Present Technology for Reduction of Vibration in Cryocooler

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Abstract

Cryocooler could be a best choice to obtain "cryogenics temperature" quickly and easily. However, if a very quiet condition is strongly required, careful consideration must be done because a cryocooler essentially needs pressure oscillation to generate low temperature. Gas pressure oscillation intrinsically causes vibration at the cold stage of cryocooler. This paper presents the basic concept about the vibration in a cryocooler, and shows the survey results on present technology for reduction of vibration in a cryocooler, especially in a pulse tube cryocooler.

1. Introduction

The recent development of the cryocooler is outstanding. It can cover the wide temperature range from 1.8 K to higher than 200 K with sufficient cooling power for relatively small heat load applications. There are many advantages to use cryocoolers instead of liquid cryogen, such as LN2 and LHe. No more special technique to handle troublesome cryogenic fluids. Only by turning on the operation switch just like a domestic refrigerator, one can get low temperature. However, one major disadvantage still lies in using the cryocooler, that is vibration, which is caused by gas oscillation in the cryocooler. This disadvantage sometimes makes it difficult to apply a cryocooler to "quiet" application fields, such as cooling cryogenic sensors, detectors etc.

2. Vibration in cryocooler

There are several types of cryocoolers, such as G-M, Stirling , V-M, pulse tube and so on. To achieve efficient expansion, G-M and Stirling cycle cryocoolers are using a solid piston which results "noisy" vibration at the vicinity of the cold stage. Only one cryocooer, a pulse tube type, uses so-called "gas piston" instead of a solid piston, and can possibly eliminate the noise and vibration of solid mass moving near the cold stage. However, almost all kind of these cryocoolers are

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Table 1. Measured vibration level in the 4 K pulse tube cryocoolers

	Cooling power W@4.2K	Operating Frequency Hz	Vibration μm (p-p)	Temp.	Measurement method
Cryomech [4]	0.5	1	25	RT	Potentiometer
Sumitomo[5]	0.7	1	46	RT	Laser
Daikin [1]	0.1	2.2	4	LT	Laser

using gas pressure oscillation to produce low temperature. It is essential to use high pressure and low pressure to realize a "cooling cycle". Even in a pulse tube cryocooler which eliminated solid piston movement, this pressure oscillation is inevitable for low temperature production. A simple equation can easily predict the displacement level (vibration at the operating frequency) in a cylindrical pipe as follows:

$$\Delta x = \Delta p R L / k t \tag{1}$$

where, Δx is displacement of the pipe end due to pressure change, Δp is the pressure difference between high pressure and low pressure, R, L and t are a pipe radius, length and thickness, respectively. k is volumetric elasticity of a material in use. For example, displacement is calculated as $\sim 8\ \mu$ when $\Delta p = 2$ MPa using 40 mm diameter and 200 mm length with 1 mm thickness stainless steel pipe.

3. Methods for reduction of vibration and achieved level

To reduce Δx in eq. (1), one can try to reduce Δp, R, L or increase t. For realistic design of cryocooler, there is no room to vary R and L too much. Increasing t, thickness of a pipe, could be one way to reduce the displacement of the pipe if one can allow an excess heat load into the cold stage. This method has reported by Daikin Co., Ltd. [1] claiming that the displacement of a second stage of a 4 K pulse tube cryocooler was reduced to be 4 μm. Alternative way is to reduce Δp, peak to peak value of pressure oscillation. By applying a thermal compressor, it is reported that Δp could be reduced from 1.2 MPa to 0.4 MPa corresponding to 1/3 reduction of displacement [2]. So far, several companies have shown the measured vibration level in the 4 K pulse tube cryocoolers, although the measuring condition is different each other. Summarized results are shown in Table 1.

4. Flexible thermal link

Alternative way to reduce the vibration at the cold stage of a crycooler is to use a flexible thermal link which can cut off only the vibration with keeping good thermal conductance. Several research groups have already developed such links.

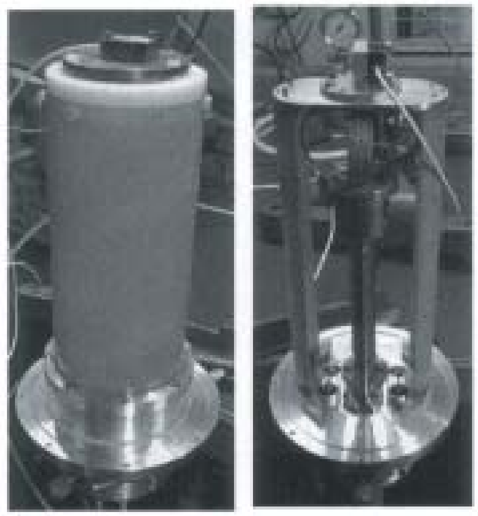

Fig. 1. Vibration reduction flexible link applied for high Tc SQUID [3]

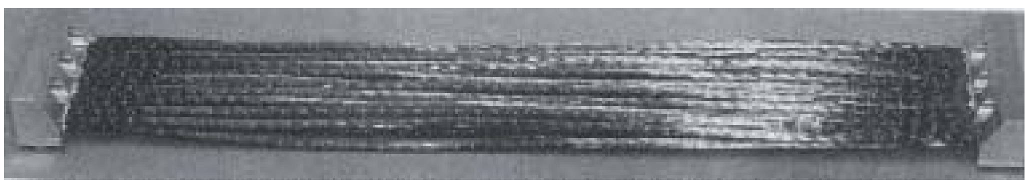

Fig. 2. K1100 graphite fiber thermal strap assembly [6]

Fig. 1 shows a picture of the flexible link developed by Giessen University group in Germany [3]. This mechanism was applied to the 80 K pulse tube cryocooler for high Tc SQUID operation. By using this vibration reduction method, the measured vibration at the cold stage was reduced to be 0.5 μm as compared to 6.0 μm without compensation. A similar method was applied to a 4 K pulse tube cryocooler by Cryomech group [4]. In this case, the second stage is connected to the plate by a simple flexible connection. It is reported that the vibration at the 4 K stage was eliminated from 25 μm to less than 3 μm. The key point of this link is a selection of materials. As for the sustaining post, G-10 tube is used because of thermal isolation between the cold stage and room temperature flange. And as for the flexible link, copper blade wire is widely used because of its excellent thermal conductivity. Recently, new material demonstrated possible candidate for this purpose. A light-weight, flexible, high-conductance graphite fiber thermal strap (GFTS) was developed for the purpose of space application in USA [6]. They claimed that a GFTS demonstrated a thermal conductance of 0.20 W/K with a 78 % weight saving over a solid copper (OFHC) bar of the same conductance. Figure 2 shows a graphite fiber strap developed by Technology Applications, Inc., USA. Total length is 28.5 cm. It consists of three rows and each row has 20 fiber bundles with 20,000 fibers. KEK and the Sumitomo Heavy Industry Co., Ltd. have been collaborating to develop a 4 K pulse tube cryocooler with extremely small vibration for the gravitational wave observatory project [7]. The basic concept for vibration reduction is to use the flexible thermal link with high purity aluminum blade wire for good thermal conductivity and light weight. An aluminum blade with 7 bundles with 2,000 fine fibers in each bundle is successfully fabricated and the measurements on thermal performance will be carried out.

5. Summary

The basic concept of intrinsic vibration in a cryocooler is summarized and showed the survey results on present technology for reduction of vibration in a cryocooler, especially in 4 K pulse tube cryocoolers.

x=Displacement, mm	p=Pressure, MPa
R=Radius of pipe, mm	L=Length of pipe, mm
t=thickness of pipe, mm	k=Volumetric elastivity

6. References

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