Brass Rotator: Background Subtraction

Compared to the often utilized and standard quartz paddle, straw, and brass sample holders, the background response of the brass rotator is significantly larger due to its unique construction. Background subtraction will often be required, especially for samples with magnetic moments less than 1×10^{-3} emu.

This Application Note serves two purposes. Firstly, to demonstrate the typical background response of the Brass Rotator as a function of applied field, temperature, and rotation angle. Secondly, to demonstrate that a simple point-by-point background subtraction protocol is sufficient for low-moment samples.

Brass Rotator Background: Temperature and Field Dependence

The typical full ±7 T field moment versus field backgrounds, measured at 2 K and 300 K, of an in-plane brass rotator are shown in Figure 1 **[1]**. The dominant high-field background response is diamagnetic. Note the magnitude of the diamagnetic susceptibility is larger at 300 K compared to 2 K. Due to trace ferromagnetic impurities in the brass, a hysteretic background is observed for field magnitudes less than 2 T (Figure 1, inset) at low temperatures. The measurements shown in Figure 1 were performed at the center of the total ∼500° angular range, defined as 0 degrees in this Application Note.

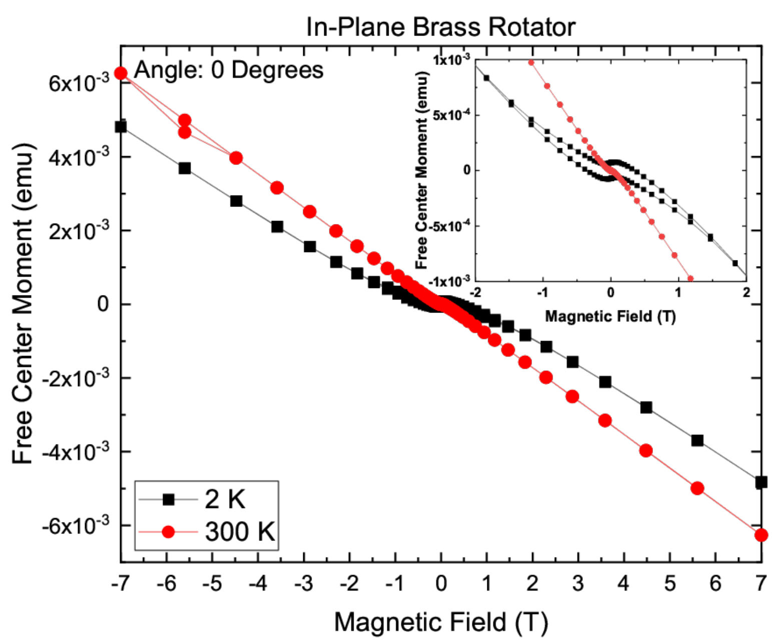

Figure 1: *Background moment vs. field measurements over the full ±7 T field range of an in-plane brass rotator measured at 2 K (black squares) and 300 K (red circles). The inset highlights the low field response.*

Brass Rotator Background: Temperature and Angle Dependence

The typical angular dependence of the backgrounds, measured at 2 K and 300 K, of an in-plane brass rotator are shown in Figure 2 at a fixed applied field of -7 T. The overall shape of the angular dependence is similar at 300 K and 2 K. Due to the larger magnitude of the diamagnetic susceptibility, the background measured at 300 K is larger than that measured at 2 K. Over a 360° angular range (between the two vertical dashed lines in Figure 2) the background varies by less than 10%.

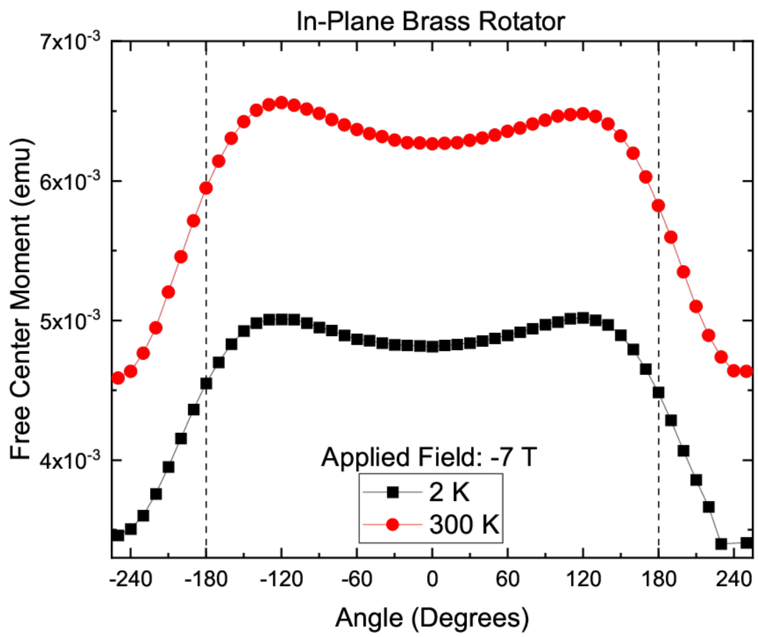

Figure 2: *Angular dependence of the background of an in-plane brass rotator at a fixed field of -7 T measured at 2 K (black squares) and 300 K (red circles).*

Point-by-Point Background Subtraction: Full Field

Test Sample: 10 nm NiFe Thin Film

The test sample chosen for this demonstration is a sputtered 10 nm thick NiFe film that has been deposited onto a 0.5 mm thick Si substrate. An additional Ta capping layer is included to prevent oxidation. The lateral size of the sample is 4 mm × 4 mm, see Figure 3 (A). The nominal saturation moment at room temperature is approximately 130×10^{-6} emu.

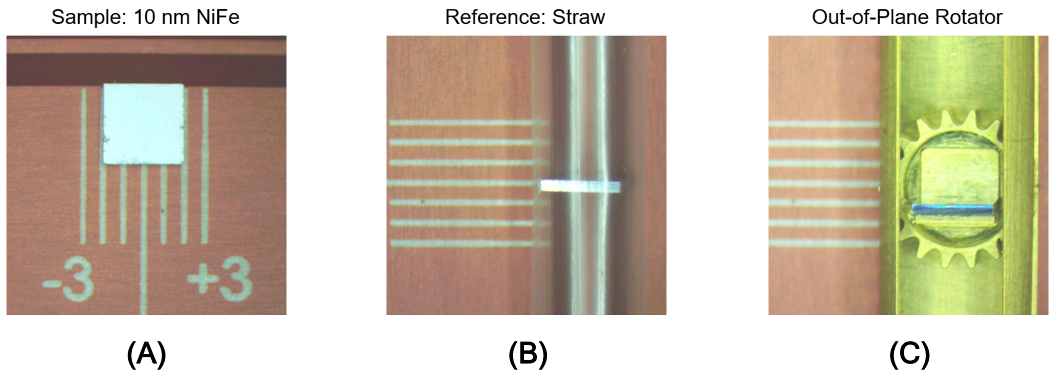

Figure 3: *(**A**) The test sample is a 10 nm thick NiFe film sputtered onto a 0.5 mm thick Si substrate. (**B**) The reference measurement is performed with the sample mounted inside a straw such that the applied field is perpendicular to the film plane. (**C**) The same NiFe test sample is glued to the out-of-plane rotator with rubber cement and measurements are performed such that the applied field is perpendicular to the film plane.*

Reference Measurement: Straw

The reference (nominally zero background) measurement is performed by mounting the sample in a straw such that the applied field is perpendicular to the film plane. The corners of the 4 mm × 4 mm sample bite into the straw such that no additional adhesives are required to secure the sample, Figure 3 (B). The moment versus field response measured over the entire ±7 T field range is shown in Figure 4. Measurements were performed at 2 K as the ferromagnetic background response of the brass rotator is largest. Due to the shape anisotropy of the film, the ferromagnetic component to the signal does not saturate until the magnitude of the applied field is nearly 1 T. For field magnitudes larger than 1 T, the dominant response is the diamagnetic Si substrate. Figure 4 (inset) shows the response with the linear diamagnetic contribution of the Si substrate removed, as is typically performed in post-processing when studying such thin film samples.

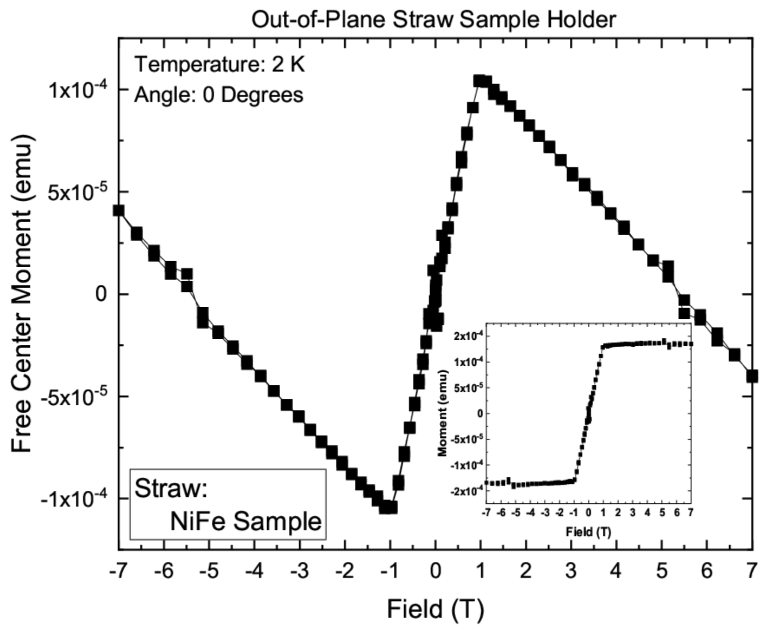

Figure 4: *Moment vs. field over the full ±7 T field range of the NiFe test sample measured at 2 K. The inset shows the response with the diamagnetic contribution of the Si substrate removed via a simple linear subtraction.*

Background and Background+Sample: Brass Rotator

The background (green circles) and background+sample (blue squares) moment versus field measurements are shown in Figure 5 over the full ±7 T field range using the out-of-plane brass rotator (Figure 3 (C)). The sample is held in place using a small amount of rubber cement. Note how similar the two measurements are, virtually overlapping completely. The biggest differences between the two measurements become most apparent for field magnitudes less than 2 T (Figure 5, inset).

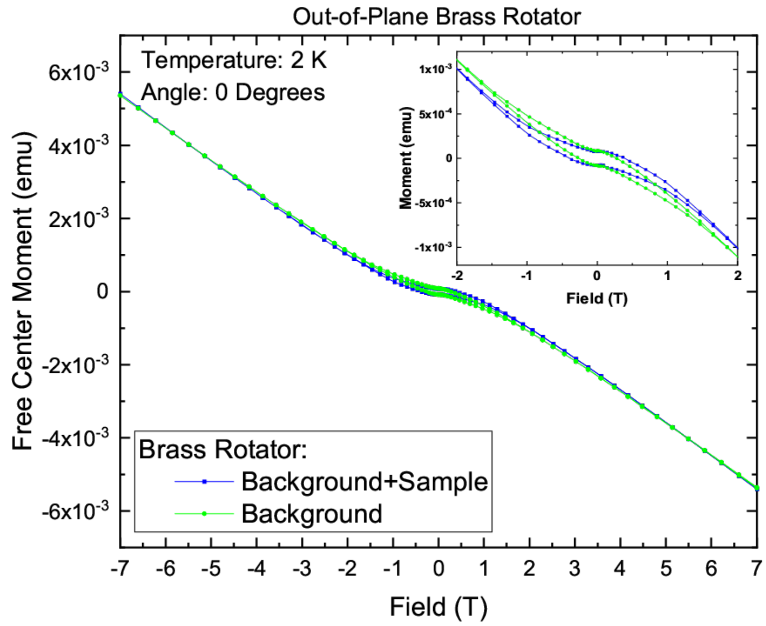

Figure 5: *Moment vs. field over the full ±7 T field range for the background (green circles) and background+sample (blue squares). The out-of-plane brass rotator was used for these measurements. The inset highlights the low-field response.*

Point-by-Point Subtraction: Brass Rotator

The result of a simple point-by-point subtraction of the background from the background+sample measurements, is shown in Figure 6 (red circles). The agreement with the reference measurement using a straw sample holder is remarkable given the comparative size of the background response (Figure 5). Small differences could be attributed to slight differences in the applied field angle between the two mounting techniques.

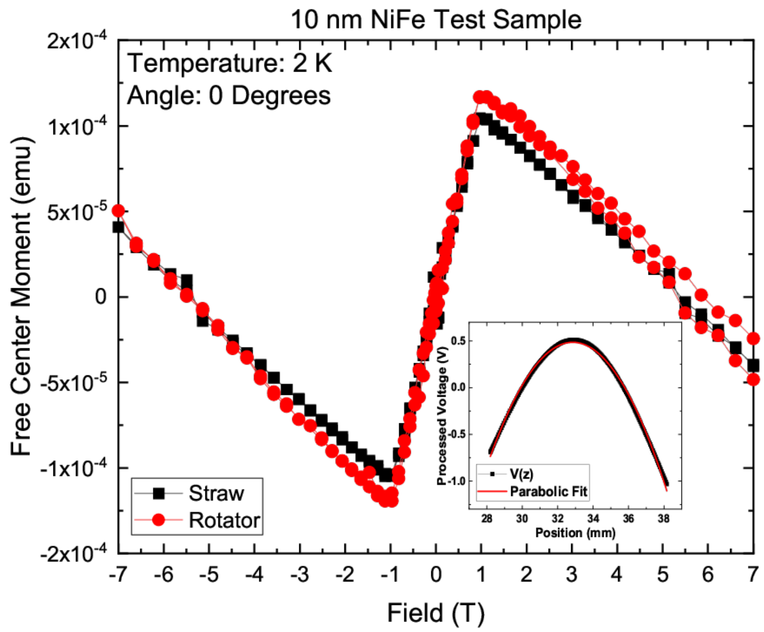

Figure 6: *The result of a simple point-by-point subtraction of the background from the background+sample measurement (red solid circles) shows good agreement with the reference measurement (black squares). The inset shows a representative $V(z)$ waveform.*

Point-by-Point Subtraction Protocol: Justification

As described at length in MPMS 3 Application Note 1500-023 **[2]**, background subtraction using the DC-scan mode is best performed by first subtracting the processed $V(z)$ voltage waveforms of the background from the background+sample and then refitting the response to extract the magnetic moment. SquidLab **[3]** is an open-source program that runs with MATLAB which can automate background subtraction using the $V(z)$ waveform subtraction and refit method just described. This technique is critically important when the $V(z)$ waveforms are not symmetric about the center position, as demonstrated in the aforementioned Application Note. However, an added benefit of the recommended 10 mm DC-scan length for the brass rotator, the $V(z)$ waveforms are symmetric and can be fit, to a high degree of accuracy, as simple symmetric parabolas, as shown in Figure 6 (inset). An asymmetric $V(z)$ voltage waveform would certainly require the more involved background subtraction procedures outlined in Application Note 1500-023 and performed by SquidLab. While it is traditional to use DC-scan lengths of 30-35 mm when using the MPMS 3, as demonstrated in Application Note 1500-020 **[4]**, the accuracy of the extracted moment from a DC-fit does not appreciably depend on the scan length.

Small Field Measurements and Background Considerations

If measurements can be performed using small (< 200 Oe) applied fields, it is possible to significantly minimize the background contribution if one first demagnetizes the brass rotator. For this demonstration the test sample is the same, except it has been cut down to an approximately 2 mm × 2 mm lateral size to further reduce the sample moment. Measurements were performed using the in-plane rotator as the NiFe film will easily saturate in less than 200 Oe for in-plane applied fields. Again, a measurement temperature of 2 K was chosen to maximize the background contribution. Before measurements the applied field was set to +7 T and then the field was set to zero in oscillate mode. This procedure will not only reduce the remanence of the superconducting solenoid, as discussed in Application Note 1500-011 **[5]**, but will also demagnetize the brass rotator. A measurement of the background (green circles) after this demagnetization procedure over ±200 Oe is shown in Figure 7. The background is virtually flat with a magnitude less than 2×10^{-6} emu. Performing a simple point-by-point subtraction of the background (green circles) from the sample+background (blue squares) shows nearly identical responses (Figure 7). Depending on the degree of accuracy required, background subtraction may not be required for these measurement parameters.

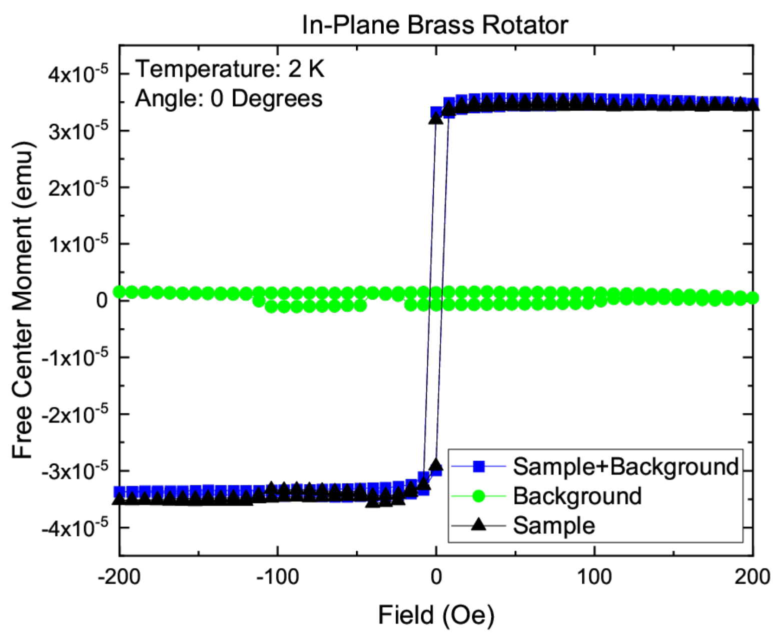

Figure 7: *Measurements of the background (green circles), background+sample (blue squares) measured over ±200 Oe after demagnetizing the in-plane brass rotator. The resulting sample (black triangles) response is found by perrforming a simple point-by-point subtraction of the background from the sample+background.*

Summary

The background of the brass rotator is significant, and background subtraction will often be required. This Application Note provides a survey of the typical background response as a function of temperature, magnetic field, and angle. Comparative measurements of a NiFe thin film test sample measured using a straw sample holder and the out-of-plane brass rotator demonstrate that a simple point-by-point background subtraction protocol is often sufficient. Furthermore, if measurements can

be performed in small fields, the background contribution can be significantly reduced by first demagnetizing the brass rotator.

References

[1] A DC-scan length of 10 mm and DC-scan time of 2 seconds was used for all measurements presented in this Application Note. There is little difference between the reported Fixed Center and Free Center moment values. However, as the Free moment tends to have a slightly better fit quality and will better track any temperature or angular dependent variations of the sample center it is recommended to use the Free Center values.

[2] Quantum Design. "Background Subtraction Using the MPMS 3." *MPMS 3 Application Note 1500-023. Pharos Digital Library*, https://www.qdusa.com/pharos/view.php?fDocumentId=3889.

[3] Matthew J. Coak, et al.; SquidLab–A user-friendly program for background subtraction and fitting of magnetization data. *Rev. Sci. Instrum.* 1 February 2020; 91 (2): 023901.

[4] Quantum Design. "Accuracy of Reported Sample Moment: Using the Sample Geometry Simulator." *MPMS 3 Application Note 1500-020. Pharos Digital Library*, https://www.qdusa.com/pharos/view.php?fDocumentId=2572.

[5] Quantum Design. "Using SQUID VSM Superconducting Magnets at Low Fields." *MPMS 3 Application Note 1500-011. Pharos Digital Library*, https://www.qdusa.com/pharos/view.php?fDocumentId=3895.