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Y-1602

Instruments

MASTER

THERMISTOR TEMPERATURE CONTROL CIRCUIT

J. J. Henry

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

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ABSTRACT

An improved temperature-control circuit has been designed that employs a thermistor bridge with a nonlinear reference leg and a single-ended transistor amplifier. This circuit provides regulation to within $\pm 0.3^{\circ}\text{C}$ for control at any selected temperature between -40 and $+70^{\circ}\text{C}$. The nonlinear reference leg allows reduction in the number of components, thus improving the reliability without sacrificing accuracy.

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SUMMARY

A simple, medium-accuracy temperature-control circuit was needed for both a radiant-heat strain-gage bonding apparatus and a small-sample refrigerator for spacecraft bioresearch. This report describes the circuitry developed for these applications and shows how it provides less complexity than prior circuits, and yet with the same stability and is capable of operating in the range from -40 through $+70^{\circ}\text{C}$. In both applications mentioned previously, it has yielded a maximum control point variance less than $\pm 0.3^{\circ}\text{C}$ in the range from 0 to 65°C .

INTRODUCTION

A request was received for a biological sample refrigerator that would be used for research into radiation-damage effects in space. In this application the design requirements were that it possess medium temperature stability (about $\pm 1^\circ \text{C}$) but high reliability. The circuitry must also operate from the 26-volt power supply of the spacecraft and pass rigid shock, vibration, interference, and environmental tests.

To achieve maximum reliability, any electronic circuit should be designed with a minimum number of components and the least possible circuit complexity. Unfortunately, the most accurate circuit is often the most complex and hence the least reliable. In an attempt to improve upon the existing circuitry used for medium-accuracy temperature control and to meet the space requirements for a circuit of the least complexity, a new type of thermistor bridge configuration was examined.

At about the same time that the circuit ideas were formulated, a request was received for a surface temperature control that could be attached to a strain-gage bonding apparatus using a quartz-tube, tungsten-filament heat lamp. Accurate temperature control was needed to achieve proper bonding. The most desirable surface temperature control was about ± 0.5 degree at 65°C , with adjustment capability. The thermistor-bridge temperature control circuit described in this report was successfully applied to both applications.

THERMISTOR TEMPERATURE CONTROL CIRCUIT

DESCRIPTION OF PRIOR CONTROLS

A simple, reliable, and medium-accuracy temperature control circuit was needed to operate a biological sample refrigerator for space biological research. Several types of primary temperature-sensing elements were considered. Finally, the thermistor was selected because of its large rate of change, stability, lack of hysteresis, and small size. Thermistors have been used previously for temperature-control applications using circuits similar to those illustrated in Figures 1 and 2. Figure 1 illustrates two types of simple low-accuracy control circuits suitable for use where a control-point variation greater than $\pm 2^\circ \text{C}$ can be tolerated. Sources of control-point change in the circuit of Figure 1(a) lie in the variation of the supply voltage and in the variation of the relay operating point versus ambient temperature at the relay. Even though this circuit has hysteresis due to the pickup and dropout differential of the relay, it has been successfully employed in such applications as filling liquid nitrogen cold traps on vacuum systems where its simplicity and reliability are attractive.

Legend:

CE	Control Element
R	Resistor
K	Relay
Eb	Supply Voltage Input
KC	Relay Contact
Q	Transistor
Rs	Set Point Resistor
T	Thermistor
Z	Zener Voltage Regulator

Figure 1. TWO EXAMPLES OF SIMPLE THERMISTOR TEMPERATURE CONTROL CIRCUITS.

Figure 2. A MEDIUM-ACCURACY CONTROL CIRCUIT.

The circuit of Figure 1(b) illustrates methods for overcoming the hysteresis and regulating the supply voltage. The transistor amplifier can eliminate the relay used in Figure 1(a) and thus also provide for improved performance in the presence of shock and vibration. The main source of inaccuracy in this circuit lies in the temperature variation of the transistor base "turn-on" voltage which can easily cause control-point variation in excess of $\pm 2^{\circ}\text{C}$ for a transistor temperature variation from 0 to 30°C . The circuit in Figure 2 overcomes these limitations by using a differential amplifier configuration and a resistance-bridge measuring circuit. The differential configuration causes cancellation of the voltage change of the transistors due to temperature if they are in close proximity to each other. This type of circuit is highly effective and, with careful design, control-point variation can be reduced to less than $\pm 0.2^{\circ}\text{C}$ for the range from 0 to 30°C . Disadvantages of this circuit are that there is a necessity for an additional regulated power supply (Eb2) and an increased circuit complexity.

A typical high-precision ($\pm 0.01^{\circ}\text{C}$) thermistor temperature control circuit uses an AC bridge, carrier amplifier and demodulator, and an ultra-stable, low-distortion reference oscillator. Variations in the amplifier DC levels and power supply are overcome by using AC coupling. These systems can be designed with greater precision than the direct-coupled circuit instabilities will allow. They are, however, much more complex and often less reliable than their simpler counterparts shown in Figures 1 and 2.

COMPARISON OF THE NEW CIRCUIT

The type of circuit required for the space bioresearch sample refrigerator and the strain-gage bonding system was to be one of medium accuracy ($\pm 1^\circ \text{C}$ or better) with capabilities similar to that of the circuit shown in Figure 2. Because of the second power supply and circuit complexity, attempts were made to improve the circuit of Figure 2 for this application.

The circuit finally developed is shown in Figure 3. If the circuit of Figure 3 is compared with that of Figure 2, it can be seen that in order to eliminate the negative power supply, the compensation for transistor temperature variation is accomplished by substituting diodes of the same type as the transistor for the reference leg of the bridge. These diodes are then kept in close proximity to the transistor so that their ambient temperatures are the same and, therefore, any variation in the transistor is compensated for by a change in the bridge balance voltage.

As can be seen by comparing Figure 2 with Figure 3, a reduction in the total number of component parts is achieved in this circuit which can improve reliability. The use of forward diodes in the bridge does limit the bridge to an integral ratio of resistance and to bridge voltages which are a multiple of the diode forward voltage.

Figure 3. IMPROVED MEDIUM-ACCURACY CONTROL CIRCUIT.

This arrangement poses no particular problem, however, because these voltages are low enough to limit the self-heating power in the thermistor to a safe value while still maintaining adequate sensitivity to provide a full output signal change for a temperature change of less than 0.3°C . The use of more than one diode in each leg of the reference section of the bridge is allowable and may be desirable when high-resistance thermistors are used. In such cases, the emitter of Q_1 is not grounded but is connected into the reference leg of the bridge one diode away from the balance point (as shown in Figure 4).

CIRCUIT CHARACTERISTICS

In the circuits of Figures 2 and 3, the set-point resistor, R_s , is selected so that the bridge is balanced at the control point. A variable resistor may be substituted for R_s to allow for an adjustment of the control point temperature. The circuit characteristics are such that an increase in temperature will cause an increase in the current to the control element. If the opposite control action is desired, the positions of the thermistor, T , and set-point resistor, R_s , may be interchanged in the circuit. The control element itself may be actuated through a power transistor, an AC silicon-controlled rectifier circuit, relay, servomotor, or other appropriate power control circuit, as desired. The space refrigerator used the circuit, as shown, with a power-transistor-series pass element and Peltier cooler. The strain-gage bonding apparatus uses the circuit with the control action inverted to operate an AC silicon-controlled rectifier circuit with quartz-tube, tungsten-filament heat lamps, as shown in Figure 4.

PERFORMANCE

Temperature control circuits similar to Figure 3 have been applied to both the space bioresearch sample refrigerator, using a Peltier cooler, and a surface-temperature control system for bonding strain gages to specimens using a heat lamp. A schematic diagram of the strain-gage bonding system is shown in Figure 4, and a picture of the apparatus in Figure 5. A draft shield normally used with this apparatus has been removed for clarity.

The refrigerator operates at about 3.9°C with a control point variation less than $\pm 0.2^{\circ}\text{C}$; the strain-gage bonding system operates from about 50 to 70°C (adjustable by the front panel control) with a control-point variation less than $\pm 0.3^{\circ}\text{C}$. Both systems employ proportional control with a proportional band (from full off to full on) of less than 0.5°C . The refrigerator was successfully orbited on Gemini 11 and the bonding apparatus has been in use for about ten months in Y-12. No control-circuit failure has occurred during this experience, indicating that the desired reliability has been achieved.

Figure 4. STRAIN-GAGE BONDING APPARATUS.

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Figure 5. STRAIN-GAGE BONDING APPARATUS EMPLOYING THE THERMISTOR TEMPERATURE CONTROL CIRCUIT AND ULTRAVIOLET HEAT LAMP.

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