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## TECHNICAL NOTE 3392

# TWO MINIATURE TEMPERATURE RECORDERS FOR FLIGHT USE

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# TWO MINIATURE TEMPERATURE RECORDERS FOR FLIGHT USE

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## SUMMARY

The description and characteristics of two small temperature recorders suitable for flight use are given. Both recorders were designed for use with thermocouples. Both operate on the null-balance principle which allows their measurements to be essentially independent of change of thermocouple lead resistance.

One recorder is of the electro-mechanical follow-up, self-balancing potentiometer type. This instrument is a self-contained recorder of quite high accuracy. The unit has provision for an expanded scale and a remote visual indicator.

The other instrument described achieves self-balance by means of an electronic feedback amplifier. The feedback current, which is proportional to the thermocouple voltage, is recorded on an external recording oscillograph. This unit has reasonable accuracy and a very fast time response.

## INTRODUCTION

During tests which involved measuring thrust in flight on airplanes equipped with afterburners two miniature temperature recorders were designed and built (ref. 1). It was necessary to design these instruments because the recorders commercially available which met the test requirements were of too large a size to use on the fighter-type aircraft involved.

The temperature measurements required for the thrust determination were of two distinct types insofar as recorder characteristics were concerned. One type required quite high precision of measurement of essentially steady-state temperatures. The other type involved temperatures where measurement precision was not quite as important; however, a fast time response of the recorder was essential. These somewhat conflicting requirements dictated the development of two recorders operating on different principles.

Both recorders had certain basic requirements in common. Operation should not be affected by the low pressure and sub-zero temperatures encountered at high altitude. The change of thermocouple lead resistance encountered under flight conditions should not affect readings. Physical size had to be considerably smaller than the usual self-balancing potentiometer-type recorder.

The requirements of the more precise, slower recorder included certain features necessary for use on other tests. Provision was made for operation of a remote panel-type indicator for use either as a cockpit indicator or as a photo-panel instrument. Another feature was the provision for expanding the scale over certain selected temperature ranges. This was particularly desirable when the recorder was used as a visual indicator of tail-pipe temperature. The range of critical operating temperature was expanded to cover about one third of the indicator scale, thus providing ease of reading at the critical temperatures.

The special requirements of the less precise, fast recorder were that, while it must be of the type in which lead resistance effects were negligible, its time lag had to be extremely short. This requirement was necessitated by the nature of the temperature measurements. Thermocouples were mounted on a power-operated swinging probe which was swung through a jet-engine afterburner exit. The probe made the traverse in approximately four seconds. Due to the thermal lag of the thermocouple, true temperature determination involved using the rate of change of thermocouple temperature. If any additional lag were added by the recorder it would have greatly complicated the computations. Thus, the recorder time lag was made negligible compared to the thermocouple time constant.

The precise, slow-response recorder used an electro-mechanical self-balancing potentiometer system which operates on principles similar to larger commercial recorders. It differs from the usual recorder primarily in its compact size.

The less precise, fast-response recorder utilized an all-electronic system which uses the feedback amplifier as its basic self-balancing mechanism. Since this recorder contains no moving mechanical parts (except for a chopper) the response time is quite short.

## DESCRIPTION OF ELECTRO-MECHANICAL RECORDER

### Principle of Operation

The recorder is completely self-contained except for an external standard cell used to adjust the reference voltage. Basic operation is of the self-balancing potentiometer type wherein the input voltage from a thermocouple is balanced by a voltage from the recorder.

Figure 1 is a block diagram of this recorder. If the voltage from the recorder follow-up potentiometer does not equal the thermocouple voltage, an error signal is present. This error signal, e, is converted to a 400 cycles per second signal by the converter, amplified, and supplied to the control phase of a two-phase servo motor. The phasing is such that the motor will drive the slider in the correct direction to reduce the difference between the balance voltage and the thermocouple voltage. Thus, at balance the mechanical position of the slide-wire arm is a measure of the thermocouple voltage.

The position of the slider arm can be calibrated in terms of temperature by using the proper relationship between thermocouple voltage and temperature. This position is recorded by two different methods. The shaft that drives the follow-up potentiometer has a cam which operates a set of instrument mirrors which in turn deflect a spot of light along the slit of a film drum. The spot position is calibrated directly in terms of temperature. The shaft is also connected to an autosyn transmitter which is used for positioning a remote indicator. The indicator may be used either as a pilot's cockpit instrument or for recording on a photo panel.

Taps are brought out from the slide wire at two points. By connecting the taps with a shunt the scale over this center position can be expanded. This expansion is used to allow more precise readings over a critical range of temperatures. Figure 2, which is a photograph of the remote indicator, illustrates the scale expansion which was achieved.

The dry cell is standardized before flight by comparison with an external standard cell.

## Complete Circuit

A complete circuit of the electro-mechanical recorder is shown in figure 3. The major part of the circuit is self-explanatory. One very important component is the converter which must be of a high quality if noise problems are to be avoided.

When a commutator is used to permit recording of several thermocouples, a lead network is installed in series with the recorder input to provide optimum damping. About 200 ohms resistance in parallel with 200 microfarads capacity usually provides sufficient damping.

## Construction

Figure 4 shows two views of the instrument. The follow-up potentiometer arm, the mirror cam, and the autosyn transmitter are all connected to a drive shaft which is driven by the servo motor through suitable gearing. The cam drives three instrument mirrors which are set at different angles so that as one mirror trace leaves the film the next mirror trace appears on the opposite edge. A small temperature-controlled compartment contains the balance network resistors. The dry cell is also temperature controlled for high-altitude flights.

## Operational Characteristics

Sensitivity.- Fifty microvolts input is required to cause motor drive. This is equivalent to a dead space of about $3^{\circ}$ F on an iron-constantan thermocouple.

Response time.- A step-function input drives the three mirrors full scale in 3.4 seconds with 27-volts motor excitation. With 45-volts excitation (used during recording) full-scale deflection takes 2.3 seconds. When fast response is necessary, the full temperature range is put on one mirror, in which case full-scale deflection requires 0.8 second. When multiple measurements are made from thermocouples near the same temperature, a commutating time of 0.5 second is sufficient for recording.

Ambient conditions.- Change of altitude from sea level to 50,000 feet with temperatures between $+100^{\circ}$ F and $-30^{\circ}$ F causes shifts of less than the instrument dead space of $3^{\circ}$ F.

# DESCRIPTION OF ELECTRONIC RECORDER

## Principle of Operation

This instrument produces a current that is proportional to the thermocouple voltage. The operation is basically that of a self-balancing potentiometer in which the balancing is done by electronic means without using follow-up motors or similar mechanical equipment. The output of the instrument is normally recorded on a recording galvanometer oscillograph although a panel-type indicating instrument can be used if fast response time is not essential.

The basic operation involves the feedback amplifier principle. Figure 5 is a block diagram of the recorder. The thermocouple is connected in series with the feedback resistor R. If the voltage developed across the feedback resistor does not equal the thermocouple voltage, an error voltage e is present at the converter. This d-c error voltage is converted to a 400 cps signal which is amplified in an a-c amplifier. The output of the amplifier is demodulated, filtered, and fed through a galvanometer to the feedback resistor.

Due to the high gain of the amplifier, the error signal is very small and the voltage across the feedback resistor is almost equal to the thermocouple voltage. It may be seen that, since the feedback resistor has a fixed value, the current necessary to develop the required voltage is a measure of the thermocouple voltage. Further, since the thermocouple voltage is balanced out, negligible current flows and lead resistance is of little consequence. Because of the high negative feedback, variations in gain of the amplifier and demodulator have little effect on the accuracy.

## Complete Circuit

Figure 6 is the complete circuit diagram of the recorder. The input signal is supplied to a 400-cycle converter, then through a step-up transformer to a high-gain voltage amplifier, thence to a cathode follower. The cathode follower drives a phase-sensitive demodulator which in turn supplies a d-c signal to the feedback resistor R. Variations in the demodulator balance will have little effect on operation because of the heavy negative feedback.

The value of the feedback resistor R is adjusted to obtain proper current for the temperature range desired. Its value may be readily computed by using ohms law, $R = E/I$, where I is the required galvanometer current and E is the full-range thermocouple voltage. Figure 7 shows the size and construction of the instrument.

## Operational Characteristics

Changes in lead resistance of from 2 ohms to 1000 ohms result in less than 0.5-percent change in output (in practice no such resistance change is ever encountered).

Frequency response.- Step-function response checks indicate a system resonant frequency of 23 cps with a 0.4 damping ratio.

Typical operation.-

Recording temperature range: $-80^\circ$ F to $+2000^\circ$ F
Feedback resistor: 176 ohms
Calibration: Theoretical current for
20 millivolts = 113.6 microamperes
Actual current for
20 millivolts = 111.2 microamperes
(In practice the actual calibration is used)

## DISCUSSION

Direct recording of the current generated by a thermocouple is one of the simplest of methods for measuring temperatures. In a jet aircraft, however, due to the extreme variations of temperature the change of thermocouple lead resistance causes this method to be inaccurate. The use of null-balance recorders eliminates this cause of inaccuracy by measuring voltage without drawing current from the thermocouple.

The usual self-balancing-type recorders are too large to install in a small-type aircraft, whereas both of the recorders described here are small enough to fit into fighter-type aircraft.

The compactness and simplicity of construction make the all-electronic recorder useful for many flight-test operations where change of lead resistance is a problem.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Feb. 2, 1955

## REFERENCE

1. Rolls, L. Stewart, and Havill, C. Dewey: Method for Measuring Thrust in Flight on Afterburner-equipped Airplanes. Aero. Eng. Review, vol. 13, no. 1, Jan. 1954, pp. 45-49.

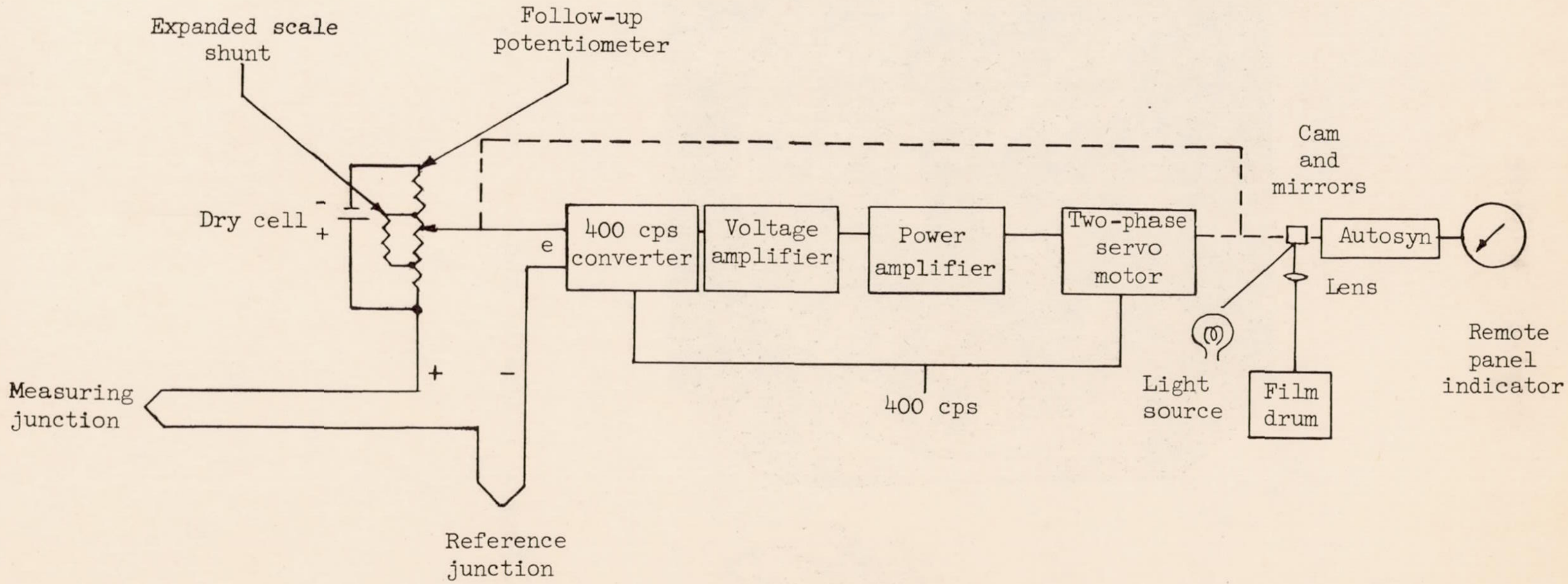


Figure 1.- Block diagram of electro-mechanical temperature recorder.

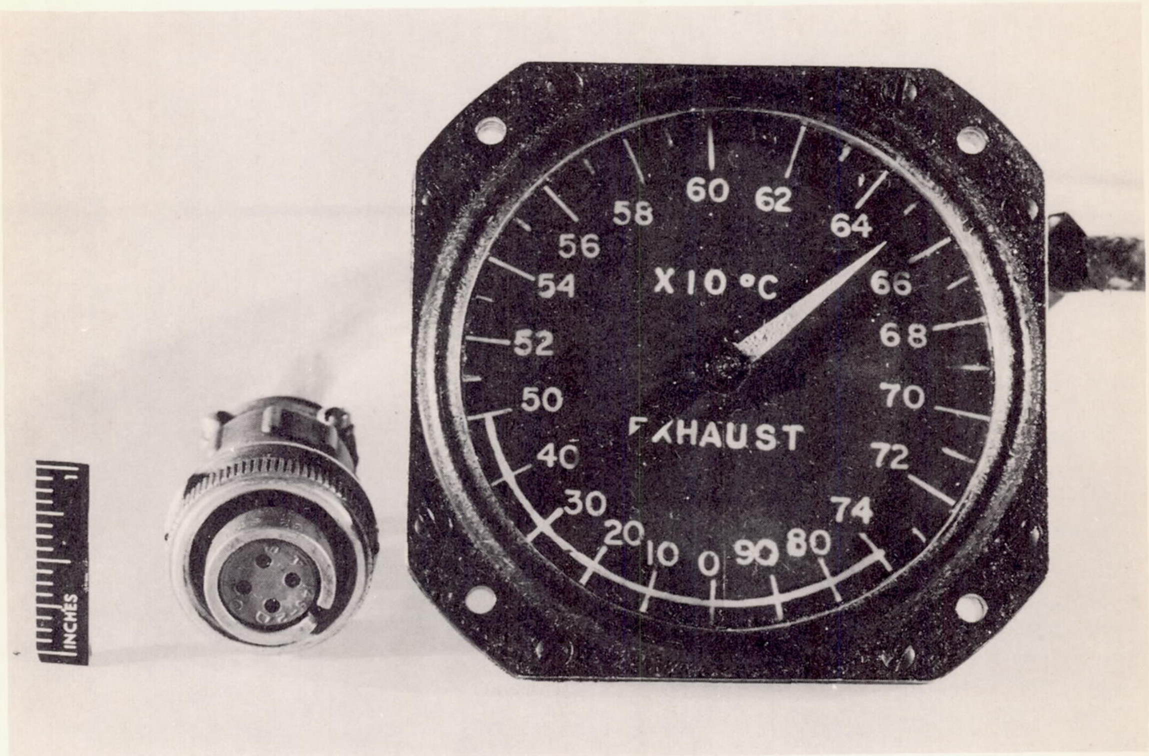


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Figure 2.- Remote indicator showing scale expansion.

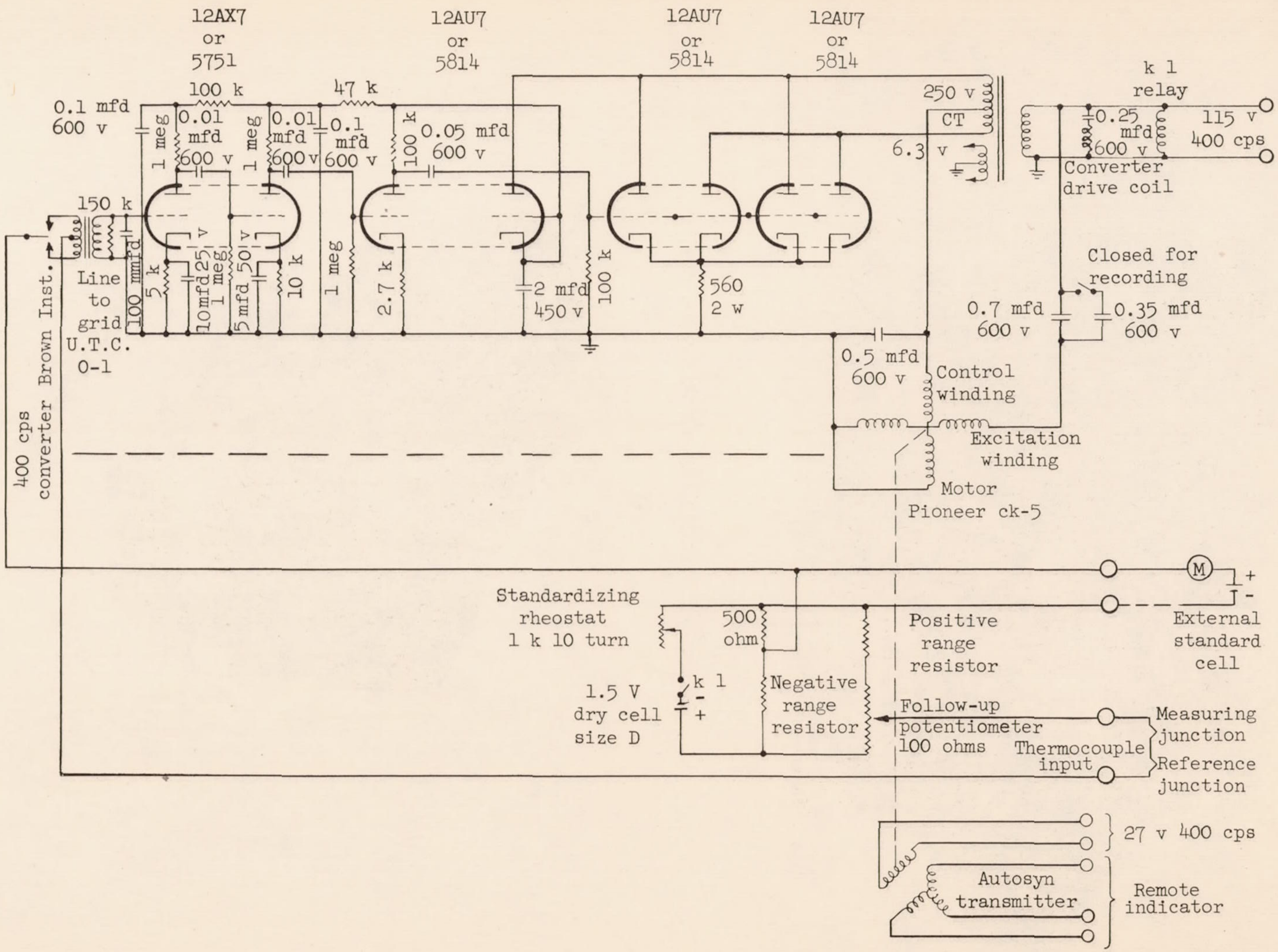
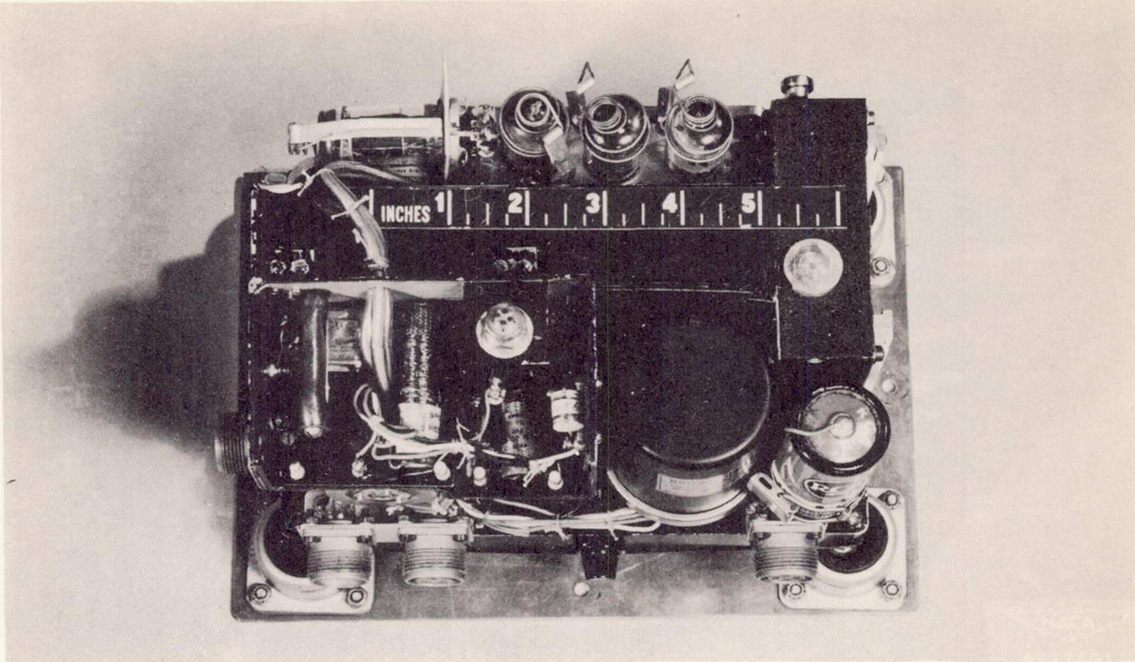



Figure 3.- Circuit diagram of electro-mechanical temperature recorder.

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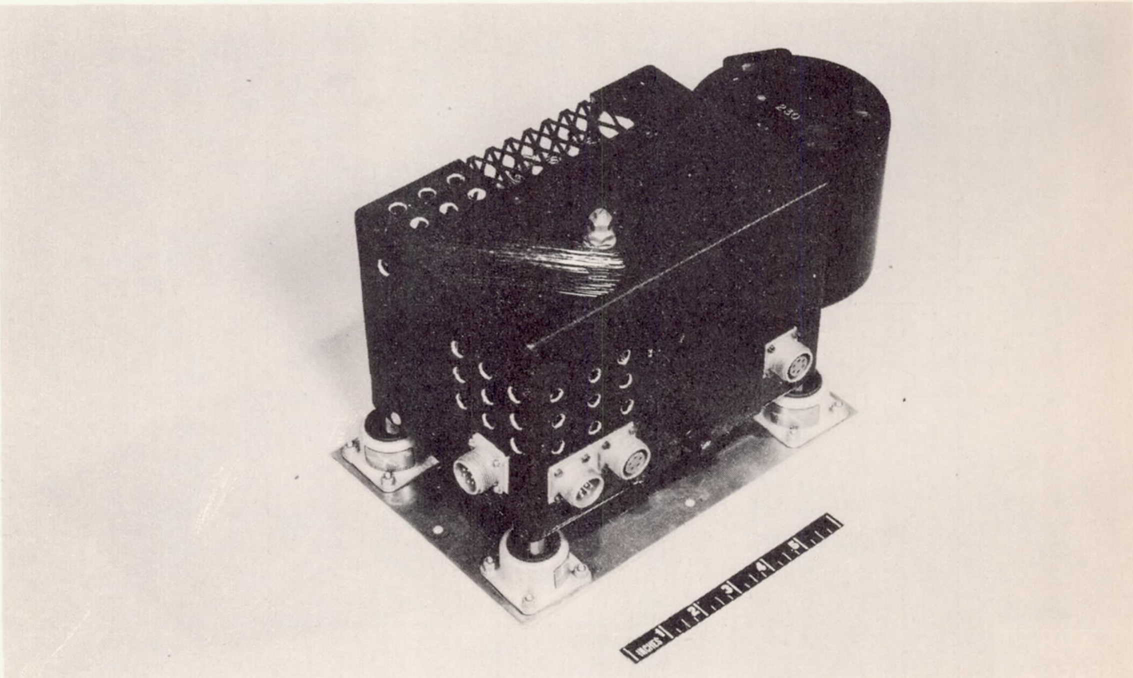
(a) Cover off and film drum removed.



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(b) Cover on and drum in place.

Figure 4.- Two views of electro-mechanical recorder.

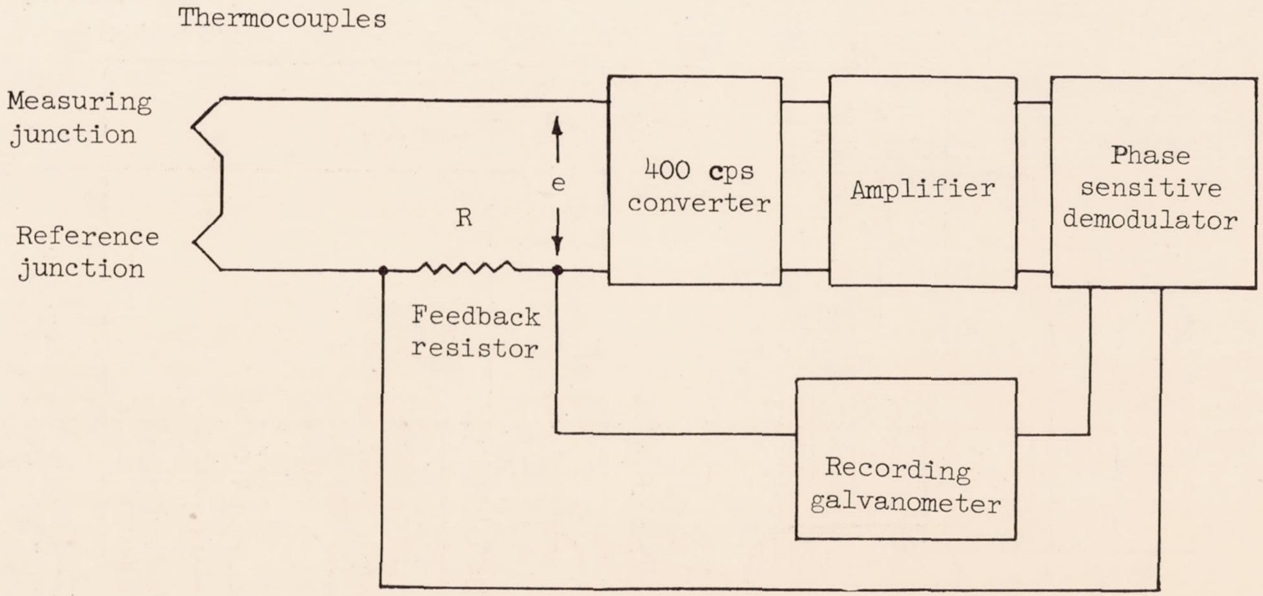
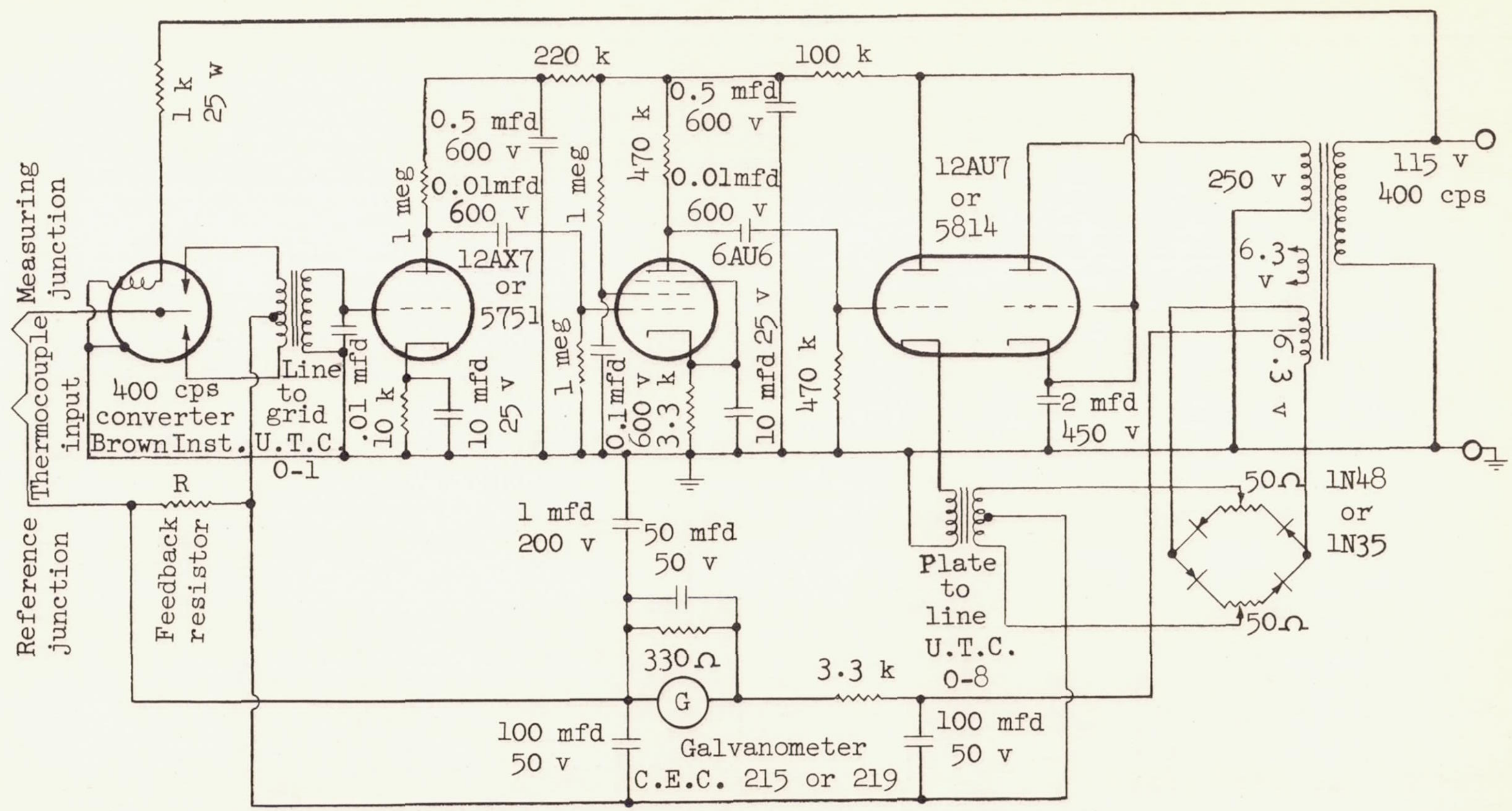



Figure 5.- Block diagram of electronic temperature recorder.




| R | Sensitivity microamps per millivolt |
|---|---|
| 100 ohm | 10 |
| 1000 ohm | 1 |

Figure 6.- Circuit diagram of electronic temperature recorder.

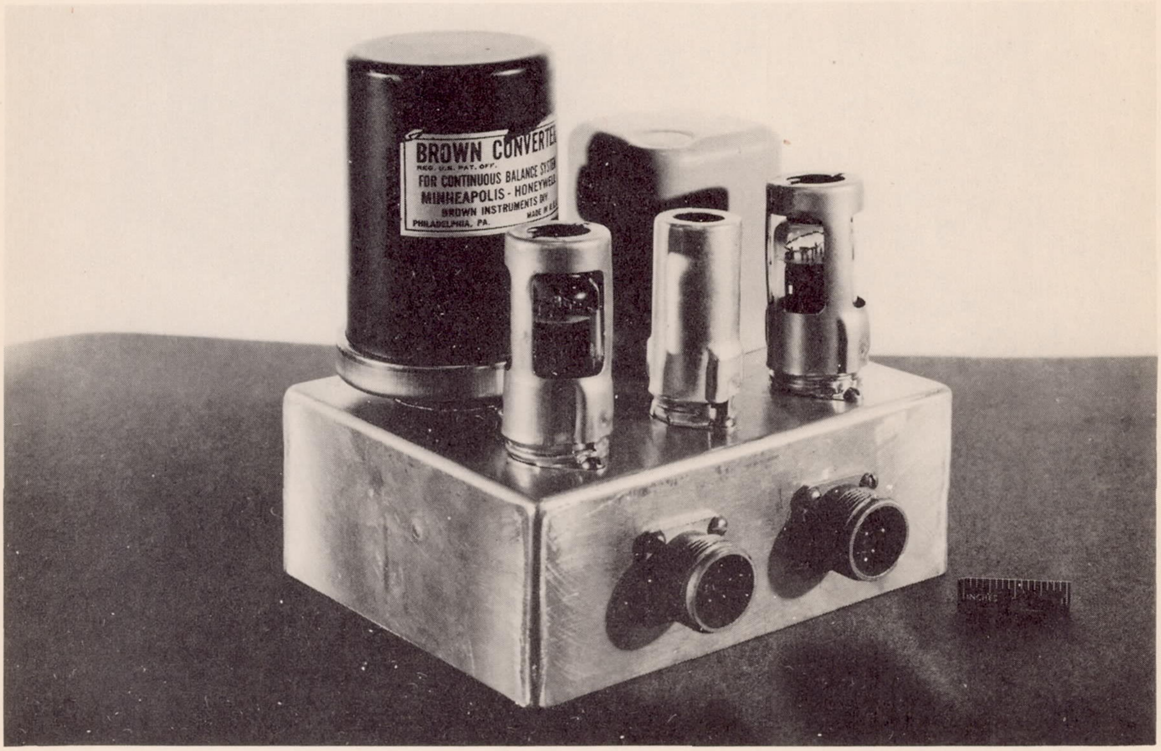



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Figure 7.- View of electronic temperature recorder.

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