Self-shielded open superconducting magnet design

F. Bertora[1], E. Molinari[1], and A. Viale[1]
[1]Brain Machine Interface, Italian Institute of Technology, GENOVA, GE, Italy

Introduction

Permanent magnet design for MRI has always followed lines that are forcedly different from those employed in designs using superconductors[1][2][3][4][5] yet, from a basic point of view, the physical principles are the same and a block of permanently magnetized material can be considered as the epitome of ambient temperature superconductivity[6][7].
When confronted with the problem of designing an open scanner for functional imaging the techniques successfully employed in designing permanent magnets can advantageously be applied to superconductive windings, particularly now that emerging materials such as $MgBr_2$ afford with relative ease the construction of cryogen-free devices. In fact in the case of superconducting windings an additional degree of freedom is gained from being able to choose any desired value for the remanence.

Method

The goal of the design is a self-shielded, wide access, U-shaped magnet employing a commercial $MgBr_2$ conductor. The overall structure is shown in the figure and follows the basic principles of a yokeless permanent magnet design[6][7]. The degree of freedom gained from relaxing the condition of a unique value of the remanence $\boldsymbol{J}$ can be exploited with the additional constraint of minimal conductor length while enforcing the coil axes to be orthogonal to the interfaces (to simplify manufacturing). Once the value and the orientation of the field in the magnet cavity and the first interface τ_0 have been chosen, the number and the orientation of the following interfaces, along with the resulting Ampere-turns values can be determined by enforcing the continuity conditions on the normal and tangential components of $\boldsymbol{B}$ and $\boldsymbol{H}$ as well as the orientation of the remanence $\boldsymbol{J}$. This gives rise to five equations at each interface that, combined with the field containment constraint (orthogonality of $\boldsymbol{B}$ and $\boldsymbol{H}$) are sufficient to determine the unknown values of $\boldsymbol{J}$,$\boldsymbol{B}$ and $\boldsymbol{H}$ beyond the interface. The last condition, stated completely in terms of the unknowns, results in a non linear equation but the solution can be easily found by means of a singular value decomposition, initially neglecting the non linear equation. It is then the matter to add to the minimum length solution thus obtained the appropriate component of null space to satisfy the final equation and obtain the desired values. The design problem is now reduced to the choice of the orientation of the interfaces that minimizes the amount of conductor employed and, given the limited number of interfaces, the problem can be solved by brute force optimization.

Conclusion

A method for the design of unconventional self shielded, open magnets for MRI imaging has been presented. It derives from the techniques employed in the design of permanent magnets and leverages on the additional degrees of freedom given by the arbitrary choice of the remanence. A strategy has been outlined for the optimization of the design in terms of conductor usage and manufacturing convenience, although the same principles could be applied to other optimization criteria.

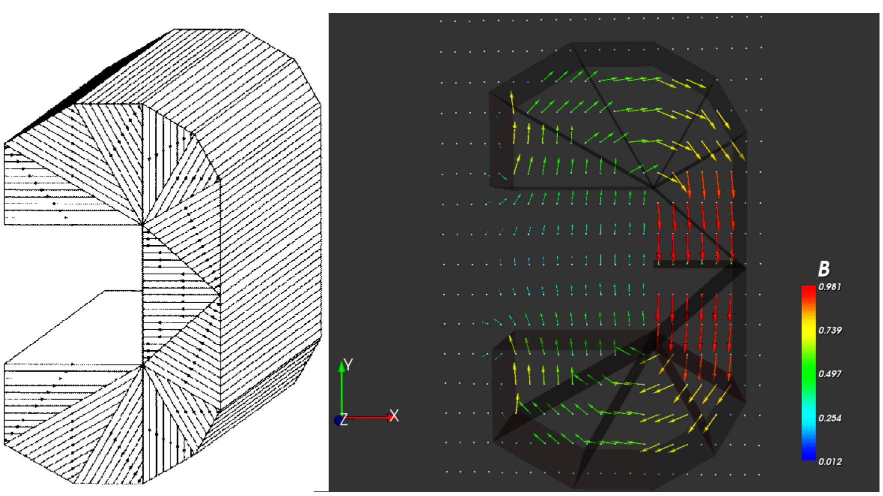

Figure 1 – Magnet schematic and field diagram showing the good field containment within the structure.

References

[1] M.Abele – *Structures of Permanent Magnets: generation of uniform fields.* New York: John Wiley & Sons, 1993.
[2] M. Abele, J, Jensen and H. Rusinek – "Generation of uniform high fields with magnetized wedges", *IEEE Transactions On Magnetics*, vol. 33 pp. 3874-3876 Sept 1997.
[3] J. Jensen and M. Abele – "Maximally efficient permanent magnet structures", *Journal of Applied Physics*, vol. 79, no. 2 pp. 1157-1163, 1996.
[4] A. Podol'skii – Design procedure for permanent magnet assemblies with uniform magnetic fields for MRI devices", *IEEE Transactions on Magnetics*, vol. 36, pp. 484-490, march 2000.
[5] Y. Yao, Y Fang, C.S. Koh and G. Ni – "A new design method for completely open architecture permanent magnet for MRI", *IEEE Transactions on Magnetics*, vol. 41, pp. 1504-1507, May 2005.
[6] M. Abele – "Equivalent structures of permanent magnets and electric currents designed to generate uniform fields", *Journal of Applied Physics*, vol. 75, pp. 6993-6995, May 1994.
[7] M. Abele – "Generation and confinement of uniform magnetic fields with surface currents", *IEEE Transactions on Magnetics*, vol. 41, pp. 4179-4181, Oct 2005.