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Cryogen-free low temperature sample environment for neutron scattering based on pulse tube refrigeration

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Abstract
Recent rapid progress in cryogen-free technology has become possible due to a new generation of commercial cryo-coolers developed during the last decade. The most successful example is the pulse tube refrigerator (PTR). A unique feature of the PTR is the absence of cold moving parts. This considerably reduces the generated noise and vibration and increases the reliability of the cold head, as expensive high-precision seals are no longer required and the cold head can be operated without service inspection. In this paper we present preliminary test results of a development system, based on the PTR, which provides a low temperature sample environment for neutron scattering experiments. The main aim of the development is to create a cryogen-free system suitable as a substitute for the conventional ILL-type Orange cryostat, the cryogenic workhorse of the neutron community for many years.

Keywords: sample environment, cryogenics, pulse tube refrigerator, low temperature, low vibration

Introduction

An average 700 neutron scattering experiments are performed at ISIS each year. Neutron beams offer the advantage of high penetration and thus samples can be enclosed in relatively thick-walled pressure cells or sample cans. Detector coverage of the ISIS instruments requires a beam-central sample position and up to 360° infrared radiation shield windows.

More than half of all neutron scattering experiments are performed under cryogenic conditions [1]. There are two fundamental reasons for this: firstly, the thermal motion of atoms is reduced which significantly improves the precision of structural measurements and secondly, cryogenic conditions provide the possibility of investigating low temperature phase transitions. Measurement times for experimental samples may be as short as 60 s and thus ease of sample change and fast cool down times are essential.

A cryogenic sample environment can be provided either by a conventional liquid helium cryostat [2] or by a cryogen-free system based on a cryo-cooler [3, 4]. Despite obvious advantages, such as operational simplicity, the use of cryogen-free systems is limited by the high level of mechanical vibrations produced by conventional cryo-coolers and the necessity of expensive and regular service inspections. A new generation of cryo-coolers, based on the pulse tube refrigerator (PTR), offers an effective solution to both problems. A unique feature of the PTR is the absence of cold moving parts which considerably reduces noise and vibrations generated by the cooler, a critical issue for a number of scientific instruments [5]. It also offers lower maintenance costs and disruption as no expensive high-precision seals are required and the cold head can be operated without any service inspection.

This paper briefly describes the design of a cryogen-free system, based on a pulse tube refrigerator, with top-loading sample facilities for neutron scattering experiments. The paper compares the results of the pulse tube system tests with the performance of a standard top-loading system based on the Gifford McMahon (G-M) CCR, both in terms of thermal and mechanical behaviour.

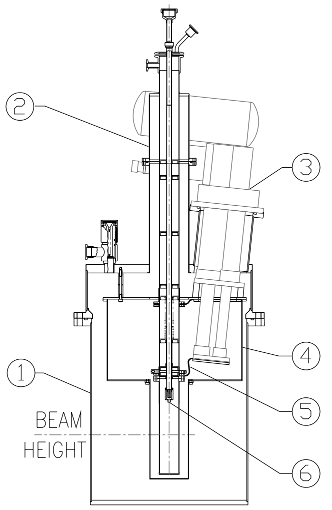

Figure 1. Diagram of the pulse tube top-loading system.

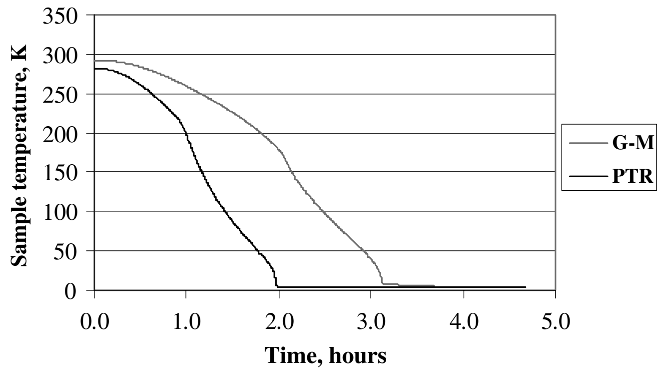

Figure 2. Cool down data for test samples in the pulse tube and G-M top-loading systems.

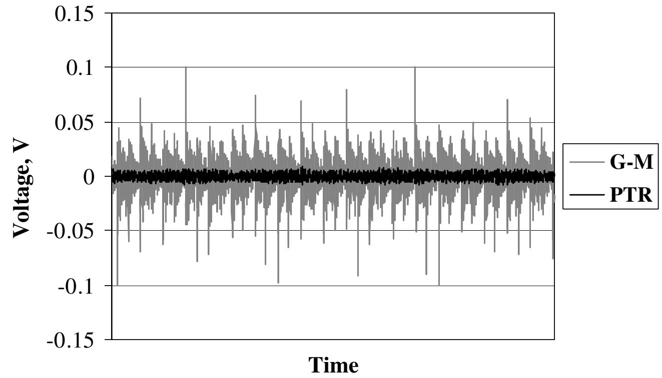

Figure 3. Velocity transducer voltage measurement data for the PTR and G-M top-loading systems recorded during 10 s. The voltage measurement is proportional to the velocity measured at the sensor.

Design of the top-loading cryogen-free system

The PTR selected for the top-loading system is a Cryomech PT410 cooler. The cooling power of the PT410 is given as 1 W at 4.2 K with an electrical input power to the compressor of 7.2 kW. The cryo-cooler was initially tested independently to assess its performance. Under the available test conditions the PT410 was found to have a slightly lower cooling power than specified (1 W at 4.4 K) but in all other respects it outperformed its given specifications.

The complete PTR top-loading system was manufactured by A.S. Scientific Products Ltd[1] and is shown schematically in figure 1. The system consists of: (1) the outer vacuum vessel, (2) the top-loading insert with an internal diameter of approximately 50 mm, (3) the pulse tube refrigerator, (4) the infrared radiation shield attached to the first stage of the PTR and (5) the thermal link between the second stage of the PTR and the insert base flange. A test sample was loaded into the insert on the end of the sample stick (6).

Rhodium iron sensors were used to monitor the temperature at the PTR's first and second stages and at the sample position. The infrared radiation shield was made of high conductivity copper and covered with high emissivity aluminium foil.

Cryogenic and vibration test results

At ISIS, top-loading systems based on standard G-M-type coolers have been used for several years. The performance of the new PTR system was thus compared to that of an existing system based on a Sumitomo SRDK-415D (1.5 W at 4.2 K) G-M cryo-cooler. The electrical input power required by the Sumitomo compressor is 6.5 kW.

Figure 2 shows the cool down curves for identical test samples in the PTR and G-M systems. In the PTR system the sample reached a base temperature of 3.6 K in under 3 h. A sample cooled in the standard G-M system reached a base temperature of 4.4 K in approximately 4 h. The G-M top-loading system has a larger maximum sample size (approximately 100 mm diameter compared to 50 mm diameter) and thus a higher background heat ingress.

One of the main advantages of PTR technology is the reduced level of noise and vibrations produced by the cryo-cooler operation. In order to compare the level of vibrations produced by the PTR and G-M cryo-coolers we performed relative vibration tests. The measurements were carried out using a Geospace velocity transducer (GS-20DM).

The sensor was installed on the top plate of each cold head. Figure 3 shows an example snapshot of the sensor voltages (which are proportional to velocity) measured on the PTR and G-M cryo-coolers. The velocity component

Table 1. Comparison between the ISIS G-M and PTR top-loading systems (PTR: Cryomech PT410; G-M: Sumitomo SRDK-415D).

Property	PTR	G-M
Base sample temperature	3.6 K	4.4 K
Time to cool down to base	<3 h	≈4 h
Cool down time after sample change	<1.25 h	<1.25 h
Initial cost of CCR system	\$38 000	£19 000
Maintenance costs: cold head	–	£5000 at 9000 h
Maintenance costs: compressor	£2500 at 20 000 h	£2500 at 20 000 h

[1] A.S. Scientific Products Ltd, Abingdon, OX14 3NB, UK; www.asscientific.co.uk

was measured in the horizontal direction with the cold head close to room temperature. The data recorded require further analysis, but provide sufficient information for a like for like comparison between the coolers. It is clear that the level of vibration produced by the PTR is nearly an order of magnitude lower than that produced by the G-M cryo-cooler. This result agrees well with comparative data previously published [6].

Discussion and conclusions

Table 1 provides a summary comparison of the PTR and G-M top-loading systems regarding cryogenic performance and financial considerations.

In summary, the top-loading system based on the PTR has

- a lower base temperature;
- a faster cool down time;
- lower maintenance costs;
- at least an order of magnitude less vibration.

With the addition of a Joule–Thomson cooled helium gas insert currently under construction at ISIS the base temperature of the PTR system may be reduced further to below 1.8 K. As such, it would provide a cryogen-free top-loading system to rival the Orange cryostat.

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