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AN IMPROVED CRYOGENIC LIQUID-LEVEL SENSOR

by

L. G. Hyman, J. F. Sheppard,
and H. Spinka

RELEASED FOR ANNOUNCEMENT
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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	4
I. INTRODUCTION	4
II. DESCRIPTION OF THE INSTRUMENT	5
III. TEST RESULTS	6
IV. DISCUSSION	8
V. REFERENCES	9

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Photograph of Assembled Sensor, Housing, and 1N34A Diode and 200- Ω Resistor Thermally Connected with Aluminum Tape	5
2.	Voltage Drop across a 1N34A Diode as a Function of Temperature.	5
3.	Scope Trace for Forward Voltage across Diode (in container) in Liquid and in Vapor.	5
4.	An Operational Circuit for the Sensor	6
5a.	Response of Voltage across Diode in a Container as a Function of Heater Power (0.10, 0.40, 0.63, 0.78, 0.90 W) in Vapor . . .	6
5b.	Response of Voltage across Diode in a Container as a Function of Heater Power (0.10, 0.40, 0.63, 0.78, 0.90 W) in Liquid	6
6.	Voltage across Diode in Container as a Function of Pulse Duration (4, 9, 14, 19, 29 sec) in Vapor	7
7.	Graph of Q vs Diode Current for Typical Diode with (0.68 W) and without (0.84 W) Container	7
8.	Graph of Q vs Heater Power for Diodes in Containers (1.00 mA and 19 sec).	7
9.	Q Values for 10 Diodes without Containers	7
10.	Graphs of Q vs Pressure with (0.63 W) and without (0.78 W) Container at 19-sec Duration	7

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ABSTRACT

A new liquid-level indicator, consisting of a diode heated by a resistor, is described. The effects of diode current, resistor power, heater pulse duration, and pressure are discussed.

I. INTRODUCTION

Many cryogenic systems require the simultaneous use of two and perhaps three of the liquids nitrogen, hydrogen, and helium. In addition, it is customary to precool a helium system with nitrogen and/or hydrogen. In such a system (which is often closed and inaccessible), an ideal liquid-level indicator has the following properties:

1. The indicator is rugged, simple, inexpensive, and requires no preselection of components.
2. No elaborate calibration is required, and no adjustments are needed to account for which liquid the device operates.
3. It is a yes-no device which is easy to operate and interpret.
4. It is insensitive to changes of circuit parameter and is independent of the number of thermal cycles.
5. It is independent of environmental conditions, such as pressure, geometry, and liquid splashing.
6. The power dissipated by the indicator is negligible compared to other heat sources in the system.

After extensive testing in nitrogen and helium, we believe the instrument described in this article very nearly satisfies all the above criteria.

II. DESCRIPTION OF THE INSTRUMENT

The operation of the instrument depends on:

1. the strong temperature dependence of the forward resistance of a germanium diode, and
2. the differences in heat transfer properties of the liquid and vapor.

The basic sensor consists of a diode thermally connected to a heat source. We have used a 1N34A diode and a conventional 1/4-W, 200-ohm carbon resistor as heater. The thermal connection is made with aluminum tape.* Figure 1 shows the sensor assembly.

In Fig. 2 is presented the voltage drop across a 1N34A diode (forward current of 1 mA) as a function of temperature.

137-1368

Fig. 1. Photograph of Assembled Sensor, Housing, and 1N34A Diode and 200- Ω Resistor Thermally Connected with Aluminum Tape

137-1378

Fig. 2. Voltage Drop across a 1N34A Diode as a Function of Temperature. Diode current is 1.00 mA.

If the sensor is immersed in liquid helium and approximately 3/4 W is supplied to the heater, there is little or no change in the diode voltage. When the sensor is placed in vapor and power is applied to the resistor, the voltage change across the diode is approximately 5 V (see Fig. 3).

137-1369

Fig. 3

Scope Trace for Forward Voltage across Diode (in container) in Liquid and in Vapor. Heater power 0.78 W, pulse duration 19 sec, diode current 1.00 mA, 5 sec/division, 2 V/division, base line 7.17 V.

*Made by Minnesota Mining and Manufacturing Co., St. Paul, Minn.

The effect is more pronounced if the sensor is placed in a housing such as shown in Fig. 1. We used stainless steel tubing ($1\frac{3}{4}$ -in. long, of 5/16-in. OD, with 0.010-in. walls), two liquid intake holes of 0.040-in. diameter, and six gas vent holes of 0.055-in. diameter.

137-1373

Fig. 4. An Operational Circuit for the Sensor

An operational circuit is shown in Fig. 4

III. TEST RESULTS

We have explored the behavior of the instrument in nitrogen and helium as a function of:

1. heater power level;
2. diode current;
3. duration of the heater power;
4. pressure.

In order to determine reasonable operating conditions, we define a figure of merit Q as

$$Q = \frac{\Delta V_{\text{gas}}}{\Delta V_{\text{liquid}}},$$

where ΔV_{gas} is the change in voltage across the diode when it is in gas and ΔV_{liquid} is the voltage change when in liquid. In addition, we require ΔV_{gas} to be large enough so it is easily detected with simple measuring devices.

With the sensor in the container, Fig. 5a shows the response in gas at various heater power levels, and Fig. 5b the corresponding responses in liquid. Figure 6 shows the response of the sensor in gas to variations in the length of time power is applied.

137-1372

Fig. 5a. Response of Voltage across Diode in a Container as a Function of Heater Power (0.10, 0.40, 0.63, 0.78, 0.90 W) in Vapor. 1.00 mA, 19 sec, 5 sec/division, 1 V/division.

137-1371

Fig. 5b. Response of Voltage across Diode in a Container as a Function of Heater Power (0.10, 0.40, 0.63, 0.78, 0.90 W) in Liquid. 1.00 mA, 19 sec, 5 sec/division, 1 V/division.

137-1370

Fig. 6. Voltage across Diode in Container as a Function of Pulse Duration (4, 9, 14, 19, 29 sec) in Vapor. 0.63 W, 1.00 mA, 5 sec/division, 1 V/division.

highest Q in nitrogen was about 0.5-2.0 W. The optimum heater voltage is approximately 25-28 V in both helium and nitrogen. Figure 10 illustrates the variation of Q with pressure.

137-1376

Fig. 7. Graph of Q vs Diode Current for Typical Diode with (0.68 W) and without (0.84W) Container. Pulse duration 19 sec and power levels to optimize Q 's.

137-1374

Fig. 9. Q Values for 10 Diodes without Containers (1.00 mA, 19 sec, and 0.63 W)

Figure 7 shows the variation of Q with diode current. An excellent operating point is at 1-mA excitation. Figure 8 is a plot of Q versus heater power. Figure 9 shows the Q values (no container) obtained for ten diodes operating at the same power level in helium. In nitrogen Q is very large ($Q \geq 90$) and the spread is of no significance. We expect that the behavior in hydrogen closely resembles the nitrogen behavior. The power level for the

137-1377

Fig. 8. Graph of Q vs Heater Power for Diodes in Containers (1.00 mA and 19 sec). Lower-power Q 's are ratios of two small numbers and are thus not very accurate.

137-1375

Fig. 10. Graphs of Q vs Pressure with (0.63 W) and without (0.78 W) Container at 19-sec Duration

A sensor was thermally cycled rapidly about one-hundred times between room and liquid nitrogen temperature with no adverse effects on its behavior. We also found the sensor reproducibly locates the liquid level to better than 1/16-in. with, as well as without, the housing. When the mass flow of gas per unit time with the sensor in vapor was varied, the device was found to be relatively insensitive to the amount of mass flow.

It was found that placing the sensor in a housing increased the value of Q by a factor which varied between 1.5 and 10. If the housing is used, there is less sensitivity to liquid splashing and the sensor has a higher Q at all pressures tested (see Fig. 10). The total area of the liquid intake and gas vent holes was varied for one diode to optimize the Q and this configuration used for other diodes.

Other germanium diodes* in most cases behaved similarly to the 1N34A. Of the diodes tested, the 1N34A appears to be the best choice for this application. The average Q is 41, and the spread in Q values appears in Fig. 9.

Sensors with the diode replaced by a conventional carbon resistor were also tested in liquid helium. They have the advantages of:

1. higher average Q (~65 at 0.036 W from a sample of 10) with less spread from sample to sample;
2. lower required heater power level.

However, for the resistor sensor to operate in nitrogen at low power levels a housing is required. We also noted long recovery times (of the order of several minutes) after the power pulse was removed.

IV. DISCUSSION

We believe the testing carried out with these sensors accurately simulated the conditions encountered in many cryogenic systems. The diode sensor with housing very nearly satisfied the six criteria stated in the introduction; the spread of Q together with the small statistical sample used indicate preselection of diodes should be carried out in liquid helium if very high- Q ($Q > 75$) sensors are required.

Several articles using similar techniques have come to our attention. In particular, we are familiar with the work of Lewin,¹ Cooper,² Cottingham and Kovarik,³ and Souzade *et al.*⁴

*Also used were 1N35S, 1N38A, 1N54A, 1N90A, 1N96, 1N270/JAN, and 1N994 germanium diodes, which exhibited similar behavior, but the 1N34A diode appears to be the best choice.

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