May 13, 1947. J. M. WILSON 2,420,578

CONDITION CONTROLLING APPARATUS

Filed Aug. 25, 1944 2 Sheets-Sheet 1

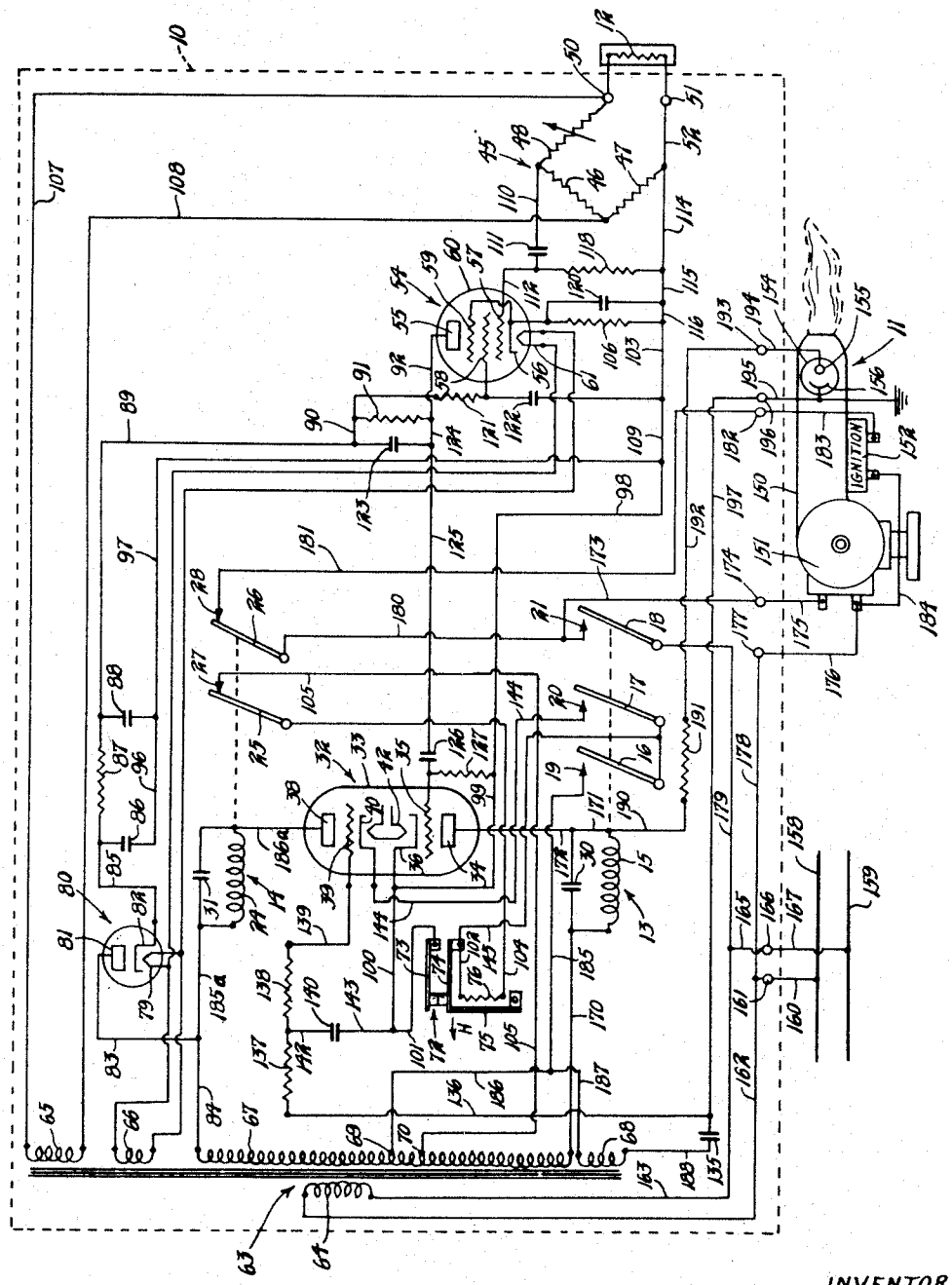

Fig. 1.

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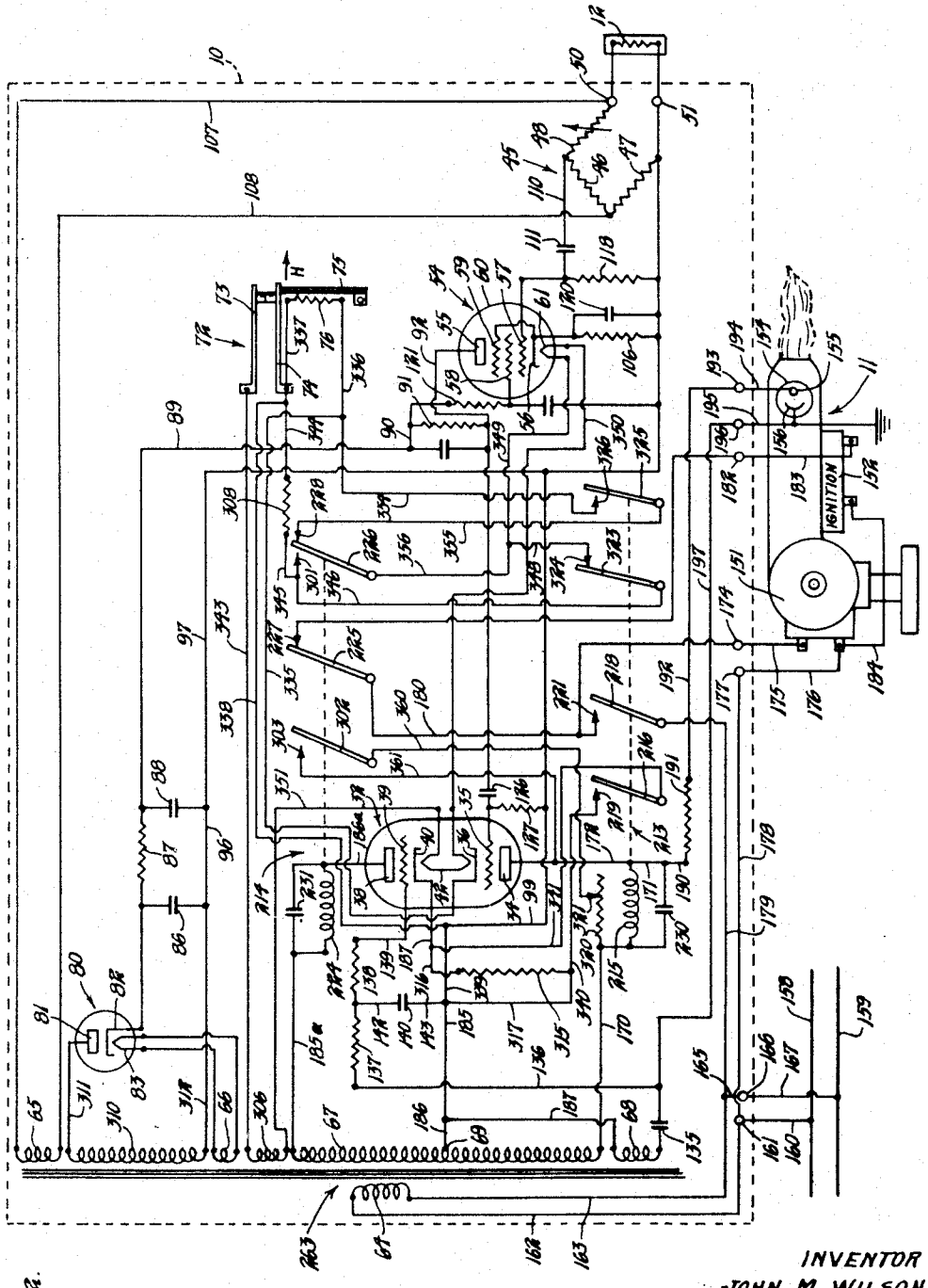

Fig. 2.

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CONDITION CONTROLLING APPARATUS

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Application August 25, 1944, Serial No. 551,226

23 Claims. (Cl. 236—1)

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The present invention is concerned with condition controlling apparatus and more particularly with apparatus employing an electronic amplifier.

Broadly, an object of the present invention is to provide an improved condition controlling apparatus of the type employing an impedance element responsive to a controlling condition and controlling the operation of an amplifier to in turn control the energization of a device which controls a condition changing device.

A further object of the present invention is to provide an arrangement of the type discussed in which an amplifier of relatively low gain is employed while at the same time maintaining a high degree of sensitivity.

A further object of the present invention is to obtain a system such as set forth in the last object in which a device controlled by the amplifier is effective as a result of the device being energized to change the value of the condition at which the device would otherwise be energized so as to increase the sensitivity of the apparatus.

A further object of the invention is to provide an improved burner control system of the electronic type in which the burner is placed into operation under the control of an impedance responsive to a controlling condition and in which means responsive to the presence of the flame is effective to operate through an electronic amplifier to control the operation of the burner.

A further object of the invention is to provide a burner control apparatus of the type just described in which a thermionic amplifier associated with the impedance bridge is effective to prevent an undesired phase shifting which would otherwise occur in connection with the means for detecting a flame.

A still further object of the present invention is to provide an improved burner control system of the electronic type in which a safety switch is provided and in which an operating element of the safety switch is initially connected in series with an electronic amplifier but upon the subsequent energization of a burner control device controlled by the amplifier is connected to a separate source of power until combustion has occurred.

A still further object of the present invention is to provide a burner control system of the electronic type in which a safety switch is provided and in which the operating element of the safety switch is connected in series with a cathode of the electronic portion of the apparatus.

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Other objects of the invention will be apparent from a consideration of the accompanying specification, claims, and drawing, of which

Figure 1 is a schematic showing of a burner control system employing one form of my condition controlling apparatus, and

Figure 2 is a schematic showing of a burner control system employing a modified form of my condition controlling apparatus.

Referring to the drawing for a more detailed understanding of my invention, the condition controlling apparatus is shown in Figure 1 as housed within a box 10. The apparatus is designed to control an oil burner 11 in accordance with the temperature conditions in the region at which a temperature responsive resistor 12 is located. The various elements will be described in more detail in the following paragraphs. Referring first to the condition controlling apparatus housed within the box 10, this apparatus comprises two relays 13 and 14. The relay 13 comprises a relay coil 15 and three switch blades 16, 17, and 18 which are adapted to cooperate with contacts 19, 20, and 21, respectively. The switch blades 16, 17, and 18 are normally biased out of engagement with contacts 19, 20, and 21 by any suitable means such as gravity. Upon energization of the relay coil 15, the switch blades are moved into engagement with their respective contacts. Relay 14 similarly comprises a relay coil 24 and two switch blades 25 and 26 which cooperate with contacts 27 and 28, respectively. Both switch blades 25 and 26 are biased into engagement with their associated contacts 27 and 28 and upon energization of the relay coil 24 are moved out of engagement therewith.

A by-pass condenser 30 is connected in parallel with relay coil 15. A similar by-pass condenser 31 is connected in parallel with relay coil 24. In each case, the purpose of the condenser is to smooth out the ripples in the pulsating D. C. current supplied to these relays by the thermionic portion of the apparatus, to be presently described.

The energization of relays 13 and 14 is controlled by a thermionic discharge device 32. This device is of the double triode type having two complete sets of triodes and a common heater for the two cathodes. The various elements of the two triodes are housed within an envelope 33. The first of the two triodes comprises an anode 34, a grid 35, and a cathode 36. The other of the two triodes comprises an anode 38, a grid 39, and a cathode 40. The common cathode heater 42 is associated with both cathodes 36 and

40. Cathode heater 42 is connected to any suitable source of power, and in order to simplify the drawing, this source of power and the connections thereto have been omitted. The triode consisting of anode 34, grid 35, and cathode 36 controls the energization of relay 13 while the other triode controls the energization of relay 14 in a manner which will be more fully explained.

The triode including anode 34 is controlled in accordance with the output voltage of a bridge generally indicated by the reference numeral 45. This bridge comprises two fixed resistance elements 46 and 47, an adjustable resistance element 48, and a temperature responsive resistance element 12, previously referred to. The temperature responsive resistance element 12 is located outside of the box 10, preferably in a space whose temperature is to be regulated by operation of the burner 11. One terminal of the temperature responsive resistance 12 is connected to a terminal 50 and the other to a terminal 51. Terminal 50 is in turn connected to adjustable resistance 48 and terminal 51 by conductor 52 to resistor 47. The junction of resistors 46 and 47 constitutes one of the input terminals of bridge 45 and terminal 50 the other input terminal. The junction of resistors 46 and 48 constitutes one of the output terminals and the junction of resistor 47 and conductor 52 the other output terminal. Resistor 12 is of a material having a relatively high temperature coefficient of resistance, such as nickel, while resistors 46, 47 and 48 are of material having a negligible temperature coefficient of resistance, such as manganin.

The resistance bridge 45 is connected to the input terminals of amplifier 32 by means including an electronic amplifier 54. This amplifier comprises an anode 55, a cathode 56, a control grid 57, a screen grid 58, and a suppressor grid 59. These various electrodes are housed within an envelope 60. The cathode 56 has associated therewith a cathode heater 61 in the conventional manner.

Power is supplied to the apparatus by a transformer 63. This transformer comprises a primary winding 64 and a plurality of secondary windings 65, 66, 67, and 68. The secondary 67 is center tapped at 69 and is provided with a further tap 70. While the values of the various other elements of the apparatus in one typical embodiment will be given later, it may be noted at this time that the primary winding 64 in this embodiment was a 110 volt winding. Secondaries 65 and 66 were 30 volt and 7 volt windings, respectively. The winding 67 was a 600 volt winding, the tap 70 being spaced from the center tap 69 by about 6 volts. In the same embodiment, the winding 68 was a 20 volt winding.

The apparatus also includes a thermal safety switch 72. This safety switch may be of any suitable type in which upon continued energization of an electrically energized actuator, the switch is opened and requires a manual resetting operation to reclose it. A switch typical of the type which may be employed is that shown in the John M. Wilson Patent 2,290,399, issued July 21, 1942. As shown in schematic form in the drawing, the safety switch 72 includes a pair of switch arms 73 and 74 held in engagement with each other by a bimetallic element 75. Associated with the bimetallic element 75 is an electric heater 76. As long as the bimetallic element 75 is not heated beyond a certain temperature, it remains in a position in which the upper end of it lies beneath the switch blade 74 so as to maintain switch blades 73 and 74 in contact making engagement. Upon continued energization of the electric heater 76, however, the bimetallic element 75 eventually warps to the left sufficiently that the left upper end thereof moves out of engagement with the switch blade 74 so as to permit switch blade 74 to drop away from switch blade 73. Thereafter, it is necessary for switch blade 74 to be manually reclosed before the circuit thereto can again be established. As will be pointed out later, where the apparatus functions in a normal manner, the circuit to heater 76 is interrupted before the switch blades 73 and 74 are separated.

The reference numeral 80 is employed to designate a diode comprising an anode 81 and a cathode 82. A cathode heater 79 is associated with the cathode 82 and is connected to secondary 66 in parallel with cathode heater 61 of tube 54. The diode 80 functions as a rectifier to supply a source of direct current power through the electronic amplifier of the apparatus. In this connection, it is to be noted that the anode 81 is connected by conductors 83 and 84 to the upper end of secondary 67. Cathode 82 is connected by a conductor 85 to a condenser 86 and a resistor 87. The condenser 86 and resistor 87, along with a further condenser 88, forms elements of a filter network. The junction of resistor 87 and condenser 88 constitutes the positive terminal of this network and is connected by conductors 89 and 90, a resistor 91, and a conductor 92 to the anode 55 of pentode 54. Condensers 86 and 88 are connected together by conductor 96 and to tap 70 of secondary 67 by conductors 97, 98, 99, 100, and 101, switch blades 73 and 74 of safety switch 72, conductor 102, heater 76, conductor 104, relay switch blade 25, contact 27, and conductor 105. The tap 70, it will be recalled, is spaced from the upper terminal of secondary 67 by a voltage of 306 volts. It will also be recalled that the anode 81 is connected to the upper terminal of secondary 67. Thus, the upper half of secondary 67 and the portion of secondary 67 between terminals 69 and 70 is connected in series with the diode 80 and the condensers 86 and 88. As previously noted, the upper terminal of condenser 88 constitutes the positive output terminal of the filter network. The lower terminal of condenser 88 constitutes the negative terminal being connected by conductors 97, 109, 103, and biasing resistor 106 to the cathode 56 of pentode 54.

The secondary 65 of transformer 63 is employed to supply alternating power to the resistance bridge 45. The upper terminal of this secondary is connected by conductor 107 to the input terminal 50. The lower terminal of secondary 65 is connected by conductor 108 to the junction of resistors 46 and 47 which, as previously noted, constitutes the other input terminal of resistance bridge 45.

The junction of resistors 46 and 48, constituting one of the output terminals of the bridge 45, is connected by conductor 110, condenser 111, and conductor 112 to the grid 57 of tube 54. The junction of conductor 52 and resistor 47, constituting the other output terminal of bridge 45, is connected by conductors 114, 115, 116, and biasing resistor 106 to the cathode 56. The output of bridge 45 is thus impressed between the control grid 57 and the cathode 56 of tube 54. A resistor 118 is connected between the grid and cathode and functions as a coupling resistor. The condenser 111 in the connection between the bridge 45 and grid 57 functions to increase

the impedance of the output circuit of the bridge to match more nearly that of the input circuit of the pentode.

A condenser 120 is connected in parallel with the biasing resistor 106 and functions in the usual manner as a by-pass condenser to by-pass the alternating current component of the current flowing through the output circuit of tube 54.

The screen grid 58 of the tube is connected to the cathode 56 in the usual manner by a condenser 122. It is connected to the anode 55 by a resistor 121, resistor 91 and a by-pass condenser 123, and conductor 92. The suppressor grid 59 is directly connected to the cathode 56 in the normal manner.

As previously pointed out, the positive terminal of the filter network constituted by condensers 86 and 88 and resistor 87 is connected to anode 55, and the negative terminal of this filter network is connected to the cathode 56. Thus, a current flows through the output circuit of tube 54, which current is dependent in magnitude upon the input voltage applied by bridge 45.

The anode 55 of tube 54 is connected through conductors 92, 124, and 125 and condenser 126 to grid 35 of the tube 32. Cathode 56 of tube 54 is in turn connected through biasing resistor 106 and conductors 103, 109, 98, and 99 to cathode 36 associated with grid 35. A resistor 127 is connected between the cathode 36 and grid 35. An output voltage dependent in magnitude upon the conductivity of pentode 54 is thus impressed through condenser 126 between the grid 35 and cathode 36 of the lower triode of tube 32. This lower triode is accordingly controlled in accordance with the unbalance of resistance bridge 45. This lower triode in turn controls the energization of winding 15 of relay 13 as will be more fully pointed out in the operation.

The voltage applied to grid 39 is controlled by a condenser 135. This condenser is connected by conductor 136, resistors 137 and 138, and conductor 139 to grid 39. A condenser 140 is connected between grid 39 and cathode 40 whenever relay 13 is energized by the following circuit: from grid 39 through conductor 139, resistor 138, conductor 142, condenser 140, conductors 143 and 101, safety switch blades 73 and 74, conductor 145, switch blade 17, contact 20, and conductor 144 to the cathode 40.

As has been pointed out previously, the apparatus 10 is designed to control the operation of an oil burner 11 in accordance with the temperature to which resistance bulb 12 is subjected. The oil burner 11 is of the conventional type being provided with a burner nozzle 150 through which is forced a mixture of fuel and oil by a blower driven by a motor 151. Secured to the burner nozzle 150 or in any other suitable point is a burner ignition means 152 which is operative when energized to supply an igniting spark to the fuel mixture. Located within the blast tube 150 or at some other suitable location is a photoelectric cell 154. This photoelectric cell is of any conventional type comprising an anode 155 and a cathode 156.

Power for operation of the burner and for the primary winding 64 of transformer 63 is obtained from line wires 158 and 159. Primary 64 is connected to line wires 158 and 159 by a circuit as follows: from line wire 158 to conductor 160, line voltage terminal 161, conductor 162, primary winding 64, conductor 163, conductor 165, line voltage terminal 166, and conductor 167 to line wire 159.

While my invention is in no way limited to the use of elements having particular values, I have found it desirable in connection with one embodiment of my invention to employ the following values for the various elements. In this embodiment, the transformer had the values previously noted. The resistors 46, 47, and 12 were each 500 ohm resistors while resistor 48 was a 480 ohm resistor. In this embodiment, the condenser 111 was a .02 microfarad condenser and resistor 118 a 1 megohm resistor. The condenser 120 was a 25 microfarad condenser while the resistor 106 was a 200 ohm resistor. The condenser 122 had a capacitance of .5 microfarad and resistor 121 a resistance of .5 megohm. Resistor 91 had a resistance of 1 megohm and condenser 123 a capacitance of .01 microfarad. The condenser 126 had a capacitance of .1 microfarad and resistor 127 was a 5 megohm resistor. Tube 54 was a 6AC7 tube and tube 32 a 7N7 tube. The resistors 137 and 138 were .25 megohm and 2.0 megohm resistors while the condenser 140 was a .02 microfarad condenser. The condenser 135 was a .02 microfarad condenser. In the power supply unit, resistor 87 was a 5,000 ohm resistor while condensers 86 and 87 each had a capacitance of 2 microfarads. A 20 ohm resistor was employed for the safety switch heater 76.

Operation

The various elements are shown in the drawing in the positions they assume when the temperature of the medium in which resistance element 12 is located is at or above the desired value. Under these conditions, the bridge 45 is appreciably unbalanced so that an alternating voltage of substantial magnitude is impressed through condenser 111 upon the grid 57 of tube 54. This in turn causes a substantial flow of current between the anode 55 and cathode 56 through resistor 91, the output circuit of tube 54 being as follows: from the upper terminal of condenser 88 (constituting the positive terminal of the power supply) through conductors 89 and 90, resistor 91, conductor 92, anode 55, cathode 56, resistor 106, and conductors 103, 109, and 97 to the lower terminal of condenser 88. The effect of this current flow is to impress across resistor 91 a voltage which is of such polarity that the lower terminal of resistor 91 is negative with respect to the upper terminal. It will be noted that the grid 35 of the lower triode of tube 32 is connected through condenser 126 and conductor 125 to the lower terminal of resistor 91. Thus, any increase in the magnitude of the voltage appearing across resistor 91 tends to drive grid 35 negative with respect to the cathode 36. Thus, with a temperature at or above the desired value, the degree of unbalance is such that grid 35 is maintained sufficiently negative with respect to the cathode 36 so as to prevent any appreciable flow of current through the lower triode of tube 32.

Now let it be assumed that the temperature of the medium to which resistor 12 is exposed drops so as to cause a decrease in the value of this resistor. The direction of unbalance of bridge 45 is such that upon a decrease in the value of resistance 12, this unbalance tends to be reduced. This in turn reduces the voltage impressed upon grid 57, which in turn decreases the voltage appearing across resistor 91. This decrease in this voltage decreases the negative voltage applied to grid 35 of the lower triode of tube 32. When the temperature of the medium surrounding resistor 12 drops below the desired value, this decrease

in the voltage applied to grid 35 is such as to raise the potential of the grid 35 sufficiently to render the lower triode sufficiently conductive to energize winding 15 of relay 13 through the following circuit: from the lower terminal of secondary 67 through conductor 170, relay winding 15, conductors 171 and 172, anode 34, cathode 36, conductors 100 and 101, switch blades 73 and 74 of safety switch 72, conductor 102, thermal safety switch heater 76, conductor 104, switch blade 25, contact 27, and conductor 105 to the tap 70 of secondary 67.

The energization of relay 13 as a result of the flow through the last traced circuit of sufficient current to energize relay 13 causes switch blades 16, 17, and 18 to move into engagement with contacts 19, 20, and 21, respectively. The movement of switch blade 18 into engagement with contact 21 causes the establishment of the following energizing circuit to the burner motor 161: from line wire 159, through conductor 167, line voltage terminal 166, conductors 165 and 179, switch blade 18, contact 21, conductor 173, burner terminal 174, conductor 175, burner motor 161, conductor 176, burner terminal 177, conductor 178, line voltage terminal 161, and conductor 160 to the other line wire 158.

At the same time, a circuit will be established to the ignition means 152 as follows: from line wire 159 through conductor 167, line voltage terminal 166, conductors 165 and 179, switch blade 18, contact 21, conductor 180, switch blade 26, contact 28, conductor 181, ignition terminal 182, conductor 183, ignition means 152, conductors 184 and 176, burner terminal 177, conductor 178, line voltage terminal 161, and conductor 160 to the other line wire 158. As a result of the energization of the burner motor and of the ignition means, the conditions necessary to the establishment of combustion have now been set up.

The movement of switch blade 16 into engagement with contact 19 results in the establishment of the following holding circuit for relay coil 15: from the lower terminal of secondary 67 through conductor 170, relay winding 15, conductors 171 and 172, anode 34, cathode 36, conductors 100 and 101, switch blades 73 and 74, conductor 145, switch blade 16, contact 19, and conductors 185 and 186 to the center tap of the secondary. It will be noted that this holding circuit is independent of switch blade 25 and contact 27 and does not include the safety switch heater 76. The safety switch heater 76 is, however, still energized by a circuit which will be traced in the next paragraph.

The moving of relay switch blade 16 into engagement with contact 19 also results in the following circuit being established: from tap 70 through conductor 105, contact 27, switch blade 25, conductor 104, electric safety switch heater 76, conductor 102, conductor 145, switch blade 16, contact 19, and conductors 185 and 186 to the center tap 69 of secondary 67. As was noted, the last traced circuit through winding 15 included the heater winding 76 of the safety switch. It is desirable to include the safety switch heater winding in the initial energizing circuit to relay 13 to insure that the heater of the safety switch is in operative condition before energization of relay 13. In view of the fact, however, that the current flowing through an electronic tube is of relatively small magnitude, it is not possible using a practical size of electric heater element, to rely upon the current flowing through such a tube circuit to energize the safety switch heater.

For this reason, the apparatus is so designed as to provide for the establishment of the circuit last traced in which the heater 76 is connected independently of the tube 32 with the portion of secondary winding 67 between taps 69 and 70. This circuit insures a supply of sufficient current to electric heater element 76 to operate the safety switch 72.

The engagement of switch blade 17 with contact 20 makes possible the establishment of a circuit through relay 14 through the following circuit: from the upper terminal of secondary 67 through conductors 84 and 185a, relay winding 24, conductor 186a, anode 38, cathode 40, conductor 144, contact 20, switch blade 17, switch blade 16, contact 19, and conductors 185 and 186 to the center tap 69.

In spite of the establishment of the last traced circuit, relay 14 will not be energized unless flame has been established at the burner 11. In the absence of such a flame, condenser 135 is effective to bias grid 39 negatively to a point wherein insufficient current flows through relay coil 24 to energize the relay 14. This effect of condenser 135 is present because of the following condenser charging circuit: from the lower terminal of secondary 68, through conductor 188, condenser 135, conductor 136, resistors 137 and 138, conductor 139, grid 39, cathode 40, conductor 144, contact 20, switch blade 17, switch blade 16, contact 19, conductor 185, and conductor 187 to the other terminal of secondary 68. Due to the rectifying effect of the grid-cathode path, current tends to flow appreciably only in this one direction so that the right-hand terminal of condenser 135 becomes charged negatively with respect to the left-hand terminal. Since grid 39 is connected to the right-hand terminal of condenser 135, the effect of the connection is to maintain grid 39 at a potential negative with respect to the cathode 40.

Upon the establishment of a flame, the photoelectric cell 154, hitherto non-conductive, becomes conductive. As a result, a new charging circuit through condenser 135 is established. This charging circuit may be traced from the lower terminal of secondary 67, through conductor 170, relay winding 15, conductor 190, resistor 191, conductor 192, photoelectric cell terminal 193, conductor 194, anode 155, cathode 156, conductor 195, photoelectric cell terminal 196, conductor 197, condenser 135, conductor 188, secondary 68, and conductors 187 and 186 to the center tap 69 of secondary 67. Thus, a voltage is impressed upon this charging circuit through the photoelectric cell, which voltage is equivalent to the voltage across the lower half of secondary 67 less the voltage of winding 68. As previously indicated, the voltage of the lower half of winding 67 is 300 volts while that of winding 68 is only 20 volts. Due to the rectifying effect of the photoelectric cell, current flows through this charging circuit only in the direction traced. It will be noted that the effect of current flowing through the condenser 135 in this direction is to cause the right-hand terminal of condenser 135 to become charged positively. It is this right-hand terminal of condenser 135 which is connected to the grid 39. Hence, the effect of the establishment of this charging circuit as a result of the occurrence of flame is to raise the potential of grid 39 with respect to cathode 40. This, in turn, renders the upper triode of tube 32 conductive so as to cause relay 14 to be effectively energized. This in turn results in switch blades 25 and 26

being moved out of engagement with contacts 27 and 28. The movement of switch blade 25 out of engagement with contact 27 interrupts the original energizing circuit for relay 13. This does not interfere with the operation of relay 13, however, in view of the previous establishment of the above traced holding circuit for relay 13 through switch blade 16 and contact 19. The movement of switch blade 25 away from contact 27 also interrupts all circuits through the safety switch heater 76. This prevents the safety switch heater from causing the safety switch to move to open position and hence insure that the apparatus remains in operation.

The movement of switch blade 26 out of engagement with contact 28 interrupts the ignition means. This is desirable since with the establishment of combustion the operation of the ignition means is no longer necessary.

The apparatus is now in normal running condition and will continue to operate until the temperature of the medium in which the resistance bulb is located has risen above the desired value. When this happens, the unbalance of the bridge 45 will again be sufficient to cause a biasing voltage to be impressed upon grid 35 such as to render the lower triode non-conductive. This in turn will cause the deenergization of relay winding 15, or, at least, reduce the energization to the point where the relay is acceptably deenergized. Deenergization of relay 13 results in the separation of switch blade 18 from contact 21 so as to cause deenergization of the burner motor. The separation of switch blade 17 from contact 20 results in the interruption of the energizing circuit to relay 14 so that this relay likewise is immediately deenergized.

Operation in the event that flame is not initially established

If a flame is not initially established, relay 14 remains deenergized with the result that switch blade 25 remains in engagement with contact 27. As long as switch blade 25 is in engagement with contact 27, current continues to flow to the electrical heating element 76. After a predetermined time normally sufficient for combustion to be established, the continued effect of the energization of heater 76 is to cause bimetallic element 75 to deflect to the left, as previously described, to cause separation of switch blades 73 and 74. When once separated, these switch blades must be manually reclosed to reestablish a circuit controlled by them. It is to be noted that the only energizing circuits for relay winding 15 pass through switch blades 73 and 74. Hence, as soon as these switch blades are separated, relay winding 15 is immediately deenergized causing switch blades 16, 17, and 18 to move away from their respective contacts. This causes deenergization of the burner motor, which condition of deenergization will continue until switch blades 73 and 74 have been manually reclosed.

Operation in the event of the interruption of combustion after once established

If combustion is interrupted after having once been established, the photoelectric cell 154 ceases to be illuminated with the result that it almost instantly becomes non-conductive. This in turn interrupts that one of the two charging circuits to condenser 135 which causes a positive charge to be impressed on the condenser. This in turn causes deenergization of relay 14 with the result that switch blades 25 and 26 are again reengaged with contacts 27 and 28. The reengagement of switch blade 25 with contact 27 results in the reestablishment of the energizing circuit for safety switch heater 76. The reengagement of switch blade 26 with contact 28 results in the reestablishment of ignition. As a result, an attempt is made to reignite the burner. If the cause for extinguishment of combustion was merely temporary, the burner will be reignited and condenser 135 will again be charged positively to cause the reenergization of relay 14. If, however, combustion is not reestablished, the safety switch 72 will open at the end of the timing period. Thus, upon a failure of combustion, one attempt is made to restart the system.

Operation of flame detection apparatus in the event of accidental short circuiting of the photoelectric cell

The apparatus is so designed that it will not respond to the presence of a flame even though the terminals of the photoelectric cell are accidentally bridged by a resistance, no matter how large or how small. Since the photoelectric cell is located in the blast tube, it is unlikely that any foreign substance will deposit on the electrodes, particularly a substance of a conductive nature. However, if for this reason or any other reason, the photoelectric cell terminals or leads are bridged by a resistance no matter how large or how small its magnitude, the apparatus will correctly respond in the absence of a flame, as though no flame is present. The reason for this is that the action of the apparatus depends upon the flow of a unidirectional current through the photoelectric cell. It is to be recalled that in tracing the charging circuit to condenser 135 which caused the right hand terminal of condenser 135 to become positive, it was pointed out that this flow of current took place in only one direction. If the photoelectric cell gap is bridged by an ordinary resistance, the flow of current through condenser 135 over this path will take place equally in both directions with the result that an alternating potential is impressed upon condenser 135. Further more, this alternating potential will be out of phase with the alternating potential impressed on anode 38 of the upper triode. This can readily be seen by the fact that the tendency of such a resistance is to establish a direct conductive connection from the lower end of secondary 67 through conductor 170, relay winding 15, conductor 190, resistance 191, conductor 192, photoelectric cell terminal 193, the bridging resistance, photoelectric cell terminal 196, conductors 197, and 136, resistance 137 and 138 and conductor 139 to the grid 39. Since the lower end of secondary 67 is at a potential 180 degrees opposed in phase with respect to the potential impressed upon anode 38, the effect of this direct conductive connection is to cause the grid 39 to be highly negative during the conductive half cycle.

Were it not for the corrective phase shifting tendencies of the lower triode, the effect just described would be offset by an undesirable phase shift which occurs by reason of condenser 135. It is to be noted that the grid 39 is in effect connected to the junction of one terminal of a phase shifting bridge. One leg of this bridge consists of a condenser 135. The other leg of the bridge consists of the resistance across the photoelectric cell gap. These two legs are connected across the lower portion of secondary 67 and secondary 68. The cathode 40 is connected to the center

tap 69 when switch 16 is in engagement with contact 19. Hence, the grid 39 is connected to a phase shifting bridge having as one leg the condenser 135 and the other leg the resistance of the flame gap. The effect of such a connection, as the resistance across the photoelectric cell decreases more and more, is to progressively shift the phase of the alternating potential that is impressed upon grid 39. This would tend, under some conditions, to cause the alternating potential to be shifted so far as to actually render the triode conductive. This effect is more fully described in the copending application of Vilynn O. Beam, Serial No. 450,613, filed July 11, 1942. As explained in that application, it was discovered that the presence of the second triode tended to correct this phase shifting tendency. Applicant has discovered that this phase shifting tendency of the second triode is present even when the second triode is employed as an amplifier for a separate signal source as in the present case in which the lower triode functions as the amplifier for the output of the bridge 45 to control the energization of relay 13. By reason of this discovery, it is possible to use only two triodes in one tube to perform three different functions. The upper triode functions as an amplifier for the detection of flame. The lower triode functions as an amplifier for the output of bridge 45 to control relay 13. Furthermore, the lower triode also functions as a phase corrective device in connection with the operation of the upper triode.

Species of Figure 2

The species of Figure 2 is similar to that of Figure 1 with the exception of the manner in which the safety switch is energized, the manner in which power is obtained for the amplifier 54, and in certain details of the amplifier circuit. In view of the similarity of many portions of the apparatus of Figure 2 to that of Figure 1, similar reference characters are employed in Figure 2 to designate those elements identical in character to the corresponding elements of Figure 1. To further aid in a comparison of the two figures, elements in Figure 2 which correspond to but differ in certain details from elements in Figure 1 have been given reference numerals 200 higher than the corresponding elements in Figure 1. All other elements of Figure 2 have been given reference numerals 300 or higher.

Relay 213 corresponds to relay 13 of Figure 1. As is the case with relay 13, it comprises a relay winding 215 which is connected in parallel with a by-pass condenser 230. Associated with the relay 213 are two switch arms 218 and 218 adapted to be moved into engagement with contacts 219 and 221.

The relay 214 corresponds to relay 14 of Figure 1. This relay comprises a relay winding 224 with which is connected in parallel a by-pass condenser 231. Associated with relay winding 224 are a pair of switch arms 225 and 226 designed to cooperate with contacts 227 and 228. Switch blades 225 and 226 are both biased into engagement with their associated contacts 227 and 228. Switch blade 226 further cooperates with a switch contact 301 with which it is moved into engagement upon energization of relay winding 224. Relay 214 in addition comprises a third switch blade 302 which cooperates with a fixed contact 303. Switch blade 302 is biased out of engagement with fixed contact 303, being moved into engagement therewith upon energization of relay winding 224.

In the present form of the apparatus, safety switch heater 76 is normally connected in series with the cathode heaters of tubes 32 and 54. In order to energize these heaters, the transformer 263 corresponding to transformer 63 of the species of Figure 1 is provided with an additional secondary winding 306. As will be described later, the connections of safety switch heater 76 to the secondary 306 are controlled by relay switch blade 226 and contacts 228 and 301. When switch blade 226 is moved from engagement with contact 228 into engagement with contact 301 the safety switch heater 76 is disconnected from the cathode heater and in order to maintain the current flow to the cathode heater uniform, a resistor 308 is connected into the circuit in series with the cathode heater in place of the safety switch heater 76. This operation and the circuits connected therewith will be described in more detail in connection with the operation of the apparatus of Figure 2.

In the species of Figure 1, the upper portion of the secondary 67 was employed as a source of power for the rectifier 80. In the present species, a separate secondary 310 is provided for this purpose. The upper terminal of this secondary is connected by a conductor 311 to the anode 81 of the diode 80. The lower terminal of secondary 310 is connected by conductor 312 to the lower terminal of condensers 86 and 88 of the filter network. The connections of the output terminals of the filter network to the anode and cathode of amplifier 254 are identical to those of Figure 1 and need not be repeated here.

A resistor 315 is connected between the cathode 40 and the center tap 69 by conductors 187, 316, 317, 185, and 186. Upon energization of the relay 213 as a result of a call for burner operation, this resistor 315 is shunted out so that the cathode 40 is connected directly to the center tap 69, as will be explained more fully later.

In order to render the apparatus more sensitive, a resistor 320 is under certain conditions connected in parallel with relay winding 215. Resistor 320 is provided with a slider 321 for adjusting the respective value of the resistance.

In one embodiment of my invention in accordance with Figure 2 of the drawing, I found it desirable to employ for tube 54 a 12B8 tube and for tube 32 a 14N7 tube. A safety switch heater 76 of approximately 23 ohms was employed and a resistor of the same resistance was employed for resistor 308. The resistor 320 connected in parallel with relay winding 215 was a 10,000 ohm resistor and the resistor 315 was a 30,000 ohm resistor. In this embodiment, the various other elements had approximately the same values as in the embodiment referred to in connection with Figure 1.

Operation of Figure 2

The operation of the lower triode of tube 32 which is controlled by the unbalance of the resistance bridge 45 is substantially the same as in the species of Figure 1 with one exception. In the arrangement of the present embodiment, the circuit to the cathode 36 includes the safety switch heater 76, the output circuit of the tube being as follows: from the lower terminal of secondary 67 through conductor 170, relay winding 215, conductor 172, anode 34, cathode 36, con-

ductor 335, conductor 336, safety switch heater 76, conductors 337, 338, 339, 185 and 186 back to the center tap 69 of secondary 67. It is to be noted that this circuit includes the safety switch heater 76. The reason for that is that by so including the safety switch heater in the initial energizing circuit for relay 215, it is impossible to energize relay 213 to initiate operation of the burner and ignition means unless the safety switch heater is operative. This is similar to the arrangement of Figure 1 except for the location of the safety switch heater in the energizing circuit.

Except for this difference in the location of the safety switch heater, the operation of the resistance bridge, the amplifier 54, and the lower triode of the tube 32 is the same as in connection with Figure 1.

Upon the energization of relay 213, switch blades 216, 218, and 325 are moved into engagement with their associated contacts 219, 221, and 326. At the same time, switch blade 323 is moved out of engagement with contact 324. Moving of switch blade 216 into engagement with contact 219 completes a circuit through relay winding 224 as follows: from the upper terminal of secondary 67, through conductor 185, relay winding 224, conductor 186, anode 38, cathode 40, conductors 187 and 341, switch blade 216, contact 219, and conductors 340, 317, 185 and 186 back to the center tap 69 of secondary 67. The establishment of this relay circuit does not, however, result in the energization of the relay until the photoelectric cell 154 is illuminated by flame. The operation of this portion of the apparatus will be described in a later paragraph.

The engagement of switch blade 218 with contact 221 establishes an energizing circuit to the burner motor and to the ignition means, which energizing circuits are identical to those of Figure 1 and need not be again retraced.

As long as switch blade 323 was in engagement with contact 324, a circuit existed to the cathode heaters 42 and 61 as follows: from the upper terminal of secondary 306 through conductor 343, safety switch blades 73 and 74, conductor 344, resistor 308, conductors 345 and 346, switch blade 323, contact 324, conductors 348 and 349, cathode heater 61, conductor 350, cathode heater 42, and conductor 351 back to the lower terminal of secondary 306. Upon the switch blade 323 moving out of engagement with switch blade 324, this energizing circuit for the cathode heaters is interrupted. Simultaneously, however, a new energizing circuit to the cathode heaters is established to the safety switch heater as follows: from the upper terminal of secondary 306 through conductor 343, safety switch blades 73 and 74, conductor 337, safety switch heater 76, conductors 336 and 354, contact 326, switch blade 325, conductor 355, relay contact 228, switch blade 226, conductors 356 and 349, cathode heater 61, conductor 350, cathode heater 42, and conductor 351 back to the other terminal of secondary 306. It will be noted that the safety switch heater 76 is now connected in series with the cathode heaters. The current flowing through the cathode heater is of a magnitude sufficient to adequately energize the safety switch heater 76. Because of the fact that the safety switch heater 76 is in series with the cathode heaters, a further check is made on the operation of the safety switch heater since if this heater is inoperative, the cathode heaters will become deenergized. Thus, upon switch blade 325 being moved into engagement with contact 326 as a result of the energization of relay 213, the safety switch heater 76 starts being heated to initiate the timing cycle of the safety switch.

Until the photoelectric cell 154 is subjected to a flame, the condenser 135 is charged negatively by reason of the following circuit: from the lower terminal of secondary 68 through condenser 135, conductor 136, resistors 137 and 138, conductor 139, grid 39, cathode 40, conductors 187 and 316, resistor 315, conductors 317, 185 and 187 to the other terminal of secondary 68. The circuit corresponds to the circuit in Figure 1 for charging the condenser 135 negatively and the action thereof is exactly the same. Upon photoelectric cell 154 being illuminated as a result of flame, a charging circuit for condenser 135 is established as follows: from the lower terminal of secondary 67 through conductor 170, relay winding 215, conductors 171 and 190, resistor 191, conductor 192, photoelectric cell terminal 193, conductor 194, photoelectric cell 154, conductor 195, photoelectric cell terminal 196, conductor 197, condenser 135, secondary 68, and conductors 187 and 186 to the center terminal of secondary 67. Again, this circuit corresponds to the circuit in Figure 1 for charging the condenser 135 positively. As was the case in connection with Figure 1, the establishment of this circuit causes the potential of grid 39 to be raised sufficiently to cause adequate energization of relay winding 224. This in turn causes movement of switch blades 302 and 226 into engagement with contacts 303 and 301 and movement of switch blades 225 and 226 out of engagement with contacts 227 and 228.

The movement of switch blade 225 out of engagement with contact 227 has the same effect as in Figure 1, that is, to deenergize the ignition means while leaving energized the burner motor.

The movement of switch blade 226 out of engagement with contact 228 and into engagement with contact 301 disconnects the safety switch heater from the cathode heater and again establishes a circuit for the cathode heater including resistor 308. This circuit may be traced as follows: from the upper terminal of secondary 306 through conductor 343, safety switch blades 73 and 74, conductor 344, resistor 308, conductor 345, contact 301, switch blade 226, conductor 356, conductor 349, cathode heater 61, conductor 350, cathode heater 42, and conductor 351 to the other terminal of secondary 306. Thus, before relay 213 is energized, the cathode heaters are connected in series with resistor 308. After relay 213 is energized but before combustion has been established, the cathode heaters are connected in series with the safety switch heater so that the current flowing through the cathode heaters is effective to energize the safety switch heater. If combustion is established, the safety switch heater is disconnected and the fixed resistance 308 again connected in series with the cathode heaters. Since resistor 308 and safety switch heater 76 have substantially the same resistance values, the cathode heaters continue to be energized to substantially the same degree.

The engagement of switch blade 302 and contact 303 connects resistor 320 in parallel with relay winding 215 as follows: from the left-hand terminal of relay winding 215 through resistor 320, contact 321, conductor 360, switch blade 302, contact 303, and conductors 361 and 172 to the other terminal of relay winding 215. The effect of connecting resistor 320 in parallel with relay

winding 215 is to decrease the current flowing through relay winding 215. This has as its effect to reduce the amount which the current flowing through winding 215 must drop in order for the various switch blades to move to the position occupied when relay 213 is deenergized. The conventional relay has an appreciable differential between the current value at which it "pulls in" and the current value at which it "drops out." The effect of resistance 320 is to materially reduce this differential. Because of this reduction in differential, the change in the value of resistance 12 exposed to the controlling temperature medium need be much less to cause relay 213 to move to deenergized position. This makes possible a much more sensitive system for a given amplifier than would be otherwise possible.

Any danger of chattering of the relay is eliminated by reason of the fact that the resistor 320 is not connected in parallel with relay winding 215 merely as a result of energization of that relay winding. This connection of resistor 320 does not occur until after combustion has been established so as to cause energization of relay 214. By this time, the conditions in connection with the energization of relay 213 are sufficiently stable that the connection of resistor 320 in parallel with the relay winding 215 thereof will not cause the relay to drop out unless the temperature affecting resistance element 12 has risen by the desired amount.

As soon as the temperature of element 12 has risen to the desired value, relay 213 will drop out stopping operation of the burner. The resulting extinguishment of the flame will cause relay 214 to also be deenergized so as to completely shut down the system.

If combustion is not initially established, the safety switch heater 76 will remain in series with the cathode heater until the safety switch opens. Since the safety switch is connected in series with the cathode heaters, this will result in deenergization of the cathode heaters which in turn will cause both tubes 54 and 32 to become nonconductive. This in turn will cause deenergization of both relays 213 and 214.

If, after combustion has been established, there is a flame failure, relay 214 will become deenergized so as to cause switch blade 225 to reengage contact 227 and switch blade 226 to move from engagement with contact 301 into engagement with contact 228. The reengagement of switch blade 225 with contact 227 will reenergize the ignition means so that an attempt will be made to reignite the burner flame. Movement of switch blade 227 from out of engagement with contact 301 into engagement with contact 228 will again connect the safety switch heater 76 in series with the cathode heater so that safety switch heater 76 will again be heated. If at the end of the timing period of the safety switch, combustion has not been reestablished, the safety switch will open and shut down the system in the manner previously described. If, on the other hand, the condition which produced the flame failure is a temporary one, combustion will be reestablished with the result that relay 214 will be reenergized. This will have the same effect as when this relay was energized in connection with normal operation.

The operation of the flame detecting mechanism is exactly the same in the event of short circuit or other abnormal conditions as in Figure 1 and need not again be described here.

Conclusion

It will be seen in connection with both figures I have provided burner control apparatus in which the operation of the burner is controlled in accordance with the temperature of an impedance element having an appreciable temperature coefficient of resistance and forming an element of an impedance bridge. The amplifying arrangement employed is extremely compact and functions to provide amplification both for the resistance bridge and also for the output of a photoelectric cell exposed to the burner flame. It will furthermore be seen that I have provided apparatus by which the operation of the apparatus is carefully checked and the apparatus is shut down whenever not functioning properly.

While I have described certain specific embodiments of my invention, it is to be understood that this is for purposes of illustration only and that my invention is to be limited only by the scope of the appended claims.

I claim as my invention:

1. In condition control apparatus, an electrically operated device for controlling operation of a condition changing means, said device being effective when energized at a first predetermined level of energization to move to an energized position and to remain in said position until the level of energization drops to a lower predetermined value, means including said device for causing operation of said condition changing means when said device is in its energized position, an impedance element separate from said condition changing means and having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of said condition changing means, means operative upon the value of said temperature condition changing in one direction beyond a predetermined value to cause said device to be energized sufficiently to move to energized position, a further impedance element connected to said condition control apparatus, switching means for changing the connections of said further impedance element to said apparatus so as to change the degree of energization of said device for any value of said temperature condition, and means operative upon the establishment of a condition resulting from operation of said condition changing means to affect said last named means so as to decrease the amount of change of said temperature condition in the opposite direction necessary to cause said device to move from its energized position.

2. In condition control apparatus, an electrically operated device for controlling operation of a condition changing means, said device being effective when energized at a first predetermined level of energization to move to an energized position and to remain in said position until the level of energization drops to a lower predetermined value, means including said device for causing operation of said condition changing means when said device is in its energized position, an impedance element having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of said condition changing means, means operative upon the value of said temperature condition changing in one direction beyond a predetermined value to cause said device to be energized sufficiently to move to energized position, a further impedance element, and means operative upon the establish-

ment of a condition resulting from operation of said condition changing means to connect said further impedance element in parallel with said electrically operated device so as to decrease the amount of change of said temperature condition in the opposite direction necessary to cause said device to move from its energized position.

3. In burner control apparatus, an electrically operated device for controlling operation of a burner, said device being effective when energized at a first predetermined level of energization to move to an energized position and to remain in said position until the level of energization drops to a lower predetermined value, means including said device for causing operation of said burner when said device is in its energized position, an impedance element having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of the burner, means operative upon the value of said temperature condition dropping below a predetermined value to cause said device to be energized sufficiently to move to energized position, a further impedance element connected to said burner control apparatus, switching means for changing the connections of said further impedance element to said apparatus so as to change the degree of energization of said device for any value of said temperature condition, and means operative upon the establishment of combustion to operate said switching means in such a manner so as to decrease the value to which said temperature condition must rise to cause said device to move from its energized position.

4. In temperature control apparatus, an electrically operated device for controlling operation of a temperature changing means, said device being effective when energized at a first predetermined level of energization to move to an energized position and to remain in said position until the level of energization drops to a lower predetermined value, means including said device for causing operation of said temperature changing means when said device is in its energized position, a resistance bridge separate from said temperature changing means and including a resistance element having an appreciable temperature coefficient of resistance and subjected to a temperature condition indicative of the need for operation of said temperature changing means, means responsive to the unbalance of said bridge and operative upon the value of said temperature condition changing in one direction beyond a predetermined value to cause said device to be energized sufficiently to move to energized position, and means operative as a result of the energization of said device to decrease the energization of said device by a fixed predetermined amount so as to decrease the amount by which said temperature condition must change in the opposite direction to cause said device to move from its energized position.

5. In condition control apparatus, a relay for controlling a condition changing means and movable to and from an energized position, an impedance element having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of said condition changing means, means operative upon the value of said temperature condition changing in one direction beyond a predetermined value to cause said relay to be energized sufficiently to cause it to move to its energized position, and means including a device responsive to a condition resulting from operation of said condition changing means for so affecting said last named means upon the establishment of said last named condition as to decrease by a fixed predetermined amount the extent of change of said temperature condition in the opposite direction necessary to cause said relay to move from its energized position.

6. In burner control apparatus, a burner relay movable to and from an energized position, an impedance element having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of the burner, means operative upon the value of said temperature condition dropping below a predetermined value to cause said relay to be energized sufficiently to cause it to move to its energized position, and means operative as a result of energization of said relay for so affecting said last named means as to decrease by a fixed predetermined amount the extent to which said temperature condition must rise to cause said relay to move from its energized position.

7. In burner control apparatus, a burner relay, movable to and from an energized position, an impedance element having an appreciable temperature coefficient of impedance and subjected to a temperature condition indicative of the need for operation of the burner, means operative upon the value of said temperature condition dropping below a predetermined value to cause said relay to be energized sufficiently to cause it to move to its energized position, and means including a combustion responsive device for so affecting said last named means upon the establishment of combustion as to decrease by a fixed predetermined amount the value to which said temperature condition must rise to cause said relay to move from its energized position.

8. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier, a safety cut-out device including an electrically energized element and operative upon continued energization of said element to cause said safety cut-out device to assume cut-out position, means including said safety cut-out device for controlling said electrically operated device, an energizing circuit for said device including said amplifier and said electrically energized element in series, means operative upon energization of said device to energize said electrically energized element independently of said amplifier, and means including a combustion responsive device for causing deenergization of said element upon said combustion responsive device being subjected to combustion conditions.

9. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier, a safety switch including an electrical heater and operative upon continued energization of said heater to open said switch, means including said safety switch for controlling said device, an energizing circuit for said device including said amplifier and said safety switch heater in series, means operative upon energization of said device to energize said heater independently of said amplifier, and means including a combustion responsive device for causing deenergization of said heater

upon said combustion reponsive device being subjected to combustion conditions.

10. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier, a safety switch including an electrical heater and operative upon continued energization of said heater to open said switch, a source of power having first and second portions, an energizing circuit for said device controlled by said amplifier and including said device, said first portion of said source of power, said safety switch, and said safety switch heater, means operative upon energization of said device to connect said heater to said second portion of said source of power, and means including a combustion responsive device for causing deenergization of said heater upon said combustion responsive device being subjected to combustion conditions.

11. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier, a safety switch including an electrical heater and operative upon continued energization of said heater to open said switch, a normally closed switch, means including a combustion responsive device for opening said normally closed switch upon the establishment of combustion, a source of power having first and second portions, an energizing circuit for said device controlled by said amplifier and including said device, said first portion of said source of power, said normally closed switch, said safety switch, and said safety switch heater, and means operative upon energization of said device to establish a new circuit for said device including said first portion of said source of power but not said normally closed switch and to connect said heater to said second portion of said source of power under the control of said normally closed switch so that upon said combustion responsive device being subjected to combustion conditions, said device remains energized but said heater is deenergized.

12. In burner control apparatus, an electrically operated device for controlling a burner, a thermionic amplifier comprising an electron emissive cathode and an electric cathode heater therefor, a safety switch including an electric heater and operative upon continued energization of said heater to open said switch, means for applying an input voltage to said amplifier whose magnitude is dependent upon the demand for burner operation, means including said amplifier and said safety switch for controlling the energization of said device, a source of power, an energizing circuit for said cathode heater including said source of power and said safety switch heater, and means including a combustion responsive device for causing deenergization of said safety switch heater but not of said cathode heater upon said combustion responsive device being subjected to combustion conditions.

13. In burner control apparatus, an electrically operated device for controlling a burner, a thermionic amplifier comprising an electron emissive cathode and an electric cathode heater therefor, a safety switch including an electric heater and operative upon continued energization of said heater to open said switch, means for applying an input voltage to said amplifier whose magnitude is dependent upon the demand for burner operation, means including said amplifier and said safety switch for controlling the energization of said device, a source of power, an energizing circuit for said cathode heater including said source of power and said safety switch heater, a resistor having substantially the same resistance value as said safety switch heater, and means including a combustion responsive device operative upon said combustion responsive device being subjected to combustion conditions to disconnect said safety switch heater from said energizing circuit and to substitute therefor said resistor so as to maintain continued energization of said cathode heater at substantially the same magnitude.

14. In burner control apparatus, an electrically operated device for controlling a burner, a thermionic amplifier comprising an electron emissive cathode and an electric cathode heater therefor, a safety switch including an electric heater and operative upon continued energization of said heater to open said switch, means for applying an input voltage to said amplifier whose magnitude is dependent upon the demand for burner operation, an energizing circuit for said device including said amplifier, said safety switch heater, and said safety switch means operative upon the energization of said device to establish a separate energizing circuit for said safety switch heater including said cathode heater, and means including a combustion responsive device for causing deenergization of said safety switch heater but not of said cathode heater upon said combustion responsive device being subjected to combustion conditions.

15. In burner control apparatus, an electrically operated device for controlling a burner, a thermionic amplifier comprising an electron emissive cathode and an electric cathode heater therefor, an energizing circuit for said cathode heater, a safety switch including an electric heater and operative upon continued energization of said heater to open said switch, means for applying an input voltage to said amplifier whose magnitude is dependent upon the demand for burner operation, means including said amplifier and said safety switch for causing the energization of said device, means operative upon the energization of said device to connect said safety switch heater in series with said cathode heater in said energizing circuit, and means including a combustion responsive device operative upon said combustion responsive device being subjected to combustion conditions to again disconnect said safety switch heater from said energizing circuit.

16. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier to control in turn the energization of said device in accordance with the value of the condition to which said condition responsive means responds, a second electrically operated device also controlling the operation of said burner, a second electronic amplifier controlling the energization of said second electrically operated device, means including a device adapted to be subjected to a flame of said burner for controlling said second amplifier to cause energization of said second electrically operated device only when said burner is ignited, said last-named means including connections tending to produce an undesirable phase shifting in said means, and connections between said first

named and said second electronic amplifier for causing said first named electronic amplifier to counteract said phase shifting tendencies.

17. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, condition responsive means for controlling said electronic amplifier to control in turn the energization of said device in accordance with the value of the condition to which said condition responsive means responds, a second electrically operated device also controlling the operation of said burner, a second electronic amplifier controlling the energization of said second electrically operated device, a condenser operatively connected to said second amplifier and controlling its operation, means including a device adapted to be subjected to a flame of said burner for charging said condenser in such a manner that said second amplifier causes energization of said second electrically operated device only when said burner is ignited, said condenser tending to produce an undesirable phase shifting in said last named means, and connections between said first named and said second electronic amplifier for causing said first named electronic amplifier to counteract said phase shifting tendencies.

18. In burner control apparatus, an electrically operated device for controlling a burner, an electronic amplifier for controlling the energization of said device, said amplifier comprising an anode, cathode, and control element, condition responsive means for applying a variable voltage to the control element of said electronic amplifier to control in turn the energization of said device in accordance with the value of the condition to which said condition responsive means responds, a second electrically operated device also controlling the operation of said burner, a second electronic amplifier controlling the energization of said second electrically operated device and also comprising an anode, a cathode, and a control element, both of said amplifiers being located within a common enclosure and having a common heating element for the cathodes thereof, means including a device adapted to be subjected to a flame of said burner for applying a variable voltage to the control element of said second amplifier to cause energization of said second electrically operated device only when said burner is ignited, and means operative in the event combustion is not established within a predetermined period of time after said burner has been placed in operation to interrupt operation of said cathode heater element.

19. In combination, a relay adapted to control the operation of a temperature changing apparatus to cause the latter to increase its temperature changing effect when said relay is energized, an amplifier having input and output circuits, a source of power having a portion thereof connected to said output circuit, means including said output circuit for causing energization of said relay when a biasing voltage less than a predetermined value is applied to said input circuit, an impedance bridge including an impedance element having an appreciable temperature coefficient of impedance and exposed to a temperature condition indicative of the need for operation of the temperature changing apparatus, means for applying a portion of said source of power to the input terminals of said bridge to energize the same, means for connecting the output terminals of said bridge to the input circuit of said amplifier, the impedances of said bridge having such relative values that when said temperature condition is at a desired value the bridge is unbalanced in such a direction and to such an extent that the output thereof results in a biasing voltage of said predetermined value being applied to said input circuit and such that upon said temperature condition changing so as to require an increase in the temperature changing effect of said temperature changing apparatus, said output voltage is decreased.

20. In combination, a relay adapted to control operation of heating apparatus to cause the latter to increase its heating effect when said relay is energized, an amplifier having input and output circuits, a source of power having a portion thereof connected to said output circuit, means including said output circuit for causing energization of said relay when a biasing voltage less than a predetermined value is applied to said input circuit, an impedance bridge including an impedance element having an appreciable temperature coefficient of impedance and exposed to a temperature condition indicative of the need for operation of the temperature changing apparatus, means for applying a portion of said source of power to the input terminals of said bridge to energize the same, means for connecting the output terminals of said bridge to the input circuit of said amplifier, the impedances of said bridge having such relative values that when the value of said temperature condition is at a desired value the bridge is unbalanced in such a direction and to such an extent that the output thereof results in a biasing voltage of said predetermined value being applied to said input circuit and such that upon said temperature condition decreasing so as to require an increase in the heating effect of said heating apparatus, said output voltage is decreased.

21. In combination, a relay adapted to control operation of a heating apparatus to cause the latter to increase its heating effect when said relay is energized, an amplifier having input and output circuits, an alternating source of power having a portion thereof connected to said output circuit, means including said output circuit for causing energization of said relay when an alternating biasing voltage out of phase with the voltage applied to said output circuit and less than a predetermined value is applied to said input circuit, a resistance bridge including a resistance element having an appreciable temperature coefficient of resistance and exposed to a temperature condition indicative of the need for operation of the temperature changing apparatus, means for applying a portion of said source of power to the input terminals of said bridge to energize the same, means for connecting the output terminals of said bridge to the input circuit of said amplifier, the resistors of said bridge having such relative values that when the value of said temperature condition is at a desired value the bridge is unbalanced in such a direction and to such an extent that the output thereof results in an out of phase biasing voltage of said predetermined value being applied to said input circuit and such that upon said temperature condition decreasing said output voltage is decreased.

22. In condition control apparatus, an electrically operated device for controlling operation

of a condition changing means, said device being effective when energized at a first predetermined level of energization to move to an energized position and to remain in said position until the level of energization drops to a lower predetermined value, means including said device for causing operation of said condition changing means when said device is in its energized position, a resistance network separate from said condition changing means and including a resistance element variable in accordance with the value of a condition indicative of the need for operation of said condition changing means, means responsive to the unbalance of said bridge and operative upon the value of said condition changing in one direction beyond a predetermined value to cause said device to be energized sufficiently to move to energized position, and means operative as a result of the energization of said device to decrease the energization of said device by a fixed predetermined amount so as to decrease the amount by which said condition must change in the opposite direction to cause said device to move from its energized position.

23. In condition control apparatus, a relay for controlling a condition changing means and movable to and from an energized position, a variable impedance variable in accordance with the value

of a condition indicative of the need for operation of said condition changing means, means operative upon the value of said condition changing in one direction beyond a predetermined value to cause said relay to be energized sufficiently to cause it to move to its energized position, a second relay, means controlled by said first relay for causing energization of said second relay, and means operative upon energization of said second relay for so affecting said first named means as to decrease by a fixed predetermined amount the extent of change of said condition in the opposite direction necessary to cause said first named relay to move from its energized position.

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