Weston
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In This Issue

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THE WESTON MODEL 1411 INDUCTRONIC® D-C AMPLIFIER

RECENTLY the new Weston Inductronic system of d-c amplification was announced as the Model 1411 Inductronic D-C Amplifier, illustrated in Figures 1 and 2. This is a sensitive precision amplifier intended primarily for application to low-level devices such as thermocouples and photocells, to provide higher accuracy, stability and response speeds than would be possible by applying indicating, controlling or recording instruments directly. It is by nature particularly adapted to industrial service requiring reliable performance continuity and its characteristic combination of high response speed and high sensitivity presents a new criterion of performance in this class of instrument.

Figure 1—Model 1411 complete.

Method

The Model 1411 Amplifier is a full-feedback type wherein a substantially infinite intrinsic gain is completely degenerated in a feedback network determining precisely the effective gain. The feedback network is contained in a plug-in unit termed a Range Standard (Model 9914) for potential or current inputs as required. In either case, the input is balanced and the amplifier is, in effect, an automatic potentiometer. With potential sources no current demand is imposed, and with current sources no potential

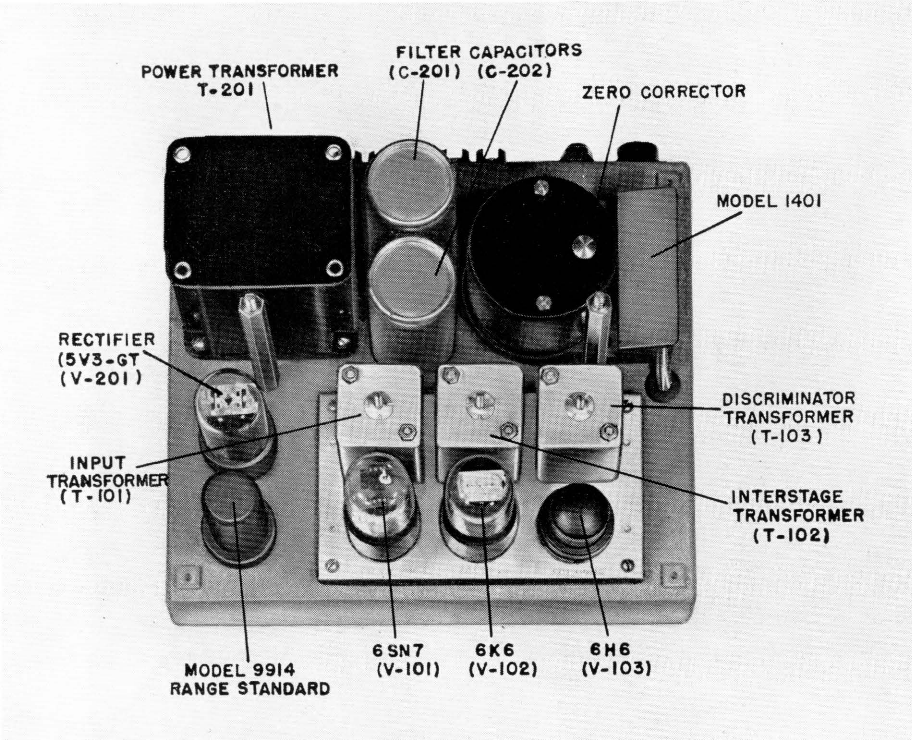


Figure 2—Model 1411 Chassis with cover removed.

drop results, other than a small error component which is normally negligible.

The amplifier output is a current of one milliampere range into a load not exceeding 5,000 ohms (5 volts maximum burden). The output is continuous through zero, and may be for example 0.5-0-0.5 milliampere or 0-1 milliampere. Changes in the burden resistance within the maximum have no influence except a slight effect upon response speed. The output current range and ability to support burden was selected as the most appropriate to operate indicating instruments, relays, direct-writing recorders and such accessory devices.

Conversion Principle

The unbalanced error is amplified by conversion to a-c, amplification as a-c and phased rectification back to d-c to develop the output for balance against the input. In general, the performance of this class of amplifier is contingent upon the efficacy of this function, particularly in respect to sensitivity and speed of response. In this case, the error is converted to a relatively high carrier frequency of 200 kilocycles per second by a newly developed device, the induction galvanometer illustrated in Figure 3. The high conversion frequency particularly allows an extremely short feedback period, provides insensitivity to spurious input disturbances, and simplifies the electronic circuit complement considerably in contrast to converter systems operating at low frequency. Also, the induction galvanometer provides gain as well as conversion, in the order of 10^8 on an energy basis, requiring only a nominal order of gain in the electronic section.

The induction galvanometer is essentially a pivoted permanent magnet-movable coil structure including a field assembly for injecting a 200-kc increment of magnetic flux through the pole pieces superimposed upon the permanent magnetic field. When the movable coil is deflected from its normal center-zero position by a d-c error component, it couples to the a-c field which induces a proportionate a-c potential having a phase dependent upon the direction of deflection.

The induced movable-coil potential is about 1.6 volts a-c per degree deflection, whereas the electronic amplifier section requires about 1 millivolt a-c to develop full-scale output. On this basis, the galvanometer excursion is in the order of 3 seconds of angle, which represents a very small order of error tolerance.

The galvanometer has no deliberate restoring force, and is equipped with conducting filaments having a minimum torque consistent with mechanical strength. In operation, restoration is entirely electrical and no motion is discernible. A zero corrector mechanism is provided for balancing the residual filament force, but normally no readjustment is required.

A pivoted rather than a suspended movement is used primarily for ruggedness. But in this case the small deflection angle and the presence of some 200 kc alternating torque completely eliminates the residual friction normally present in pivoted systems.

Frequency Shift Amplifier

The electronic amplifier section functions on a frequency shift system particularly suited to the induction galvanometer. The amplifier consists of three stages peaked to the center frequency of 200 kc. The output stage is conductively regenerated back to the input of the second stage so that the last two stages are in stable oscillation at 200 kc. The output stage excites the galvanometer field, which couples to the movable coil upon deflection to introduce a second feedback path back through the first amplifier stage. This feedback, however, is in quadrature, leading or lagging depending upon the direction of gal-

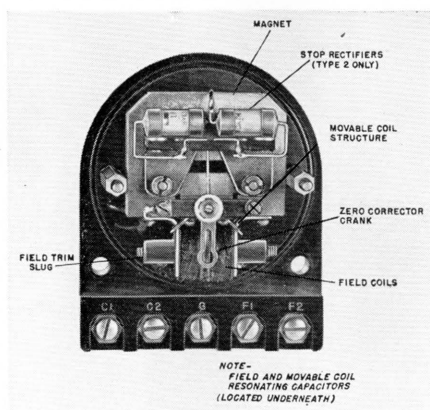


Figure 3—Induction Galvanometer complete with cover removed.

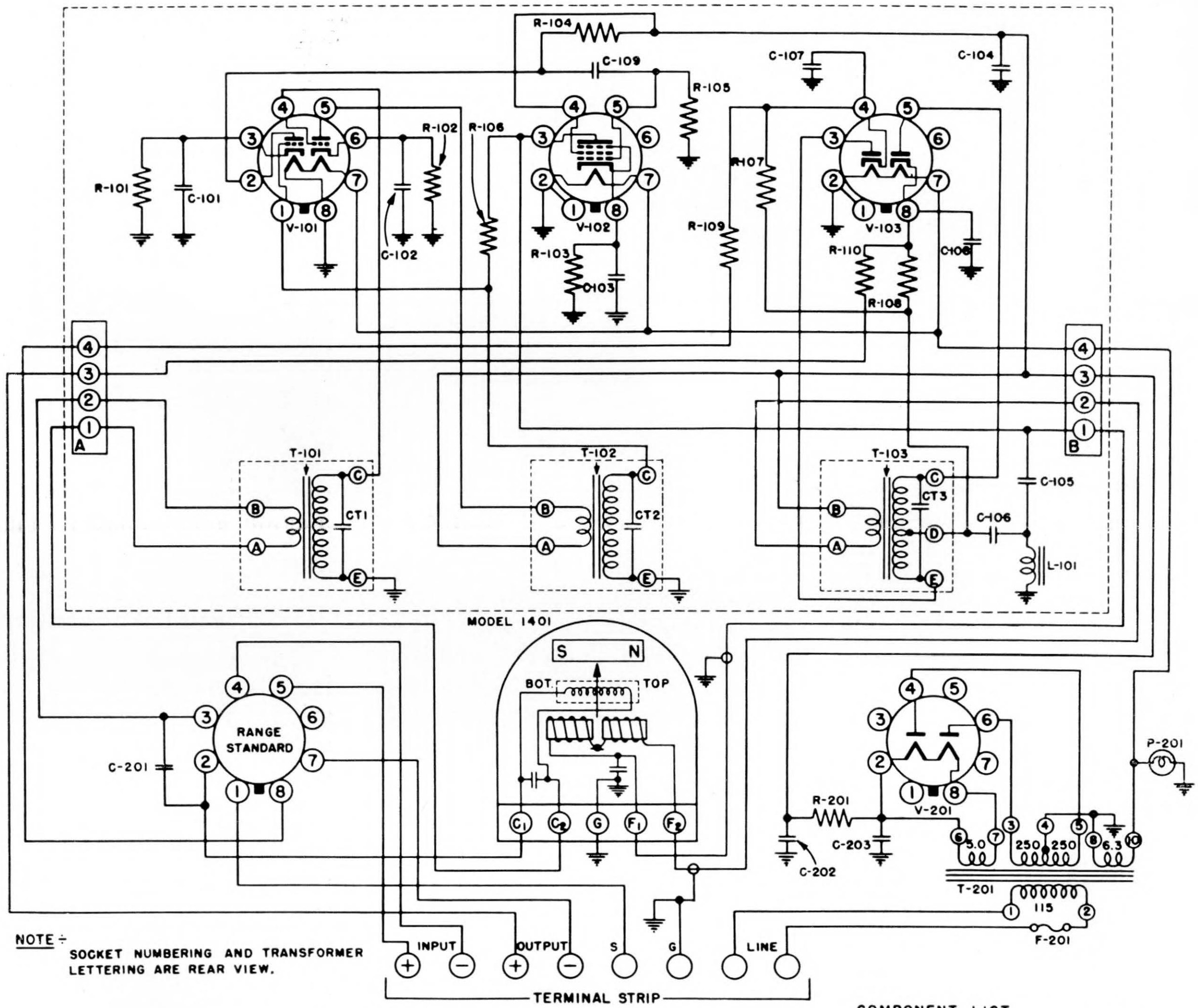
vanometer deflection, and will cause the frequency to shift proportionally from the 200 kc center frequency in response to deflection. The amplifier output frequency is then detected by a frequency-discriminating rectifier to develop the d-c output. The complete circuit is shown in Figure 4 wherein the a-c amplifier proper is included between the two 4-point terminal strips.

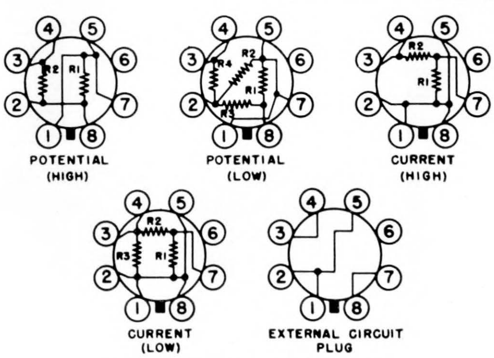
The frequency-shift system is considered superior to an amplitude system having the same tube complement because the over-all response is primarily determinable by the nature of the coupling impedances, particularly the galvanometer field-discriminator coupling coefficient. By flat topping the coupling impedance, the system may be made sensitive beyond the ability of a comparable amplitude system.

Range Standards

The plug-in feedback network, or Range Standard, is a mutual resistance network in the case of potential input, and a current ratio network in the case of current input. It also includes a galvanometer shunting resistance to provide damping when the connected external input source circuit is high in resistance.

For practical reasons of adjust-





RANGE STANDARD CONNECTIONS

COMPONENT LIST

C-101	2-.01 MFD. 500WV. (IN PARALLEL)	L-101	WESTON CHOKE 10 MH. 70 OHMS ± 10%
C-102	SAME AS C-101		
C-103	SAME AS C-101		
C-104	.01 MFD. 600WV.	V-101	6SL7/GT
C-105	SAME AS C-104	V-102	6K6/GT
C-106	SAME AS C-104	V-103	6H6
C-107	SAME AS C-104		
C-108	SAME AS C-104		
C-109	500 MMFD. MICA 600WV.	C-201	.02 MFD. 200WV.
		C-202	2 MFD. 600WV.
R-101	1K .5W 10%	C-203	SAME AS C-202
R-102	SAME AS R-101		
R-103	2K 2W 10%	R-201	2K 10W 10%
R-104	50K 1W 10%		
R-105	1M .5W 10%	F-201	2AMP. FUSE
R-106	500K .5W 10%		
R-107	50K .5W 10%	P-201	LAMP 6.3V
R-108	SAME AS R-107		
R-109	2K .5W 10%		
R-110	SAME AS R-109	T-201	POWER TRANSFORMER 250-0-250 5V. - 2A 6.3V. - 2A CT 115 INPUT
T-101	WESTON 200KC INPUT TRANSFORMER		
T-102	WESTON 200KC INTERSTAGE TRANS.		
T-103	WESTON 200KC DISCRIMINATOR TRANS.	V-201	5Y3/GT

Figure 4—Model 1411 Wiring Diagram.

ment the Range Standard networks are designed to have no resistors lower than 10 ohms. When, for example, a potential range requires a mutual resistance less than 10 ohms, a pi network is used rather than a single resistor.

In addition, an External Circuit Plug is available containing jumper connections to bring the galvanometer and output circuits independently to the terminals for special external networks. The input and output circuits are then conductively isolated within the amplifier and may be connected externally without regard to internal continuity.

Range Standards are normally adjusted to 1 per cent accuracy, but are available to 0.1 per cent when required.

Resolution Sensitivity

The sensitivity of resolution may be divided into two components, zero drift and error demand per increment of deflection. But in this case, the drift component is the larger, and the resolution sensitivity may be expressed in terms of drift expectancy. This is almost entirely due to parasitic thermal potentials within the galvanometer and the internal wiring, and occurs during warm-up periods when the internal temperature gradients are shifting.

The normal total observed drift from a cold start is in the order of 3 microvolts at the galvanometer terminals, and is stated as 5 microvolts maximum. After warm-up, this may be adjusted out by means of the galvanometer zero corrector, and the resolution sensitivity thereafter is a matter of the fineness of adjustment. However, the normal recommended ranges are sufficient to make zero drift proportionally inconsequential and no adjustment is required.

It is to be noted that zero drift does not occur in the vacuum tubes as a function of warm-up or aging, and no long-term drift is effective as in the case of conductively coupled amplifiers.

Accuracy

In operation, the working error is the sum of the resolution sensitivity and the adjustment error of the Range Standard, with the resolution sensitivity calculated to include the external input source circuit resistance if appreciable. Ideally potential sources should have zero resistance and current sources a high resistance. In general, when potential sources have a resistance lower than 50 ohms and current sources a resistance higher than 50 ohms, the resolution loss due to input resistance may be neglected. The 50-ohm figure is the match resistance of the galvanometer. In terms of current, the resolution sensitivity is 5 microvolts across 50 ohms, or 0.1 microampere. With unfavorable source resistance, the minimum range should be raised proportionally to 50 ohms. Thus on ranges not lower than those recommended, 1 millivolt and 20 microamperes, and where the input source resistance is not excessive, the over-all accuracy is essentially that of the Range Standard, or 1 per cent.

Service Life

The service life expectancy is effectively that of the vacuum tubes, and with routine tube replacement should be unlimited, or alternatively, long-life, ruggedized tube-type equivalents are available. The galvanometer suffers no normal deterioration, and the electrical components are permanent in character; no electrolytic capacitors are used.

Mechanical Construction

The unit is chassis-mounted with a removable cover including a carrying handle. Universal mounting brackets are supplied for permanent surface or wall installation. The galvanometer is separately cased for dust protection, and in crowded locations the chassis cover may be left off for better ventilation or for convenient access to the tube locations.

All connections are made to an 8-point terminal strip with terminal pairs for input, output and power line circuits, and a jumper ground for the input circuit.

Input Circuit

Because of the high operating frequency, the input circuit is not sensitive to a-c strays, and shielding is not necessary in contrast to low-frequency converter systems. However, grounding is desirable to avoid d-c leakage strays. Grounding is provided by a jumper connection on the terminal strip, and in cases where input grounding is not permissible, or is grounded externally, the jumper may be removed. Otherwise the input and output circuits are conductively isolated from the electronic section, and may be operated up to 100 volts above ground potential.

SPECIFICATIONS

SIZE: 9¼″ wide x 8½″ deep x 6⅛″ high, overall.
WEIGHT: 13 lbs. (28.7 kilograms).
MOUNTING: Supplied with carrying handle for portable service, and mounting brackets for permanent installation.
RANGES: Determined by interchangeable plug-in Range Standards, potential or current types; normal minimum ranges 1 millivolt and 20 microamperes; and normal maximum ranges 5 volts and 1 milliampere. Lower ranges available but are susceptive to thermal drift; correspondence is invited.
INPUT: Maximum current demand on potential ranges, 0.1 microampere; maximum potential demand on current ranges, 5 microvolts; input grounding optional by terminal strip jumper.
OUTPUT: 1 milliampere range, any zero position, maximum output burden 5,000 ohms (5 volts).
INPUT MATCH RESISTANCE: 50 ohms, approx.
RESPONSE SPEED: Better than 0.1 second on lowest recommended ranges: faster on higher ranges.
POWER REQUIREMENTS: 105-125 volts a-c, 50-1,600 cps, approx. 35 watts demand, internally fused for 1 ampere.
OPERATING FREQUENCY: Conversion frequency, 200 kilocycles center with frequency-shift range of approx. ±15 kc.
VACUUM TUBE COMPLEMENT: One each of the following standard types: 6SL7, 6K6, 6H6, 5Y3.
METHOD: Potential or current balance feedback, with error conversion, amplification as a-c and phased rectification.
CONVERTER: Weston induction galvanometer.

Special Applications

The relatively high feedback velocity permitted by the high operating frequency advances several applications not normally practicable with d-c amplifiers of lower speed resolution. For example, reactive feedback networks may be employed to perform functions of integration or differentiation of the input potential or current. Also, resistive feedback networks developing negative resistance at the input terminals are entirely practical. These are helpful for example in some photocell applications where strict linearity is necessary. And where a slow response is desired for averaging a fluctuating input, reactive feedback damping may be included to increase the response time far beyond that obtainable by damping the indicating instrument.

It is intended to describe some of these special applications in future issues of WESTON ENGINEERING NOTES.

E. N.—No. 84 —*R. W. Gilbert.*

THERMAL PROBLEMS RELATING TO MEASURING AND CONTROL DEVICES—PART VIII

Electric Heating of a Conductor the Resistance of Which Varies With Temperature

Introduction

IN PREVIOUS studies on the electric heating of conductors, it was assumed that their resistances were independent of temperature. In the case of relatively short conductors connected between terminals used for shunts, this condition could be assumed without serious error as they are usually constructed of material having a negligible temperature coefficient of resistance. However, in other forms of conductors, such as bus bars, transformer windings, movable and field coils of instruments, and similar devices, the temperature coefficients are relatively large and, therefore, have a considerable effect upon the time constants and final temperatures of conductors when heated by current.

23. TO DETERMINE THE INCREASE IN TEMPERATURE OF A CONDUCTOR THE RESISTANCE OF WHICH VARIES WITH TEMPERATURE, WHEN HEATED BY AN ELECTRIC CURRENT, AT ANY TIME AFTER THE INITIAL APPLICATION OF THE HEATING CURRENT, WHEN THE HEAT NOT ABSORBED IS DISSIPATED TO THE SURROUNDING MEDIUM.

23(a). When the Current Through the Conductor Is Constant.

When the conductor is heated by a constant current, the change in temperature resulting causes an increase in the resistance and a consequent added increment in the heat generated. The object of this analysis is to determine the resulting temperature increase at any time.

Let R_o = resistance of conductor at initial temperature; ohms.

a = temperature coefficient of resistance of conductor in ohms per ohm per deg. cent.

θ = increase in temperature of conductor at any time, above the initial temperature.

θ_r = final increase in temperature.

R = resistance of conductor at any temperature $= R_o(1+a\theta)$.

I = constant heating current; amperes.

W = rate of addition of heat at any temperature $= I^2R$; watts.

W_o = rate of addition of heat at initial temperature $= I^2R_o$; watts.

h = rate of heat dissipation from conductor to surrounding medium; watts per deg. cent.

M = mass of conductor; grams.

s = specific heat capacity of conductor; joules per gram per deg. cent.

It is assumed that the initial temperature of the conductor is the same as that of the surrounding medium. Then as will be shown later, the increase in temperature, θ, of the conductor, considered as a simple body, at any time t after the initial application of the heating current, is

$$\theta = \theta_r(1-\epsilon^{-t/t_r}) \qquad (161)$$

where

$$\theta_r = \frac{W_o}{h - W_o a} \qquad (162)$$

is the final increase in temperature, and

$$t_r = \frac{Ms}{h - W_o a} \qquad (163)$$

is the time constant.

It will be observed that Equation (161) has the same form as Equation (2)[1], for the case of a body heated at a constant rate, differing only in the values of the final temperature and the time constant. The curves in Figure 1 can therefore be used for the present case, where the resistance of the conductor changes with temperature, by the use of the appropriate values of final temperature and time constant, given by Equations (162) and (163).

$$\theta_r = \left(\frac{h}{h - W_o a}\right)\theta_m \qquad (164)$$

and

$$t_r = \left(\frac{h}{h - W_o a}\right)t_o \qquad (165)$$

that is, the effect of a temperature coefficient of resistance upon the final temperature and the time constant of a conductor is to change both in the same ratio from the values which would result if the resistance were constant, that is $a=0$.

Positive Temperature Coefficient of Resistance. Most of the conductor materials used in instruments and control devices, such as copper, aluminum, nickel, and most of their alloys, increase in resistance with increase in temperature, and, therefore, have a positive temperature coefficient of resistance. Under this condition, therefore, the final temperature and time constant are greater than for the case where the temperature coefficient is zero, because of the constant increase in the heat generated as a result of the increasing resistance, and are computed by Equations (162) and (163).

Negative Temperature Coefficient of Resistance. Some materials, such as carbon, some so-called semi-conductors, and even manganin and constantan between certain temperatures, reduce in resistance when the temperature increases, and, therefore, have a negative temperature coefficient of resistance, that is, a is negative. If then $a = -a_1$, and we substitute this value in Equations (161) to (165), we find that the final temperature and the time constant are less than would result if the temperature coefficient were positive or even zero. It should be pointed out, however, that no known material has a constant or even nearly constant negative temperature coefficient of resistance. If any such material existed, its resistance would reduce to zero and even become negative for some definite increase in temperature. Therefore, the equations given, which are based upon constant or practically constant coefficient, are principally of academic interest when a is negative except within the narrow limits where the coefficient may be considered constant.

Critical Heating of Conductors:
Case (I); $h = W_o a$.

If the rate, h, at which heat is transferred from the conductor to the medium per degree difference in temperature is equal to the increment, $W_o a$ in the heat generated as a result of the increase in resistance per degree change in temperature, then from Equations (162) and (163) when the temperature coefficient is positive, both θ_r and t_r become infinite, and Equation (161) becomes (infinity) × (zero) which is indeterminate. However, this can be evaluated very simply by remembering that in general where the exponent x in the quantity ϵ^{-x} becomes very small and approaches zero, $\epsilon^{-x} = 1 - x$. Applying this to Equation (161), we have for a positive temperature coefficient,

$$\theta\Big]_{h = W_o a} = \frac{W_o}{h - W_o a}\left[1 - 1 + t\left(\frac{h - W_o a}{Ms}\right)\right] = \frac{W_o t}{Ms} \quad (166)$$

This shows that under the assumed conditions, where $h = W_o a$, the temperature increases indefinitely in direct proportion to time. This could have been deduced also from purely physical reasoning, since the heat dissipated just balances the increment in the heating rate resulting from the increase in resistance. The remainder of the heat, which is added at the initial constant rate, must be continually absorbed by the material and thus raise its temperature at a constant rate. In practice this result can continue, of course, only until the material undergoes a change in state such as, for example, melting or boiling, or a change in temperature coefficient.

Case (II); $W_o a$ is greater than h. When the heat increment $W_o a$ resulting from the change in resistance is greater than the rate h at which heat is dissipated, and a is positive, then from Equations (162) and (163), both θ_r and t_r become negative, and Equation (161) becomes

$$\theta = \frac{W_o}{W_o a - h}\left[\epsilon^{+\left(\frac{W_o a - h}{Ms}\right)t} - 1\right] \quad (167)$$

which shows that under the condition assumed, the temperature continues to increase indefinitely at a constantly increasing rate, since the exponent of ϵ is positive. This is also evident qualitatively from physical reasoning.

Example:

Compute the final temperature and the time constant of the movable coil of an instrument having a copper coil winding, the resistance of which is 123 ohms at 25.5 deg. cent., through which a current of 230 milliamperes is passed. Assume as known that the coil dissipates heat by convection to the surrounding parts at the rate of $h = 0.125$ watt per deg. cent. difference in temperature, and that its total heat capacity is $Ms = 0.7064$ joule per deg. cent. The rate at which heat is generated at the initial temperature is $W_o = I^2 R_o = (0.230)^2 \times 123 = 6.51$ watts. The temperature coefficient of copper at 25.5 deg. cent. is $a = 1/(234.5 + 25.5) = 0.00384$ ohm per ohm per deg. cent., where 234.5 is the effective "absolute zero" of copper resistance. Then the final temperature increase of the coil, from Equation (162), is

$$\theta_r = \frac{W_o}{h - W_o a} = \frac{6.51}{0.125 - 6.51 \times 0.00384} = 65.1 \text{ deg. cent.}$$

and the time constant, from Equation (163), is

$$t_r = \frac{Ms}{h - W_o h} = \frac{0.7064}{0.125 - 6.51 \times 0.00384} = 7.06 \text{ seconds.}$$

If the resistance of the coil had not been affected by temperature, that is, if $a = 0$, then, from Equation (1)[1], the values of the final increase in temperature, and the time constant would have been, respectively,

$$\theta_m = W_o/h = 6.51/0.125 = 52.1 \text{ deg. cent.}$$

and

$$t_o = Ms/h = 0.7064/0.125 = 5.65 \text{ seconds.}$$

23(b). When the Voltage Applied Directly to the Conductor Is Constant.

Positive Temperature Coefficient. When a constant voltage, rather than a constant current, is applied directly to a conductor which increases in resistance with increase in temperature, the rate at which heat is generated diminishes as the temperature rises, as a result of the increased resistance. As will be shown later, the time relative to a time constant, required under this condition for the conductor to reach any temperature up to its final and maximum value, is

$$\frac{t}{t_o} = \frac{1}{2} \log\left[\frac{1}{1 - \theta/\theta_m - a\theta_m(\theta/\theta_m)^2}\right] + \frac{1}{2\sqrt{1 + 4a\theta_m}} \log\left[\frac{1 - \frac{1}{2}\left(\frac{\theta}{\theta_m}\right) + \frac{1}{2}\left(\frac{\theta}{\theta_m}\right)\sqrt{1 + 4a\theta_m}}{1 - \frac{1}{2}\left(\frac{\theta}{\theta_m}\right) - \frac{1}{2}\left(\frac{\theta}{\theta_m}\right)\sqrt{1 + 4a\theta_m}}\right] \quad (168)$$

where θ_m and t_o are the final temperature increase and time constant respectively, which would result if the resistance were constant, that is, when $a = 0$.
From Equation (1)[1] these values are

$$\theta = W_o/h$$

and

$$t_o = Ms/h$$

The final temperature can be obtained from Equation (168). This is reached when the time t is infinity. Referring to the equation, this results when

$$1 - \frac{\theta_r}{\theta_m} - a\theta_m \left(\frac{\theta_r}{\theta_m} \right)^2 = 0 \qquad (169)$$

from which the final and maximum temperature increase is

$$\theta_r = \frac{1}{2a} \left(\sqrt{1 + 4a\theta_m} - 1 \right) \qquad (170)$$

It will be noted that Equation (168) is in a dimensionless form expressed as a function of the dimensionless parameter $a\theta_m$, which is the relative change in resistance resulting from a change in temperature equal to that which would result if the resistance were constant, namely $\theta_m = W_o/h$.

Figure 22 shows the relative change in temperature at any time, for various values of the parameter $a\theta_m$, computed from Equation (168). The corresponding curve for $a=0$, that is where the resistance is not affected by temperature, is given for comparison.

Figure 23 gives the maximum values of the temperature reached after a relatively long time, as a function of $a\theta_m$.

Example:

As an example consider the movable coil used in a previous example given under Equation (167). Let

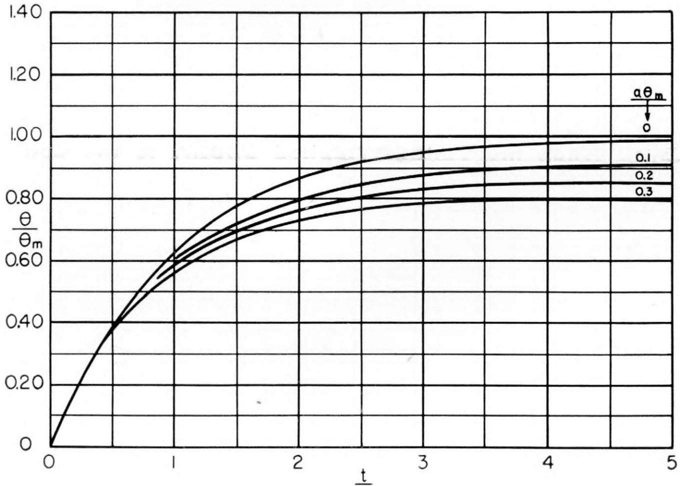


Figure 22—The increase in temperature of a conductor, having a positive temperature coefficient of resistance, when heated by the electric current produced by the application of a constant voltage to its terminals, at any time after the initial application of the voltage, for various values of the parameters $a\theta_m$, including zero coefficient. Time and temperature are given in terms of the time constant t_o, and the temperature θ_m respectively.

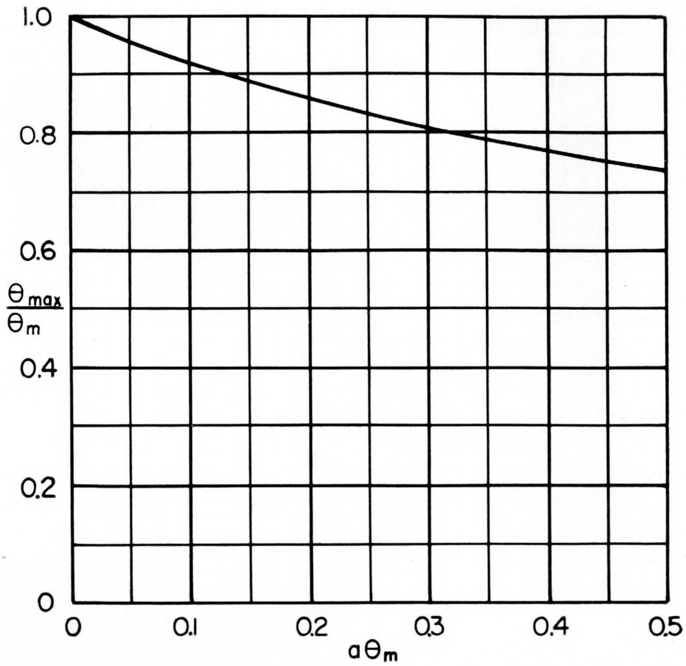


Figure 23—The final increase in temperature reached by a conductor having a positive temperature coefficient of resistance, when heated by the current produced by the application of a constant voltage to its terminals, as a function of the parameter $a\theta_m$. Time and temperature are given in terms of the time constant t_o, and the temperature θ_m respectively.

us assume that a constant voltage is applied to the coil, of such a value that it produces the same wattage in the coil at an initial temperature of 25.5 deg. cent. as was produced by 230 milliamperes through a constant resistance of 123 ohms, namely, 6.51 watts. Then as in the previous example, since the rate of heat dissipation per 1 deg. cent. is 0.125 watt, the temperature θ_m, which would result if the resistance remained constant, is

$$\frac{6.51}{0.125} = 52.1 \text{ deg. cent.}$$

The temperature coefficient of copper at 25.5 deg. cent., as given previously, is 0.00384 ohm per ohm per deg. cent. Therefore, the parameter

$$a\theta_m = 0.00384 \times 52.1 = 0.2$$

The temperature of the coil at any time can now be determined by Equation (168) or by using the curve in Figure 22 corresponding to $a\theta_m = 0.2$; and from Figure

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23, the final temperature increase corresponding to $a\theta_m = 0.2$, is 85.8 per cent of the increase which would have resulted had the resistance remained constant. It will be noted from Equation (168) that no simple expression for time constant similar to that for the simple exponential law of heating is possible in the present case. However, if we assume for practical purposes the same law as found for the simple exponential case, namely, that 63.2 per cent of the final change in temperature occurs in a time equal to the time constant, then the practical time constant can be determined from data found in the curves in Figure 22 and Figure 23.

In the present example Figure 23 shows that for $a\theta_m = 0.2$, the final temperature change is $0.858\theta_m$. Therefore the practical time constant corresponds to the temperature $0.632 \times 0.858\theta_m = 0.542\theta_m$, which from the curve in Figure 22 corresponding to $a\theta_m = 0.2$ is 0.87, that is, it is 87 per cent of the time constant which would have resulted had the resistance been constant.

Negative Temperature Coefficient:

For conductors having negative temperature coefficients of resistance, as was pointed out under the constant current problem, the equations are limited in practical use to the narrow limits only within which the temperature resistance relations may be considered linear.

E. N.—No. 85 —*W. N. Goodwin, Jr.*

The remainder of Part VIII will appear in a future issue of Weston Engineering Notes. *It will consider the heating of conductors, the resistances of which vary with temperature, from which practically no heat is dissipated, such as would occur during short circuits or heavy overloads. Also the fundamental Equations (161) and (168) will be derived.*

FIELD SERVICE STATIONS

The independent field service stations listed below are equipped to handle minor repairs and adjustments on Weston and/or Tagliabue Instruments.

BALTIMORE 18, MD.—(W)—Edgerly Instrument Laboratories, 2022 St. Paul Street

BEAUMONT, TEXAS—(W)—Straughn Radio and Electronic Service, 1254 Euclid Avenue

BOSTON, MASS.—(W)—Alvin S. Mancib Company, 26 Wallace Street, West Somerville 44, Mass.

BUFFALO 16, N. Y.—(W)—Electrical Instrument Laboratories, 1487 Hertel Avenue

CHICAGO 10, ILL.—(W)—Illinois Testing Laboratories, Inc., 420 North LaSalle Street

CLEVELAND 14, OHIO—(W)—Christie Laboratories, Inc., 616 St. Clair Avenue, N.E.

CLEVELAND 3, OHIO—(T)—Industrial Instruments, Inc., 1988 East 83rd Street (at Euclid)

DENVER 16, COLO.—(WT)—Insco Company, 4947 Colorado Boulevard

DETROIT 26, MICH.—(W)—Electrical Inspection and Servicing Co., 528 United Artists Building

KANSAS CITY 3, MO.—(W)—Boutros Instrument Laboratory, 1627-29 East 31st Street

LOS ANGELES 16, CALIF.—(W)—W. R. Turner, 4831 West Jefferson Boulevard

MIAMI 37, FLA.—(W)—Florida Precision Instrument Repair Co., 1221 Biscayne Boulevard

MINNEAPOLIS 16, MINN.—(W)—M. E. Todd, 3924 Natchez Avenue, St. Louis Park

NEW YORK 13, N. Y.—(W)—Nilsson Electrical Laboratory, Inc., 103 Lafayette Street

PHILADELPHIA 32, PA.—(W)—Rubicon Company, Ridge Avenue at 35th Street

PITTSBURGH 13, PA.—(W)—Electric Instrument Service Company, 107 Meyran Avenue—Oakland Station

ST. LOUIS 3, MO.—(W)—Industrial Service Laboratories, 1602 Locust Street

SAN FRANCISCO 5, CALIF.—(WT)—Pacific Electrical Instrument Lab., 120 Main Street

SEATTLE 99, WASH.—(W)—The Instrument Laboratory, Inc., 934 Elliott Avenue, West

SYRACUSE 7, N. Y.—(W)—Syracuse Instrument Laboratories, 2904 South Avenue—Elmwood Station

WICHITA 11, KAN.—(W)—Standard Products, Inc., 650 East Gilbert

AJAX, ONTARIO, CAN.—(W)—Bayly Engineering Limited, 5 First Street

MONTREAL, QUEBEC, CAN.—(W)—Northern Electric Co. Ltd., 1736 St. Patrick Street

VANCOUVER, B. C., CAN.—(W)—Instrument Service Laboratories, 21 West Broadway

W—Equipped to repair Weston instruments. T—Equipped to repair Tagliabue instruments. WT—Equipped to repair Weston and Tagliabue instruments.

CORRECTION NOTICE

We wish to call your attention to an error in the article, "The Use of Weston Type 30 Volume Level Indicators on 150 Ohm Lines" which appeared in Volume 5, Number 3, issue of Weston Engineering Notes. The diagram shown in the middle of page 8 of that issue is incorrect. The correct diagram is printed below. Any reader desiring to correct his copy of Volume 5, Number 3, may clip the diagram below and paste it over the incorrect diagram.