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Reduction of vibrational noise from continuously filled 1 K pots

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We have examined the vibrational noise originating from 1.3 K pumped helium chambers (1 K pots) that are continuously filled from the 4.2 K bath through an impedance. The noise can be largely eliminated by either heating the pot or by heating the impedance directly. Noise in 1 K pots has detrimental consequences for the operation of audio frequency torsional oscillators and for high precision thermometry. © *1998 American Institute of Physics.* [S0034-6748(98)03512-6]

I. INTRODUCTION

Vibrations in cryostats are a cause of unwanted heating and can result in the degradation of the signal-to-noise ratios for experiments. Typically, external sources of noise such as mechanical pumps which are coupled to the apparatus through flexible lines are dealt with using standard techniques.[1] While performing experiments involving torsional oscillators or high resolution thermometry we encountered vibrations that originated inside the cryostat. For torsional oscillators operated under favorable circumstances, an amplitude stability of 10^{-4} and frequency stability of 10^{-9} are possible, but this performance is easily degraded through interactions with vibration sources. Similar degradation of signal to noise has been observed in a cryostat where the magnetization of a paramagnetic salt is monitored by a superconducting quantum interference device (SQUID) as part of a high resolution thermometry arrangement.[2]

In order to reduce the consumption of liquid helium, cryostats are normally built to pump on only a small volume (1 K pot) filled with ^{4}He which is continuously replenished from the bath through an impedance.[3] The pot maintains a temperature of about 1.3 K, and is a necessary first stage of cooling for a dilution refrigerator. In practice, the impedance is set so that the pot is always overfull—with the level of the liquid–vapor interface extending into the pumping line—in order to accommodate increases in the heat load.[4] We will show that this state causes unwanted vibrations in the apparatus.

A variable impedance would be needed to accommodate a variable heat load and maintain the helium level at a specified level in the pot. Valves to vary the impedance are difficult to incorporate into an apparatus and frequently they do not provide a fine enough control. For practical reasons we chose to concentrate on thermal methods to control the flow because they can be applied to all existing cryostats. We installed a heater directly at the 4.2 K end of the impedance to reduce the flow of liquid into the pot. Previous measurements[5] indicated that the vibrations in the 1 K pot could be suppressed by heating the pot to lower the level of helium. We also investigated this method of reducing the 1 K pot noise.

II. EXPERIMENTAL DETAILS

The two cryostats[6] used for these measurements were constructed inhouse. Cryostat A, used for the first study, was isolated from building vibrations by suspending it on rubber tubing. Cryostat B, was supported on three 1 cm^2 pieces of Isomode[7] corrugated neoprene pads to reduce coupling to external low frequency vibrations. For cryostat B, the 1 K pot is a brass cylinder with a diameter of 5.25 cm, and height of 5.25 cm. The impedance is copper nickel tubing 4 m long, and 0.1-mm-inner diameter. The middle third of this impedance was wrapped around and soldered to a 1-cm-diameter copper spool clamped to the 1 K pot pumping line to isolate the 1 K pot from heat added to the impedance. The remaining length of copper nickel tubing is loosely coiled, greased down, and tied in a 1-cm-diameter bundle. This impedance allowed a flow of 0.2 mL/min of helium at room temperature at a pressure difference of 0.5 bar. The level of liquid helium in both the 1 K pots was measured using coaxial cylindrical capacitors.

Vibrations were measured using a piezoelectric cantilever[8] whose resonant frequency (30 Hz), was well below the bandwidth of noise. On cryostat B, the voltage across the sensor was fed to a PAR model 116 differential voltage preamplifier, and then to a Krohn–Hite model 3323R 48 dB/octave band pass filter set to pass signals between 300 Hz and 20 kHz. The signal was then sent to a Hewlett–Packard model 3562A signal analyzer from which power spectra were obtained by averaging for 30 s. The spectra obtained under various conditions were plotted and then digitized. Cryostat A employed a similar setup with the exception that each spectrum was integrated over the range 4–50 kHz.

Cryostat A, used solely to investigate the changes in vibrational noise associated with the helium level in the 1 K pot, was equipped with a single heater on the pot. Two heaters were used during the investigation on cryostat B. The first is a 172Ω resistor attached to the 1 K pot. The second (290Ω) resistor is clamped to the fill line at the 4.2 K end of the impedance. Either heater could be connected to a voltage source with a maximum output of 3 V.

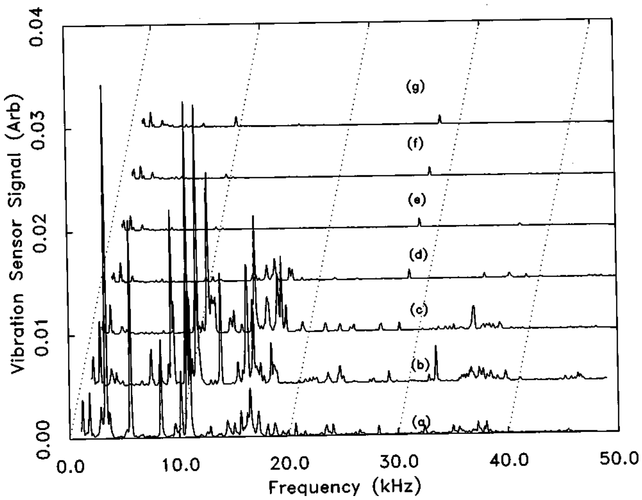

FIG. 1. Data obtained while emptying pot on cryostat A. The noise is plotted on a *linear* scale vs frequency. The lowest trace corresponds to the full state. Traces (b)–(g) were obtained as the pot was emptied. Trace (b) is the noisiest, and the others show a progressive decrease in the noise. The curves are offset both vertically and horizontally for clarity.

III. LEVEL DEPENDENCE: CRYOSTAT A

In the study on cryostat A, the helium level was altered by applying heat and the level was monitored with the capacitor. We used a PID with the capacitance as the input and the heater as the output to control the level of ^{4}He in the pot. We obtained a series of frequency spectra (shown in Fig. 1) as a function of level in the 1 K pot. The sequence of spectra show large peaks below 10 kHz which, as the level decreases, grow larger at first then drop rapidly into the noise. Several other smaller peaks at higher frequency exhibit the same behavior. Below 4 kHz a portion of the vibration spectrum appears to be completely independent of level.

We integrated the vibration spectra from 4 to 50 kHz, and plot the integral versus helium level in Fig. 2. The noise reaches a peak when the level is close to 80% full, and then falls quickly as the helium level drops. Below the 50% full level, the 1 K pot noise is not detectable with our sensor. The drop in noise is at least a factor of 10 in this study.

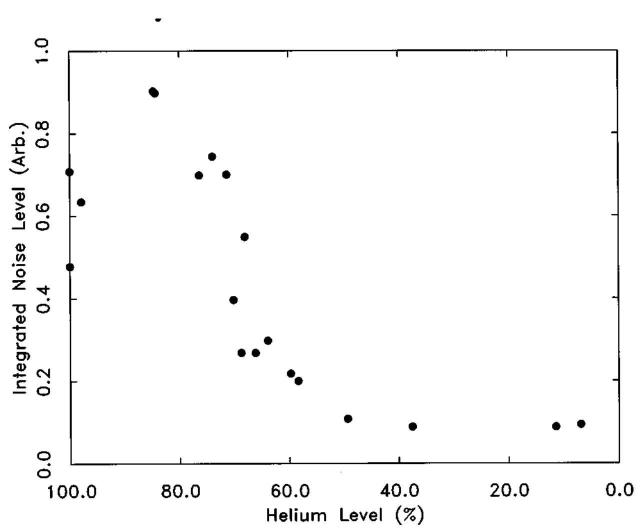

FIG. 2. The integrated noise from 4 to 50 kHz for the data shown in Fig. 1. A maximum in noise is seen at 80% full and below 50% the noise is reduced by an order of magnitude.

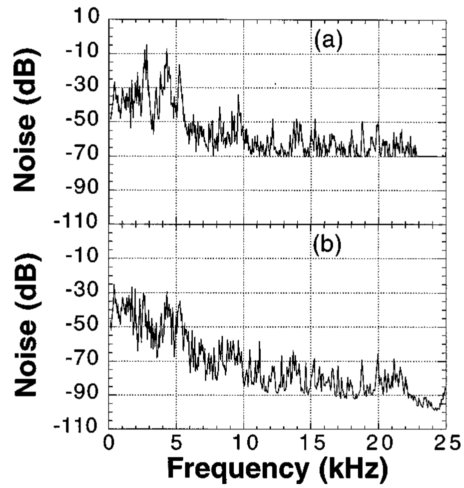

FIG. 3. (a) Noise spectrum with no heat applied and the pot full (state I). (b) Noise spectrum with no heat to the fill impedance but with helium level below the critical value in cryostat B. Peaks in the noise at 3 and 4.5 kHz visible in (a) are absent.

IV. LEVEL DEPENDENCE: CRYOSTAT B

The spectrum characteristic of the noisy state (state I) observed on cryostat B, with the pot full and with no heat applied is shown in Fig. 3(a). We find high amplitude vibrations below about 5 kHz which fall off by two orders of magnitude at higher frequencies. Above 6 kHz, the noise shows large variations, but does not drop off as the frequency increases. In order to study the level dependence of the noise we heated the 1 K pot at 52 mW using the 290Ω resistor, which emptied the pot at 10% of its total volume every hour, and raised the temperature to 1.38 K. A significant reduction in the magnitude of vibration in the cryostat from state I was observed once the helium level fell below 95% full [Fig. 3(b)]. In this state the noise peaks at 3 and 4.5 kHz are suppressed and the high frequency components were reduced by about 20 dB.

We also note the following characteristics. The transition between the noisy and quiet regimes is characterized by a transient increase in the intensity of the noise (to be described below). We observe the change in the noise at the same level regardless of whether the pot is emptying or filling. While emptying the temperature is 1.38 K, and when the pot is filling (without any heat applied) $T=1.18$ K. Thus, the reduction in noise is not related to temperature. There is also no hysteresis in the correlation of the noise to the level, with the noise recovering to the original level as the level increases past 95% full. All of these are consistent with the measurements from cryostat A.

V. FLOW DEPENDENCE

To investigate the effect of flow into the 1 K pot on noise we heated the fill impedance. We started with no heat, $T=1.27$ K, pot filled completely and heated the fill line at 12

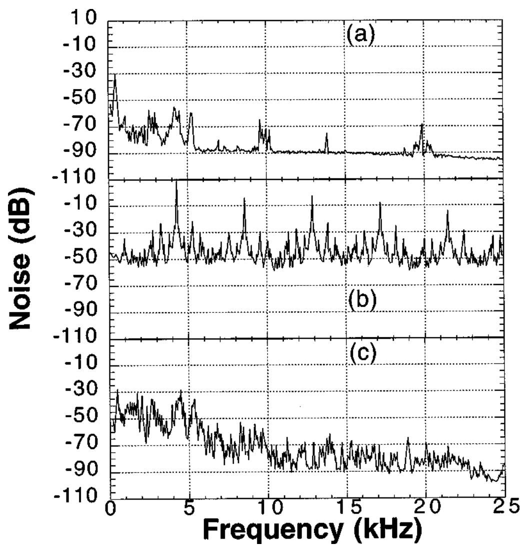

FIG. 4. (a) Noise spectrum with 12 mW applied (state II). Note that with the exception of a peak at 500 Hz (−30 dB) the entire noise spectrum decreases. (b) Noise spectrum measured at the transition from state I to state II. (c) Noise spectrum for helium below the critical level with 7 mW applied to the impedance, sufficient to maintain a steady state. The low frequency portion of the spectrum is reduced by a few dB relative to that in Fig. 3(b).

mW. In this state (state II), we found that the signal from the vibration detector dropped by two orders of magnitude [Fig. 4(a)], even if the pot was full. The signal changes very little as the power across the heater is increased to 27 mW. Heating the impedance at lower power had no effect on the characteristic noise of the system, and it remained in state I. With the fill line heated, the inflow of ^{4}He decreased because the applied heat vaporizes some of the liquid. The vapor has a lower density than the liquid and thus decreases the net transport rate through the impedance, which can be visualized as an increase in the ''effective'' impedance. In this state the pot level decreases because the inflow of helium is too small to compensate for the evaporation rate. With heat applied, the temperature decreased over a period of 10 min,[9] eventually leveling off at 1.22 K.

State II exhibits a noise spectrum reduced by 30 dB relative to state I for frequencies less than 5 kHz, while above 5 kHz the reduction is about 25 dB. State II is qualitatively different from the quiet state obtained by reducing the pot level [as shown in Fig. 3(b)] which exhibits large fluctuations in the amplitude of the vibrations at high frequencies. The transition between state I and the quiet states (however attained) is invariably associated with a very noisy spectrum, characterized by sharp resonances at 4.2 kHz and harmonics in the spectrum [Fig. 4(b)]. This behavior is similar to the noise peak shown in Fig. 2 and the evolution of spectra shown in Fig. 1.

The vibrational noise is reduced in state II, but a steady state cannot be maintained in this mode because the pot empties. Alternatively if the heat applied to the fill line is reduced below 12 mW with the pot full, there is a transition back to state I. We found that we were able to maintain a noise-free state[10] by lowering the level in the pot below the critical depth and heating the impedance at 7 mW. At this heat input, we found that the level was constant and the noise was reduced to an acceptable level [Fig. 4(c)]. The heat input is smaller than that required to induce the transition to state II.

In this state (heated fill line and the level below the critical level in the 1 K pot), the magnitude of the noise below 5 kHz [Fig. 4(c)] was smaller by a few dB compared to the already quiet partially filled state [Fig. 3(b)]. The application of heat to the impedance allowed the pot to maintain a colder temperature (1.19 K) compared to 1.27 K in state I, with no heat applied. If more power was applied (12 mW) to the impedance the noise level decreased by another 5 dB, and most of the high frequency structure was eliminated, precisely as we found when we heated the fill line with the pot completely full [Fig. 4(a)]. However, this additional heat to the fill line had the undesirable effect of destroying the steady state and caused the pot to empty.

We present the following summary. When the pot is full, the incoming helium is injected into the cold liquid, and induces the noise. A 12 mW heat input to the impedance vaporizes the helium (evidenced by the decrease in helium level). Thus, the critical level for the pot is the depth to which the fill line extends into the pot. Once the level is less than the critical level, a 7 mW heat input partially vaporizes the helium, and the net flow is reduced allowing a steady state to be maintained. While the mechanism of noise generation is beyond the scope of this investigation, we have shown that significant vibrational noise is associated with pumping on a full pot. We have also found that this noise can be virtually eliminated by heating the fill impedance (which has the desirable effect of allowing the pot to run colder), or by directly heating the pot.

ACKNOWLEDGMENTS

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[7] Vibration Control Pad manufactured by Kohary Industries Inc., New Haven, CT.
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[9] The temperature behavior of the system suggests that the thermal ground of the impedance successfully diverted the heat flow away from the 1 K pot.
[10] We found that the system could be kept in this state for over an hour, and there is no reason why this is not an equilibrium state.