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A VENTING ALARM SYSTEM FOR CRYOGENIC LIQUIDS

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A VENTING ALARM SYSTEM FOR CRYOGENIC LIQUIDS*

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SUMMARY PAGE

THE PROBLEM

The storage of liquid helium and nitrogen required for the operation of high-field superconducting magnets creates a potentially hazardous situation should the venting of the heat-vaporized gases be restricted. A plug of frozen air or water vapor within the vents of the cryogen storage vessels constitutes such a restriction and may be preliminary to a buildup of pressure. To minimize the likelihood that such a plug may go undetected requires repeated checking of the cryogen storage facilities throughout the period of operation of the magnet. The need was thereby created for an alarm system which would continuously monitor the venting and would provide a reliable and unmistakable indication should a plug begin to form.

FINDINGS

An alarm system was designed that continuously monitors the gas output from vessels in which cryogenic liquids are either stored or used. The system is fail safe in nature. It gives a visual and an auditory alarm in the event that venting provisions are restricted or a component failure takes place. Repeated manual checking of venting is eliminated, thus allowing the experimenter to concentrate upon the investigation without risk that high pressures may be developing within the system.

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INTRODUCTION

The operation of superconducting magnets and other apparatus designed to operate at cryogenic temperatures requires that liquefied gases be stored and handled in such a manner that heat leaks to the cryogens are minimized. This requirement is responsible for the creation of a situation which is potentially hazardous to the personnel, equipment, and experiments involved. Although vacuum-insulated Dewars are quite effective in protecting stored cryogens from ambient temperatures, thermal isolation is not complete, and there is always a heat leak from the external environment to the very cold interior of the Dewar, with resultant vaporization of the liquid. Since the liquid-to-gas expansion ratio of the cryogen is very high (approximately 1 to 700 at S.T.P.), unrelieved pressure within the Dewar may reach a critical level.

At the interface between these two widely divergent environments temperatures are sufficiently low to solidify water vapor and atmospheric gases that have freezing points higher than that of the stored cryogen. This interface may be located within the neck of the storage Dewar, may shift in exact location as a function of the boil-off rate of the cryogen, and may be so located as to be undetectable by visual examination. Should the vents of the Dewar be restricted or completely closed by the ice block formed from such solidification, pressures within the relatively fragile container could reach values which exceed the rupture strength of the vessel. This pressure increase may be quite insidious if the boil-off rate of the cryogen is low; however, once a fault develops so that the cryogen is exposed to ambient temperature, the sudden increase in volume of the material as it changes from a liquid to a gas is capable of causing a pressure explosion of considerable force.

The need was therefore created for a relatively simple alarm system which would continuously monitor the venting of equipment in which the cryogens were either stored or used. Although the alarm system described here was designed for use with a superconducting magnet using liquid helium and liquid nitrogen (at temperatures of 4.2° and 77° K, respectively), it could be applied, with minor modifications, to the detection of gas output from any source provided the pressure was greater than atmospheric.

Specific requirements for the system as designed were that:

1) component or power failure would not disable the alarm without warning and thus it would be fail safe;

2) cross-sectional area of venting arrangements would not be restricted;

3) gases evolved at different and/or changing rates could be monitored;

4) transfer of liquid nitrogen without activation of the alarm would be possible;

5) sensors would be located remote from the Dewars;

6) heat inleak to the cryogen should not be increased;

7) a visual indication of the venting conditions would be provided which could be interpreted with minimum attention by untrained personnel;

8) both visual and auditory alarms would be provided;

9) easy and rapid repairs could be made by personnel with a minimum of training in electronics.

All of these objectives were accomplished by the system described.

ALARM SYSTEM

DESCRIPTION

The alarm system for the superconducting magnet consists of six individual but similar circuits for the following system components: 1) magnet helium Dewar, 2) magnet nitrogen jacket, 3) liquid helium storage Dewar, 4) storage Dewar nitrogen jacket, 5) main nitrogen storage Dewar, and 6) an auxiliary nitrogen storage Dewar.

All of these Dewars are monitored continuously with the exception of those for nitrogen storage. During transfer of liquid nitrogen to the magnet the Dewar providing the nitrogen is pressurized, thereby precluding venting. For this period only, the alarm to the Dewar supplying the nitrogen is automatically disconnected. The following description applies to each of the six individual subsystems of the total alarm.

The gas-handling section of the alarm consists basically of two test tubes connected in series to each other and to the gas source by rubber or plastic tubing. The tube proximal to the gas source serves as a trap to protect the source from the mineral oil contained within the distal tube. This second tube contains mineral or other light oil through which bubbles the venting helium or nitrogen gas. At low rates of cryogen boil-off these bubbles may be the sole visible evidence that venting is actually effective since the gases themselves are colorless and odorless. A sensor composed of a photocell and light source mounted adjacent to the tube provides an electrical signal as long as bubbling and, therefore, venting continues.

Figure 1 is a block diagram of a single venting circuit showing the relationships between the gas-handling and electrical components.

Sensor Circuit

The sensor consists of a photoresistor and a light source opposed diametrically at the outer tube surface. The photoresistor is, therefore, illuminated by light which has passed through the bubbling mineral oil. These oil bubbles change the angle of incidence of the light reaching the photoresistor, thereby increasing its resistance.

This increase in resistance in turn reduces the current flowing in the circuit, thus producing an alternating output voltage whose amplitude is related to the size and number of bubbles per unit time interrupting the light beam. Figure 2 shows the sensor orientation, Figure 3 the sensor circuit, and Figure 4 a schematic of the complete system.

a-c Amplifier

The output signal from the sensor (about 20 mV, rms) is further increased in amplitude in this circuit.

Amplitude Detector

The a-c output from that amplifier is rectified and filtered to obtain a d-c voltage proportional to the rms value of the alternating signal.

d-c Amplifier

The d-c voltage from the amplitude detector drives this amplifier to saturation, insuring that its output approaches the saturation voltage. If bubbling stops, the output from the amplitude detector goes to zero, and this amplifier is cut off; i. e., its output voltage rises to a value equal to that of the supply.

Delay Firing Circuit

The output from the d-c amplifier is fed to a unijunction transistor through a resistor-capacitor series connection. When the output from the d-c amplifier reaches a voltage equal to that of the V supply, the voltage across the capacitor increases at a rate primarily determined by the RC time constant, thus providing a time delay. (A delay of 60 seconds was selected for this application.) When the voltage across the capacitor equals a peak of about 11 volts, the unijunction transistor conducts heavily, producing a pulse and discharge of the capacitor voltage. This discharge, in turn, produces a positive output pulse from an NPN transistor amplifier.

Solenoid Amplifier

The positive pulse from the delay circuit cuts off the solenoid amplifier, thus de-energizing the solenoid or relay RY1 (Figure 4). One of the relay contacts provides a latching or inhibiting action so that once the relay is de-energized, it remains in that state even though the input pulse goes to zero. A second contact on RY1 is used to de-energize relay RY2 which activates light indicators and an alarm.

The solenoid amplifier has a manual reset switch which returns the amplifier to its original state before triggering.

Alarm Circuit

The alarm consists of a 6-volt buzzer, activated through RY2, which is fed by the output from the secondary of a step-down transformer whose primary is energized by 115-volt, 60 cy/sec current.

Safety Features

The system was designed in such a manner that failure of any of the circuit components would activate the alarm. Should any of the light circuits fail to operate, a d-c amplifier is cut off, producing an output voltage which de-energizes the solenoid amplifier. In the event of a-c line power failure, the entire vent alarm system automatically switches to battery-powered operation so that venting protection is not interrupted.

Transfer Operation

During either manual or automatic transfer of liquid nitrogen from the nitrogen storage Dewars to the magnet, a relay prevents the output of the d-c amplifier from activating the delay circuit and thus the alarm. Once the transfer is terminated, the amplifier-delay circuit connection is automatically re-established and the alarm function restored.

Maintenance

The sensors are mounted in an aluminum rack which simultaneously supports the test tubes and positions the light source, photoresistor, and tubes in the proper relationship to each other. Either of the components may be changed without disturbing the others.

Circuit components are mounted on plug-in cards to permit exchange by untrained personnel. Several spare cards kept on hand permit rapid restoration of the alarm circuit to operating condition in the event of component failure.

Conclusions

The described vent alarm system has met all of its design objectives. It has been operated continuously on several occasions for periods up to 36 hours with no significant problems. With this system in operation the attention of the investigator can be primarily devoted to operation of the magnet and to the experiment in progress rather than to constant checking of the venting conditions of the cryogens. The safety of unattended overnight storage of cryogens is considerably increased since the circuit can be easily arranged to energize an alarm located remote to the magnet installation, as for example, at a night watchman's station.

Although the alarm was designed for use with cryogenic liquids, it could be used to monitor any escaping gas provided the pressure is greater than atmospheric.

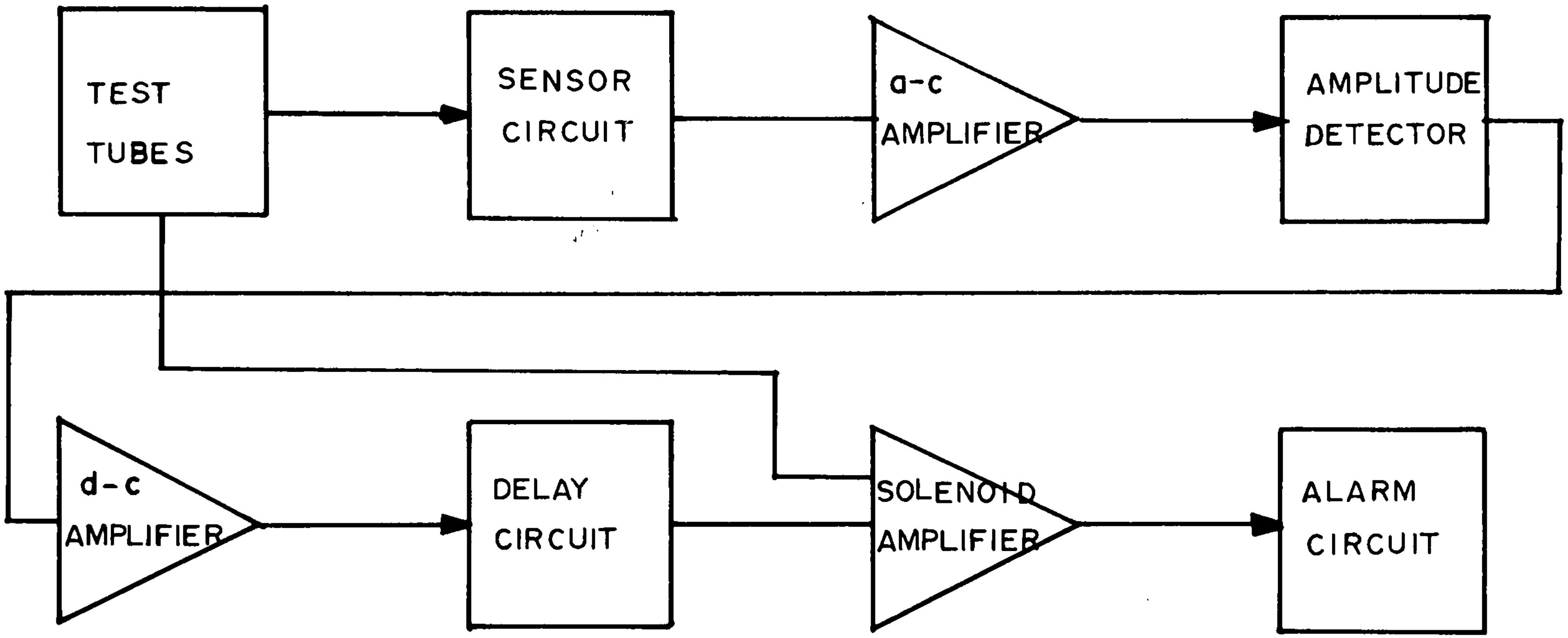

Figure 1

Block Diagram of a Single Venting Circuit

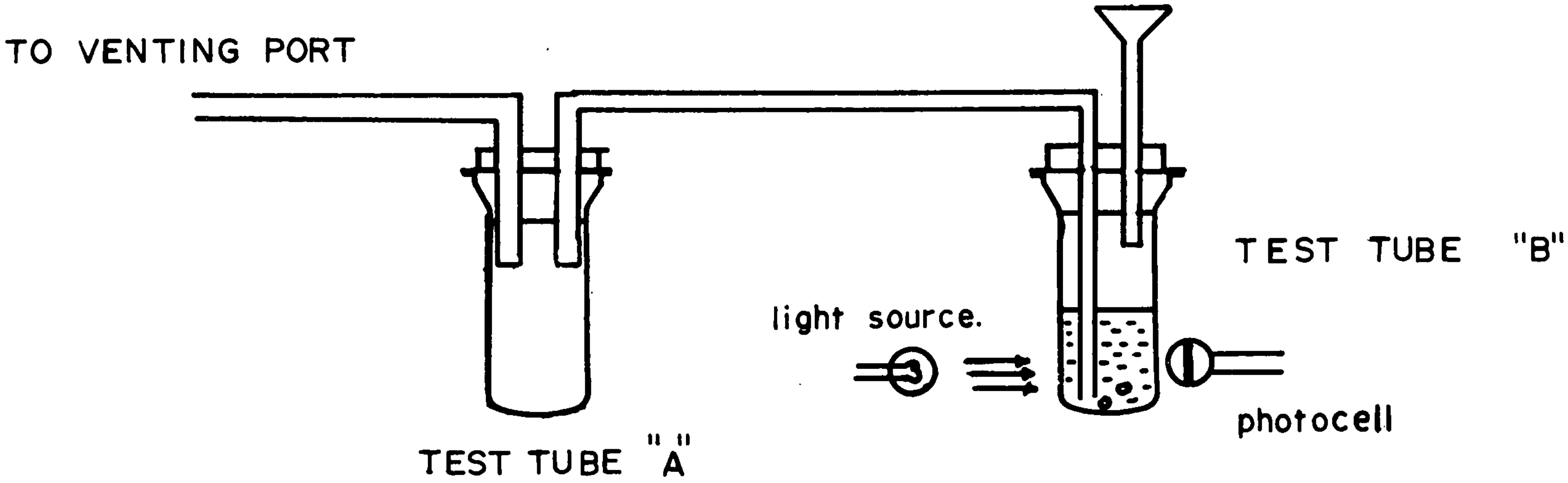

Figure 2

Sensor Orientation

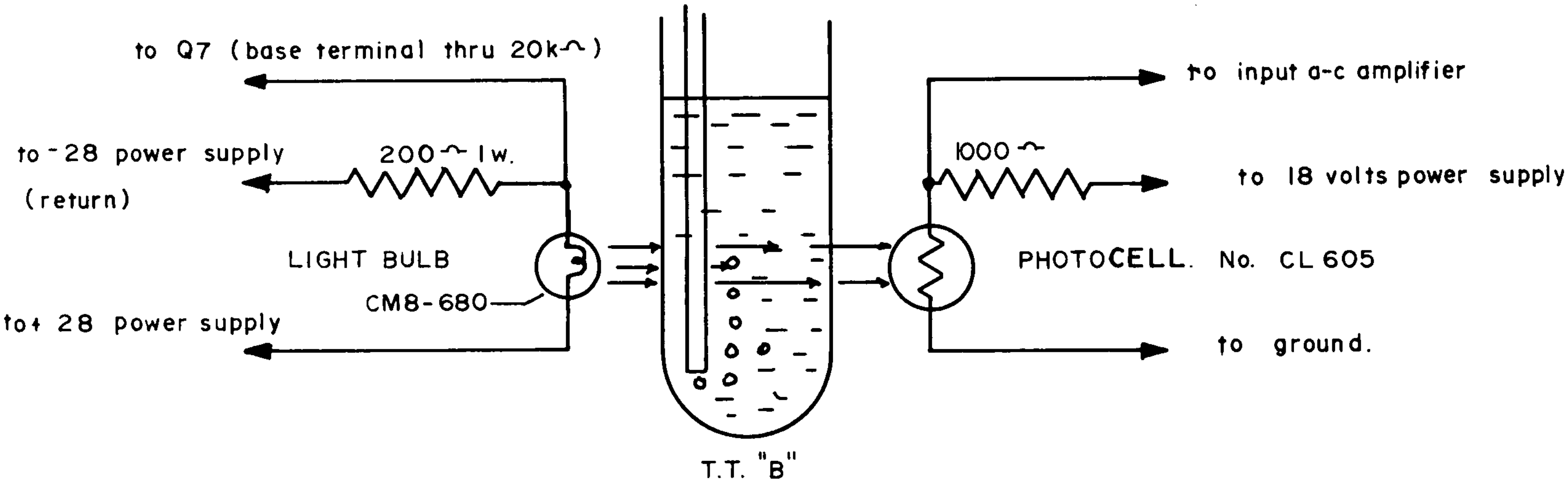

Figure 3

Sensor Circuit

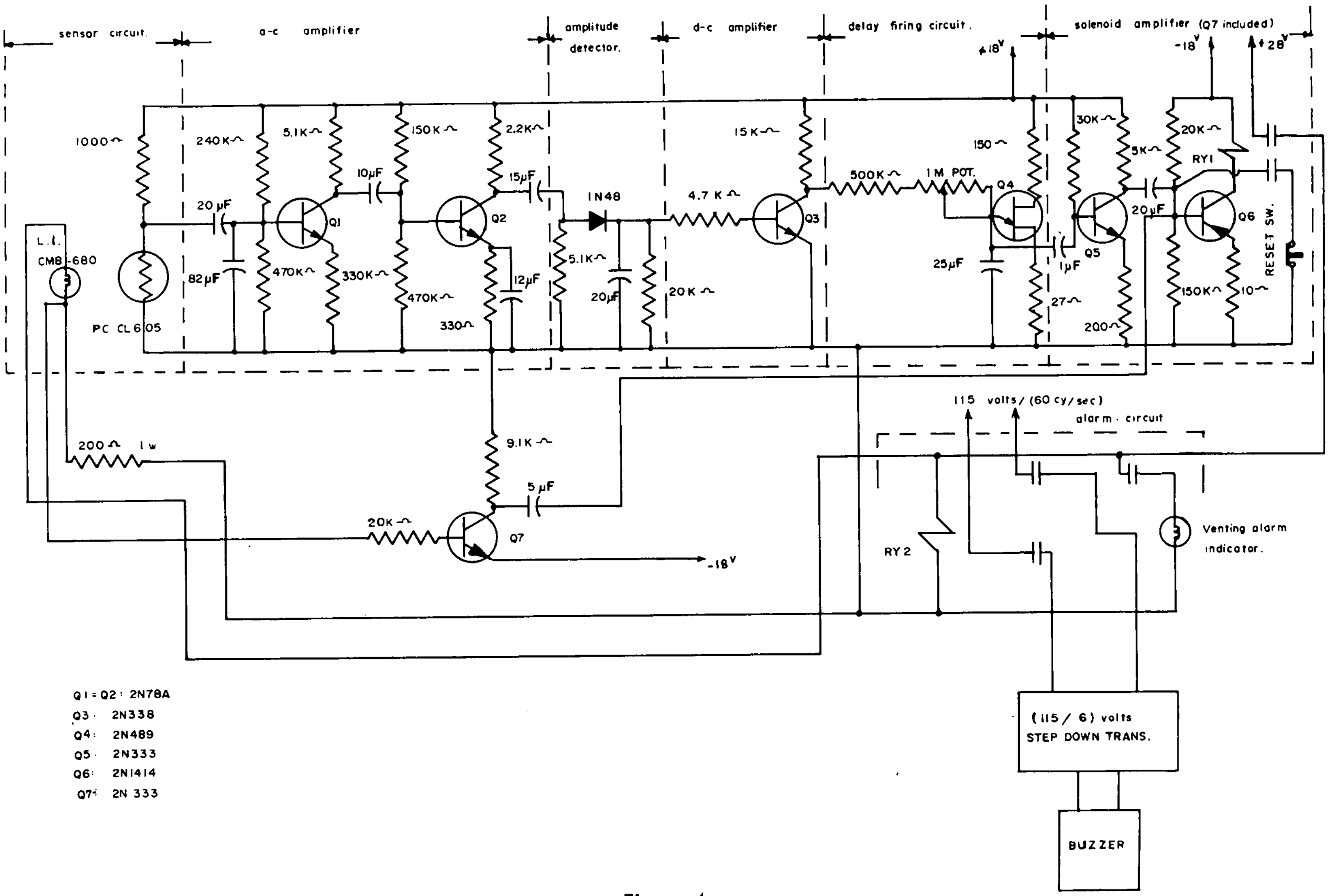

Figure 4

Schematic Diagram of Venting Circuit

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13. ABSTRACT

An alarm system was designed which continuously monitors the gas output from vessels in which cryogens are either stored or used. The system is fail safe in nature. It provides a visual and an auditory alarm in the event that venting is restricted or a component failure takes place. Repeated manual checking of venting is eliminated, thus allowing the experimenter to concentrate upon the investigation without risk that high pressures may be developing within Dewars containing the cryogenics.

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