TDO isolation to reduce frequency noise

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Abstract
The TDO technique is extremely sensitive to mechanical vibrations, as well as temperature fluctuations, causing heightened noise levels. Such conditions call for an improvement to the technique in order to minimize the noise in the frequency readings and obtain more precise data. To achieve this, an isolating chamber was designed and implemented in order to protect the TDO circuit and coil from fluid flow which could cause these conditions. The chamber was seen to be effective in reducing noise in liquid nitrogen, reducing the noise by an order of magnitude from data taken without the isolating chamber present.

Introduction

The purpose of the Tunnel Diode Oscillator (TDO) technique is to detect changes in physical properties by recording resonant frequencies of a tank circuit. This is done by placing a sample inside of the coil. The resonant frequency of such a circuit is given by

$$f = \frac{1}{\sqrt{LC}},$$

where L is the inductance of the circuit and C is the capacitance. Any changes in the inductance or capacitance will lead to a change in frequency.

The inductance of a coil is

$$L = \frac{\mu N^2 A}{l}.$$

If it is assumed the number of turn and length of the coil remains constant, it is seen that changes in the effective area, and well as the permeability of the coil, will change the inductance of the coil, and in turn change the resonant frequency of the tank circuit.

This technique has been shown to be very successful in measuring magneto resistance, penetration depth in superconductors, as well as magnetic susceptibility. Due to the precision to which frequency can be measured, small changes in such physical properties can be seen very well using this technique. However, if such small changes are to be seen, the noise level should be reduced to a minimum.

It is thought that a significant source of noise is due to fluid motion around the tank circuit. In liquid nitrogen a temperature gradient is present due to the nitrogen air interface. This gradient causes hydrodynamic flow of the nitrogen through thermal exchange.

If this flow of nitrogen is present, it can cause both mechanical oscillations as well as temperature oscillations in the tank circuit. Mechanical vibrations of the TDO circuit cause changes in the relative position of the coil with respect to the circuit, as well as the coil's leads with respect to each other. This results in changes in the net capacitance and

inductance in the circuit, which will change the resonant frequency.

The TDO circuit is sensitive to temperature as well, due mostly to the temperature dependence of inductors and capacitors. If temperature changes occur as the nitrogen flows around the circuit, this too would cause the net capacitance and inductance to vary, causing changes in the resonant frequency.

In order to minimize the noise level, an isolating chamber was constructed in order to isolate the coil from fluid flow and temperature changes which would cause fluctuations in the frequency, increasing the noise level.

Isolating chamber design

The isolating chamber, seen in figure 1, was designed in order to be compatible with probes made for high magnetic field experimental physics at the National High Magnetic Field Laboratory in Tallahassee Florida. Due to the limited size of the bores used in high magnetic fields, care had to be taken to ensure there was room enough to fit the TDO circuit inside the isolating chamber, while still leaving room for a mechanical rotator which can change the orientation of samples with respect to the magnetic field. These parameters limited the dimension of the chamber to less than 0.5'' in diameter and less than 1.5'' in length.

To ensure true isolation, the chamber was designed to achieve a leak tight seal in super fluid helium. A three piece design was employed to press an indium seal. A cap screw applies downward pressure on a plug, which squeezes the indium in order to fill any gaps. The plug is intended not to rotate as the cap in screwed down, so as not to damage the seal.

Rigid coax cables, as well as wiring for a thermometer were run through the top hole, which was then filled with epoxy to maintain the leak tight seal. The design used two coax lines to allow for the coil, the circuit, or both to be isolated within the chamber. Four wires were also used for the thermometer in case of failures of the wires.

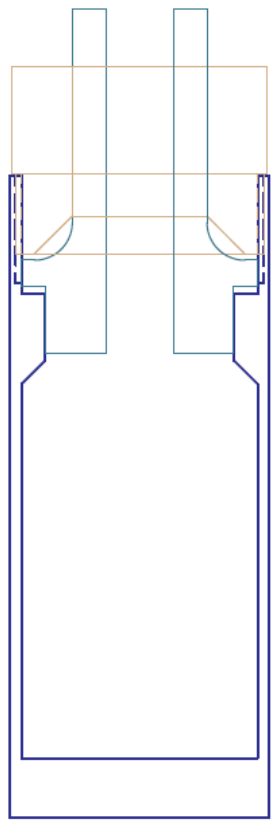

Figure 1. A three piece design was employed to achieve a leak tight seal in the isolating chamber. A cap screws down on a plug, squeezing an indium seal. Rigid coax cables run through the top hole, which is then filled with epoxy.

Experimental Results

Room temperature data was taken with the coil inside of the isolation chamber. The experiment was allowed to run for several hours, and typical

noise levels of around 1 KHz were observed. Data was then taken at room temperature without the isolation chamber. Here the noise level is seen to be slightly larger, but still in the 1 KHz range. A comparison of the frequency reading with and without the isolating chamber can be seen in figure 2.

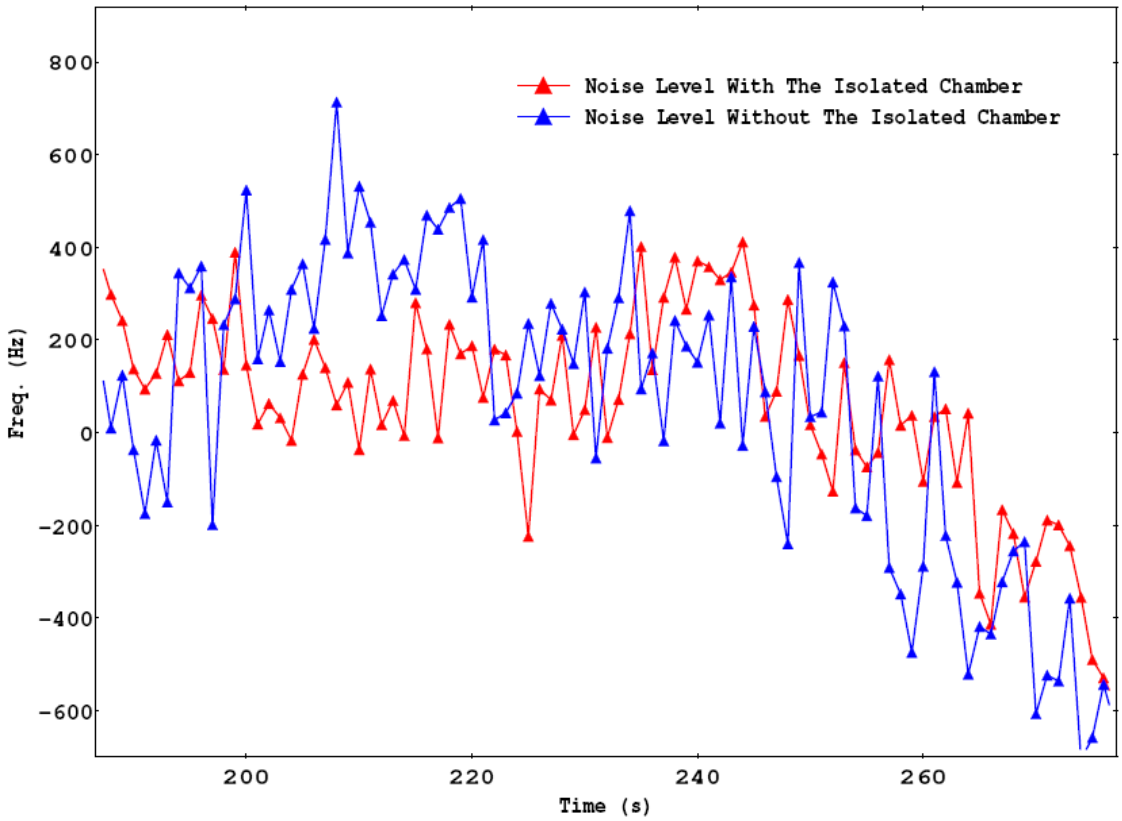

Figure 2. Frequency vs. time for TDO measurements with and without the isolating chamber. No significant change is seen, although it appears without the chamber the noise is slightly greater.

At liquid nitrogen temperatures, data was taken with the coil inside and outside the isolation chamber. With the coil inside, again the data show noise levels of about 1 KHz. With the coil outside the noise level was drastically increased to about 10 KHz. A comparison can be seen in figure 3.

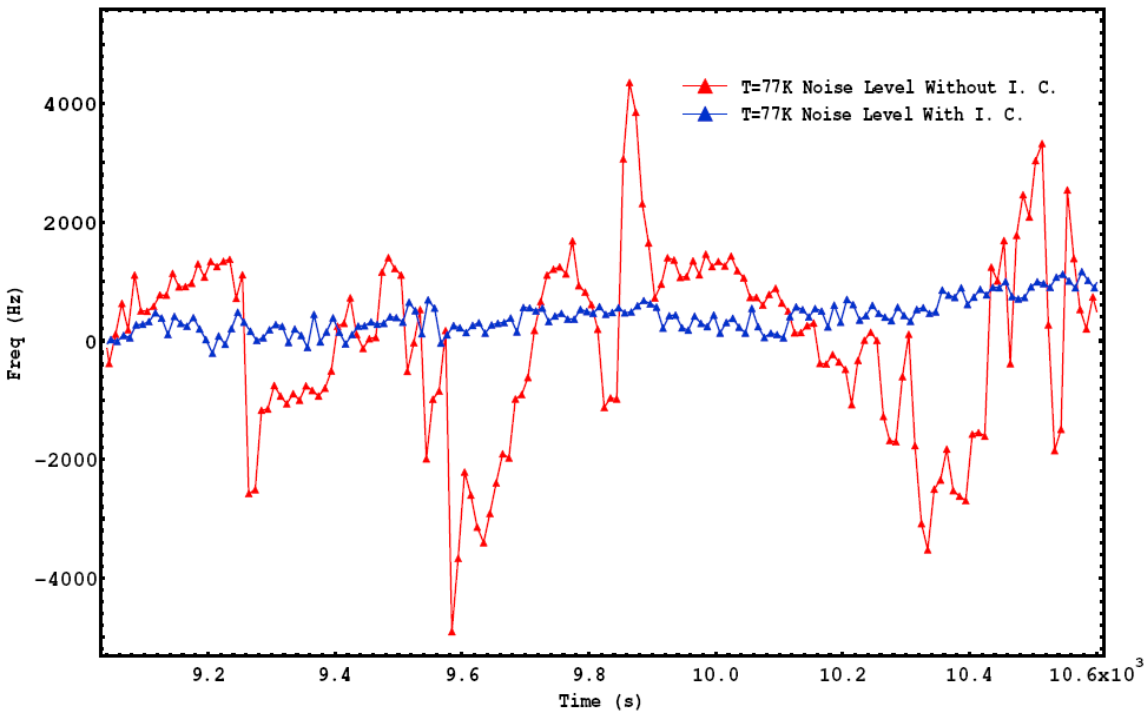

Figure 3. Frequency vs. time data at 77 K. The noise level with the coil inside the isolating chamber is around an order of magnitude smaller.

Discussion

The room temperature data showed virtually no improvement on the noise level, but this should be expected due to the lack of a temperature gradient in air. The fluid flow of the air around the TDO circuit and coil should not be significant, thus should not be a major factor in the noise level.

In liquid nitrogen there is a drastic improvement in the noise level which is seen in the data. This reduction is believed to be attributed to the fluid flow around the circuit and coil due to the temperature gradient in the nitrogen. It is interesting to note that in the isolation chamber, the noise level in the liquid nitrogen data show similar results as the data at room temperature. This suggests that the isolation chamber was successful in preventing fluid flow from disturbing the TDO measurements.

Typical TDO frequencies used here are around 500 MHz. Noise levels of 1 KHz are only 1 part in 10^5, while noise levels of 10 KHz are 1 part in 10^4.

Conclusions

The data show significant improvements in the noise level of the TDO frequency measurements when the circuit and coil are placed inside the designed isolation chamber. This suggests that fluid flow in liquid nitrogen is a considerable source of noise. In addition, it also suggests that the isolation chamber was successful in reducing noise due to this fluid flow.