Feasibility Study of Hybrid Magnetic Cloak for Accelerator Magnets

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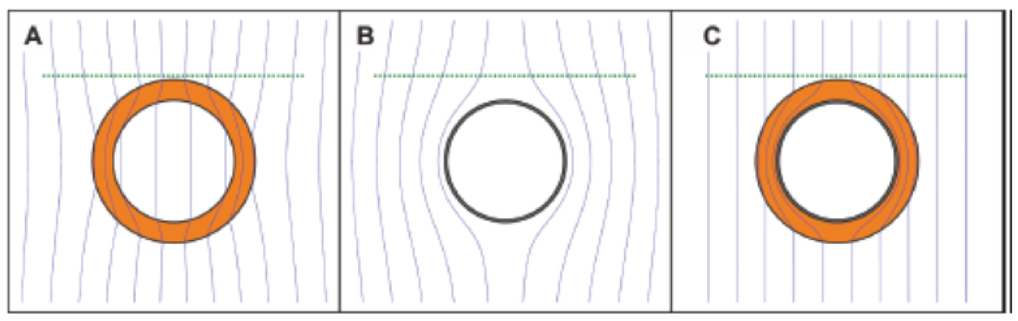
Abstract

It is well known that superconducting (SC) materials repel magnetic field, whereas paramagnetic ones concentrate flux lines in their interior. By using concentric tubes of the two materials, the magnetic field inside a cylinder is canceled without modifying the external applied field. Analytical solutions exist, which provide a relation between the thickness of the paramagnetic material and the relative permeability necessary for a complete cloaking. In this paper we perform a feasibility study on whether this concept works to shield large magnetic fields, by using bulk MgB_2 superconductor prepared by the Reactive Liquid Infiltration (RLI) in-situ process. With conventional ovens, it is possible to produce large superconducting bulk pieces using this patented technology. A number of paramagnetic materials will be searched for, and their magnetic permeability measured. Tube junctions will be studied, as well as effects of tube ends, geometry and flux jumps. A successful hybrid cloak would find immediate application at FNAL in the Muon g-2 experiment, which presently relies on a SC inflector magnet to cancel the 1.5 Tesla storage ring field seen by the muon beam at injection.

Magnetic Field Cloaking

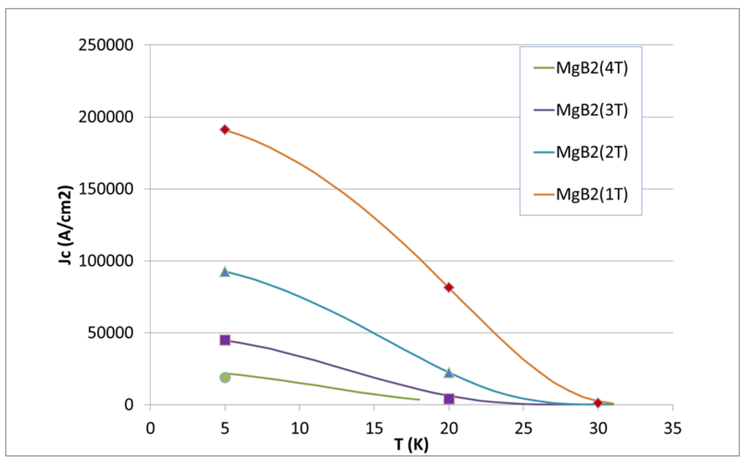
It is well known that superconducting materials repel the magnetic field (Figure B), and on the contrary, ferromagnetic and paramagnetic materials concentrate in their interior the flux lines (Figure A). Both materials, taken separately, modify the behavior of the flux lines in their vicinity, according to the Maxwell equations. But an appropriate combination of the two materials is able to cancel the magnetic field inside a cylinder without modifying the external applied field (cloaking effect, as in Figure C). A recent paper on this subject illustrates clearly the simple example of a circular geometry, which can be solved analytically [ref], providing a relation between the thickness of the paramagnetic material and its relative permeability which allows a complete cloaking.



[ref] F. Gomory et al. “Experimental Realization of a Magnetic Cloak” Science 335, 1466 (2012)

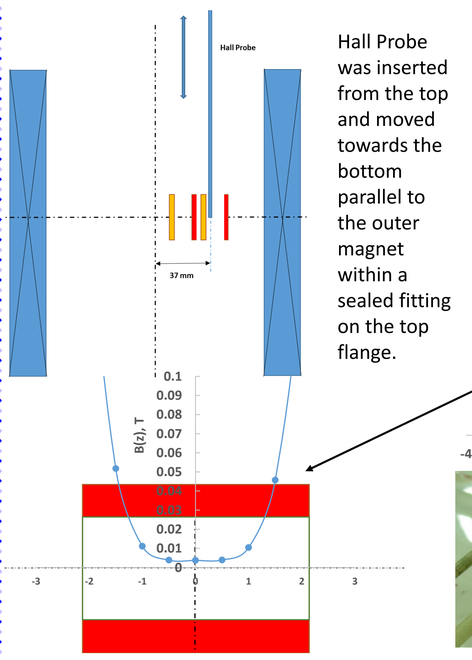
MgB2 Shielding Capability

MgB_2 superconductor, prepared by the Reactive Liquid Infiltration (RLI) process [ref], reaches very high density, 90% of the theoretical value (2.63 g/cm3), without the need of using Hot Pressing apparatuses. Therefore, using conventional ovens, it is possible to produce large superconducting pieces, and their critical current density is high enough to shield magnetic fields of the order of several Tesla. Typical values of $J_c(B,T)$ are given for MgB_2-RLI below.The values are measured via magnetization cycles at different temperatures on a small (few mm’s) sample.

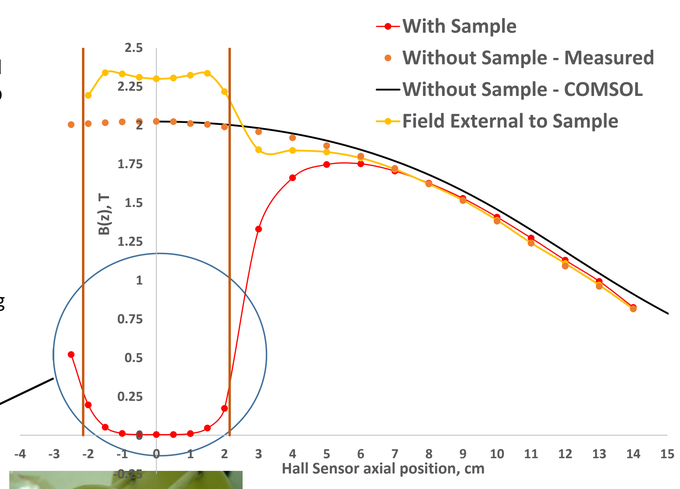


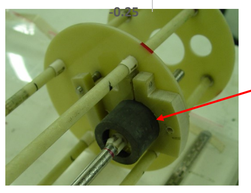
[ref] G. Giunchi “High density MgB2 obtained by reactive liquid Mg infiltration” International Journal of Modern Physics B17, Nos. 4, 5 &6 (Mar 2003) 453-460

Hall Sensor Measurements (1)



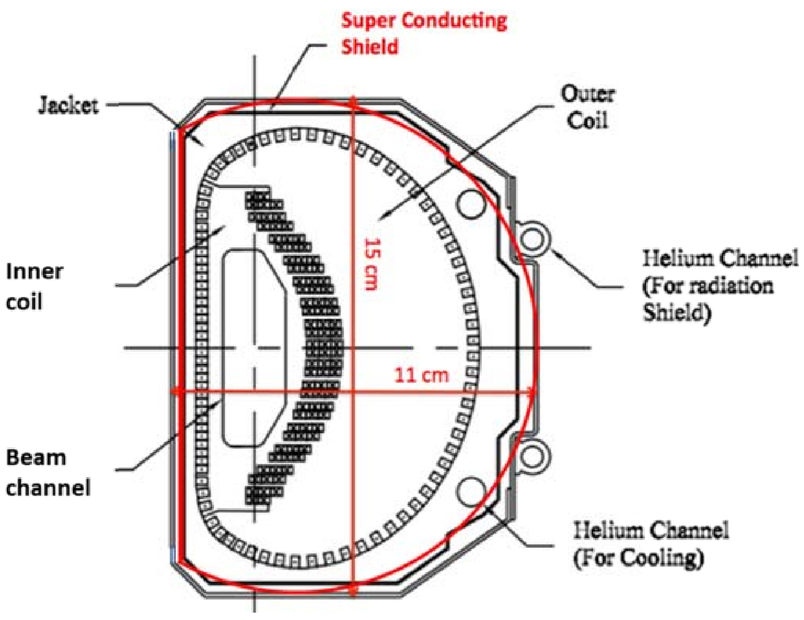
Hall Probe was inserted from the top and moved towards the bottom parallel to the outer magnet within a sealed fitting on the top flange.

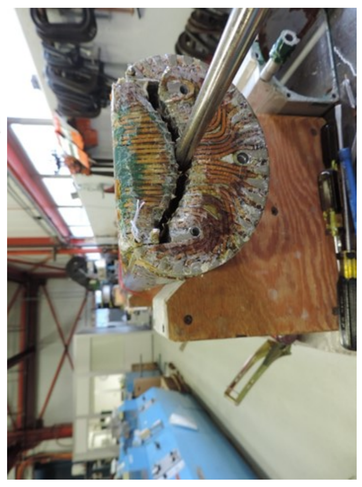




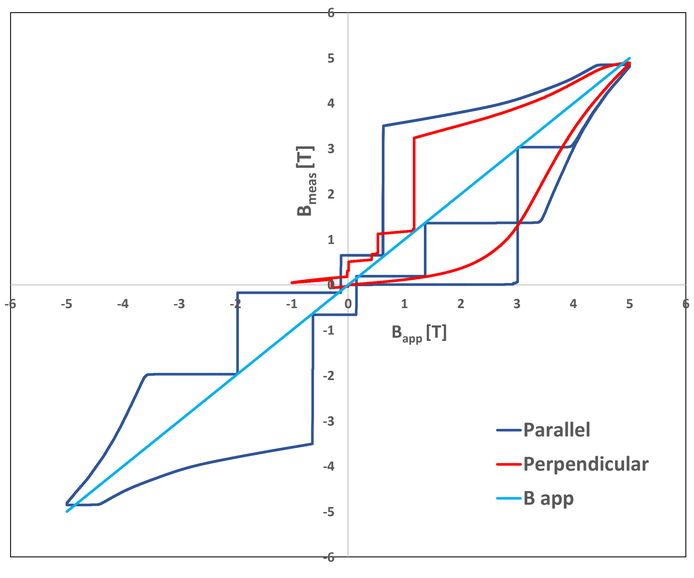
Sample Size
OD/ID=40.3 mm/25.5 mm; H=42.5mm

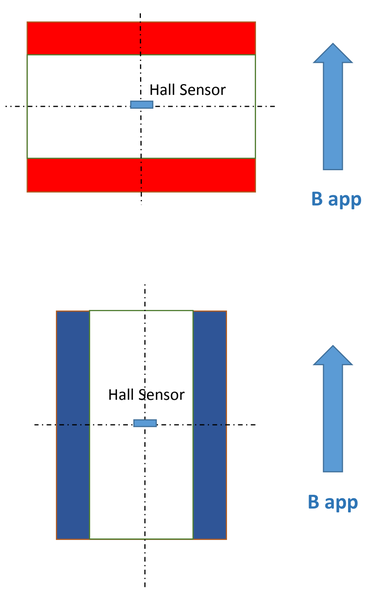
Muon g-2 Inflector Cross Section





Hall Sensor Measurements (2)





Summary

STUDY	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A - Non SC junctions	■	■	■	■					
B - SC junctions				■	■	■	■		
C - End effects		■	■	■	■				
D - Flux jumps	■	■	■	■					
E - Permeability				■	■	■	■		
F - Geometry				■	■	■	■		
G – Mechanical properties		■	■	■	■	■	■		
H - Short 0.4 m model						■	■	■	■