

An Improved Pulse Magnetic Field Method for Measuring Permanent Magnet Materials with Field Shaper

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The precise measurement of permanent magnet (PM) materials' performance is crucial for related electrical equipment design. Currently, high-coercivity PM materials' demagnetization curves are mainly measured by pulse magnetic field (PMF) method. However, with PM materials' development, their coercivity rises and requires more discharge energy. The large discharge energy affects coil's force and temperature, influencing its lifespan. To address these, an improved PMF method with a field shaper is proposed. The field shaper concentrates the magnetic field in the sample area, reducing discharge energy and keeping the sample's field strength. A new pickup coil is also proposed to calculate H , J and B via two built-in coils. The experimental results demonstrate that this method can enhance the magnetic field intensity by 34% under the same discharge voltage, thereby expanding the testing range of the device and enabling precise measurement of the demagnetization curve of the sample.

Index Terms—Permanent magnet materials, Measurement, Pulsed magnetic field, Field shaper, Pickup coil

I. INTRODUCTION

Permanent magnet(PM) materials, renowned for their high residual magnetic induction, coercivity, maximum magnetic energy product and extensive hysteresis curve, have been widely used in industries like automotive and aerospace. The correct measurement of permanent magnet materials is a prerequisite for designing these electrical equipment.

The magnetic measurement of the permanent magnet(PM) materials is commonly carried out by the closed-circuit electromagnet method[1], which usually generates a maximum magnetic field strength of 1950kA/m($H_{\max}=1950\text{kA/m}$). As permanent magnet materials evolve, The NdFeB N38EH grades now boast coercivities exceeding 2500kA/m, which is larger than the $H_{\max}$. The vibrating sample magnetometers (VSM) method can measure the ultra-high coercivity of PMs. However, the VSM method has high requirements for sample size, which is inconvenient for measurement.

Some scholars have proposed the pulsed magnetic field (PMF) method to measure the coercivity of PM materials[2]. The method involves passing a pulsed high current through a capacitor into the pulsed magnet coil over a short period to generate a sufficient pulsed magnetic field for measuring the demagnetization curve of a permanent magnet[3]. With the advancement of permanent magnet materials, their coercivity will increase, necessitating a higher current to be passed through the pulsed magnet coil, typically ranging from several kA to tens of kA. The increase in current also implies a greater demand for energy. Furthermore, the increase in current will make the coil's operating conditions more extreme, with risks of overheating, force-induced expansion, and even rupture, significantly affecting the coil's service life[4].

This paper proposes an improved PMF method with a field shaper to address the aforementioned issues. By incorporating a field shaper to enhance the magnetic field strength in the region of the permanent magnet sample under test, it is possible to reduce the discharge current while increasing the magnetic field strength, thereby achieving the goal of extending the coil's lifespan. However, the introduction of a Field Shaper will impact the calibration of the H coil; hence, this paper introduces a novel pickup coil that utilizes two coils

to simultaneously measure the magnetic field strength H , magnetic flux density B , and magnetic polarization intensity J .

II. PRINCIPLES OF THE IMPROVED PMF METHOD WITH FIELD SHAPER

Fig. 1 illustrates a comparison between the existing PMF method and the improved PMF method. The primary distinction between the two methods lies in the incorporation of a field shaper in the improved PMF method. In addition, the use of two pickup coils simplifies the coil configuration. Moreover, by picking up signals twice and processing the picked-up signals, the J signal and the H signal can be obtained. The final demagnetization curve is corrected using the $f/2f$ method, which is currently widely applied in the measurement of permanent magnetic materials.

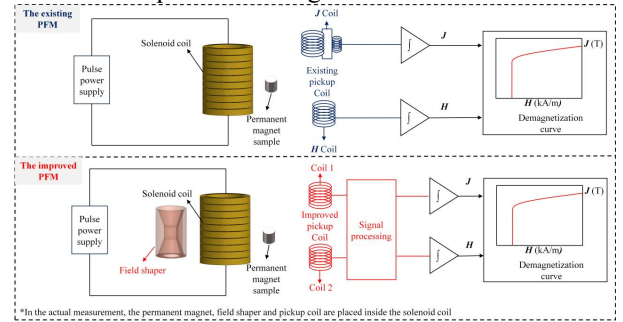


Fig. 1 Comparison of the schematic diagrams between the existing PMF method and the improved PMF method with field shaper

1) Field shaper

The field shaper can alter the spatial distribution of the electromagnetic field, enabling the magnetic field's strength to be controlled within the region of the sample under test, thereby making the shaping process more flexible and variable[5]. The three-dimensional diagram of the field shaper designed in this instance is depicted in Fig. 1. The overall two-dimensional axisymmetric diagram illustrating the relative positional relationships is shown in Fig. 2. Upon the initiation of discharge within the system, the pulsed high current induces eddy currents within the field shaper. Due to the skin effect, these eddy currents are concentrated near the outer surface. The eddy currents pass through the gap to form a closed loop on the inner surface of the field shaper, as shown in the top view of the field shaper in Fig. 2, where the red line represents

the path of the current. Since the inner surface area of the field shaper is smaller than the area of the induction region, the density of the eddy currents is higher at this point, achieving the effect of enhancing the magnetic field in the region of the sample under test.

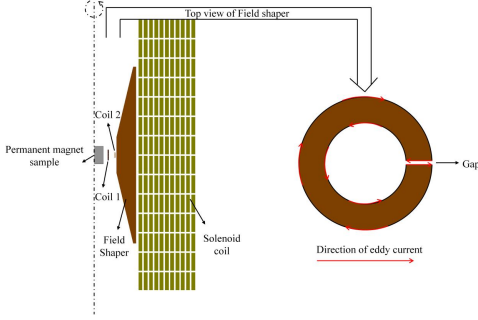


Fig. 2 The overall structure diagram of the improved PFM method

2) Pickup coil and signal processing

The pickup coil proposed in this paper needs to collect signals twice. Firstly, when there is no sample, the induced voltage $u_{1*}(t)$ and $u_{2*}(t)$ of the two coils is

$$u_{1*}(t) = \mu_0 N_1 \cdot \pi \cdot r_1^2 \frac{dH}{dt} \quad (1)$$

$$u_{2*}(t) = \mu_0 N_2 \cdot \pi \cdot r_2^2 \frac{dH}{dt} \quad (2)$$

where N_1, N_2 are the number of turns of Coil 1 and Coil 2, r_1, r_2 is the radius of the two coils, c_1, c_2 are the coupling coefficients between the magnet and the coil. Then, when the sample is placed, the induced voltage $u_1(t)$ and $u_2(t)$ of the two coils is

$$u_1(t) = \mu_0 N_1 \cdot \pi \cdot r_1^2 \frac{dH}{dt} + c_1 \frac{dJ}{dt} \quad (3)$$

$$u_2(t) = \mu_0 N_2 \cdot \pi \cdot r_2^2 \frac{dH}{dt} + c_2 \frac{dJ}{dt} \quad (4)$$

a) J signal

$N_1, N_2, r_1,$ and r_2 are all known quantities, note $\frac{N_1 \cdot r_1^2}{N_2 \cdot r_2^2} = m$. After calculating $u_1(t) - m \cdot u_2(t)$, the magnetization strength J can be calculated.

$$J = \frac{1}{c_1 - mc_2} \int u_1(t) - m \cdot u_2(t) dt \quad (5)$$

where $\frac{1}{c_1 - mc_2}$ can be obtained through calibration.

b) H and B signal

Note $\frac{u_1(t) - u_{1*}(t)}{u_2(t) - u_{2*}(t)} = \frac{c_1}{c_2} = n$ after calculating (3)- $n \cdot$ (4),

the magnetic field strength H can be calculated.

$$u_1(t) - n \cdot u_2(t) = (\mu_0 N_1 \pi r_1^2 - n \mu_0 N_2 \pi r_2^2) \frac{dH}{dt} \quad (6)$$

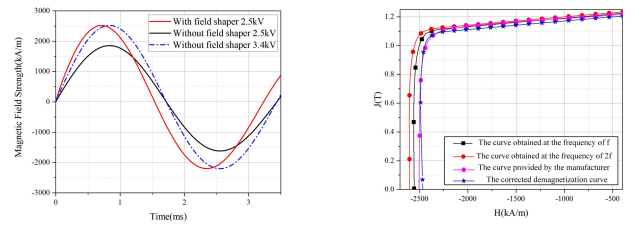
$$H = \frac{1}{\mu_0 N_1 \pi r_1^2 - n \mu_0 N_2 \pi r_2^2} \int u_1(t) - n \cdot u_2(t) dt \quad (7)$$

The magnetic flux density B can then be calculated from the magnetic field strength H , and the magnetization strength J .

III. RESULT

As depicted in Fig. 3 (a), the test sample selected is N38EH, with discharge capacitors of the same capacitance at 500 μF and a discharge voltage of 2.5 kV, a comparison of the magnetic field strength with and without a field shaper reveals that the inclusion of a field shaper can significantly enhance the magnetic field strength in the region of the sample under test, with an increase of 34%. By increasing the discharge voltage to 3.4kV in the absence of a field shaper, the magnetic field strength can be made equivalent to that with a field shaper. Calculations indicate that the incorporation of a field shaper results in a 45% reduction in discharge energy.

By increasing the capacitance of the capacitor to double the current frequency, and then employing the $f/2f$ method to obtain the demagnetization curve of the material, the final results are compared with the curve provided by the manufacturer as shown in Fig. 3(b).



(a) Comparison of magnetic field strength

(b) Comparison of test results with manufacturer's data

Fig. 3 Test results of demagnetisation curves

IV. CONCLUSION

This paper presents an improved PMF method with a field shaper. Firstly, the field shaper is introduced, which enables this method to increase the magnetic field intensity in the measurement area by 34% under the same discharge energy, thereby expanding the detection range of the device. Meanwhile, the required magnetic field intensity can be obtained with a smaller voltage, and the discharge energy can be reduced by 45%. As a result, the force exerted on the coil and the heat generated by it can be decreased, and further the lifespan of the coil can be prolonged. In addition, a new type of pickup coil is proposed, through which H, J and B can be calculated simultaneously by means of two coils. Compared with the traditional H pickup coil that calibrates the magnetic field strength by passing current, the pickup coil proposed in this paper directly captures the magnetic field signal in the region to be measured, resulting in more accurate results.

V. REFERENCES

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