

CRYOSTATION™ Stability Study

Introduction

The Cryostation was designed for both vibration and temperature stability of the sample. This stability of the sample space is a unique performance differentiator among closed cycle cryostats, and enables many experiments which otherwise would be not possible. The Cryostation controls vibrations by coupling the sample in the sample space very rigidly to the optical table just like any other optic on the table would be rigidly mounted to the table, and isolating the cryocooler vibrations using a very specialized thermal link. This design is effective in isolating external vibrations both from the optics on the table and from the sample area. Temperature stability is achieved by using a combination of active temperature control and passive thermal damping materials that isolate even small thermal variations from the sample. This report discusses how both the vibrations and temperature were measured and what the results were.

This report will show that

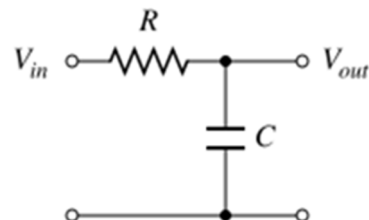
- the short term vibrations of the Cryostation are less than 3nm,
- the sync feature of the Cryostation may be used to achieve vibrations of significantly less than 1nm,
- the long term drift of the system with respect to external equipment is driven by room temperature fluctuations,
- the temperature stability of the sample is better than 10mK, and

All of the data sets used for this study are available for user analysis.

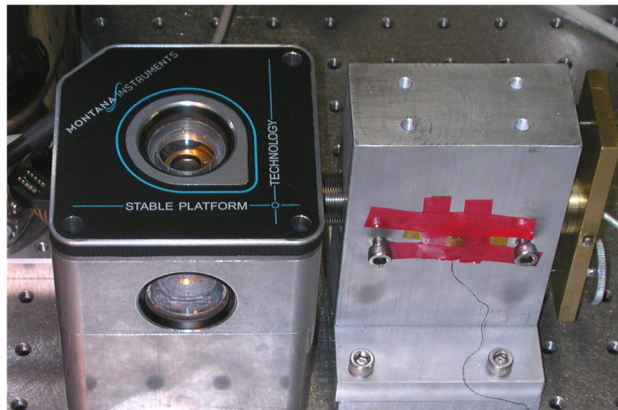
Vibration Measurement Process

Vibration measurements were taken on a standard Cryostation optical cryostat using a Model CPL190 capacitive displacement sensor made by Lion Precision. The sensor provides an analog voltage output proportional to the displacement and is valid over a relatively large range.

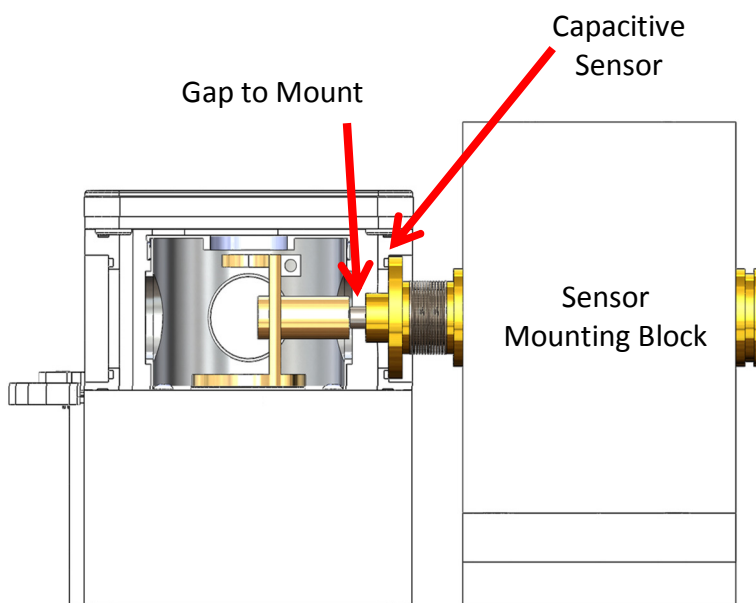
The raw sensor voltage contained some high frequency variations due to local EMI. These were attenuated with a front end analog single pole low pass filter using an RC circuit as shown in the diagram. The values for R and C were chosen to provide a cutoff frequency of 1kHz.



The Lion sensor was mounted through an optical access hole with a hermetic seal and bellows and positioned approximately 150 microns away from the sample mount. The sensor output an analog voltage proportional to the distance from the sensor to the sample mount. This analog signal was captured using a PicoScope 4424 PC-based digital oscilloscope. Data sets of about 250k – 1M points per file with up to 32 of these files depending on the setup were saved. The digital filter feature of the scope was also set to attenuate spurious high frequency signals above 1KHz. With the 1kHz low pass filtering used as described, the peak to peak noise level of the sensor was about 250-300 picometers. All measurements were made using DC coupling to the scope.



This image and line drawing show the measurement setup. The large sensor mounting block is very rigidly coupled to the table and has an interface which extends into the sample space with the capacitive sensor on it. A user thermometer was taped to the side of the sensor mounting block to monitor temperature effects on the hardware due to room temperature variations. The cable that exits the right of the image goes to the Lion control unit. The output of the Lion unit is an analog signal that is connected via coax to the Picoscope. All measurements used for this paper correspond to the X or Y direction of movement which are identical due to symmetry. Z axis vibrations were measured to be similar or better than X and Y. All the sample stage measurements taken for this paper were below 4 Kelvin.



Measurements were taken once the Cryostation had converged and stabilized at its target temperature and the compressor was operating in the stabilized idle run mode.

Expected results

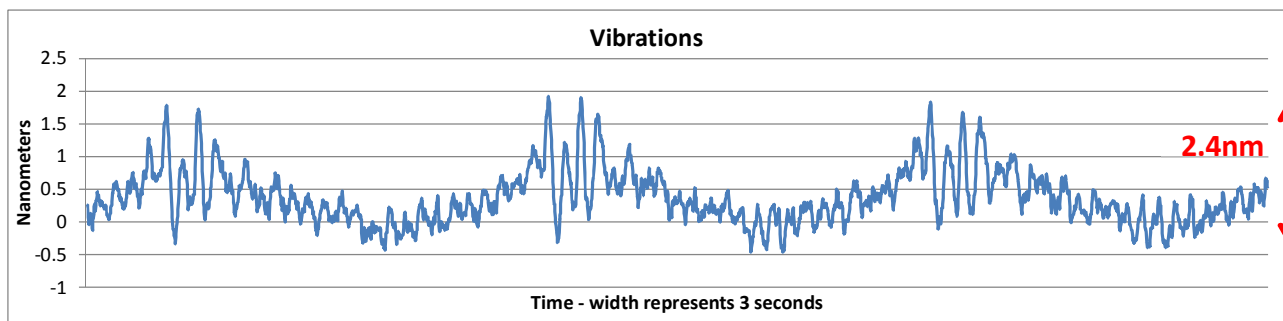
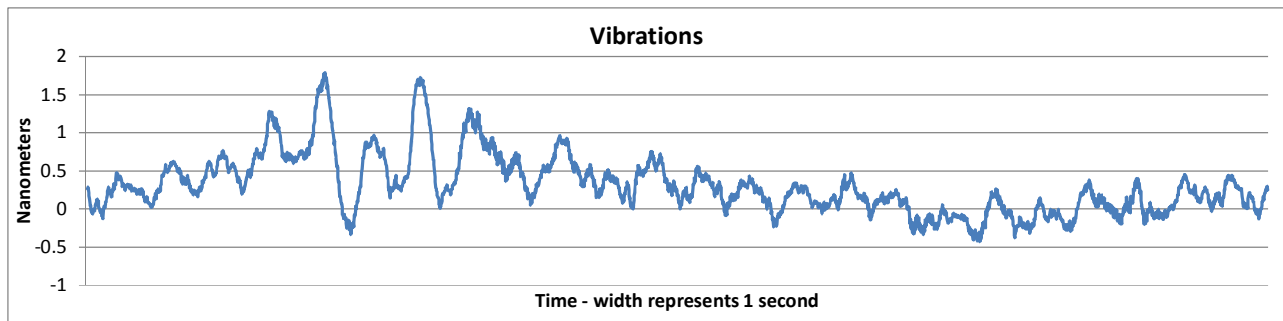
To understand the problem well, it was important to know the primary sources of vibration in the system, regardless of their origin, as well as the first few harmonics if present. The alternating sources of vibrations in the cryostat include:

- 60 Hz due to the line voltage
- 1Hz to 1.4 Hz due to oscillating pressure variations in the cryocooler
- 14Hz to 25 Hz depending on the compressor operating speed
- 40 to 70 Hz depending on the coldhead operating speed
- 20Hz resonant frequency of the floating cryocooler mount

Since all of the possible forcing frequencies of the vibration sources are below 100Hz, it was determined that filtering at 500Hz or 1KHz would be sufficiently high to not compromise the data.

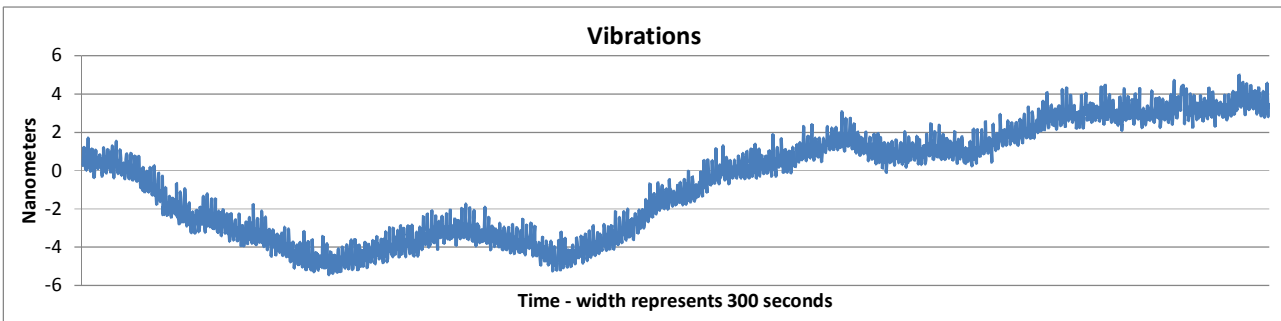
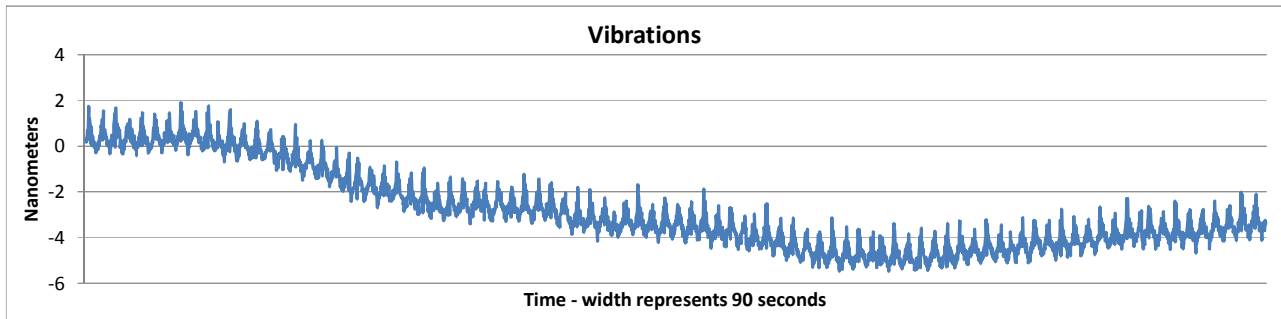
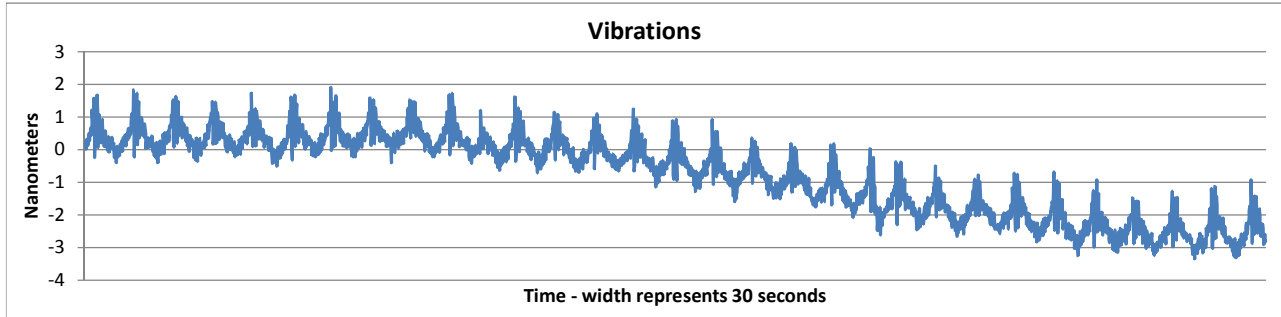
Vibration Results at 3.3K

The measurement system was set to capture data at 26 kHz for 300 seconds, with data stored in CSV files of 10 seconds at about 261,785 points per file. By subsampling from this data with an interval of 9 points, the first 3000 points can be selected to cover about 1 second. Similarly, subsampling at 27 points covers about 3 seconds. The resultant graphs are:



First note the peak to peak vibration (position variation) is less than 2.5nm. The plot is dominated by large pulses at an interval of 1.00 seconds. Additionally, there is a much smaller dominant frequency of 22 Hz. This is due to a resonant frequency of the cryocooler structure.

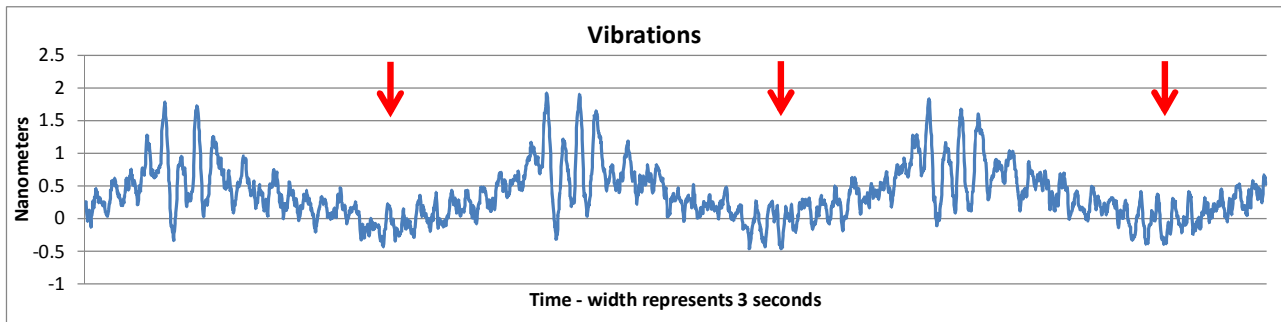
Below are graphs for 30, 90, and 300 second periods, taken from the same data set.



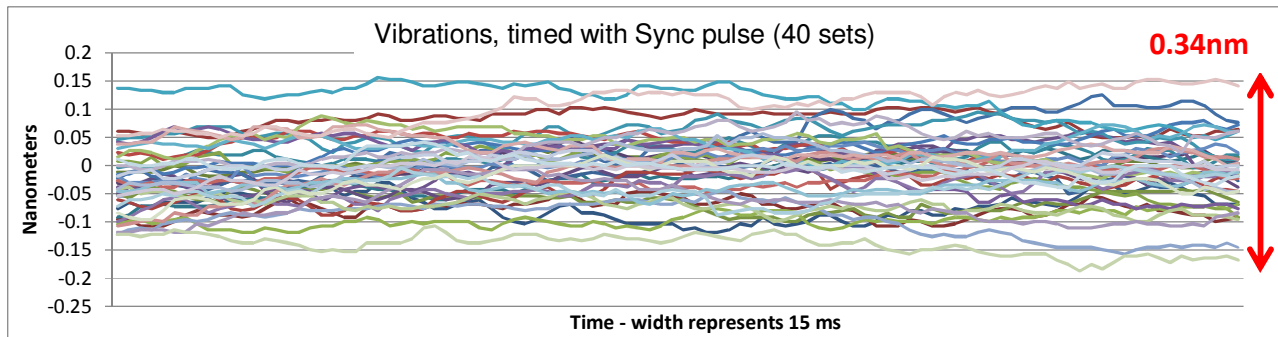
When looking at these larger timeframes, the waveforms are seen along with a small DC drift. This is due to small temperature variations in our laboratory optical table setup during these 5 minutes. Even without any temperature control of the room environment, the overall variation of the signal was still less than 10nm peak to peak. With better temperature control, the peak to peak variation could be limited to 3nm.

Measurements taken using Sync feature of the Cryostation

Since vibrations of the Cryostation are repeatable in nature, the Sync feature of may be used to time data collection with vibrations of less than 1nm. The Sync feature outputs a digital signal corresponding to the exact timing of the cryocooler operating frequency. The graph below shows three compressor pulses at a repeating interval of about 1 second.



At each sync pulse, the vibrations were captured for a period of about 15ms. Here is a plot of 40 such intervals. The peak to peak variations are about 0.34nm for this data.

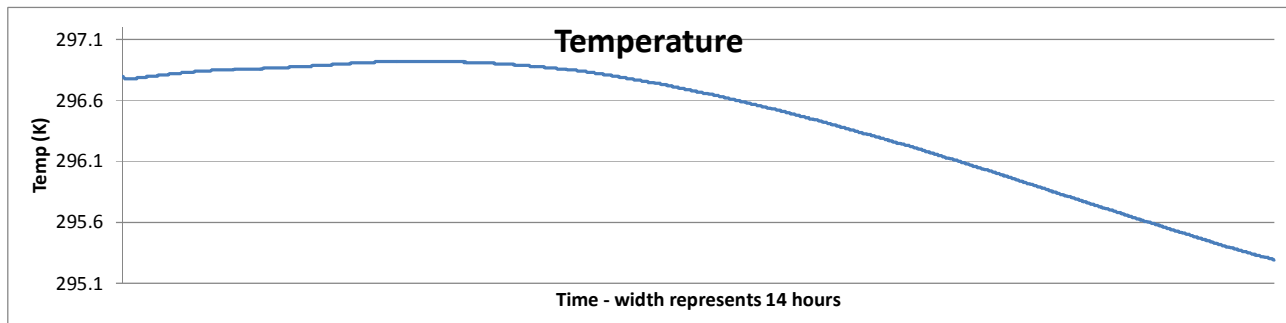
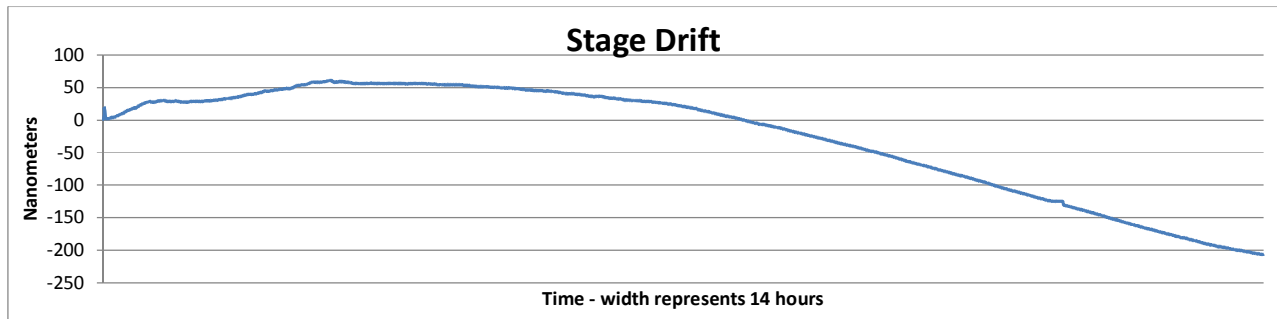


This feature is particularly useful for measurements of short duration. If the user can synchronize their measurements between the pulses of the cryocooler, then very stable performance can be achieved over long time intervals.

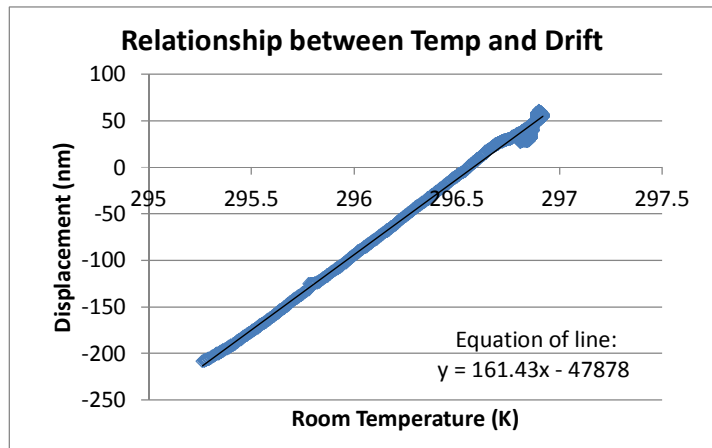
Drift at Room Temperature

In order to understand the drift component of the system, a thermometer was mounted directly to the table near the base of the position sensor mount. The same capacitive sensor measured the position drift on the sample enclosure with respect to a fixture on the optical table. As expected, the position drift correlates to the table temperature.

Below are the graphs of the stage drift and the room temperature over a course of 14 hours. As you can see, the drift is directly correlated to the temperature.

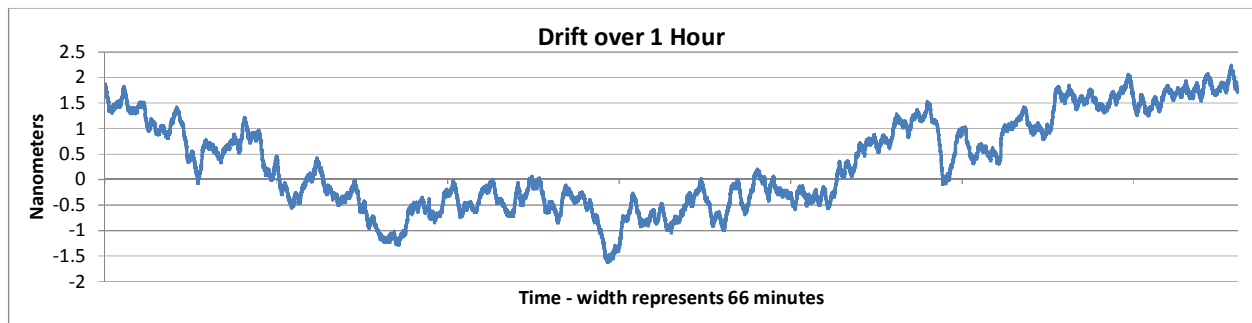


The figure here shows a correlation graph between table motion and room temperature. With few exceptions, the displacement is directly proportional to the temperature. The formula for the linear regression is shown on the graph. The graph slope indicates that the change in displacement per change in temperature is 161.4 nm/K. This can be used to “calibrate” the system. So by knowing the temperature fluctuation of the room accurately, the drift due to table expansion can be estimated and removed from the captured data.



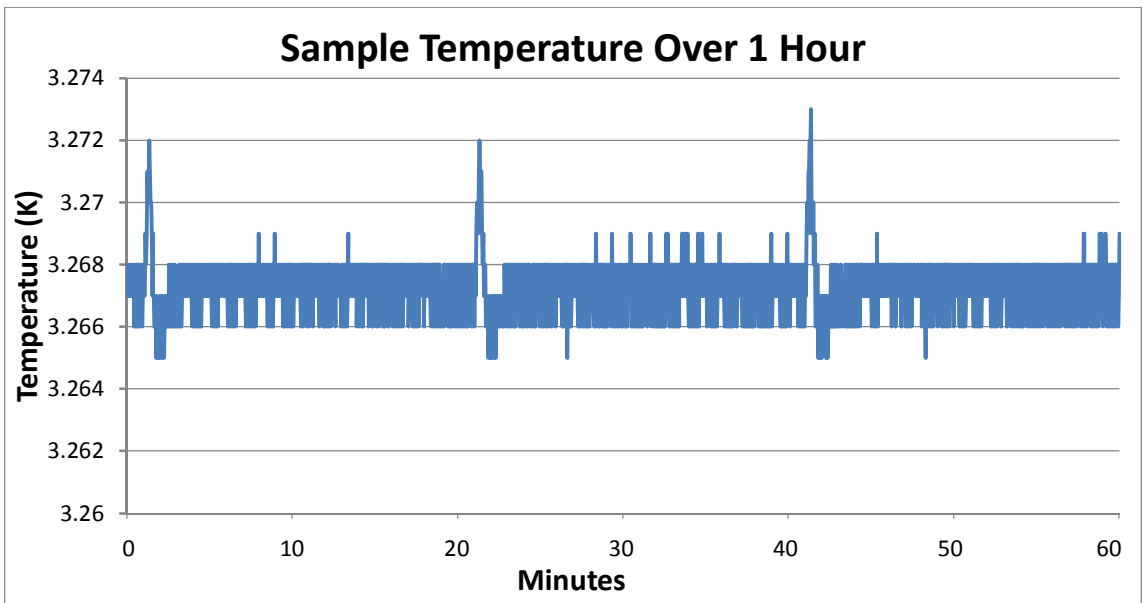
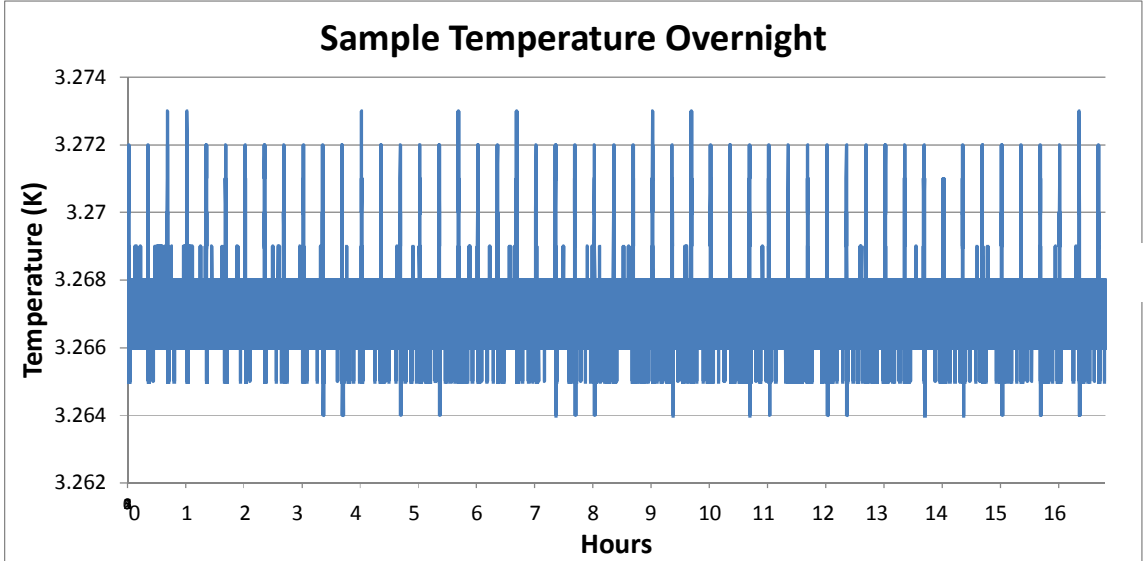
Long Term Drift at 3.3K

The drift of the system is dependent on room temperature. If the temperature is carefully controlled, the system will reach a steady state level. Similar displacement data was captured using the same capacitive sensor, but with a lower sampling rate of approximately 10 samples per second. The result is a plot of position or drift over the course of an hour. The peak to peak variation is less than 4nm for this period.



Long Term Temperature Stability

The temperature performance of the Cryostation was measured using the built-in Cernox thermometers, and the data collection capability of the system. The thermometers are calibrated over a range from 3K to 350K. The graphs below show the temperature stability of the Cryostation for a period of 16 hours, and 1 hour respectively. These are measured at the sample mount where the vibrations are also measured. Note that the peak to peak variation in both cases is less than 0.010 degrees Kelvin. The lower graph shows that most of the variation comes from a temperature impulse every 20 minutes, corresponding to the compressor oil level adjustment which is a normal function of the system. Note that the temperature variation between the spikes is about 2-3mK. So experiments that require only 15 minutes of very stable temperature can achieve stability of 2-3mK.



Conclusions

From this data we observe:

- 1) Vibrations of the sample mount can be measured below 4 Kelvin in the Cryostation using a capacitive sensor,
- 2) The waveform of those vibrations, over periods ranging from 1 second to 14 hours,
- 3) That the peak to peak variations without table drift are less than 3nm,
- 4) That vibrations of less than 0.5nm can be achieved by using the Sync feature,
- 5) The drift of the sample relative to other equipment on the optical table is directly driven by the expansion of the optical table due to room temperature variations, and
- 6) The temperature stability of the system is better than 10mK over short and long time periods.

Data File References

Montana Instruments is making the vibration data available for interested users who may want to reconstruct the data or calculate other properties like spectra. The files are:

Vibration Results at 3.3K (346MB)

The files are named:

vib test 30 x 10sec sets 4-6-2011_XX.CSV

where the last two digits (XX above) of the filename range from 01 to 31

Each file contains three columns:

Time (seconds)

Measurement voltage (where 0.4 volts represents one micrometer)

A calculated value of 2500 times the above measurement represents nanometers.

Due to the difficulty of working with 31 files of 260K points, the data was combined into one file, called

vib test 30 x 10sec sets 4-6-2011 COMBO.xls

This file has the third column of all the files, along with the first two columns of the first file. The second sheet of the excel spreadsheet contains a list of points subsampled from the above 8 million points. This list is 3000 points long and is used simply to create a graph of a portion of the above data. The yellow box in C3 sets the subsampling interval. Setting this to 3 uses every third sample, again with a limit of 3000 points. The graph then shows these 3000 points plotted. The title for the horizontal axis is not automated, so you must reset this before copying the graph out.

Measurements taken using Sync feature of the Cryostation (60MB)

This data set consisted of 32 files with 32,504 points with file names of:

Vibes 5 sec x 32 sets 50kS_XX.csv

Where XX is the file sequence of 01 to 32.

The data is combined into a single file for analysis of:

Vibes 5 sec x 32 sets 50kS with sync COMBO b.XLS

Drift at Room Temperature (37MB)

This data set consists of 26 files each with 32,511 points with names of:

vibes ref on table 26 sets 33min 16bit res lp 5-5-2011_XX.csv

and combined into one data file of:

MI_DiagnosticsDataLog 05_05_2011 COMBO.xls

Long Term Drift at 3.3K

This data set consists of 1 file with 64445 points named

vibes 33min 3.3K 16 bits flat 5-12-2011.xls

Long Term Temperature Stability (5MB)

This is one file with 107,245 data points named

MI_TempDataLog 01_14_2011 Long Term.xls

Please contact the engineers at Montana Instruments if you wish to receive and analyze this data.