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Instruments

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A VERSATILE RECORDING POTENTIOMETER

by

C. O. Ballou

Applied Physics Division

February 1960

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ABSTRACT

A Brown "Electronik" recording potentiometer was modified to provide a versatile instrument that can be applied to a variety of problems without time-consuming changes. Ranges may be selected in six spans, from 0.5 to 100 millivolts. No adjustments of amplifier gain are required when switching from one range to another. Zero suppression is continuously variable over a ±100 millivolt range by means of coarse and vernier controls. Cold junction compensation is provided for four standard thermocouples, and chart speeds from 1/2 to 16 inches per hour may be selected at will.

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A VERSATILE RECORDING POTENTIOMETER

INTRODUCTION

Recording potentiometers are widely used to make electrical measurements in the laboratory because of their inherent accuracy and ability to measure voltage without current drain. However, a typical instrument with a fixed range fails to meet the varying requirements of general laboratory use. This report concerns the modification of a standard instrument to meet those requirements.

SUMMARY

A Brown "Electronik" recording potentiometer was modified to make it a multirange instrument adaptable to general laboratory use. Any one of six spans from 0.5 to 100 millivolts may be selected in discrete steps by means of a switch. Four standard thermocouple compensators were incorporated and may be selected by means of a second switch. Zero suppression is continuously adjustable over a ±100 millivolt range by means of coarse and vernier controls. Terminal provisions were made for a spare compensator to meet the demands of experimental or newly developed thermocouples. Terminals were provided for mounting span and range resistors when odd spans are desired within the 0.5 to 100-millivolt range. The circuit was designed so that no amplifier gain adjustments are required under ordinary conditions when switching from one range to another.

DISCUSSION

THE INSTRUMENT

Recording potentiometers are used throughout the Savannah River Laboratory to record data that vary with time. In general, each laboratory situation requires some modification of the measuring circuit. In an effort to reduce the time required for modification, a Brown "Electronik" recording potentiometer was modified to make it a multirange instrument capable of general laboratory use.

Such a recorder is not available commercially due to the difficulty in changing ranges without, at the same time, changing the span and amplifier sensitivity. The instrument described in this report overcomes these problems by moving the span resistor to a point in the circuit at which high value resistors can be switched without regard to small contact resistance changes, and by shunting the amplifier on each range to provide a constant sensitivity.

The following description of the instrument modification is addressed to a reader who is interested in making the actual modifications in a similar potentiometer.

MEASURING CIRCUIT

Brown instrument nomenclature[1,2] is used in describing resistors in the multirange potentiometer circuit as shown in Figure 1. The downscale and upscale resistors that are present in the new design are referred to as downscale or upscale equalizing resistors and are designated as R_d and R_u, respectively. The amplifier shunts are designated as S_a and the upper branch shunts as R_s. The compensators are referred to as R_{ni-C} or R_{ni-T} when referring to the compensator or thermocouple portions. The upper branch of the measuring circuit is a normal 100-millivolt circuit that uses a standard Brown 20-ohm helical slide wire with resistor R_t omitted. The lower branch of the measuring circuit has been modified by including switches that provide span changes and introduce any one of a selection of thermocouple compensators.

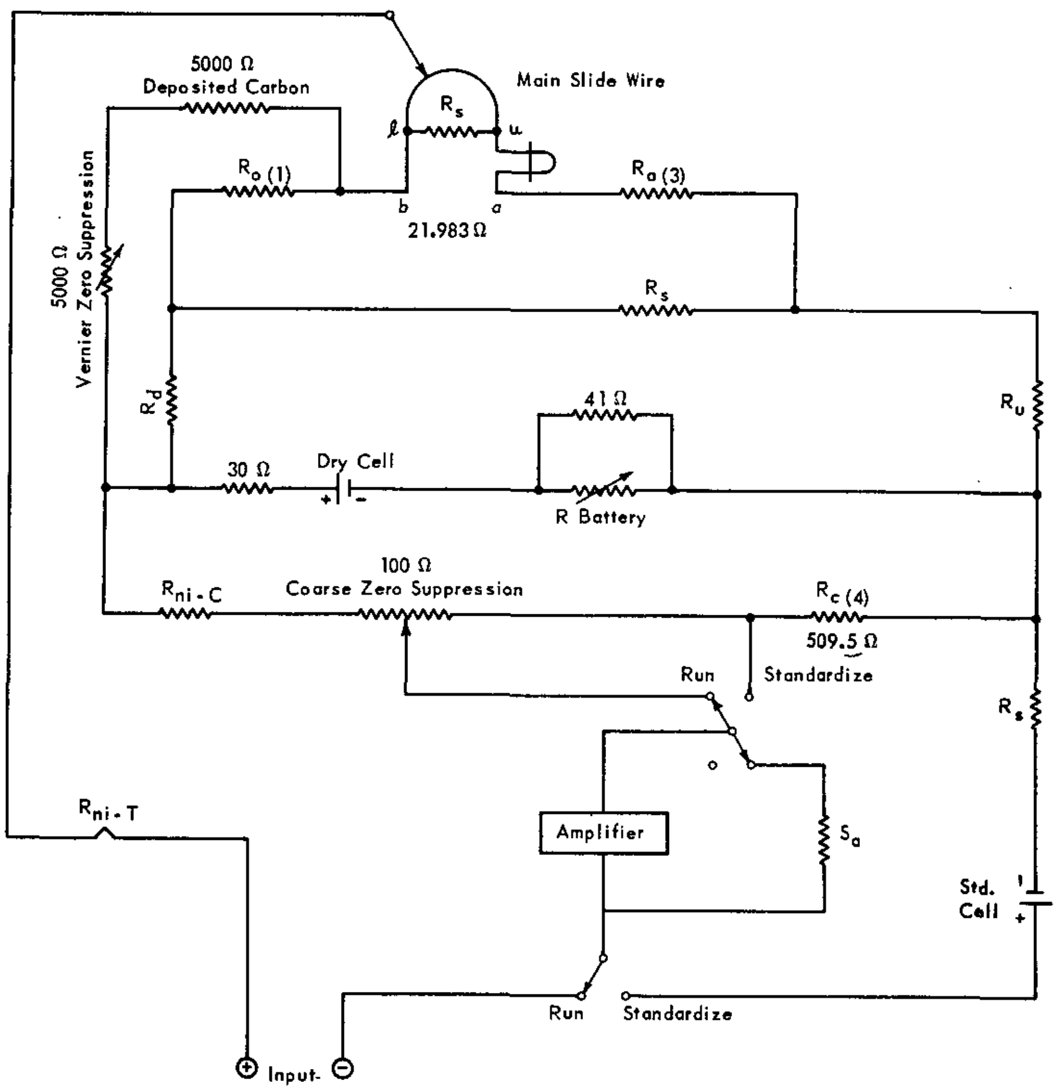

FIGURE 1 – SIMPLIFIED WIRING DIAGRAM OF MODIFIED MEASURING CIRCUIT

SWITCHES

Cutler-Hammer 7200 series switches were selected for switching in the multirange potentiometer because they are compact, are available in stacked decks, and have a measured variation in contact resistance of less than 0.0005 ohm with a total terminal-to-terminal resistance of approximately 0.003 ohm.

In order to prevent the contact resistance from producing undesirable variations in span, a circuit design was adopted in which 1.18 ohms is the lowest value of resistor that is switched, and the shunts (R_s) are switched across the entire upper branch of the potentiometer rather than across the slide wire alone. Equalizing resistors (R_d and R_u) are simultaneously switched, in a second and third deck of the span switch, to maintain constant current and a constant zero. A fourth deck switches the amplifier shunts (S_a) to eliminate amplifier gain adjustment when the spans are changed.

The switches are mounted on an aluminum chassis that is covered with an engraved "Bakelite" panel. The chassis is open at the bottom, ends, and back to obtain air circulation to ensure temperature equality of the input terminals and cold junction compensators. The switch panel is mounted on threaded studs that were attached to the terminal and relay channels on the back of the instrument case (Figure 2).

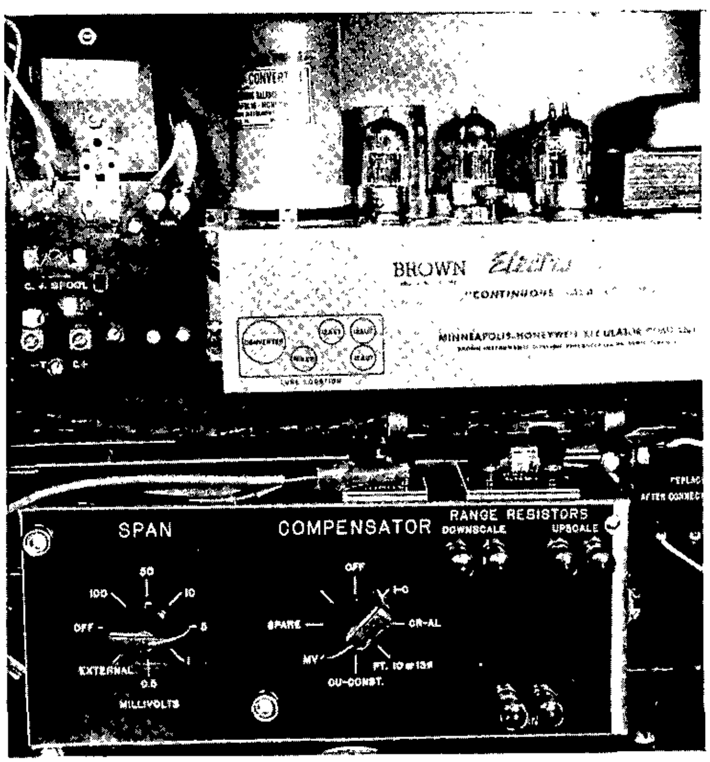

FIGURE 2 – INTERIOR ARRANGEMENT

ZERO SUPPRESSION AND STANDARDIZING

A coarse zero suppression of ±100 millivolts was obtained by means of a 100-ohm potentiometer that was inserted between the standardizing resistor and the cold junction compensators. This potentiometer consists of a special Type SAJ ten-turn Helipot, which was mounted as shown in Figure 3.

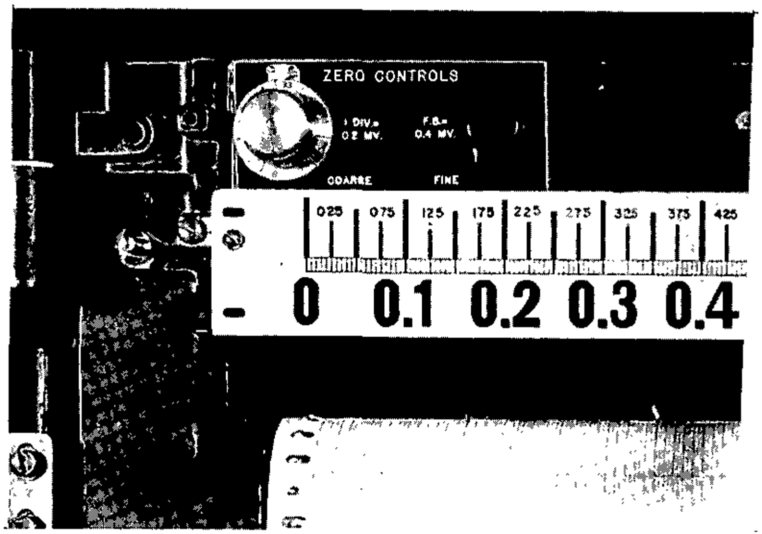

FIGURE 3 - ZERO SUPPRESSION CONTROLS

A standard Type AJZ Helipot was used initially but was found to produce a 1-microvolt/^{o}F zero drift. The Type AJZ is wound with wire that has a low temperature coefficient of resistance but that has a high thermoelectric effect when in contact with its copper slider. A special Type SAJ Helipot was obtained that is mechanically identical to the Type AJZ but is wound with manganin wire and fitted with a manganin slider. The special Type SAJ Helipot reduces the thermal drift to a negligible level.

A 5000-ohm Allen Bradley Type J potentiometer was used to provide a fine vernier control of the zero suppression. It was mounted next to the coarse control as shown in Figure 3. The range of the vernier adjustment was limited by a 5000-ohm, deposited-carbon resistor, which was wired in series to give an adjustment range of 5000 to 10,000 ohms.

The "100-ohm", zero-suppression Helipot actually measured 97.60 ohms, and consequently the full design range was not realized. The Helipot was padded out to 100.00 ohms, the pad being inserted on the upscale end of the adjustment.

With the 100-ohm slide wire incorporated in the lower branch, the bridge voltage increased 0.2 volt above that of the standard Brown design, and consequently battery life is decreased to about three months. Another consequence of this change is the loss of about two-thirds of the useful range of the standardizing rheostat, i.e., even with a new battery in place, the battery life indicator signaled a nearly exhausted battery. To correct this, a 41-ohm manganin resistor was shunted across the standardizing rheostat so that the full winding is utilized.

Standard Brown thermocouple compensators are wound with copper wire and have resistance values from 0.796 to 6.787 ohms. In an instrument in which these compensators are switched, the potentiometer voltage will vary with different compensators. Extreme changes are approximately 6 ohms in 615 ohms, or roughly, 1%, resulting in a similar span error. To correct this fault, all the compensator (R_{ni-C}) windings were padded out to approximately 6.8 ohms with manganin wire. Thus the bridge voltage remains constant when different compensators are selected. The manganin wire pads were wound directly on the compensator spools. One end was soldered to the compensator lead and the other end was clamped directly to the screw terminal of the switch.

STANDARDIZING SWITCH ALTERATION

The inclusion of the zero-suppression potentiometer in the lower branch of the bridge required a modification of the Brown standardizing switch.

The amplifier must be switched from the zero-suppression potentiometer to the standardizing resistor during the standardizing cycle. The switching from the input position to the standard cell position must occur while this switch is open, otherwise the recorder pen jiggles severely. Simultaneously, the amplifier shunt must be removed from the amplifier to avoid excessive dead zone during the standardizing cycle.

To obtain the required switching, a 3-blade, single-pole double-throw switch stack was added to the standardizing switch and the switch stack that normally inserts the standard cell was reversed and used to switch the amplifier shunts. The switch details are shown in Figure 4. To minimize pickup of stray signals by the amplifier when it is open circuited, the input transformer leads were shielded, the wires were dressed for minimum hum pickup, and the cable that connects the amplifier and standardizing switch was shielded.

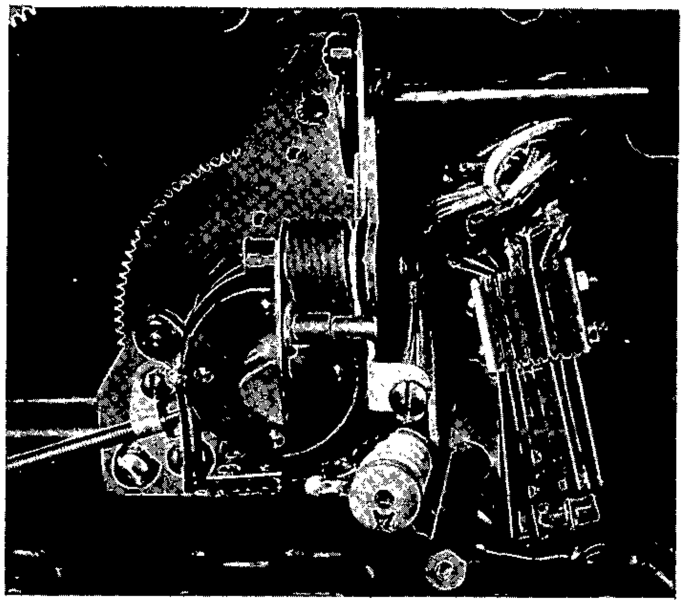

FIGURE 4 - STANDARDIZING SWITCH
(Unfastened to Show Detail)

SLIDE WIRE

Brown slide wires are nominally wound to approximate 40 ohms and then are precisely shunted to 20 ohms ±0.1%.

The following measurements were obtained on the particular recorder in question after the cable gear stop is removed to permit 100% slide wire travel:

Terminals 1 to u on slide wire	19.993 ohms
Terminals a to b, (resistor #2 on mounting board)	21.983 ohms
Resistance change for full-scale travel of slider	19.106 ohms

The first two measurements were made with a five-decade Wheatstone bridge. The third measurement was made with a potentiometer since a bridge measurement of slider resistance change would introduce serious errors due to the compensating wire.

After the 100-millivolt span is calibrated the slide wire index shown in Figure 5 should be reset. At one time, after the initial completion of the instrument, a slide wire cable had to be replaced, and it required hours of effort to accurately locate the zero position of the slider since the index had not been reset. This difficulty will not arise on instruments that use a straight slide wire, since the indicator and slider are independent of cable length.

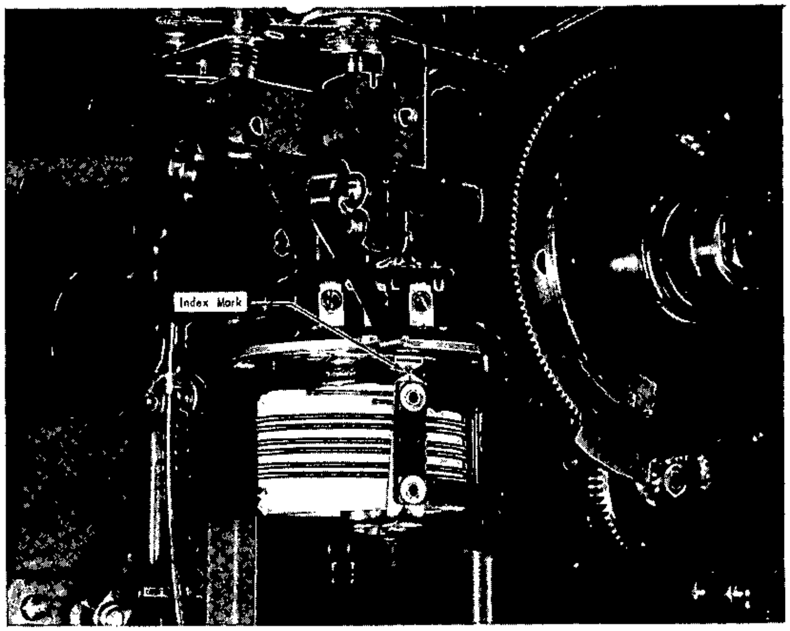

FIGURE 5 – MAIN SLIDE WIRE INDEX

RESISTOR ADJUSTMENT

Because of the higher bridge voltage and the large zero suppression, standard-range Brown resistors were not readily available. Stabilized resistors were made up as described in Appendix A and were brought into precise adjustment in the instrument using a Leeds and Northrup K-2 potentiometer as a potential source.

After an accurate and stable 100-millivolt adjustment was obtained, the resistance of the upper branch was measured at the newly installed span switch terminals. From this measurement the required equalizing and shunt resistor values were computed as shown in Appendix B.

The upscale equalizing resistors (R_u) were connected to the switch without change. The span and zero equalizing resistors (R_s and R_d) were adjusted in the instrument to give precisely the correct span and negligible zero change when the ranges were switched. Considerable difficulty was experienced in adjusting the equalizing resistors for the narrow downscale span, because they were wound with No. 30 wire. These resistors should be wound with No. 20 wire to make the adjustment easier.

The resistance of the amplifier shunts (S_a), (R_5), and the value of the limiting resistor for the standard cell current, were determined empirically. The amplifier gain control was turned to maximum on the half-millivolt range (no hunting occurred) and a decade resistor box was substituted for R_5. The resistance box was adjusted until the dead zone during standardization was equal to the dead zone of the half-millivolt range. A composition-type radio resistor of the correct value was substituted for the resistance box and was permanently installed at resistor terminals R_5. Resistors S_a were determined in the same manner to make the amplifier dead zone satisfactory on each span setting. Composition resistors of the nearest standard value were then permanently connected to appropriate contacts of the switch.

AMPLIFIER

The amplifier used was a Brown No. 356410-1(X12) that has a dead zone of about 1 microvolt, or approximately 0.3% on the half-millivolt range.

CHART DRIVE

The chart speed was made variable by the installation of an Insco Company variable speed gear train (Figure 6). The chart speeds available with the Brown gear train that was employed were: 0.5, 1, 2, 4, 6, 8, 12, and 16 inches per hour.

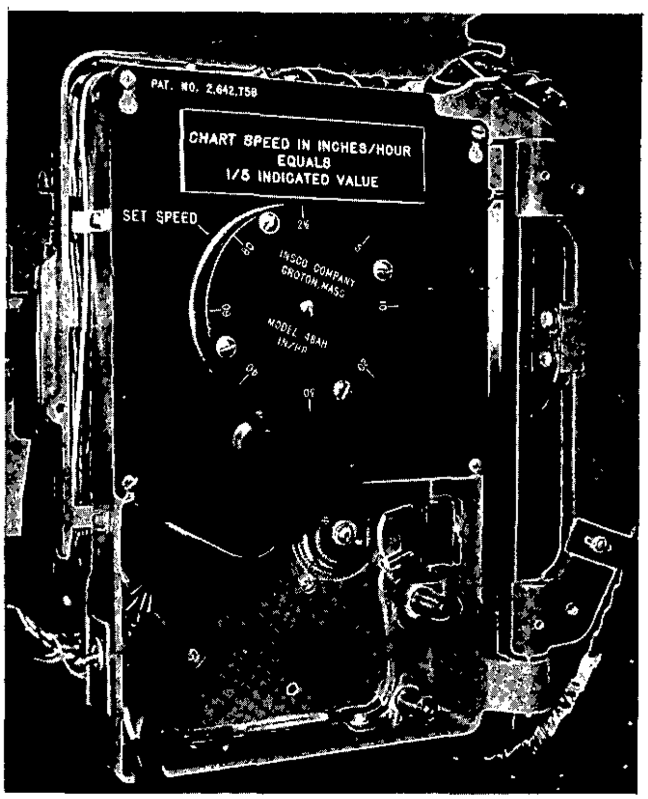

FIGURE 6 - VARIABLE SPEED CHART DRIVE

It was found that if the Insco indexing mechanism was not set precisely, the driven stud of the Brown gear train would bend and cause the gears to bind. This was corrected by installing a milled brass plate on the back of the gear train, which prevented the slots in the driving studs from coming in contact with the driven stud unless the indexing was precise.

PERFORMANCE

For a given span and amplifier input transformer, the dead zone of a standard Brown recorder increases rapidly as the resistance of the potential source increases above a critical value. Experience indicates that with spans of 10 to 50 millivolts, the potential source should not exceed the nominal input transformer impedance by a factor of more than 3 or 4 to keep the dead zone under 0.5% of the span. In this multirange instrument, measurements indicated that the shunt was much less critical than the above "rule of thumb" criteria would indicate.

The following tabulation is indicative of the dead zone performance of the multirange recorder under different conditions.

Span, mv	Amplifier Shunt, ohms	Source Resistance for a Dead Zone of 0.5% of Span, ohms	Span Dead Zone for Zero Source Resistance, %
0.5	Infinite	800	0.3
1.0	1000	1000	0.2
5.0	75	2000	0.1
10.0	27	1700	Negligible
50.0	4.7	1500	Negligible
100	1.2	1100	Negligible

Where conditions require higher source resistance a piece of "Scotch" tape can be inserted between the switch contacts of the amplifier shunt at the standardizing switch, thus disconnecting the amplifier shunt resistor. Amplifier gain adjustment will then be required when ranges are switched. Under these conditions the following dead zone performance can be expected.

Span, mv	Approximate Source Resistance for 0.5% Dead Zone, ohms
0.5	800
1.0	1,000
5.0	20,000
10.0	30,000
50.0	30,000
100	40,000

As an example of its laboratory uses, the recorder was connected to measure the drift of a 1500-volt power supply of high stability. The 1500-volt output was divided with a series of resistors to 100 millivolts and the recorder used on the 0.5- and 1.0-millivolt ranges with a zero suppression of about 100 millivolts. With this arrangement, the full-scale span was equal to 7.5 and 15 volts, respectively, at the 1500-volt level. The recorder operated without trouble for several weeks in this test of power supply stability.

C. O. Ballou/HSS
C. O. Ballou
Applied Physics Division

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1. Brown "Electronik" Instrument Service Manual, Class 15 Instruments No. 15019M, Issue 7, Minneapolis-Honeywell Regulator Co., Brown Instrument Division, Philadelphia 44, Pa.

2. Jacob, G. R. and M. Lafferty, "Characteristics of the Brown Continuous Balance System," Bulletin No. B15-12A, Minneapolis-Honeywell Regulator Co., Brown Instrument Division, Philadelphia 44, Pa., 1956.

APPENDIX A

RESISTOR CONSTRUCTION

A total of 18 manganin-wound resistors were required to construct the multirange recorder. In addition the thermocouple zero compensators were padded out with manganin wire. A large accumulation of Brown resistors resulting from frequent range changes on other recorders were available for winding forms.

Resistors that were to be completely rewound were soaked overnight in a half-and-half mixture of "Xylol" and "Toluol" and then stripped of wire. To avoid rewinding resistors of 40 ohms or more, the resistors were soaked for an hour or so, to soften the "Glyptal" so that the binding could be cut and the adjustment end of the wire could be located and unwound.

After the stripped forms were wound with bifilar windings and the adjustment end was loosely bound, the resistor was dipped in red "Glyptal" varnish. They were artificially aged by an overnight baking at 100°C. This aging provides relief of winding strain and reduces the resistance value as much as 1% in the heavier gage wires. Consequently such resistors should be wound to the required value plus 1%, plus about 5% for adjustment leeway.

The resistors were adjusted about 1% high by means of a Wheatstone bridge and then were rebaked at 200°C for an hour. They were installed in the instrument and brought into precise adjustment. The ends were then bound with thread, dipped in "Glyptal", and baked dry at 100°C.

Resistors that were partially unwound were brought into precise adjustment, bound, dipped in "Glyptal", and baked at 100°C for the time necessary to dry the "Glyptal".

The thermocouple pads were merely thread bound. Changes in these resistors due to aging would have a negligible effect upon instrument performance.

The standardizing 41-ohm shunt was wound with manganin wire on a stripped ceramic ("precision resistor") coil form. It was neither varnished nor aged. Its position is shown in Figure 4.

APPENDIX B

RESISTOR COMPUTATION

BRIDGE VOLTAGE

The voltage drop across the bridge is equal to the sum of voltage drops in the standardizing ($R_{c(4)}$), compensating (R_{ni-C}), and coarse zero suppression resistors. As the standardizing resistor is 509.5 ohms and the standard cell potential is 1.0190 volts, the current in this branch is 0.002 ampere. A detailed circuit diagram is shown in Figure 7.

Resistance Values on Span Adjustment Switch, ohms

Span, mv	R_d	R_s	R_u	S_a
100 (1)	0	∞	0	1.2
50 (2)	10.849	235.49	106.90	4.7
10 (3)	19.529	26.166	192.41	27
5 (4)	20.614	12.394	203.10	75
1 (5)	21.482	2.3786	212.65	1000
0.5 (6)	21.590	1.1833	212.72	∞

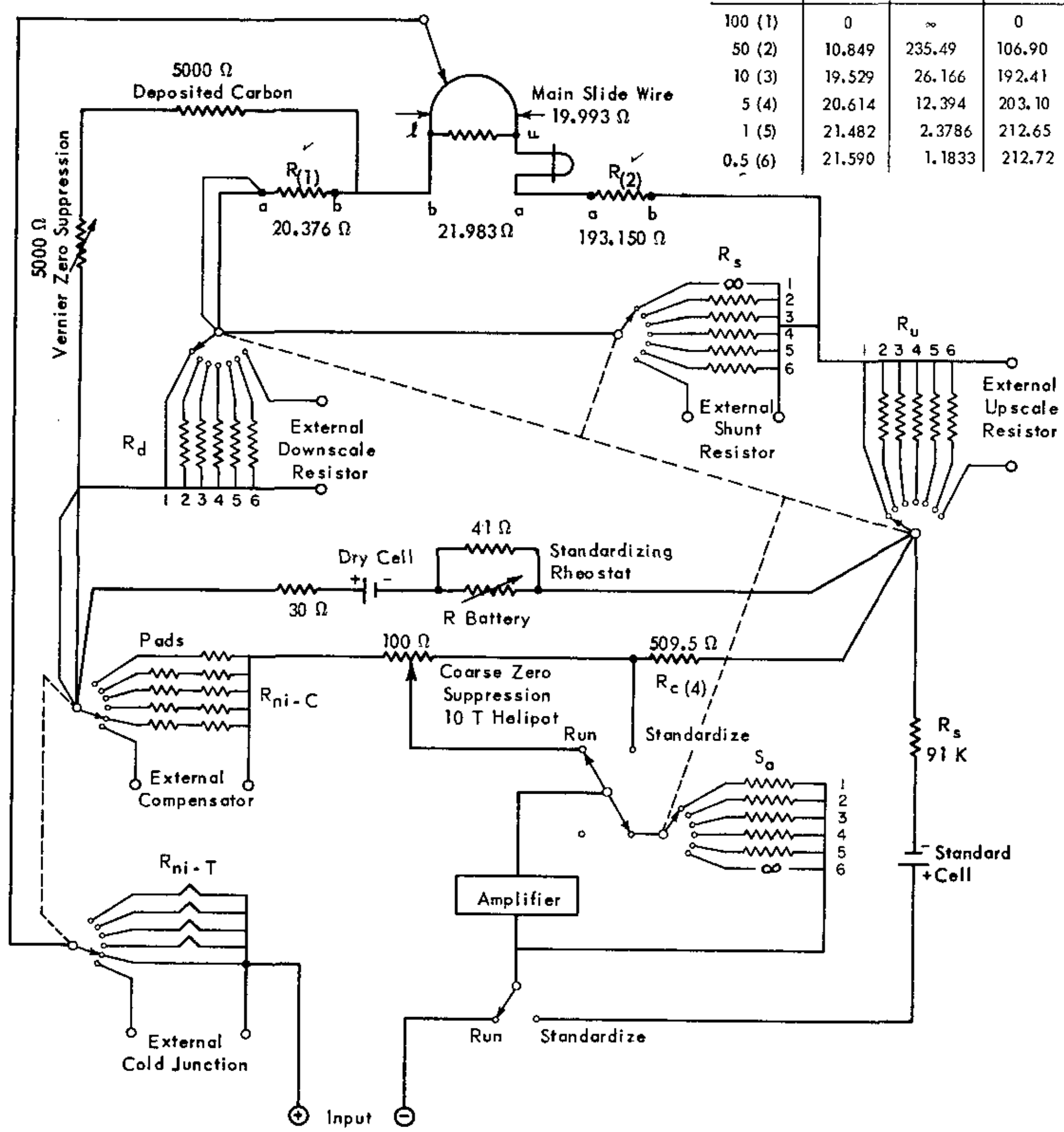

FIGURE 7 – CIRCUIT DIAGRAM OF MULTIRANGE RECORDER

Tabulating the lower branch resistors and multiplying by 0.002 amp:

Resistor	Value, ohms
Standardizing	509.5
Zero Suppression	100.0
Compensators	6.787
	616.287 ohms

Multiplied by 0.002 amp = 1.232574 volts

MEASURING CIRCUIT CURRENT

The current in the upper branch for a 100-mv span is equal to the span voltage divided by the active resistance of the slide wire

$$I = \frac{0.100 \text{ volt}}{19.106 \text{ ohms}} = 0.0052339 \text{ amp}$$

ZERO SUPPRESSION RESISTOR

The value of the zero suppression resistor (R_1) is determined by making its IR drop equal that of the cold junction compensator plus one-half of the drop in the coarse zero suppression slide wire (for zero at mid-position of the coarse zero suppression dial).

The IR drop in the compensator and zero control is

$$E = (6.787 + 50.00)0.002 \text{ amp} = 0.11357 \text{ volt}$$

Computing the resistance of R_1

$$R_I = \frac{0.11357 \text{ volt}}{0.0052339 \text{ amp}} = 21.699 \text{ ohms}$$

Actually R_1 will be smaller than the computed value due to wiring and switch resistance. In addition, the inactive part of the slide wire, which is adjustable over nearly 1 ohm, is effectively part of R_1.

The copper wire connecting R_1, terminal a, to the cold junction compensator becomes an unintentional cold junction compensator. Because of the relatively high temperature coefficient of resistance for copper this circuit resistance must be kept as low as possible to prevent zero shifts on the millivolt range or faulty cold junction compensation on thermocouple ranges. Multiple conductors were used through this circuit to obtain a minimum copper cross section equal to No. 16 wire.

UPSCALE RESISTOR

The value of the upscale resistor R_3 is computed by differences. In this case the total slide wire resistance was used. It measured 21.938 ohms at terminal a-b of R_2 on the resistor mounting board.

The potential drop from terminal a of R_1 to terminal a of R_2 (including R_1 and the slide wire) is:

$$E = 0.11357 + (0.0052339 \times 21.983)$$
$$= 0.22863 \text{ volt}$$

Subtracting this from the full potentiometer voltage of 1.23257, we obtain 1.00394 volts to drop in R_3;

$$\text{and } R_3 = \frac{1.00394}{0.0052339} = 191.81 \text{ ohms}$$

As mentioned before, the position of the slide wire relative to the pen carriage and scale will affect the value of R_1 and R_3 over a range of about 1 ohm. However, the sum of the resistors should be very close to the computed value.

RESISTANCE CHECK

In the instrument described, R_1 and R_3 were adjusted in place using a Leeds and Northrup K-2 potentiometer as an accurate potential source. The values finally arrived at compared to the computed values were:

Resistor		Final Adjustment, ohms	Computed, ohms
R_1		20.376	21.699
R_3		193.150	191.810
Slide Wire		21.983	21.983
	TOTAL	235.509	235.492

An over-all measurement gave 235.49 ohms at the span switch terminals. This value was used for computing the span and the equalizing resistors.

POTENTIOMETER SHUNT RESISTORS

After the 100-millivolt range was adjusted accurately and the slide wire index was set so that the indicator slide wire relationship could be re-established in case of slide wire cable replacement, the values of the multiranging resistors were computed.

The values of the shunts (R_s) were computed by the following equation derived from Ohm's Law:

$$R_s = \frac{I_{sw} R_{sw}}{I - I_{sw}}$$

where I_{sw} = slide wire current

R_{sw} = upper branch resistance (R_1 + SW + R_3)

I = total current

The computed resistance of the shunts is as follows:

Span, mv	Shunt Resistor (R_s), ohms
100	Infinite
50	235.49
10	26.166
5	12.394
1	2.3786
0.5	1.1833

EQUALIZING RESISTORS

The purpose of the equalizing resistors is twofold; to maintain a constant current in the upper branch of the potentiometer, and to maintain the zero indication constant without zero suppression adjustment when switching spans.

When the instrument is on the 100-millivolt span with the indicator on zero, the slider is 0.11357 volt above the low end of the potentiometer. As narrower ranges are selected, the IR drop in R_1 is lowered proportional to the degree of shunting. Equalizing resistors (R_d) introduce additional IR drops to maintain the zero end of the slider at a constant potential above the low end of the potentiometer.

In a single-span instrument minor errors in the value of the downscale resistor (R_1) can be corrected by moving the slide wire relative to the indicator. Where multiple spans are involved, this adjustment can be made only on the widest range, and the equalizing resistors must be brought into precise adjustment using the instrument itself as a measuring device.

Although the equalizing resistors (R_d) may be adjusted to any reasonable degree of accuracy before they are installed in the instrument, it is probable they will require readjustment after installation. For this reason these resistors, in particular, were made about 2 ohms larger than computed, were thoroughly aged, and were inserted in the circuit and adjusted to the correct value using the instrument itself as an indicator.

Computation of the values of the equalizing resistors involves obtaining the potential difference of the zero due to the various shunts and then using the current in the upper branch to obtain the resistance. For example, on the 5-millivolt range the zero point on the slide wire is 1/20 of the 100-millivolt value and is equal to 0.11357/20 = 0.0056785 volt.

The equalizing resistor must drop 0.11357 - 0.0056785 = 0.10789 volt, and $R_d = \frac{0.10789}{0.0052339} = 20.614$ ohms.

For all spans these resistors were computed to be:

Span, mv	R_d, ohms
100	0
50	10.849
10	19.529
5	20.614
1	21.482
0.5	21.590

The values of the upscale equalizing resistors (R_u) were computed by adding the parallel resistance of the upper element to the downscale equalizing resistors and subtracting the sum from the 100-millivolt upper branch resistance. The computed values were:

Span, mv	R_s Shunt Resistance, ohms	R_d Resistance, ohms	Sum (R_s + R_d), ohms	R_u (235.49 - sum)
100	235.49	0	235.49	0
50	117.745	10.849	128.594	106.90
10	23.549	19.529	43.078	192.41
5	11.775	20.614	32.389	203.10
1	2.355	21.482	22.837	212.65
0.5	1.177	21.590	22.767	212.72