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Optimization of Magnetic Field Residual and Gradient in Permalloy-Ferrite Shielding System for SERF Magnetometer Based on Electro-Thermal Demagnetization

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Abstract—Soft magnetic materials, characterized by high magnetic permeability, are typically utilized in the magnetic shields. Among these, a composite shielding system comprising outer layer Permalloy and inner layer manganese-zinc (Mn-Zn) ferrite has demonstrated exceptional performance in providing an extremely-low magnetic interference environment for spin-exchange relaxation-free (SERF) magnetometers, owing to its synergistic combination of high shielding efficiency and low magnetic noise. This magnetic shielding system gets magnetized over time and during disassembly and assembly, and needs to be demagnetized regularly. To minimize the magnetic field residual and gradient introduced by magnetic shielding system, and further improve the sensitivity of the magnetometer, alternating current (AC) electric demagnetization method is commonly employed to achieve effective degaussing. However, compared to permalloy, large-scale ferrite shields have higher coercivity, electric demagnetization methods are not effective enough, limiting the application in large electromagnetic shielding systems and high-precision instruments. Therefore, electro-thermal demagnetization method is proposed. Thermal demagnetization is used for ferrite, while multi-layer permalloy continues to use electric demagnetization. A double-layer counter-wound non-magnetic heating film to heat the ferrites is designed to suppress the magnetic field introduced by itself. The effectiveness of the method is verified through theoretical modeling, simulation analysis and experiments. Parameter optimization is also conducted. The results indicate that, within ±15 mm of the center, the electro-thermal demagnetization reduces the residual magnetic field to below 0.2 nT with a gradient less than 0.015 nT/cm (radial) and below 0.05 nT with a gradient less than 0.013 nT/cm (axial). Compared to the traditional electric demagnetization method, the residual magnetic field and its gradient of electro-thermal demagnetization are reduced more than 5 and 10 times respectively. This article supports the application of large-scale Permalloy-ferrite magnetic shields for measurement instruments especially in atomic magnetometers and in cutting-edge physics research.
Key Words —Electro-thermal demagnetization, Ferrite, Magnetic shielding, Permalloy, SERF magnetometer

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