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DESIGN AND CONSTRUCTION OF A CRYOGENIC LIQUID LEVEL-TEMPERATURE TRANSDUCER

WILLIAM E. ALEXANDER

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
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NOTICES

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FOREWORD

This report was prepared by the Experimental Mechanics Branch, Structures Division, Air Force Flight Dynamics Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio.

The work reported was accomplished under Project No. 1347, "Structural Testing of Flight Vehicles," Task No. 134702, "Measurement of Structural Response." William E. Alexander was the principal investigator, while James L. Mullineaux is the task engineer.

The action was undertaken to provide pump starvation warning devices: the pumps are integral to the Structures Test Laboratory cryogenic fuel simulant system. In operation, the pipelines connected to pumps should remain full of liquid. Therefore, liquid level transducers have been installed within the pipes to give warning of pipeline evacuation. These same transducers also monitor the temperature of vaporous nitrogen at various times. These liquid level-temperature transducers were developed in the Structures Division's laboratories.

Important contributions were made by personnel of the Structures Test Branch of the Structures Division. Bernard Boggs proposed the design concept; John Taylor devised novel fabrication techniques; and Airman John Kelly conducted the performance tests.

This technical report has been reviewed and is approved.

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Chief, Experimental Mechanics Branch
Structures Division

ABSTRACT

This report summarizes the design and construction of a cryogenic liquid level-temperature transducer. Its sensitive element is a flattened Chromel-Alumel thermocouple. The element is heated radiantly, producing an above ambient temperature output signal. The output increases 6.5 millivolts when a drop in liquid level occurs. Ambient temperatures are monitored when the thermocouple is not heated.

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ILLUSTRATIONS

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INTRODUCTION

Cryogenic liquid level changes can be detected by various methods:

a. Position changes of floating objects

b. Gas pressure changes within tubes

c. Spontaneous oscillation of gas in open tubes

d. Absorption changes in gamma radiation, visible light, and thermal energy

e. Dielectric changes

Thermal energy absorption or thermal interaction is one of the more economical methods. Functionally, several measurable parameters of a warmer object change when the object is immersed in a cryogenic liquid. The resistance, temperature, length, thermal conductivity, and other properties increase or decrease. Of these, temperature and resistance changes are easily monitored because the necesssary detection devices are technically simple.

Heated resistors and thermocouples are examples of devices which react to temperature changes associated with thermal interactions. The resistor undergoes an increasing resistance as cryogenic liquid engulfing it recedes below its in situ position. The resistor, a wheatstone bridge arm, causes bridge unbalance, and signals a liquid level change. This method would be more economical if signaling could be achieved without dependence on the wheatstone bridge.

A heated thermocouple is more advantageous than a resistor. Its output is a direct function of thermal action at the measuring junction. No complex signal conditioning equipment is required to render the output intelligible. A thermocouple transducer would be capable of cryogenic liquid-level detection and temperature measurement. The transducer would signal liquid-level changes when the thermocouple is being heated. When no heat is applied, the output would be a function of cryogenic fluid temperature. The subject of this report is the development of such a transducer.

SECTION II

PRINCIPLES OF OPERATION OF A CRYOGENIC LIQUID LEVEL TRANSDUCER

The basic operation is outlined in Figure 1. A metal foil to which a thermocouple is attached is shown in contact with the liquid nitrogen. Radiant energy is being absorbed by both from a small resistance heater. The thermocouple signal increases sharply as the liquid surface recedes below the foil. The signal decreases to the original value when the liquid rises and contacts the foil. This signal change is proportional to the change in heat transfer rate between the foil and nitrogen. Heat is transferred by convection when the foil is within the gaseous nitrogen. However, the heat transfer is due to surface boiling upon the foil through liquid contact, and is much greater.

SECTION III

DESIGN AND CONSTRUCTION

The transducer's outer configuration is probe shaped. Two probes are shown in Figure 2, one of which has a threaded fitting.

The inner components are sketched in Figure 3, which shows that the stainless steel jacket encloses the thermocouple and heater to protect them from moving liquid forces. The protective enclosure is sealed with an Inconel foil. These components and the others were formed and assembled as follows:

a. Seven turns of 30-gauge platinum wire around a spindle formed the miniature heater.

b. The heater leads of 19-gauge copper wire were attached by peening.

c. The sensing element was formed by flattening a 36-gauge Chromel-Alumel thermocouple to a 55-gauge thickness at the junction; it was then welded to the center of a 0.25-inch diameter by 0.0015-inch Inconel foil (Figure 4). In effect, an insulated attachment between the heater and the thermocouple was achieved. The air gap separating the two provided a good electrical insulator and a good thermal transmitting medium.

d. 24-gauge Chromel-Alumel wires were used as extension leads of the finer wire thermocouple.

e. A binding of high temperature tape secured the relative positions of the components during insertion into the 0.25-inch stainless steel tube. The tape insured firm positioning during sealing.

f. The tube was sealed with the Inconel disk by capacitance welding (Figure 5).

The components are shown with respect to a battery, an indicator, and a switch in Figure 6. These three items are not embodiments of the transducer, but are essential to its operation.

SECTION IV

PERFORMANCE SUMMARY

The transducer was designed to undergo a 5 mv change in less than 0.5 seconds. Zero would correspond to immersion in liquid nitrogen, and 5 mv to detection of cryogenic nitrogen vapor.

The completed transducers were tested to verify performance predictions. Each was energized and immersed into an open liquid nitrogen bath. The decrease in the room temperature output was recorded and the time over which the total change occurred. The power applied was varied for different tests.

Performance exceeded the design requirements. Changes were observed from 6.5 to 7 mv. The maximum time response observed was 0.15 seconds. To achieve this performance, 2.85 to 3.18 amps were applied to the transducer heaters.

SECTION V

CONCLUSIONS

An economical cryogenic liquid-level transducer can be constructed easily with inexpensive tools and the fabrication methods are simple. Other materials and thermal detectors may be used instead of those reported.

SECTION VI

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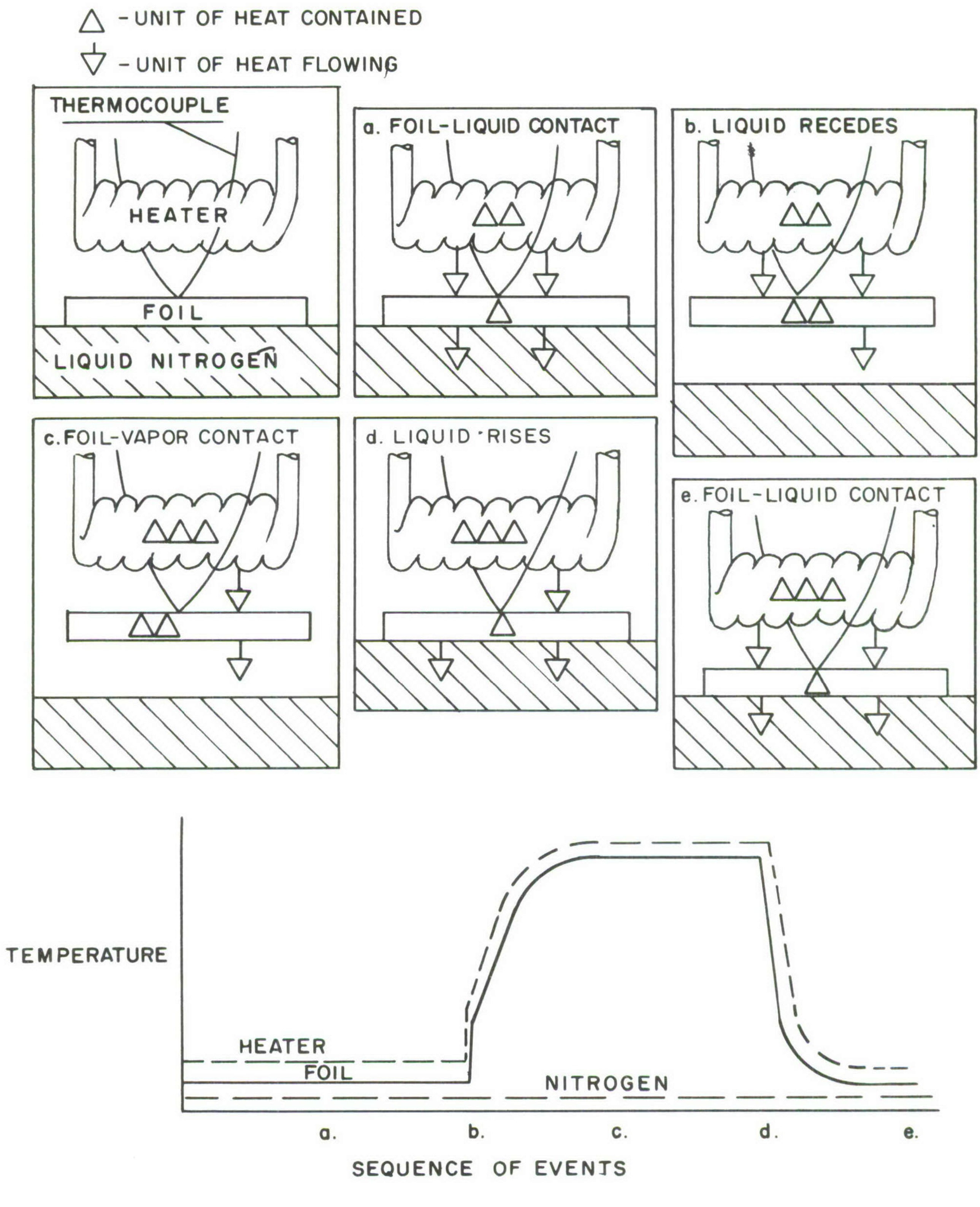

Figure 1. Cryogenic Liquid Level Transducer Thermal Behavior

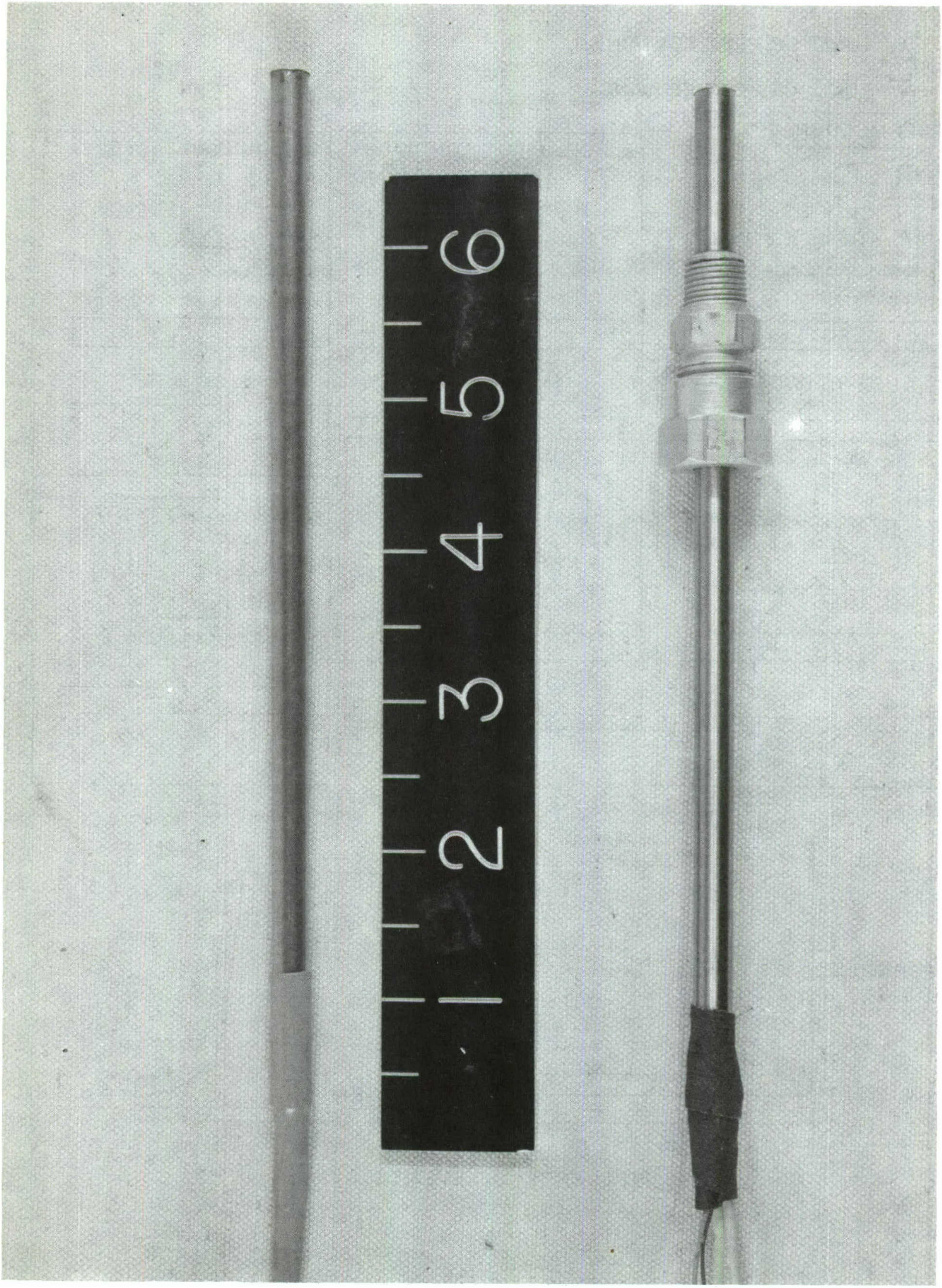

Figure 2. Assembled Transducers

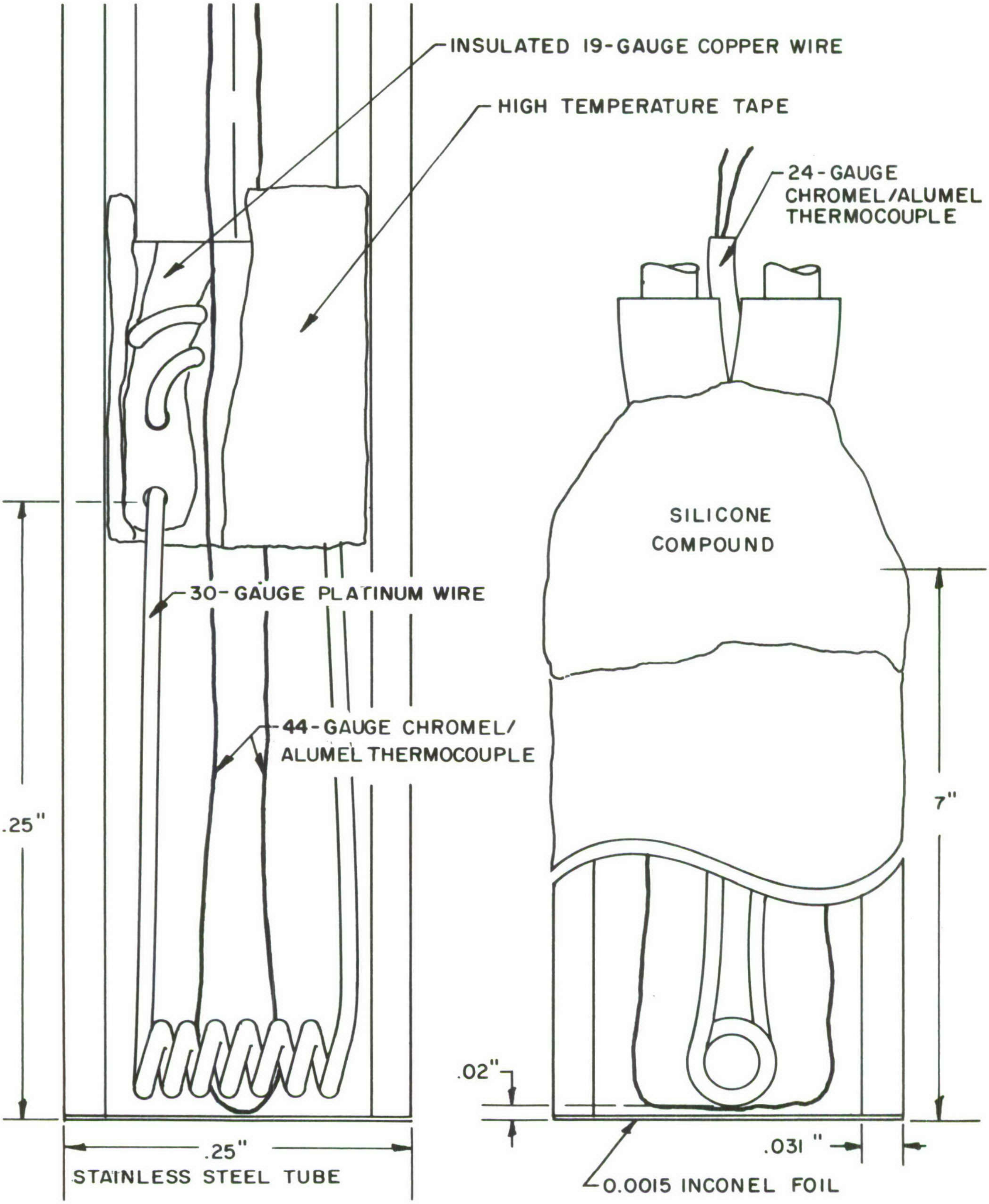

Figure 3. Cryogenic Liquid Level-Temperature Transducer Design

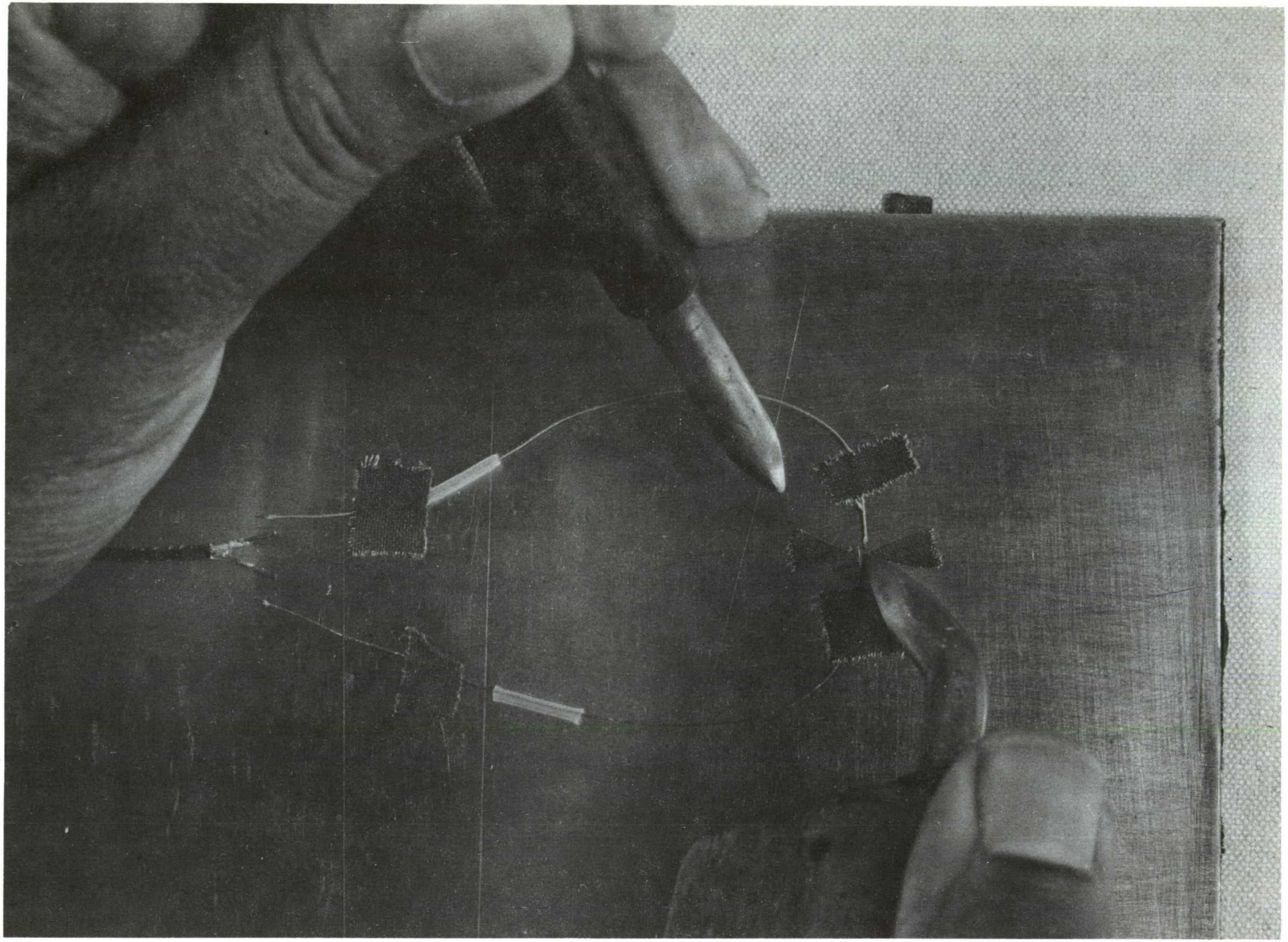

Figure 4. Thermocouple is Welded to Foil Disk

Figure 5. Foil Disk is Welded to Stainless Steel Tube

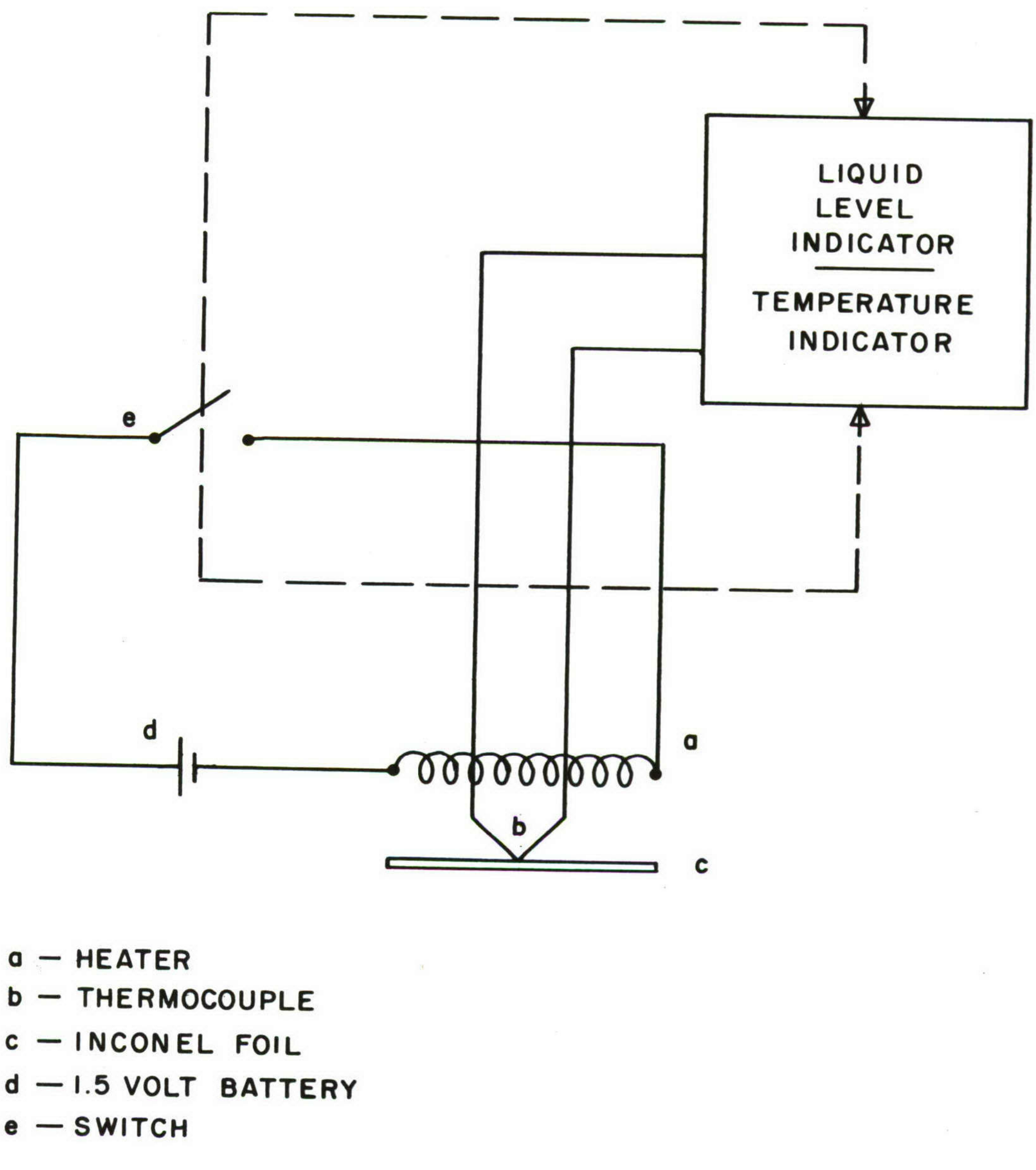

Figure 6. Electrical Circuit

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