

## Correcting for the Absolute Field Error using the Pd Standard

As described at length in prior Application Notes (1014-208, 1070-207, 1500-011) superconducting magnets, while easily capable of generating fields on the order of 10+ Tesla, can present additional challenges when trying to accurately set fields of less than 10's of Oe due to e.g. flux trapping and pinning. Additionally, since the magnetic field reported in MultiVu to the user is based only on the current from the magnet power supply, such remanent fields can produce field errors up to ~20 Oe in a 9 Tesla magnet and up to ~200 Oe in a 16 Tesla magnet in QD instruments. Such remanent field errors can present significant artifacts to hysteresis loop measurements of ferromagnetic samples with low coercivities, often resulting in an "inverted" loop where the switching field along the descending (ascending) branch of the hysteresis loop occurs for positive (negative) fields.

The Application Notes referenced above provide several techniques to mitigate these effects, including using a pure paramagnetic sample to directly measure/calculate the true magnetic field. This can be easily accomplished because the remanence properties of the magnet are very reproducible as long as the same field charging procedure is followed for each measurement. This Application Note provides a step-by-step guide on using this technique to correct "inverted" hysteresis loops. While the MPMS3 is used in this note, the techniques described here are applicable for the MPMS, SVSM, MPMS3, and VSM for PPMS, DynaCool, and VersaLab measurement systems alike.

### Step 1: Measure the Pd Standard

Firstly, using the exact same sequence (with the exception of the measurement temperature) intended for the sample, measure the Pd standard at 298 K by stabilizing at each field point. The measurement temperature of 298 K is chosen as the susceptibility of the Pd is known to a high degree of accuracy at this temperature. Additionally, as the superconducting magnet is always at the same temperature, its remanent field behavior does not depend on the sample chamber temperature. Furthermore, it is important to stabilize at each measurement field, as opposed to sweeping, such that substituting the corrected field values in the sample measurement straightforward. An example sequence is shown below in [Figure 1](#).

Note, in the example sequence, the magnetic field is first set to 2 T and then the field is set to 0 T in Oscillate mode. This will further help ensure the same initial condition before the hysteresis loop is measured. Also, in the example above the VSM measurement mode of the MPMS3 was used, however DC scans in the MPMS XL and MPMS3 will also work. Finally, the VSM measurement option found on the PPMS, DynaCool and VersaLab measurement platforms can also be used, where it is strongly recommended to stabilize at each measurement field.

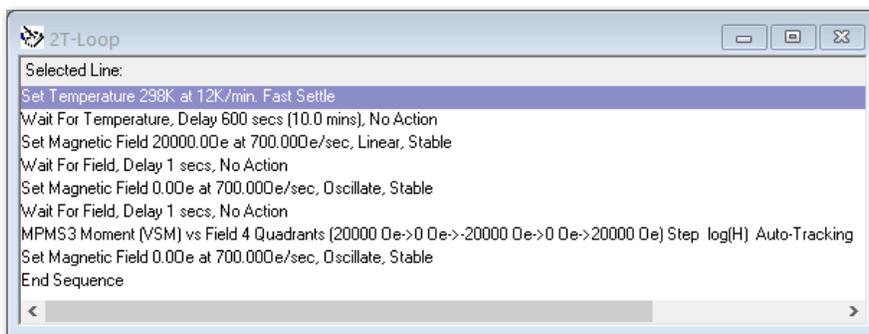


Figure 1: Example sequence.

Figure 2 shows the resulting data, color coded for the descending (red) and ascending (blue) branches of the loop as a function of the reported field. At large fields the behavior is highly linear. However, as clearly observed in Figure 2 (inset) at low fields the moment is hysteretic and at zero reported field the moment is not zero as would be expected for a perfect paramagnet. This behavior is exactly what we expect from a superconducting solenoid and is the “tell-tale” sign of a remanent magnetic field.

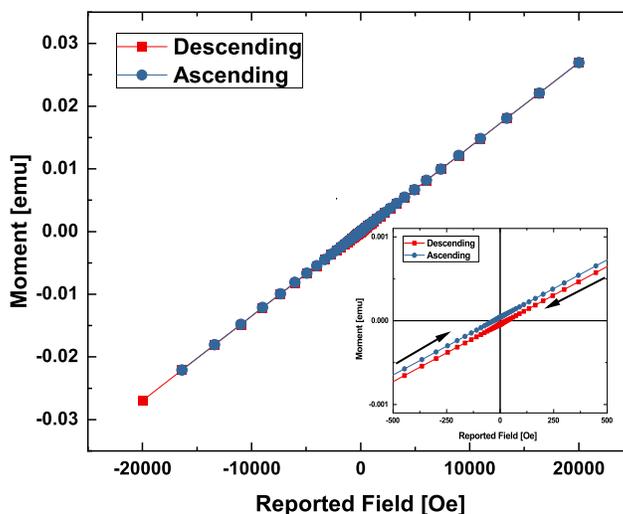


Figure 2: Pd standard measurement.

### Step 2: Calculate the True Field

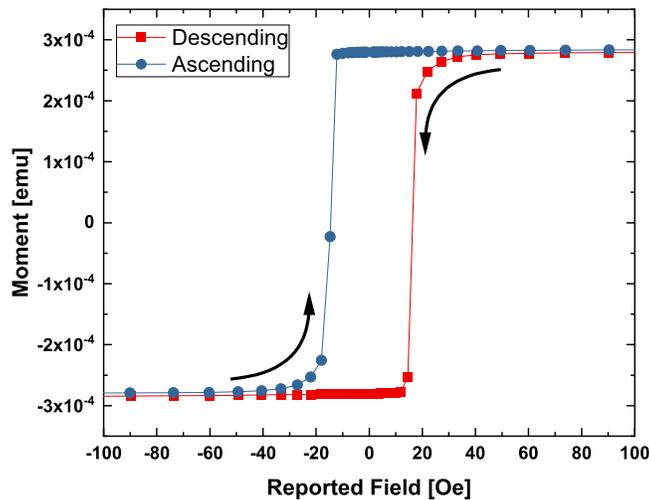
The Pd data, shown above in Fig. 2, can then be used to calculate the true field. At 298 K the susceptibility of the Pd standard is  $\chi_g = 5.25 \cdot 10^{-6} \frac{\text{emu}}{\text{Oe}\cdot\text{g}}$ . Therefore, to calculate the true field, simply divide the measured moment by  $(\chi_g \cdot \text{mass}_{\text{Pd}}[\text{grams}])$ . The mass of the Pd standard is written on the protective tube for the mounted Pd standard. For this example,  $\text{mass}_{\text{Pd}} = 0.2595 \text{ g}$ . In Figure 3 a screen shot from Origin where this calculation has been done is shown, forming a new column entitled “True Field”.

	A(X)	B(Y)	C(Y)
Long Name	Reported Field	Moment	True Field
Units	Oe	emu	Oe
Comments			
F(x)=			Col(B)/(5.25E-6*0.2595)
Sparklines			
1	19999.71289	0.02697	19797.62226
2	19999.69922	0.02698	19801.81849
3	16373.87695	0.02207	16200.77964
4	13404.96289	0.01807	13264.78863

**Figure 3:** Calculation of the true field using the known susceptibility of Pd at 298 K using the software package Origin.

### Step 3: Measure the Sample of Interest

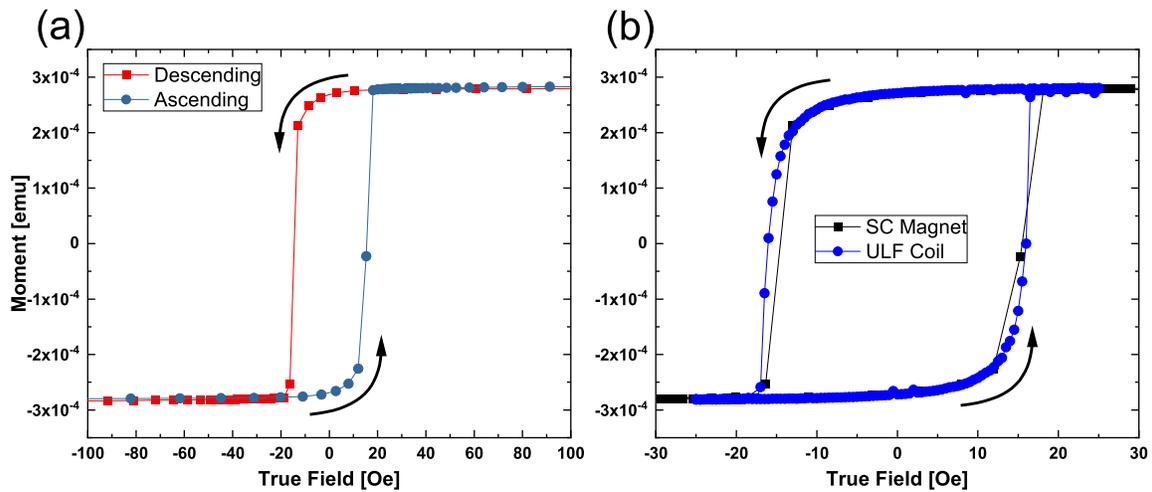
As an example, a 10 nm thick Fe film (sputtered on a Si substrate) is measured using the exact same sequence used to measure the Pd discussed in Step 1. Note, for this test a measurement temperature of 298 K was chosen for simplicity, but some other temperature could be used as well without adversely affecting the field correction. See [Figure 4](#) for the measured sample data as a function of the reported field. Note the “inverted” loop in which the descending (ascending) branch shown in red (blue) switches for an apparent positive (negative) field.



**Figure 4:** 10 nm thick Fe film measurement.

### Step 4: Substitute the True Field Values Calculated in Step 1 in the Sample Measurement

The reported field values for the sample measurement shown in Step 3 can be simply replaced by the true field values calculated in Step 2 for the Pd standard, as shown in [Figure 5\(a\)](#).



**Figure 5:** (a) 10 nm thick Fe sample measurement as a function of the true field calculated using the Pd standard. (b) Comparison of the corrected measurement shown in (a) with data measured using the ULF option and modulation coil.

When plotted as a function of the true field calculated using the Pd standard in Step 1 the 10 nm thick Fe film shows the expected behavior, [Figure 5\(a\)](#). As a comparison, the corrected data is compared with a measurement utilizing the ultra-low field (ULF) capabilities for the MPMS3, which not only allows for nulling the remanent magnetic field, but also measuring a hysteresis loop (max field 20-25 Oe) with a field resolution of 0.002 Oe utilizing the in-situ modulation coils.

For questions contact [apps@qdusa.com](mailto:apps@qdusa.com).