

Quantum Design



## MAGNETOMETRY

THE PPMS IS DESIGNED TO FULFILL THE WORK-CENTER CONCEPT. THE PPMS MAGNETOMETRY APPLICATION INCORPORATES, IN A FULLY INTEGRATED MODULAR SYSTEM, ALL THE HARDWARE AND SOFTWARE NEEDED FOR PRECISE MAGNETIC MEASUREMENTS. WHETHER YOU WANT TO PER-

FORM AC SUSCEPTIBILITY AND DC MAGNETIZATION AT ULTRA LOW FIELDS, OR TORQUE MAGNETOMETRY MEASUREMENTS, POWERFUL SOFTWARE PERMITS CONFIGURING THE SYSTEM QUICKLY TO YOUR SPECIFIC NEEDS, AND EASILY RECONFIGURING FOR THE NEXT USER.



### AC/DC MAGNETOMETRY

The Model P500, AC/DC Magnetometry System (ACMS), performs AC susceptibility as well as DC magnetization measurements in a single sequence. You do not have to reconfigure the hardware or electronics between the two measurements.

#### DESIGN

The ACMS coil set, which provides the excitation field for AC measurements, includes the detection coils that measure the sample's magnetic response. Both sets of copper coils are wound on sapphire coil forms which provide excellent thermal properties. The ACMS probe attachment is concentric with the primary DC superconducting magnet. The detection coils are arranged in a first-order gradiometer configuration which rejects background signals. An AC compensation



coil is wound around the AC drive coil to actively reduce environmental noise during AC measurements. To increase the accuracy of the phase and amplitude calibration during each measurement, a calibration coil array, situated in the middle of each of the two detection coils, is used. This feature is found only on the Quantum Design ACMS.

The ACMS drive and detection coils are connected to the PPMS electronics through the 12-pin connector at the base of the PPMS sample chamber. This utilizes the standard PPMS hardware, thus eliminating the need for additional wiring and connectors on the ACMS probe subsystem. The ACMS package uses a Digital Signal Processor (DSP) board, which is housed in the Model 6000 PPMS Controller, to generate the excitation waveforms and record the detected response signal.

#### AC MEASUREMENTS

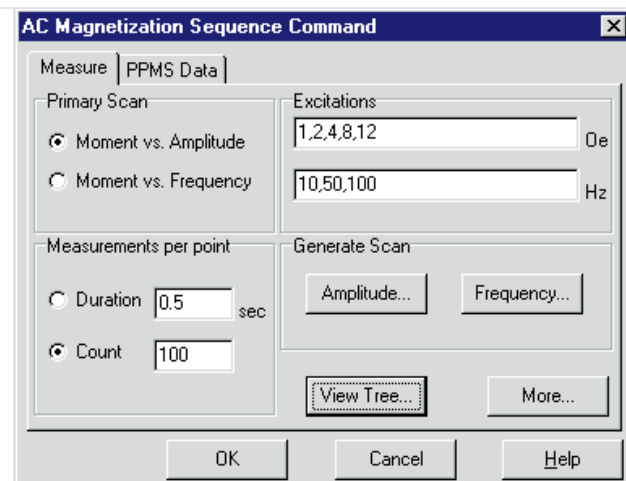
Quantum Design's ACMS incorporates several features to provide improved background subtraction and signal processing. These features are summarized in the following:

##### Environmental Noise Reduction Using a Compensation Coil

The compensation coil ensures that the excitation field is confined to the volume of the coil set, thereby avoiding interaction with any materials outside the region of measurement (i.e., sample chamber walls, magnet core, etc.).

##### Accurate Magnitude and Phase Correction Using Calibration Coil

One of the most notable features of the ACMS is its ability to separate real and imaginary components of the AC response with high accuracy by using the calibration coil array. All instruments



► AC Susceptibility parameters input screen

have phase shifts between the drive signal and the measured signal due to time constants in the electronics and coil set, depending on temperature, field, and frequency. Removing this instrument-dependent phase shift from the raw data is necessary to accurately determine the real and imaginary components of the sample's AC response. The ACMS corrects for this background phase shift by measuring the instrumental phase shift for each measurement. This direct measurement nulling uses a low-inductance calibration coil at the center of each of the pickup coils to determine the instrumental phase shift. In contrast, other systems rely on interpolation matrices or calibrations at a single temperature; they cannot correct for system changes such as aging electronics, coil relaxation, and environmental variations.

To perform an AC measurement, a signal is applied to the drive coil and the sample is centered in one of the two detection coils. The DSP then records the voltage across the detection coils for a predetermined amount of time. Multiple AC waveforms are averaged point-by-point to reduce noise with a single averaged waveform as the final output. The sample is sequentially positioned in the second

detection coil, and the time domain response is again measured.

The two sets of average waveforms are subtracted to eliminate imbalance effects between the drive coil and the counter-wound sense coils.

The calibration coil array is used to precisely determine the instrument phase lag and also the amplitude of the

applied AC magnetic field for improved B-H measurements. The detection system phase shift can then be removed from the sample signal. These two capabilities combine to give the ACMS an effective method of separating the sample signal from instrumentation effects.

#### Digital Signal Processor (DSP) Improves Signal-to-Noise Ratio without Removing Part of the Wanted Signal

By using a DSP chip rather than a lock-in amplifier, the PPMS takes advantage of digital filtering. This vastly improves signal-to-noise performance over

analog filters, which have to sacrifice accuracy in order to perform over a wide frequency band.

#### DC MEASUREMENTS

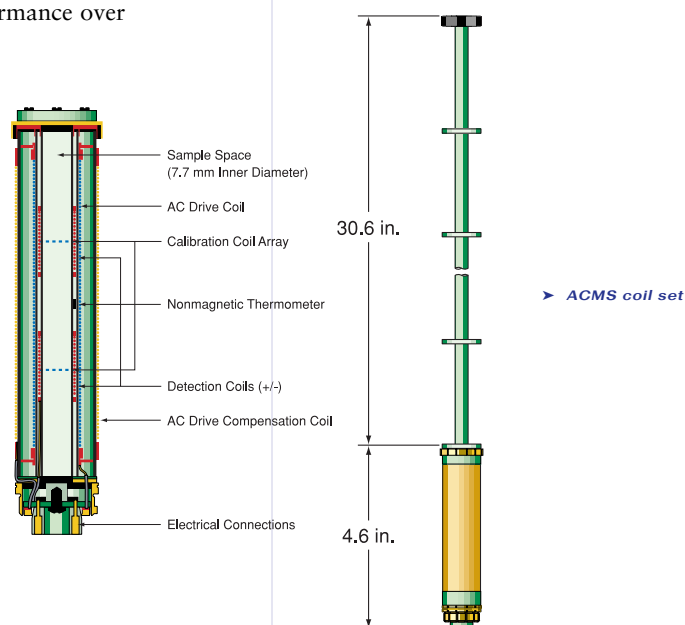
The ACMS utilizes a DC measurement technique called Extraction Magnetometry. Moving a magnetized sample through the detection coils induces a voltage in the detection coil set. The amplitude of this signal is proportional to the magnetic moment and speed of the sample during extraction. The DC servo motor employed in the ACMS can extract the sample at a speed of approximately 100 cm per second, thus significantly increasing the signal strength over conventional extraction systems. The greater extraction speed also reduces any errors that may result from non-equilibrium time-dependent effects.

#### SPECIFICATIONS

Drive Coil Frequency: 10 Hz to 10 kHz

Temperature Range: 1.9 K to 350 K  
(400 K for periods not to exceed 2 hours)

Drive Amplitude: 2 mOe to 15 Oe



# magnetometry

AC Susceptibility Sensitivity:  $2 \times 10^{-8}$  emu  
 ( $2 \times 10^{-11}$  Am<sup>2</sup>) @ 10 kHz  
 DC Magnetization Range:  
 $2.5 \times 10^{-5}$  emu to 5 emu  
 ( $2.5 \times 10^{-8}$  Am<sup>2</sup> to  $5 \times 10^{-3}$  Am<sup>2</sup>)  
 Sample Chamber Diameter: 7.7 mm  
 Sample Rod: Thin carbon fiber  
 Sample Size: 5.3 mm diameter x 12.0 mm  
 length

The ACMS cannot be used with the 7-T Transverse system. Performance is reduced in the 14-T system due to lower field homogeneity. Temperature stability may be reduced at low temperatures due to sample movement.

## TORQUE MAGNETOMETRY

The PPMS Model P550 Torque Magnetometer option (Tq-Mag)<sup>1</sup> incorporates a torque-lever chip mounted on a PPMS horizontal or vertical rotator platform<sup>2</sup> for performing fully automated, angular-dependent magnetic moment measurements at a wide range of fields and temperatures. Specifically designed for measuring small, anisotropic samples (e.g., single crystals, thin film samples, etc.), this highly sensitive torquemeter utilizes a piezoresistive technique to measure the torsion of the lever created by the applied magnetic field on the sample moment

$$\tau = m \times B.$$

The twisting of the lever produced by the torque,  $\tau$ , is measured to a high degree of sensitivity by the change in resistance of piezoresistive elements in a Wheatstone bridge configuration directly incorporated on the torquemeter chip. This patented torquemeter chip offers superior balance and stability. An integrated current loop that is on the torque lever produces a well-defined magnetic moment and is used as a calibrating standard for the torsion of the torque lever. Tq-Mag provides excellent sensitivity in high magnetic

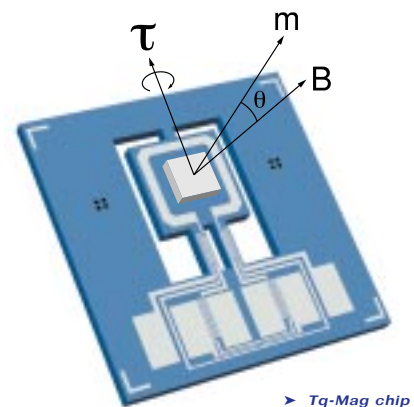
fields normally not accessible in other measurement techniques.

This torque detection system offers substantial immunity to gravity effects and minimal temperature dependence, which is accounted for in an automated calibration of the torque lever. Other advantages of the Tq-Mag include fast data acquisition and the ability to sweep temperature during torque measurements. This feature enables you to gather temperature-dependent torque data with an unprecedented level of speed and accuracy.

This option consists of the following components:

- 1) Torque magnetometer chips
- 2) Special rotator platform sample boards with chip holder
- 3) Software module that integrates into the PPMS operating system

Tq-Mag may be used in both the longitudinal and transverse magnet configurations. The required rotator aids in locating the angle of the sample that gives the largest signal when measuring torque versus field. Sample rotation can also be performed to measure angular-dependent torque.

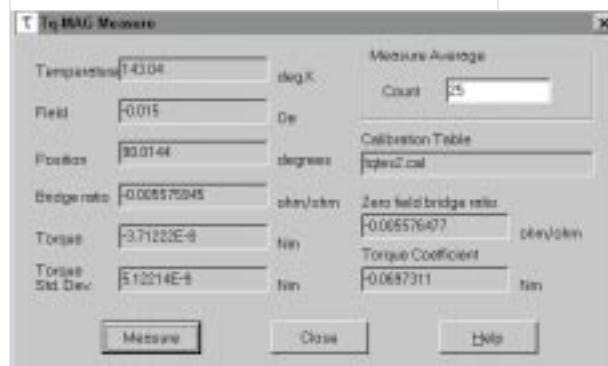


► Tq-Mag chip

To perform a measurement, you simply affix the sample to the chip, mount the chip onto the special rotator sample board (no wire bonding or soldering required), plug the platform into the PPMS rotator and install the rotator into the sample chamber. Once a measurement sequence is initiated, the system will automatically perform all necessary temperature and field settings; run the measurements; and acquire, process and plot the resulting data.

<sup>1</sup> Quantum Design developed the Torque Magnetometer in collaboration with the IBM Research Division, Zürich Research Laboratory, and the Physik-Institut der Universität Zürich, Switzerland.

<sup>2</sup> Rotator not included.



► Torque Magnetometry measurement screen

#### SYSTEM REQUIREMENTS

- P310 Horizontal or P305 Vertical Sample Rotator
- P400 Resistivity Option

#### SPECIFICATIONS/FEATURES

##### Physical Dimensions:

Torque-lever chip dimensions:

6 x 6 x 1 mm<sup>3</sup>

Sample mounting area: 2 x 2 mm<sup>2</sup>

##### Sample Dimensions:

Maximum sample size:

1.5 x 1.5 x 0.5 mm<sup>3</sup>

Maximum sample weight:

Up to 10 mg

##### High Sensitivity Chip:

RMS Torque noise level:

1 x 10<sup>-9</sup> Nm for 40-sec. sampling time

RMS Moment sensitivity:

1 x 10<sup>-7</sup> emu at 9 T for 40-sec. sampling time

7 x 10<sup>-8</sup> emu at 14 T for 40-sec. sampling time

Maximum Torque: 1 x 10<sup>-5</sup> Nm

##### Larger Moment Chip (preliminary\*):

RMS Torque noise level:

2 x 10<sup>-8</sup> Nm for 40-sec. sampling time

RMS Moment sensitivity:

2 x 10<sup>-6</sup> emu at 9 T for 40-sec. sampling time; 1 x 10<sup>-7</sup> emu at 14 T for 40-sec. sampling time

Maximum Torque: 1 x 10<sup>-4</sup> Nm

See Electro-transport supplemental brochure for more information on the Horizontal and Vertical rotators.

\* Actual specifications have yet to be determined.

#### ULTRA LOW FIELD

Model P700, the Ultra Low Field (ULF) for the PPMS, actively cancels residual magnetic flux in the PPMS superconducting magnets so samples can be cooled in a very low field.

The PPMS ULF option uses an additional superconducting coil wound directly on a specially designed coil form that fits between the magnet and the PPMS outer vacuum jacket. The field in the sample space is measured using a custom-designed fluxgate magnetometer. An automated routine measures the remanent field in the sample chamber and uses the

superconducting nulling coil to cancel the remanent field. It then performs a controlled quench of the primary superconducting magnet to trap this zero flux state so that the power to the nulling coil can be turned off. The process is iterated to achieve extremely low remanent field. You may null the field at any axial location within the sample chamber. The fluxgate also allows low field profiling of the magnetic field in the sample chamber, up to fields of 4 Oe.

#### SYSTEM REQUIREMENTS

Since the field profiling requires the ACMS sample transport, the P500 ACMS option is required for proper operation of this feature.

#### SPECIFICATIONS

Residual Field: < 0.1 Oe (0.05 Oe typical)

Residual Field Uniformity: ±0.1 Oe (±0.05 Oe typical) along 4 cm at the center of the ACMS coil set

Not available for 7-T transverse, 14-T, or 16-T systems.

Quantum Design



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