

Low Vibration, Low Thermal Fluctuation System for Pulse Tube and Gifford-McMahon Cryocoolers

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ABSTRACT

A compact, integrated mechanical vibration isolation and thermal dampening system, which works for both pulse tube (PT) and Gifford-McMahon (G-M) cryocoolers, has been built and tested. This system provides mechanical vibration reduction to a level less than 22 nm at 1.4 Hz and thermal stability to fluctuation of ~ 1 mK. The unit provides easy sample access and a base temperature of <3 K. The system is described, and data is presented which shows both the vibration and thermal performance of the vibration isolation system, as well as a description of how the results were obtained. The cryogenic work is a key enabling component for several applications where a stable cryogenically cooled environment is required, such as for basic research, superconducting electronics, quantum computing and optical signal processing, among others.

INTRODUCTION

Cryogenic cooling can enable many new applications and research, but the integration of cryocoolers with cooled components is fraught with challenges that hinder system performance and technology advancement. If a stable cryogenic environment can be created that is isolated from cryocooler vibrations and thermal fluctuations, an increasing number of technologies can be enabled and advanced. The need for the low vibration, low thermal fluctuation cryogenic system arose in S2 Corporation's efforts to mount a cryogenically cooled crystalline material for spectroscopic type applications in relation to a laser beam that irradiates the sample. Vibrations and sample movement can cause beam misalignment, unwanted Doppler shifts and material performance degradation due to inconsistent phonon interaction. As a result of engineering efforts to develop the low vibration, low thermal fluctuation system, vibrations and thermal fluctuations were reduced to levels that were acceptable for S2 Corporation's system testing efforts in a compact and conveniently usable form factor. Further improvements are ongoing at S2 Corporation to advance the cryogenic enabling technologies.

TECHNOLOGY OVERVIEW AND PERFORMANCE TESTING

Vibration Isolation

The vibration isolation hardware integrates with both PT and G-M cryocoolers in a single, compact and rugged structure (see Figure 1), so that it can be conveniently placed in an optical

setup with no external support or isolation of the vibrating cryocooler necessary. S2 Corporation has utilized both a Cryomech PT403 and a Sumitomi Heavy Industries 101D 4K (SHI 101D) in the optical setup with similar processing performance results. Only the SHI results are presented here.

The large cold space (2.37 inches diameter by 3 inches height) allows for a variety of S2 Corporation material mounting structures to be cooled, and can be accessed easily by the removal of two plates. The radiation shield can be easily accessed from the same sample space area. It has slots for cold windows for insertion that reduce the heat load on the cooled material.

Vibrations levels are measured for an SHI 101D cryocooler with and without vibration isolation. Figure 2 shows the vibration displacement of a stock SHI 101D cryocooler along with the vibration isolated SHI plotted against time. Figure 3 shows the frequency dependent vibrations of the stock SHI and a vibration isolated SHI cryocooler, each operating around 4 K. In Figure 3, the plot on the left shows vibrations from 1 Hz to 50 Hz, and the plot on the right shows vibrations from 50 Hz out to 1 kHz. Maximum displacements of the isolated SHI are approximately 22 nm at 1.4 Hz. Notice that there is a significant amount of vibration energy at some of the higher frequencies, specifically near 120 Hz, representing the resonant vibration frequency of the cryocooler in the radial plane. At these frequencies, the vibration isolation reduces displacements by over 500 times. Both the axial and radial displacements of the cryocooler were analyzed, however, only radial data (x-axis) is represented here. Axial (z-axis) data did not show vibration features that were above the noise level. Work is continuing to lower the noise on specific components of the interferometer system. It is expected that the axial direction vibrations will be much smaller than the radial because the vibration isolation structure has approximately ten times greater stiffness in that direction.

Figure 4 shows a block diagram of the modified Mach-Zender interferometer setup used to measure the vibrations of various cryocoolers. Each path of the interferometer contained an 80 MHz acousto-optic modulator (AOM). The frequency shift in each path differed by a small amount, e.g. 50 kHz. A mirror was attached to the sample mount of the cryocooler to be measured and was incorporated into one of the paths of the interferometer. The reflected light from the mirror was recombined with the light in the other path to generate the interference signal at the detector. The output from the detector was observed on both an oscilloscope and a digitizer card. The data from the card was collected with a LabVIEW application and analyzed with custom MATLAB software that was written at S2 Corporation.

Thermal Damping

Thermal fluctuations of a typical 4 K cryocooler are measured to be approximately 200 mK peak to peak without any external dampening mechanism. An innovative solution was sought that does not require the use of cryogenics that make the system complex and less reliable for defense

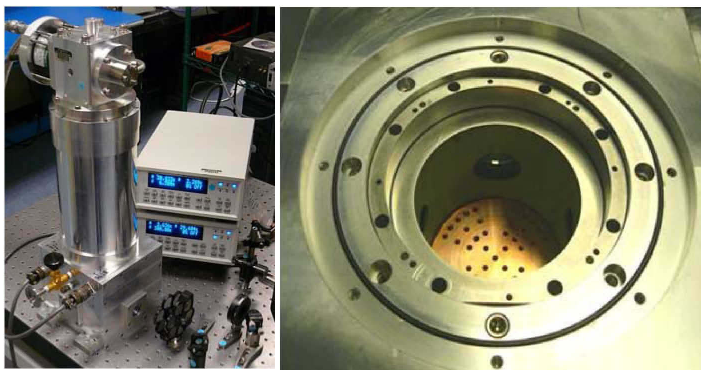


Figure 1. S2 Corporation's latest version of the low vibration, low thermal fluctuation system integrated with an SHI 101D cryocooler operating at a temperature of 2.68 K at the sample space (left), and a view of the sample space, (right). Removal of two round plates allows access to the sample space.

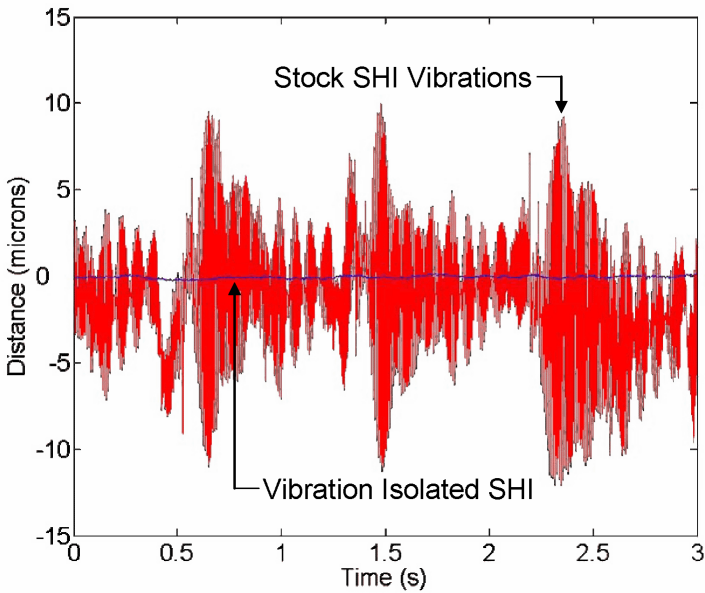


Figure 2. Time dependent vibrations of a stock SHI and a vibration isolated SHI show a significant improvement in the isolated data. These reduced vibration levels were necessary for S2 Corporation’s radar signal processor to be field tested with a cryogen-free cryocooler.

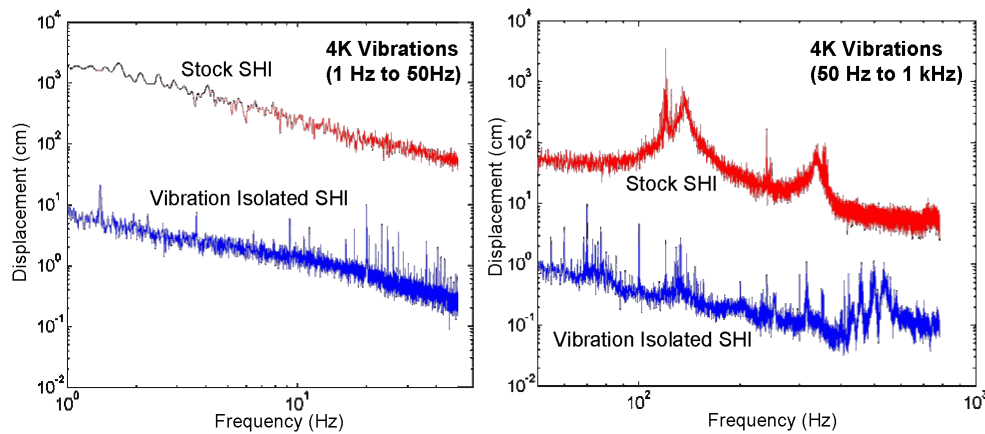


Figure 3. Vibrations of a stock SHI and a vibration isolated SHI operating at 4 K are shown from 1 Hz to 50 Hz (left), and from 50 Hz to 1 kHz (right).

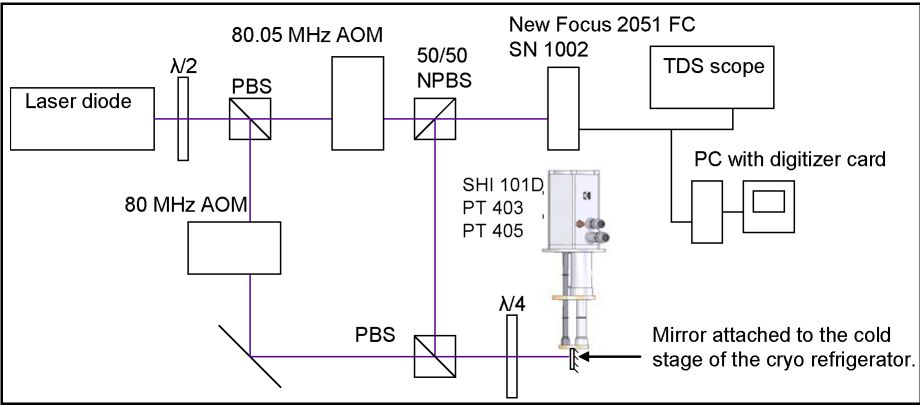


Figure 4. The experimental measurement apparatus layout of interferometer used to measure the cryocooler cold stage vibrations.

applications. A solid state prototype thermal damper was built to fit into the 2.37 inch diameter space of the vibration isolation structure to provide a stable thermal environment for superconducting electronics, stable laser, and signal processing applications. The thermal damper can be easily installed and removed as needed.

Figure 5 shows the prototype thermal damper that was constructed and tested with initial test results. A test was performed using two low temperature calibrated diodes. The gradient and fluctuations were measured for various active heat loads at the sample stage of the vibration isolation structure. With a 20 mW heat load, the thermal damper exhibited a 0.6 degree temperature gradient and a damping factor of 200, resulting in a thermal fluctuation at the sample stage of 1 mK. This prototype was the first damper of this type constructed, and it is expected that future work will reduce the gradient across the damper without significantly decreasing the damper factor.

CONCLUSION AND FUTURE WORK

A compact vibration isolation and thermal damping system was developed which can be an enabling component for several applications where a stable cryogenically cooled environment is required, such as for basic research, superconducting electronics, quantum computing and optical

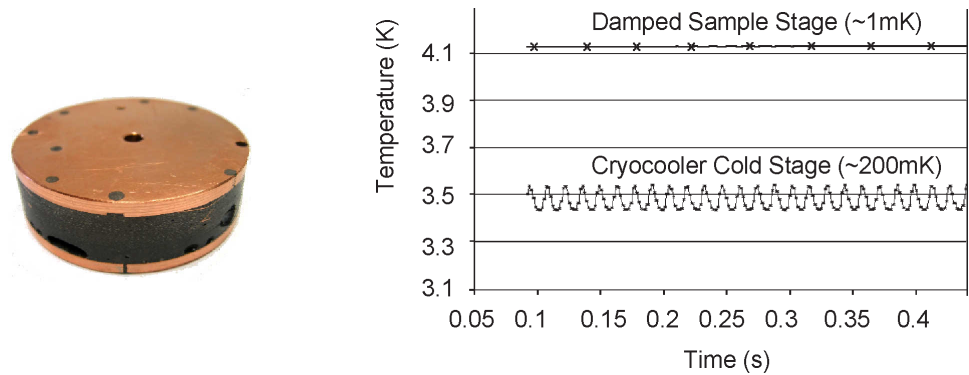


Figure 5. The prototype thermal damper (left) was used with a head load of 20 mW, which reduced the thermal fluctuations from a 200 mK level at ~3.5 K (measured by a sensor above the dampener), to a ~1 mK level at ~4.1 K (measured by a sensor below the dampener). Further improvements to the thermal damper will reduce the temperature gradient across it. (Nonproprietary image of prototype is shown)

signal processing. Both the PT and G-M based low vibration, low thermal fluctuation systems served as key enabling components for S2 Corporation's spectroscopic application demonstrations. Approximately 20 nm level vibrations and ~1 mK thermal fluctuation were achieved. Ongoing work is being completed which will improve the system capabilities.

ACKNOWLEDGMENTS

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