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Superconducting and hybrid systems for magnetic field shielding

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Abstract

In this paper we investigate and compare the shielding properties of superconducting and hybrid superconducting/ferromagnetic systems, consisting of cylindrical cups with an aspect ratio of height/radius close to unity. First, we reproduced, by finite-element calculations, the induction magnetic field values measured along the symmetry axis in a superconducting (MgB_2) and in a hybrid configuration (MgB_2/Fe) as a function of the applied magnetic field and of the position. The calculations are carried out using the vector potential formalism, taking into account simultaneously the non-linear properties of both the superconducting and the ferromagnetic material. On the basis of the good agreement between the experimental and the computed data we apply the same model to study the influence of the geometric parameters of the ferromagnetic cup as well as of the thickness of the lateral gap between the two cups on the shielding properties of the superconducting cup. The results show that in the considered non-ideal geometry, where the edge effect in the flux penetration cannot be disregarded, the superconducting shield is always the most efficient solution at low magnetic fields. However, a partial recovery of the shielding capability of the hybrid configuration occurs if a mismatch in the open edges of the two cups is considered. In contrast, at high magnetic fields the hybrid configurations are always the most effective. In particular, the highest shielding factor was found for solutions with the ferromagnetic cup protruding over the superconducting one.

Keywords: magnetic shielding, superconducting/ferromagnetic composites, MgB_2

(Some figures may appear in colour only in the online journal)

1. Introduction

Shielding of magnetic fields is crucial for several applications requiring an ultralow magnetic field environment (e.g. biomedical applications) or the mitigation of the magnetic field produced by an electronic device in order to guarantee the electromagnetic compatibility with the surrounding environment or to reduce the electromagnetic signature of the devices (e.g. electromagnetic compatibility between different equipment or military applications).

Due to their electromagnetic properties, superconducting (SC) and ferromagnetic (FM) materials are natural candidates for passive magnetic shields in the low-frequency field range. Among superconductors, both low-temperature superconductors [1, 2], high-temperature SC cuprates [3, 4] and MgB_2 [5, 6] have been successfully employed in passive shields. Moreover, in the last decade, investigations on the combined use of SC and FM materials in passive shielding have led to promising experimental results [6–11] including the cloaking of dc and ac magnetic fields [12–14].

In addition, the parallel development of numerical codes allowed complex problems to be addressed, such as the distribution of the current density and of the induction magnetic field inside superconductors of several geometries [15–18], even in the presence of other materials with non-linear magnetic properties, such as ferromagnets [14, 19–21].

