# Vibration Characteristics of 8 K Level High Frequency Pulse Tube Cryocooler

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## ABSTRACT

This paper displays the research results of micro-vibration characteristics of 8 K level high frequency a two-stage pulse tube (2PT) crycooler. The output vibration signature in the frequency domain consists of a series of spikes at the fundamental drive frequency and its harmonics. In order to accurately investigate the micro-vibration characteristic of PT cooler, we built a dynamic vibration force measurement system which has less than 5% relative error in the range from 0 Hz to 200 Hz. According to experimentation results, the second-stage cooler X axis vibration force is the highest and Z axis is the weakest. The first-stage cooler vibration force is weaker than second-stage cooler and first-stage vibration force⩽0.2 N. The first-stage cooler first order vibration force is highest and second-stage cooler fifth order vibration force is the highest. Higher input power, higher vibration force and different input power have the same vibration mode.

## INTRODUCTION

Demand of a low vibration cryocooler is expected by the technical development of a pulse tube (PT) cryocooler. Instruments for which such a low vibration cryocooler is needed are a high resolution gamma-ray spectrometers, a THz space detection, an electron microscope for science, an infrared detector and so on. High frequency PT cryocooler have significant advantages in size, input power and vibration over Gifford-McMahon (GM) pulse tube cryocooler[3]. For an electron microscope, it is reported that the resolution of the microscope was improved by exchanging a PT[2] for a GM cryocooler.

In 2014, our laboratory successfully coupled the THz component studied by the Purple Mountain Observatory (PMO), CAS and our two-stage high frequency pulse tube cryocooler. The THz component worked well at 8K with total 450 W input power[1]. Figure1 show the detailed information. For precise optics and semiconductor equipment, the mechanical vibrations of a cooler and its substantial impact are the main restraint problem. The exported vibration of a PT cooler is caused by the acceleration of the moving masses in the cooler during its periodic motion. The reciprocating motion of the pistons,

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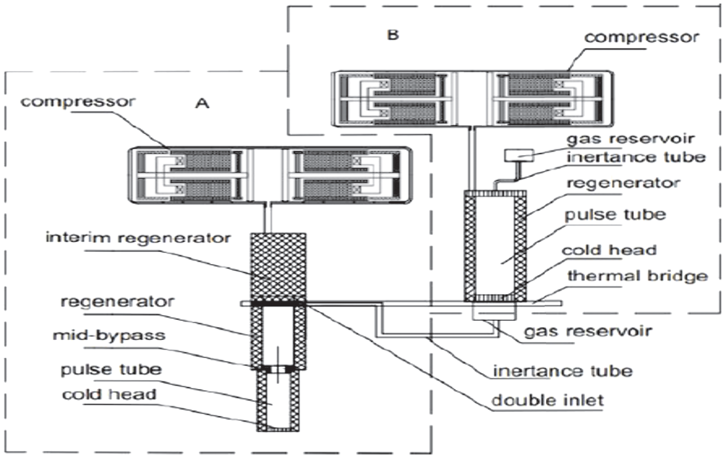


| Cooler | First-stage | Second-stage |
|---|---|---|
| Frequency (Hz) | 42 | 18 |
| Input power(W) | 200 | 200 |
| Cooling Performance | 1.5W@70K | 30mW@8K |

**Figure 1.** Two-stage high frequency PT cooler cooling characteristic.

the elastic response of the structures and the dynamic fluid-structure interaction in the cold head are the three main sources of vibration. Pulse tube coolers generate a smaller vibration level than Stirling coolers and GM cooler because PT coolers contain no cold moving displacer.

In this paper, the micro-vibration force dynamic testing system is built in order to research PT cooler vibration characteristic and testing system relative error ≤5% in rage 0~200 Hz. Exported three-dimensional vibration data of 8 K level two-stage high frequency PT cooler are presented for different input powers.

## MICRO-VIBRATION TEST APPARATUS

The micro-vibration testing system is shown in Figure 2. Measurements were made with a three-axis dynamometer Kistler 9257B which is rigidly fixed in stable and rigid vibration damping

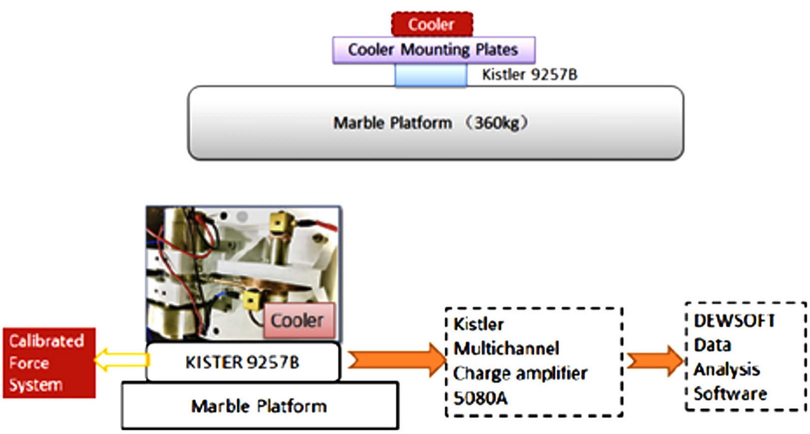


**Figure 2.** Micro-vibration test apparatus.

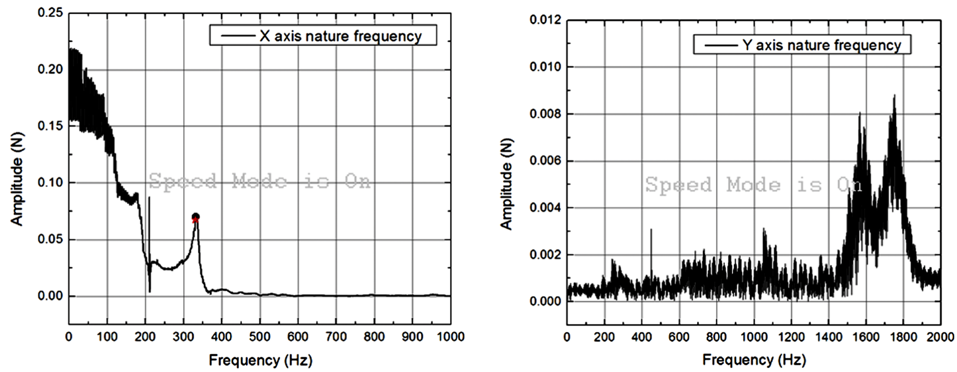


**Figure 3.** Micro-vibration test system natural frequency.

marble platform. The cooler is mounted in the dynamometer with a rigid steel plate. Thus, we need to calibrate the micro-vibration test system usable frequency range and relative errors.

## Dynamometer Calibration

Frequencies up to about one-third of the natural frequency can be resolved without excessive measuring errors. A heavy workpiece mounted on the dynamometer may alter the usable frequency range, thus we measure the micro-vibration test system (with coolers) natural frequency. The 2PT cooler is tapped with a rubber harmer and the spectrum of disturbance force amplitudes are analyzed. Figure 3 shows the natural frequencies of micro-vibration test system in the X and Y axes which are 330 Hz and 1500 Hz respectively. Furthermore, a vibration exciter JZK10 is introduced to calibrate the test system as a reference vibration source. Figure 4 shows the calibration test system configuration. The Kistler 9257B force sensor is mounted to a rigid platform and shaken by the JZK10 through the cooler mounting plates; the excitation force can be measured with a one-dimensional

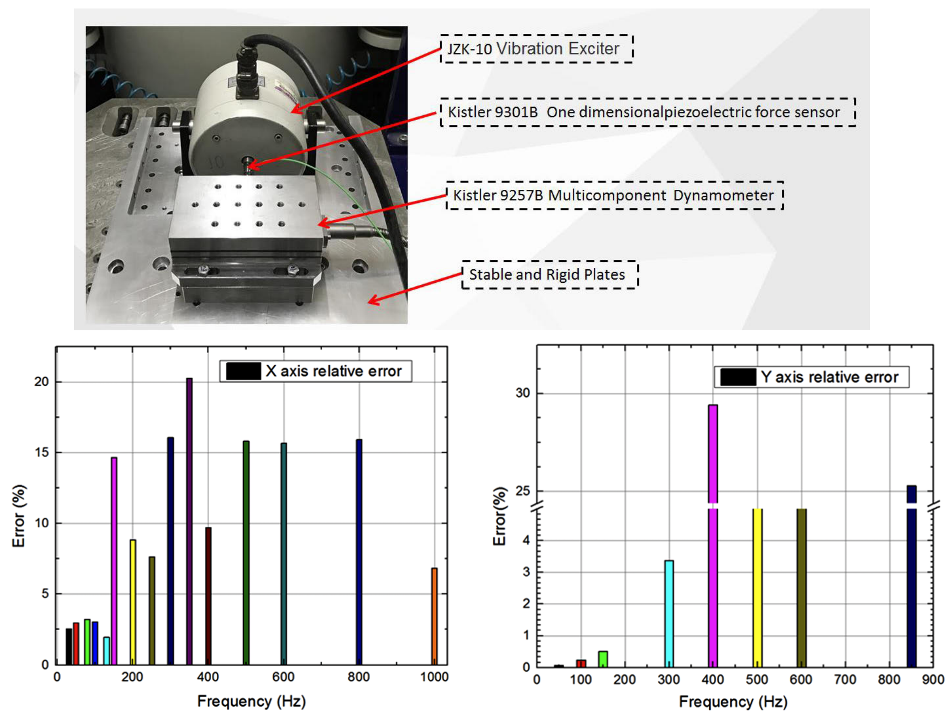


**Figure 4.** Calibration test configuration & Measurement relative errors.

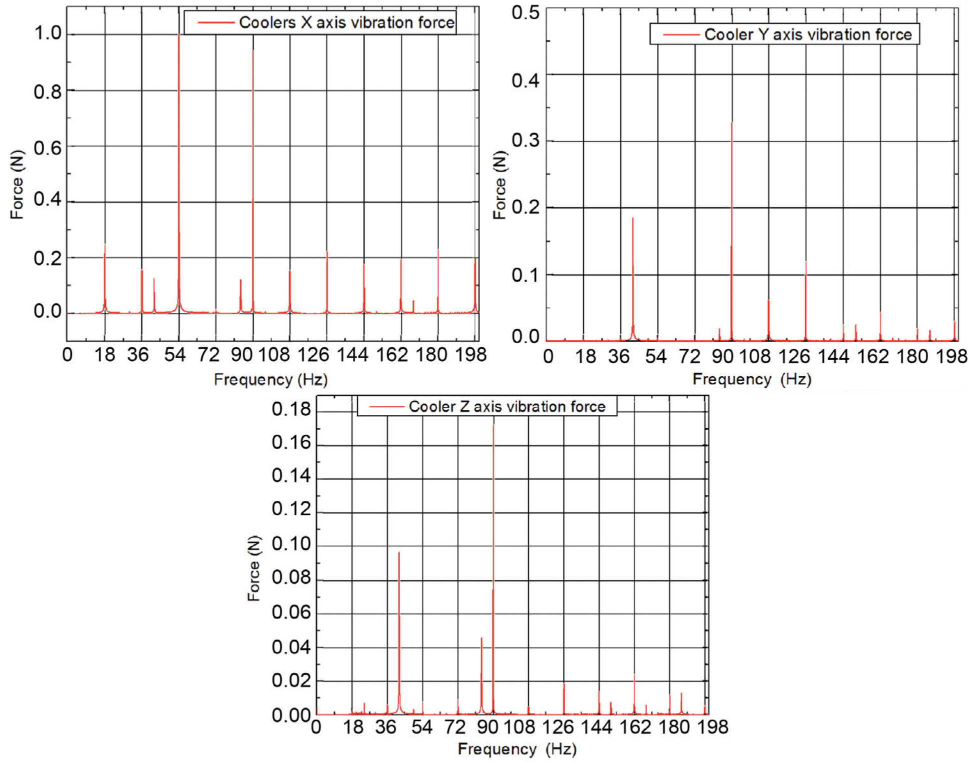


**Figure 5.** Spectrum of disturbance force amplitude exported by 2PT cooler.

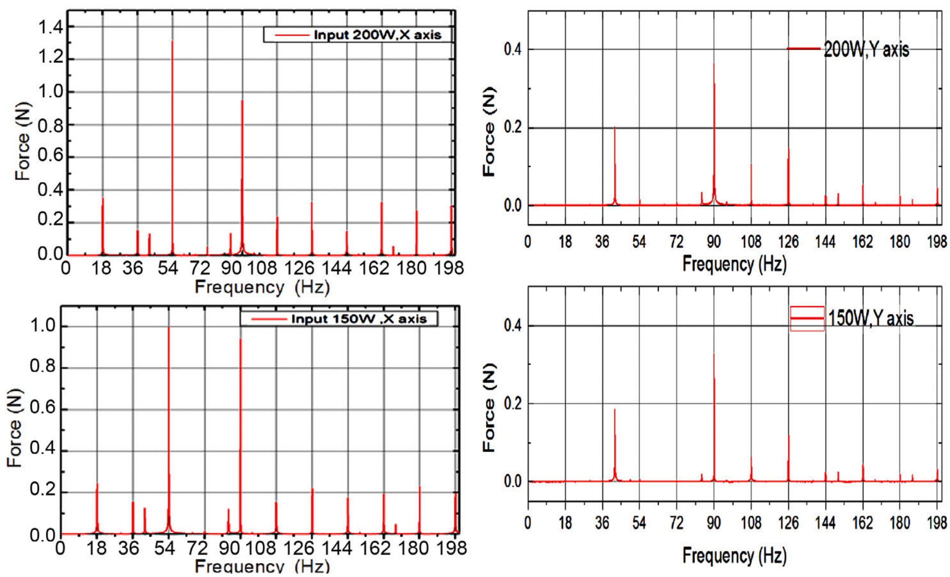


**Figure 6.** Exported vibration 150 W and 200 W input electrical power.

piezoelectric dynamic force sensor Kistler 9301B at the connection point. The JZK-10 can export sine vibration force. Consistency between the measurement value of the Kistler 9301B and Kistler 9257B is insured as a frequency response function and the relative errors of 5% over a frequency range less than 200 Hz as shown in Figure 4.

## VIBRATION CHARACTERISTICS OF CRYOCOOLER

The 2PT cooler can produce 22 mW of cooling power at 8K with a two-stage thermal-coupled high frequency pulse tube coolers. The 2PT cooler is used for the space application of terahertz technologies and SNSPD. We measured the vibration of the 8K level high frequency 2PT cryocooler with a micro-vibration test system.

The 2PT cooler ws hard mounted to the Kistler 9257B force table and the 9257B was mounted on a stable and rigid platform. The measured vibration output is shown in Figure 5 for each of the 3 axes. The X axis compressor horizontal radial， the Y axis compressor vertical radial and the Z axis compressor axial. Figure 5 shows the first-stage (42 Hz) compressor vibration is weaker than second-stage (18 Hz) compressor vibration and The first-stage compressor exported vibration force ⩽0.2 N. The X axis of second-stage cooler vibration force is the highest. The first order (42 Hz) vibration of first-stage compressor and the fifth order (90 Hz) vibration of second-stage are the highest. Vibration in the X axis is the strongest and the Z axis is the weakest. In a word, 2PT cooler vibration is lower than a GM cooler.

Figure 6 shows the vibration characteristic of 2PT at 150 W and 200 W input power. Vibration exported at different input powers has the same spectrum of disturbance vibration and higher input power has higher exported vibration force.

## CONCLUSION

This paper describes a multicomponent dynamometer vibration force system. The usable frequency of the test apparatus is less than 200 Hz and relative error less than 5%. It is suitable to measure the exported vibration of the 2PT cooler. This paper also displays the exported vibration characteristic of 2PT cooler. The cooler vibration force is less than 0.2 N and second-stage cooler X axis and 2PT cooler vibration forces are less than GM coolers.

## ACKNOWLEDGMENT

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