Sept. 22, 1953 R. J. EHRET ET AL 2,653,279

CONTROL APPARATUS

Filed March 26, 1952

FIG. 1

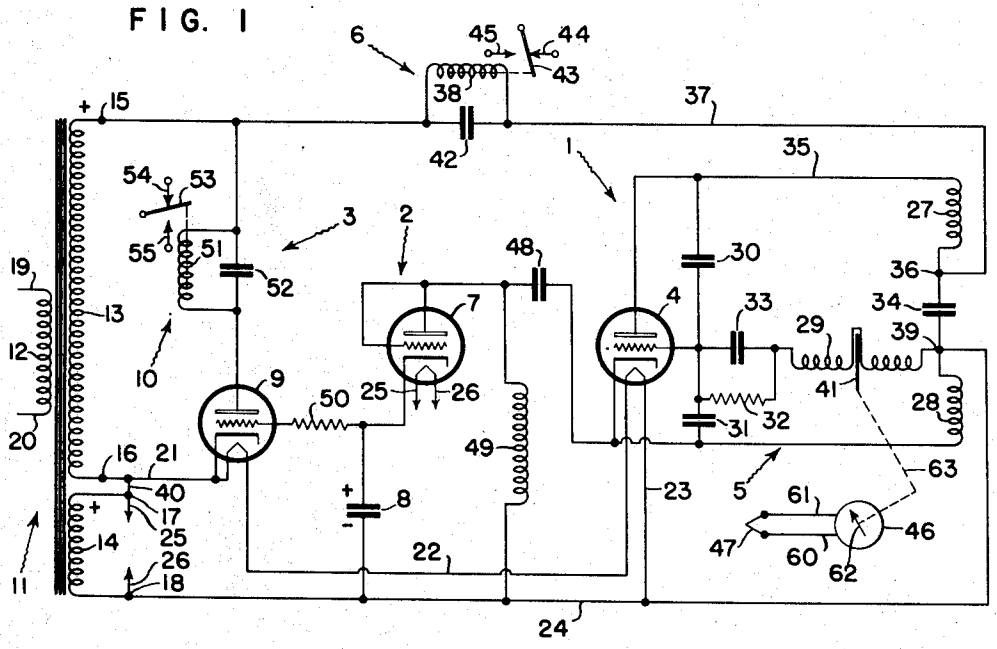
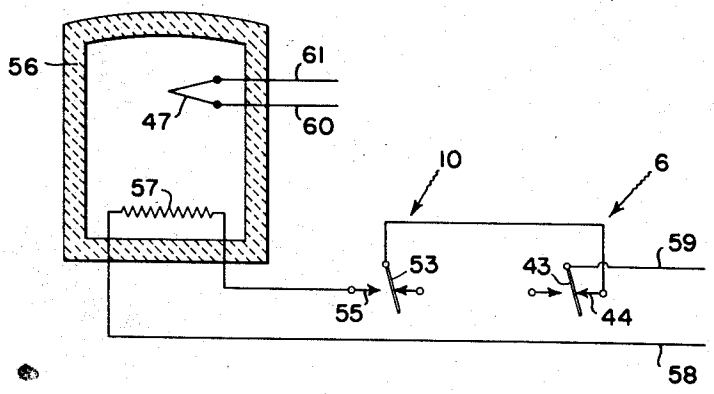


FIG. 2



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CONTROL APPARATUS

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14 Claims. (Cl. 317—135)

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The present invention relates generally to control apparatus of the type which includes means to prevent the establishment of potentially unsafe control actions due to the failure of one or another component of the apparatus. More specifically, the invention relates to novel control apparatus of this type which provides safe-failure operation through the conjoint action of two devices which are responsive in opposite manners to the condition of a controlling portion of the apparatus.

A general object of the present invention is to provide improved control apparatus of the type including provisions for preventing the establishment of unsafe conditions because of the failure of some component of the apparatus. A specific object of the invention is to provide such control apparatus wherein safe-failure operation is secured through the use of two responsive devices which are responsive in opposite manners to the condition of a controlling portion of the apparatus.

A more specific object of the invention is to provide apparatus of the type just specified which includes a control portion having one or another condition, depending upon the adjustment of the portion, and which also includes a first responsive device adapted to be operatively energized when the control portion assumes one condition and not to be so energized when the control portion assumes the other condition, and a second responsive device adapted to be operatively energized when the control portion assumes said other condition and not to be so energized when the control portion assumes said one condition.

An even more specific object of the invention is to provide apparatus as just described including an oscillator portion, means responsive to the state of oscillation thereof, a first responsive relay included in the oscillator load circuit and adapted to respond to the value of the oscillator load current, means adapted to increase this current when oscillation of said portion is prevented, a second responsive relay included in the responsive means and adapted to respond to the value of current flow therein, means adapted to increase the last mentioned current when said portion is oscillating, and control connections including the contact means of both of the relays.

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Other specific objects of the invention are to provide apparatus of the above type wherein a repeater electron tube is adapted to energize the second relay in response to the oscillation signal of the oscillator, wherein such a tube is biased to be substantially non-conductive in the absence of the oscillation signal, and wherein the first or oscillator relay includes normally-closed contacts which are connected in a control circuit in series with normally-open contacts included in the second or repeater relay.

The control apparatus of the present invention represents an improvement over the known forms of control apparatus including various means for preventing one or another type of failure from effecting unsafe operation. Thus, insofar as we are aware, no previous form of control apparatus of this type included the two responsive devices or relays which we employ according to the present invention, one of which relays is responsive to the oscillation and non-oscillation of an oscillator through the medium of the oscillator load or energizing current, and the other of which relays is responsive to the oscillation and non-oscillation of an oscillator through the medium of the oscillation signal of the oscillator. Moreover, we believe that we are the first to provide control apparatus of the type just described wherein the contacts of the two relays are adapted to be interconnected in an advantageous manner so that the controlling actions or effects produced by the apparatus are under the joint control of the two relays, whereby certain safe failure actions are provided by the present invention which are not obtainable with the types of apparatus previously known.

Accordingly, it is a prime object of the present invention to provide novel control apparatus including a first relay responsive to the state of oscillation of an oscillator through the medium of the magnitude of the energizing or supply current of the oscillator, and including a second relay responsive to said state of oscillation through the medium of the magnitude of the oscillation signal produced by the oscillator, and wherein the first relay is adapted to complete a control circuit through a normally-closed relay contact when said energizing current is below a predetermined magnitude, while said second relay is adapted to complete said control circuit

through a normally-open relay contact when said oscillation signal is at or above a predetermined magnitude. By virtue of the arrangement of elements just described, the apparatus of the present invention provides novel and highly desirable operation characterized by being in the safe direction in the presence of numerous component and similar failures.

According to the present invention, a preferred embodiment of the apparatus thereof includes an oscillator circuit or portion including a coupling element, shown as a coil, which is adapted to cause or prevent the oscillation of the oscillator as the reactance of the coil is varied, as by a vane, above and below a critical value. The oscillator includes bias means which causes the oscillator energizing or supply current to have a first or higher value when the oscillator is not oscillating, and to have a substantially lower value when the oscillator is oscillating, whereby a first relay, which has its operating winding included in the oscillator energizing circuit, is adapted to close a pair of normally-closed relay contacts whenever the oscillator is oscillating or whenever said energizing current has said lower value or is interrupted, and is adapted to open these contacts whenever the oscillator is not oscillating or the energizing current has said higher value.

Also included in the illustrated preferred form of the invention is a rectifier which rectifies the oscillation signal, which the oscillator produces when it is oscillating, to produce a unidirectional bias or control voltage which is utilized to control the conductivity of a repeater electron tube. This voltage is developed across an impedance element, shown as a condenser, which is included in the input circuit of the tube, and has the polarity required to increase the tube conductivity.

The repeater tube includes in its output or load circuit the operating winding of a second relay, whereby the latter is adapted to close a pair of normally-open relay contacts whenever the oscillator is oscillating and the conductivity of this load circuit, and the resulting load current, have corresponding high values. These contacts are adapted to be opened by the second relay, however, when the oscillator is not oscillating or the conductivity and load current of the repeater tube are reduced.

Accordingly, a control circuit including the aforementioned normally-closed and normally-open relay contacts connected in series is one which provides control which is characterized by being in the safe direction, or in such a direction as not to cause an unsafe condition, upon the occurrence of a component of similar failure.

The various features of novelty which characterize this invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages and specific objects obtained with its use, reference should be had to the accompanying drawings and descriptive matter in which is illustrated and described a preferred embodiment of the invention.

Of the drawings:

Fig. 1 is a circuit diagram of a preferred embodiment of the safe failure control apparatus of the present invention; and

Fig. 2 is a diagram showing a preferred manner of employing the apparatus of Fig. 1 to effect automatic temperature control.

The preferred control apparatus embodiment of the present invention illustrated in Fig. 1 includes an oscillator circuit or portion 1, a responsive, control signal-producing portion 2, and a repeater portion 3. The oscillator portion 1 includes a triode electron tube 4 which has the usual anode, control grid, cathode, and cathode heater elements. The oscillator 1 also includes an adjustable oscillation-controlling portion 5 which includes various components to be described hereinafter. Also included in the circuit of the portion 1 is a first responsive device or oscillator relay 6.

The portion 2 includes a triode electron tube 7, an impedance element or condenser 8, and other components to be described below.

The repeater portion 3 includes a triode electron tube 9, a second responsive device or repeater relay 10, and other components which will be described below. Each of the triodes 7 and 9 includes the usual anode, control grid, cathode, and cathode heater elements.

The Fig. 1 apparatus also includes an energizing or supply voltage transformer 11 having a primary winding 12, a high voltage secondary winding 13, and a low voltage secondary winding 14. The winding 13 has respective end terminals 15 and 16, while the winding 14 has respective end terminals 17 and 18. The primary winding 12 is connected across supply conductors 19 and 20 which are assumed to supply alternating energizing current of conventional frequency. By way of example, this frequency will be assumed to be sixty cycles per second.

As shown by the plus signs adjacent the windings 13 and 14, it will be assumed herein that the terminal 15 is rendered positive with respect to the terminal 16, and that the terminal 17 is rendered positive with respect to the terminal 18, during the first half cycles of the supply voltage, while, during the alternate or second half cycles, the terminal 16 is rendered positive with respect to the terminal 15 and the terminal 18 is rendered positive with respect to the terminal 17.

As shown, the cathode heaters of the triodes 4 and 9 are connected in series between the terminals 17 and 18 of the transformer winding 14. To this end, the terminal 17 is connected by a conductor 21 to one cathode heater terminal of the triode 9, while the other cathode heater terminal of the latter is connected by a conductor 22 to one of the cathode heater terminals of the triode 4. The remaining cathode heater terminal of the latter is connected by a conductor 23 and a common conductor 24 to the remaining terminal 18 of the winding 14. The cathode heater of the triode 7 is directly connected between the terminals 17 and 18 by respective, partially-shown conductors 25 and 26.

The adjustable oscillator circuit portion 5 includes an oscillator output coil 27, an oscillator input coil 28, a regenerative coupling coil 29, and tuning condensers 30 and 31. The circuit 5 also includes a bias resistor 32, a bypass condenser 33, and a bypass condenser 34.

The circuit portion 5 and the triode 4 are interconnected in the Fig. 1 apparatus so as to constitute a controllable oscillator circuit. By way of illustration and example, the oscillator 1 is shown as being of the type disclosed and claimed in the copending application of Warren Moore, Jr., Serial No. 106,796, which was filed on

July 26, 1949. It is to be understood, however, that the present invention is not limited in its usefulness to the inclusion of a controlled oscillator of this particular type, but may include any other of the many suitable types of controlled oscillators known in the art.

To the end of providing a controlled or controllable oscillator of the type disclosed in the aforementioned Moore application, the anode of the triode 4 is connected to one terminal of the coil 27 by a conductor 35, and the other terminal of this coil is connected to a junction 36. The latter is connected by a conductor 37 and through the operating winding 38 of the relay 6 to the transformer winding terminal 15. The junction 36 is also connected by the condenser 34 to a junction 39 which in turn is connected by the coil 28 to the cathode of the triode 4. The junction 39 is also connected by the conductor 24 to the terminal 18 of the winding 14, while the terminal 17 of the latter is connected by a conductor 40 to the terminal 16 of the winding 13.

The coil 29 has one end terminal connected to the junction 39 and has its other end terminal connected through the bias resistor 32 to the control grid of the triode 4. The condenser 33 is connected in parallel with the resistor 32. Finally, the condenser 30 is connected between the anode and control grid of the triode 4, while the condenser 31 is connected between the control grid and cathode of the triode 4.

The manner in which the foregoing connections cause the portion 1 to be a controllable oscillator will now be described. The oscillator output or anode-control grid circuit can be traced from the anode of the triode 4 through the conductor 35, the coil 27, the condenser 34, the coil 29, and the parallel-connected resistor 32 and condenser 33 to the control grid of the triode 4. Also, the oscillator input or control grid-cathode circuit can be traced from the cathode of the triode 4 through the coil 28, the coil 29, and the parallel-connected resistor 32 and condenser 33 to the control grid of the triode 4. Finally, the load or energizing circuit of the portion 1 can be traced from the anode of the triode 4 through the conductor 35, the coil 27, the conductor 37, and the relay winding 38 to the transformer winding terminal 15, and from the other terminal 16 of the latter through the conductor 40, the transformer winding 14, the conductor 24, and the coil 28 to the cathode of the triode 4.

The foregoing description should make it readily apparent that the oscillator 1 of Fig. 1 is a controllable oscillator of the common-grid type disclosed in the aforementioned Moore application. Since the basic manner and theory of operation of such an oscillator forms no part of the present invention, but is illustrated and described in detail in said Moore application, it is deemed to be sufficient herein to state that, when a part, such as the vane 41 shown in Fig. 1, is at such a position relative to the coil 29 that the reactance or self-inductance of the latter is not reduced below a critical value, the circuit will be in oscillation during the aforementioned first half cycles of the energizing voltage. Under this condition, a minimum value of energizing current will be caused to flow in the oscillator load circuit through the relay winding 38. Therefore, the relay 6 will not be operatively energized, but will be maintained in the dropped-out position.

When the vane 41 is moved toward the coil 29 to a position between the halves of the latter at which the reactance of the coil is reduced below the aforementioned critical value, the oscillation of the circuit will be prevented, and the energizing current flowing in the load circuit of the triode 4 and through the relay winding 38 during the first half cycles of the supply voltage will have its value substantially increased. This will cause the relay 6 to be operatively energized, which will in turn cause the relay to assume the picked-up position. A condenser 42 which is connected in parallel with the relay winding 38 prevents the relay 6 from being actuated into the dropped-out position, during the second halves of the supply voltage cycles, whenever the relay is operatively energized during the alternate, first half cycles of the supply voltage.

It is apparent from the foregoing that the coil 29 constitutes an element adjustable to cause and prevent the oscillation of the circuit 1, and that the oscillation of the circuit causes the oscillator energizing current to have a sufficiently low value to prevent the operative energization of the relay 6. Moreover, it can be seen that any action which prevents the oscillation of the oscillator will cause the energizing current to be increased substantially in magnitude, whereby the relay 6 will be operatively energized. As previously noted, the specific manner in which the adjustment of the reactance of the coil 29 by the vane 41 to a value which is above or below a critical value respectively causes and prevents the oscillation of the oscillator, and hence respectively prevents and causes the operative energization of the relay 6, is described in detail in said Moore application, and need not be further elaborated on herein.

As shown, the relay 6 includes a movable contact 43 and stationary contacts 44 and 45. The contacts 43 and 44 are adapted to be in engagement when the relay 6 is not operatively energized, whereby these contacts may be referred to as normally-closed contacts. Further, the contacts 43 and 45 are adapted to be in engagement whenever the relay 6 is operatively energized, whereby the last mentioned contacts may be referred to as normally-open contacts. Thus, when the oscillator 1 is oscillating, or when no energizing current flows through the winding 38, the normally-closed contacts 43 and 44 will be in engagement, whereas the normally-open contacts 43 and 45 will be in engagement when the circuit 1 is not oscillating and when the energizing current flowing from the winding 38 has a correspondingly high value.

For the purpose of illustrating the desirable safe-failure operation provided by the apparatus of the present invention, the vane 41 has been shown in Fig. 1 as being actuated by a galvanometer or millivoltmeter of instrument 46 which in turn is responsive to the output voltage and temperature of a thermocouple 47. As will be brought out hereinafter, we have chosen to illustrate this form of actuation of the vane 41 and control of the oscillator 1 because of the especially advantageous operation obtainable with the invention when employed with such actuating or measuring means as the instrument 46.

The triode 7 of the responsive portion 2 is connected to operate as a rectifying diode, and will be so referred to hereinafter. Thus, the anode and control grid of the tube 7 are directly connected together, and are connected through a coupling condenser 48 to the cathode of the oscillator triode 4. A choke coil 49 is connected

between the anode of the diode 7 and the conductor 24. The cathode of the diode 7 is connected through the aforementioned condenser 8 to the conductor 24, whereby the portion 2 is adapted to rectify or convert the oscillation signal produced across the coil 28, when the oscillator 1 is oscillating, into a unidirectional bias or control voltage across the condenser 8. This voltage produced across the condenser 8 will have the polarity shown in Fig. 1.

The control voltage produced by the portion 2 as just described is utilized to control the conductivity and load current of the repeater portion 3. To this end, the input circuit of the triode 9 is connected across the condenser 8 and the transformer winding 14 connected in series. Specifically, the control grid of the triode 9 is connected through a resistor 50 to the upper or positive terminal of the condenser 8, while the lower or negative terminal of the latter is connected through the conductor 24 to the terminal 18 of the winding 14. The input circuit of the triode 9 is completed by the connection of the terminal 17 of the winding 14 through the conductors 40 and 21 to the cathode of the triode 9. The winding 14 constitutes a source of negative grid bias for the triode 9 as will be explained hereinafter.

The load or output circuit of the repeater triode 9 includes the operating winding 51 of the relay 10. Accordingly, the anode of the triode 9 is connected through the winding 51 to the terminal 15 of the transformer winding 13, while the terminal 16 of the latter is connected to the cathode of the triode 9 by the conductor 21. From this it is evident that the degree of conductivity of the triode 9, and the resulting magnitude of the triode load or energizing current, determine whether or not the relay 10 is operatively energized. A condenser 52 is connected in parallel with the relay winding 51 to prevent the relay from being actuated into the dropped-out position, during the second half cycles of the supply voltage, whenever the relay is operatively energized during the alternate, first half cycles.

The operation of the portions 2 and 3 as just described will now be explained. For purposes of simplification, the remainder of the description will be directed to the operation of the apparatus during the operative, first half cycles of the supply voltage throughout which the terminals 15 and 17 are rendered positive with respect to the associated terminals 16 and 18. The operation during the alternate, second half cycles need not be considered, since the conditions existing during the operative half cycles determine the positions of the relays 6 and 10 during the alternate, inoperative half cycles.

When the oscillator 1 is not oscillating, no oscillation signal is produced across the coil 28, and no control voltage is developed across the condenser 8. Accordingly, no positive grid bias voltage is applied to the triode 9, whereby only the bias voltage produced by the winding 14 is applied to the input circuit of the triode 9. Since this bias voltage will render the control grid of the triode 9 negative with respect to the cathode thereof, the conductivity of the triode will be at a minimum, and the energizing current in the output circuit of the triode 9 and in the relay winding 51 will have a minimum value which will not effect the operative energization of the relay 10. The latter will, therefore, be maintained in the dropped-out position.

When the oscillator 1 is in oscillation, the aforementioned oscillation signal is produced across the coil 28, and is applied to the portion 2. As a result, the aforementioned positive bias voltage is developed across the condenser 8, through a circuit which can be traced from the lower, cathode terminal of the coil 28 through the condenser 48, the diode 7, the condenser 8, and the conductor 24 back to the junction 39 at the upper end of the coil 28. Since this positive bias voltage opposes the negative bias voltage of the winding 14 in the input circuit of the triode 9, the presence of the voltage across the condenser 8 will cause the conductivity of the triode 9 to be significantly increased, and will cause a higher value of energizing current to flow through the relay winding 51. This higher value of current flow will effect the operative energization of the relay 10, whereby the latter will be caused to assume the picked-up position.

As in the case of the relay 6, the relay 10 includes contacts actuated by the energization of the winding 51. Specifically, the relay 10 includes a movable contact 53 and stationary contacts 54 and 55. The contacts 53 and 54 are normally-closed contacts, and are maintained in engagement when the winding 51 is not operatively energized. The contacts 53 and 55, however, are normally-open contacts, and are in engagement only when the winding 51 is operatively energized.

Normal operation of the apparatus

It is believed that the inclusion of a specific operating example will illustrate to best advantage the manner in which the various portions and components of the Fig. 1 apparatus cooperate to provide the normal control operation of the apparatus. In order to make this operative illustration complete, we have shown in Fig. 2 a preferred manner of advantageously interconnecting the relay contacts of the Fig. 1 arrangement in a control circuit which controls the temperature to which the thermocouple 47 is responsive. Specifically, Fig. 2 diagrammatically shows a furnace or similar structure 56 enclosing a space within which the temperature is to be controlled by the Fig. 1 apparatus. As shown, the thermocouple 47 is located within the furnace 56 so as to be responsive to the temperature to be controlled. Also included in the furnace 56 is a heating element 57, the energization of which is controlled jointly by the relays 6 and 10. To this end, a supply conductor 58 is connected directly to one terminal of the heater 57, while a second supply conductor 59 is connected through the normally-closed contacts 43 and 44 of the relay 6, and through the normally-open contacts 53 and 55 of the relay 10, to the remaining terminal of the heater 57. It can thus be seen that the heater 57 can be energized by the voltage supplied by the conductors 58 and 59 solely when the relay 6 is not operatively energized and hence is in the dropped-out position at the same time that the relay 10 is operatively energized and therefore is in the picked-up position.

As shown in Fig. 1, the thermocouple 47 is connected to the instrument 46 by means of conductors 60 and 61. Further, the instrument 46 has a pointer 62 which is adapted to be moved to positions corresponding to the values of temperature within the furnace 56 as measured by the thermocouple 47. The vane 41 is positioned by the instrument 46 through a suitable mechanical linkage 63 connected to the pointer 62. Accordingly, the vane 41 is positioned relative to the coil 29 by the instrument 46 in accordance with the

temperature within the furnace 56. When the instrument 46 is of the galvanometer or similar type, the vane 41 may be directly carried and positioned by the pointer 62 as shown in the aforementioned Moore application and as well known in the art.

In connection with the following description, it is assumed that the relative positions of the vane 41 and coil 29 are suitably related to the position of the pointer 62 so that, when the temperature within the furnace 56 has a predetermined, desired set-point value, the reactance of the coil 29 will be adjusted by the vane 41 to a value just below the critical value and at which oscillation of the oscillator 1 will just be prevented. It is also assumed that an increase in the measured furnace temperature causes the vane 41 to move toward the coil 29, and that decreases in the measured temperature cause the vane to move away from the coil 29.

With regard to the foregoing description and assumptions, when the furnace temperature or temperature measured by the instrument 46 is below the desired, set-point value, the vane 41 will be out from between the halves of the coil 29 sufficiently far to cause the adjusted reactance value of the coil to be above the aforementioned critical value. Therefore, the portion 1 will be caused to oscillate, whereby the current flowing in the load circuit of the portion 1 will have a low value which is insufficient to effect the operative energization of the relay 6. Accordingly, the latter will be in the dropped-out position, and the normally-closed contacts 43 and 44 will be in engagement.

Since the circuit 1 is oscillating under the condition being considered, the oscillation signal will be present across the coil 28, whereby the resulting control voltage across the condenser 8 will cause the flow of a sufficiently high value of current through the repeater output circuit to effect the operative energization of the relay 10. Therefore, the relay 10 will be in the picked-up position, and the normally-open relay contacts 53 and 55 will be in engagement. Since, as noted above, the normally-closed relay contacts 43 and 44 of the relay 6 will also be in engagement at this time, the energizing circuit for the furnace heater 57 will be closed, and heat will be supplied to the furnace. It can be said that this condition results from the establishment by the apparatus of a second control effect, which effect is produced when the relay 6 is not operatively energized and the relay 10 is simultaneously operatively energized.

As the measured temperature increases as a result of the energization of the heater 57, the vane 41 will be suitably moved into the space between the halves of the coil 29. The apparatus will maintain the second control effect, and the measured temperature will continue to increase, whereby the reactance of the coil 29 will be continually decreased and will subsequently be reduced below the critical value. At that time, the oscillation of the oscillator will be prevented, and the energizing current in the oscillator load circuit will be increased to a sufficiently high value to cause the relay 6 to be operatively energized. As a result, the relay 6 will be actuated into the picked-up position, the normally-closed relay contacts 43 and 44 will be moved out of engagement, and the supply of energizing current to the furnace heater 57 will be interrupted. This condition can be referred to as a first control effect established by the apparatus wherein the relay 6 is in the picked-up position irrespective of the position of the relay 10.

It should be noted, however, that the relay 10 will normally be in the dropped-out position for the condition now being considered. Specifically, since the oscillator will not be oscillating, no oscillation signal will be present across the coil 28, and no positive bias voltage will be produced across the condenser 8. Accordingly, the conductivity of the repeater triode 9 will be reduced, and the repeater output circuit current will have a substantially smaller value than when the oscillator was oscillating. As a result, the relay 10 will not be operatively energized, and hence will be in the dropped-out position as noted. This will cause the contacts 53 and 55 to be out of engagement, but this condition will not affect the control effect then produced, since the opening of the contacts 43 and 44 will already have deenergized the furnace heater 57 as previously noted.

The temperature increase which was assumed to have occurred in the operating phase just described will have carried the measured temperature above the set-point value, and no further energization of the heater 57 will take place as long as this condition prevails. However, the furnace temperature will subsequently drop to and below the set-point value, at which time the oscillator 1 will be caused to oscillate, the relay 6 will be actuated into the dropped-out position, whereby the contacts 43 and 44 will be actuated into engagement, the relay 10 will be actuated to the picked-up position, whereby the contacts 53 and 55 will be engaged, and the second control effect and the energization of the heater 57 will therefore be reestablished. This cycling of the apparatus between the first and second control effects will continue as necessary to maintain the measured temperature as close as possible to the desired, set-point value.

Safe-failure operation

The foregoing description has dealt with the normal operation of the Fig. 1 apparatus, which operation was assumed to be free from the occurrence of any component or similar failure. However, since the apparatus of the present invention is characterized by its ability to fail safely, or to establish safe control actions, upon the occurrence of such failures, a discussion and description of the operation of the apparatus in the presence of such failures will now be presented.

It is well known in the art that there are certain automatic control applications which render it necessary or at least desirable to provide the control apparatus with safe-failure provisions. As the name implies, such provisions operate to prevent the failure of some portion of the control apparatus from establishing an unsafe condition of operation or control. As previously mentioned, the broad means chosen for illustration as the actuating means for the vane 41 herein were so chosen because of their being representative of the type of control application which usually renders necessary the inclusion of safe-failure provisions.

In explanation of the above, it is noted that the interruption or failure of the supply voltage of the conductors 19 and 20 would establish a so-called unsafe condition in the apparatus of Figs. 1 and 2 were it not for the inclusion of the portions 2 and 3 and the relay 10. Specifically, such supply voltage failure would prevent the

relay 6 from being operatively energized no matter what the state of oscillation of the oscillator, whereby the relay 6 would be maintained in the dropped-out position in spite of the value of the measured temperature. Therefore, were the relay 10 and its controlling portions not included in the apparatus, the resulting continued engagement of the contacts 43 and 44 would cause the energization of the furnace heater 57 to be continued even though the measured temperature would rise to unsafe values.

However, under the condition of failure being considered, the apparatus of Figs. 1 and 2 will not be placed in an unsafe condition, but will instead be caused to fail safely. Such safe failure will take place by virtue of the fact that the relay 10 will be deenergized by the failure of the supply voltage. Accordingly, the energizing circuit to the heater 57 will be opened by the resulting disengagement of the contacts 53 and 55, and the heater 57 will not be energized until the energization of the control apparatus from the conductors 19 and 20 is reestablished.

From the above it is evident that the nature of the measuring means shown in Fig. 1 inherently makes it possible for a simple failure to establish what would be an unsafe control effect if it were not for the cooperative action of the relays 6 and 10 and the portions of the apparatus which control the operation of these relays.

Since there are numerous conditions of component and similar failure which could occur in connection with the illustrated apparatus, it is impractical, from the standpoint of space, to attempt to discuss all of such possible failures. Therefore, only several of the more obvious or more likely types of failure will be considered in the following paragraphs.

Broadly, any failure of the apparatus which causes the relay 6 to be maintained in the picked-up position, irrespective of the position of the relay 10, and any failure which causes the relay 10 to be maintained in the dropped-out position, irrespective of the position of the relay 6, will effect the safe failure of the apparatus, since the result will be that one or the other of the pairs of contacts 43 and 44, and 53 and 55, will be held out of engagement upon the occurrence of such failure. Therefore, the only failures which would be so-called unsafe failures would be those which would establish the second control effect, wherein the relay 6 is in the dropped-out position while the relay 10 is in the picked-up position. However, it will be shown below that none of the failures likely to occur in such apparatus are operative to establish this second control effect, and hence are not operative to establish an unsafe control action or condition.

As a first example of a possible failure, let it be assumed that the cathode heater of the triode 4 becomes open-circuited. Because of the series energization of the cathode heaters of the triodes 4 and 9, such a failure would render the triode 9 totally non-conductive, whereby the contacts 53 and 55 would be maintained out of engagement. In addition, the resulting inoperative condition of the triode 4 would prevent the oscillator from oscillating, whereby the triode 9 would still be prevented from operatively energizing the relay 10 even if the triode 9 should not be deprived of cathode heater energizing current due to insulation failure or some similar failure in the apparatus.

In a similar manner, noted as a second example, open-circuiting or short-circuiting of the cathode heater of the triode 9 will prevent the operative energization of the relay 10, as will similar failure of the cathode heater of the diode 7.

As a third example, let it be assumed that the cathode heater of the oscillator triode 4 becomes short-circuited. Although this condition will leave the relay 6 in the dropped-out position with the contacts 43 and 44 in engagement, the resulting absence of oscillation will leave the relay 10 in the dropped-out position with the contacts 53 and 55 disengaged.

By way of a fourth example, let it be assumed that the operating winding of either or both of the relays 6 and 10 becomes short-circuited. If only the winding 38 so fails, the apparatus will continue to effect the proper control in the normal manner through the medium of the contacts 53 and 55 of the relay 10. Should the winding 51 alone so fail, the apparatus will fail safely with the contacts 53 and 55 disengaged. A similar condition will be produced upon simultaneous short-circuiting of both of the relay windings 38 and 51. Open-circuiting of either or both of the windings 38 and 51 will cause the apparatus to fail safely, since opening of the winding 38 will deenergize the oscillator triode 4 and will prevent any oscillation thereof, and hence will prevent the operative energization of the relay 10. Obviously, opening of the winding 51 will prevent the relay 10 from assuming the picked-up position.

As a fifth example, let it be assumed that the triode 9 develops a conductive failure or short-circuit between the elements such that the relay 10 is maintained in the picked-up position at all times. For this failure, the apparatus would continue to provide the proper control in the normal manner through the medium of the contacts 43 and 44 of the relay 6.

As a sixth example, it is noted that any conductive failure within the triode 4, such as the short-circuiting of any of the elements thereof, will not only maintain the relay 6 in the picked-up position with the contacts 43 and 44 disengaged, but will also prevent oscillation of the apparatus and hence will maintain the contacts 53 and 55 of the relay 10 out of engagement. Thus the apparatus will fail safely even in the presence of simultaneous conductive failures within both of the triodes 4 and 9.

As a seventh example, it is noted that any component failure which prevents the oscillator portion from oscillating and which either causes or prevents the operative energization of the relay 6 will produce a safe condition wherein the apparatus will fail safely with the relay 10 maintained in the dropped-out position. Such loss of oscillation could be caused by the open-circuiting or short-circuiting of any or all of the coils 27, 28, and 29, for example.

By way of an eighth example, let it be assumed that the coil 28 becomes open-circuited, whereby the relay 6 remains in the dropped-out position by virtue of the opening of its energizing circuit through the coil 28. Under these conditions, the presence of the coupling condenser 48 and the choke 49 prevents the anode voltage from being rectified by the tubes 4 and 7 in series, and hence prevents the triode 9 from operatively energizing the relay 10.

As a ninth and final example, it is noted that if the contacts of either of the relays 6 and 10 become welded or otherwise held in the engaged position, the proper control will be effected by whichever of the contacts are not so restricted.

It is believed that the foregoing description and examples clearly point out and describe the manner in which the various relays and associated components of the apparatus are operative to provide a novel and highly advantageous form of control which is characterized by safe-failure provisions for all of the component and similar failures most likely to occur in and in connection with apparatus of the type described.

While, in accordance with the provisions of the statutes, we have illustrated and described the best form of the invention now known to us, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention as set forth in the appended claims, and that in some cases certain features of the invention may sometimes be used to advantage without a corresponding use of other features.

Having now described our invention, what we claim as new and desire to secure by Letters Patent is as follows:

1. Control apparatus, comprising a portion including a load circuit and means adjustable to cause said portion to assume one or another condition, means adapted to produce current flow of a first magnitude in said load circuit when said portion assumes one of said conditions and to produce current flow of substantially smaller magnitude in said load circuit when said portion assumes the other of said conditions, a responsive means connected to said portion, responsive solely to the condition assumed thereby, and including an output circuit, means included in said responsive means and adapted to produce current flow of a first magnitude in said output circuit when said portion assumes said other of said conditions and to produce current flow of substantially smaller magnitude in said output circuit when said portion assumes said one of said conditions, and first and second current responsive devices individually connected in said load and output circuits, respectively, each of said responsive devices being adapted to assume a first condition when the current flow in the respective circuit has the respective one of said smaller magnitudes, to assume a second condition when the last mentioned current has the respective one of said first magnitudes, and to assume said first condition when there is substantially no current flow in the respective circuit.

2. Apparatus as specified in claim 1, including contact means adapted to be controlled by said responsive devices jointly and adapted to produce a first control effect whenever said second device assumes said first condition, adapted to produce a second control effect whenever said first device assumes said first condition and said second device assumes said second condition simultaneously, and adapted to assume said first control effect whenever said first device assumes said second condition.

3. Control apparatus, comprising an oscillator portion including a load circuit and an element adjustable to cause and prevent oscillation of said portion, energizing means adapted to produce current flow in said load circuit, means adapted to cause said current to have a first value when said portion is not oscillating and to have a substantially lower value when said portion is oscillating, a responsive means connected to said portion, responsive solely to the oscillation and non-oscillation thereof, and including an output circuit, energizing means adapted to produce current flow in said output circuit, means included in said responsive means and adapted to cause the last mentioned current to have a first value when said portion is oscillating and to have a substantially lower value when said portion is not oscillating, and first and second current responsive devices individually connected in said load and output circuits, respectively, each of said responsive devices being adapted to assume a first condition when the current in the respective circuit has the respective one of said lower values, to assume a second condition when the last mentioned current has the respective one of said first values, and to assume said first condition when there is substantially no current flow in the respective circuit.

4. Control apparatus, comprising an oscillator portion including a load circuit and an element adjustable to cause and prevent oscillation of said portion, a first relay device having an operating winding connected in said load circuit, means adapted to connect said load circuit to a source of energizing current, bias means connected in said oscillator portion and adapted to cause current of a first value to flow in said winding when said portion is prevented from oscillating and to cause current of a substantially smaller value to flow in said winding when said portion is oscillating, a responsive means connected to said portion, responsive solely to the oscillation and non-oscillation thereof, and including an output circuit, a second relay device having an operating winding connected in said output circuit, means adapted to connect said output circuit to a source of energizing current, means included in said responsive means and adapted to cause current of a first value to flow in the last mentioned winding when said portion is oscillating and to cause current of a substantially smaller value to flow in said last mentioned winding when said portion is prevented from oscillating, and separate contact means individual to each of said relays, each of said contact means being adapted to be actuated into a first position when the current in the respective winding has the respective one of said smaller values, to be actuated into a second position when the current in the respective winding has the respective one of said first values, and to be actuated into said first position in the absence of current flow in the respective winding.

5. Apparatus as specified in claim 4, wherein each of said contact means is connected in series with the other between a pair of terminals, and wherein a circuit is completed between said terminals solely when the contact means individual to said first relay device assumes said first position and the contact means individual to said second relay device simultaneously assumes said second position.

6. Apparatus as specified in claim 4, wherein the one of said contact means which is individual to said first relay device includes first and second contacts which are adapted to be closed when the last mentioned contact means is actuated into said first position and to be open when said last mentioned contact means is actuated into said second position, wherein the other of said contact means includes third and fourth contacts which are adapted to be open when said other contact means is actuated into said first position and to be closed when said other contact means is actuated into said second position, and wherein said first, second, third, and fourth

contacts are adapted to be connected in series between a pair of control terminals.

7. Control apparatus, comprising an oscillator portion including input, output, and load circuits, adjustable means adapted, when adjusted in one manner, to couple said input and output circuits for the production of an oscillation signal by said portion, and adapted, when adjusted in another manner, to prevent the production of said signal by said portion, a first relay device having an operating winding connected in said load circuit, means adapted to connect said load circuit to a source of energizing current, bias means connected in said portion and adapted to cause current of a first value to flow in said winding when said portion is prevented from oscillating and to cause current of a substantially smaller value to flow in said winding when said oscillation signal is present, rectifying means connected to said portion and adapted to derive a unidirectional control signal from said oscillation signal, when present, control means having an input portion and an output portion, a second relay device having an operating winding connected in said output portion, means adapted to connect said output portion to a source of energizing current, means connecting said rectifying means to said input portion for the application of said control signal thereto, said control means being adapted to cause current of a first value to flow in the last mentioned winding in the presence of said control signal and to cause current of a substantially smaller value to flow in said last mentioned winding when said control signal is absent, and separate contact means individual to each of said relays, each of said contact means being adapted to be actuated into a first position when the current in the respective winding has the respective one of said smaller values, to be actuated into a second position when the current in the respective winding has the respective one of said first values, and to be actuated into said first position in the absence of current flow in the respective winding.

8. Control apparatus, comprising an oscillator portion including a first electron tube having anode, control grid, and cathode elements, adjustable coupling means interconnecting said elements and adapted, when adjusted to provide one value of coupling, to cause the oscillation of said portion, and adapted, when adjusted to provide another value of coupling, to prevent the oscillation of said portion, a first relay device having an operating winding, conductors connecting said winding and said anode and cathode in series between a pair of terminals adapted to be connected to a source of energizing current, bias means connected between said cathode and said control grid and adapted to increase the conductivity of said tube when the oscillation of said portion is prevented and to decrease said conductivity when said portion is oscillating, contact means included in said device and adapted to be actuated by said winding into a first position when said conductivity is reduced and into a second position when said conductivity is increased, a second electron tube having anode, control grid, and cathode elements, a second relay device having an operating winding, conductors connecting the last mentioned winding and the anode and cathode of said second tube in series between said terminals, a rectifier and an impedance element connected in series between points in said portion between which said portion is adapted to produce an oscillation signal when oscillating, conductors connecting said element between the control grid and cathode of said second tube and adapted to increase the conductivity of said second tube when said portion is oscillating and to decrease the last mentioned conductivity when the oscillation of said portion is prevented, and contact means included in said second device and adapted to be actuated by said last mentioned winding into a first position when the conductivity of said second tube is reduced and into a second position when the last mentioned conductivity is increased.

9. Apparatus as specified in claim 8, wherein said impedance element is a condenser.

10. Apparatus as specified in claim 8, including a pair of terminals adapted to be connected to a source of bias voltage, wherein said element is connected between the control grid and cathode of said second tube in series with the last mentioned terminals, and wherein the last mentioned connection is adapted to drive the last mentioned cathode positive with respect to the last mentioned control grid when the oscillation of said portion is prevented.

11. Control apparatus, comprising an electronic oscillator having input and output circuits, a first electro-responsive device having an operating portion effectively included in said output circuit, an impedance device effectively coupled to one of said circuits and adapted to have produced between its terminals a voltage drop of a magnitude dependent upon the state of oscillation of said oscillator, a repeater device having an output circuit and having an input circuit coupled to said impedance device for the control of the last mentioned output circuit in accordance with changes in said voltage drop across said impedance device, a second electro-responsive device having an operating portion effectively included in said repeater output circuit, and means adapted to vary a characteristic of said oscillator which varies the state of oscillation thereof, said first electro-responsive device being adapted to be operatively energized and deenergized, respectively, accordingly, as said oscillator is not or is oscillating, and the other of said electro-responsive devices being adapted to be operatively energized and deenergized, respectively, accordingly as said oscillator is or is not oscillating.

12. Apparatus as specified in claim 11, wherein said oscillator includes a first electron tube having an anode and a cathode connected in series with the operating portion of said first electro-responsive device in said oscillator output circuit, wherein said repeater device includes a second electron tube having an anode and a cathode connected in series with the operating portion of said second electro-responsive device in said repeater output circuit, and wherein said second tube also includes a control grid connected in series with the last mentioned cathode across said impedance device in said repeater input circuit.

13. Apparatus as specified in claim 11, wherein each of said electro-responsive devices is a relay having a contact portion adapted to be controlled solely in accordance with the operative energization and deenergization of the operating portion of the device, and wherein said contact portions are interconnected and adapted to produce a first control effect whenever said second device is not operatively energized, a second control effect when said second device is operatively

energized but said first device is not operatively energized, and said first control effect whenever said first device is operatively energized.

14. Apparatus as specified in claim 13, wherein the contact portion of said first device includes first and second contacts which are adapted to be closed when said first device is not operatively energized and to be open when said first device is operatively energized, wherein the contact portion of said second device includes third and fourth contacts which are adapted to be open when said second device is not operatively energized and to be closed when said second device is operatively energized, and wherein said first, second, third, and fourth contacts are adapted to be connected in series between a pair of control terminals.

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