

Feb. 3, 1959

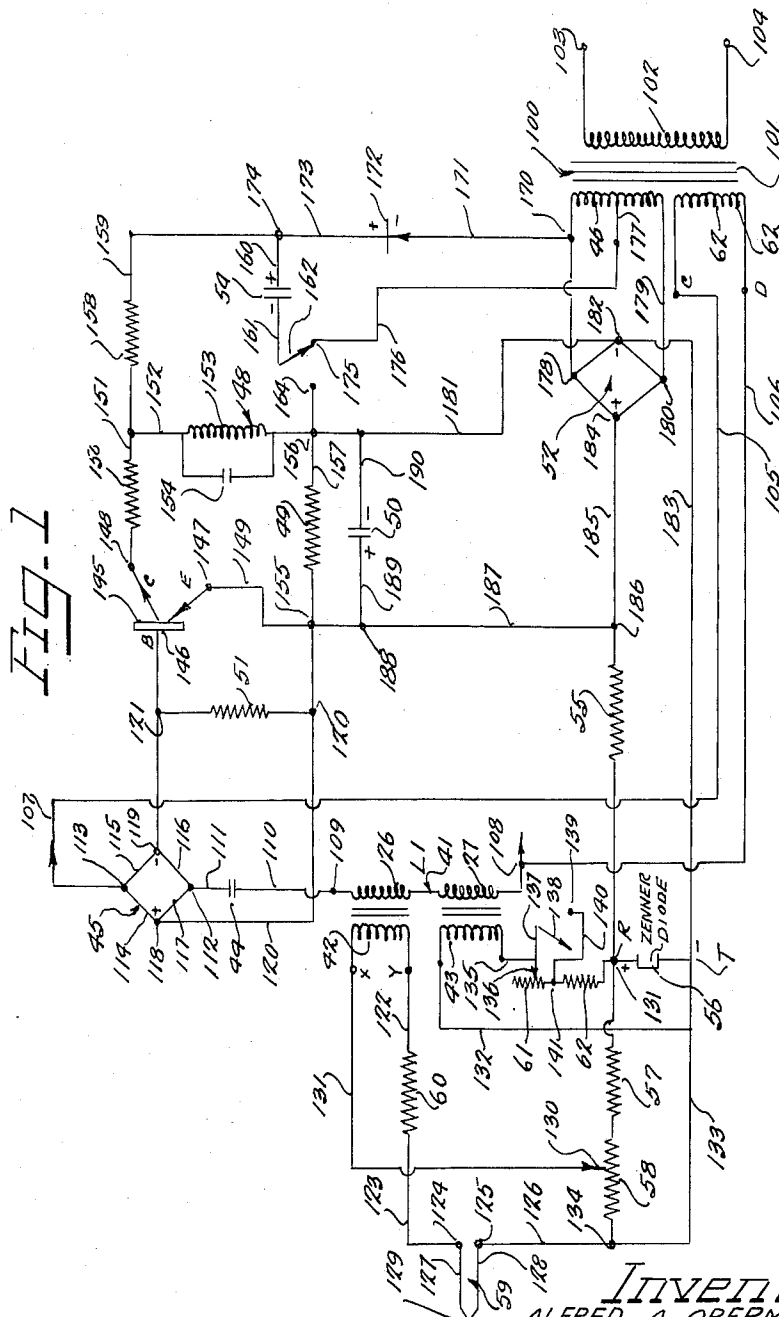
A. A. OBERMAIER

2,872,556

HEATER CONTROL CIRCUITS

Filed July 23, 1957

4 Sheets-Sheet 1



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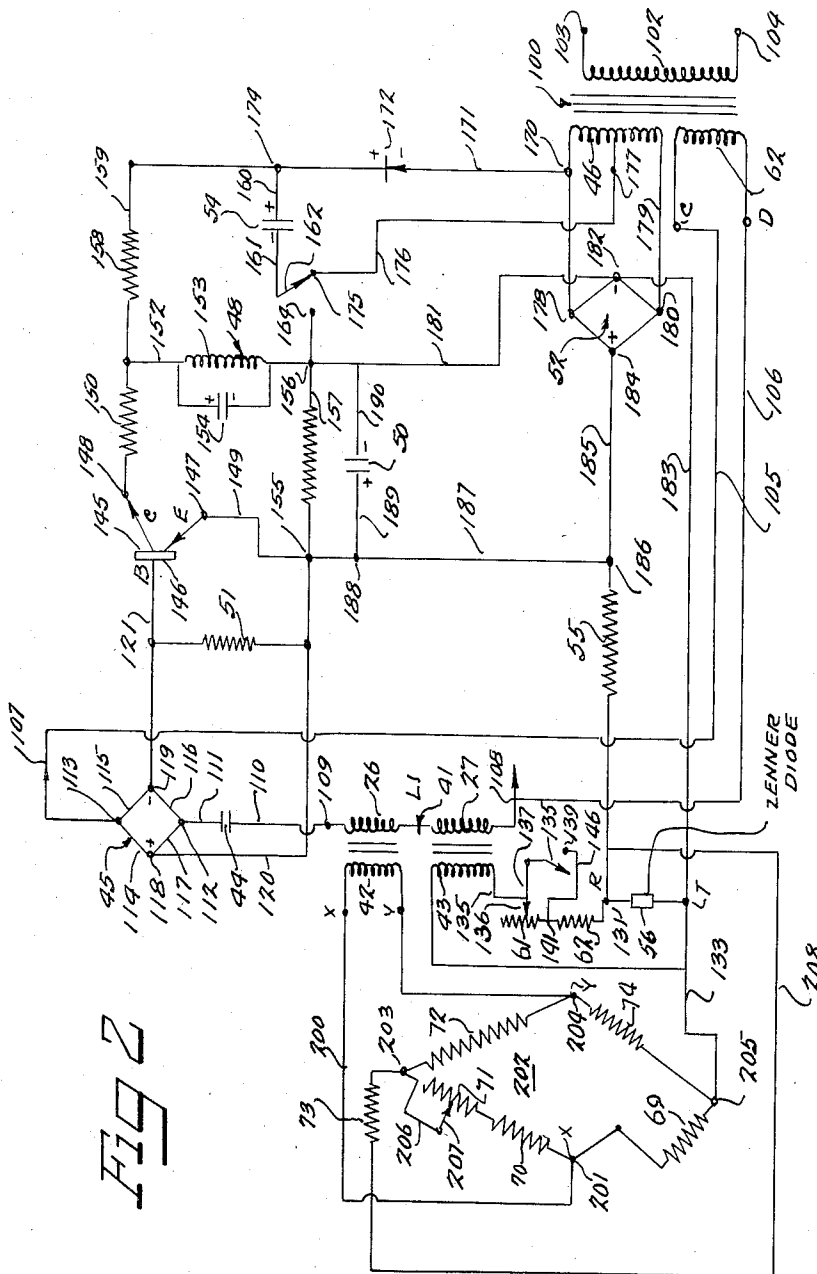
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4 Sheets-Sheet 2



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HEATER CONTROL CIRCUITS

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4 Sheets-Sheet 3

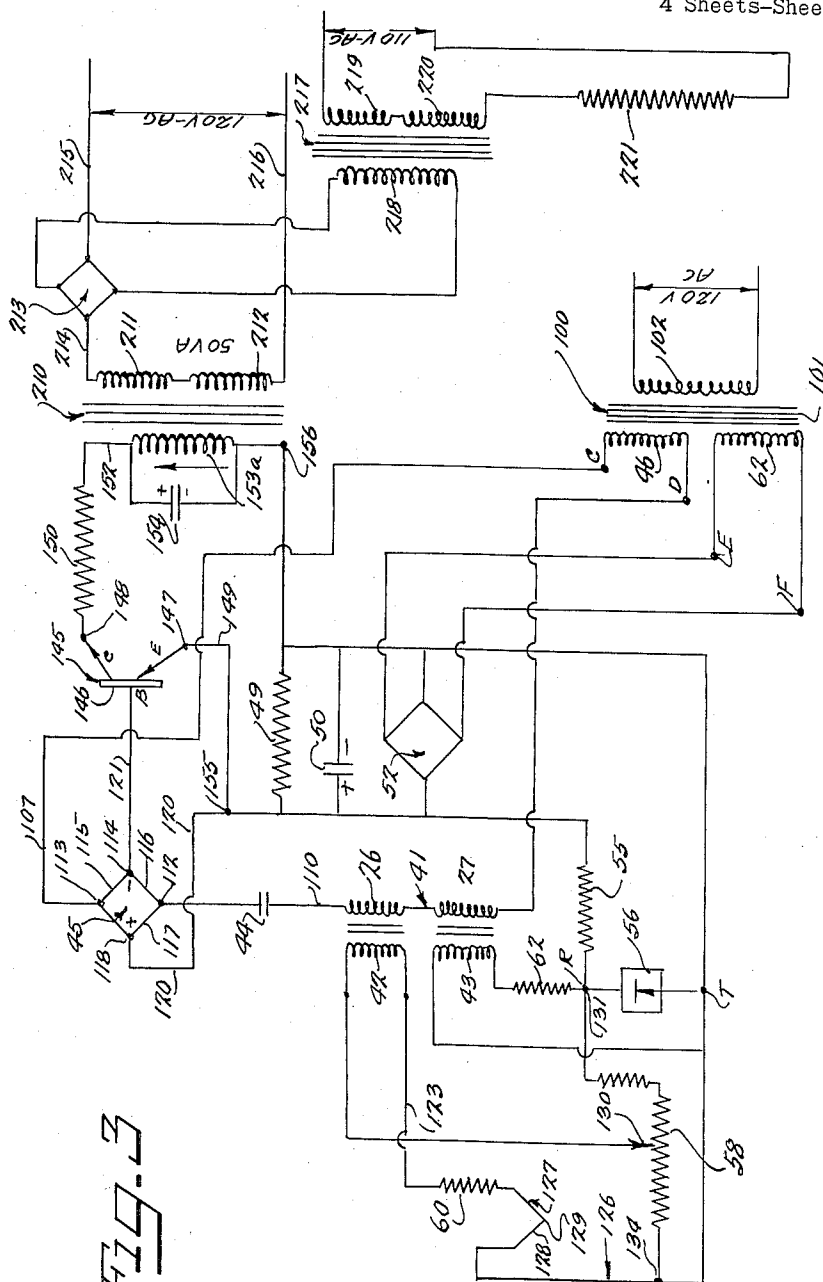


FIG. 3

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4 Sheets-Sheet 4

Fig. 4

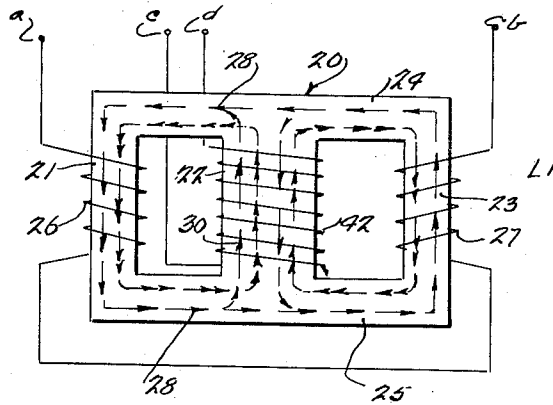
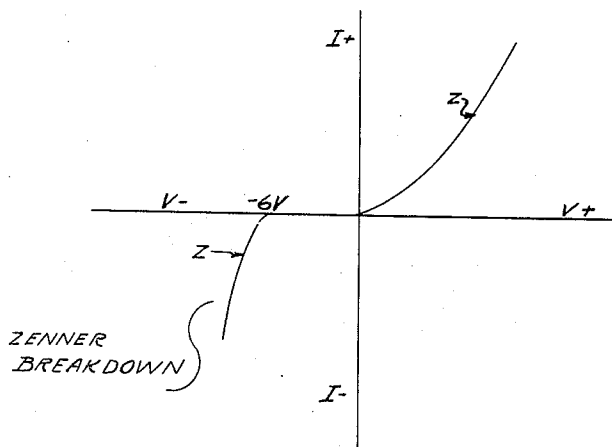


Fig. 5



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2,872,556

HEATER CONTROL CIRCUITS

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Application July 23, 1957, Serial No. 673,647

10 Claims. (Cl. 219—20)

The present invention relates to heater control circuits, and is particularly concerned with improvements in heater controlling circuits of the type employing a saturable iron core reactor such as that employed in the U. S. patent to Victor W. Breitenstein, No. 2,341,526, issued February 15, 1944, the disclosure of which is hereby incorporated herein by reference thereto.

One of the objects of the invention is the provision of an improved heater controlling circuit of the class described which has improved operating characteristics with equal sensitivity, and which is more flexible in its application to the control of heaters because it can more easily be made in a control of the "on" or "off" type or a control of the proportioning type.

Another object of the invention is the provision of an improved heater controlling circuit in which the circuit and its component parts can be manufactured and assembled more economically, and in which the second reactor stage may be eliminated, and a low cost transistor may be employed in the second stage.

Another object of the invention is the provision of an improved heater controlling circuit utilizing a saturable core reactor in which the oscillating type of operation is employed, and in which the period of oscillation can be made variable by adjusting the resistance so that the period may be a sub-multiple of the normal oscillations as the operation approaches the control point or, if the period desired is more than the normal period of the circuit, it may be operated as an "off" or "on" control.

Another object of the invention is the provision of an improved circuit of the class described in which a "Zener" reference diode is employed for providing constant potentiometer current, and in which the condenser, which provides current for the relay, is pre-charged by direct current, utilizing a full wave or half wave rectifier for the reason that the output of the transistor is not sufficient to charge the condenser fully.

Another object of the invention is the provision of an improved circuit in which the second reactor stage may be eliminated by the use of a transistor in its place, allowing the first ferro-resonant reactor stage to be operated as a sub-harmonic oscillator, as the control point is reached, so that the controller can be made to operate as a strictly "on-off" control or a modulating type with a variable band width, which can be accomplished by varying the R. C. time constant of the relay holding circuit.

Another object of the invention is the elimination of the reactor type voltage rectifier employed in the Breitenstein patent by the use of a "Zener" reference diode as a constant voltage for the potentiometer circuit.

Another object of the invention is the provision of an improved control circuit of the class described including a pre-charging circuit for the R. C. network for holding in the relay for the reason that when the controller starts oscillating and the control point is reached, the initial charge to the condenser from the transistor circuit would

2

be too small to hold in the relay, thereby making it necessary to pre-charge the condenser.

Other objects and advantages of the invention will be apparent from the following description and the accompanying drawings, in which similar characters of reference indicate similar parts throughout the several views.

Referring to the four sheets of drawings accompanying the specification,

Fig. 1 is a wiring diagram of the control circuit;

Fig. 2 is a modified wiring diagram in which the resistance thermometer is employed instead of a thermocouple;

Fig. 3 is a modified wiring diagram in which the relay is eliminated, and in which a 50 v. a. reactor controls a 25 kw. reactor that controls the furnace heater;

Fig. 4 is a diagrammatic view of the type of saturable core reactor employed;

Fig. 5 is a diagram showing the Zener diode characteristics. A Zener reference diode is defined as a silicon junction diode used at its Zener break-down point.

Referring to Fig. 1, this is a wiring diagram of an amplifying circuit for a low to medium impedance input, such as a thermocouple. The circuit preferably includes a saturable iron core reactor in its first stage, generally indicated by L1, the structure of which is also diagrammatically shown in Fig. 4.

The reactor is of the type having a closed magnetic circuit, and preferably includes three legs in its magnetic circuit for receiving coils, such as the core 20 of Fig. 4, having the legs 21, 22, 23 joined by the side portions 24 and 25 of the core.

The central leg 22 is preferably of twice the cross-sectional area of either one of the end legs 21 and 23, so that the cross-section of the central leg is equal to the sum of the cross-sections of the end legs.

The reactor is provided with balanced windings, including the windings 26, 27 for alternating current on the legs 21 and 23, connected in series, and in the same direction of rotation, considering the magneto-motive turns of the coils as producing a flux extending in the same direction about the outer circuit of the core, as shown by the arrows 28.

The terminals of these balanced windings 26 and 27 for alternating current may be indicated by "a" and "b", for association for similar terminals in other circuits.

The central leg 22 is provided with a winding 42 which has the terminals indicated by "c" and "d"; and the winding 42 is made in such a direction as to produce a flux in the direction of the arrows 3, pointing upward in Fig. 4.

The two outer legs are surrounded by the alternating current or reactance coils 26, 27, previously mentioned, connected in series in such a way that the alternating current flux produced by these two coils in the center leg oppose or cancel each other, making the center leg fluxless in so far as alternating current is concerned.

The center leg holds the direction current or Ho-coil, and no transformer action takes place between this coil and the alternating current coils as long as no direction current is super-imposed.

Reference may be had to the said prior patent for the size of the parts of the core in relation to the ampere turns and for one example of the sizes and structures which may be employed.

All of the constants given herein are merely exemplary of those which may be employed in one exemplary circuit.

Referring to Fig. 1, this is a diagram of the control circuit which embodies improvements over the said prior patent, which give an improved performance and may be constructed more economically due to the use of a lesser number of components, which may also be of lower

cost, and which are adapted to accomplish substantially the same general results, but with improved performance.

The basic ferro-resonant control circuit of said prior patent is employed with the following changes. For example, a three legged reactor L1 is employed, and indicated at 41 in Fig. 1, in series with a condenser 44 and a full wave copper oxide rectifier 45. The circuit includes a rectifier 45 connected to the energizing winding 62 at the points C and D.

The potentiometer input circuit of Fig. 1 is essentially the same as said prior patent, and consists of a network including the thermocouple 59, a resistance 60, a winding 42 on the reactor 41, a potentiometer 58, and a resistance 57.

Referring again to the energizing circuit for the reactor, this includes the transformer 100, having a magnetic core 101 and a primary winding 102, the terminals 103 and 104 of which are adapted to be connected to a 120 volt 60 cycle lighting current circuit. The transformer 100 has two secondary windings, one of which, indicated at 62, has terminals C and D, which may be connected by conductors 105 and 106 to terminals bearing similar legends, and indicated at 107 and 108.

Terminal 108 is a primary terminal for the reactor 41. The primary windings 26 and 27 of the reactor are energized by alternating current and are connected in series with each other and with the terminal 108. The other terminal of the reactor A. C. windings 26 and 27 is indicated at 109 and is connected by conductor 110 to one terminal of the condenser 44, which may, for example, be a 200 volt condenser having a capacity of .25 mfd. The other terminal of the condenser 44 is connected by conductor 111 to one of the terminals 112 of the rectifier circuit, the opposite terminal of which is indicated at 113.

The rectifier 45 includes four conductors 114, 115, 116, and 117 connected in the nature of a bridge, and including the copper oxide rectifier discs in such manner that the two opposite terminals or corners of the bridge 118 and 119 are the plus and the minus terminals of the rectifier 45, as indicated by the legends.

The alternating current input to the rectifier is by way of conductors 111 and 107; and the direct current output is from the terminals 118 and 119 by conductors 120 and 121.

Referring again to the potentiometer input circuit, which includes the network 59, 60, 42, 58, and 57, the elements of this circuit are described in more detail, as follows.

The central leg of the reactor L1 is provided with the control winding 42 and with the bias winding 43. The control winding 42 is connected by conductor 122 to the resistor 60, which has its other terminal connected by conductor 123 to the positive or plus terminal 124 of thermocouple 59. The negative terminal 125 of thermocouple 59 is connected by conductor 126 to one terminal of the potentiometer 58, which may, for example, be a 40 ohm potentiometer.

The thermocouple 59 consists of a pair of dissimilar metallic conductors 127 and 128 joined at a hot junction 129 and having their cold junction located at 124 or 125 spaced from the hot junction 129.

The potentiometer 58 may consist of a series of windings of resistance wire engaged by a slide wire contactor 130, which is connected by conductor 131 to the other terminal of the control coil 42. The contactor 130 is adjustable to vary the amount of resistance included in the circuit by the potentiometer 58 and contactor 130.

A series resistor 57 is connected to the right terminal of potentiometer 58 and is connected to the terminal 131 bearing the legend R of the bias coil circuit.

The bias coil 43 for the reactor may have one terminal connected by conductor 132, 133 to the terminal 134 of the potentiometer 58. The other terminal of the bias

coil 43 is connected by conductor 135 to a slide wire contact 136 engaging a resistor 61, which may, for example be 1500 ohms, and which is in series with resistor 62 of 112 ohms, for example, the other terminal of which is connected to the terminal R or 131.

The terminal 131 is connected to a Zener diode 56, which has its other terminal connected to conductor 133 at a terminal T.

The slide wire contactor 136 is connected by conductor 137 to a movable contact 138 engaging a fixed contact 139, which is connected by conductor 140 to the terminal 141 located between the resistors 61 and 62.

The purpose of the switch 138, 139 is as follows:

All the switch contacts shown in the diagram are operated by the relay 48, and the switch 138, 139 serves as an anticipating control, being normally open and being closed when the relay 48 is energized.

When the relay 48 is energized by discharge of the condenser 54, the switch is closed at contact 139 by switch arm 138. This causes the system to operate as an anticipating control, which turns off the heater before the desired temperature is reached, to prevent over-shooting that temperature. The circuit is then turned on again for a short time and off again by the control to supply heat in successively smaller increments until the desired temperature is reached.

For example, assume the control is calibrated for a certain temperature on the temperature dial. When the temperature reaches that point, such as 300 degrees F., an equal and opposite control signal may be applied to the thermocouple circuit to turn off the heater at 300 degrees. This would permit the heater to over-shoot the desired temperature of 300 degrees.

To avoid over-shooting, the resistor 61 is adjusted to such a value that the heater will be turned off at 250 degrees F., when the pointer is still at 300 degrees F. The switch 138 short circuits the resistor 61, when contact is closed at 139 by relay 48; but when the circuit is not closed at 139 by relay 48, the resistor 61 is in circuit.

The circuit is on true control point when the switch 138, 139 is closed; but circuit is on reduced anticipating 250 degree F. control point when resistance 61 is in circuit and switch 138, 139 is open. When relay 48 is actuated, resistor 61 which is in circuit to stop heat at 250 degrees, is shorted by closing switch 138, 139.

When furnace heater is cut off at 250 degrees by rising temperature at the thermocouple, resistor 61 is cut out, setting the control back to the true control point. Then the furnace not having reached 300 degrees F., it is turned on again and off again to supply successively smaller increments of heat until it reaches 300 degrees F.

Whenever the control current reaches zero current or balance, the heater is turned off and then on and off by small increments of heat input until the temperature of 300 degrees F. is reached. Thus the anticipating control avoids over-shooting of the desired temperature setting.

The purpose of the circuit which includes the resistors 61 and 62, Zener diode 56, and bias winding 43 is to place a constant voltage on the bias coil 43 of the reactor 47 to provide a constant voltage for the potentiometer input by means of the Zener reference silicon diode 56. This is connected to the circuit at the terminals indicated by legends R and T; and the regulation of this unit is dependent on its nonlinear characteristics when a negative voltage is applied to its break-down point.

In Fig. 1 the terminal 131, bearing legend R, is indicated as plus or positive; and the terminal indicated by legend T is negative, for applying the negative voltage to the Zener diode.

Referring to Fig. 5, this is a diagram showing the voltage characteristics of the Zener diode. The vertical axis is indicated at the top by plus I and at the bottom by minus I. The horizontal axis is indicated at the

left by minus V and at the right by plus V, indicating minus voltage and plus voltage.

The curve Z indicates a curve for a Zener diode, showing the resulting voltage of plus or minus, which is brought about by applying predetermined plus or minus currents to the diode.

It will be noted that the positive end of the curve Z curves gradually upward; but the negative end of the curve Z extends horizontally along the axis; and upon application of a negative voltage of, for example, minus 6 volts, the curve Z extends downward and approaches a straight line characteristic, indicating that in this "regulating region," as shown by the legend, the voltage applied by the Zener diode to the bias coil 43 may be substantially constant at minus 6 volts.

By means of this circuit including the Zener diode, a substantially constant voltage may be applied to the bias coil 43; and the voltage regulation which is effected thereby is extremely stable.

The second reactor stage of the circuit of said patent may thus be eliminated and replaced by the common emitter transistor circuit producing improved results and utilizing less expensive components.

The purpose of the resistance 57 in the potentiometer circuit is to provide a calibration resistance for setting the range of the potentiometer circuit.

The purpose of the fixed resistor 62 is to serve as a current limiting resistor, limiting the current to the bias coil.

The present control circuit differs from the patented circuit in the use of a transistor 145 having the base indicated at B by numeral 146, the emitter indicated at E with its terminal 147, and the collector indicated at C with its terminal 148.

Various types of transistors may be employed, such as, for example, the General Electric 2N187A or Raytheon CK761.

The base 146 has its terminal connected by conductor 121 to the minus terminal 119 of the rectifier 45. The positive terminal 118 of rectifier 45 is connected by conductor 120, and conductor 149 to the emitter terminal 147.

The resistor 51 of, for example, 210 ohms is connected across the conductors 121 and 120 as a parallel current bleeder to limit the base current of the transistor. The collector output circuit from terminal 148 of the collector C is connected to a series resistor 150, which may, for example, be 560 ohms, 1 watt, which is connected by conductors 151 and 152 to the coil 153 of the relay, which, for example, may have 1000 ohms.

The relay is indicated in its entirety at 48 and has the terminals of its coil bridged by a condenser 154, which may, for example, be 4 mfd. The conductor 120, extending from rectifier 45, is connected to a resistance 49, which may be of 510 ohms and is also connected at 155 to the emitter terminal 147 by conductor 149.

Resistor 49 is connected to the terminal 156 of the relay coil 153 by conductor 157. The conductors 151 and 152, extending to relay 48, are connected to a resistor 158, which has its opposite terminal connected by conductor 159 to conductor 160 leading to the positive or plus terminal of a condenser 54, which, for example, may be 4,000 mfd.

The negative terminal of condenser 54 is connected by conductor 161 to a movable switch arm 162 adapted to engage a contact 164. Contact 164 is connected to terminal 156 of the relay and is adapted to be used to apply the direct current charge, which is stored by condenser 54, to the relay 48 to provide sufficient current to keep the relay coil energized over a series of pulses from the control circuit.

The charging circuit of Fig. 1 includes the secondary 46 of the transformer 100, which has one terminal 170 connected by conductor 171 to the half wave rectifier

172 at its negative side, the plus being connected by conductor 173 to the conductors 159 and 160 at 174.

The switch arm 162 is adapted to engage two contacts numbered 164 and 175. Contact 175 is connected by conductor 176 to an intermediate tap 177 on the transformer secondary 46 to utilize nine volts of this transformer's secondary for impressing the voltage on the half wave rectifier to produce a direct current for charging the condenser 54.

The entire winding 46 is connected by conductor 170 to one of the terminals 178 of the rectifier 52; and the other end of the secondary 46 is connected by conductor 179 to the opposite terminal 180 of rectifier 52.

This rectifier is used for impressing suitable D. C. voltage on the transistor 145 and the relay coil 153. Conductor 181 connects the minus terminal 182 of rectifier 52 to the terminal 156 of the relay coil, which is connected to contact 164 and to resistance 49. This terminal 182 of the rectifier is also connected by conductor 183 to the input circuit T, that is, to the conductor 133.

The plus terminal 184 of the rectifier 52 is connected by conductor 185 to the terminal 186 of resistor 55, which may, for example, be 2700 ohms, and which in turn is connected to terminal 131, bearing legend R, in the input circuit. It is the rectifier 52 that provides energization for the biasing coil 43, maintaining constant voltage by means of the Zener diode 56.

Another conductor 187 extends from terminal 186 to terminal 188, where it is connected to the positive side of the condenser 50, which is a 25 volt, 50 mfd. condenser. The positive side of this condenser is connected by means of conductor 189 to conductor 187; and the negative side of this condenser 50 is connected by conductor 190 to conductor 181.

Thus condenser 50 is bridged across the resistor 49, and the condensers 154 and 50 are used for providing a matched impedance in the collector circuit of the transistor 145.

The operation of the heater controlling circuit described is as follows:

In the said patent there are described four modes of operation or operating conditions, Nos. 1, 2, 3, and 4, on page 5 of the patent.

The present circuit is adapted to be operated in the first ferro-resonant reactor stage, involving reactor 41, as a sub-harmonic oscillator. The operating conditions of this circuit are those of condition No. 3, called "Case No. 3" in the patent, in which the reactor is biased with a magnetizing force of a value which is slightly less than the value indicated at M in Fig. 9 of the patent.

Since the Breitenstein patent is already incorporated by reference thereto in column 1 hereof, the operating conditions No. 3 of the patent are explained with regard to Fig. 9 of the patent.

As stated in the patent, page 5, column 1, line 34, operating conditions No. 2 are attained by operating the circuit at a higher alternating voltage, which causes the current to jump up to the point P in Fig. 9; but it does not break out in oscillations; and the current value stays there as long as the current saturation plus the controlling increment remains the same.

For operating conditions No. 3 at the point P on the curve, the circuit is responsive only to an impulse of incremental saturation current and will be unaffected by a positive increment of saturation current, as stated in the patent, page 5, column 2, lines 8-10.

This brings about the following operating conditions in the present circuit.

This causes the current to stay at the point O on the curve of Fig. 9, and is the condition in which the present circuit is when the potentiometer is so adjusted with respect to the thermocouple to reduce the input current to zero.

When an additional increment of magnetizing force is applied in the same sense as the biasing magnetizing

force, under conditions of Case 3, the current jumps from the point O on the curve in Fig. 9 to the point P and stays there until it is opposed by an impulse of the same magnitude, but of opposing polarity, when it will return to the point O.

Thus the application of a signal from the thermocouple causes a very large change in the amount of current in the output circuit of the reactor 41; and this change is impressed upon the rectifier 45 and applied to the input circuit of the transistor 145.

The transistor replaces the second reactor stage of the said patent and operates similarly, inasmuch as when no current flows in the ferro-resonant first stage, the collector current energizing the relay coil is zero. When an oscillation current is produced by the first ferro-resonant stage and impressed on the collector circuit, this collector circuit starts conducting and thereby energizing the relay.

The weak current pulses of the ferro-resonant first stage are in the order of 0.5 milliamperes; and the amplification by the transistor circuit produces a 20 milliamperes pulse through the relay coil. This is sufficient to actuate the relay; and the relay moves the contact arm 162 from the contact 175 to the contact 164.

The purpose of this is to provide the RC timing network with such energization, with one-half of the transformer winding 46, that the relay coil may be kept energized for a series of pulses from the control circuit. The reason for applying external power to the RC network is that under initial conditions, when the potentiometer input is balanced, no pulses are produced in the ferro-resonant circuit; but if the input is unbalanced, due to an error signal, the circuit starts oscillating, so that the relay would also pulse.

The object of an RC time delay network is to hold the relay in for a given number of pulses so that there is no excessive wear on the local contacts. Due to the short duration of the pulses of current in the relay, it is necessary to pre-charge the condenser from an external power source, as previously described.

This charge, which is applied to the condenser 54 by means of the upper half of the winding 46 and the half wave rectifier 172, may charge the condenser when the arm 162 engages contact 175. The relay 48 having moved the arm 162 into engagement with the contact 164, due to the pulses in the relay coil, the condenser 54 may then discharge through the relay coil.

This allows the RC time to hold the relay energized so that subsequent pulses from the control circuit can build up sufficient charge to keep the relay energized during the period the error signal persists.

Another important feature of the operation is that the winding 46 connected to rectifier 52 supplies both the collector current for the transistor 146 and the voltage regulated bias current for coil 43 and the potentiometer input.

This voltage must be maintained constant; and this is done by means of the Zener reference silicon diode 56, which is a commercially available voltage regulated device connected between points R and T. The regulation of this unit is dependent on its nonlinear characteristics.

The voltage current characteristics of such a diode are shown in Fig. 5, where negative voltage is applied to the diode at the left.

Negative voltages from zero to minus 6 volts produce practically zero current, but adjacent minus 6 volts on the curve Z, the Zener break-down occurs; and the curve Z extends downward slightly.

This is the regulating region of the Zener curve; this type of voltage regulation can be made extremely stable in the regulating region.

The current may vary greatly, while the voltage remains substantially constant.

The elimination of the second reactor stage of the patented device, and performance of its functions by a transistor, allows the first ferro-resonant reactor stage to be

operated as a sub-harmonic oscillator as the control point is reached.

The period of oscillation can be varied by means of the resistance 61 so that the period can be a sub-multiple of the oscillations as the controller approaches the control point. If the resistance is so adjusted that the time of one oscillation is more than the period of the relay, then the circuit operates on and off.

Another important feature of the invention is the use of the Zener reference diode, which is used for the constant voltage potentiometer circuit. This element of the circuit costs less than the reactor stage described in said patent for maintaining constant potentiometer current and also accomplishes an extremely stable regulation of the potentiometer current.

Another important feature is the arrangement of the charging condenser and the circuits by means of which the condenser is pre-charged by the D. C. current which may be produced by a full wave or half wave rectifier.

The output of the transistor is not sufficient to charge the condenser; but in the present circuit the condenser is charged from a charging circuit and then discharged through the relay for holding in the relay. Such a pre-charging circuit for the RC network is necessary for holding in the relay.

When the controller starts oscillating as the control point is reached, the initial charge to the condenser from the transistor would be too small to hold in the relay; and therefore it is necessary to pre-charge the condenser.

Referring to Fig. 2, this is a modification in which a resistance thermometer is employed as the temperature responsive element instead of a thermocouple. This circuit utilizes the same elements as Fig. 1, beginning at x and y in Fig. 1, but substitutes the resistance thermometer bridge for the thermocouple and potentiometer of Fig. 1.

All other parts of the circuit may be the same as in Fig. 1, beginning at the points R and T on opposite sides of the Zener diode in Fig. 1; and all of the parts of the circuit to the right of R and T employ the same reference numbers and operate in the same way.

Beginning at the point x, which is one of the terminals of the control winding 42, a conductor 200 extends to the point x or terminal 201 on the resistance bridge, indicated in its entirety by No. 202. This bridge includes four resistances, indicated at 70, 71, 72, 74, and the temperature responsive resistance 69.

The terminals of the bridge are 201, 203, 204, and 205. The temperature responsive resistance 69 is that element which is subjected to the temperature produced by the furnace to be controlled; and this element is of such material that it changes its electrical resistance with change of temperature, this being the usual operation of a resistance thermometer.

The resistances 70 and 71 are connected in series between the terminals 201 and 203; and the terminal 203 is connected by the conductor 206 to a slide wire contactor 207 engaging the coiled resistance 71 and short circuiting part of this resistance to vary the voltage drop in this part of the bridge and adjust the output current from the resistance thermometer to zero.

The resistance 72 is connected between the terminals 203 and 204; and the resistance 74 is connected between the terminals 204 and 205. The signal output from this resistance thermometer is at x and y or terminals 201 and 204 and is applied to the coil 42.

The resistance thermometer is energized from the transformer 100 by means of the rectifier 52, which applies appropriate voltages to this resistance thermometer circuit at the points R and T. The point R is connected by conductor 208 through resistance 73 to the terminal 203 of the bridge. The point T is connected to the terminal 205 of the bridge by conductor 133.

The operation of this type of circuit is substantially the same as that described in Fig. 1 except that the

signals for turning the heater on and off are generated by the resistance thermometer bridge 202.

Referring to Fig. 3, this is a circuit showing a modification similar to Fig. 1 except that the relay coil is replaced or used as a control winding for a large saturable core reactor.

In this case there is no charging circuit for the relay condenser, since there are no contacts employed. Instead of the relay coil, a control coil 153a is employed and connected in the same manner previously described and bridged by means of a condenser 154.

The coil 153a is the control winding of a large saturable core reactor, indicated at 210. This saturable core reactor may have the usual biasing coils (not shown) for bringing the reactor up to the point adjacent saturation. Reactor 210 also has two alternating current windings 211 and 212 in series; and the A. C. output from these windings is further rectified by a rectifier 213.

The rectifier 213 may be connected by conductors 214 and 215 to an energizing circuit having 120 volts A. C. between conductors 215 and 216. The output from the rectifier 213 may be fed to a very large reactor 217 by means of coil 218; and the large reactor 217 may have A. C. coils 219 and 220 energized from 110 volts A. C. and connected in series with the heater 221 for a large furnace.

The advantage of such a system is a stepless control unit with no local contacts. Each of the two reactors 210 and 217 would be provided with the usual bias coils for raising their saturation to a predetermined point.

It will thus be observed that I have invented improved heater controlling circuits utilizing the first reactor stage of the patent mentioned and eliminating the second reactor stage by the use of a transistor, allowing the first ferro-resonant reactor stage to be operated as a sub-harmonic oscillator, which can be made to operate as a modulating type by varying the amount of resistor 61.

The expensive reactor type voltage regulator of said prior patent has been eliminated by the use of a Zener diode for providing a constant voltage source for the potentiometer circuit. The entire circuit may be constructed more economically, as it employs elements which are lower in cost, but which perform better and with equal sensitivity, and provide a more flexible system that can readily be adapted for on and off control or a proportioning type of control.

While I have illustrated a preferred embodiment of my invention, many modifications may be made without departing from the spirit of the invention, and I do not wish to be limited to the precise details of construction set forth, but desire to avail myself of all changes within the scope of the appended claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. A heater control system comprising a heater, a temperature responsive element subjected to the temperatures produced by the heater, a saturable iron core reactor having windings energized by alternating current for producing a predetermined flux in the core reactor, said core reactor having a biasing winding, a control winding, a rectifier energized from the output of said core reactor, and a transistor having its base and emitter energized by said rectifier, said transistor having a collector connected to the winding of a control relay, the output of said transistor being normally insufficient to actuate said relay, and a condenser connected across the coil of said relay and connected to a rectifier to be charged by the output circuit sufficiently so that when it discharges through the relay coil its output is sufficient to actuate the relay and hold the relay energized during the period the control signal persists.

2. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of

balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a "Zener" diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said temperature responsive member comprising a thermocouple and its means for adjusting its input current comprising a potentiometer.

3. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said temperature responsive member comprising a resistance thermometer, the resistance of which is one of four resistances forming a bridge, and the means for adjusting the input current to zero comprises a slide wire contact and conductor for shorting out part of one of said four resistors.

4. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said output circuit to the transistor including a resistance connected across the conductors extending to the base and to the emitter of the transistor for limiting the base current thereof.

5. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, and an energizing transformer having a secondary winding connected to said balanced reactor windings, the secondary windings being connected to a rectifier to supply direct current to a resistor in the relay circuit.

6. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alter-

nating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said system including a resistor in series with the relay coil, said relay coil and latter resistance each being bridged by a condenser, said condensers being chosen to give matched impedance in the collector circuit of the transistor.

7. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said relay coil being connected to a network including a condenser to be charged by a rectifier, and a switch actuated by the relay coil to change the connections from a circuit charging the latter condenser to a circuit discharging the condenser through the relay coil to hold the relay in over a plurality of current pulses from the output circuit of the transistor.

8. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, and an auxil-

iary circuit controlled by the relay and arranged to apply additional current to the relay coil to hold the relay in closed position.

9. A heater control system comprising a saturable core reactor having an easily saturable core and a pair of balanced windings connected in series with a capacitive reactance to provide a resonant circuit, a source of alternating current for energizing said balanced windings, a bias coil on said reactor, and a Zener diode circuit maintaining constant voltage on said bias coil, an input coil on said reactor, and a temperature responsive member and circuit having means for adjusting its input current to zero, and an output circuit including said balanced windings, a rectifier, a transistor and circuit, and a relay coil controlling a heater, said transistor amplifying the weak current impulses in the reactor output circuit to provide a sufficient current to actuate the relay, said relay coil comprising the control winding of a large saturable core reactor, the alternating current output of which is rectified and controls a large reactor supplying heater current for the furnace.

10. A heater control system comprising a heater, a temperature responsive element subjected to the temperatures produced by the heater, a saturable iron core reactor having windings energized by alternating current for producing a predetermined flux in the core reactor, said core reactor having a biasing winding, a control winding, a rectifier energized from the output of said core reactor, and a transistor having its base and emitter energized by said rectifier, said transistor having a collector connected to the winding of a control relay, the output of said transistor being normally insufficient to actuate said relay, and a condenser connected across the coil of said relay and connected to a rectifier to be charged by the output circuit sufficiently so that when it discharges through the relay coil its output is sufficient to actuate the relay and hold the relay energized during the period the control signal persists, the said control coils including a Zener diode operating within its regulating region and maintaining a substantially constant voltage for the bias coil.

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