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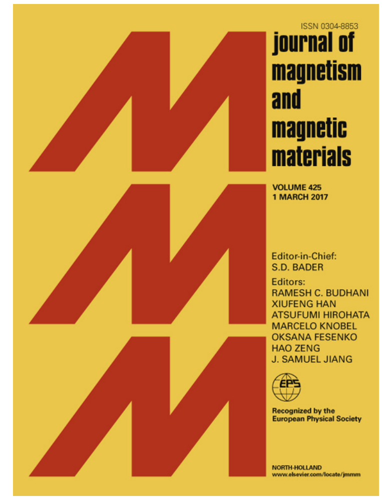

Research articles

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Topology optimization of magnetic source distributions for diamagnetic and superconducting levitation

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Abstract

Topology optimization is used to obtain a magnetic source distribution providing levitation of a diamagnetic body or type I superconductor with maximized thrust force. We show that this technique identifies non-trivial source distributions and may be useful to design devices based on non-contact magnetic suspension and other magnetic devices, such as micro-magneto-mechanical devices, high field magnets etc. Diamagnetic and superconducting suspensions are often used in physical experiments; we believe that topology optimization approach will be interesting to physics community as it may generate non-trivial and often unexpected topologies and may be useful to create new experiments and devices.

1. Introduction

Levitation and applications

In non-contact suspensions a solid body is held in space without mechanical contact to a support due to the body's force interaction with electromagnetic field. The absence of mechanical contact minimizes friction, wear, and energy dissipation, motivating use of non-contact suspensions in a number of applications including motion guidance, sensors, energy storage, and creating extreme environments.

Most attractive for applications are passive suspensions, where a body is suspended stably in static magnetic field. Such suspensions are very simple and reliable due to the absence of a control system and may not require energy supply if permanent or superconducting magnets are used to generate the magnetic field, which is especially appealing for applications where energy conservation is critical. According to the Earnshaw-Braunbeck theorem[1-3] stable levitation in a static magnetic field is only possible when diamagnetic materials are present in the system, either on levitated body or on the support. A diamagnetic (or superconducting) body placed in a magnetic field is pushed to a region with weaker field. The energy is determined as square of the magnetic field magnitude and the force is defined by the product of magnetic field and its gradient. Stability of equilibrium can be achieved with the presence of a magnetic potential well within the spatial magnetic field distribution [4-5]. It is possible to create isolated minimum of magnetic field magnitude for certain configurations of sources. With the development of new powerful magnets capable of generating magnetic fields greater than 10T, it became possible to suspend weakly diamagnetic materials, which in turn has garnered significant interest in magnetic levitation over the past few decades [16-18].

Levitation of a diamagnetic body was predicted by Thomson (Lord Kelvin)[6] and experimentally realized by Braunbeck[7] with an electromagnet, followed by Boerdijk using a permanent magnet[8,9]. Historical development of diamagnetic levitation and applications may be found in review articles[10,11].

Upon discovery of superconductivity, Arkadiev in 1946[12] demonstrated a superconducting levitation. Type I superconductors may be treated as ideal diamagnetics due to the Meissner effect. Various aspects of superconducting levitation are discussed (for example) in [13-15].

The concept of magnetic suspension is naturally appealing and a number of applications have been proposed, including use in accelerometers[19,20], flywheels[21,22], energy harvesters[23,24], and motors[25], and for achieving vibration isolation [26,27], precision positioning[28], manipulation of biological objects [29,30], self-assembly of electronic components[31,32], and separation of micro-objects[33,34]. It has also been proposed for simulating special environments, such as low gravity[35-37]. Devices on non-contact suspensions are most attractive in situations where energy conservation is critical[14], such as aerospace and space systems.