Basics of measurement mode behaviors in the MPMS-3 SQUID

The MPMS-3 magnetometer measures the magnetic fields produced by small samples by using superconducting detection coils coupled to an extremely sensitive magnetic sensor called a SQUID (Superconducting Quantum Interference Device), depicted in Figure 1 below. For more detailed information about the system and measurement schemes, see the MPMS3 User Manual as well as AC measurements and Oven manuals located here.

The diagrams show simple cartoons of the measurement scheme in DC Scan (Fig 1) and VSM (Fig 2) modes. In top figure, blue detection coils are superconducting (NbTi) wire wound in a "second order gradiometer" with coil winding sense of -/++/- with an overall length of 16mm. The sample is moved vertically through these coils by the linear motor at top of the probe, and if pulled through the full length then the SQUID voltage output produces a DC Scan (red), which is fit to an ideal function for a dipole and converted into a total sample magnetic moment in units of emu or A-m2. The SQUID functions to convert the small changes in detection coil currents into large DC voltages.

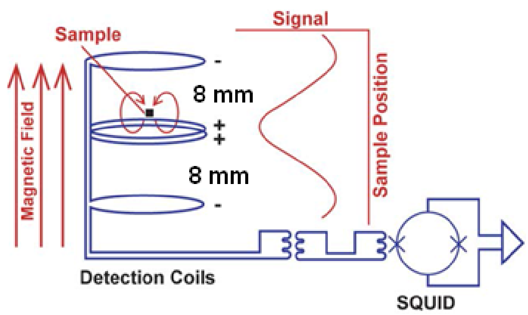

Figure 1: DC Scan mode.

In the VSM mode (Fig 2) the sample is oscillated at the center coil (++) at a frequency *f* and this produces a SQUID voltage at 2*f* due to the parabolic response of the gradiometer in that region.

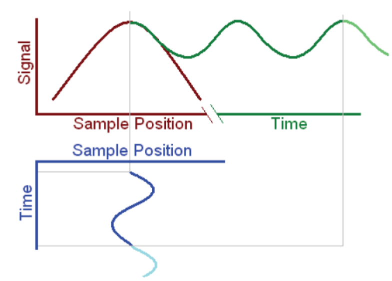

Figure 2: VSM mode. Note that moving the sample at a frequency f creates a SQUID signal at 2f.

In addition to the measurement of the static magnetic moment, the MPMS-3 has the ability to measure AC susceptibility, i.e., the response of a sample to an AC magnetic field. For this scheme, the sample is held stationary at various positions in the response function of the gradiometer (Fig 3) and a small vertical oscillatory field is superimposed on the DC applied magnetic field using a modulation coil wound coaxially in the bore of the main magnet solenoid. The same detection coils are used for AC measurements.

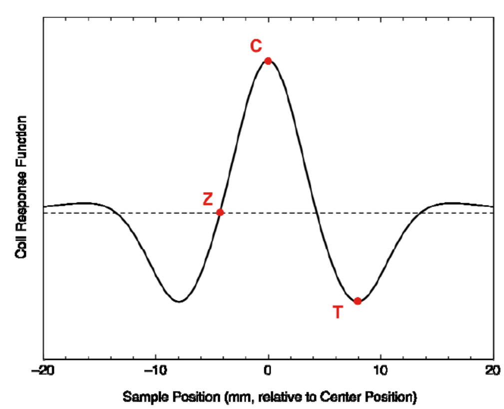

Figure 3: sample positions used in AC measurements, for Nulling (Z), Center (C), and Top (T).Note that the x-axis here is the vertical axis in the MPMS-3.

The SQUID detection circuit: a simplified diagram

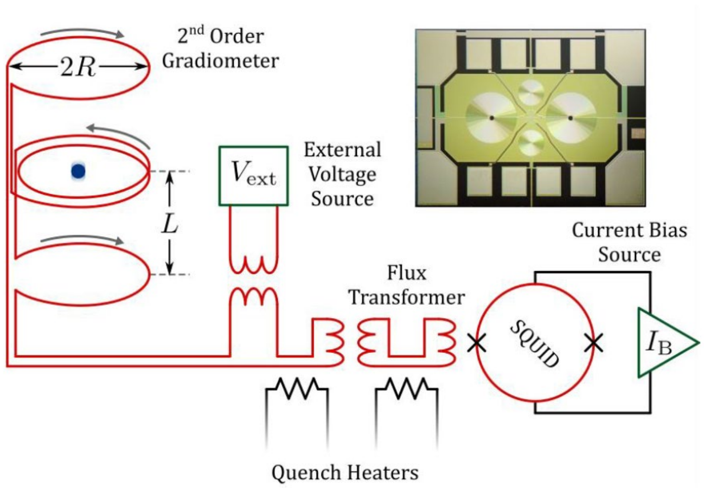

Figure 4: Superconducting elements, including the SQUID, flux transformer, and gradiometer coils, are shown in red. Normal wiring is shown in black with external electronics indicated by green. The gradiometer geometry parameters R and L are labeled; gray arrows indicate the directionality of the coil windings. A small blue circle shows the position of a vibrating sample during a VSM measurement. The inset image depicts an example of a SQUID chip configuration. Figure taken from "Magnetic Measurement Techniques for Materials Characterization", Ed. B. Dodrill and V. Franco, Springer (2020).

The detction of a magnetic moment is based on a "nulling" mode whereby an external voltage source Vext drives a current which inductively couples to the detection wires and counteracts any flux changes introduced by the movement of the sample. It is called a "nulling" method because the voltage source keeps the SQUID at the same current bias. The flux in the circuit stays the same so it is called a "flux locked loop".