Real-time control of multiple coils for the generation of gradient and shim fields

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INTRODUCTION

MRI-scanners typically have two independently acting systems to manipulate the B0-field. The gradient system generates linear field profiles for signal encoding. The shim system generates multiple higher order field profiles which are used for homogenizing the main magnetic field.
In this study a novel gradient/shim design is presented, which combines both systems in an advantageous manner. The new design is capable of generating both linear gradient fields for imaging and at the same time high order shim fields. Using an array of individually driven coils, arranged in two planes, allows us to compose a large number of different field profiles by superposing the magnetic fields of the single coils. Therefore each coil has to be driven with an individual current. Using a home-build gradient amplifier capable of switching up to 50 coils simultaneously grants the possibility to switch gradient and shim fields very fast at the same time. The gradient system is combined with the MR console manufactured by "Pure Devices" which allows real-time control of rf-pulses and gradients as well as data acquisition directly out of matlab.

METHODS

In order to show the real-time shimming and imaging capabilities a biplanar system with 50 square coils was simulated and built. Furthermore the novel system was used to correct inhomogeneities in the main field introduced by a tissue. Additionally a spin echo image has been acquired of a sample.
The gradient amplifier is controlled by a by an MR console which allows to control the currents in all coils separately during the measurement. These currents as well as the rf-pulses can be controlled directly from Matlab. Therefore shimming and imaging experiments can be done in real-time. Fieldmaps of a linear gradient as well as a higher field profile were acquired in a whole body system and have been compared with the simulations.
The shimming capabilities have been proved by placing 2 gramm of iron in 5 cm distance to the rf-coil. Multiple magnetic field-orders have been adjusted in order to shim the main magnetic field and correct the induced inhomogeneities. To demonstrate the possibility to switch complex magnetic field profiles fast enough for imaging, a 2D spin echo experiment was performed using the novel biplanar gradient system. For this image the main magnetic field has been homogenized using the real-time shim described before. This shim field was added to the gradient fields used for image encoding.

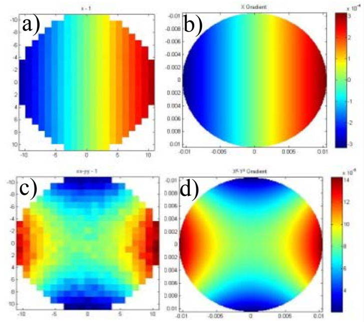

Fig. 1: Measurement (a) and simulation (b) of linear gradient field, exemplarily shown for the x-

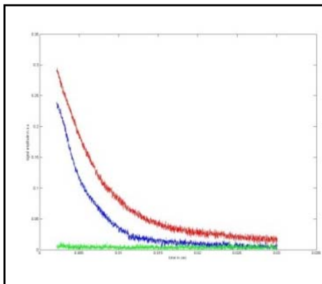

Fig. 2: Free indutcion decay (FID) in an inhomogeneous field created by inserting iron next to the sample (green). FID after linear shimming with the

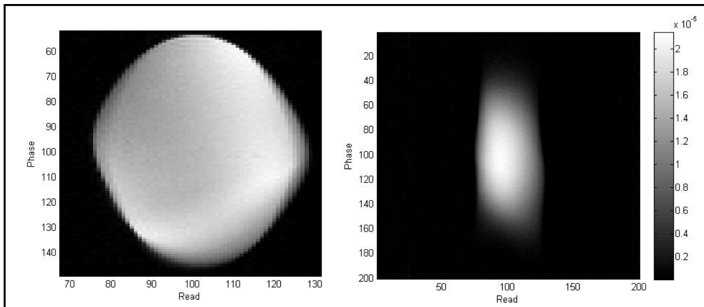

Fig. 3: Image of an oil sample. Transversal (left) and sagittal (right).

RESULTS

Highly linear gradient fields with high amplitude have been simulated and generated with the experimental setup of the 5x5 matrix gradient system. Exemplarily a linear x and a x^2-y^2 gradient is demonstrated here. The strength of the linear x gradient is 30 mT/m/A in simulations and 26 mT/m/A in field mapping experiments. Both field profiles are shown in FIG1(a & b). A deviation of under 0.7% for both x and y as well as the z gradient from a perfect linear gradient field was achieved in the FOV.
The measurement and simulation of the x^2-y^2 gradient is shown in FIG1 (c&d). Strength of 0,92 mT/m/A for the quadratic profile was achieved for x^2 and y^2 directions. The deviation from the perfect quadratic profile stays under 1.2% in the field of view of 20 mm.
FIG2 shows the FID of an oils sample in an inhomogeneous field which was created by placing iron next to the sample. Graph 1 (green) shows the decay of the signal in the inhomogeneous field. T2* is shorter than the dead time of the data acquisition and therefore almost no signal is visible. Graph 2 (blue) is the FID after shimming with only linear field profiles. After shimming with all available orders, Graph 3 (red) has been acquired. Almost all inhomogeneities have been compensated.
A 2D spin echo experiment of a tube filled with oil is shown in FIG3. The slightly disturbed left and right sides of the images results from the fact, that the tube has not been placed perpendicular to the dimensions of the gradients system. Therefor the upper and lower part of the tube protruded from the linear area of the gradient system.

CONCLUSION

The novel design is able to create strong and highly linear gradient fields and at the same time shim fields of multiple orders. Shimming and imaging capabilities have been successfully demonstrated in experiments using the possibility to control the gradient coils in real-time.
Moreover it is possible to build an arbitrary matrix gradient system for almost every given geometry.
Also, the possibility to switch high order shims as fast as linear gradients is advantageous e.g. for individual slice shim in multislice experiments.

REFERENCES

Patent Application DE1020080182656