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Automatic Precise Recording of Temperature

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An apparatus is described which automatically and continuously records small temperature changes. The principal components are a platinum resistance thermometer, a modified G–2 Mueller Wheatstone bridge, a direct current amplifier, and a potentiometric, strip-chart recorder. Frequent zero checking is unnecessary because the system is extremely stable. In systems where the general dependence of temperature on time is known, a nearly uniform change of 0.00001 °C per minute is easily discernible over a recording period of 10 minutes or more. However, the measurement of temperature at any given instant is limited by an inherent electronic noise band of 0.00004 °C. A similar arrangement, using a thermocouple pair and a potentiometer instead of the platinum thermometer and the Wheatstone bridge, is also described.

1. Introduction

The results of many laboratory operations are more valuable if there is a continuous and highly precise record of temperature. One of the most precise temperature measuring systems in general laboratory use consists of a platinum resistance thermometer, a Mueller Wheatstone bridge, a sensitive suspension galvanometer, and a competent operator. Temperature differences of 0.0002 °C can be detected, but the manual operations are tedious, boring, and expensive. A system for automatically recording temperature is desirable, provided it can be achieved without a sacrifice in accuracy or precision.

Armstrong and coworkers [1] [1] describe the use of a direct current amplifier and recorder to balance a Mueller resistance bridge. They recorded temperature with a precision of 0.0001 °C, while maintaining a response time of approximately 5 sec. The automatic temperature recording system described in this paper was designed specifically for use in observing time-temperature cooling curves of very nearly pure substances [2]. In this sytem temperature is recorded with a precision of 0.00002 °C, but the response time is approximately 40 sec. In order to maintain such a high precision, the most essential requirement is long-term bridge stability, since frequent bridge zeros cannot be taken.

The apparatus appears to be generally useful in experimental systems wherein the maximum temperature range to be recorded is less than 1 deg and the greatest rate of temperature change is 0.002 °C per minute while recording at maximum sensitivity. The allowable temperature span and the rate may be increased with a corresponding decrease in sensitivity.

[1] Figures in brackets indicate the literature references at the end of this paper.

2. Equipment and Techniques

In this automatic system the galvanometer is replaced by a high-gain amplifier. The operator is replaced by mechanical controls and a strip-chart, recording-potentiometer.

In general practice, the bridge dials are set for a particular experiment, and this setting is not changed except to make a sensitivity check at the end of the experiment. The off-balance current from the bridge is fed into an amplifier. The amplified signal is attenuated, filtered, and recorded. A block diagram of the system is shown in figure 1.

The specific components and the modifications and adaptations of these, as used in this automatic recording system, are described in the following sections.

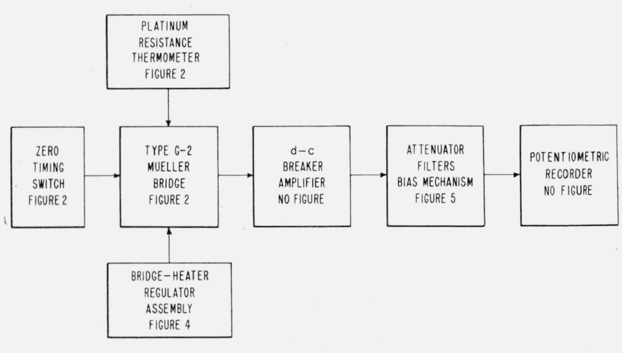

FIGURE 1. *Block diagram of the automatic temperature recording system.*

2.1. Wheatstone Bridge

Leeds and Northrup, Type G–2, Mueller Bridge. Measuring Arm—0 to 111.1110 Ohms Graduated in Steps of 0.0001 Ohms [3]

The following modifications were made to the bridge in order to eliminate electrical and thermal disturbances:

The galvanometer switches and damping resistance, not essential in this work, were disconnected. The binding posts used for connecting the bridge to the amplifier and a switch for taking the bridge-zero automatically were installed. These changes are shown in figure 2, which was taken in part from the manufacturer's catalog [3], which contains a detailed description of the drawing.

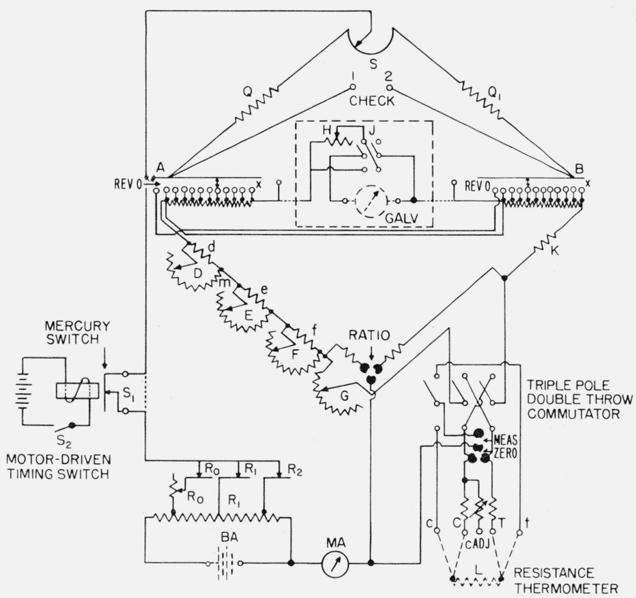

FIGURE 2. *G–2 Mueller Wheatstone bridge with modifications* [3].

The portion of the bridge which was disconnected is enclosed by dashed lines.

2. The thermostated aluminum case, which contains the principal bridge resistors, was connected directly to earth ground. This earth ground was obtained by means of a heavy copper wire connected to an iron stake driven firmly into the ground. (This connection was used where earth grounds are indicated; all other grounds were the usual waterpipe connections.) The true earth ground was necessary to avoid the introduction of ground currents into the amplifier.

3. Thermal emf's generated at junction points were stabilized by insulation. The empty space, in the wooden case which encloses the bridge, was filled with glass wool and the bridge was surrounded by a 3-in. layer of expanded polystyrene. This eliminated convection currents inside the case. These convection currents produced negligible changes in bridge resistances, but large changes in the existing thermal emf's. Possible accumulation of electrostatic charge was avoided by incorporating a network of fine copper wire within the glass wool. This network was grounded to a copper grid placed in the bottom of the bridge case. The grid was in turn earth grounded. The insulated bridge was placed inside a 3/16 in. thick aluminum box. An additional 3-in. layer of polystyrene was used to cover the outside of this box. The aluminum box was connected to earth ground.

4. Bakelite extensions were attached to the bridge controls to allow changes in the setting of the bridge dials through the insulation. A diagram of one of these extensions is shown in figure 3.

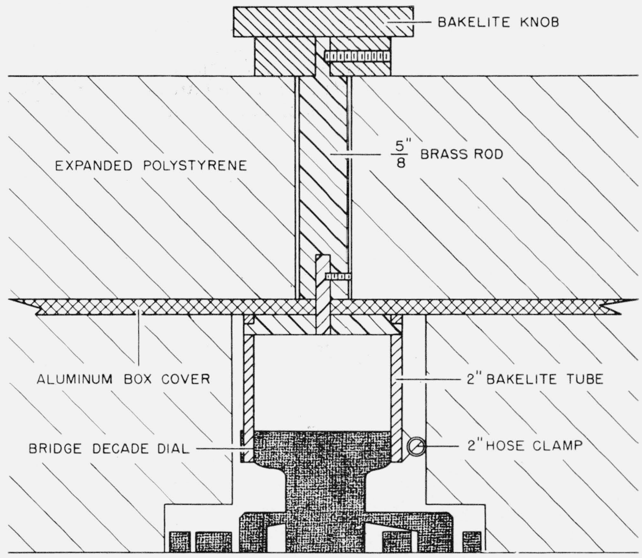

FIGURE 3. *Bridge control extension.*

5. Sixty cycle alternating current interference, generated by the heater current, was eliminated during recording operations by using a 6-v lead storage battery to supply the heater power. When the bridge is not in use, the heating system for the thermostated resistors is maintained by the alternating current power supply (fig. 4).

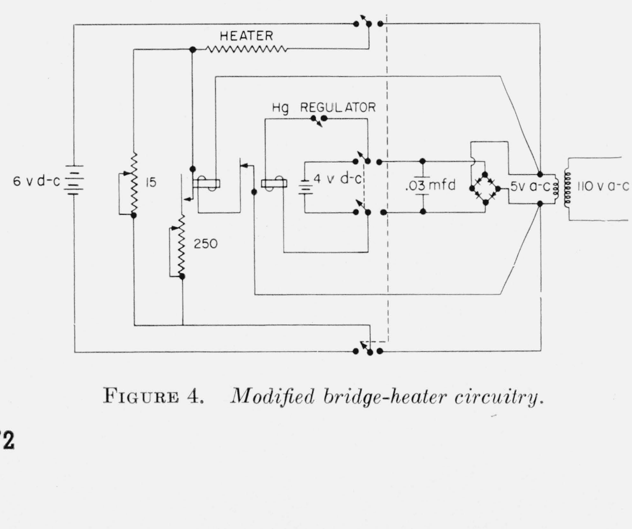

FIGURE 4. *Modified bridge-heater circuitry.*

6. Induction peaks caused by changing heater currents were minimized by using the modified circuitry shown in figure 4. The salient feature of this modification is the heater-relay bypass which supplies about 85 percent of the current necessary to keep the thermostated bridge resistors at a constant temperature. The relay, on closing, supplies the additional 15 percent through the shunted circuit. Since switching of the relay does not change the heater current drastically, "overshoot" in the heating cycle is reduced. The two principal resistance decades in the G–2 bridge are mounted in an aluminum block. This block is separated from the electrically heated box by balsa wood insulation. This serves as a low-pass filter capable of damping out cyclic heating-cooling effects if the cycle is less than 5 min. Variable resistors in the heater control network permitted regulation of the heating cycle by regulating the heater current. A 4 min heating-cooling cycle, with equal high-low current periods, was found to be most effective in reducing overshoot. The use of a longer cycle is not desirable, since the temperature of the resistors would then follow the changing temperature of the controlled aluminum case.

7. Shielded, coaxial cable was used for all bridge leads. These shields were earth grounded.

2.2. Amplifier

Liston-Becker Direct-Current Amplifier, Model 14. 8 Cycle Floating Input. Maximum Gain—1×10^7, With Continuously Variable Gain Controls. Internal Calibration Test Signal From 0.1 to 100 Microvolts

In the automatic recording system, the off-balance signal from the bridge was fed directly into the amplifier. The shielded, coaxial lead from the bridge to the amplifier was wrapped with 1 in. of glass wool, covered with foil, and the shield and foil earth grounded.

A peculiarity in the construction of the amplifier created an appreciable temperature difference between the inner and the outer connection of the input plug. Thermal emf's resulting from this difference were eliminated by installing glass wool around the inner connection and by wrapping the outside connection with glass wool and aluminum foil.

2.3. Recorder

Minneapolis-Honeywell Regulator Company, Brown Instrument Division—"Electronik," Potentiometric One Millivolt, Extended Range Recorder

The only difficulty encountered with the recorder was the problem of impedance matching. The recorder is a low impedance input-type, and the amplifier is a high impedance output-type. The network shown in figure 5 was used to couple these instruments. It is composed of a variable attenuator, figure 5A, and filtering-damping circuits, figure 5B. Two alternate low-pass filter systems are shown.

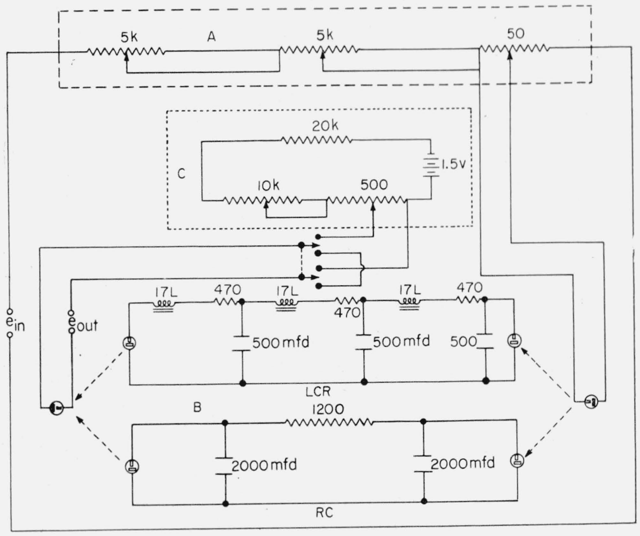

FIGURE 5. *Attenuator, bias mechanism, and filters.*

Either performs satisfactorily, although the RC filter has a smaller time constant.

The output signal from the amplifier was attenuated in accordance with the manufacturer's instructions, quoted as follows: "It is desirable to operate the amplifier output with a minimum output of 0.5 volts for a full scale deflection so noise originating after the gain controls will not cause difficulty. Where potentiometric type recorders with full scale ranges of less than 100 millivolts are employed with the amplifier, a simple resistance attenuator should be used between the amplifier and recorder" [4]. The attenuation normally used was of the order of 500 to 1, but the variable attenuator added flexibility to the use of the measuring system.

2.4. Thermometer

Meyers, Bifilar, Single Layer Helix, Platinum Resistance Thermometer. Resistance—Approximately 25 Ohms at 0 °C

Thermal and electrical interferences in the thermometer were stabilized or eliminated by means of insulation and shielding. The thermometer head and leads were covered with a braided copper shield, an inch thickness of glass wool insulation, and a layer of aluminum foil. The shield was electrically earth grounded.

2.5. System Zero

The device for obtaining the zero automatically consists of a timing mechanism to activate a solenoid and a mercury switch.

A bridge current cycle of 8 min is used and it is cut off for 1 min of each cycle. This interruption allows the recording of the zero. The cycle is generated by a motor-driven timing switch which operates a direct current solenoid. The motor-driven timing switch and the mercury switch used to interrupt bridge current are depicted schematically in figure 2 as S_2 and S_1, respectively. The solenoid is encased in iron and mounted on the outside of the aluminum box that contains the bridge. The solenoid rotates a lucite rod that extends through the box and insulation. A mercury switch, attached to the rod, interrupts the bridge current at point S_1, figure 2, when the solenoid is activated. A mercury switch is used in order to obtain reproducible contacts, and it is put inside the aluminum box to eliminate thermal disturbances.

2.6. Procedure

Since resistance changes from contact to contact of the bridge dials may exceed 5 microhms, it is desirable to set the bridge at a predetermined resistance value and not change this setting during the experiment. At the beginning of an experiment the preset bridge resistance value may differ markedly from the thermometer resistance value. The recorder input voltage must be biased if the bridge dials are not to be changed. This was accomplished by using a 1.5-v mercury battery, across a shunted voltage divider, in series with the recorder input (fig. 5C).

In a resistance bridge there are small thermal emf's generated wherever an electrical connection is made. Because of the variety of construction materials and the different temperatures existing in the bridge case, these thermal emf's do not necessarily cancel one another. One method of taking a zero involves reversing the polarity of the bridge current. This produces an opposite shift in off-balance current, so that the "true" zero is represented by one-half the difference of the two readings. At high amplification, the thermal emf's in the bridge may make the taking of the zero by the current-reversal method impossible. Since the thermal emf's do not change polarity when the current is reversed, they represent such a sizeable emf that the "forward" and "reverse" current cannot be recorded without changing the bridge setting. Consequently, at highest sensitivity, zeros were taken by the method of bridge-current interruption. This method consists of shutting off the bridge current and recording the "true" zero or system balance point.

Two separate 6-v lead storage batteries were used as current sources for the system. One supplied current to the bridge-thermometer assembly and another supplied current to the heater relay-unit and the direct-current solenoid. The batteries are kept fully charged by a trickle-charger during inactive periods.

3. Thermocouple and Potentiometer

The amplifier-recorder assembly has also been used in conjunction with a thermocouple and a student-type potentiometer replacing the resistance thermometer and the Mueller bridge. A potentiometer of higher sensitivity and greater stability would have made the problem of precise temperature recording easier and would have given the value of the temperature interval to a greater degree of accuracy. In this arrangement the potentiometer was insulated in the same fashion as the Mueller resistance bridge. The box enclosing the potentiometer was constructed of soft iron instead of aluminum, because both electrostatic and electromagnetic interferences were more of a problem here than with the bridge. Braided copper shields covered the thermocouple leads and connecting cables to eliminate electrical interference. A water triple-point cell was used as the reference temperature for the reference junction. The off-balance signal was amplified, attenuated, filtered, and recorded as previously described for the bridge and thermometer system.

This thermocouple system is capable of measuring temperature changes of 0.00005 °C [5, 6]. The absolute temperature is not known to this degree of accuracy because of uncertainties in reading the potentiometer and of calibrating the thermocouple. The continuous aging of the thermocouple pair necessitates frequent recalibrations and limits its use as a temperature interval sensing element, but for measuring small temperature differences its sensitivity approaches that of the platinum resistance thermometer.

4. Results and Conclusions

The overall capabilities of the system, when used with the platinum resistance thermometer, are best shown graphically (fig. 6). The graph shows two recordings of the temperature of water at its triple point and a trace of the stability of the amplifier-recorder network with no load.

The triple-point cell was the type used for calibrating thermometers with a thermometer immersion depth of 13 in. [7].

Trace A, on the graph, shows the temperature of water at its triple point as recorded with the system described in this paper. The background noise band is equivalent to 0.00004 °C and the drift over an hour period is about 0.00002 °C.

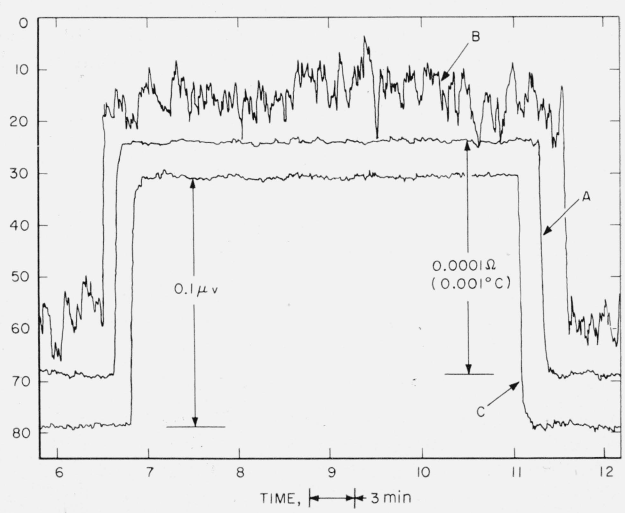

FIGURE 6. *Temperature of water triple point cell (a) recorded with modified equipment; (b) recorded with conventional bridge and thermometer; and (c) amplifier with zero load.*

The chart was rewound and trace B was recorded. This trace shows the temperature of water at its triple point when recorded with a type G–2 Mueller Bridge and platinum resistance thermometer as supplied by the manufacturer. The background noise is the equivalent of 0.0003 °C and the drift is approximately 0.0002 °C. Also noticeable are the long-term cyclic effects from the temperature changes in the room and from the bridge thermal regulator. At best, temperature readings can be made from this trace to ± 0.0005 °C. Again the chart was rewound and trace C was made. This trace shows the stability of the amplifier-recorder network. In this case the bridge and thermometer were disconnected from the system, and the amplifier input leads were shorted. In terms of temperature the background noise band is approximately 0.00004 °C and the long-term drift is about 0.00002 °C, the same as for the triple-point cell in trace A.

There are similarities in the frequency and amplitude of the background noise bands in both traces A and C. This indicates that the greatest part of the system instability is from the fine structural noise originating in the amplifier. The bandwidth of this noise is 0.00004 °C, and this limits the precision of an instantaneous measurement of temperature. However, in systems wherein the general variation of temperature with time is known, a nearly uniform change of 0.00001 °C/min is easily discernible for recording periods of 10 min or more. This represents a 10-fold gain in accuracy and precision over manual techniques previously used. Because of the long response time of the filter, rapid temperature changes cannot be adequately recorded with the present systems. For rapid temperature changes a different coupling network would have to be used.

The specific values of resistance and capacitance which are given were dictated by the characteristics of the recorder and amplifier which were available. Some changes would be necessary if instruments with other characteristics were to be used. However, with some modification, this arrangement for recording temperatures can be used for many purposes.

5. References

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