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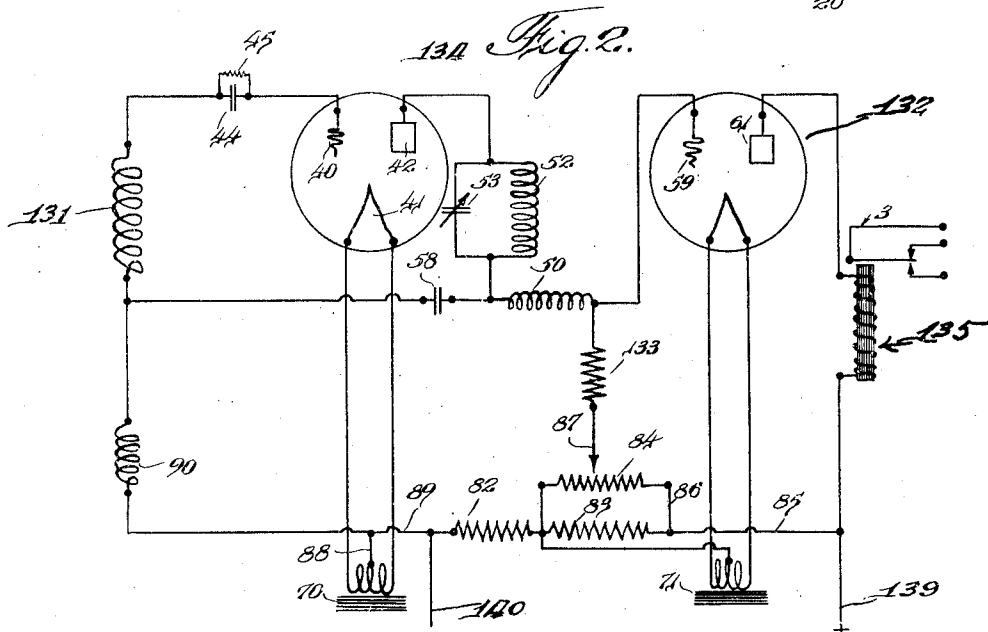
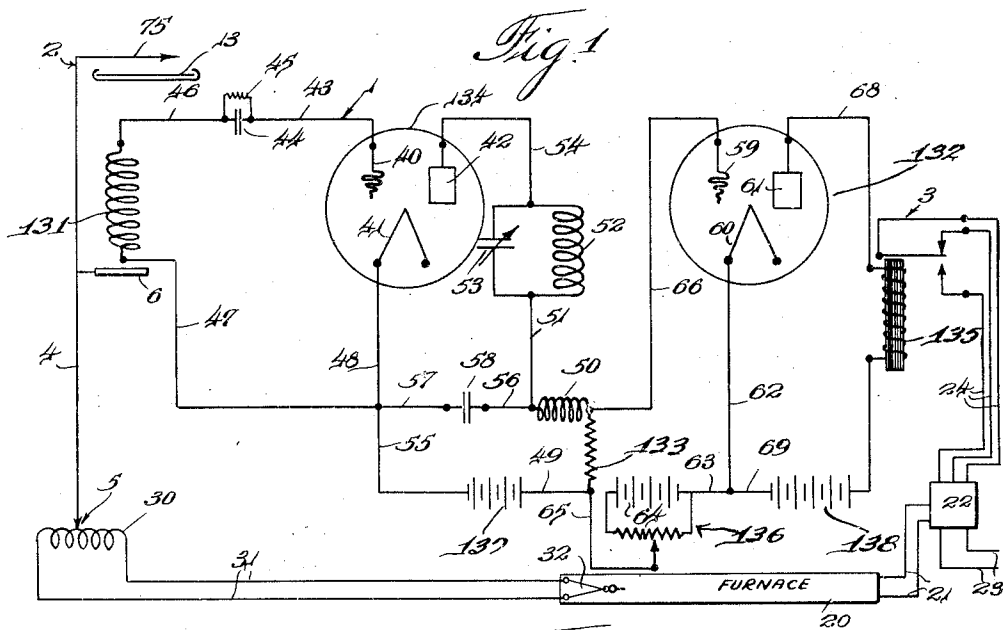
T. A. COHEN

2,228,163

ELECTRICAL CONTROL APPARATUS

Filed April 27, 1936

3 Sheets-Sheet 1



INVENTOR.

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Jan. 7, 1941.

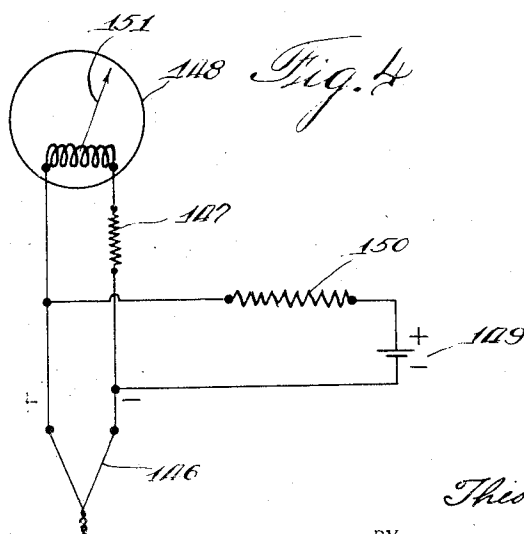
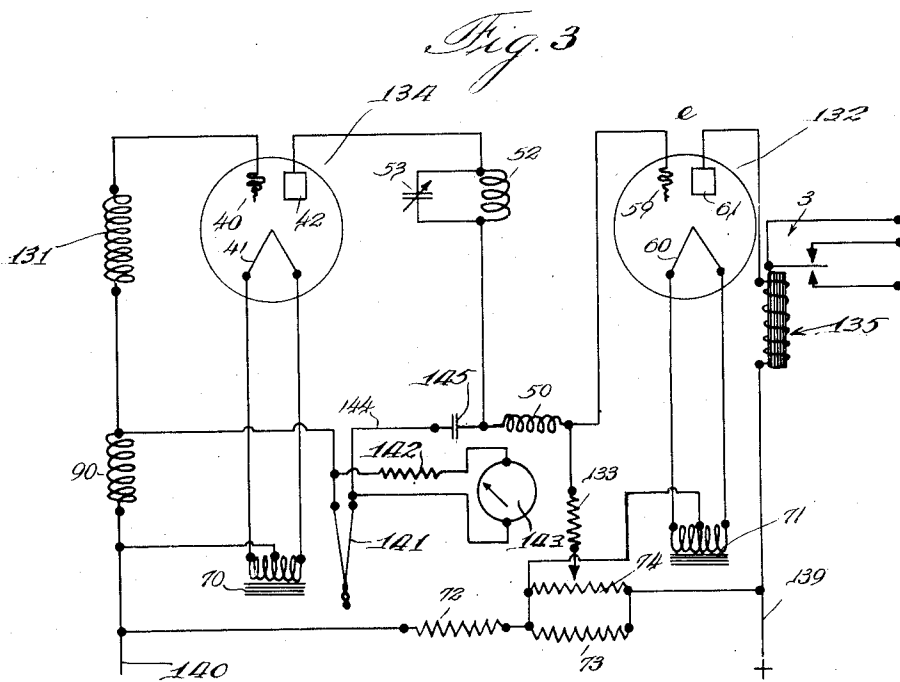
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ELECTRICAL CONTROL APPARATUS

Filed April 27, 1936

3 Sheets-Sheet 2



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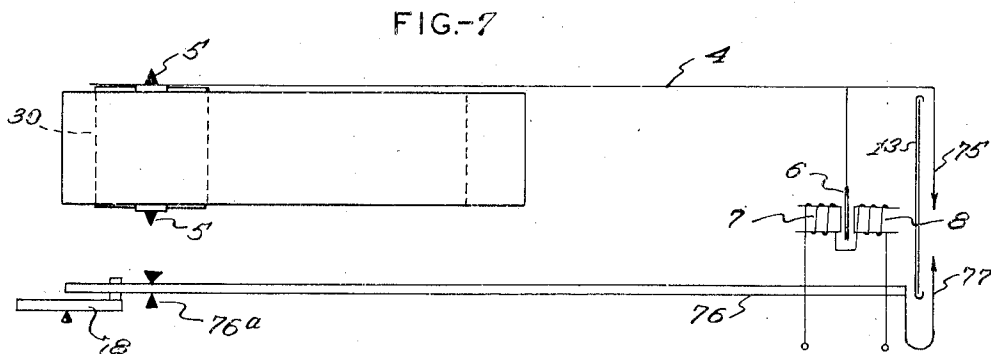
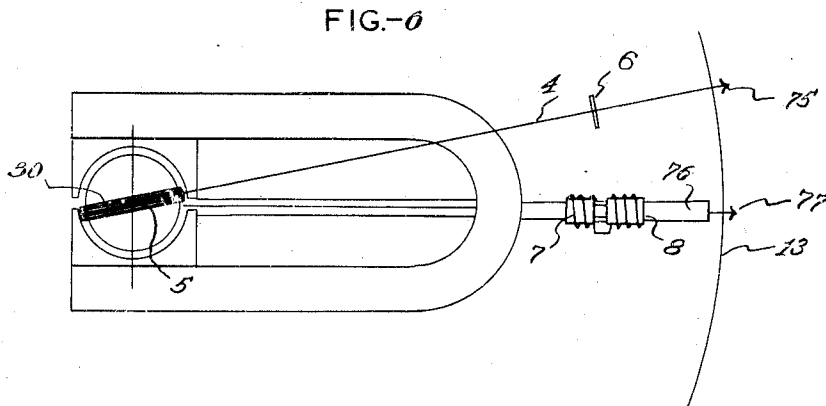
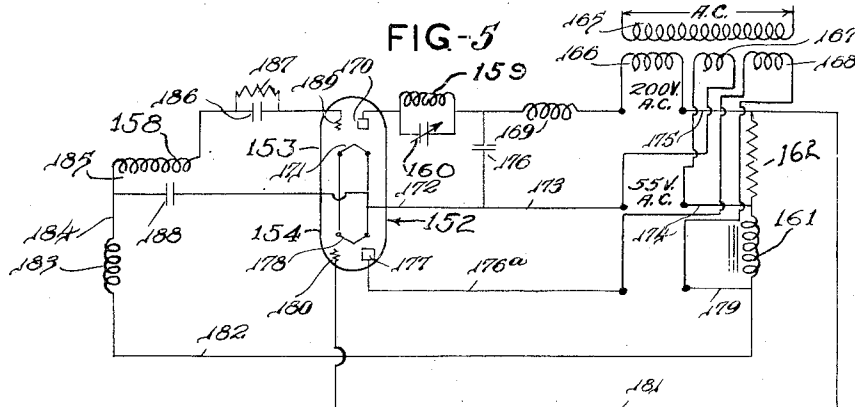
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ELECTRICAL CONTROL APPARATUS

Filed April 27, 1936

3 Sheets-Sheet 3



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2,228,163

ELECTRICAL CONTROL APPARATUS

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Application April 27, 1936, Serial No. 76,708

23 Claims. (Cl. 236—69)

My invention relates to electrical control apparatus.

One of the objects of my invention is to provide improved apparatus for enabling a vacuum tube oscillator to control a relay, which apparatus does not necessitate the engagement and disengagement of contacts for controlling the oscillator.

A further object of my invention is to provide such an apparatus which will be accurate and reliable in operation.

When a relay to be controlled by an oscillator circuit is directly connected for energization from the oscillator circuit itself, it is necessary to provide an extremely sensitive relay because of the small magnitude of the oscillator output current. Such sensitive relays require frequent and precise adjustment, and it is accordingly a further object of my invention to provide a control apparatus of the type indicated in which sensitive relays are eliminated and which provides a high degree of consistency of operation with a minimum amount of servicing.

Further objects and advantages of the invention will appear from the description and claims.

In the drawings, in which several embodiments of my invention are shown,

Figure 1 illustrates somewhat diagrammatically a control apparatus embodying my invention applied to the control of an electric furnace or the like;

Fig. 2 is a diagrammatic view showing another form of apparatus and circuit embodying my invention;

Fig. 3 shows still another form;

Fig. 4 is a fragmentary circuit diagram illustrating another arrangement of a sensitive instrument and thermo couple circuit for use in the control apparatus of Figs. 1, 2, and 5;

Fig. 5 is a circuit diagram illustrating what is now considered to be a preferred embodiment of my invention;

Fig. 6 is a plan view showing a preferred form of contactless control apparatus and sensitive instrument means, such as a voltmeter, for use in connection with the circuits and apparatus shown in Figs. 1 to 5, inclusive; and

Fig. 7 is a side elevation of the apparatus shown in Fig. 6.

In the specific embodiments shown, the apparatus and circuits in general include an oscillator circuit having a load impedance in the output circuit, an amplifier or repeater tube controlled by the voltage drop across the load impedance, a relay controlled by the output circuit

of the repeater or amplifier tube, and a contactless means for affecting the tuning of the oscillator circuit, thereby causing a change in the current flowing through the load impedance to control the repeater tube and effect the operation of the relay. As is well known in this art, the plate current of an oscillator in oscillating condition is of a fixed value, depending upon plate voltage and grid bias. When the oscillator goes out of oscillation or oscillation changes occur, the grid bias changes, causing a change in plate current. In the specific embodiment shown, I provide contactless apparatus comprising sensitive instrument means responsive to a condition to be controlled for affecting the oscillator circuit, thus causing a change in the oscillator plate current flowing through the load impedance, and take advantage of this current change for controlling the relay so as properly to control the condition to which the sensitive instrument means is responsive.

The apparatus and circuit of Fig. 1 comprises, as will be more fully described hereinafter, an oscillator circuit 1 which includes a tuning coil 131, contactless sensitive instrument means 2 for affecting the oscillator circuit, and relay apparatus 3, controlled by the oscillator output change for controlling a condition to which the sensitive instrument means 2 is responsive. As shown in Fig. 1, the condition to be controlled is the temperature of an electric furnace 20, shown diagrammatically as including a heating circuit 21 connected through suitable contactors or other control apparatus 22 to a suitable source of energy represented by the supply conductors 23. The control apparatus 22, which may be of any suitable type well known in the art, is connected through a plurality of control wires 24 to the contacts of the relay 3, whereby operation of the relay effects corresponding operation of the control apparatus 22 to control the heating circuit of the furnace 20. The sensitive instrument means 2, as shown best in Figs. 6 and 7, comprises a pointer or arm 4 mounted to swing about a pivot 5 and carrying a leaf or flag 6 of a metallic substance which, in the movement of the arm 4 about its pivot, swings between a pair of coils 7 and 8. In Fig. 1 the tuning coil 131, which corresponds to the coils 7 and 8 of Figs. 6 and 7, is shown as a single coil, but it may obviously be formed in two parts corresponding to coils 7 and 8 of Figs. 6 and 7.

The arm 4, on which the leaf or flag 6 is mounted, preferably carries an indicating pointer 15 cooperating with a scale 13 and may be

part of any sensitive indicating system, such as a voltmeter or the like. The metallic leaf may be of any suitable shape or form and may be formed from any suitable metal or metals, depending upon the characteristics desired.

In Fig. 1 the sensitive instrument means 2, the detailed construction of which will be more fully described in connection with Figs. 6 and 7, is shown as including an operating winding 30 connected through suitable conductors 31 to a thermo couple 32 located within the furnace 20 so as to be influenced by the temperature of the furnace. As will be apparent to those skilled in the art, fluctuations of the furnace temperature affect the thermo couple 32 so as to vary the energization of the winding 30, whereby fluctuations in the furnace temperature are converted into corresponding movements of the arm 4 and the flag 6, movement of the flag 6 being effective, through the circuits shown in Fig. 1, to control the relay means 3, as will be hereinafter described, and thus control the heating circuit of the furnace.

Referring now to Figs. 6 and 7 which show one form of the sensitive instrument means 2 illustrated diagrammatically in Fig. 1, this sensitive instrument means, as shown, constituting a D'Arsonval type indicating movement, such as a voltmeter comprising a movable coil 30 and a pointer 4 pivotally mounted at 5, having an index finger 75 cooperating with an arcuate scale 13 and carrying the flag 6 which cooperates with the coils 7 and 8 to affect the tuning of the oscillator circuit. These coils 7 and 8 may be mounted on a setting lever 76 which may be pivotally mounted at 76a coaxially with the pointer 4 and which setting lever may also carry an index finger 77 cooperating with the arcuate scale 13 and which setting lever 76 may be set to any desired position by means of any suitable lever adjusting mechanism 78. As indicated above, when the flag 6 closely approaches the coils 7 and 8, an oscillator circuit will be affected, causing the operation of a relay. Such apparatus is useful in various situations, and in Fig. 1 is shown in connection with furnace temperature control, in which case the voltage controlling the position of the voltmeter pointer 4, as hereinbefore indicated, is produced by a thermo couple so that when the voltage occasioned by the action of the thermo couple causes the flag to approach closely the coils 7 and 8, the relay will be operated to control the furnace temperature in any suitable manner.

Considering now the embodiment of the invention shown in Fig. 1, the oscillator circuit, indicated generally by the reference numeral 1, includes an electron discharge device or vacuum tube 134 having a control electrode or grid 40 and a pair of output electrodes comprising a cathode or filament 41 and an anode or plate 42. As shown, the input or grid circuit of the tube 134 extends from the control electrode 40, through the conductor 43, the usual grid condenser 44 and grid leak 45, and through the conductor 46 to the upper end of the tuning coil 131, the circuit being completed from the lower end of the coil 131 through a conductor 47 and a conductor 48 which is connected to the filament or cathode 41.

The output circuit of the tube 134, as shown, is supplied from a battery 137, although obviously other suitable energy sources may be used, and this output circuit may be traced from the positive side of the battery through the conduc-

tor 49, a load impedance or resistor 133, a radio frequency choke coil 50, a conductor 51, a tank circuit including an inductance 52 and a variable condenser 53, and through the conductor 54 to the anode or plate 42. From the other side 5 of the battery the output circuit may be traced through the conductors 55 and 48 to the filament 41 and a by-pass circuit including conductors 56 and 57, and a by-pass condenser 58 is connected between the conductors 51 and 48, 10 which by-pass circuit, in conjunction with the choke coil 50, prevents the flow of high frequency oscillatory currents through the load impedance 133 and the battery 137, only the non-pulsating component of the plate current flowing through 15 the load impedance and the battery.

As will be apparent to those skilled in the art, a fixed grid bias is applied to the control electrode 40 due to the grid leak 45 and the grid condenser 44, and the above-described input circuit of the tube 134 constitutes a tuned circuit by reason of the distributed capacity of the tuning coil 131. Thus, when the output or plate circuit of the tube 134 is tuned by adjustment of the condenser 53, so that the plate circuit is 25 in resonance with the grid or input circuit, the metal flag 6 being remote from the tuning coil 131 so that the coil is not affected thereby, sustained oscillations will be produced by the tube 134, the necessary feed-back coupling being provided by the interelectrode capacity of the tube and the by-pass condenser 58.

The vacuum tube constants of the oscillator 134 are so chosen that in the normal oscillating condition the non-pulsating component of the 35 plate current through the resistor 133 is low.

In order to effect operation of the relay 3 in response to changes in the plate current of the oscillator circuit 1, a repeater or amplifier tube 132 is provided having an input electrode or grid 40 59, and output electrodes including a filament 60 and a plate 61. As shown, the load impedance 133 is common to both the output circuit of the oscillator tube 134 and the input circuit of the repeater tube 132, the latter circuit extending 45 from the filament 60 through the conductors 62 and 63, the potentiometer 136 which is connected across a suitable bias battery 64, a conductor 65, the load impedance 133, and by way of a conductor 66 to the input electrode or grid 50 59. Normally with the oscillator tube 134 in oscillatory condition, the potentiometer 136 is adjusted so as to provide a voltage slightly less than the voltage drop across the load impedance 133, and accordingly a small negative bias is 55 applied to the grid circuit of the tube 132, the voltage drop across the load impedance being due to the flow of normal low plate current in the oscillatory circuit.

The output circuit of the tube 132 is energized, 60 as shown, from a suitable battery 138 and extends from the positive side of the battery through the conductor 67, the winding 135 of the relay 3, and by way of a conductor 68 to the plate 61. From the other side of the battery 138, this output circuit extends through conductors 69 and 62 to the filament 60. With a small negative bias on the grid 59, as indicated above, a relatively large current flows in the output circuit of the tube 132 and the winding 135 is accordingly en- 70 ergized so as to operate the movable contact of the relay 3 from the uppermost position shown in Fig. 1 into engagement with the lower stationary contact of the relay, engagement of these contacts being effective to energize a control cir- 75

cuit including the conductors 24 so as properly to operate the furnace controlling contactors indicated diagrammatically at 22.

Upon the occurrence of a predetermined change in the temperature existing within the furnace 20, the thermo couple 32 and the energizing winding 30 of the sensitive instrument means 2 are affected so as to move the arm 4 and cause the metal flag 6 to approach the tuning coil 131 and effect a change in the tuning of the oscillator tube 134. Upon the vacuum tube oscillator 134 being affected by the approachment of the flag 6 to the coil 131 so as to disrupt the oscillatory condition, the plate current of the oscillator increases, causing a corresponding increase in the voltage drop across the load impedance 133 and a similar increase in the negative bias upon the vacuum tube 132. As a result of the increased negative bias on the input circuit thereof a consequent large decrease occurs in the plate current of the tube 132. This change in plate current correspondingly decreases the energization of the winding 135 of the relay 2 which controls the external contacting apparatus to the furnace 20, the movable contact of the relay 2 being released for movement to the uppermost position shown in Fig. 1. As indicated above, a fixed grid bias for the vacuum tube 132 to prevent cut off, due to the normal drop through the resistor 133 is derived from the potentiometer 136 and is of such value and nature as to allow the grid circuit of the tube 132 to be placed in the proper operating condition for efficient relay action.

The construction shown in Fig. 2 is quite similar in most respects to that of Fig. 1 except that in Fig. 2 the apparatus is operated from an ordinary rectified alternating current power supply 139, 140, the rectifier not being shown as it is well known in the art. These circuits may also be operated from unrectified alternating current in a so-called self-rectifying state as will of course be understood by those skilled in the art.

Since the operation and arrangement of the embodiment shown in Fig. 2 is so similar in its fundamental aspects to the embodiment of Fig. 1, it is not believed necessary to trace in detail all of the individual circuits, similar reference numerals being used to identify similar parts in the two embodiments. In Fig. 2, the sensitive instrument means for controlling the tuning of the coil 131 and the means controlled by the relay 3 have been omitted in order to simplify the drawings, but it will of course be understood that the embodiment shown in Fig. 2 is intended for use with similar means. The cathodes or filaments 41 and 60 are shown in Fig. 2 as connected to the midpoints of the secondary windings of suitable filament heating transformers 70 and 71, and it will of course be understood that similar heating means may be associated with the filaments of all of the embodiments of the invention herein shown, such heating means being omitted from Figs. 1 and 5 in order to simplify the drawings.

In Fig. 2 a potentiometer, comprising a pair of fixed resistors 82 and 83 and an adjustable resistor 84, is connected across the source of supply represented by the supply conductors 139 and 140. The output circuit of the oscillator tube 134 extends from the positive source of supply 139 through the conductors 85 and 86, the right-hand portion of the resistor 84 and the adjustable terminal 87 of the potentiometer, the load impedance 133, the choke coil 50, the plate tank circuit including the inductance 52 and the condenser 53,

the plate 42, the filament 41, the conductors connecting the filament to the heating transformer 70, and through the conductors 88 and 89 to the negative source of supply 140 which is connected to the left-hand fixed terminal of the potentiometer. The by-pass circuit for preventing the flow of radio frequency energy through the load impedance 133 and for providing suitable feed-back coupling to the input circuit of the tube 134, is similar to the embodiment shown in Fig. 1 in that it includes a coupling and blocking condenser 58. If desired, an additional inductance coil 99 may be included, as shown in Fig. 2, in the grid circuit between the tuning coil 131 and the filament 41.

It is thought that the remaining circuits in the embodiment shown in Fig. 2 will be obvious without further description, in view of the description already given in connection with Fig. 1, and it will of course be understood that the potentiometer utilized in Fig. 2 is so adjusted that the voltage drop across the left-hand portion of the resistor 84 corresponds to the voltage supplied by the bias battery 64, the potentiometer 136 of Fig. 1 thereby compensating for a portion of the normal voltage drop across the load impedance 133 and applying a desired minimum negative potential to the grid 59 of the tube 132 when the oscillator tube 134 is in oscillatory condition.

Fig. 3 shows apparatus and circuit similar to that of Fig. 2 but arranged so that a thermo couple 141 corresponding to the thermo couple 32 of Fig. 1, an associated line resistor 142 and a sensitive instrument means or indicator meter 143 corresponding to the sensitive instrument means 2 of Fig. 1, are included in the feed-back circuit of the oscillator.

In control apparatus, such as being discussed, it is very important that in case of thermo couple breakage, the apparatus be turned to "off" position. If this is not done, the possibility of the furnace being left in the "on" position is present, which might result in a furnace burn-out, which in commercial work is serious.

The circuit and apparatus of Fig. 3 is designed to obviate this condition of the furnace being left in "on" position in case of thermo couple breakage.

Referring further to Fig. 3, since from the above explanation it will be understood that in the normal operating condition the plate current of the oscillator 134 is of low value, it follows that if the feed-back coupling circuit or oscillator return lead 144 from the coupling condenser 145, which corresponds to the coupling condenser 58 of Figs. 1 and 2, is open, the plate current will immediately rise, due to the cessation of oscillation.

This rise of the plate current flowing through the load impedance 133 will cause a drop in the plate current of the vacuum tube 132, as hereinbefore explained, with a consequent opening of the relay. This operation takes place if the thermo couple 141 which is in series with the condenser 145 in the feed-back circuit burns out or opens, leaving closed the feed-back circuit 65 through the resistance 142 and meter 143. Since the oscillator circuit constants are so chosen that a small increase in resistance in the oscillator return lead will cause the oscillator to go out of oscillation, protection from furnace burn-out due to thermo couple breakage is assured.

It will of course be understood that the thermo couple 141 of Fig. 3 corresponds to the thermo couple 32 of Fig. 1, and in actual operation would be subjected to the furnace temperature or the

condition to be controlled so as to operate the sensitive instrument means 143, the pointer of which carries a metal flag (not shown) corresponding to the flag 6 on the pointer 4 of Fig. 1 for controlling the tuning coil 131. In Fig. 3 no attempt has been made to show the instrument 143 in its proper relation to the coil 131, since by positioning the instrument 143 as shown in Fig. 3 the illustration of the circuit connections is greatly simplified.

In Fig. 4 is shown a form of apparatus to insure protection from furnace burn-out, due to thermo couple breakage, wherein the protective apparatus is external to the oscillator circuits of the control apparatus. In this figure the apparatus shown includes a thermo couple 146, a pyrometric multiplier non-inductive resistor 147, with low temperature coefficient, well known in the art, and an instrument indicator 148 which may be of the usual millivoltmeter type connected across the thermo couple. To this circuit is connected in proper polarity a battery 149 in series with a higher resistance 150. The pointer 151 of the millivoltmeter may carry a flag which will cooperate with the pick-up coils of an oscillator circuit, such as previously described in connection with Figs. 1 and 2, to control the operation of a relay which controls the temperature of a furnace or the like with which the thermo couple is associated.

Normally, because of the very low resistance of the commercial thermo couple, the voltage drop across the thermocouple 146 from the battery resistor circuit is very low, very much smaller than can be discerned upon the scale of the indicator. However, should the thermocouple 146 break or burn out, a large voltage is immediately occasioned across the thermocouple terminals, with an immediate throwing of the pointer of the millivoltmeter 148 to the top portion of the scale where it will be in juxtaposition to the pick-up coils of the oscillator control apparatus, such as previously described, causing a change in tuning of the oscillator and a consequent action of the relay controlled thereby to cause the furnace temperature to be reduced.

In Fig. 5 is shown a circuit arrangement which constitutes a preferred embodiment of my invention and in which a dual type of vacuum tube 152 is used, the method of operation being intended to simulate the action of a "Thyratron" tube of the self-rectified type, with alternating current grid voltage used for control without the necessity of the use of either the hot or cold cathode type grid control rectifier, which is commonly called the electron tube. With the circuit as shown, plate current changes take place between cut-off and saturation, without any intermediate plate current fixation. The operation of the circuit is as follows: One triode portion 153 of the dual type tube 152 is connected in a simple oscillator type circuit, consisting of plate tank 159, 160 and grid coil 158, with its associated grid leak and condenser 186 and 187. The grid coil 158 is so arranged as to be affected by the approachment of a flag such as previously described (not shown).

Alternating current voltages are obtained from a multi-winding transformer having a primary winding 165 connected to a suitable source of alternating current, as indicated, and having a plurality of secondary windings 166, 167, and 168 respectively arranged to supply suitable voltages to the tube circuits. Although my invention is not limited thereto and other suitable voltages

may be employed, the secondary windings 166, 167, and 168 in the embodiment illustrated are arranged to supply voltages of the magnitudes indicated in Fig. 5, i. e., 200 volts, 55 volts, and 185 volts respectively. For simplicity of description, these voltages will be considered as instantaneous values, the voltages across each of the secondary windings of the transformer being at all times in phase with each other, and since the tube sections 153 and 154 function as rectifiers the operation will be described only with respect to the positive half cycles of the alternating current voltages.

The output circuit of the oscillator tube section 153 may be traced from the left-hand or positive terminal of the secondary winding 166 through a radio frequency choke coil or inductance 169, the plate tank circuit 159, 160, the anode or plate 170, the cathode or filament 171, the conductors 172 and 173, the secondary winding 167, the voltage of which is in phase with the voltage of the winding 166, the conductor 174, the load impedance or resistor 162, and by way of the conductor 175 to the right-hand terminal of the secondary winding 166. A by-pass condenser 176 is connected, as shown, and in conjunction with the choke coil 169 prevents the flow of high frequency oscillatory currents through the transformer windings and through the load impedance 162. As will be apparent, the total voltage thus impressed across the load circuit of the tube section 153 in the embodiment shown, is the sum of the voltages of the secondary windings 166 and 167, i. e., 255 volts.

The output circuit for the repeater or amplifier tube section 154 may be traced from the left-hand or positive terminal of the secondary winding 168 through the conductor 176a, the anode or plate 177, the cathode or filament 178, the conductors 172 and 173, the secondary winding 167, the voltage of which is in phase with the voltage of the winding 168, the conductor 174, the operating winding 161 of the relay, and by way of the conductor 179 to the left-hand terminal of the secondary winding 168. Thus a total voltage of 240 volts is impressed on the load circuit of the amplifier tube section. It will of course be understood that the relay winding 161 corresponds to the winding 135 of the relay 3 in the embodiments shown in Figs. 1, 2, and 3, and is arranged to control suitable apparatus such, for example, as the furnace shown in Fig. 1, in the manner hereinbefore described.

The grid bias for effecting proper operation of the repeater tube section 154 is obtained in a manner similar to the hereinbefore described embodiments of the invention by connecting the grid or control electrode 180 to one end of the load resistor 162 through a conductor 181, the remaining portion of this circuit extending from the filament 178 through the conductors 172 and 173, the secondary transformer winding 167, and the conductor 174 to the opposite end of the load resistor 162. It will be apparent that the voltage across the winding 167 is in opposition to and thus compensates for a portion of the voltage drop across the load impedance 162, and accordingly when the oscillator section 153 is in oscillatory condition so that a plate current of low value flows through the load impedance 162, a minimum negative bias equal to the difference between the voltage of the winding 167, i. e. 55 volts and the voltage drop across the load impedance is impressed on the grid 180. The tube constants and the value of the load resistance

are so prechosen as to provide a slightly negative grid bias under these conditions corresponding to the maximum amplifier output current desired for proper operation of the relay.

5 An important feature of this embodiment of my invention resides in the connections for the input or grid circuit of the oscillator section 153, a regenerative coupling being provided between the grid 189 of the oscillator section and the
10 output circuit of the repeater section. As shown, the grid circuit for the oscillator tube section extends from the cathode or filament 171 through the conductors 172 and 173, the transformer winding 167, the conductor 174, the relay wind-
15 ing 161, a conductor 182, a radio frequency choke coil 183, conductors 184 and 185, the tuning coil 158, and by way of a suitable grid condenser and grid leak 186 and 187 to the grid or input electrode 189. A suitable blocking or by-pass
20 condenser 188 is connected between the filament 171 and the oscillator grid circuit as shown.

It will be apparent from the above-traced circuit that a fixed grid bias is applied to the grid 189 which is equal to the voltage drop across the
25 relay winding 161 minus the voltage of the winding 167, and the resistance of the winding 161 is so chosen that with maximum current flowing in the output circuit of the amplifier tube section the maximum desired negative bias is ap-
30 plied to the grid 189 of the oscillator section.

As heretofore explained in connection with Fig. 1, the plate tank circuit is tuned to resonance with the tuning coil in the oscillator grid circuit, with the metal flag in a position remote
35 from the tuning coil, so that sustained oscillations are produced by the oscillator tube section. With the metallic flag in a remote position relative to the pick-up coil 158, the oscillator portion is in a normal state of oscillation with
40 plate current of a low value, with the result that a low voltage drop exists across the load resistor 162 and a corresponding small bias is applied to the input circuit of the amplifier section 154, which positions its plate current rather high up
45 on its grid voltage plate current graph. All conditions are in a state of stability.

Upon the flag approaching the pick-up coil 158, the oscillator circuit is de-tuned, causing its plate current to rise sharply, increasing the
50 voltage drop across the resistor 162, which correspondingly increases the negative bias upon the amplifier section 154, with a consequent drop in its plate current through the relay 161. The decrease in current through the relay 161 causes
55 a decrease in the negative grid bias applied to the grid of the oscillation section 153, which tends to further increase the plate current of the oscillator section 153. This increase in the oscillator plate current further increases the
60 voltage drop across the load resistor 162 and the negative bias upon the amplifier section 154 with the consequent effect of dropping the amplifier plate current to the cut-off point, which causes zero level in plate current. When the flag re-
65 ceedes from the pick-up coil 158, the reverse occurs. The oscillator plate current drops, decreasing the drop across resistor 162, which decreases the negative bias on the amplifier section 154; the plate current of the amplifier section
70 tends to increase, increasing the drop across the relay 161, which increases the negative bias on the grid of the oscillator 153, aiding in dropping the oscillator section plate current, which further tends to decrease the bias upon the am-
75 plifier section 154, etc., with the result that the

final positioning of the plate current of amplifier section 154 is at saturation. By the judicious choosing of load resistance 162, of the resistance of the relay winding 161 and the proper apportioning of bias voltages as shown, the
5 limits of plate current between cut-off and saturation may be fixed at any desired value. The result is that control of this plate current change is always maintained with the obtaining of abrupt plate current changes of a very rapid
10 nature. The result obtainable is comparable to the triggering off of a "Thyratron" type hot cathode grid control rectifier without the necessity of using gas-filled tubes.

It is not necessary that the apparatus be
15 limited to the use of a dual purpose vacuum tube, containing double triode elements, since this type of tube has been only chosen as a matter of convenience. Separate triode elements may be operated in the same manner
20 with either alternating current or direct current voltages applied, the use of the self-rectified circuit being only a matter of choice or convenience as is readily apparent.

In summary, the advantages of this circuit are
25 manifest, inasmuch as a relay with a high throw-out percentage is not necessary, since the plate current changes through said relay are very rapid and very large. It is impossible to lose control of the oscillator, since, because of
30 the fact that it is self-rectified, oscillations, no matter how minute, will always reoccur. Other variations of this circuit will readily occur to those versed in the art, such as the use of a
35 common power supply, with a self-rectified circuit, instead of separate voltages as shown. Such circuits have been designed and are entirely feasible, the one shown being one of a family of such circuits and being chosen as the most
40 descriptive of the above-explained operation.

Further modifications will be apparent to those skilled in the art and it is desired, therefore, that the invention be limited only by the prior art and the scope of the appended claims.

Having thus described my invention, what I
45 claim and desire to secure by Letters Patent is:

1. In a control system, the combination of a vacuum tube oscillator having input and output
50 circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled to said load impedance to control the output circuit of said repeater in accordance with changes in the voltage drop across said load impedance, an electro-responsive device having an operating winding
55 effectively included in said repeater output circuit, and means responsive to a condition to be controlled by said electro-responsive device for affecting the tuning of said oscillator circuit to vary the voltage across said load impedance
60 whereupon said repeater causes operation of said electro-responsive device.

2. In a control system, the combination of a vacuum tube oscillator having tuned input and
65 output circuits, a load impedance effectively included in said output circuit adapted to be traversed only by the nonpulsating component of the current in said output circuit, a vacuum tube repeater having an input circuit coupled
70 to said load impedance for energization in accordance with the voltage drop across said impedance, a repeater output circuit, a relay having an operating winding connected in said repeater output circuit, and means responsive to
75 a condition controlled by operation of said relay

including a part movable toward and away from a portion of said oscillator input circuit to change the tuning of said oscillator, whereby the voltage drop across said load impedance is varied to effect operation of said relay.

3. In a control system, the combination of an oscillator circuit including input and output circuits coupled with the input and output electrodes of an electron discharge device, means including a variable position control element responsive to a condition to be controlled, said element being movable with respect to a portion of said oscillator circuit to change the tuning thereof, a load impedance effectively included in said output circuit so as to be traversed only by the non-impulsing component of the output current, an amplifier circuit including input and output circuits coupled with the input and output electrodes of a second electron discharge device, said amplifier input circuit being so coupled with said load impedance as to vary the amplifier output current in accordance with changes in the voltage across said load impedance, and an electro-responsive device controlled by said amplifier output current for controlling said condition upon movement of said variable position control element.

4. In a control system, an electron discharge tube comprising two sections each including input and output electrodes, a tuned input circuit coupled between the input electrodes of one of said sections, a tuned output circuit coupled between the output electrodes of said one section, said tuned circuits being so coupled as to provide for operation of said one section as an oscillator, an input circuit coupled between the input electrodes of the other of said sections, an output circuit coupled between the output electrodes of said other section, said last mentioned input and output circuits providing for operation of said other section as a repeater, impedance means common to said oscillator output circuit and said repeater input circuit for causing variations in the current flow in said repeater output circuit upon changes in the tuning of said oscillator section, means movable with respect to a portion of one of said circuits of said oscillator section to change the tuning thereof, and relay means responsive to the consequent changes in the output current of said repeater section.

5. In a control system, an electron discharge tube comprising two sections each including input and output electrodes, a tuned input circuit coupled between the input electrodes of one of said sections, a tuned output circuit coupled between the output electrodes of said one section, said tuned circuits being so coupled as to provide for operation of said one section as an oscillator, an input circuit coupled between the input electrodes of the other of said sections, an output circuit coupled between the output electrodes of said other section, said last mentioned input and output circuits providing for operation of said other section as a repeater, impedance means common to said oscillator output circuit and said repeater input circuit for causing variations in the current flow in said repeater output circuit upon changes in the tuning of said oscillator section, an electro-responsive device having an operating winding effectively included in said repeater output circuit for operating said device in response to predetermined changes in the output current, and means responsive to changes in a condition controlled by said electro-responsive device including a variable position part

movable with respect to a portion of one of said oscillator circuits for changing the tuning thereof and causing operation of said electro-responsive device.

6. In a control system, the combination of a vacuum tube oscillator having tuned input and output circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled for energization in accordance with the voltage across said load impedance, an output circuit for said repeater, an electro-responsive device having a winding effectively included in said repeater output circuit, means movable with respect to a portion of said oscillator for affecting the tuning thereof to vary the current flowing in said oscillator output circuit and said load impedance whereby the input circuit of said repeater is influenced to cause a change in the energization of said winding, and a coupling between said winding and said oscillator input circuit for causing a cumulative change in the output of said oscillator in response to said change in the energization of said winding so as further to change the energization of said winding, whereby minute movements of said means to vary the tuning of said oscillator effect sharp variations in the output current of said repeater between cut-off and saturation quickly to operate said electro-responsive device.

7. In a control system, the combination of a vacuum tube oscillator having tuned input and output circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled for energization in accordance with the voltage across said load impedance, an output circuit for said repeater, an electro-responsive device having a winding effectively included in said repeater output circuit, means movable with respect to a portion of said oscillator for affecting the tuning thereof to vary the current flowing in said oscillator output circuit and said load impedance whereby the input circuit of said repeater is influenced to cause a change in the energization of said winding, and means coupling said winding with said oscillator input circuit so proportioned and arranged that changes in the energization of said winding are reflected through said oscillator and repeater to cause further changes in the energization of said winding in a cumulative sense, whereby a change in the tuning of said oscillator of sufficient magnitude to effect a change in the output current of said repeater causes a sharp variation of said output current between cut-off and saturation quickly to operate said electro-responsive device.

8. In a control system, the combination of a vacuum tube oscillator having tuned input and output circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled for energization in accordance with the voltage across said load impedance, an output circuit for said repeater, an electro-responsive device having a winding effectively included in said repeater output circuit, means movable with respect to a portion of said oscillator for affecting the tuning thereof to vary the current flowing in said oscillator output circuit and said load impedance whereby the input circuit of said repeater is influenced to cause a change in the energization of said winding, and a regenerative coupling between said winding and said oscillator input circuit for effecting a sharp variation of the repeat-

er output current between saturation and cut-off in response to a change in the tuning of said oscillator independently of the magnitude of said change and the degree of movement of said movable means.

9. In a control system, the combination of an oscillator circuit including input and output circuits coupled with the input and output electrodes of an electron discharge device, a variable position control element responsive to a condition to be controlled and movable with respect to a portion of said oscillator circuit to change the tuning thereof, an amplifier circuit including input and output circuits coupled with the input and output electrodes of a second electron discharge device, means coupling said amplifier input circuit with said oscillator output circuit whereby a change in the tuning of said oscillator circuit effects a change in the output current of said amplifier, an electro-responsive device having an operating winding adapted to operate said device between two positions upon changes of predetermined magnitude in said amplifier output current, and a regenerative coupling between said winding in said amplifier output circuit and said oscillator input circuit for effecting a sharp variation of said amplifier output current between cut-off and saturation in response to an initial change in the tuning of said oscillator of sufficient magnitude to effect a slight change in said amplifier output current, whereby said electro-responsive device is quickly operated between said two positions in response to a critical movement of said control element regardless of the magnitude or speed of said movement.

10. In a control system, an electron discharge tube comprising two sections each including input and output electrodes, a tuned input circuit coupled between the input electrodes of one of said sections, a tuned output circuit coupled between the output electrodes of said one section, said tuned circuits being so coupled as to provide for operation of said one section as an oscillator, an input circuit coupled between the input electrodes of the other of said sections, an output circuit coupled between the output electrodes of said other section, said last mentioned input and output circuits providing for operation of said other section as a repeater, impedance means common to said oscillator output circuit and said repeater input circuit for causing variations in the current flow in said repeater output circuit upon changes in the tuning of said oscillator section, means movable with respect to a portion of one of said circuits of said oscillator section to change the tuning thereof, relay means responsive to predetermined changes in the output current of said repeater section, and a regenerative coupling between said repeater output circuit and said oscillator input circuit for effecting a sharp variation of said repeater output current upon a slight change in the tuning of said oscillator section quickly to operate said relay means independently of the magnitude of said change in tuning.

11. In a temperature control system, the combination with an electro-responsive device for controlling the temperature source and temperature responsive means affected by the temperature of said source, of a vacuum tube oscillator having input and output circuits at least one of which is tuned to provide sustained oscillations, said output circuit being effectively coupled to said electro-responsive device to control the oper-

ation thereof, a variable position part connected for operation by said temperature responsive means, said part being movable to effect the tuning of said oscillator, and means for controlling said oscillator to effect operation of said electro-responsive device upon interruption of said connection between said temperature responsive means and said variable position part.

12. In a temperature control system, the combination with a relay for controlling the temperature source and a thermocouple circuit affected by the temperature of said source, of a vacuum tube oscillator having tuned input and output circuits, means for effecting operation of said relay in response to changes in the current in said output circuit, an instrument having a variable position part controlled by said thermocouple circuit, said variable position part being arranged upon movement thereof to affect the tuning of said oscillator input circuit whereby operation of said relay is accomplished, and means for effecting operation of said relay upon interruption of said thermocouple circuit.

13. In a temperature control system, the combination with a relay for controlling the temperature source and a thermocouple circuit affected by the temperature of said source, of a vacuum tube oscillator having tuned input and output circuits, means for effecting operation of said relay in response to changes in the current in said output circuit, an instrument having a variable position part controlled by said thermocouple circuit, said variable position part being arranged upon movement thereof to affect the tuning of said oscillator input circuit whereby operation of said relay is accomplished, and means for effecting a change in the tuning of said oscillator upon interruption of said thermocouple circuit to cause operation of said relay.

14. In a temperature control system, the combination with a relay for controlling the temperature source and a thermocouple circuit affected by the temperature of said source, of a vacuum tube oscillator having tuned input and output circuits, means for effecting operation of said relay in response to changes in the current in said output circuit, an instrument having a variable position part controlled by said thermocouple circuit, said variable position part being arranged upon movement thereof to affect the tuning of said oscillator input circuit whereby operation of said relay is accomplished, and means effectively coupling said thermocouple circuit with said oscillator input circuit to effect a change in the current flowing in the said oscillator output circuit upon interruption of said thermocouple circuit thereby to cause operation of said relay.

15. In a temperature control system, the combination with a relay for controlling the temperature source and a thermocouple circuit affected by the temperature of said source, of a vacuum tube oscillator having tuned input and output circuits, means for effecting operation of said relay in response to changes in the current in said output circuit, an instrument having a variable position part controlled by said thermocouple circuit, said variable position part being arranged upon movement thereof to affect the tuning of said oscillator input circuit whereby operation of said relay is accomplished, and means for effecting movement of said variable position part upon interruption of said thermocouple circuit to change the tuning of said oscillator and cause operation of said relay.

16. In combination, an electron discharge tube having input and output circuits adapted to be tuned to resonance to cause said tube to operate as an oscillator, a load impedance effectively included in said output circuit so as to be traversed only by the non-pulsating component of the oscillator output current, whereby the voltage drop across said impedance increases when the oscillatory condition of said tube varies from resonance, a repeater tube having input and output circuits, a source of biasing potential, and means connecting said load impedance and said source in series relation in said repeater input circuit with the voltage of said source in opposition to and of less magnitude than said voltage drop when said oscillator is in resonant condition, whereby the resulting bias voltage impressed on said repeater input circuit is a desired minimum during resonant conditions and increases to a desired maximum upon the cessation of oscillations to control the output of said repeater tube.

17. In combination, a vacuum tube oscillator having tuned input and output circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled for energization in accordance with the voltage across said load impedance, whereby changes in the tuning of said oscillator are effective to control said repeater, an output circuit for said repeater, and means coupling said output circuit of said repeater with said input circuit of said oscillator so proportioned and arranged that changes in the output of said repeater tube are reflected through said oscillator and repeater to cause further changes in the output of said repeater in a cumulative sense, whereby a change in the tuning of said oscillator of sufficient magnitude to effect an initial change in the output of said repeater causes a sharp variation of said repeater output between cut-off and saturation.

18. In combination, a vacuum tube oscillator having tuned input and output circuits, a load impedance effectively included in said output circuit, a vacuum tube repeater having an input circuit coupled for energization in accordance with the voltage across said load impedance, whereby changes in the tuning of said oscillator are effective to control said repeater, an output circuit for said repeater, and a regenerative coupling between said repeater output circuit and said oscillator input circuit for effecting a sharp variation of the repeater output current between saturation and cut-off in response to a change in the tuning of said oscillator independently of the magnitude of said change.

19. In combination, an electron discharge tube having tuned input and output circuits coupled for the generation of sustained oscillations upon proper tuning thereof, a load impedance effectively included in said output circuit so as to be traversed only by the non-pulsating component of the current in said output circuit whereby the voltage drop across said impedance varies with variations in the tuning of said circuits, a repeater tube having input and output circuits, a source of biasing potential, means connecting said load impedance and said source in series relation in said repeater input circuit with the voltage of said source in opposition to and of less magnitude than said voltage drop when said tuned circuits are in resonance, whereby a desired minimum bias is impressed on said repeater input circuit which increases with changes in the tuning of said tuned circuits, and a regenerative coupling

between said repeater output circuit and said tuned input circuit for varying in a cumulative sense the energization of said tuned input circuit upon a change in tuning of said tuned circuits of sufficient magnitude to effect a change in the repeater output current, whereby a sharp variation of said repeater output current between saturation and cut-off without intermediate fixation is caused by a slight change in the tuning of said tuned circuits.

20. In a temperature control system, the combination with an electro-responsive device for controlling a temperature source and temperature-responsive means affected by the temperature of said source, of a vacuum tube oscillator having input and output circuits tuned to provide sustained oscillations, a load impedance effectively included in said output circuit for traversal only by the non-pulsating component of the oscillator output current whereby the voltage drop across said impedance increases when the oscillatory condition of said tube varies from resonance, a repeater tube having input and output circuits, a source of bias potential, means connecting said load impedance and said source in series relation in said repeater input circuit with the voltage of said source in opposition to and of less magnitude than said voltage drop when said oscillator is in resonant condition, whereby the resulting bias voltage impressed on said repeater input circuit is a desired minimum during resonant conditions, said electro-responsive device being effectively coupled in the output circuit of said repeater tube for operation in response to variations in the repeater output current, a variable position part connected for operation by said temperature-responsive means, said part being movable to control the tuning of said oscillator and thereby increase to a desired maximum the voltage drop across said impedance and the bias voltage impressed on said repeater input circuit upon the cessation of oscillations, whereby operation of said electro-responsive device is effected, and means for so controlling said oscillator as to effect operation of said electro-responsive device upon interruption of said connection between said temperature-responsive means and said variable position part.

21. In a control system, the combination of an electron discharge tube having input and output circuits adapted to be tuned to resonance to cause said tube to operate as an oscillator, a load impedance effectively included in said output circuit so as to be traversed only by the non-pulsating component of the oscillator output current, whereby the voltage drop across said impedance increases when the oscillatory condition of said tube varies from resonance, a repeater tube having input and output circuits, an electro-responsive device having an operating winding effectively included in said repeater output circuit, a source of biasing potential, means connecting said load impedance and said source in series relation in said repeater input circuit with the voltage of said source in opposition to and of less magnitude than said voltage drop when said oscillator is in resonant condition, and means responsive to a condition to be controlled by said electro-responsive device for varying the tuning of said oscillator from said resonant condition, whereby the resulting bias voltage impressed on said repeater input circuit is a desired minimum during resonant conditions and increases to a desired maximum when operation of said condition-responsive means to

cause a cessation of oscillations, said increase in the resulting bias voltage being effective to control the output of said repeater tube and cause operation of said electro-responsive device.

5 22. In a temperature control system, the combination of an electron discharge tube having input and output circuits adapted to be tuned to resonance to cause said tube to operate as an
10 oscillator, a load impedance effectively included in said output circuit so as to be traversed only by a non-pulsating component of the oscillator output current, whereby the voltage drop across
15 said impedance increases when the oscillatory condition of said tube varies from resonance, a repeater tube having input and output circuits, a source of biasing potential, means connecting
20 said load impedance and said source in series relation to said repeater input circuit with the voltage of said source in opposition to and of less magnitude than said voltage drop when said oscillator is in resonant condition, an electro-responsive
25 device having an operating winding effectively included in said repeater output circuit for controlling a source of temperature in response to variations in the energization of said winding, and temperature-responsive means affected
30 by the temperature of said source including a variable position part movable to control the tuning of said oscillator circuit, whereby the bias voltage impressed on said repeater input circuit varies from a desired minimum during resonant
35 conditions to a desired maximum upon movement of said variable position part to cause a cessation of oscillations, said variation in the bias voltage controlling the output of said re-

peater tube to operate said electro-responsive device in accordance with a change in the temperature of said source.

23. In combination, an electron discharge tube comprising two sections each including input and output electrodes, a tuned input circuit coupled between the input electrodes of one of said sections, a tuned output circuit coupled between the output electrodes of said one section, said tuned circuits being so coupled as to provide for operation of said one section as an oscillator, a load impedance effectively included in said output circuit so as to be traversed only by a non-pulsating component of the oscillator output current, whereby the voltage drop across said impedance increases when the oscillatory condition of said tube varies from resonance, an input circuit coupled between the input electrodes of the other of said sections, an output circuit coupled between the output electrodes of said other section, the last-mentioned input and output circuits providing for operation of said other section as a repeater, a source of biasing potential, and means connecting said load impedance and said source in series relation in said repeater input circuit with the voltage of said source in opposition to and of less magnitude than the said voltage drop when said oscillator section is in resonant condition, whereby the resulting bias voltage impressed on said repeater input circuit is a desired minimum during resonant conditions and increases to a desired maximum upon the cessation of oscillations to control the output of said repeater tube section.

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