Estimation of B_0 and B_1 MR Inhomogeneity via Relaxations

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Abstract. *The authors describe a method for the basic and RF field inhomogeneity estimation in NMR based on the measurement of T2 and T2*. The method combines the gradient and spin echo acquisition techniques to differentiate the T2 and T2* relaxation times. Exponential approximation of the relaxation process has to be performed. Experimental results for the plastic and copper specimens are shown.*

Keywords: NMR, Inhomogeneity, B0, B1, Relaxations

1. Introduction

The physical phenomenon in which the magnetic field of the nuclei of some atoms contained in the examined substance reacts with a rotating magnetic field is referred to as NMR (Nuclear Magnetic Resonance). NMR spectroscopy and tomography require the basic magnetic field B_0 to be generated with a high homogeneity [1]. Homogeneity of the basic magnetic field can be distorted by the measured object, and this object does not necessarily have to be magnetic: image distortion may occur already as a result of different susceptibility.

High homogeneity of the RF (Radio Frequency) field in the working space of an MR tomograph depends on the structure and setting of the applied probe. Mapping of the RF magnetic field is commonly based on MR image measurement of the homogeneous test specimen; in the measurement, the flip angle is optimally determined to ensure the maximum contrast of the measured RF magnetic field map, [2] and [3]. The local B_1 field strength in each slice can be obtained using repeated acquisitions with different RF-impulse amplitudes (‘transmit gain’, ‘flip angle’) [4]. The inhomogeneity can be corrected by the use of a map of the spatial distribution of the B_1 field acquired either through computer simulation or through the measurement of the field. The actual measurement of the B_1 distribution provides two major advantages: it makes the registration of the map against the MR images easier, and the measured B_1 field compensates for imperfections in the coil design. The paper describes the first instance of relaxation measurement using the SE (Spin Echo) and GE (Gradient Echo) methods applied for the B_0 inhomogeneity estimation. The method of B_1 estimation from the relaxation times via the magnetization transfer ratio is described in the following chapter of this article.

2. Inhomogeneity estimation from relaxation times

The GE and SE methods are well known within NMR measurement techniques, [4]. We can measure the relaxation process after excitation by changing the echo time, Fig. 1a. The number of realized measurements depends on the requirements and the time available. The measurement proper can be performed by a hard excitation pulse on the whole specimen, on a selectively chosen layer or area of the specimen, or on a pixel/voxel in an imaging sequence.

The measured data is must be approximated by an exponential function. Both constants of the exponential course, namely the magnetization after excitation M_{xy} and the time constant T_2 or T_2*, are needed. At least three measured magnitudes of the FID (Free Induction Decay) signal at different TE echo times are necessary for the approximation. The TE echo times should be chosen with care. The first echo time should be set to the lowest possible value with respect to technical parameters of the tomograph. The last echo time can be chosen either on the basis of the known inhomogeneity or experimentally. Other echo times can be distributed linearly between these two points. If a whole image is measured, we need to perform approximation in every pixel/voxel of the image. For high-resolution images, it is important to consider the computational complexity of the approximation algorithm. For example, the genetic algorithm is not a suitable option.

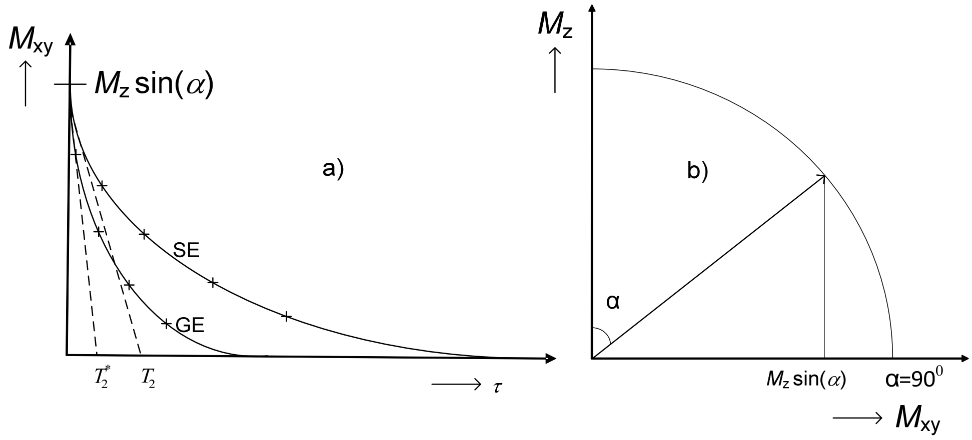

Fig. 1. a) Relaxation process after excitation b) flip angle representation.

The basic field inhomogeneity B_0 exerts influence on the relaxation process; thus, any deformation of B_0 causes the dephasing of magnetization. Dephasing leads to a faster drop of the FID signal and shortens the relaxation time T_2*. Figure 2 shows five magnitude images obtained by the GE and SE technique. Magnitude drop in the bottom left corner is marginal; it is caused by the B_0 inhomogeneity not successfully corrected by the shim coils. This is a limiting factor for any successful approximation of relaxation.

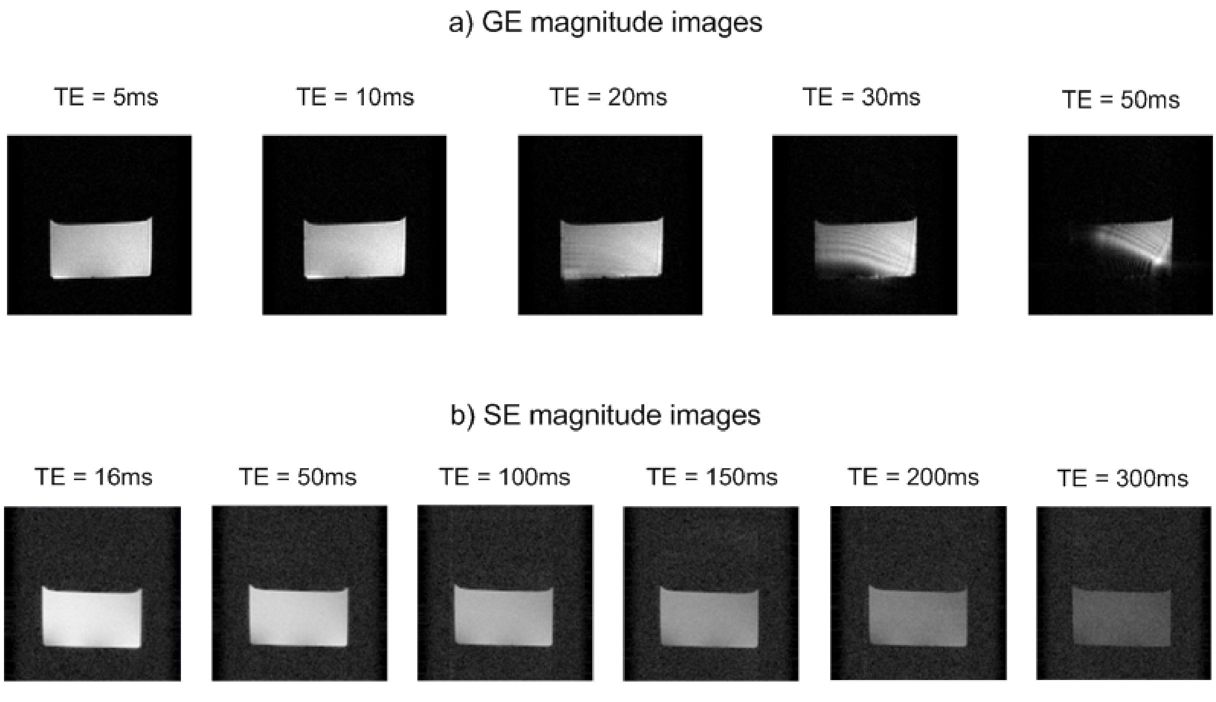

Fig. 2. Magnitude images a) for the GE sequence, b) SE sequence.

B_0 inhomogeneity estimation

The SE method compensates inhomogeneity B_0; therefore, we measure true relaxation T_2. It is, however, necessary to select a suitable specimen to exclude the influence of diffusion and movements. The basic field inhomogeneity B_0 is given by

$$\frac{1}{T^*_2} = \frac{1}{T_2} + \frac{1}{T'_2} = \frac{1}{T_2} + \gamma\Delta B_0,$$
$$\Delta B_0 = \frac{\frac{1}{T^*_2} - \frac{1}{T_2}}{\gamma}, \qquad (1)$$

where γ is the gyromagnetic ratio of ^{1}H. The value ΔB_0 is the overall and, in a way, average value of the B_0 inhomogeneity in any pixel/voxel.

Figure 3 shows the B_0 inhomogeneity maps measured using a 4.7 T tomograph. A cube filled by long- relaxing water was used. The specimen, namely a plastic or copper plate placed on a glass vessel, was inserted in the cube. The B_0 inhomogeneity with no sample is presented as background and can be subtracted from the measurement. The plastic sample is non-conducting and exhibits a significant (not exactly determined) value of susceptibility. In the plastic sample, B_0 changes significantly in the whole space of the water-filled cube. The maximal value of B_0 inhomogeneity is $4{\cdot}10^{-7}$ T. The B_0 inhomogeneity map for cooper sample will be presented on poster. Copper sample is a good conductor with a low susceptibility value; this sample exerts minimal influence on the B_0 inhomogeneity in compare to plastic sample.

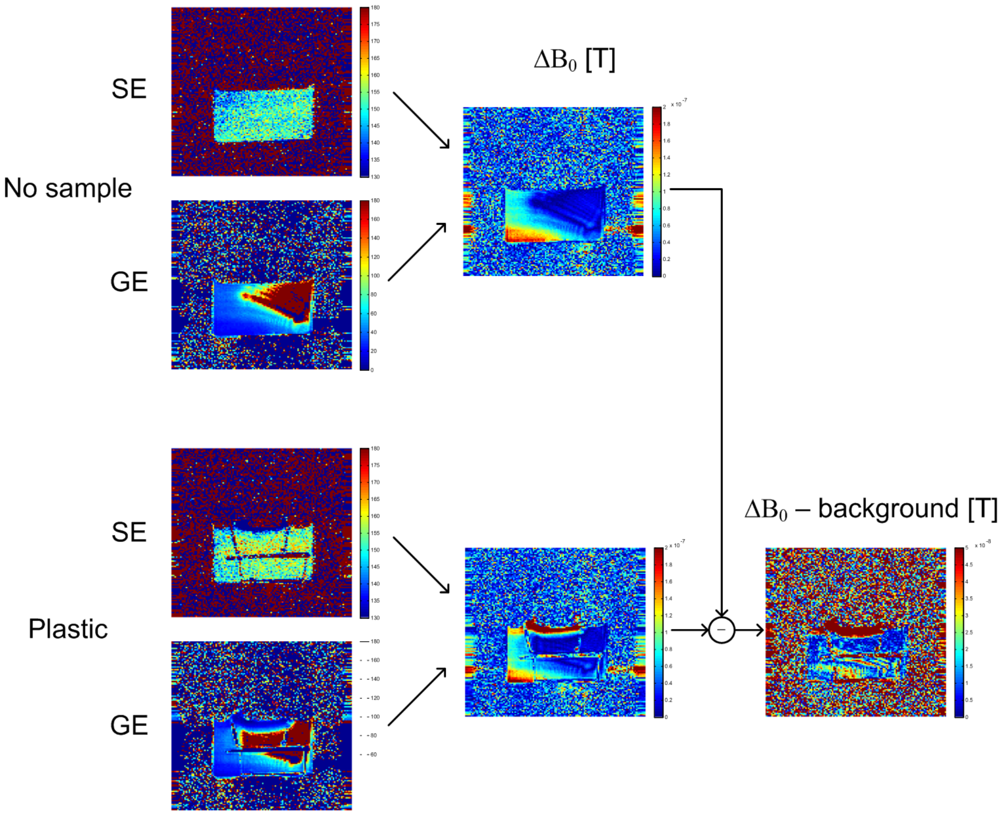

Fig. 3. Maps of the B_0 inhomogeneity estimation, and the final results.

B_1 inhomogeneity estimation

Immediately after excitation, the NMR signal magnitude is proportional to the basic field strength represented by M_{xy} and flip angle α. The magnetization is expressed by:

$$M_{xy}=M_z \cdot \sin(\alpha). \qquad (2)$$

The flip angle is a linear function of the B_1 field strength and length of the excitation pulse t_e:

$$\alpha = \gamma B_1 t_e. \qquad (3)$$

The B_1 inhomogeneity map can be represented by the map of flip angle α. The task is to find M_{xy} in time $t = 0$. The M_{xy} ratio is theoretically the same for both the GE and SE methods. We can use the average M_{xy} of the GE and SE weighted by the exponential approximation accuracy. The B_1 inhomogeneity map for cooper and plastic sample will be presented on poster. Result show that the plastic sample exhibits minimal influence of excitation in the whole space. Conversely, the copper sample has a substantial effect on the RF field; there are regions where the nuclei are over-stimulated or inadequately excited.

The major disadvantage of the proposed method is that we cannot recognize if the flip angle is over or below 90°. For example, the magnitude of the signal after excitation is the same for flip angles of 80°and 100°. That disadvantage can be suppressed by choosing small flip angle to avoid over-excitation.

3. Conclusions

Estimation of the B_0 and B_1 inhomogeneity from relaxation times T_2 and T_2* and initial magnetization after excitation M_{xy} is a useful method. The benefit consists in the fact that there does not have to exist any mutual influence between the inhomogenities. The described approach is limited by two aspects, namely loss of the FID signal magnitude below the noise level in the case of a high inhomogeneity and the fact that we know only the absolute flip angle error. The quality of the B_0 inhomogeneity strongly depends on successful approximation of T_2.

Acknowledgements

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