CEBAF LINAC CRYOGENIC INSTRUMENTATION REQUIREMENTS AND A REVIEW OF THE AVAILABLE SENSORS

M. G. Rao
Superconducting Radio Frequency Technology Division
The Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue
Newport News, VA 23606

Abstract

CEBAF's Linac and the associated cryogenic refrigeration system need to be carefully instrumented for their successful installation and operation. The important cryogenic instrumentation requirements include temperature, pressure, liquid level and flow. In this paper a critical review of the available sensors will be presented. Further, the wide operating temperature range, interchangeability and high radiation hardness requirements of the sensors will also be discussed.

Introduction

The important parameters that require continuous monitoring and/or control in CEBAF's cryogenic systems are temperature, pressure, liquid level and flow. In the following a review of the available sensors for this application are presented, together with some experimental results on the effect of radiation in temperature and pressure sensors.

Temperature

The major criteria in selecting a cryogenic temperature sensor for CEBAF's use are interchangeability, wide operating temperature range, high reproducibility, two-wire configuration, cost, and resistance to radiation damage. Table I summarizes these characteristics for the likely candidates: carbon, carbon-glass, cryogenic linear temperature sensor (CLTS), germanium, platinum, rhodium-iron resistance and Si diode thermometers.

Though carbon, carbon-glass and germanium resistance thermometers have high sensitivity in the temperature range of interest (1.5-10K), they have limited operating temperature range. By using them in conjunction with a platinum resistance thermometer the operating temperature can be extended, but at the expense of additional cost in cable, connectors, feed throughs and installation. Furthermore, transmitting these low-level signals over cable lengths of 200 feet or more will present difficulties with respect to thermal emfs and electrical noise. With the exception of Si diodes, all the other sensors need to be calibrated for achieving temperature measurement accuracies of better than 0.5K, and this is prohibitively expensive. In view of the recent successful 5 Mrad irradiation results obtained on Si diodes, they should be seriously considered, since they do not require calibration, can be interchanged, have good reproducibility, can cover the whole temperature range, have high output signal level, and need only two leads[1].

Pressure

The measurement of pressure in cryogenic systems is generally accomplished via pressure tappings and capillary tubes leading to an ambient temperature pressure sensor. Such a system suffers from the disadvantages of limited frequency response, thermoaccoustic oscillations, failure due to a leak or block in the gauge lines, added heat leaks, and complicated installation procedures due to the gauge lines[2].

Calibrated pressure sensors operating in the cryogenic environment do not suffer from these problems; moreover, they give good accuracy in pressure measurement at reduced cost. Figure 1 shows the calibration data for a cold pressure sensor operating in a LHe bath. The calibration curve has very good linearity with 160 μV/Torr/mA sensitivity.

Liquid Level

At present only two types of continuous liquid level sensors are available. One of them is more commonly used and is based on the superconducting transition of a superconductor at the liquid vapor interface. This sensor is known to have reliability problems, even operating at 4.2K. The manufacturers themselves recommend incorporating two sensors into a system so as to have a backup sensor. When it comes to operating the sensors at subatmospheric pressures, the problems seem to multiply. This is shown in Figure 2. Illustrations a, b, and c are the plots of sensor voltage with increasing and decreasing current. The hysteresis curve (c) is normal for a properly working sensor[3], whereas curves (a) and (b) indicate that the level sensor is not functioning properly. A detailed description of the possible reasons for such behavior will be presented elsewhere.

The second sensor is based on the variation of capacitance between two coaxial conductors with liquid level. These sensors have very poor resolution for helium. Their usage in CEBAF's system is ruled out because the electronics that must be mounted at the level probe would not withstand moderate radiation dose levels.

Flow

Recent inquiries concerning commercial flow meters operating at ~2K and at subatmospheric pressures drew a blank. It appears that CEBAF needs to develop sensors for measuring helium vapor flow from

*This work was supported by the U. S. Department of Energy under contract DE-AC05-84ER40150.

TABLE I

Sensor	Interchange-ability	Tempera-ture Range	Signal level	Reproducibility	Number of leads	Cost (uncalibrated)	Resistance to Radiation
Carbon	no	0.1 - 100K	<10mV	Poor (~20/charge)	4	<$1	yes
Carbon-glass	no	1 - 300K	1-10mV	1mK	4	$155	no
CLTS	no	4 - 300K	20mV	0.2K	4	$310	no
Germanium	no	0.02- 100K	1-10mV	<1mK	4	$150	yes
Platinum	no	15 - 700K	1-100mV	10mK	4	$100	yes
Rhodium-iron	no	1 - 800K	1-50mV	10mK	4	$395	no data
Si diode	yes	1 - 475K	0.1-1.8V	20mK	2	$180 (Calibration not required)	yes

individual cryomodules in order to monitor the Q of the SRF cavities. An elegant solution for this problem is to use the principle of heat transfer from heated wall to the boundary layer, i.e., the temperature difference between a thermometer in front of a heater placed on the helium flow tube and another thermometer placed after the heater would be a function of helium mass flow.

Radiation Effects

Si diode thermometers from Southampton University, Lakeshore Cryotronics and CEBAF are being irradiated with γ rays at room temperature in steps of decades of rad for determining radiation effects in them. Silicon strain gauge pressure sensors from Siemens are also being irradiated for the same purpose. Figures 3 and 4 show the preliminary results of the radiation effect on temperature and pressure sensors respectively. The difference between the temperature before the sensors were irradiated and the temperature after each decade radiation dose for the three types of Si diode sensors at 4.2K is within ±0.1K. This temperature difference includes the variation of bath temperatures due to ambient pressure changes during the past year. Although radiation had a small effect on the temperature sensors at 4.2K, there is likely to be a considerable effect above 30K in the intrinsic range of the sensors due to the increase in surface leakage currents as a result of irradiation above 1 Mrad.

The cold pressure sensor output variation is less than ±5 mbar at 4.2K due to the irradiation, and this is within the calibration accuracy of the sensor. Further irradiation tests are continuing with γ rays, and irradiation with neutrons is being planned.

Acknowledgements

The author wishes to acknowledge the support of Geoffrey Stapleton of CEBAF, and the University of Virginia, Charlottesville, in getting the sensors irradiated.

References

1. M. G. Rao, "Semiconductor Junctions as Cryogenic Temperature Sensors," Temperature its measurement and control in science and industry, vol. 5, American Institute of Physics, pp. 1205-1211, 1982.

2. M. G. Rao and R. G. Scurlock, "Cryogenic Instrumentation With Cold Electronics -- a Review," Advances in Cryogenic Engineering, vol. 31, pp. 1211-1230, 1986.

3. K. R. Efferson, "A Superconducting (Nb-Ti) Liquid Helium Level Detector," Advances in Cryogenic Engineering, vol. 15, pp. 124-131, 1970.

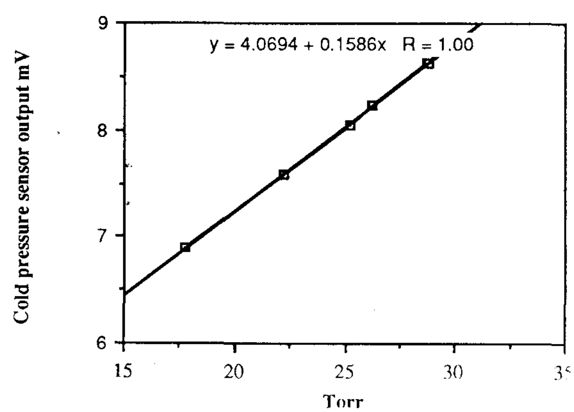

Figure 1. Cold pressure sensor output as a function of pressure at LHe temperature.

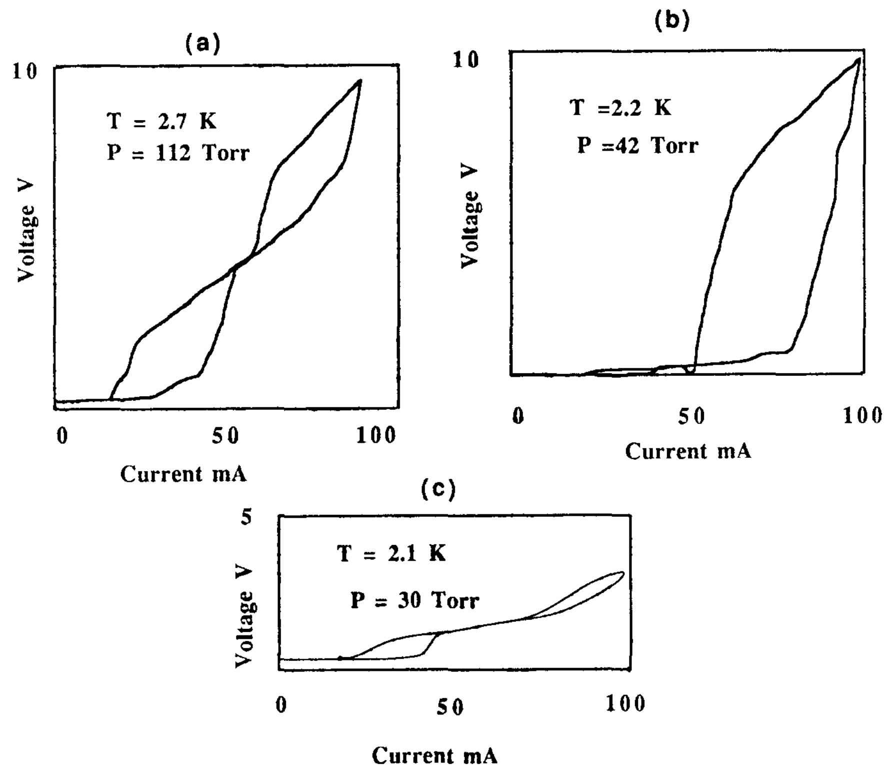

Figure 2 V - I characteristics of LHe level sensor at different temperatures

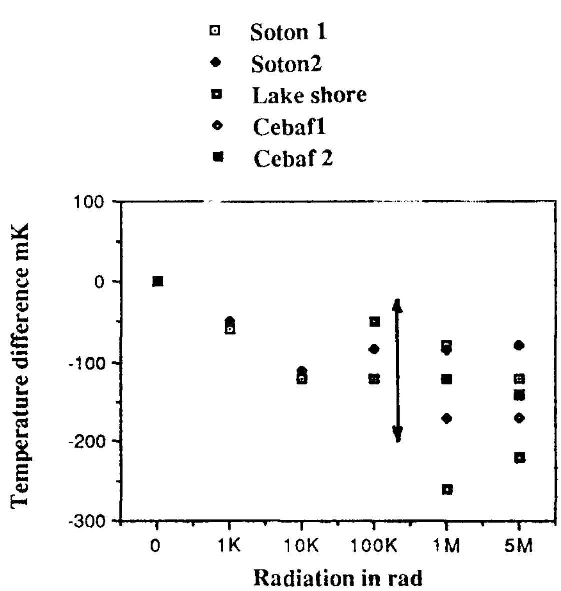

Figure 3. Radiation effect on temperature sensors at 4.2K.

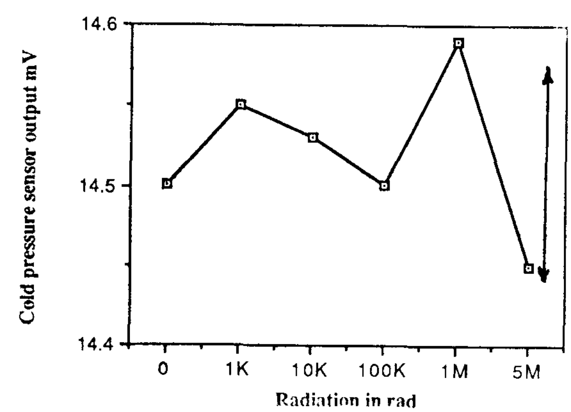

Figure 4. Radiation effect on cold pressure sensor at 4.2K.