A cryogen-free cryostat for scientific experiment in the pulsed high magnetic field

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Introduction

A measurement cryostat is one of the basic tools for scientific experiment in the pulsed high magnetic field. In order to obtain the temperatures 4 K and below, traditional cryostat (e.g. helium bath cryostat and helium-gas-flow cryostat) for scientific experiment in the pulsed high magnetic field uses liquid helium as the cooling source. Because of the high price of liquid helium, a first generation cryogen-free cryostat based on a GM cryocooler has been developed for a 60 T pulsed magnetic field measurement cell at Wuhan National High Magnetic Field Center. The first generation cryogen-free cryostat has 16 mm outer diameter of the tail and 8 mm sample space. In the process of using the first generation cryogen-free cryostat, the temperature stability is unsatisfying, especially from 5 K to 20 K.

After several years of development, Wuhan National High Magnetic Field Center has designed a 60 T pulsed magnet with a bore of 21 mm diameter. In order to develop a new cryogen-free cryostat with a greater stability that can be inserted into a 60 T pulsed magnet with inner diameter of 21 mm, we designed and fabricated a second generation cryogen-free cryostat based on a GM cryocooler (model RDK415D with compressor F-50H, 1.5 W @ 4.2 K) with a temperature-control insert.

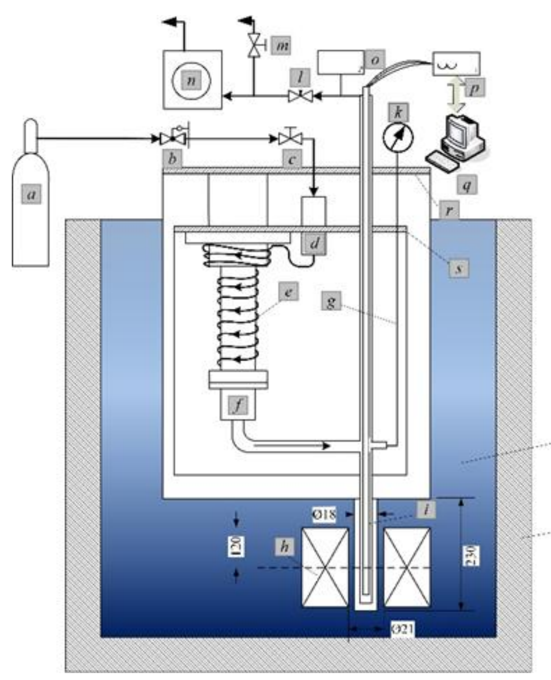
Conclusion

- The cryogen-free cryostat can be used in a 60 T pulsed magnet with a 21 mm bore.
- The lowest temperature of the cryostat is 1.4 K.
- A temperature-control insert was designed to obtain a stable sample temperature. In order to eliminate the sample temperature fluctuation caused by the eddy current heating during the pulse, the inner layer is made from fiberglass tubing with epoxy coating.
- Using the temperature-control insert, the stability of the sample temperature is obtained: ±0.01 K at 1.4 K - 20 K and ±0.05K at 20 K - 300 K.
- The cryogen-free cryostat can be widely used in scientific experiments in the pulsed high magnetic field.

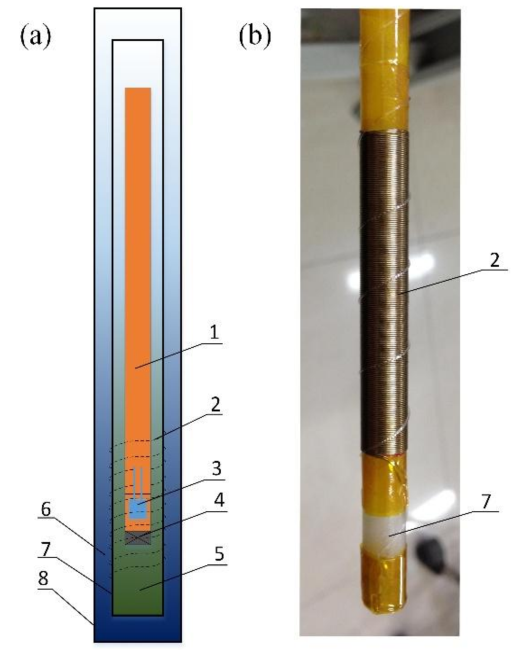
Experimental Setup

The Measurement Setup with the Cryostat

a – helium gas cylinder; b – pressure regulator; c –helium gas inlet valve; d – helium gas cold trap; e – spiral heat exchanger; f – helium condenser; g – tube for pressure measurement; h – magnet; i – temperature-control insert; j –liquid nitrogen; k – pressure gauge; l – needle valve; m – helium gas atmospheric valve; n – vacuum pump; o – vacuum gauge; p – cryogenic temperature controller; q – computer, r – vacuum jacket; s – first stage cold head radiation shield; t –LN_2 Dewar.



The Temperature-control Insert

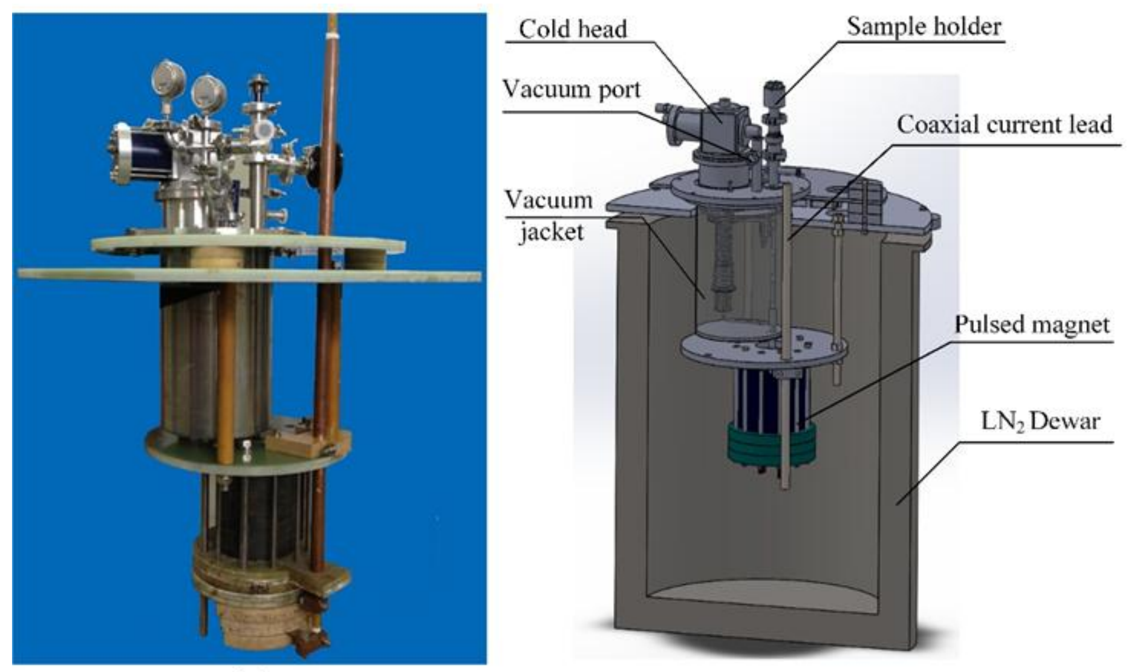


(a) schematic diagram of the temperature-control insert, (b) photo of the inner tubing with the heater.

1 – sample holder, 2 – heater, 3 – temperature sensor, 4 – sample, 5 – inner helium gas, 6 – middle helium gas, 7 – inner tubing, 8 – outer tubing.

The temperature-control insert consists of a closed inner (7) and outer tubing (8). In order to eliminate the sample temperature fluctuation caused by the eddy current heating during the pulse, the inner tubing is made from fiberglass tubing with epoxy coating. For obtaining a stable temperature, a 50 Ω electrical heater (2) is wound on the outer surface of the inner tubing. The sample holder, the inner tubing and the outer tubing are separated by the inner (5) and the middle helium gas (6).

The Facility with the Cryostat

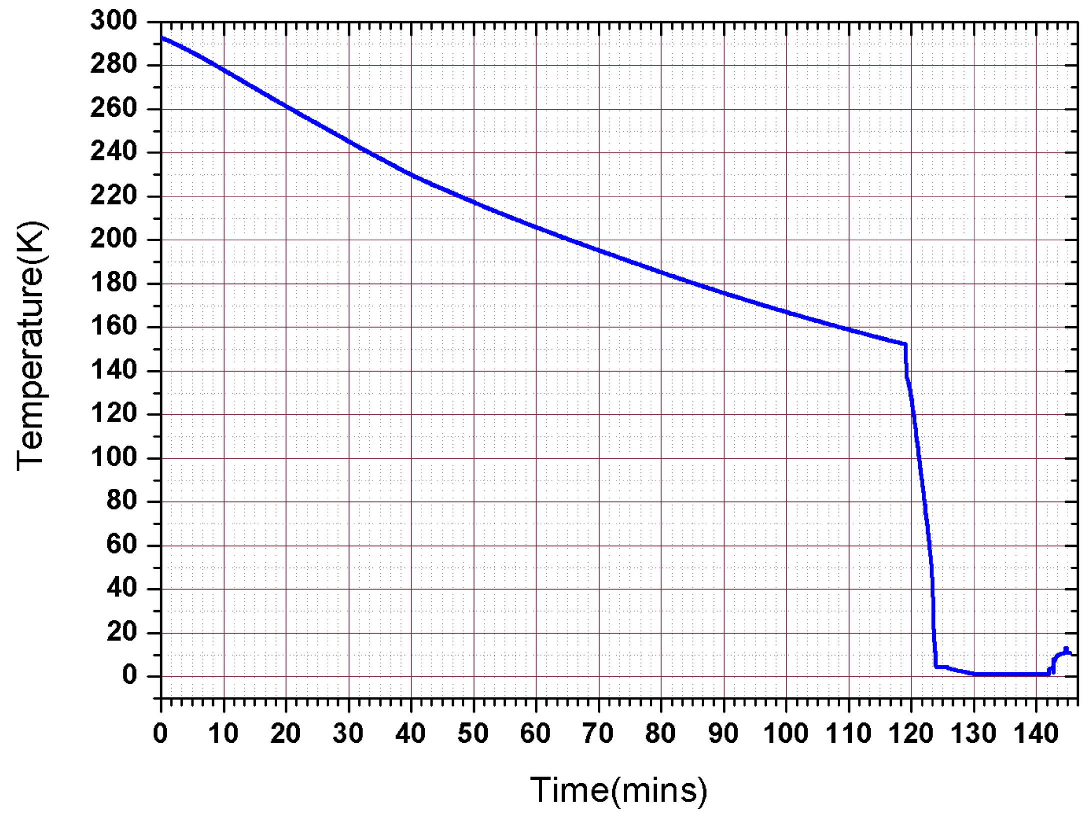


(a) (b)

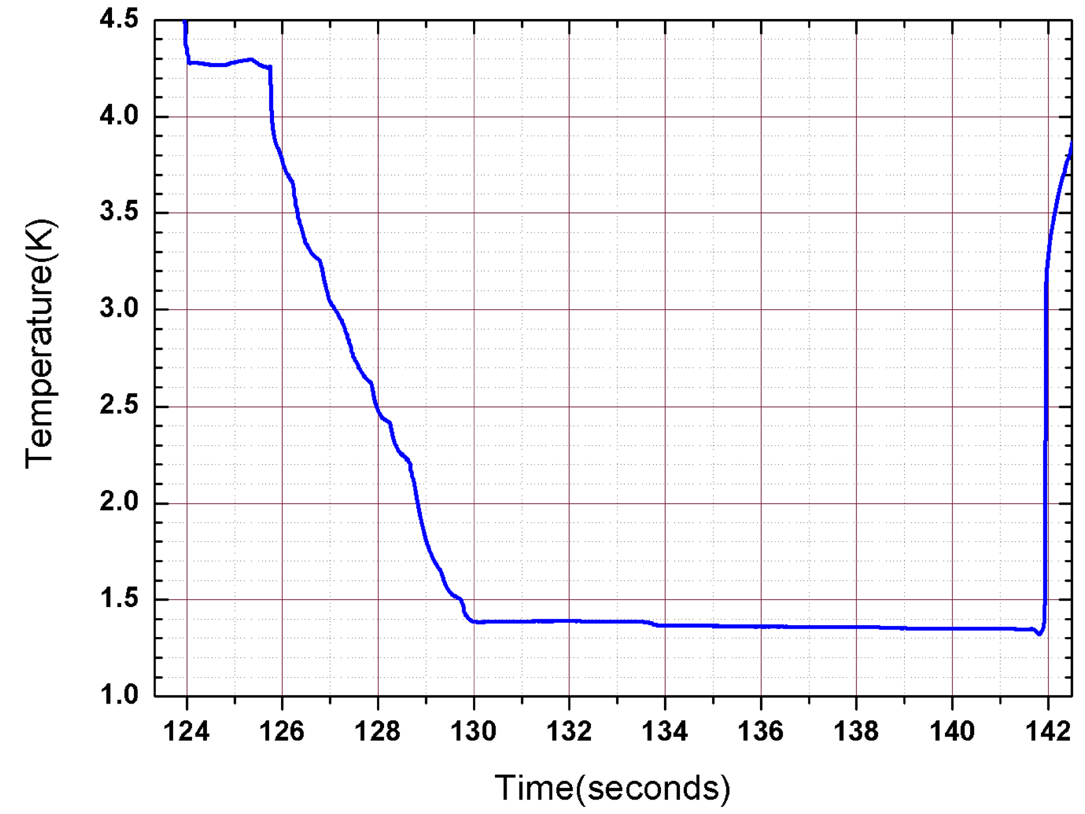
- The facility consists of the cryogen-free cryostat, the pulsed magnet, the LN_2 Dewar, the coaxial current lead and some supporting parts for the magnet.
- the pulsed magnet, the LN_2 Dewar, the tail of the cryostat and the sample holder are concentric.
- The pulsed magnet and the lower part of the cryostat are immersed in liquid nitrogen which is stored in the top-open LN_2 Dewar.
- The supporting plates for the cryostat and the magnet are made from epoxy.
- The material of the cryostat's vacuum jacket is 316L stainless steel.
- The center of the coaxial current lead is a copper rod, and the outside is a copper tubing. The rod and tubing are separated by epoxy.

Results

Cooling Curve

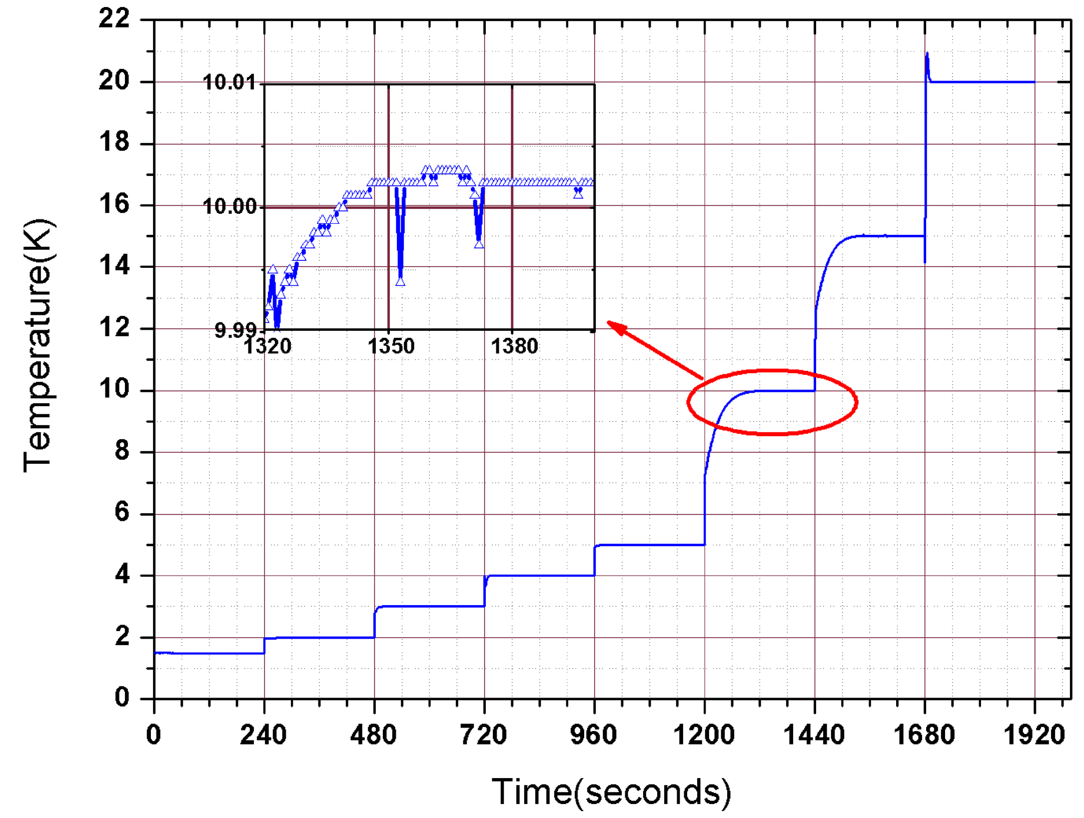


After operating the GM cryocooler for about 2 hours, the sample temperature were cooled down to 4.2 K. About 2 minutes later, closing the helium gas inlet valve and turning on the vacuum pump, the sample temperature decreased quickly to 1.4 K.

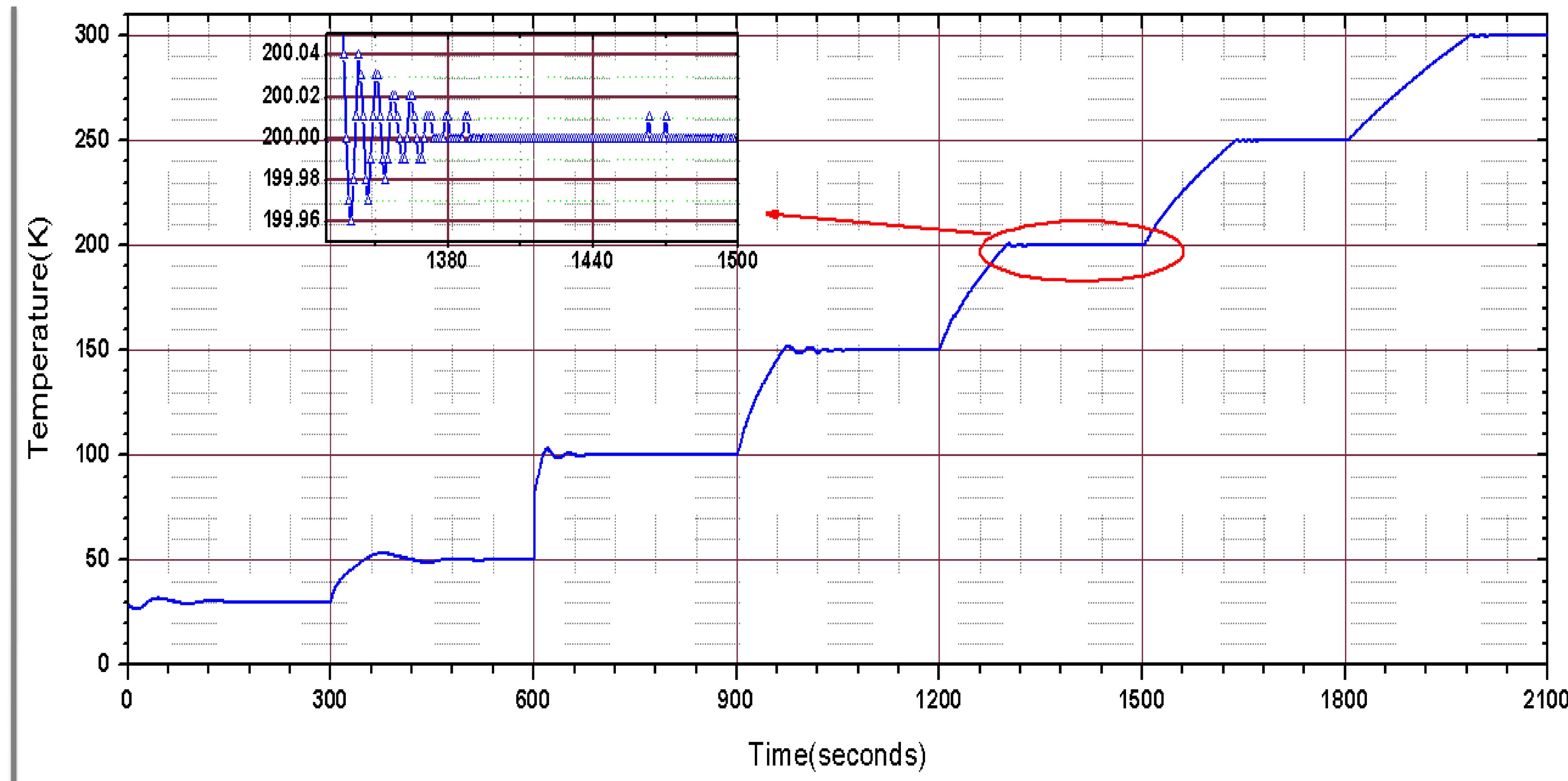


The figure shows the temperature stability details at 1.4 K, which demonstrates that the sample temperature can be kept at 1.4 K for 12 minutes. The time interval in which the temperature is stable is long enough by comparison to the pulse duration of several milliseconds of the magnetic field pulse.

Temperature-control Curve



The temperature stability of the cryostat with the temperature-control insert is ±0.01 K in the range of 1.4 K-20 K.



The inset in figure shows, the sample temperature becomes steady after several oscillations (about 1 minute) and is stable within ±0.05 K at 20 K - 300 K.

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