Proteox high-temperature operation

Continuous temperature control across four orders of magnitude

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1 Introduction

Dilution refrigerators typically operate in the mK regime. Whilst the ability to operate over a wide temperature range is often beneficial for experiments [1], users of some systems [2] have described high-temperature operation as

> ...non-trivial above 1.2 K and nonviable above 1.5 K.

Here we describe how the unique design features of the **Proteox**® platform allow for seamless operation of the system from millikelvin temperatures up to tens of kelvin - all in an applied magnetic field.

2 System design

A key feature of the Gas Gap Heat Switch (GGHS) pre-cooling system, shown in figure 1, is the 'remote' adsorption pump for removing the exchange gas when the switches are to be opened. Whilst it can be convenient to design GGHSs to be 'passive' [3] [4] such that their switching behaviour is simply determined by the temperature of one end of the switch, this behaviour would be undesirable should the cryogenic system be intended to operate over a wide temperature range.

2.1 Remote adsorption pump

By employing a remote adsorption pump, weakly coupled to the Pulse Tube Cooler (PTR) second-stage plate (PT2), it is possible to achieve reliable switching performance of the GGHSs independent of the switch temperature[1].

The strength of the thermal link is chosen such that keeping the sorption pump out-gassed (at ~ 30 K [5]) requires a heat input of around 200 mW; this does not impact the PTR performance too significantly (as these have cooling capacities > 1 W at 4 K), whilst also allowing the sorb to cool from 30 K to below 6 K (which is sufficient to evacuate the switches) in around 20 minutes.

[1] This heat switch configuration is protected by patents in various jurisdictions e.g. EP4111107B1; US12247774B2.

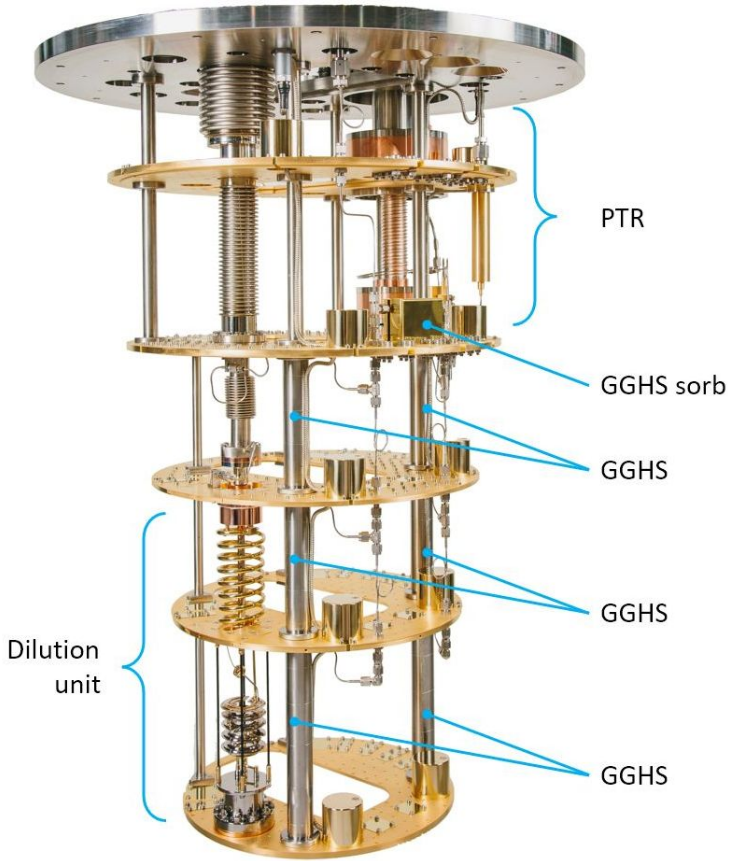

Figure 1: Image showing the internal details of the cryogen-free dilution refrigerator insert discussed in the main text. There is a stainless steel 'top plate' which forms part of the vacuum enclosure. Below this are the PT1 and PT2 stages, both coupled to the PTR, and the still plate, cold plate and mixing chamber plate, all coupled to the dilution unit. The GGHSs are shown, as is the 'remote' sorption pump (GGHS sorb).

3 High temperature operation

Data acquired on a Cryofree® dilution refrigerator system equipped with a 6:3:1.5 T vector-rotation magnet are shown in figure 2. The mixing chamber temperature is controlled at a range of elevated temperatures (up to 30 K) whilst the magnet is swept[2] (here the 6 T coil to full field).

[2] Further details of these experiments are presented in this article https://doi.org/10.1016/j.cryogenics.2023.103632

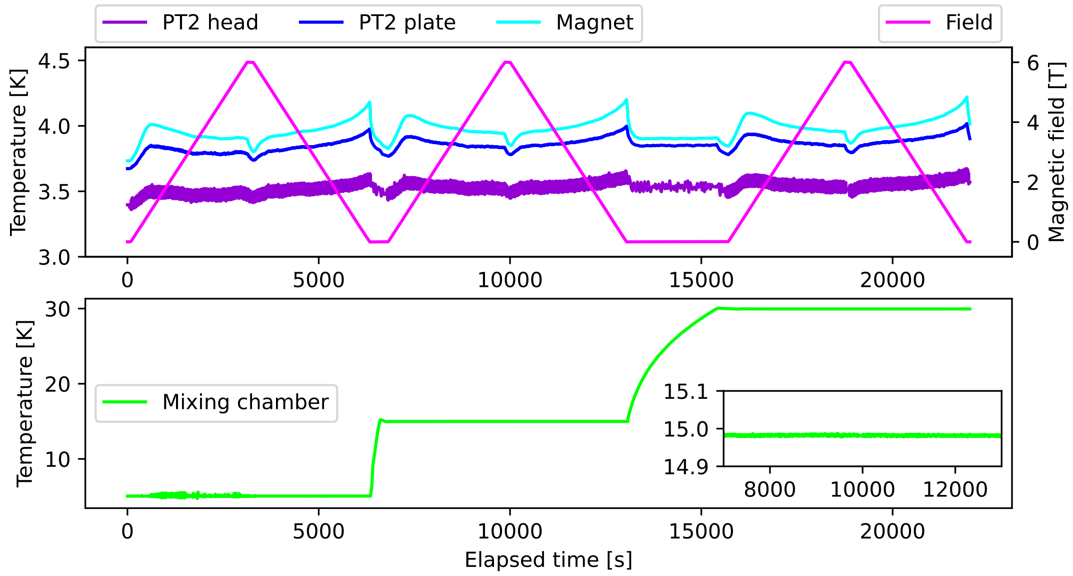

Figure 2: Plots showing (upper panel) the temperature of the PTR second stage (PT2 head), the associated plate and the magnet temperatures whilst the field is swept. The peaks in the magnet temperature at low fields occur due to the increase in AC-losses in this range. (lower panel) The mixing chamber temperature which is controlled at a range of temperatures during the magnetic field sweeps and, (inset) a closer view of a portion of these data.

3.1 Control near 2 K

Temperatures below 2 K can still be attained in 'high temperature mode' providing useful overlap with the standard dilution refrigerator operating regime. The mixing chamber temperature stabilising at a range of temperatures between 10 K and $\sim$ 1.2 K is shown in figure 3. Of note here is the good stability attained around 2 K which can sometimes prove difficult to achieve when the dilution refrigerators are operated traditionally.

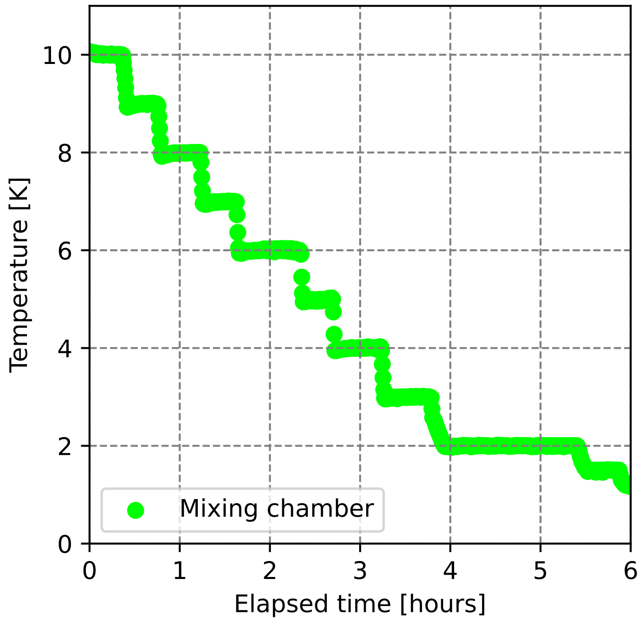

Figure 3: Plot showing the mixing chamber temperature of the dilution refrigerator system as the temperature control set-point is stepped down from 10 K. The temperature is stable to a few mK when controlling at 2 K.

References

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[3] I. Park, D. Yoo, J. Park, and S. Jeong, *Development of a Passive Helium Heat Switch for Fast Cool down by Two-Stage Cryocooler*, in *Cryocoolers 18*, edited by S. D. Miller and R. G. Ross Jr (ICC Press, Boulder, Colorado, 2014), p. 577.

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[5] A. V. Itterbeek and W. V. Dingenen, Adsorption isotherms and heats of adsorption of helium gas on charcoal between 20 K and 6 K - new desorption experiments -, Physica **5**, 529 (1938).

About Proteox

The **Proteox** dilution refrigerator enables a step change in Cryofree system modularity – designed for enhanced adaptability, reliability and increased experimental capacity.

ProteoxS: Delivering faster characterisation in a smaller size, with no compromise on performance.

ProteoxMX: The largest in its class dilution refrigerator with extensive capacity for components, experimental services and sample mounting for high input/output applications.

ProteoxLX: Providing maximum qubit counts with large sample space and greater coaxial capacity for quantum computing scale-up.

Proteox5mK: The coldest, continuous, cryogen-free dilution refrigerator available; providing an ultra-low base temperature of $<$ 5 mK and a high cooling power of $>$ 25 μW at 20 mK.

Find out more about the Quantum Design Oxford Proteox product range.

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