 1414 Hz.

3. Results and discussion

We measured the variation of the $B_p$ along the length of the solenoid with the magnetic field sensor and shown in Fig. 2. As expected a linear relation can be appreciated along the longitudinal axis of the coil. The linear region covers almost entirely the MR imager, assuring a fairly uniform polarising of the sample to be imaged. Symmetry around the same axis also indicates that coil is producing a characteristic magnetic field for polarising purposes.
The field measurements taken at the ends of the coil showed an important difference of around $10^9 \mu T$. It is worth mentioning that these measurements of the field were carried out slightly over the coil length. This may explain why the initial and last values are not the same. Despite the fact that the room temperature was 24ºC, the solenoid coil for polarising process showed a very good performance. However, it is necessary to decrease the room temperature to reliably conduct and assure the good quality of the MRI experiments. We expect that the field measurement difference will drastically decrease, and the image quality will improve. We obtained temperature measurements using an infrared camera as a function of time. We video recorded the increment of the temperature for a duration of 600 s. Fig. 3 shows some prints of the readings taken at different times.

With data of Fig. 3, profiles of the temperature distributions inside the imager were calculated and shown in Fig. 4. These results show that temperature reaches its maximum value at the centre of the axial axis of the MR imager, and it decreases as moving away from the centre.

The temperature distribution shows a symmetrical pattern and that the bore wall has a relatively high temperature and close to the room temperature. An important increment of temperature of around 10°C occurs within 5 cm from the opposite sides. The temperature increases more sharply towards the centre of the bore from either side too. An important 20°C difference is produced by the solenoid from the bore wall to its center.
Figure 4. a) Temperature distributions inside the imager as a function of time. Profiles were taken along the blue line as indicated in (b).

Figure 5. Temperature as a function of time inside the MR imager.

We then determined a linear equation between the temperature and the process time inside the EFNMR system. The linear regression equation of the experimental readings is

\[ T = 8.6 \times 10^{-3} t + 41.265 \]  

with \( R^2 = 0.987 \). The slope of the linear regression is less than half a degree Celsius, so the temperature rate is really low for this time interval. However, Fig. 4 shows an important increment on the temperature after 200 s. The temperature within the EFNMR system increased around 5°C for a total time of 570 s. This temperature increase may alter the subject integrity. This is an important temperature increment that it should be considered when running imaging experiments of biological subjects. It also poses a challenge to develop cooling system, new coil designs, pulse sequences to attenuate the unwanted effect of power delivering into the object to be imaged.
4. Conclusion
In this study, analysis of the temperature in an Ultralow-field Nuclear Magnetic Resonance show a linear dependence on the time of exposition. These a very encouraging results because allow us to compute the optimal time to avoid causing any important damage to the sample. This is particularly important when imaging biological samples which constitution may be altered by the increment of the temperature. Consequently, it may importantly affect the imaging quality and the relevant information provided by the image itself.

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