

The simulated evaluation of remanence in MSR for degaussing situation

Di Zhang¹, Minxia Shi^{1,*}, Yuzheng Ma¹, Leran Zhang¹, Shuai Yuan¹

¹ Key Laboratory of Ultra-Weak Magnetic Field Measurement Technology, Ministry of Education, School of Instrumentation and Optoelectronic Engineering, Beihang University, Beijing 100191, China

* Corresponding author: Minxia Shi (Email: shiminxia@buaa.edu.cn)

The permalloy sheet, acting as the dominant shielding material, mainly determines static and low frequency shielding performance of magnetically shielded room (MSR). However, the lack of precise measurement and corresponding hysteresis model of shielding sheet around geomagnetic field would lead to the nonnegligible evaluation error for MSR performance. The demagnetization process brings the material to the anhysteretic state, which reduces the residual magnetic field inside MSR. Therefore, this paper proposes an estimation technique for the remanence that considers the nonlinear magnetic characteristics of the permalloy sheet, evaluated using a single sheet tester (SST) under degaussing situation.

Index Terms—MSR, Demagnetization, Permalloy Sheet, SST

I. INTRODUCTION

A nearly zero magnetic field environment is a prerequisite for the high-sensitive performance of atomic sensors. MSR, which is made of high permeability ferromagnetic walls and reduce the external electromagnetic field interference by flux shunt effect, can provide the magnetic environment with low residual field and field gradient for the study and calibration of atomic sensors [1]. The remanence inside the permalloy walls should be eliminated by a decaying alternating magnetic field to achieve the low spatial residual magnetic field inside MSR, which is called demagnetization [2].

The demagnetization of the permalloy is to reduce the residual magnetic field in shielding walls by guiding the magnetic moments in random spatial orientations. However, the magnetic properties are evaluated using a toroidal permalloy sample [3], which can be affected by various physical factors, such as mechanical stress from electric wire cutting, and variations in heat treatment temperature across batches. Therefore, the measurement method should be optimized for the quicker and more indicative test of magnetic properties of the permalloy sheet for practical application in MSR under degaussing excitation.

In this paper, an optimized method for measuring the magnetic properties of the permalloy sheet under demagnetization for application in MSR is proposed, and the corresponding analysis and application methods of the tested results are discussed. The anhysteretic magnetic (AM) curve is measured and fitted by Jiles-Atherton model. The remanence distribution inside the scaled-down MSR is deeply analyzed by combing the AM and FEM simulation.

II. MEASUREMENT SYSTEM FOR PERMALLOY SHEET MAGNETIC PROPERTIES

Fig. 1 shows the SST sketch for exciting and testing the magnetic field inside the permalloy sheet. The device consists of two spatial-parallel C-shape yokes and two multilayer exciting coils around the corresponding parallel magnetic cores.

The pending tested permalloy sheet sample is placed between the two yokes, with the magnetic flux through the sample (B_{sample}) oriented in the opposite direction to that through the yoke (B_{yoke}), thereby generating a relatively uniform and strong magnetic field at the center of the sample.

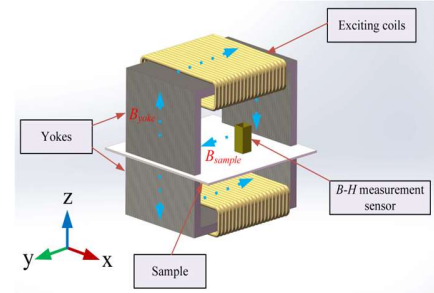


Fig. 1. The SST structure.

The prototype of the proposed feedback control system is shown in Fig. 2, which consists of a multifunction I/O device, a power amplifier, SST and a preamplifier. The approximate sinusoidal excitation from I/O device is amplified by the power amplifier and applied to the exciting coils of the SST. The signal from the B - H measuring sensor is amplified and filtered by the preamplifier and then send back to I/O device.

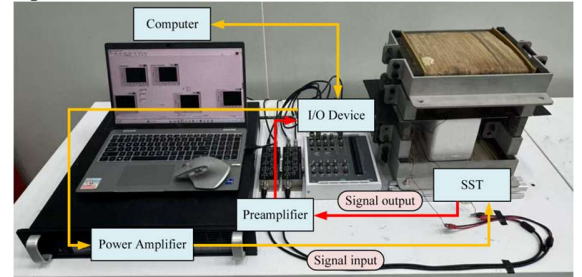


Fig. 2. The prototype of the proposed feedback control system.

AM curve can characterize the magnetization state of MSR in practical application. The detailed test flow is divided into four steps: Step 1: Demagnetize the sample sheet and test the hysteresis loop at a 0.1 Hz magnetic field, recording the saturated flux B_s , the corresponding H_s , and the exciting current peak value I_s ; Step 2: Demagnetize the sample sheet at a 1 Hz

magnetic field with the DC bias field I_{dc} , and apply an AC field with the frequency of 0.1 Hz and peak value of I_{ac} combined with a DC-biased field I_{dc} , where $I_{ac} = I_s - I_{dc}$; Step 3: Integrate the induced voltage V_{test} to obtain the maximum value of the integration B_m , and calculate the anhysteretic parameters B_{an} and H_{an} , where $B_{an} = B_s - B_m$, $H_{an} = \frac{I_{dc}}{I_s} H_s$; Step 4: Repeat Step 2 and

Step 3, when I_{dc} ranges from 0 to I_s , and output the AM curve.

The induced voltage V_{test} of B coil during the AM curve test procedure is shown in Fig. 3. A degaussing excitation is operated to the SST and the sheet is drove to the anhysteretic state. The 0.1 Hz AC field I_{ac} with a DC-biased field I_{dc} is applied to the sample sheet. The difference of the induced voltage peak ΔV_{test} with and without V_{dc} indicates the various point of AM curve and distinct anhysteretic state.

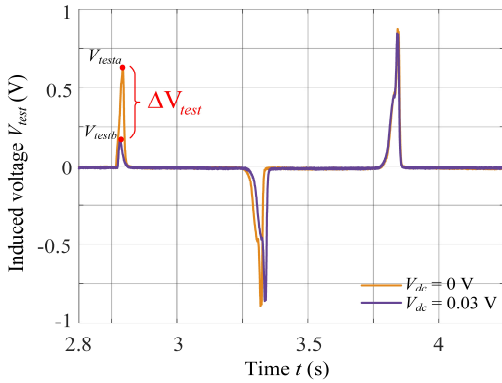


Fig. 3. The AM curve measurement method.

III. THE SIMULATION AND APPLICATION OF AM CURVE

In dynamic Jiles-Atherton model, the magnetization is divided into two parts: the irreversible component M_{irr} and the reversible component M_{rev} . M_{irr} corresponds to the magnetostatic energy plus the dissipated loss due to pinning sites. A quadratic related to M and M_{an} is derived as:

$$\left(\frac{\mu_0 d^2}{2\rho\beta} \frac{dH}{dt} \right) \left(\frac{dM}{dH} \right)^2 + \left[k\delta - \alpha \left(M_{an} - M + k\delta c \frac{dM_{an}}{dH_e} \right) \right] \frac{dM}{dt} - \left(M_{an} - M + k\delta c \frac{dM_{an}}{dH_e} \right) = 0 \quad (1)$$

The five parameters (M_s , α , a , c , k) of the dynamic Jiles-Atherton model is pending fitted based on the tested AM curve for the simulation of B - H relationship under various exciting conditions. The optimal parameters are shown in Table I.

TABLE I
THE OPTIMAL PARAMETERS OF THE DYNAMIC J-A MODEL

Parameter	M_s	a	c	k	α
Value	5.775×10^5 A/m	14.500 A/m	0.280	9.305 A/m	6.841×10^5

The corresponding calculated AM and basic magnetic (BM) curves are compared with the measured ones, as illustrated in Fig. 4. The calculated results are applied to the

prediction and simulation of B - H behavior under unmeasured magnetic field.

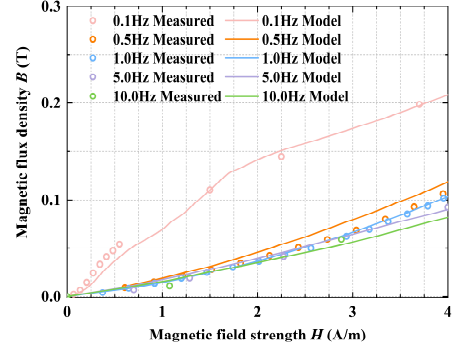


Fig. 4. The comparison of tested and calculated AM and BM curves.

To apply the measured degaussing data to FEM calculation, the AM curve is introduced into COMSOL software for calculating the magnetic field distribution of a scaled-down MSR model, and the scaled-down MSR is shown in Fig. 5.

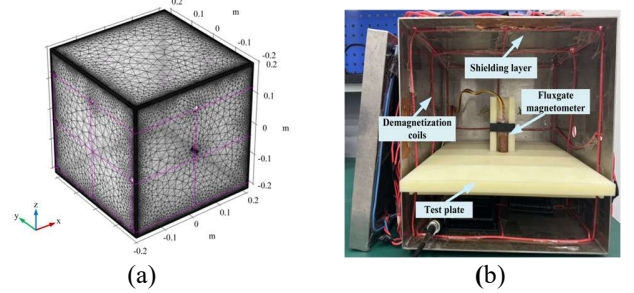


Fig. 5. Scaled-down MSR. (a) 3-D model and (b) prototype.

The normalized residual magnetic field of different heights are calculated based on the FEM algorithm combined with AM curve and compared with the measured ones, as shown in Fig. 6. It is found that the relative error of the studied points is less than 10%, which indicates that the distribution of the computed remanence of SST method in the center region of MSR model suitably matches that of the tested distribution.

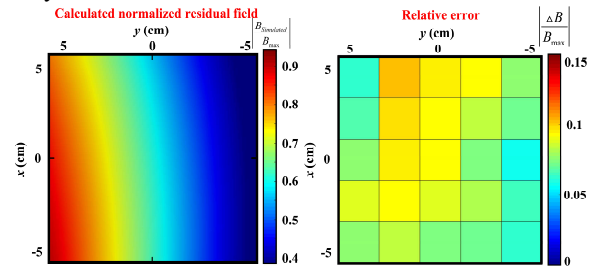


Fig. 6. The calculated normalized residual magnetic field distribution based on SST method and the relative calculated error.

REFERENCES

- [1] M. Shi, L. Zhang, X. Zhang, et al, "A Novel Magnetic Suppression Technique for Asymmetric-Distributed Magnetic Disturbance in CMS for MCG Test," *IEEE Trans. Instrum. Meas.*, vol. 74, pp.1-10, 2025.
- [2] F. Thiel, A. Schnabel, S. Knappe-Grüneberg, et al, "Proposal of a demagnetization function," *IEEE Trans. Mag.*, vol. 43, no.6, pp.2959-2961, 2007.
- [3] L. Li, Z. Sun, D. Pan, et al, "An approach to analyzing magnetically shielded room comprising discontinuous layers considering permeability in low magnetic field," *IEEE Trans. Mag.*, vol. 50, no.11, pp. 1-4, 2014.