REVIEW OF LIQUID HELIUM LEVEL SENSORS*

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ABSTRACT

Reliability of liquid helium level sensors becomes critical whenever a cryostat needs to be completely welded and accessibility becomes limited. This paper presents a review of the currently available continuous LHe level sensors from the viewpoint of reliability and wide operating temperature range (1.5 – 5.0 K). The most commonly used superconducting wire LHe level sensors seem to be reliable only in limited temperature segments 3.0 – 4.6 K and below the λ-point. Specifications of a new, simple and wide temperature range level sensor which dissipates very low power ($\sim$ 6 mW) into the cryogenic system and that can measure level of any cryogenic liquid are also presented here.

INTRODUCTION

Two types of continuous liquid helium level sensors are presently in use. The first one is known as magnehelic gauge. This gauge measures the difference in pressure head between the liquid surface and the bottom of the liquid column, and indicates the height of the liquid column. These indicators very often fail due to a blockage in the gauge lines. Further these indicators are mechanical devices with no electrical signal output for interfacing with computerized data acquisition and control systems. As a result, their use is very much restricted.

The second type of level indicator is more commonly used and is based on the transition of a superconductor from superconducting to normal state at the liquid vapor interface[1]. These level sensors appear to be reliable in limited operating temperature ranges 3.0 – 4.6 K, and below the λ point.

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Electrical capacitance level sensors, in which the variation of capacitance between two coaxial conductors with liquid level is the measuring parameter, were used in the early fifties and sixties[2]. These gauges do not seem to be in use for LHe level measurement probably because of their poor resolution due to the small dielectric difference (0.05) between the liquid and vapor phases. Further, the drive electronics need to be mounted on the sensor itself in order to minimize the effect of stray capacitances.

This paper discusses the problems of the SC wire level sensors with respect to reliable wide temperature range operation and presents specifications of a newly developed sensor.

THE PROBLEM OF THE SC WIRE LEVEL SENSOR

The normal operation of the superconducting wire LHe level sensor depends on the difference in heat transfer between the liquid and vapor phases of He. On the other hand, reliable operation of the level sensor in a wide operating temperature range (1.5 – 5 K) relies on the critical heat flux of saturated pool boiling on the SC wire of the sensor for a given operating current. The critical heat flux of the level sensor is related to the operating temperature and current of the sensor.

Figure 1 shows the voltage-current characteristics of the sensor at different temperatures. The hysteresis curve 'C' is normal for a properly working sensor.

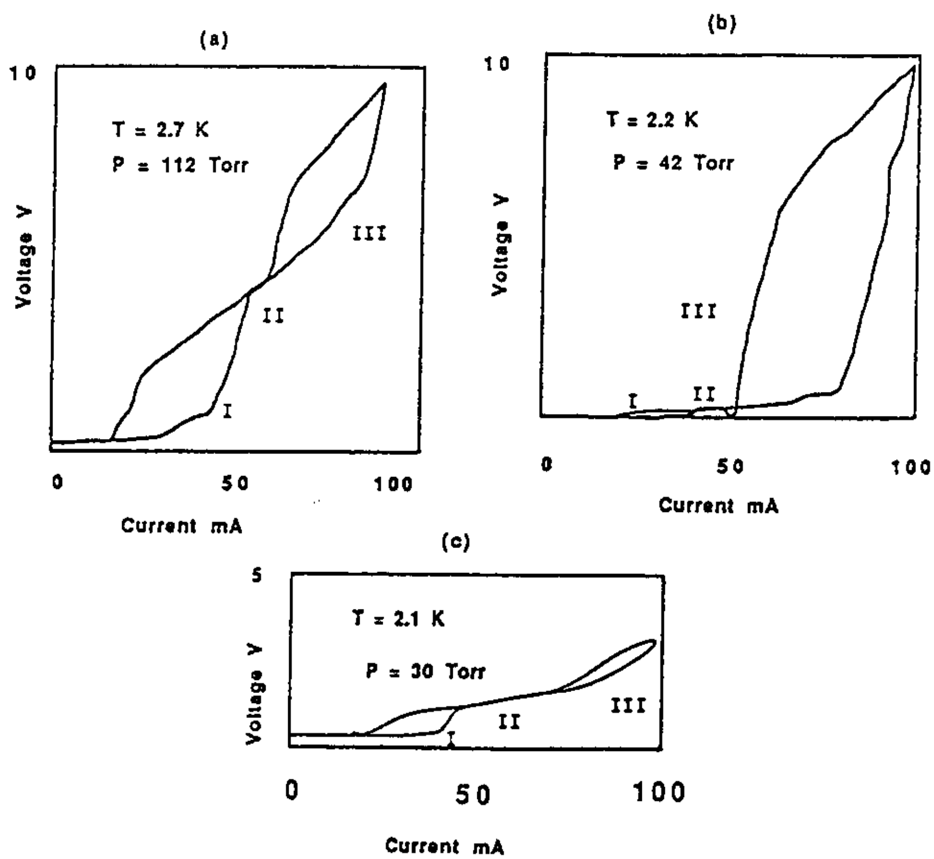

Figure 1 V - I Characteristics of LHe level sensor at different temperatures

The characteristic consists of non-linear (I), linear (II) and non-linear segments (III). The first non-linear portion is related to the growth of the normal zone of the superconductor towards the liquid-vapor interface with increasing current. The linear segment is due to the linear dependance of the fixed normal zone of the superconducting wire above the liquid vapor interface with increasing current. The second non-linear part is due to the driving down of the superconductor–normal interface inside the liquid because of the initiation of the film boiling. The current corresponding to the onset of the non-linear segment (III) can be termed as the critical current at which film boiling begins.

Figures 2 and 3 give the critical current for the LHe level sensor as a function of LHe bath pressure and temperatures respectively. For comparison, Figures 4 and 5 show the critical heat flux versus pressure for horizontal cylinders[4] and critical heat flux versus temperature for flat surfaces[5] respectively. The qualitative agreement between the figures is much evident from their similar characteristics despite the difference in orientation and type of the heat transfer surfaces.

The characteristics shown in Figures 2 and 3 are for American Magnetics, Inc. sensor made out of 25 micron NbTi superconductor. These sensors are normally operated with 70 mA current and a line is drawn in Figure 3 to indicate this operating current. The following conclusions can be drawn from Figure 3.

The sensor will function normally in the temperature range 3.0–4.6 K and below 2.18 K since the critical current is above the normal operating current of 70 mA. The sensor will either indicate lower level or hang up (does not respond to changes in liquid level) at temperatures above 4.6 K[6] and in the temperature range 2.18 – 3.0 K[7], because the critical current is below the optimum sensor excitation current of 70 mA. One could lower the sensor current to avoid the above difficulties. This may reduce the sensor response time or may make it unstable depending on the helium flow conditions near the sensor. In essence, one has to adjust the sensor current to make it reliable for a given temperature and helium flow conditions at any particular time.

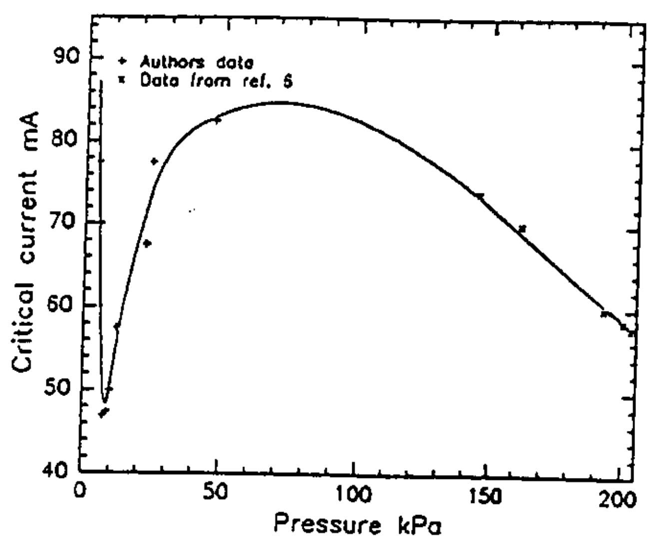

Figure 2 Critical current vs pressure for LHe level sensor

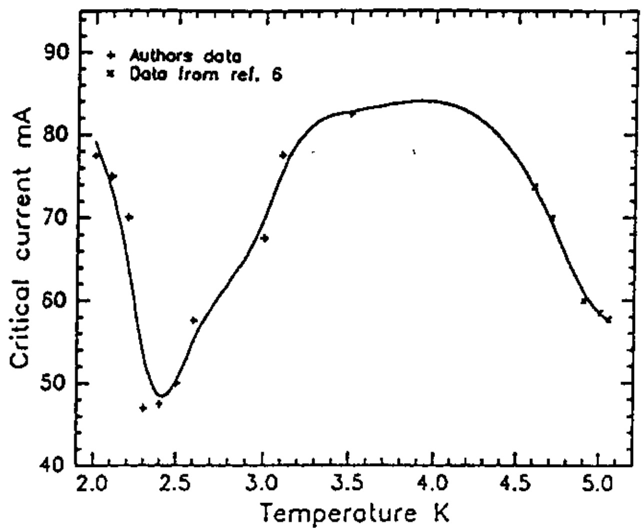

Figure 3 Critical current vs temperature for LHe level sensor

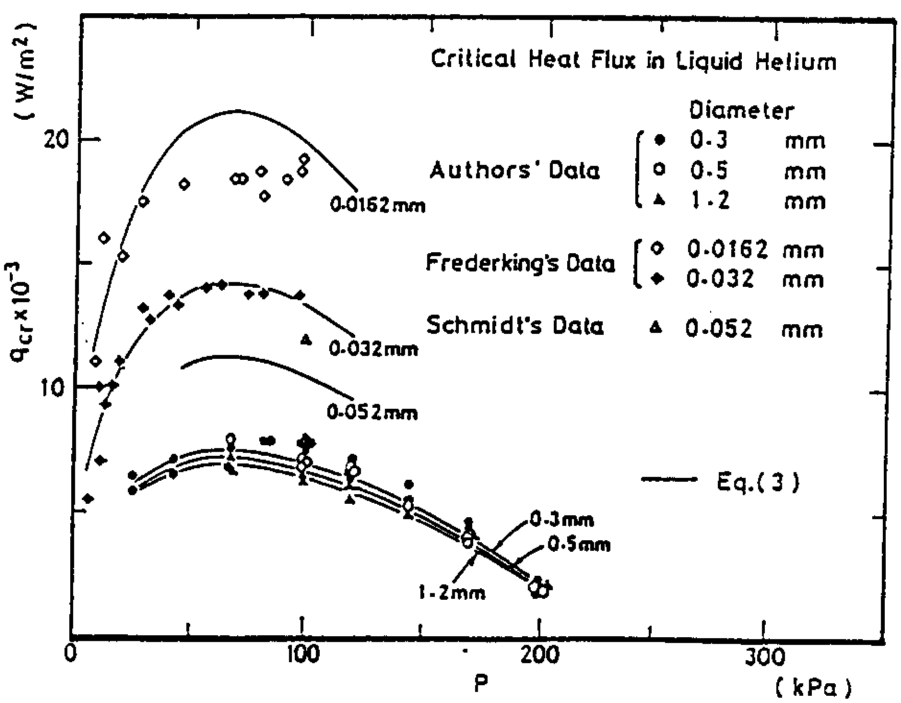

Figure 4 Critical heat flux vs pressure for horizontal cylinders in LHe from ref. 5

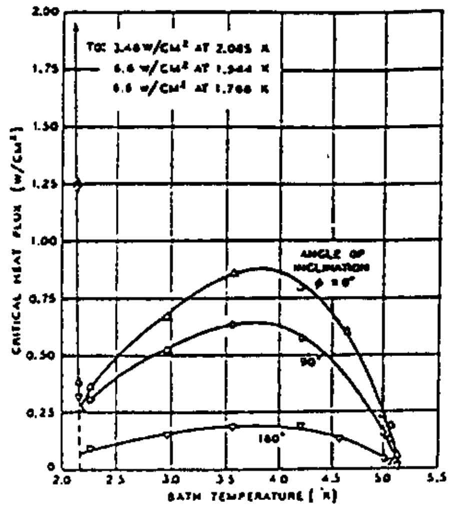

Figure 5 Critical heat flux vs temperature for flat polished platinum in LHe from ref. 4

THE NEW LEVEL SENSOR

A new level sensor has been recently developed at CEBAF to alleviate the above difficulties. The detailed description and operating principle of this sensor will be presented elsewhere.[8] This new sensor dissipates very low power into the cryogenic system, typically $\sim$ 6 mW. These sensors can be used to measure the level of any cryogenic liquid in wide operating temperature ranges. They have a sensitivity of $\sim$ 40 μV per mm of liquid helium, have linear response, and can be made to measure wide ranges of liquid heights.

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