PROCEEDINGS OF SCIENCE

Hands on CUORE: investigation on the vibrations and temperature control of the cryostat

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CUORE is a 741 kg array of TeO_2 bolometers that will search for the neutrinoless double beta decay of ^{130}Te. The CUORE cryostat is able to cool down a 0.75 tonne detector to a temperature around 10 mK and it is the crucial equipment necessary to run the experiment. During our activity at the Gran Sasso Summer Institute, we were introduced to cryogenic technologies and we participated to the commissioning operations. In particular, we carried out a study about the cryostat plates oscillations due to the surrounding operating hardware. The aim was to try to identify the major sources of vibrational noise. Simultaneously, since temperature is very important for bolometers, we put in operation a low temperature noise thermometer and compared its behavior and performances with other kinds of thermometers already installed inside the cryostat.

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1. The CUORE Experiment

The neutrinoless double-beta decay ($0\nu\beta\beta$) is so far the only known phenomenon that can be exploited to investigate whether neutrinos are Majorana particles or not. The Cryogenic Underground Observatory for Rare Events (CUORE) is an upcoming experiment designed to search for $0\nu\beta\beta$ decay of ^{130}Te using an array of 988 TeO_2 crystal bolometers operated at 10 mK, [1]. At such low temperature the heat capacity of the bolometers is low enough to react with a detectable temperature rise when a few keV of energy are deposited by a particle. Hence, the amplitude of the temperature increase is proportional to the energy deposited and a great energy resolution can be achieved (< 5 keV at ~ 2 MeV, [1]).

The cryogenics system comprises the cryostat and a cryogen-free cooling system, the former consisting of six nested copper vessels while the latter comprising five pulse-tube coolers (to reach T $\sim$ 3.5 K) and a dilution-refrigerator unit (to reach T $\sim$ 8 mK). To reduce vibrational noise, the detector will be suspended from a Y-beam whose supports are decoupled from the surrounding building structure and the cryostat. Just a few days before the beginning of our activity in CUORE within the framework of the Gran Sasso Summer Institute, the cryostat reached the base temperature of 6 mK.

2. Our activities

During our experience at the Gran Sasso Summer Institute, we could work actively together with some of the scientists of the collaboration. In particular, our aims consisted in putting in operation a noise thermometer on one side, and in studying the effects of the cryostat vibrations on the temperature stability on the other.

Because of the strict requirements that CUORE has to fulfill in order to reach the target sensitivity, the control on the cryostat temperature is fundamental for the success of the experiment. The cryostat's temperature is read also with other thermometers already installed and fully operative, like a CMN thermometer and a reference point sensor. However these other instruments are not able to offer the same accuracy and reliability provided by the noise thermometer. The noise thermometer we characterized [2] showed very high accuracy ($\simeq 1\%$) over a broad dynamic range (from $\sim$10 mK to 1200 mK).

Since many different devices are needed to cool down the cryostat, it is important to study the effects of the vibrations on the stability of the temperature. The cryostat is suspended with a complex system that decouples it from the environmental vibrational noise. Nevertheless, all the cryogenics technology and especially the pulse tubes are in contact with the cryostat plates and so their effects are not negligible and need to be studied. In the next chapters we will briefly report on our activity and results on these tasks.

3. Study of the cryostat vibrations

We carried out different measurements of the cryostat vibrations in different configurations. We were equipped with 3 movable accelerometers (that we could position on the top of the cryostat) and 2 geophone sensors mounted in fixed locations on the 4 K plate (see the left panel of Fig. 2). We studied:

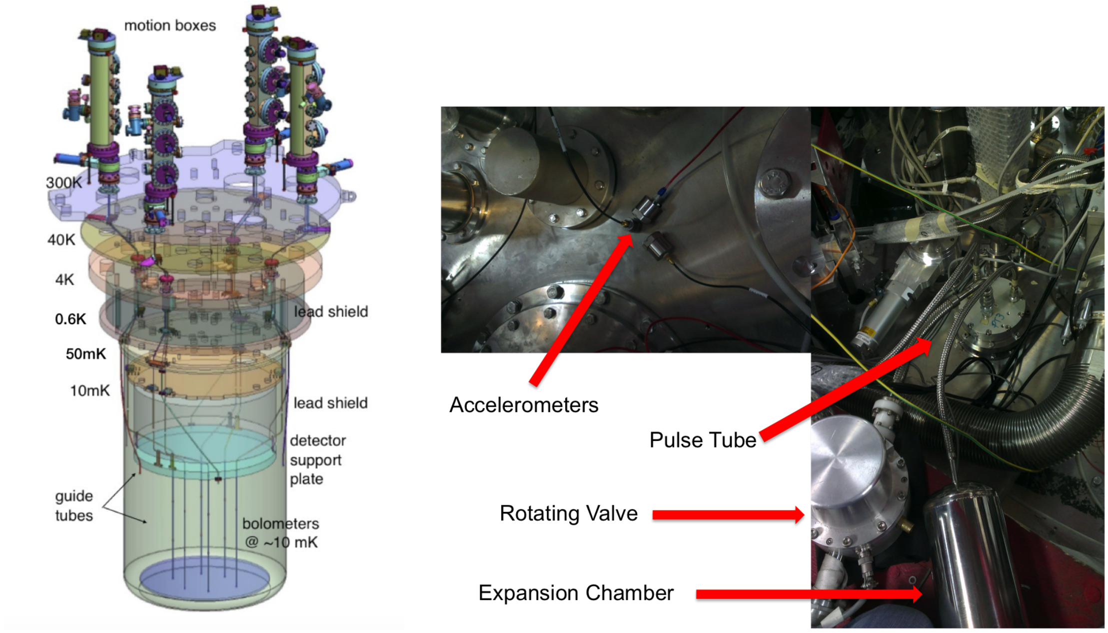

Figure 1: Left panel: A scheme of CUORE's cryostat, [1]. The different shells are kept at different temperatures, decreasing inward. **Right panel:** Pictures of the cryostat 300 K plate with the positioning of the accelerometers. The structure of a pulse tube (head on the 300 K plate, rotating valve and expansion chamber) is visible, too.

- what happens if the 300 K plate is blocked, instead of free and able to oscillate on the suspensions
- the effects of the single pulse tube coupling with the 300 K plate.

We implemented a simple DAQ system using LabVIEW Express in order to digitize the signals both from the accelerometers and the geophones and we computed the power spectrum for each sensor. The right panel of Fig 2 shows the 3 accelerometers and the pulse tubes on the 300 K plate.

Firstly, we monitored the oscillations by only modifying the 300 K plate blockage, i.e. blocking and freeing it. From Fig. 3, it is clear that leaving the plate free is better in order to reduce vibrations. This is good news, since it confirms that the suspensions are actually working well. By moving the accelerometers in different positions, we also observed that the mechanical coupling between the rotating valve of the pulse tube and the cryostat is the main source of vibrational noise. Also, depending on how the coupling is actually realized, we observed a prevalence in the induced vibrations in the vertical plane for pulse tube "number 5" and a dominance in the horizontal plane for the other 3 pulse tubes.

4. Noise thermometry

There are different kind of thermometers used to keep the temperature under control in CUORE. Measuring mK temperatures with high precision is challenging and using a variety of different techniques is needed. A Cerium Magnesium Nitrate thermometer (CMN) and a Superconductive

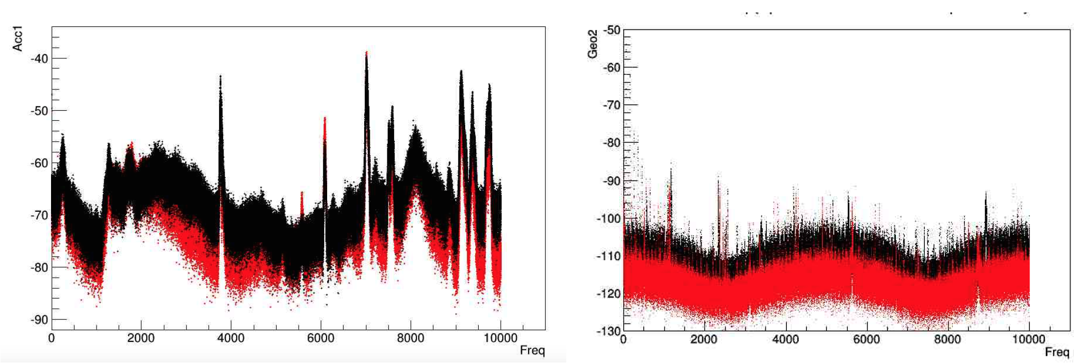

Figure 2: On the left, the power spectrum of the oscillations in the horizontal plane induced by pulse tube "number 1" is shown. On the right, the power spectrum is referred to the geophone sensor "number 2" on the 4 K plate. The two spectra superimposed show the difference between 300 K plate free (red) and blocked (black). Unity of measurements are Hz for the frequency and dB for the intensity.

reference point sensor (SRD, fixed points) were already installed in the cryostat. Our goal consisted in characterizing a Magnetic Field Fluctuations Thermometer (MFFT) recently installed in the apparatus. While the CMN relies on the measurement of the dependence of a magnetic susceptibility upon the temperature (see e.g.[3]) and the SRD can give information detecting the superconductive transition of some of its components (see e.g. [4]), the MFFT measures the thermal noise produced by its active part using a SQUID [2]. As shown in Fig. 4 the MFFT the noise resistor consists in an high purity copper based sensor. The thermal noise currents inside the copper body cause magnetic-field fluctuations across its surface. These fluctuations are inductively detected by a SQUID gradiometer as thermal magnetic flux noise (TMFN). The power spectral density (PSD) of the noise is proportional to the thermodynamic temperature and the power spectral density (PSD) of the TMFN can be described by the following empirical relation [2]:

$$S_{\Phi}(f,T) = \frac{S_0(T)}{(1+(f/f_c)^{2a})^b} \tag{4.1}$$

where $S_0(T)$ is the zero-frequency value of $S_{\Phi}(f,T)$, f_c is the characteristic fall-off frequency of the TMFN (around 1 kHz), and a and b are constants of the order of one. For a fixed configuration of the SQUID gradiometer and the temperature sensor, $S_0(T)$ is proportional to temperature and electrical conductivity of the MFFT sensor. In this case, all the parameters are constant, therefore S_{Φ} shows a “low-pass-like” frequency dependence which is independent of temperature. The fall-off frequency is determined by the geometry of the temperature sensor as well as by the bandwidth of the DAQ electronics.

During our activity, we used the CMN thermometer as a general reference to have an idea of the temperature of the cryostat. Starting from the record temperature of 6 mK, the cryostat was slowly heated up in order to reach the transition points of some of the superconductors contained in the SRD thermometer. This allowed us to reach well defined temperatures and gave the chance of having neat, absolute calibration points. Using again LabVIEW Express, we acquired the signal from the SQUID and calculated its PSD.

Fig. 4 shows the PSD computed for three different temperatures of the cryostat, corresponding at different values of the temperature inside the cryostat. We already filtered out some well known

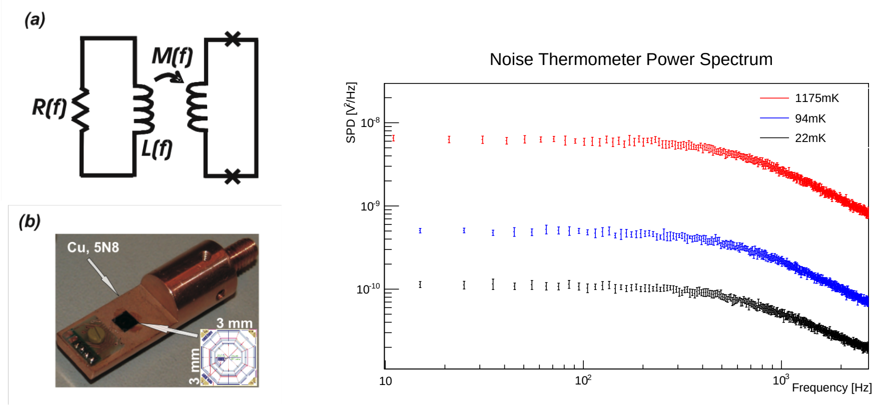

Figure 3: Left panel: Schematic diagram (a) and principle layout (b) of the MFFT sensor body made of copper with the SQUID gradiometer. $R(f)$ and $L(f)$ denote the frequency dependent resistance and inductance of the temperature sensor, which is coupled to the SQUID by the mutual inductance $M(f)$, [**?**] **Right panel:** Plot of the PSD computed for the MFFT for three different temperatures of the cryostat.

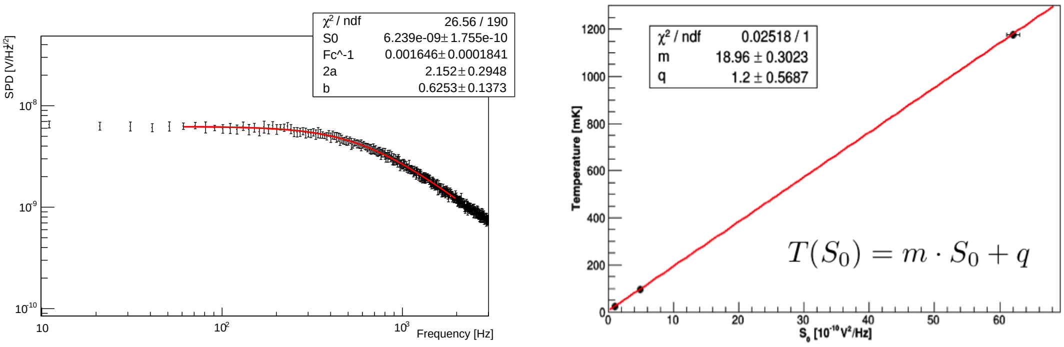

Figure 4: Left panel: Fit of the PSD for the 94 mK calibration point. **Right panel:** Calibration line for the MFFT, which shows surprisingly good linearity over more than 3 decades in temperature.

electronics noise components, such as 50 and 100 Hz. The shape of the PSD does not depend upon temperature and this allows to calibrate the MFFT using only one calibration point since, after measuring T_{ref} and $S_0(T_{ref})$, the temperature T can be obtained as following:

$$T = T_{ref}\frac{S_0(T)}{S_0(T_{ref})}. \tag{4.2}$$

The parameters that determine the shape of the PSD are found by fitting the measured PSD at the reference temperature T_{ref} with the functional form of Eq. 4.1. After this step, there are various possibilities in order to extract a measured temperature from an acquired PSD. One for instance could fit the PSD leaving as the only free parameter $S_0(T)$, or determine $S_0(T)$ by only fitting or averaging the points in the plateau for $f \lesssim 200$ Hz. We tried all these three possibility checking that the result is independent upon this choice.

In Fig. 4, we show the fit of the PSD acquired for the 94 mK calibration point with the functional form of Eq. 4.1 and also the calibration line obtained with 3 transition points of the

SRD. We observed a good linearity over more than 3 decades in temperature and a $\sim 1\%$ accuracy in the mK region. We also noticed a $\sim 10\%$ discrepancy between the CMN and the MFFT which is probably due to a not really precise calibration of the CMN itself.

5. Conclusions

During the two weeks at the Gran Sasso Summer Institute, we got deeply in touch with the experimental activities carried out in the commissioning of CUORE's cryostat. We learnt the basis of the technology required for the mK cryogenics of ton-scale devices and its thermometry.

We studied the effects of the environmental vibrational noise on the cryostat and we confirmed that the suspensions provide the designed reduction in vibrational noise. The main source of noise was identified to be the coupling between the rotating valve of the pulse tubes and the 300 K plate of the cryostat. The way this coupling is physically implemented influences also the direction of the induced vibrations (horizontal or vertical), which we observed to be different among the pulse tubes.

We also characterized a high performance noise thermometer and calibrated it by comparison with a superconductive fixed point thermometer. The noise thermometer showed really good accuracy and linearity over a broad dynamic range.

6. Acknowledgments

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References

[1] D. R. Artusa *et al.* [CUORE Collaboration], "Searching for neutrinoless double-beta decay of ^{130}Te with CUORE," arXiv:1402.6072 [physics.ins-det].

[2] J Engert *et al.* 2012 J. Phys. Conf. Ser. 400-052003.

[3] D. Greywall, S. Dennis and P.A. Busch, "Fast cerium magnesium nitrate (CMN) thermometer for the low millikelvin temperature range", Review of Scientific Instruments, 60, 471-473 (1989)

[4] C. Enss and S. Hunklinger, "Low-Temperature Physics", Springer Science & Business Media (2005)