

Aug. 2, 1960

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2,947,875

ELECTRICAL CONTROL APPARATUS

Filed July 23, 1954

2 Sheets-Sheet 1

FIG. 1

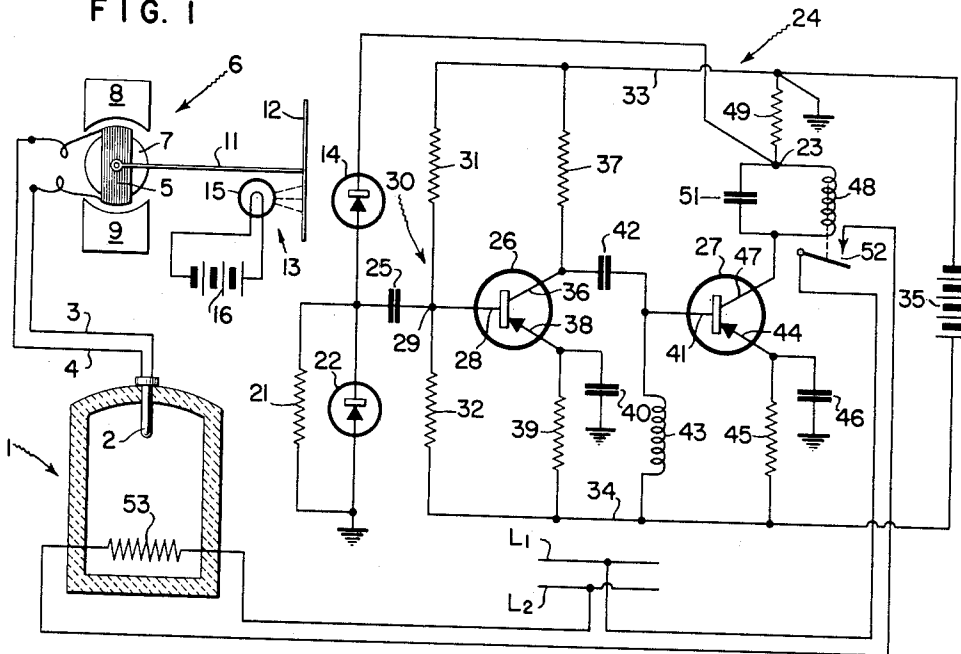
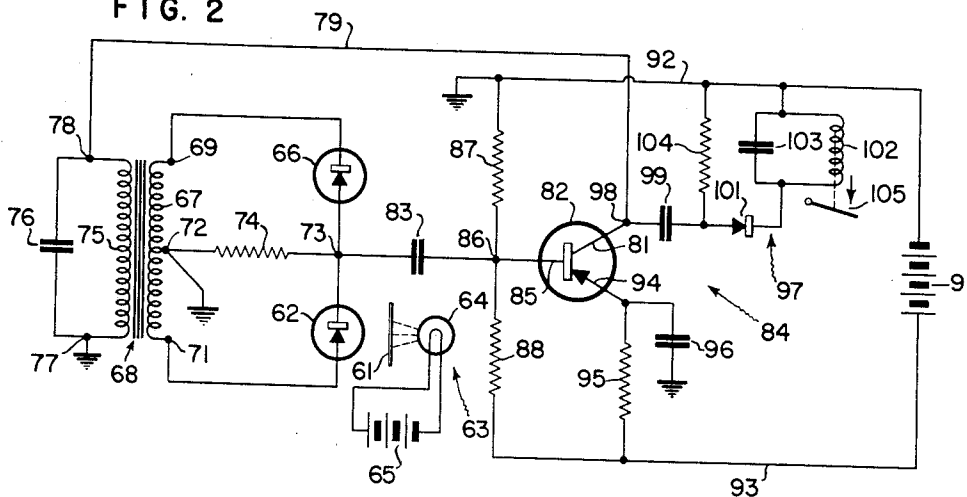


FIG. 2



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FIG. 3

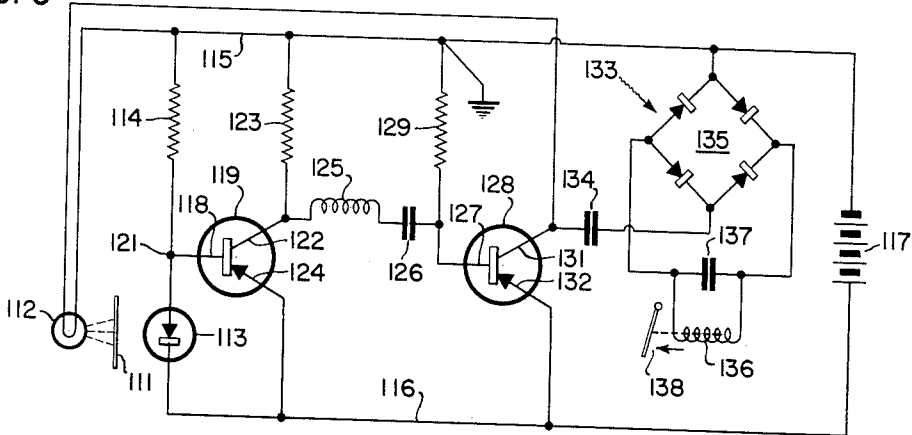


FIG. 4

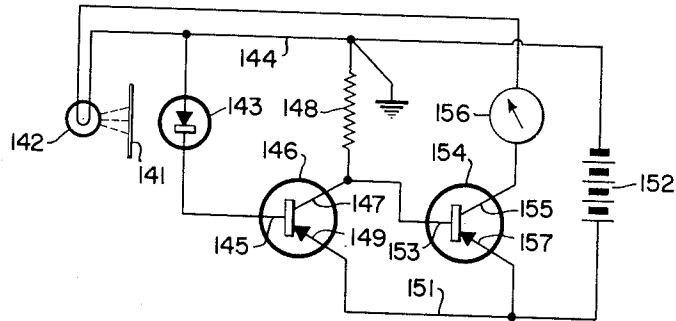
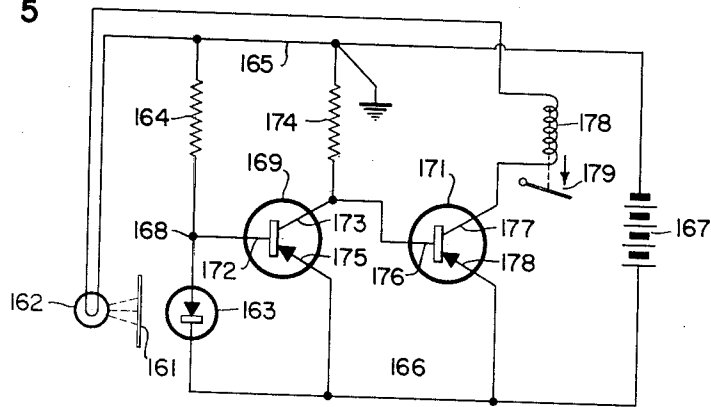


FIG. 5



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ELECTRICAL CONTROL APPARATUS

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19 Claims. (Cl. 250-214)

A general object of the present invention is to provide a new and improved electrical control apparatus. More specifically, the present invention is concerned with a controller of the type in which a galvanometer, responsive to the condition being controlled, is employed to position a vane relative to some electrical means sensitive to the presence of the vane.

Galvanometer type vane controllers are widely used in industry as inexpensive process controllers. Such controllers to be acceptable, however, must be arranged so that upon the failure of any component, the controller will operate in such a manner that it will prevent the controlled variable from going in a direction which will cause the destruction of any of the apparatus associated therewith. In addition, such a controller must be adapted to provide stable operation even when subjected to widely varying ambient conditions, particularly that of changing temperature.

A specific object of the present invention is to provide an inexpensive yet reliable controller in which a galvanometer is employed to position a vane so as to regulate the amount of light transmitted from a light source to a photosensitive semiconductor element.

Another specific object of the present invention is to provide a new and improved temperature stabilized vane controller employing both semiconductor photosensitive elements and semiconductor amplifying elements.

Still another specific object of the present invention is to provide a controller in which a signal from a control signal source is modulated by feedback from the output of the control circuit.

A further object of the present invention is to employ feedback from the output of the control circuit to modulate either the amount of light transmitted from a light source to a photosensitive element or to modulate the output of the photosensitive element by controlling the voltage across it.

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

Of the drawings:

Fig. 1 is a circuit diagram of an oscillating photosensitive vane controller in which the photosensitive elements are connected in the feedback loop;

Fig. 2 is a circuit diagram of a modification of the circuit shown in Fig. 1;

Fig. 3 is a circuit diagram of an oscillating photosensitive vane controller in which the light source is connected in the feedback loop;

Fig. 4 is a circuit diagram of a non-oscillating photosensitive motion to current transducer or vane controller in which the light source is connected in a feedback loop

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to produce an output proportional to the displacement of the vane between the light source and a photosensitive element; and

Fig. 5 is a circuit diagram of a non-oscillating photosensitive controller in which the light source is connected in the feedback loop to obtain "snap action" relay operation.

Referring now to Fig. 1, there is shown an embodiment of the present invention adapted to control the operation of the furnace 1. The temperature of the furnace 1 is sensed by means of the thermocouple 2 which is connected through the conductors 3 and 4 to the moving coil 5 of the galvanometer 6. In addition to the coil 5, the galvanometer 6 includes the cylindrical core piece 7, the magnetic poles pieces 8 and 9, and the arm 11 which carries an opaque vane or light shield 12. Current flowing in the coil 5 produces a flux field which interacts with the flux field set up by the pole pieces 8 and 9 to position the arm 11 and the vane 12 with respect to the light source 13 and the photosensitive semiconductor diode 14. The light source 13 is shown here as a lamp 15 energized by the battery 16.

The photodiode 14 is connected in series with the parallel circuit comprising the resistor 21 and the photodiode 22 between ground and the junction point 23 in the output circuit of the amplifier 24. The light source 13, the galvanometer 6, and the photodiodes 14 and 22 together with the resistor 21 form a control signal source which is coupled to the input of the amplifier 24 by means of a capacitor 25.

The amplifier 24 is a two-stage reactively coupled amplifier employing transistors 26 and 27 as its amplifying elements. The transistors 26 and 27 are pnp junction type transistors having the usual collector, emitter, and base electrodes. The base 28 of the transistor 26 is connected to the junction point 29 of the resistors 31 and 32. The resistors 31 and 32 are connected in series to form a voltage divider 30 between the conductors 33 and 34 which are connected to a source of direct current, shown here as the battery 35. The collector 36 of the transistor 26 is connected through the resistor 37 to the conductor 33. The emitter 38 of the transistor 26 is connected to the conductor 34 through the resistor 39 which is by-passed to ground by means of the capacitor 40. The collector 36 of the transistor 26 is coupled to the base 41 of the transistor 27 through the capacitor 42. Base 41 of the transistor 27 is also connected to the conductor 34 through the inductor 43. The emitter 44 of the transistor 27 is connected to the conductor 34 through the resistor 45 which is by-passed to ground by means of the capacitor 46. The collector 47 of the transistor 27 is connected through the relay coil 48 to the junction point 23 which, in turn, is connected to the conductor 33 through the resistor 49. The relay coil 48 is shunted by the capacitor 51. The relay 48 has a pair of contacts 52 which are connected in series with the heating element 53 of the furnace 1 and a suitable source of electrical power represented by the conductors L_1 and L_2 . The relay 48 is thus operative to control the heating of the furnace 1.

In considering the operation of the oscillating controller shown in Fig. 1, the photosensitive diodes 14 and 22 can be considered as constituting a single ended photomodulator with an output determined by the illumination of the diode 14. The controller is constructed so that the diode 22 is shielded from the lamp 15, the light from which falls on the diode 14 as the vane is withdrawn. In addition, the diode 22 is mounted adjacent to the diode 14 so that it is subject to approximately the same ambient temperature. Since the temperature sensitive reverse current flow from the diode 22 flows in the resistor 21 in such a direction as to oppose the potential

drop across this resistor due to the temperature sensitive reverse current of the diode 14, the diode 22 compensates for changes in temperature. As a result, the diode 14 produces an output in accordance with the voltage applied across it and the degree of its illumination.

The thermocouple 2 and the galvanometer 6 cooperate in such a manner that upon a decrease in the temperature of the furnace 1, the vane 12 is withdrawn from the light path between the lamp 15 and the photodiode 14. As this occurs, the increased illumination of the diode 14 will cause an increased current flow through the resistor 21. This will raise the potential with respect to ground of the junction point 29 in the voltage divider 30 and hence decrease the negative base current flowing in the transistor 26. As this negative base current decreases, the transistor collector current decreases lowering the potential with respect to ground of the collector 36 and the potential of the base 41 of the transistor 27 coupled thereto. This causes an increase in the negative base current flowing in that transistor which results in an increase transistor collector current. As the current in the collector circuit of the transistor 27 increases, the potential with respect to ground of the junction point 23 is raised, since the potential of the junction point 23 is the potential across the photo-modulator circuit, the output from that circuit is increased which, in the manner just described, causes a still further increase in the potential of the junction point 23. This regenerative process causes sustained oscillations to occur at a frequency determined by the phase shift and amplitude characteristics of the amplifier gain. The maximum amplitude of these oscillations is determined by the limiting action of either the photodiode modulator or saturation of one of the transistors. The system thus oscillates until the vane 12 is repositioned so as to again shield the photodiode 14 from the light of the lamp 15.

The transistor 27 is initially biased near the collector current cut-off condition. As oscillations build up, the average value of collector current increases to a value sufficient to activate the relay 48. The voltage across this relay is maintained constant by the capacitor 51 and the relay is activated as long as oscillations are maintained. When the relay 48 is activated, the contacts 52 are closed energizing the heating element 53 of the furnace 1 to restore the temperature condition within the furnace to the desired level. When the temperature condition within the furnace reaches a desired level, the thermocouple 2 responsive to that condition will cooperate with the galvanometer 6 to position the vane 12 so as to again shield the photosensitive diode from the light of the lamp 15.

Several features of the circuit configuration employed in the controller shown in Fig. 1 serve to make it a highly practical control apparatus. The energization of the relay 48 is accomplished for the most part by the increase in the D.C. component of the transistor collector current caused by the application of a suitable alternating signal to the base of the transistor 27. In this respect, the use of the inductor 43 instead of a resistor in the base circuit permits higher average base current and hence higher average collector current to be obtained for a given A.C. signal level.

In addition to the use of the photodiode 22 to compensate for changes in the output of the photodiode 14 with temperature, several other features of the circuit of Fig. 1 help to make it a highly temperature stable controller. The resistor 39 in series with the emitter 38 of the transistor 26 provides, in cooperation with the voltage divider 30, a means for obtaining transistor bias with minimum dependence on the temperature sensitive collector saturation current (I_{co}) of the transistor. The low D.C. resistance of the inductor 43 used to connect the base 41 of the transistor 27 to conductor 34, and the resistor 45 in series with the emitter 44 minimize changes with temperature in the bias and hence the collector cur-

rent of that transistor. The coupling capacitor 42 tends to prevent the amplification of changes in the D.C. operating point of the transistor 26 in the second amplifier stage.

To be acceptable, any controller must be arranged so that upon the failure of any component, the control apparatus will operate in such a manner as to prevent the controlled variable from going in a direction which will cause the destruction of any of the apparatus associated therewith. With regards to the safe failing features of the apparatus shown in Fig. 1, it should be noted that any failure causing a loss of the oscillating control signal to the input of the last amplifier stage will render the relay 48 inoperative to hold the contacts 52 in engagement. For example, the short circuiting of the photosensitive diode 22, or the transistor 26, cause the loss of the A.C. signal to the last amplifier stage and consequently safe failure. Similarly, any open circuit condition causing the loss of the A.C. control signal to the last amplifier stage will prevent activation of the relay 48, assuring safe failure.

The frequency of oscillation of this system depends primarily upon the value of the capacitor 42 and the inductor 43 and to a lesser extent upon the values of certain other circuit components. By way of illustration and example, and not by way of limitation, the following list of components is typical for the embodiment of the invention shown in Fig. 1 and provide a highly effective and practical controller which oscillates at about 2000 c.p.s.

Resistor 21.....	120,000 ohms.
Resistor 31.....	15,000 ohms.
Resistor 37.....	6,800 ohms.
Resistors 32 and 39.....	10,000 ohms.
Resistors 45 and 49.....	100 ohms.
Capacitor 46.....	5.0 mfd.
Capacitors 25 and 42.....	0.1 mfd.
Capacitors 40 and 46.....	1.0 mfd.
Inductor 43.....	0.5 henries, 30 ohms D.C.
Lamp 15.....	(Mazda) #17.
Photodiodes 14 and 22.....	(Radio Research and Development Corp.) #RD1795.
Transistor 26.....	2N34.
Transistor 27.....	(Honeywell) 2N57.
Relay 48.....	1250 ohms coil, 250 milli-watts.
Supply voltage.....	30 volts D.C.

Referring now to Fig. 2, there is shown a circuit diagram of a modification of the circuit shown in Fig. 1. The numeral 61 indicates an opaque vane or light shield which is positioned between the photosensitive diode 62 and the light source 63. The light source 63 is shown here as a lamp 64 energized by means of the battery 65. The photosensitive diode 62 is connected in series with a photosensitive diode 66 across the secondary winding 67 of the transformer 68. The secondary winding 67 of the transformer 68 has end terminals 69 and 71 and a center tap 72. The junction point 73 between the photodiode 66 and 62 is connected through the resistor 74 to the center tap 72 of the secondary 67 of the transformer 68. As shown, the center tap 72 is connected to ground. The transformer 68 has a primary winding 75 shunted by the capacitor 76 and having one end terminal 77 connected to ground and its other end terminal 78 connected by means of the conductor 79 to the collector 81 of the transistor 82.

The transformer 68 and the photosensitive diodes 62 and 66 constitute a phase sensitive photo-modulator which is coupled by means of the capacitor 33 to the input of a single stage transistor amplifier 84. The amplifier 84 employs the transistor 82 as its amplifying element. The transistor 82 is a pnp junction type transistor having the usual collector, emitter, and base electrodes. The base 85 of the transistor 82 is connected

to the junction point 86 between the resistors 87 and 88. The resistors 87 and 88 constitute a voltage divider connected across power supply 91 by means of the conductors 92 and 93. As shown, the conductor 92 is grounded. The emitter 94 of the transistor 82 is connected to conductor 93 through a resistor 95 which is by-passed to ground by the capacitor 96. A relay circuit 97 is coupled to the junction zone 98 in the collector circuit of the transistor 82 by means of the coupling capacitor 99. This circuit includes a diode rectifier 101 connected in series with the relay coil 102 between the capacitor 99 and the conductor 92. The relay coil 102 is shunted by the capacitor 103. A D.C. return path for the relay current is provided by the resistor 104 connected between the conductor 92 and the junction of the capacitor 99 and the rectifier 101. The relay 102 has a pair of contacts 105 which may be employed to control an external circuit in accordance with the position of the opaque vane 61 with respect to the light path between the lamp 64 and the photosensitive diode 62.

In the operation of the circuit shown in Fig. 2, photodiodes 62 and 66 constitute a photo-modulator placed in the positive feedback loop of an oscillating system in such a manner that no signal is fed through the modulator unless there is a difference in illumination of the photodiodes. In the construction of this controller, the diode 66 is shielded from the lamp 64, the light from which falls on the diode 62 when the vane 61 is withdrawn. In addition, the photodiodes 62 and 66 are mounted adjacent to one another to insure that they are subject to approximately the same ambient temperature. The temperature sensitive reverse current flow from the diode 66 flows in the resistor 74 in such a direction as to oppose the potential across this resistor due to the temperature sensitive reverse current of the diode 62. The diode 66 thus compensates for changes in temperature and the diode 62 produces an output in accordance with the applied voltage and the degree of its illumination.

If the vane 61 is withdrawn from the light path between the lamp 64 and the photodiode 62, the increased illumination of the diode 62 will cause a current to flow through the resistor 74. The direction of this current flow is such as to reduce the potential with respect to ground of the junction point 73 and the junction point 86 coupled thereto. As the potential with respect to ground of the junction point 86 in the voltage divider formed by the resistors 87 and 88 is decreased, the negative base current flowing in the transistor 26 will be increased. As this negative base current increases, the transistor collector current will increase raising the potential with respect to ground of the circuit point 98 and hence the potential across the primary winding 75 of the transformer 68. The increasing current flow through the primary winding 75 of the transformer 68 will induce voltages in the secondary winding 67 of the transformer 68 of such a polarity that the end terminal 69 of the secondary winding 67 is made more positive than the center tap 72 and the center tap 72 is made more positive than the end terminal 71. Since the voltage induced in the secondary winding 67 of the transformer 68 is applied across the photodiodes 66 and 62, the output from diode 62 will be increased, which will still further decrease the potential of the circuit point 73. In the manner just described, the reduction of the potential with respect to ground of the circuit point 73 will cause a still further increase in the potential across the secondary winding 75 of the transformer 68. This regenerative process causes sustained oscillations to occur at a frequency determined by the phase-shift and amplitude characteristics of the system gain. The maximum amplitude of these oscillations is determined by the limiting action of either the photodiode modulator or saturation of the transistor 82. The system will os-

cillate until the vane 61 is repositioned so as to again shield the photodiode 62 from the light of the lamp 64.

The A.C. voltage across the primary winding 75 of the transformer 68 is coupled by the capacitor 99 to the relay circuit 97 wherein the rectifier 101 causes a pulsating unidirectional current to flow through the relay coil 102. Due to the rectifier 101, the relay current will be a pulsating unidirectional current. The voltage across this relay is maintained constant by the capacitor 103. The relay 102 will remain activated as long as the system oscillates and the contacts 105 may thus be utilized to perform a suitable control operation.

From the foregoing it will be apparent that the relay 102 will be energized only when there is an alternating component of the collector current of the transistor 82. Importance of this is readily apparent since changes in transistor collector current due solely to changes in ambient temperature will be ineffective to cause relay operation. This, in addition to the temperature compensation achieved in the photo-modulator circuit, combine to make the controller of Fig. 2 a temperature stable device.

With regards to the safe-failing features of this apparatus, it should be noted that any failure causing the loss of the oscillating control signal will render the circuit ineffective to cause relay operation. For example, the short-circuiting of the elements of the transistor 82 will cause the loss of the A.C. signal, and the system will fail safe. Similarly, any open circuit condition, causing the loss of the A.C. control signal will cause the relay to remain deenergized.

An additional safety feature is provided by the circuitry employed in the phase discriminating photo-modulator circuit. This portion of the apparatus insures that only a properly phased A.C. signal from that circuit will be effective to cause relay energization. Thus, the effects of stray signals which may be picked up will be minimized and the relay will not be falsely energized.

The frequency of oscillation of this system depends primarily upon the value of the capacitor 76 and the various inductances of the transformer 68 and to a lesser extent upon the values of certain other circuit components. With regard to the transformer 68, it should be noted that the impedance of the secondary winding 67 is sufficiently high to limit the current drawn through the photodiodes 66 and 62 in the forward direction. If a transformer with a low impedance secondary is employed, suitable resistors or diodes can be connected in series with the photodiodes 62 and 66 to limit the forward current. By way of illustration, the following list of components is typical of the embodiment of this invention shown in Fig. 2 and provides a highly effective and practical controller which will oscillate at about 120 c.p.s.

Resistor 87	8,200 ohms.
Resistor 95	100 ohms.
Resistor 104	10,000 ohms.
Resistors 74 and 88	100,000 ohms.
Capacitor 76	0.5 mfd.
Capacitors 83 and 99	1.0 mfd.
Capacitors 96 and 103	5.0 mfd.
Lamp 15	Mazda #47.
Photodiodes 62 and 66	(Radio Research and Development Corp.) #RD1795.
Transistor 82	(Honeywell) 2N57.
Relay 103	4000 ohm coil, 1 milliwatt.
Diode 101	1N34.
Transformer 68	V.T.C. #72876.
Supply voltage	120 volts D.C.

Referring now to Fig. 3, there is shown a circuit diagram of an oscillating photosensitive vane controller in which the light source is connected in the feedback loop. The number 111 refers to an opaque vane or light shield positioned in the light path between the lamp 112 and the photosensitive diode 113. Diode 113 is connected in series with the resistor 114 across the conductors 115 and 116. The conductors 115 and 116 are connected to a

source of direct current, shown here as the battery 117. As shown, the conductor 115 is grounded. The base 118 of the transistor 119 is connected to the junction point 121 of the resistor 114 and the diode 113. The collector 122 of the transistor 119 is connected to the conductor 115 through the resistor 123. The emitter 124 of the transistor 119 is connected directly to the conductor 116. The collector 122 of the transistor 119 is coupled through the inductor 125 and the capacitor 126 to base 127 of the transistor 128. The base 127 of the transistor 128 is connected through the resistor 129 to the conductor 115. The collector 131 of the transistor 128 is connected through the lamp 112 to the conductor 115, and the emitter 132 of the transistor 128 is connected directly to the conductor 116. The relay circuit 133 is coupled to the collector 131 of the transistor 128 by the capacitor 134. This circuit includes a full wave bridge rectifier 135 the input of which is connected between the capacitor 134 and the conductor 115. The relay 136 and the capacitor 137 are connected in parallel across the output terminals of the bridge rectifier 135. The relay 136 has a pair of contacts 138 which may be employed to perform a suitable control operation.

In the operation of the circuit of Fig. 3, the photodiode 113 and the resistor 114 constitute a voltage divider connected across the power supply 117 by means of the conductors 115 and 116. As the vane 111 is withdrawn from the light path between the lamp 112 and the photodiode 113, the increased illumination of the diode 113 will cause an increased current to flow through the diode 113. The increased current flow through the diode 113 will raise the potential with respect to ground of the point 121 and hence the potential of the base 118 of the transistor 119 which is connected thereto. This will cause a decrease in the negative base current flowing in the transistor 119 and hence decrease that transistor's collector current thereby lowering the potential with respect to ground of the collector 122. As the potential with respect to ground of the collector 122 is reduced, the potential of the base 127 of the transistor 128 is reduced causing an increase in that transistor's negative base current flow. This increasing base current flow causes an increasing collector current flow which, in turn, produces an increasing amount of illumination from the lamp 112. In the manner just described, this will cause a still further increase in the collector current in the transistor 131. This regenerative process causes sustained oscillations to occur at a frequency determined by the phase-shift and amplitude characteristics of the amplifier gain. The maximum amplitude of these oscillations is determined by the limiting action of one of the transistors. The system thus oscillates until the vane is repositioned so as to again shield the photodiode 113 from the light of the lamp 112.

The A.C. voltage across the lamp 112 is coupled by the capacitor 134 to the relay circuit 133 wherein the rectifier 135 causes a pulsating unidirectional current to flow through the relay coil 136. Condenser 137 shunting the relay 136 prevents the relay from chattering when so energized.

The utilization of only the A.C. component of collector current for relay energizations serves to provide the circuitry of Fig. 3 with a fair degree of temperature stabilization. In addition, an increase in current flow through the photo-diode 113 due solely to a temperature increase will not cause the system to oscillate if the vane 111 is shielding the diode 113 from the light of the lamp 112. As noted in connection with the discussion of the operation of the circuit of Fig. 2, the use of only the A.C. component of collector current for relay operation also provides good safe failure characteristics.

The frequency of oscillation of this circuit depends primarily upon the value of the capacitor 126 and the inductor 125 and to a lesser extent from the values of other components. By way of illustration, the following list of components is typical for the embodiment of the inven-

tion shown in Fig. 3 and provides a highly effective and practical controller which oscillates at about 5 c.p.s.

Resistor 114	470,000 ohms.
Resistor 123	7,000 ohms.
5 Resistor 129	29,000 ohms.
Capacitor 126	2.0 mfd.
Capacitor 134	100 mfd.
Capacitor 137	50 mfd.
Inductor 125	1.25 henries.
10 Transistor 119	2N34.
Transistor 128	2N57 (Honeywell).
Bridge Rectifier	(4) 1N93.
Relay 136	2,500 ohms coil, 30 milliwatts.
15 Photo diode 113	(Radio Research and Development Corp.) #RD1795.
Lamp	Westinghouse #A-1.
Supply voltage	30 volts.

Referring now to Fig. 4, there is shown a circuit diagram of a non-oscillating motion to current transducer or vane controller in which the light source is connected in the feedback loop to produce an output proportional to the displacement of the vane between the light source and the photosensitive element. The numeral 141 refers to an opaque vane or light shield positioned between the lamp 142 and the photosensitive diode 143 in such a manner as to shield the diode from the light of the lamp. The diode 143 is connected between the conductor 144 and the base 145 of the transistor 146. The collector 147 of the transistor 146 is connected to the conductor 144 through the resistor 148. Emitter 149 of the transistor 146 is connected to the conductor 151. As shown, the conductors 144 and 151 are connected across a suitable source of direct current shown here as the battery 152. The conductor 144 connected to the negative terminal of the battery 152 is grounded. The collector 147 of the transistor 146 is directly connected to the base 153 of the transistor 154. The collector 155 of the transistor 154 is connected through the ammeter 156 and through the lamp 142 to the conductor 144. The emitter 157 of the transistor 154 is connected directly to the conductor 151.

In the operation of the circuit shown in Fig. 4, the lamp 142 and the photodiode 143 constitute a control signal source connected to the input of a two-stage transistor amplifier. The lamp 142 is connected in the collector circuit of the transistor in the last amplifier stage. The amplifier phasing is such that the current to the lamp produces negative feedback and consequently the collector current in the last amplifier stage is proportional to the displacement of the vane 141 between the lamp 142 with the photodiode 143. As the vane 142 is withdrawn from the light path between the lamp 142 and the photodiode 143, the increased illumination of the diode 143 will cause increased current to flow through the diode 143. This will lower the potential with respect to ground of the base 145 of the transistor 146 and hence increase the negative base current flowing in that transistor. As this negative base current increases, the transistor collector current will increase raising the potential with respect to ground of the base 153 of the transistor 54 and hence decrease the negative base current flowing in that transistor. This will cause a decrease in the collector current of the transistor 154. As the current in the collector circuit of transistor 154 decreases, the light from the lamp 142 will decrease and the system will stabilize at a point where the current in the collector circuit in the transistor 154 is proportional to the displacement of the vane 141 in the light path between the lamp 142 and the photodiode 143. The ammeter 156 is connected in series with the lamp 142 in the collector circuit of the transistor 154 and can be calibrated to indicate the position of the vane 141 with respect to the aforementioned light path. If, on the other hand, the circuit is to be used as a controller, a suitable

relay can be substituted for the ammeter. It should be noted that because of the negative feedback employed in the circuit of Fig. 4, that circuit is relatively temperature stable.

By way of illustration, the following circuit components are typical of those which could be employed in the embodiment of the invention shown in Fig. 4.

Resistor 148	15,000 ohms.
Transistor 146	2N34.
Transistor 154	(Honeywell) 2N57.
Photodiode 143	(Radio Development and Research Corp.) #RD1795.
Lamp 142	(Westinghouse) #A-1.
Supply voltage	30 volts D.C.

Referring now to Fig. 5 there is shown a circuit diagram of a non-oscillating photosensitive vane controller in which the light source is connected in the feedback loop to obtain snap action relay operation. The number 161 refers to an opaque vane or light shield which is positioned in the light path between the lamp 162 and the photosensitive diode 163. Photosensitive diode 163 is connected in series with the resistor 164 between the conductors 165 and 166. The conductors 165 are connected across a suitable direct current source shown here as the battery 167. The conductor 165 which is connected to the negative terminal of the battery 167 is grounded. Junction point 168 between the resistor 164 and the photodiode 163 is directly coupled to the input of a two-stage transistor amplifier, employing the transistors 169 and 171 as its amplifying element. The transistors 169 and 171 are pnp junction type resistors having the usual, emitter, collector, and base electrodes. Junction point 168 is directly connected to the base 172 of the transistor 179. The collector 173 of the transistor 169 is connected through the resistor 174 to the conductor 165. The emitter 175 of the transistor 169 is directly connected to the conductor 166. The collector 173 of the transistor 169 is directly coupled to the base 176 of the transistor 171. Collector 177 of the transistor 171 is connected through the relay coil 178 and the lamp 162 to the conductor 165. The emitter 181 of the transistor 171 is directly connected to the conductor 166.

In considering the operation of the circuit shown in Fig. 5, it should be noted that the photosensitive diode 163 is connected to the input of the amplifier in such a manner as to produce positive feedback through the light path and hence a snap action change in the output current when the vane 161 is withdrawn from the light path between lamp 162 and the photodiode 163. As the vane 161 is withdrawn from this light path, the increased illumination of the diode 163 will cause an increase in current flow through that diode. This will raise the potential with respect to ground of the junction point 168 in the voltage divider formed by the resistor 164 and the photodiode 163 and hence decrease the negative base current flowing in the transistor 169. As this negative base current decreases, the transistor collector current will decrease, lowering the potential with respect to ground of the collector 173. The change in collector potential of the transistor 169 changes the potential of the base 176 of the transistor 171 coupled thereto causing an increase in the negative base current flowing in that transistor and hence increasing its collector current flow. As the collector current of the transistor 171 increases, the light from the lamp 162 increases, still further raising the potential of the base 172 of the transistor 169. This regenerative process continues until no further increase in the collector current of the transistor 171 will occur even with an increase in that transistor's negative base current. As the current in the collector circuit of the transistor 171 rapidly increases, that current will quickly become suffi-

cient to energize the relay 178 closing the contacts 179 which may be utilized for control purposes.

By way of illustration, the following list of components is typical for the embodiment of the invention shown in Fig. 5 and provides a relatively non-complex snap action controller.

Resistor 164	470,000 ohms.
Resistor 174	10,000 ohms.
Transistor 169	2N34.
Transistor 171	(Honeywell) 2N57.
Lamp 162	(Westinghouse) #A-1.
Photodiode 163	(Radio Research and Development Corp.) #RD1795.
Relay 178	1250 ohms, 250 milliwatts.
Supply voltage	30 volts D.C.

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

Having now described this invention; what is claimed as new and for which it is desired to secure Letters Patent is:

1. An electrical controller comprising in combination circuit control means including a photosensitive semiconductor diode, a light source positioned to transmit light to said photodiode, and a movable vane, positioned by means responsive to the condition to be controlled, for regulating the light transmitted from said light source to said photodiode, a transistor amplifier having an input and an output, means connecting the output of said control means to said amplifier input, means electrically connecting said amplifier output to said circuit control means in regenerative feedback controlling relationship to produce an oscillating signal in said amplifier output for predetermined positions of said vane, and signal utilization means connected to said amplifier output and responsive to the presence of said oscillating signal.
2. A control apparatus comprising in combination a photosensitive semiconductor device, a light source arranged to illuminate said device, a movable vane, means responsive to the condition to be controlled for positioning said vane in such a manner with respect to said device and said light source as to physically regulate the illumination of said device by said light source, an electrical amplifier having an input and an output, circuit means connecting said device to the input of said amplifier, regenerative feedback circuit means electrically connected to said amplifier output for electrically varying the effect of said light source on said photosensitive device in a regenerative feedback manner to produce an oscillating signal in said amplifier output for predetermined positions of said vane, and signal utilization means connected to said amplifier output and responsive to the presence of said oscillating signal.
3. An electrical controller comprising in combination a transistor amplifier having an input and an output, a control signal source connected to the input of said amplifier, said control signal source comprising a source of light, a light sensitive semiconductor diode and a movable vane positioned to vary the amount of light from said light source falling on said light sensitive diode, said vane being so positioned by means responsive to the condition being controlled, an electrical regenerative feedback path connected between said amplifier output and said control signal source for producing an oscillating signal in said amplifier output for predetermined positions of said vane, and means connected to said amplifier and responsive to the presence of said oscillating signal.
4. A control circuit comprising in combination a light

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source, a light sensitive semiconductor diode, an opaque shield positioned by means responsive to the condition being controlled in accordance with the condition being controlled so as to vary accordingly the amount of light from said light source falling on said photodiode, a transistor amplifier having an input and an output, said diode being connected to the input of said amplifier, an electrical regenerative feedback path connected to said amplifier output for effectively modulating the output of said photodiode in a regenerative feedback manner to produce an oscillating signal in said amplifier output for predetermined positions of said shield, and signal utilization means connected to said amplifier and responsive to the presence of said oscillating signal.

5. An electrical control circuit comprising in combination a transistor amplifier having an input and an output, a light sensitive semiconductor diode connected to the input of said amplifier, means responsive to the condition being controlled for illuminating said diode in accordance with a variation in said condition, a signal utilizing device connected to the output of said amplifier, and a regenerative electrical feedback path connected between the output of said amplifier and said diode to vary the voltage across said diode to produce an oscillating signal in said amplifier output for predetermined conditions of said illumination of said diode, said device being responsive to the presence of said oscillating signal.

6. An electrical control circuit comprising in combination a transistor amplifier having an input and an output, a light source, a light sensitive diode illuminated by said light source, a movable vane for shielding said diode from said light source, means responsive to the condition being controlled for moving said vane, means connecting said diode to the input of said amplifier, signal utilizing means connected to the output of said amplifier, and means connecting said light source to the output of said amplifier.

7. An electrical controller comprising in combination a transistor amplifier, a light sensitive diode connected to the input of said amplifier, signal utilization means connected to the output of said amplifier, a lamp connected to the output of said amplifier and being positioned so as to illuminate said diode, said amplifier phasing being such that the current in said lamp produces negative feedback, and a movable opaque vane for shielding said diode from the light from said lamp, said vane being positioned according to the condition being controlled by means responsive to said condition.

8. In combination, a two stage direct coupled transistor amplifier, a photosensitive diode connected between the collector and base of the transistor in the first stage, signal responsive means and a light source connected in the collector circuit of the transistor in the last amplifier stage, said light source being positioned so as to illuminate said photodiode, and a movable opaque vane for shielding said photosensitive diode from the light from said light source, said vane being positioned by means responsive to a condition being controlled.

9. In combination, a two stage direct coupled transistor amplifier, a photosensitive diode connected between the base and emitter of the transistor in the first amplifier stage, signal responsive means and a lamp connected in the collector circuit of the transistor in the last amplifier stage, said lamp being positioned so as to illuminate said photosensitive diode, and a movable opaque vane for shielding said photosensitive diode from the light of said lamp.

10. An electrical controller comprising in combination a transistor amplifier having an input and an output, signal responsive means connected in said amplifier output, a lamp connected in said amplifier output, a photosensitive diode connected to the input of said amplifier and physically located with respect to said lamp as to be illuminated by it, and a movable opaque vane positioned by means responsive to the condition being con-

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trolled with respect to said lamp and said photosensitive diode as to shield said diode from the light from said lamp, the phasing of said amplifier and the connections of said diode to the amplifier input being such that positive feedback is provided through the light path between said lamp and said diode.

11. In combination, a multistage reactively coupled transistor amplifier having an input and an output, a control signal source having an input, and having an output connected to the input of said amplifier, said signal source also comprising a light source connected to said input of said signal source, a photosensitive diode connected to said output of said signal source, and a movable opaque vane positioned with respect to said light source and said photodiode as to control the amount of light falling on said photodiode from said light source, signal sensitive control means connected to the output of said amplifier, and circuit means connecting said input of said signal source and hence said light source to said amplifier output.

12. Apparatus specified in claim 11 wherein said signal sensitive control means are capacitively coupled to said amplifier output.

13. An oscillating electric controller comprising in combination a two stage transistor amplifier, each of said amplifier stages employing a transistor connected in a common emitter configuration, said stages being coupled by reactive elements, a photosensitive diode connected between the base and emitter of the transistor in said first amplifier stage, a lamp connected in the collector circuit of the transistor in said last amplifier stage, said lamp being physically positioned with respect to said photosensitive diode so as to radiate light upon said photosensitive diode, and a movable opaque vane positioned with respect to said lamp and said photosensitive diode in accordance with the magnitude of the conditions being controlled by means responsive to said condition so as to control the amount of said radiation falling upon said photosensitive diode.

14. An electric controller comprising in combination a reactively coupled two stage transistor amplifier having an input and an output, a control element connected in said amplifier output, a pair of photosensitive semiconductor diodes connected in series to said amplifier output, circuit means connecting the junction of said photodiodes to the input of said amplifier, a light source positioned so as to radiate upon one of said photodiodes, and a movable opaque vane positioned by means responsive to the condition being controlled for regulating the radiation transmitted from said light source to said photosensitive diode, the illumination of said diode causing the system to oscillate.

15. An oscillating electric controller comprising in combination a light source, a photosensitive semiconductor modulator circuit, a movable opaque shield positioned by means responsive to the condition being controlled so as to regulate the amount of light transmitted from said light source to said photo-modulator circuit, a transistor amplifier having an input and an output, means connecting said photo-modulator circuit to said amplifier input, electrical regenerative feedback means connected to said amplifier output for electrically modulating the output of said photo-modulator circuit in a regenerative feedback manner to produce an oscillating signal in said amplifier output for predetermined positions of said shield, and control means connected to said amplifier output and responsive to the presence of said oscillating signal.

16. In combination a two stage amplifier, each of said amplifier stages employing as its amplifying element a transistor connected in a grounded emitter configuration, said amplifier stages being reactively coupled, a pair of photosensitive diodes connected in series with each other and to the collector circuit of the transistors in said last amplifier stage, circuit means connecting the

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junction of said photodiodes to the base circuit of the transistor in said first amplifier stage, a light source for illuminating one of said photodiodes, and a movable opaque shield for regulating the light falling upon said photodiodes from said light source.

17. A photo-modulator controlled oscillator comprising in combination a transistor amplifier having an input and an output, a pair of photosensitive semiconductor diodes connected to said amplifier input, means for illuminating one of said photosensitive diodes, an electrical positive feedback path connected between said amplifier output and said photodiodes for electrically modulating the output from said photodiodes to produce an oscillating signal in said amplifier output for predetermined conditions of said illumination of said one of said photodiodes, and means responsive to the presence of said oscillating signal.

18. An oscillating electric controller comprising in combination a single stage common emitter transistor amplifier having an input and an output, a pair of photosensitive diodes connected to the input of said amplifier, means for regulating the illumination of said photodiodes including a lamp and an opaque vane positioned by means responsive to the condition being controlled, a control element coupled to the output of said amplifier, and an electrical feedback path connected to said amplifier output for modulating the output of said photodiodes.

19. An electrical controller comprising in combination circuit control means including a photosensitive element, a light source positioned to transmit light to said photosensitive element, and a movable vane, positioned

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in accordance with the condition being controlled, for regulating the light transmitted from said light source to said photosensitive element by means responsive to said condition, an amplifier having an input and an output, means connecting said photosensitive element to said amplifier input, means connecting said amplifier output in an electrical regenerative feedback controlling relationship to said circuit control means to produce an oscillating signal in said amplifier output for predetermined positions of said vane, and signal utilization means connected to the output of said amplifier and responsive only to a changing amplifier output produced by the presence of said oscillating signal.

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