



Vibrational and thermal noise reduction for cryogenic detectors

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Abstract

In this paper we present the excellent results obtained by mechanical decoupling of our thermal detectors from the cryostat. The starting point of this work is the necessity to improve the performances of thermal detectors and, besides, to eliminate the non-constant noise resulting from the overall cryogenic facility; this second point results to be crucial for rare-events experiments and the fundamental task for Dark Matter search. Tested on our bolometer, consisting of a 750 g tellurium oxide absorber coupled with an NTD thermistor and operated at ~ 9 mK in an Oxford 200 dilution refrigerator, this powerful technique can, moreover, provide advantages for a large variety of thermal detectors. A good energy resolution of 3.9 keV FWHM was obtained for 2.615 MeV γ -rays. The 4.2 keV average FWHM resolution for the 5407 keV ^{210}Po α decay line is the best ever obtained for α -particles with any type of detector. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the last years the use of thermal detectors in different fields of physics has been more and more increasing. The use of bolometric detectors proves to be absolutely promising in several fields of physics, spanning from the neutrino physics to Dark Matter search. The reason lies in the need of having particle detectors with a continually improving

energy resolution. Thermal detectors are, up to now, the only devices which can, in principle, achieve energy resolutions down to a few eV.

Despite the extremely good energy resolutions obtained with microdetectors and macrodetectors, the intrinsic theoretical limit is, in most cases, far away. Certainly, a big source of noise originates from the vibrations induced by the cryogenic facility; these vibrations can dissipate power in the detector inducing therefore thermal noise. The only way to eliminate this noise is to damp, as much as possible, the vibrations reaching the detector.

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2. Cryostat vibrations

We started our work by studying the vibration spectra of our cryostat; this test was carried out by mounting four ceramic piezoelectric accelerometers at different temperature stages of the dilution unit, namely 1 K-pot, still, mixing chamber and crystal holder. The piezoelectric sensors were operated both at room and base temperature, thus allowing us to investigate the different vibration modes resulting in various work conditions of the cryostat, and to correlate mechanical vibrations with thermal noise induced on the bolometer. The accelerometers had a capacitance of 350 pF; they were glued on the various plates with a two-component epoxy glue; the wires and the read-out used were the same used for the bolometer.

Unfortunately, the various accelerometers were not intercalibrated. The calibration was done at room temperature but, due probably to thermal contraction and stress induced by the temperature variation, once returned at room temperature, the response of the accelerometer was different.

For dilution refrigerators, like the one we use, a common source of noise is the 1 K-pot. It is well known that the continuous ^4He filling of the pot induces thermal noise. Therefore, we measured the vibration spectra in “normal condition”, i.e. with the needle valve that controls the filling open; after that we closed the valve and we took new spectra. The vibration spectra are shown in Fig. 1. As mentioned before, the piezoelectric accelerometers were not intercalibrated, therefore we were not able to produce a vibrational transfer function between the various stages of the dilution unit. In any case, what can be done is to calculate the ratio of the integral noise for each accelerometer for various running conditions of the cryostat. When we did such measurements, one of the two needle valves had a fixed flow impedance in series (in order to have a constant pressure gradient between the helium main bath, kept at ~ 1 bar and the 1 K-pot, kept at ~ 1 mbar). The results of the noise measurement obtained in these three operating conditions are shown in Table 1.

As can be deduced from Table 1, the noise resulting from the filling of the 1 K-pot fortunately decreases as the distance from it increases; moreover this damping increases with the frequency.

3. Experimental set-up

Due to the fact that the vibrational noise contribution resulting from the 1 K-pot was mainly at high frequencies, we decided to build a two-stage low-pass mechanical filter. It consisted of a Teflon-damped stainless-steel spring (to damp longitudinal oscillations) hanging from the mixing chamber at whose extremity the crystal holder was suspended through two copper wires, resulting in a pendulum (see Fig. 2a). The 2 OFHC copper wires (0.75 mm diameter, 7 cm length) provide both the mechanical suspension (and transversal vibrational damping) and the thermal link with the mixing chamber. The mechanical vibration spectra measured in this configuration on the holder show a clear damping in the high-frequency region with respect to the previous configuration (see Fig. 2b); the base temperature reached by the crystal in this configuration do not show appreciable difference compared with the previous runs. The comparison between the vibrational spectra with the same crystal and the same holder before and after the mechanical suspension is shown in Fig. 3. After the excellent results obtained with the suspension, which practically eliminates the low-frequency thermal noise, to further improve the energy resolution the bolometer was connected to a pair of cooled JFETs kept at a temperature of ~ 120 K inside the cryostat. The two 10 G Ω load resistors were also kept at the same temperature. This was done in order to reduce the microphonic noise due to the wires and to decrease the Johnson noise of the load resistors that were previously at room temperature. The three energy-noise spectra obtained with the same detector in three different runs are reported in Fig. 4. The reduction in the thermal noise due to the suspension is clearly seen in the typical thermal bandwidth (~ 0 –6 Hz); the drastic reduction in the microphonic of the wires, due to the cold electronics, is also clear.

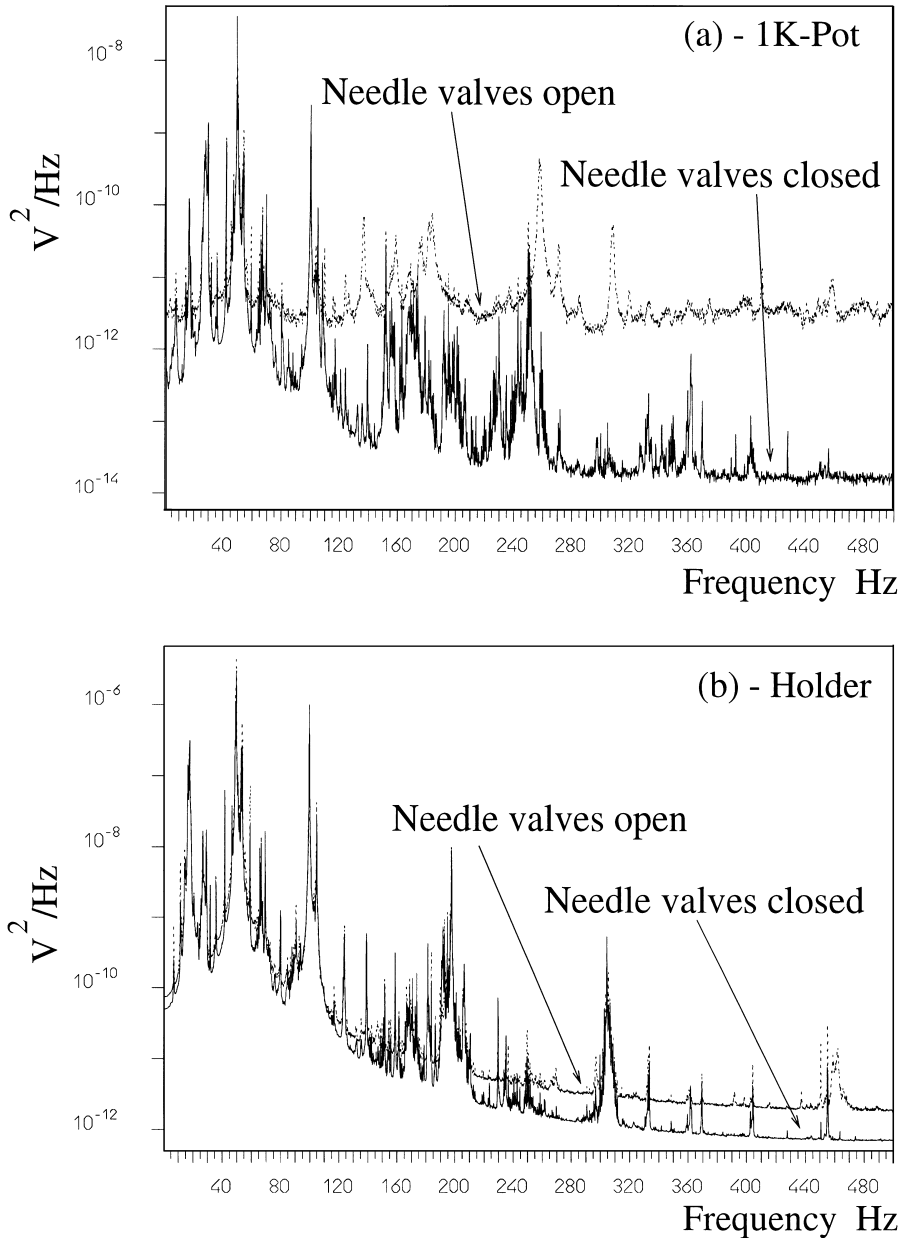


Fig. 1. Different vibrational spectra obtained in different cryostat conditions on: (a) 1 K-pot. (b) Crystal holder.

4. Physics results

The calibration spectrum obtained in 47 h of effective running time with a ^{232}Th source placed immediately outside the shield shows an

impressive improvement in the resolution at all energies with respect to our previous results. The FWHM resolution of the baseline is 1.4 keV. The energy achieved threshold is ~ 5 keV.

Table 1

Integrated noise (200–500 Hz) for each accelerometer, normalized for the 1 K-pot running with closed valves

	1 K-pot	Still	MC	Holder
Closed valves	1	1	1	1
Flow impedance	7	1.8	1.2	1.1
Open valve	16.3	2.6	1.6	1.4

The resolutions at various relevant lines are near to those of a 526 cm^3 , 113% efficiency Ge diode directly exposed for 5 h to the same ^{232}Th source (Table 2). They are comparable to those reachable with Ge diodes, despite the fact that the source was placed outside the shields of our bolometer, with a consequent poorer statistics and larger background.

In order to evaluate the resolution for α -particles we have considered the line at 5407 keV (Fig. 5) due to the internal contamination of ^{210}Po , which is a common impurity in Te-based materials [1]. The average FWHM resolution of our bolometer is $4.2 \pm 0.3 \text{ keV}$, much better than for any α -particle

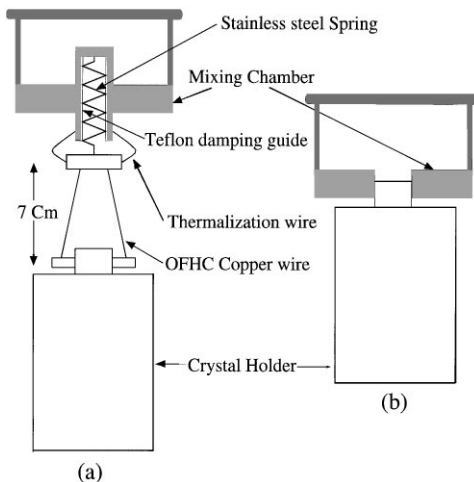


Fig. 2. Experimental set-up. (a) Crystal holder suspended from the mixing chamber with a two-stage mechanical damping system. (b) Crystal holder simply screwed to the mixing chamber.

detector [2]. A considerable left–right asymmetry exists. It could be partly due to some decays of ^{210}Po from the chain of ^{222}Rn , implanted by the decay of this nucleus in the detector. These decays

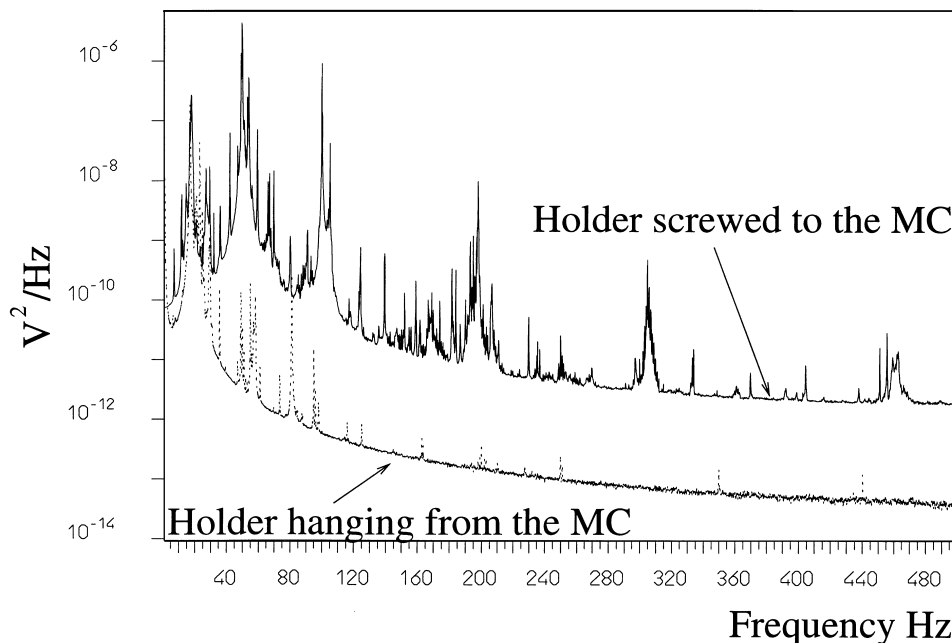


Fig. 3. Vibrational noise spectra of the same crystal holder, measured before and after the mechanical suspension.

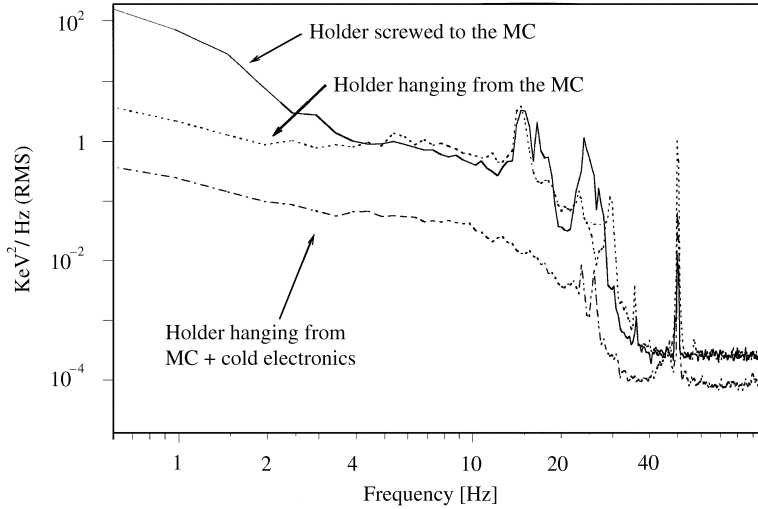


Fig. 4. Energy noise spectra obtained with the same detector in different runs. The electronics has a 4-pole 12 Hz Bessel filter.

Table 2
FWHM resolutions (keV) of a 113% Ge diode and the TeO₂ crystal

Energy (keV)	238	583	911	2615
Ge diode	1.2 ± 0.1	1.4 ± 0.1	1.7 ± 0.1	3.0 ± 0.3
TeO ₂	1.5 ± 0.2	2.0 ± 0.3	2.4 ± 0.2	3.9 ± 0.7

would occur in a thin region very near to the surface: as a consequence a fraction of the α -particles or of the recoils would leave the detector before releasing all of their energies, thus simulating a lower decay energy.

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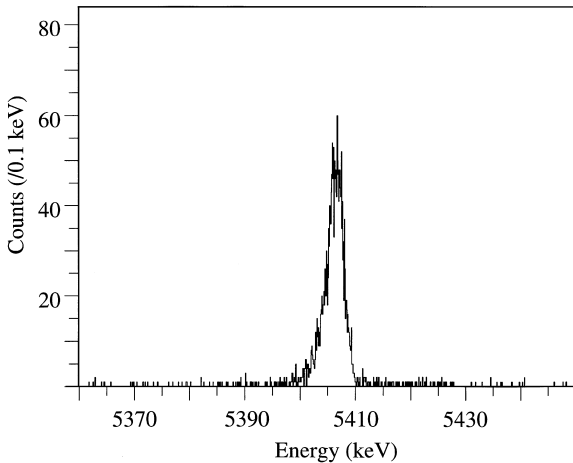


Fig. 5. The α peak of ²¹⁰Po at 5.407 MeV.