Genetic Optimization of the Main Magnetic Field B_0 of a Portable Nuclear Magnetic Resonance Device

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Introduction—The resolution and sensitivity of magnetic resonance images strongly depends on the homgeneity and field strength of the primary magnetic field B_0 over the volume of interest (FOV). In clinical tomographs homogeneous fields are produced by solenoid coil windings with high current excitation. Those high currents require active shielding of the stray fields and helium cooling equipment. These solutions are unsuitable for mobile usage because of acquisation costs, maintenance expenses and especially weight. This paper introduces a genetically optimized magnetic circuit for a Mobile Universal Surface Explorer called MOUSE which fulfills the requirements for mobile usage concerning sufficient homogeneity and both lower weight and costs.

Design of the NMR–MOUSE—For mobile usage the essential B_0 flux density can be produced by highly remanent magnets as NdFeB. Figure 1 shows the principle arrangements of rare earth magnets, iron yokes and pole shoes within a portable NMR scanner for B_0–field generation. The homogeneity shall be influenced by the MOUSE' geometrical shape. The basic shape must follow the design of a C–core. In addition to a static B_0–field MRI sensitive samples need excitation by an externally applied high frequency field B_1. By the choice of this C–core geometry and appropriate RF–coils B_0 and B_1 are expected to be always perpendicular to each other. An analytical solution of this field problem is hardly possible. So one must think of an intelligent empirical Finite Element examination of the arrangement. The use of optimization techniques presents itsself. Expanded examinations of really different design sets of the magnetic circuit are only possible by the application of stochastic algorithms instead of simple parameter variations. Those methods allow the generation of the best external shape of the main magnet and the above pole shoe by which the homogeneity of the B_0–field is significantly influenced. The stochastic optimization tool bases on genetic strategies and was implemented with the aid of an object–oriented programming language [1]. The tool has been successfully applied to the dimensioning of planar gradient coil systems for another magnetic resonance device [2]. During the evolution process the genetic algorithm uses more efficiently the provided search domain depending on population diversity and selective pressure. So–called chromosomes present feasible design sets of the MOUSE and are evaluated by the optimizer. The optimization progress depends on the choice of the multi–objective function of the optimization task. The first cost function takes into account the optimization target of the desired field strength $B_0^{desired}$ in relationship to the complete weight of the magnet system (Formula 1). In order to select a thin slice profile (thickness of about 0.5 mm) in direction of the specimen´s penetration depth with a lateral extension of 30 mm the magnetic design must fulfill the second requirement (Formula 2) with a lower limit for the sensitivity (Formula 3).

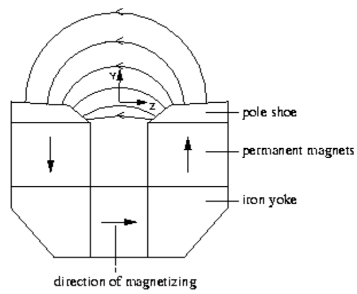

Figure 1. Principle configuration of the mobile surface

$$\varepsilon_1(\underline{x}) = \iiint\limits_{FOV} \left| B_{0_i}^{ANSYS} - B_0^{desired} \right|^2 \cdot W(\underline{x})dV + \frac{w_i^{ANSYS}}{w^{desired}} \qquad (1)$$

$$\frac{G_y(y)}{G_z(z)} \leq 30 \qquad (2) \qquad\qquad \frac{B_0^2(y)}{\sqrt{G_y(y)}} \geq 0.022 \qquad (3)$$

Optimization results—A selection of different MOUSE shapes during the optimization from the 1st to the 50th iteration is shown in figure 2 below. The last geometry fits the desired requirements of a mobile NMR surface scanner at best.

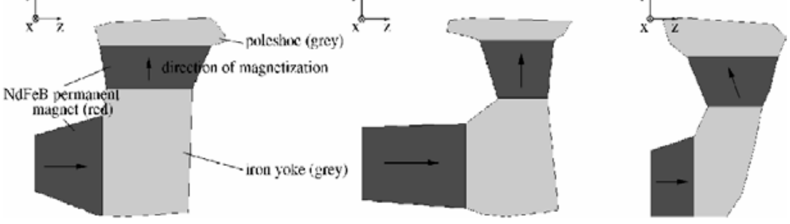

Figure 2. Finite Element models of the genetically MOUSE shape after the 1st, 25th and 50th iteration step

[1] H. Popella, Genetic Algorithms for Two–dimensional Design Optimization of a Magnetic Resonance Device, International Journal of Applied Electromagnetics and Mechanics, Vol. 15, pp. 219–223, 2001.
[2] H. Popella, Optimal Gradient Coil Design of a Planar Gradient Coil System for a Mobile Magnetic Resonance Device, Proceedings of the 43th Experimental Nuclear Magnetic Resonance Conference, 2002.