A self-contained ^{3}He melting curve thermometer for dissemination of the new provisional low temperature scale

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Abstract

We report progress in the development of a self-contained ^{3}He Melting Curve Thermometer, designed to be both easy to construct and simple to operate. It is based on a cylindrical pressure gauge, with good linearity of pressure versus inverse capacitance making calibration straightforward. The gas handling system is compact and in principle automatic. The readout electronics is based on a tunnel diode oscillator circuit, since one of the capacitance plates of the gauge is necessarily grounded. We present preliminary data on the performance of the thermometer, which will allow convenient dissemination the new provisional low temperature scale PLTS-2000.

Key words:
Low temperature thermometry

1. Introduction

The new Provisional Low Temperature Scale, PLTS-2000 provides temperatures from 0.9 mK to 1 K and is defined in terms of the melting pressure of ^{3}He. It extends down to the solid ordering transition [1]. We report here progress in the development of a self-contained ^{3}He melting curve thermometer, designed to be both simple to construct and easy to operate. This thermometer will allow convenient and direct dissemination of the PLTS-2000.

The melting pressure sensor is based on a cylindrical pressure gauge [2], and is designed to be simple to fabricate. It exhibits a good linearity of pressure versus inverse capacitance, making calibration straightforward. The gauge has a capacitance of ∼70 pF at 1 Bar, rising by ∼2 pF when pressurized to 14 Bar at room temperature. The sensitivity should be reduced by a factor of around two at low temperatures due to an increase in Young's modulus. In this design one of the capacitance plates has to be grounded, therefore a conventional bridge cannot be used to measure the capacitance.

We use capacitance read-out electronics based on a tunnel diode oscillator circuit, similar to that described by Van Degrift [3]. The circuit uses a low power back-diode (BD7) [4] as the active device. Initial tests of the oscillator circuit were carried out at 4.2 K, in a helium transport dewar, using a 68 pF silver mica capacitor to simulate the sensor. We used the BD7 to avoid excessive dissipation (it is the lowest power device in the BD series). The high magnitude of the negative resistance of this device meant that the circuit would not oscillate at either room temperature or 77 K when optimized. Cooling to 4.2 K was necessary to achieve a high enough tank circuit quality factor, Q, for oscillation. We experimented with both a copper wire coil and a superconducting wire coil for the tank circuit inductance, giving quality factors of 100 and 600 respectively at 4.2 K. The oscillator frequency was 3.2 MHz. The output of the oscillator was preamplified then mixed

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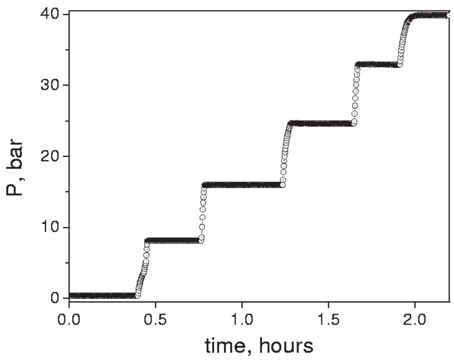

Fig. 1. Operation of the gas handling system. Pressure steps suitable for calibration of the sensor.

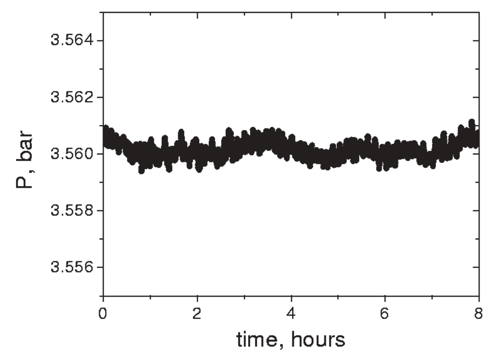

Fig. 2. Stability of a single step. Data taken at with the pressure sensor at room temperature.

down to a frequency of about 150 Hz, which was measured by an HP 5335A Universal Frequency Counter. The short term frequency stabilities for both coils was better that a part in 10^8. When the thermometer is installed on a cryostat the inductance must be located remote from the capacitative sensor, either on the 1 K pot or 4 K flange, and connected via a superconducting wire to minimize thermal conduction to the sensor. We simulated this situation by connecting the superconducting coil to the capacitor via a metre long superconducting wire. In this case a short term frequency stability of 35 parts in 10^9 was achieved, using a 4 s measurement time. Taking into account the predicted low temperature pressure-capacitance characteristic of the pressure sensor, this frequency stability corresponds to a temperature stability of the ^{3}He melting curve thermometer of $\sim 6\ \mu$K at 200 mK and $\sim 2\ \mu$K below 100 mK. A stringent test of long term stability needs to be performed.

The gas handling system is designed to allow for computer automation, including automatic calibration of the sensor. The system uses a set of relief valves and a cryopump together with an electronic pressure sensor. We are using a GEM 4000 series high performance pressure transducer in these measurements[5]. The gas handling system could be made compact enough to be located on the top plate of a refrigerator however our prototype, which contains additional valves for diagnostic purposes, is larger. The system has been tested to 40 Bar and the operation of the relief valves confirmed. By appropriate warming and cooling of the cryopump it is possible to set any pressure for calibration purposes from 1 to 40 Bar, which remains stable once set. Fig. 1 shows a set of pressure steps. Fig. 2 shows the stability of a typical step with the pressure sensor at room temperature. This pressure stability together with the good linearity of the sensor will make calibration straightforward. Calibration could in principle be done under computer control with the sensor sitting at 1.5 K.

We are presently evaluating the self-contained ^{3}He melting curve thermometer at low temperatures. The oscillator uses a copper wire inductance and is heatsunk to the 4 K flange. A comparison with a current sensing noise thermometer [6] down to 20 mK is in progress.

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References

[1] R. Rusby, M. Durieux, A.L. Reesink, R.P. Hudson, G. Schuster, M. Kühne, W.E. Fogle, R.J. Soulen, E.D. Adams, J. Low Temp. Phys. **126** (2002) 633.

[2] V.A. Mikheev, N. Masuhara, Th. Wagner, G. Eska, P. Mohandas, J. Saunders, Cryogenics **34** (1994) 167.

[3] C.T. Van Degrift, Rev. Sci. Instrum. **46** (1975) 599.

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[5] Gem Sensors, Lennox Road, Basingstoke, Hampshire, RG22 4AW, UK.

[6] C.P. Lusher, Junyun Li, V.A. Maidanov, M.E. Digby, H. Dyball, A. Casey, J. Nyéki, V.V. Dmitriev, B.P. Cowan, J. Saunders, Meas. Sci. and Tech. **12** (2001) 1, and in these proceedings.