Development of a Small Vibration Cryocooler for CLIO

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Abstract

A small vibration cryocooler system for the CLIO is under development. This system was designed based on an experimental evaluation of vibrations for cryocoolers. The result of the evaluation shows that although a pulse tube cryocooler is suitable, it has larger vibrations than the requirement for the CLIO. We plan to reduce the vibrations by introducing a vibration reduction stage and a support stage of the cold head.

1. Introduction

The Cryogenic Laser Interferometer Observatory (CLIO) is a prototype of a cryogenic interferometric gravitational wave detector under construction in the Kamioka mine[1]. The displacement-sensitivity goal of the detector is the same order as that of the LCGT[2]. In developing a cooling system of the CLIO, we have focused to develop a 'quiet' cooling system, since small heat generation in the detector is estimated. The specification of vibration for the cooling system is the ground-vibration level in the Kamioka mine ($10^{-9}/f^2$ [m/$\sqrt{\text{Hz}}$]).

At first, we investigated the vibration amplitude and the vibration mechanism for cryocoolers. Based on the measured results, we designed a 'quiet' cryocooler system for the CLIO.

2. Vibration Measurement for Cryocoolers

We measured the vibrations of a newly developed 4 K pulse tube (PT) cryocooler[3] and a widely used 4 K Gifford-McMahon (GM) cryocooler, produced by Sumitomo Heavy Industries Ltd. PT cryocoolers are expected to be more quiet than GM cryocoolers.

Fig. 1. shows the vibration measurement system developed for the cryocoolers[4]. A feature of this system is to be able to measure not only the cold

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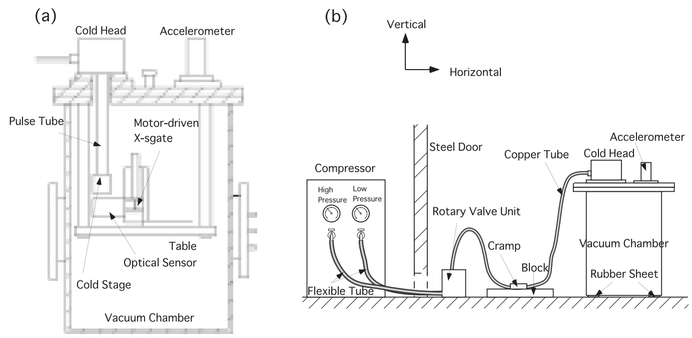

Fig. 1. Vibration measurement apparatus for cryocoolers. (a) shows the setup of the sensors, and (b) shows the whole setup. The part of the "pulse tube" is called a "cylinder" for GM cryocoolers.

stage vibration, but also the whole cold head vibration at a thermally steady state. A separate measurement of these vibrations is useful to understand their vibration mechanism. A measurement at the thermally steady state of the cryocooler is important to know the correct vibration amplitude. The cold stage vibration was measured by an optical displacement-sensor. The sensor was calibrated just before each measurement. The vibration of the whole cold head was measured by accelerometers. For the PT cryocooler, a rigid copper-tube was connected between the cold head and a rotary valve unit, and was anchored on a block of 24 kg. For the GM cryocooler, flexible tubes were directly connected to the cold head, and were also anchored. The measurement system and the compressor were partitioned by a steel door to eliminate any sound effects.

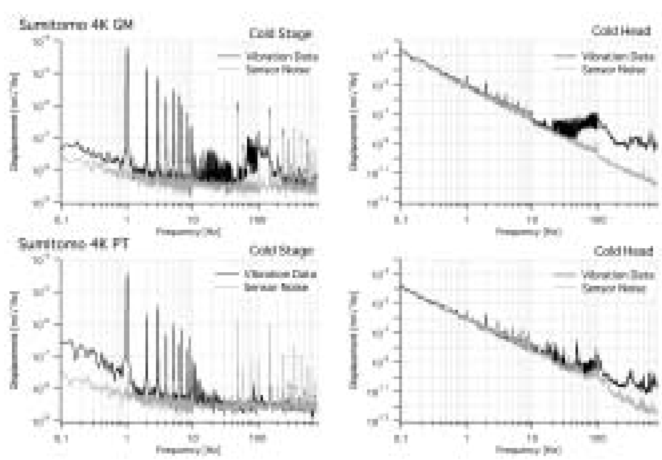

Fig. 2. Power spectrum densities of the vibration amplitude for the 4 K cryocoolers. The cold head vibration for the GM cryocooler was measured by a piezo-electric accelerometer and that for the PT cryocooler was measured by a laser accelerometer.

Fig. 2. shows the measured power spectrum densities of the vibrations for the cryocoolers. The features of the spectrum are large vibrations in the frequency range above 10 Hz for the cold head of the GM cryocooler, and sharp peaks of 1 Hz and their higher harmonic frequencies in the cold stage vibrations for both cryocoolers. The vibration of the cold head for the GM cryocooler mainly comes from the motion of the displacer. Since the PT cryocooler has no displacer, its vibration amplitude of the cold head was two orders of magnitude smaller than that of the conventional GM cryocooler. The sharp peaks of 1 Hz come from an elastic deformation of the 'pulse tube' due to pressure oscillation of working gas. These amplitudes for both cryocoolers were almost the same.

From the results of these measurements, we decided to adopt the PT cryocooler for the CLIO.

3. Vibration Reduction of a PT Cryocooler

Although the PT cryocooler has smaller vibrations than the conventional GM cryocooler, its vibration level is still higher than the requirement for the CLIO. Our concept of vibration reduction of the cooling system for the CLIO is to separate the vibration sources from the main cryostat and to anchor them to the ground, since the ground in the Kamioka mine is a quiet and hard monolith. Fig. 3. shows the concept of the vibration-reduction system.

To reduce the vibration from the cold head, it is not set on the cryostat directly, but on the support stage independently. The cold head is connected to the cryostat by a soft welded bellows, and damping rubber sheets are put between the bellows to reduce the vibrations through its surface. We simulated the resonant frequencies of the stage by using a finite element method (FEM). The size of the stage is 52 cm in width and 80 cm in hight. The props of the stage are 9 cm×9 cm in width and have crossbeams. A cold head of 15 kg was set on the stage. The result shows that the lowest resonant frequency was 170 Hz. Additionally, we estimated the vibration amplitude of the stage by using the data of a vibration measurement and a FEM simulation. The result showed that the horizontal vibration amplitude was 10^{-7} m. Although this value is much larger than the requirement, the vibration will not conduct to the main cryostat, since the stage is completely isolated from it.

In the cryostat for the cold head, a vibration reduction stage is set to reduce the cold stage vibration. The stage consists of eight glass-epoxy pipes of 16 mm in outer diameter, 1.5 mm in thickness, 110 mm for the first stage and 190 mm for the second stage in length, and two copper plates. Heat link wires are connected between the cold stage and the vibration reduction stage. The lowest resonant frequency of the stage calculated by the FEM is 93 Hz. Although it is difficult to estimate the vibration reduction rate of the stage, there is a report that the cold stage vibration was reduced to about 1/10 by using a simple vibration

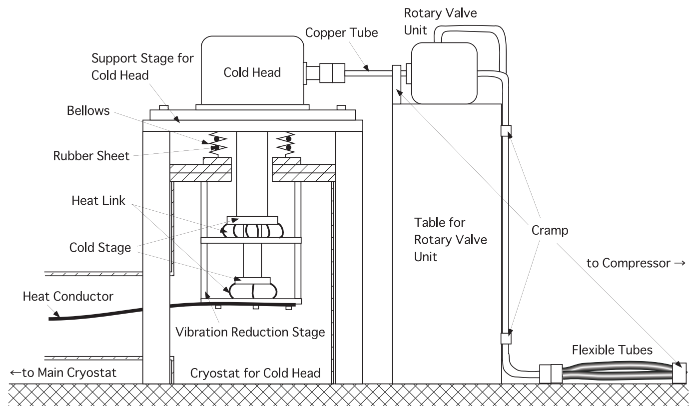

Fig. 3. Concept of the vibration reduction of the PT cryocooler.

reduction stage[5].

4. Conclusion

We evaluated the vibration of the cryocoolers. The result shows that the PT cryocooler is suitable for the CLIO. However, since its vibration amplitude is still larger than the requirement for the CLIO, we are developing a small vibration cryocooler system, which has a vibration reduction stage and a support stage for the cold head. By using this vibration reduction system, we aim to reduce vibrations by two orders of magnitude. To achieve the specifications of the CLIO, we plan to reduce the surplus vibrations of the cryocooler system by more two orders of magnitude in the heat conduction system between the cryocooler system and the main cryostat.

We are designing the cooling system of the CLIO. We will produce one unit of the system in 2003, and will test its vibrations in early 2004.

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