Quantum Design

Application Note 1505-001

High Temperature AC Measurements in the SVSM

Introduction

The SQUID VSM measurement platform brings unparalleled flexibility in parameters for making measurements using a SQUID magnetometer. Seeking to push the boundaries further, we bring the first SQUID measurement system that is capable of looking at the AC susceptibilities from temperatures spanning 1.8K-1000K in the same machine. Combining the Oven and the AC options in the SVSM allows for examination of the AC susceptibility of a sample to temperatures of 1000K. In this application note we will present the results of these measurements with known standards. We will also discuss the issues present with making these measurements and hopefully steer people clear of the problems that can arise.

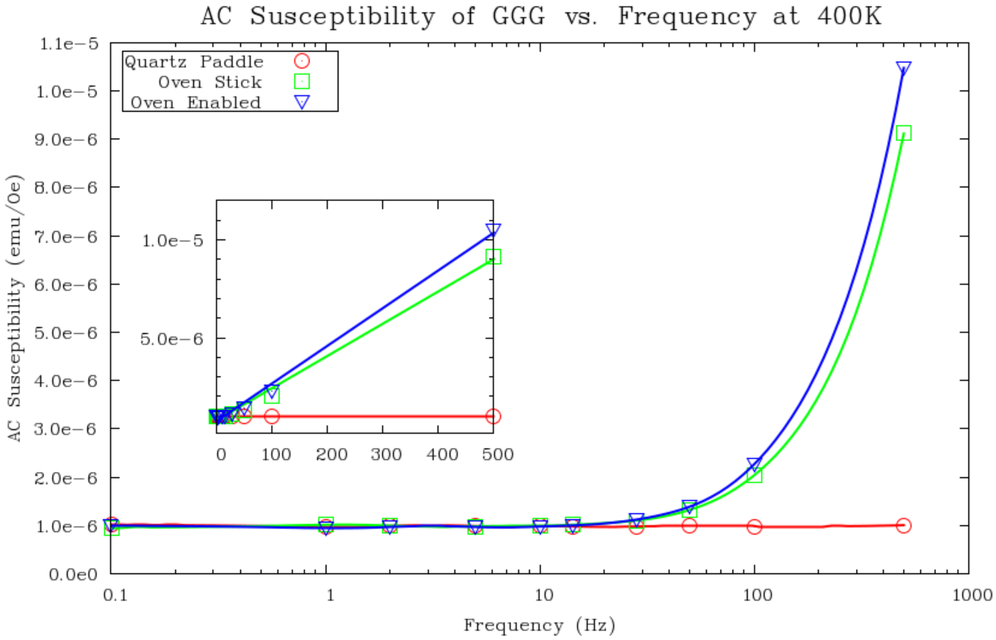
To Begin an Oven and AC Measurement

To make an AC measurement on a sample at oven temperatures, there are no special tools or mounting techniques outside of those normally utilized for oven samples. Make sure there is enough insulating cement between the copper foil and the sample. The copper foil, as we will see later, does cause some attenuation in the AC measurements at the highest frequencies, but this is largely confined to χ''. Install the sample under investigation as normal using the sample install wizard.

CAUTION: Always take care when mounting and unmounting oven samples because the surfaces of the oven sticks are easily damaged leading to non-functioning sticks.

To perform automated measurements, select the AC parameters desired for the measurement from the sequence command dialogue and begin measuring. It should be seamless. We suggest using the built in MvsH and MvsT commands that are found under the Measurement Commands->VSM heading in the sequence command tool bar. These perform all the needed steps to make accurate measurements within the parameters of the system. Measurements of blank oven holders and the copper foil is suggested so that one is familiar with the parameters of the background and how it effects the measurements of the samples.

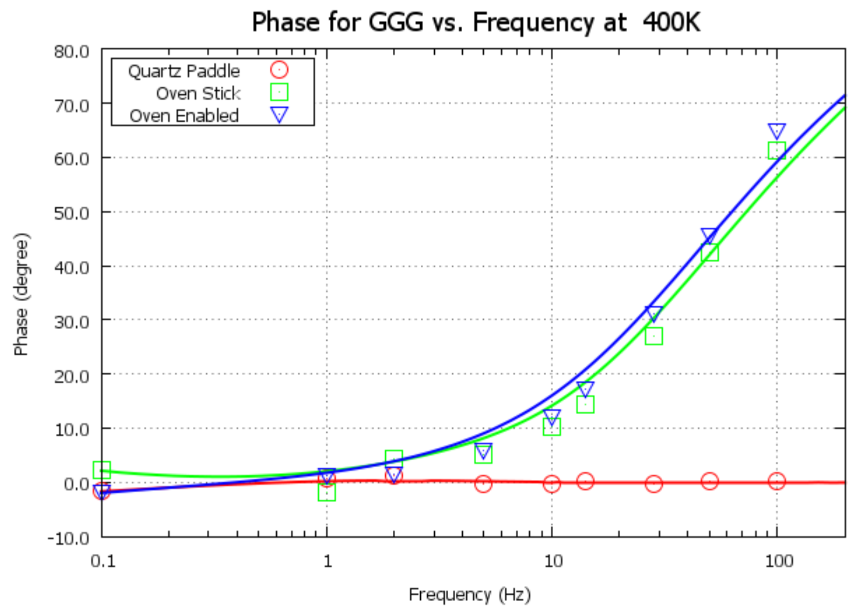
Sample Data – GGG

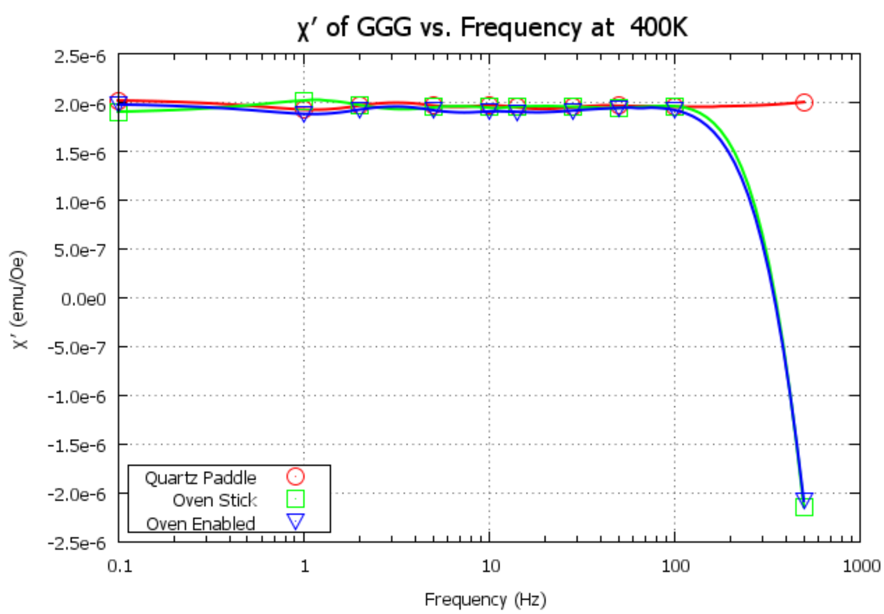


GGG is used as a proof of principle for these measurements and demonstration of the background present due to the copper foil and heater signal. GGG's shape lends itself to a better thermal equilibrium across the sample than the Er-YAG standard that we normally use as a standard for AC measurements. GGG possesses the same properties as Er-YAG magnetically that make it an exceptional standard for AC measurements and calibrations. It has a zero response in the imaginary component of the AC susceptibility. The DC response is linear with field change which allows an easy comparison between the DC susceptibility and the AC susceptibility.

We can see from the plots that there is a strong dependence on the moment and the frequency as expected from a sample covered in copper. This effect is largest with the largest frequencies where eddy currents forming in the copper foil are largest. The linear dependence on frequency shows that this indeed is caused by eddy currents. The AC susceptibility at the lowest frequencies (5 Hz) gives data that agrees quite closely with the expected value based on DC magnetization measurements. On closer inspection we see the effect of the eddy currents is primarily limited to the imaginary component of the AC susceptibility. We retain useful information about χ' through AC drive frequencies of 100 Hz.

At the examined frequencies, there was not a dependence in the AC susceptibility on the applied heater power. As with all AC measurements, which are more susceptible to external noise, there might be frequencies that are not appropriate to conduct measurements at. However, as far as we can tell the applied AC heater power for the oven stick has no effect on the measurements. In order to minimize crosstalk from the heater and get the best possible results one would typically choose a non-integer value for the frequency or perform a frequency scan over frequencies around the desired value to find the frequency that exhibits the smallest number of dropped or bad data points. The results are independent of drive amplitude as well.



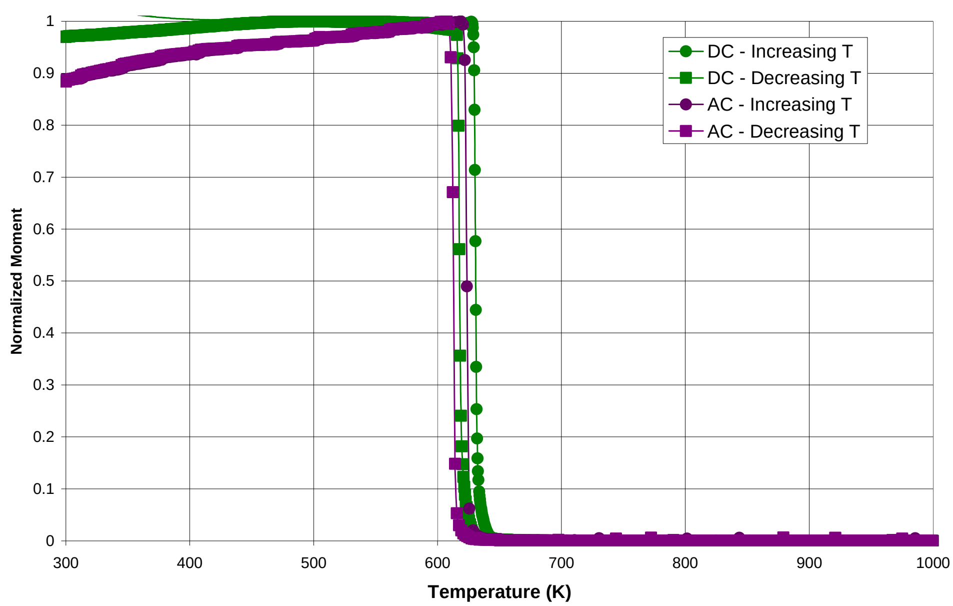


Sample Data – Nickel

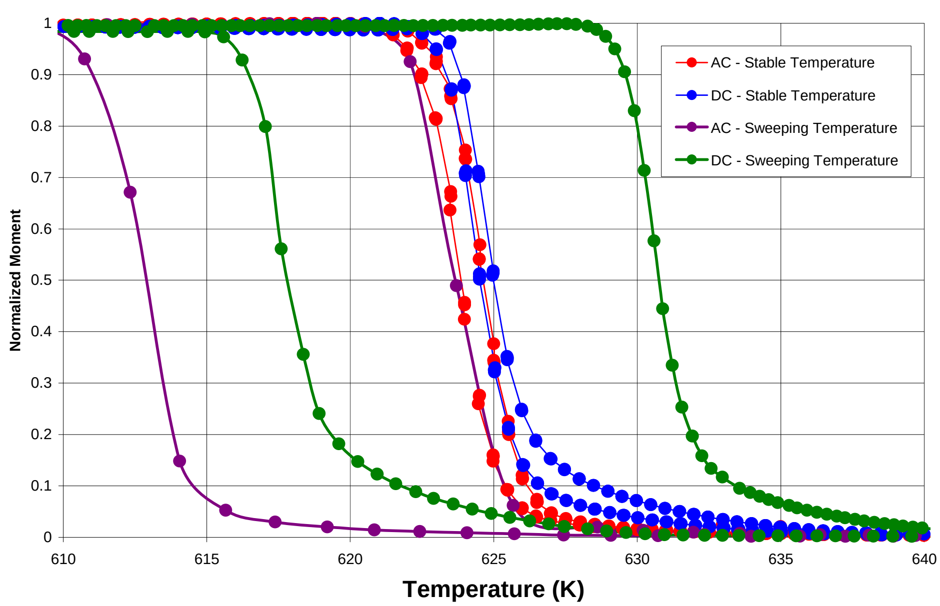
Nickel is selected as a demonstration of measuring a thermal transition using the AC susceptibility. The Curie point of nickel (T_c) is well documented at 627K. We can use this information to show that we can accurately measure the temperature in this region. A comparison with traditional DC measurements is also done with the same measurement parameters to probe the sensitivity to a magnetic transition that is provided by the AC measurement option.

The first plot of the nickel transition using the oven option uses similar parameters for both the AC and the DC measurements. The measurements were collected using 5 K/min sweep rate from 300K to 1000K and then back down. Both sets of data were collected with a field set using the ULF option of 0.5 Oe. For the DC data, 5mm amplitude along with 4 second averaging time was used. These parameters yield a DC moment of ~10^{-3} emu. The AC measurement parameters used a 2 Hz and 0.1 Oe AC field averaging over 10 cycles with a 3 point measurement yielding approximately 15 seconds between AC measurements. This yields AC moments of 10^{-4} emu for the nickel sample under these conditions.

SVSM Oven Nickel Transition - Sweeping Temperature



SVSM Oven Nickel Transition



There is very little difference in the transition temperature measured with the AC option and the standard DC measurements while sweeping. Even collecting a point every 15 seconds while sweeping 5 K/min we will have exceptional temperature accuracy with the system. Slowing the measurements down even further and stabilizing the measurements in the region of the transition we can significantly improve the accuracy of the temperature of the measurements at the expense increasing the measurement time. Each point in the stabilization data is actually 3 data points at the specified temperature which is slightly more evident in the AC data collected.

Results

The AC option is fully compatible with the oven option and combining these two in the SVSM we are able to provide an exceptional platform for examining high temperature AC susceptibility. We can maintain the same temperature specification with the SVSM oven and DC measurements with AC measurements. The higher frequency ranges of the AC option will be limited by the copper shield which is needed by the oven option for temperature stability.

Specifications

All measurements specifications should remain the same as the SVSM AC option except for those noted here:

Frequency Range	**Same as standard AC specification**
	*Limited accuracy on χ'' above 5Hz and accuracy on χ' above frequencies of 100Hz as documented
Sensitivity (ac moment)	**< 5×10^{-6}emu**
Frequency Dependence	
AC Moment	AC frequency dependence is as shown and dependant on copper foil and how the sample is mounted
AC Phase	AC phase dependence is as shown and dependant on copper foil and how the sample is mounted

Appendix

Supplemental Data

Attached is so more detailed data looking at oven enabled and the GGG sample. The dependence of χ' and χ'' on the frequency is quite clear. A comparison of the Susceptibility made through DC measurements and AC measurements is shown in the first plot and it agrees quite closely for a properly calibrated system.