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Application-Oriented In-Situ Testing Methods for Permanent Magnet Characterization

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Summary:

The long-term performance of permanent magnets is critical, as even small variations in field or temperature can cause irreversible demagnetization. In this paper, a test framework is presented with three different setups that enable comprehensive magnetization analysis and monitoring of commercial magnets, capturing both direct and time-dependent losses, while bridging the gap between material testing and application requirements.

Keywords: testing methods and arrangements, in-situ demagnetization monitoring, application-oriented demagnetization measurements, permanent magnets behavior

Introduction

Permanent magnets play a crucial role in actuators, sensors, and measurement technology. Preventing irreversible magnetization losses is a key challenge, as demagnetization occurs due to field or temperature changes and time-dependent effects [1]. Integral methods like hysteresisgraphs, vibrating sample magnetometers (VSM) [2], and Helmholtz coils assess overall magnetization [3]. Hysteresisgraphs suffer from fluxmeter drifting, making them unsuitable for long-term studies. VSMs are limited by sample size [4], while larger moment measurement coils, typically in a Helmholtz coil arrangement, lack external field and temperature control. Local methods, such as field mappers, map the sample's field using a moving Hall probe, allowing the detection of field inhomogeneities but also lacking active field and temperature control. This highlights the necessity of a comprehensive framework that bridges material characterization with application requirements. To address this, three testing concepts are developed and tested. This study focuses on measuring and monitoring direct magnetization losses, time-dependent viscosity S, and the magnetic viscosity parameter S_v. S_v allows for the prediction of magnetization losses, by defining an effective fluctuation field: $H_{eff} = S_v * \ln(\Delta t)$ [1]. This enables the extrapolation of results over the entire lifetime of a component. Furthermore, the testing arrangement enable in-situ field scans for visualization of the demagnetization process.

Testbench Framework

Concept 1

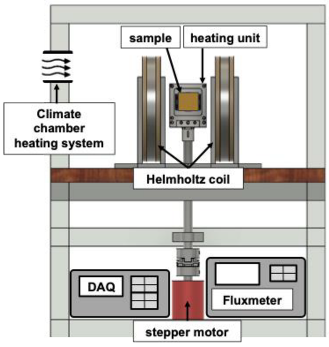

Fig. 1. General overview of concept 1.

The first concept, based on a classical Helmholtz coil with fluxmeter measurement, is enhanced by a stepper motor [5] for sample rotation (Fig. 1). Additionally, a heating unit capable of reaching temperatures up to 250 °C was integrated. The fluxmeter converts the induced voltage into magnetic flux. Fluxmeter drifting is minimized by rotating the sample within the Helmholtz coil, enabling long-term measurements (magnetic viscosity S) at various temperatures.

Concept 2

The second concept combines classical Helmholtz measurements with the functionality of a field mapper under varying field and temperature conditions (in situ) (Fig. 2) [6]. The sample, mounted on a rotating sample disc, can be heated up to 200 °C. During one rotation, it is exposed to an external field within the yoke's air gap (H_{ext} = 1800 kA/m), measured integrally via the Helmholtz coil with a fluxmeter, and locally analyzed by a scanning Hall probe. This enables both the integral measurement of the entire demagnetization curve (hysteresis curve) and detailed local field mapping.

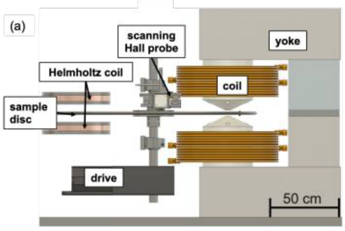

Fig. 2. General overview of concept 2.

Concept 3

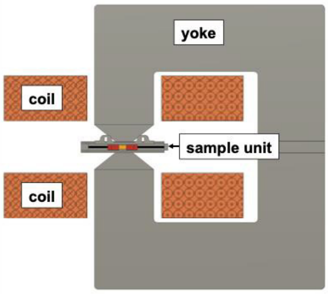

Fig. 3. General overview of concept 3.

The third concept enables both rapid field changes and constant fields. It is based on a yoke made of electrical steel sheet, with excitation coils generating external field strengths of up to 1500 kA/m (Fig. 3). The sample can be heated up to 250 °C and is measured using Hall probes in the air gap between the sample and the yoke. This setup is designed for measuring demagnetization curves as well as time-dependent behavior over short time frames. It enables the routine determination of the magnetic viscosity parameter S_v for full-size samples.

Data acquisition

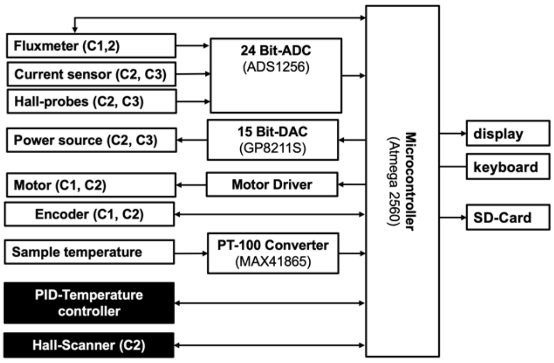

Fig. 4. General overview of the DAQ system with concept-specific components indicated in parentheses.

Measurement acquisition and process control are managed by an ATmega 2560 microcontroller. Each setup includes a microcontroller with an ADC (Analog-to-Digital Converter) for acquiring measurement signals, such as Hall probe readings and/or the magnetic moment from the fluxmeter (Fig. 4). This enables discrete data acquisition and precise control of process parameters (Tab. 1), including driving the current source via a DAC (Digital-to-Analog Converter) and controlling the motor drive. Additionally, Concept 2 includes a field mapping unit alongside the main acquisition and process control unit, synchronizing its stepper motor with the sample's rotation for field mapping.

Tab. 1: Summary of measurement methods, process parameters, and key results for all concepts.

Concepts	Measurement methods	Measurement variables	Relative measurement accuracy (at applied process parameters in medium conditions)	Process parameter	Key results
1	Helmholtz-coil with Fluxmeter	J [T]	J: ≈ 0.005 %	Temperature: 20-250 °C	Magnetic viscosity: *S*
	Thermocouples	T [°C]	T: ≈ 0.5 %	Time	Temperature ramps: *J(T)*
2	Helmholtz-coil with Fluxmeter	J [T]	J: ≈ 0.01 %	Field (H_{ext}): 0-1800 kA/m	In-situ field maps: *B(x,y)*
	Hall-probes	H [kA/m]	H: ≈ 0.1 %	Temperature: 20-200 °C	Hysteresis curves: *J(H)*
	Thermocouples	T [°C]	T: ≈ 2.5 %		
3	Hall-probes	J [T]	J: ≈ 0.1 %	Field (H_{ext}): 0-1500 kA/m	Magnetic viscosity: *S*
	Current Sensor	I [A]	I: ≈ 0.5 %	Temperature: 20-250 °C	Viscosity parameter: S_v
	Thermocouples	T [°C]	T: ≈ 1 %	Time	Hysteresis curves: *J(H)*

Conclusions

The proposed testing framework enables a detailed analysis of demagnetization effects in permanent magnets by combining integral and local measurement techniques. Concept 1 allows long-term monitoring of magnetic viscosity, concept 2 provides in-situ field mapping, and concept 3 determines viscosity parameters. These approaches bridge the gap between material testing and applications, improving the reliability of magnet stability assessments.

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