APPRAOCH TO DESIGN AN EFFICIENT RESISTIVE MAGNET FOR MRI

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Introduction
One of the ways to obtain a low cost whole body Magnetic Resonance Imaging (MRI) machine is to use a resistive magnet as a main magnetic field generator. For a good magnet design, not only homogeneity and stability of magnetic field are needed. Other requirements like high efficiency, low cost, low resistive losses, compactness, good access to the Region of Interest (ROI) must be taken into account. In 1992, Pissaneztsky defined a current density as a function of coordinates and divided the possible solutions region in many small identical coils elements [1]. The procedure, applied for superconductor magnets designs, produces low efficiency configurations. In the objective function only the field homogeneity is optimized. H. Xu et. al presented an elegant method where the optimum number of coils is selected automatically from the constraints and the applied algorithm [2]. However, when the current density is a given constraint, as in our case, it is very complicated to satisfy the necessary current density to reproduce the target field. For this reason the purpose of this paper is: 1- to describe a new alternative method to design low cost and efficient whole body resistive magnet for MRI; 2- to obtain an efficient low field resistive magnet for a MRI machine.

Methods
The method assumes K coil elements with axial and radial dimensions located over cylindrical surface of radius IR. The axial position (zj), external radius (ERj), number of radial turns (Nj), operating current value (I) and the current density Jj(Nj)=I/Nj define the j coil element. The parameter b is the element width and IR is the inner radius that defines the bore size. Assuming the figure of merit as: 
indicator the problem can be stated as maximizing \( \Gamma_j \) through Linear Programming optimization as: 
\[
\min \gamma \frac{R_j}{I} \cdot N_j \quad \text{Such that: } \frac{1}{\gamma} \sum_j B_{j_0} \cdot J_j(N_j) \leq B_0(1-\varepsilon), \quad 0 \leq N_j \leq N_{\max}
\]
Where \( W_j \) is the power dissipated by the jth coil element, \( B_0 \) is the desired field in the ROI, \( \Gamma = Ij \) (number or target points), \( N_{\max} \) is an upper bound constraint that defines the maximal number of radial turns for all elements, \( B_{j_0} \) is the magnetic field produced at the target point \( t \) by the coil element \( j \), \( R_i \) is the coil element resistance and \( \varepsilon \) could be between 1 and 10 ppm [2]. The upper constraint defines the current density to be the same value for all coils. The lower bound constraint avoids negative ampere-turns in the magnet. The target points \( t \) are specified along a quarter of circle of radius \( c \) (radius of ROI). The procedure is a closed loop that finishes when the difference between the actual and the last current density is less than a predefined convergence error. In each iteration the current density is actualized and constrained to the same given value in all coils. In the process an efficient numerical optimization algorithm is introduced in order to find the optimal axial position of all magnet to fulfill the problem constraints. When the main process finish the \( J_1 \) value is rounded in order to become the solution in a practical magnet. Then, the axial and radial positions of each coil are calculated through optimization algorithm to improve the field homogeneity.

Results and Discussion
When the procedure is called an interesting phenomenon is produced. In certain regions, the same values of current density are clustered, forming the coils of the magnet; other regions with zero current are created forming empty spaces. Varying the \( \Gamma_j \) and \( 2L/H \) relation that defines the optimal magnet length given the coil height is obtained. Both parameters, determine the field homogeneity and optimal coil’s clusterization. See fig. 1 (a). The linear relation was obtained assuming \( B_0=0.1088 \) T, \( c=0.2 \) m, \( \varepsilon=5 \) ppm, \( lR=0.4 \) m and operation current of 125 A. The coil element dimension was equivalent to a copper wire of 25 mm × 3.15 mm. The fig.1 (b) shows a quarter of cross section of the magnet obtained with our method taking into account the obtained linear relation. The peak-peak uniformity over ROI was 10.71 ppm, with an efficiency of 8.7·10⁻⁴ T/A, a dissipated power of 13.2 kW and a mass of 2.8 tons. Our last design [3] needs 1.11 more conductor and dissipates 1.2 kW more than the new design. The new magnet is 1.1 times more efficient than our last four coil low field resistive magnet [3].

Conclusions
A new automatic methodology to design efficient and low cost whole body resistive magnet have been presented. The method has been applied to design a low field resistive magnet. The procedure produces irregular shape coils. These are more efficient than traditional rectangular shape coils. The procedure produces the same current density in all coils.