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Vibrations on pulse tube based Dry Dilution Refrigerators for low noise measurements

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ABSTRACT

Dry Dilution Refrigerators (DDR) based on pulse tube cryo-coolers have started to replace Wet Dilution Refrigerators (WDR) due to the ease and low cost of operation. However these advantages come at the cost of increased vibrations, induced by the pulse tube. In this work, we present the vibration measurements performed on three different commercial DDRs. We describe in detail the vibration measurement system we assembled, based on commercial accelerometers, conditioner and DAQ, and examined the effects of the various damping solutions utilized on three different DDRs, both in the low and high frequency regions. Finally, we ran low temperature, pseudo-massive (30 and 250 g) germanium bolometers in the best vibration-performing system under study and report on the results.

Introduction

Due to helium shortage and increasing price of liquid helium, in the last decade, research groups performing experimental physics at low temperatures have begun to replace the usual Wet Dilution Refrigerators (WDR) with pulse tube-based Dry Dilution Refrigerators (DDR). The success of DDRs relies on the low-cost and ease of operation. In particular, the high level of automation of the gas handling systems and the lack of liquid helium bath allow for a nearly autonomous cool down and running. However, pulse tubes induce vibrations which are so far the most serious drawback of this technology [1,2]. Indeed, vibrations can drastically affect the results of experiments as in the case of Scanning Tunnelling Microscopy, Johnson Noise Measurements and Bolometers [3,4].

The ultimate goal for DDR technology is to provide, through an efficient vibration decoupling system, a low temperature and low vibration environment as good as the one obtained with WDRs. Throughout this paper we assume that, in first approximation, running a DDR fridge with its pulse tube turned OFF is equivalent in terms of vibrations to running a WDR.

In this work, we propose a vibration measurement standard (§2), built with market-based components, that allows for a rigorous and unambiguous comparison between vibration levels of DDRs, at room temperature. We set three vibration limits to classify systems as *noisy*, *typical* and *quiet*. We report on vibration measurements on three (four) different DDRs (setups) and draw conclusions on their vibration performances (§3).

Finally (§4), we show how vibration levels as measured with accelerometers compare with bolometers, highlighting the need for vibration levels below 10 μg to operate these correctly.

1. Description of the DDR units under study

Here below we list the three (four) DDRs (setups) under study and describe the various vibration damping solutions utilized by each one (Fig. 1).

1. **Hexadry Standard (Hex std):** produced by Cryoconcept, it is the standard model of the Hexadry Hexagas™ series [5]. It is equipped with a PT410 Cryomech pulse tube with a remote rotary valve. The pulse tube cold head is tightly fixed onto the 300 K flange, without any dedicated vibration decoupling system. The pulse tube intermediate and cold stages are thermally coupled to the cryostat intermediate (50 K) and cold (4 K) plates via low pressure gas-exchangers (Hexagas™) to avoid any mechanical contact and hence reduce the propagation of vibrations down to the various cold stages of the fridge. No special care was devoted to the positioning of the remote motor, which was held on the main DDR unit frame [5]. The unit was installed at the *Institut de Physique Nucléaire de Lyon* (IPNL) and devoted to detector R & D for the *EDELWEISS* dark matter search experiment [6].
2. **Hexadry Ultra Quiet Technology (Hex UQT):** it is exactly the same aforementioned DDR unit but upgraded with the UQT (Ultra

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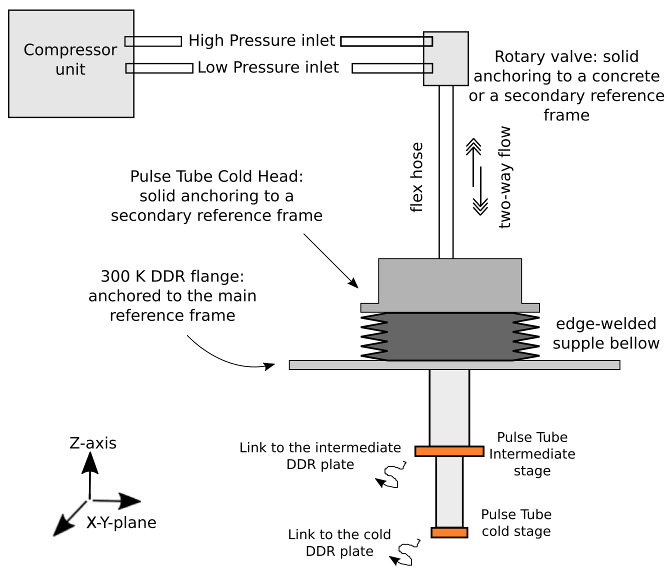

Fig. 1. General scheme depicting how to efficiently filter the vibrations injected by the pulse tube on the DDR unit. Orientation and positioning of the rotary valve and flex hose do matter.

Quiet Technology™) option. This option is especially conceived to provide a low vibration environment at low temperatures. It consists in a mechanical decoupling of the pulse tube head from the rest of the cryostat via an edge-welded supple bellow.[1] A few mm-thick neoprene O-ring is installed between the bellow and the 300 K flange to cut out high frequency vibrations. A solid secondary frame, physically separated from the main one, is firmly mounted on the ceiling and rigidly holds the pulse tube head [5]. The rotary valve may be mounted on the ceiling to further decouple from the cryostat. An analogous system, **Hex UQT (STERN)**, has kindly been set at our disposal by Cryoconcept and Bar-Ilan University (Israel) [7] to study the reproducibility of the vibration performances with respect to the unit and installation site. For this unit, the pulse tube head and rotary valve were both mounted on a secondary frame, separated from the cryostat main frame.

3. **Oxford Triton 400 (Triton):** produced by Oxford Instruments [8], the system is especially conceived to provide a low temperature, low vibration experimental environment. This design utilizes an edge-welded bellow to insulate the vibrations coming from the pulse tube head and provides thermal contacts between the pulse tube stages and the cryostat intermediate (50 K) and cold (4 K) plates via supple copper braids. The system comes mounted on a single solid frame (main frame). All the different dilution unit cold plates down to the coldest (10 mK plate) are rigidly triangulated. The unit uses the same pulse tube as the Cryoconcept models with a remote rotary valve option. For our experimental studies we evaluated a system installed at the Laboratory for Nuclear Science at MIT, currently used for ongoing *CUORE/CUPID* detector R & D [9].

In this work we will see that the vibrations induced by the pulse tube can be transmitted to the dilution unit both via the cold head (300 K pulse tube flange) and the cold stages. Hence, an efficient vibration damping solution must take both into account.

The gravitational wave experiment *CLIO* [11] first realized a 4 K non vibrating cold plate cryostat, by decoupling the pulse tube cold head with an edge-welded supple bellow and utilizing supple copper braid thermal links between the pulse tube stages and the intermediate (50 K) and cold (4 K) cryostat plates. Since, this decoupling solution is commonly adopted in dry refrigerators.

Nevertheless, the *CLIO* experiment observed residual vibrations on the cryostat plates; it demonstrated these were transmitted mainly by the mechanical thermal links and negligibly from the edge-welded bellow. This prompted Cryoconcept to opt for thermal couplings through gas-exchangers[2] through the Hex UQT™technology.

A special care must be applied in choosing and dimensioning the edge-welded bellows to decouple the pulse tube cold head; in fact, bellows efficiently damp vibrations along their axial direction z, whereas they perform poorly along the radial direction r[3]. Fortunately, though pulse tube vibrations are not negligible along the radial direction, the majority of these are along the axial direction [10].

2. Description of the measurement system

To measure the vibrations at the Mixing Chamber (10 mK cold plate) of the different DDRs and setups, we selected and set up a measurement system standard, composed of a high sensitivity *PCB-393B04* seismic accelerometer (PCB Piezo-electronics, typical sensitivity of 1 V/g in the 1–750 Hz frequency region), a *PCB-480E09* signal conditioner and a 16-bit National Instrument DAQ-6218. The measurement chain has been carefully chosen to evidence the residual low level of vibrations injected by the pulse tube down to $0.2\ \mu g\sqrt{\mathrm{Hz}}$, in the 1 Hz − 1 kHz frequency range.

Two other accelerometers were tested: *PCB-351B41*(cryogenic) and *Kistler-8762A* (3-Axes). They have been rejected because their intrinsic noise was too large to appreciate vibrations at the required level.

We mounted the accelerometer on the Mixing Chamber (10 mK plate), allowing it to sense along the vertical and radial directions. For reading the signal, we used an anti-tribo-electric coaxial cable, tightly fixed to the rigid structures of the DDRs (to avoid spurious signal induced by the stress or vibrations of the cable). A leak-tight electrical feedthrough was used to connect this latter cable to the conditioner which sat outside the cryostat. We performed the measurements with the OVC (Outer Vacuum Chamber) under vacuum to prevent the accelerometer from picking up the acoustic environmental noise through air.

All measurements have been performed at room temperature, for three reasons: 1) the lack of any low budget easy-to-handle cryogenic accelerometer with sufficiently low intrinsic noise; 2) to first order, we assume that the room temperature acceleration measurements are representative of the vibration level at low temperatures. Indeed, no large difference between the 300 K and 4 K values of the elastic constant k and Young's modulus E is observed for stainless steel and copper [13], which are the main materials used for the rigid structures of the DDR units; 3) room temperature measurements can be performed rapidly by any user, with much less constraints as those at low temperatures.

3. Acceleration and displacement: results and discussion

3.1. Accelerations

We measured the acceleration of the Mixing Chamber (10 mK cold plate) of the three (four) DDR units (setups) via the acquisition chain described in the previous section. The signals from the conditioner were sampled at 16 bits, 10 kHz, over a ±1 V range.

[1] The edge-welded bellow employed has an elastic constant of 30N/mm along the z axis whereas the radial constant is of 2200N/mm.

[2] A gas-exchanger consist of two annular, entangled counter-radiators. The fixed radiator is accommodated on the cryostat intermediate (cold) plate whereas the counter-radiator is tightly fixed on the pulse tube stage(s). This latter sits inside the fixed radiator with a gap of few mm, without any mechanical link. Low pressure helium gas establishes the thermal link between the two counter-radiators. This gas-exchanger technique is a trademark of Cryoconcept.

[3] The stiffness coefficient k_z of the edge-welded bellow along z direction is much smaller than the radial one k_r.