CONF-900689--2

A Refrigerated Dewar for the Josephson Array Voltage Calibration System

Robert V. Duncan
Sandia National Laboratories
Albuquerque, NM 87185

SAND--89-3134C

DE90 005237

Abstract

A refrigerated Dewar has been used successfully with the Josephson array voltage calibration system. It has been used to re-liquify helium with no degradation of the calibration system's performance. The independence of the array voltage from temperature has been confirmed to three parts in 10^8 per Kelvin using this Dewar.

Introduction

Series arrays of Josephson junctions have been developed which are capable of producing quantized voltage levels over a wide voltage range [1]. These arrays have been used in a voltage calibration system since February 10, 1987 to maintain the U.S. Legal Volt [2] at the National Institute of Standards and Technology (NIST, formerly NBS). A similar system within the Primary Standards Laboratory (which is operated for the Department of Energy, Albuquerque Operations Office by Sandia National Laboratories (SNL)) has been in operation since July, 1989. Complete automation of these and other such systems will require the development of an automated cryogenic subsystem. Here we present details on the design and performance of a new refrigerated Dewar to maintain the Josephson junction array near 4K with no liquid helium loss and no routine operator intervention. No degradation in the stability of the array-based voltage calibration system was noticed while it was used with the refrigerated Dewar, even when re-liquification of helium was underway.

System Design

The refrigerated Dewar design is displayed in Figure 1. It was manufactured for SNL by the Research and Manufacturing Co., Inc. (RMC) of Tucson, AZ. The Dewar's helium space consists of a 3.81 cm diameter neck, a 25.4 cm diameter belly section with a 15 liter capacity, and a 4.45 cm diameter tail section, all made of stainless steel. The liquid helium region is surrounded by two coaxial copper heat shields which attach to the neck at their appropriate positions. Each shield is wrapped with a few turns of thin metalized plastic. The outer heat shield is cooled to about 60K by the first stage of a Gifford-McMahon cycle (GM) refrigerator [3]. The second stage of the GM cools the inner shield to about 17K. A Joule-Thomson cycle (JT) loop [4] then provides in excess of 1.5 Watt of useable refrigeration power to the liquid helium bath through an annular heat exchanger located at the top of the belly region. The temperature of the liquid helium in the belly can be varied from 3.8K to 5.2K by varying the regulated return pressure on the JT line. Thermometers are located on the two heat shields, the JT expansion nozzle, and on the tail section of the Dewar. Their temperatures are read out by a controller which may be automated over an IEEE-488 bus. The flow rate of helium gas in the JT loop is monitored by a flow meter with a digitizable analog output. Finally, the compressor's supply tank pressure may be monitored through the analog output of a pressure transducer. Hence all parameters critical to the performance of the refrigerated Dewar may be computer monitored. If necessary the JT return line pressure regulator can be computer actuated, resulting in fully automated temperature control of the Dewar. The thermometer in the tail section of the Dewar is located 8.9 cm above the bottom of the helium space, which places the thermometer at the same height as the array during voltage calibrations. Consequently this thermometer will accurately read the array temperature even if a vertical temperature gradient exists in the column of liquid helium.

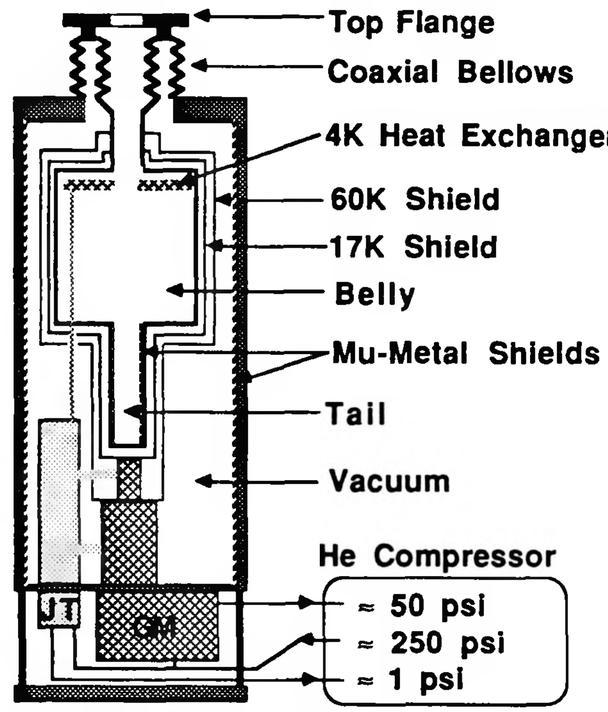

Figure 1: Refrigerated Dewar design. The compressor is located 15 meters from the Dewar during operation.

A set of coaxial bellows separate the top flange from the neck of the Dewar. This permits the apparatus mounted on the top flange to be mechanically isolated from the rest of the Dewar which is rigidly mounted to the refrigerator. Two coaxial mu-metal shields were located in the Dewar to protect the array from stray magnetic fields. One was located next to the outer wall of the vacuum space while the other was located within the helium space in the tail section of the Dewar.

The array used in this work contains 2,076 Josephson junctions connected in series [1]. It was manufactured at NIST in Boulder, CO, USA on February 24, 1987 and was numbered 211-03. The SNL array voltage calibration system is quite similar to the NIST system [2]. Only the differences between these systems are mentioned here. The SNL system utilizes a probe which features cryogenic filtering, and a lower heat loss than conventional probes which also use metal waveguides [5]. The SNL system operates with the Dewar pressure approximately 1 psi above ambient, while the NIST system operates near ambient pressure. Hence the array temperature in the SNL system was about 70 mK warmer [4] than the NIST system when they were both operated at sea-level. The SNL system uses an automated switch while the

NIST system uses a manual switch to inter-compare the array and unknown voltages. The measurement procedures described in Ref. 2 are identical to those used in this work, except that these data were taken manually during development.

Results and Discussion

The entire SNL array system was transported between Albuquerque, NM, Gaithersburg, MD, and Tucson, AZ during 1989. The SNL system was operated with the refrigerated Dewar only in Tucson. The results of using the SNL system to calibrate a single DC voltage reference over the last nine months are displayed in Fig. 2. Both the SNL system and the DC reference appear to transport nicely, as evidenced by the good repeatability between the different locations. While in Gaithersburg the SNL system was compared directly with the NIST system. Both systems experienced the same 0.01μV noise level during 12 calibrations of this 1.018V reference. The SNL system was found to read 0.026μV below the NIST system, and hence a 0.026 ppm difference has been taken into account for the SNL system calibrations. The source of this difference has not been determined.

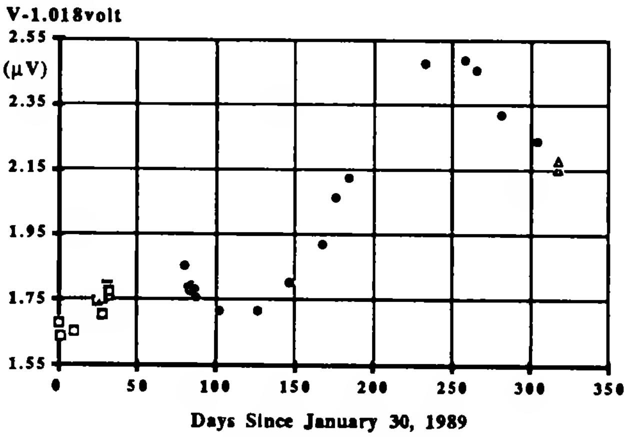

Figure 2: SNL array system calibrations of the voltage reference versus time. The data represented by squares were taken in Gaithersburg, by circles in Albuquerque, and by triangles in Tucson.

The refrigerated Dewar was used with the SNL system in Tucson to check for any dependence of the quantized array output voltage on its temperature. The DC reference of Fig. 2 was calibrated five times within a 13 hour interval and with the array at different temperatures. The drift history of the DC reference leads to a predicted drift in its nominal 1.018V output of -0.005μV per day when it was used with the refrigerated Dewar. The array temperature was set by varying the JT return pressure. The array was biased with 83,440,600,000(5) Hz. radiation, and the n = 5,900 step of the array was used to create a quantized array voltage of 1.018002194 V, using the 2e/h value of 0.483593420 GHz/μV. The results of these five measurements are shown in Fig. 3. No systematic variation of the array voltage with temperature was detected. These measurements were taken as the array temperature was raised, lowered, and raised again. This indicates that any temperature coefficient of the array voltage must be less than 0.03μV/K over the range 3.94K < T < 4.59K. The 4.35(1)K measurements in Fig. 3 were made at 1.0 bar and 1.7 bar, and no systematic variation of the array voltage with pressure was detected.

Similar array voltage standards are in use in laboratories at elevations ranging from sea level to about 2,000 meters. The corresponding temperature of the liquid helium which bathes these arrays during calibration varies from 4.21K at sea level to 3.94K at 2000 meters [4]. (Here standard pressure conditions and equilibrium of the liquid helium with its saturated vapor are assumed). The results presented here show that no more than a 0.009μV systematic variation between these laboratories may exist in ≈1V calibrations due to array temperature effects. Since the noise level of these measurements is about 0.01 ppm, and since the physical value of the volt is known to 0.3 ppm [6], such a tiny systematic error with elevation would be of little consequence. This result also shows that differences in the helium bath temperatures between the NIST and SNL array calibration systems can not account for the 0.026 ppm discrepancy described above.

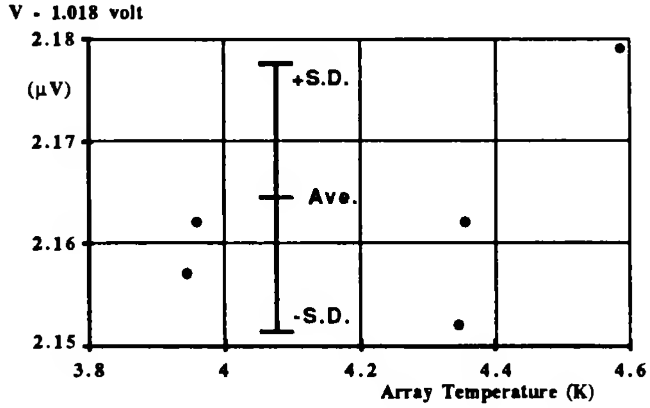

Figure 3: Temperature-independence of the array voltage. The calibration system noise level is indicated.

This refrigerated Dewar is capable of producing over four liters of liquid helium from room-temperature gas per day. Calibrations using the array voltage standard were not disrupted by helium liquification. Hence ^{4}He may be recovered from other cryogenic apparatus (ie. a cryogenic current comparitor or a quantum Hall effect resistance standard) and re-liquified by this refrigerated Dewar. With all refrigeration to this Dewar off, the steady state liquid helium loss rate was less than two liters per day.

Acknowledgements

The assistance of Dr. Richard Steiner of NIST and of Dr. E.T. Swartz of RMC Cryosystems is gratefully acknowledged.

References

[1] F.L. Lloyd et al., "A Josephson Array Voltage Standard at 10V", IEEE Electron Device Letters, Vol. EDL-8, pp. 449-450, October, 1987.
[2] R.L. Steiner and B.F. Field, "Josephson Array Calibration System: Operational Use and Verification", in Proceedings of the Conference on Precision Electromagnetic Measurements, 1988, pp. 1-2.
[3] H.O. McMahon, Cryogenics, Vol. 1, pp. 65-70 (1960).
[4] G.K. White, Experimental Techniques in Low Temperature Physics. Oxford, U.K.: Clarendon Press, 1987, ch. 1, and p. 307.
[5] R. Duncan, "A New Cryoprobe for the Josephson Junction Array Voltage Standard", Bulletin of the American Physical Society, Vol. 34, pp. 1535-1536, June 1989.
[6] E. Richard Cohen and Barry N. Taylor, Journal of Research of the National Bureau of Standards, Vol. 92, pp. 85-95, 1987.