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Dec. 23, 1941. C. O. FAIRCHILD ET AL 2,267,682

CONTROLLING SYSTEM

Filed April 17, 1937 2 Sheets-Sheet 1

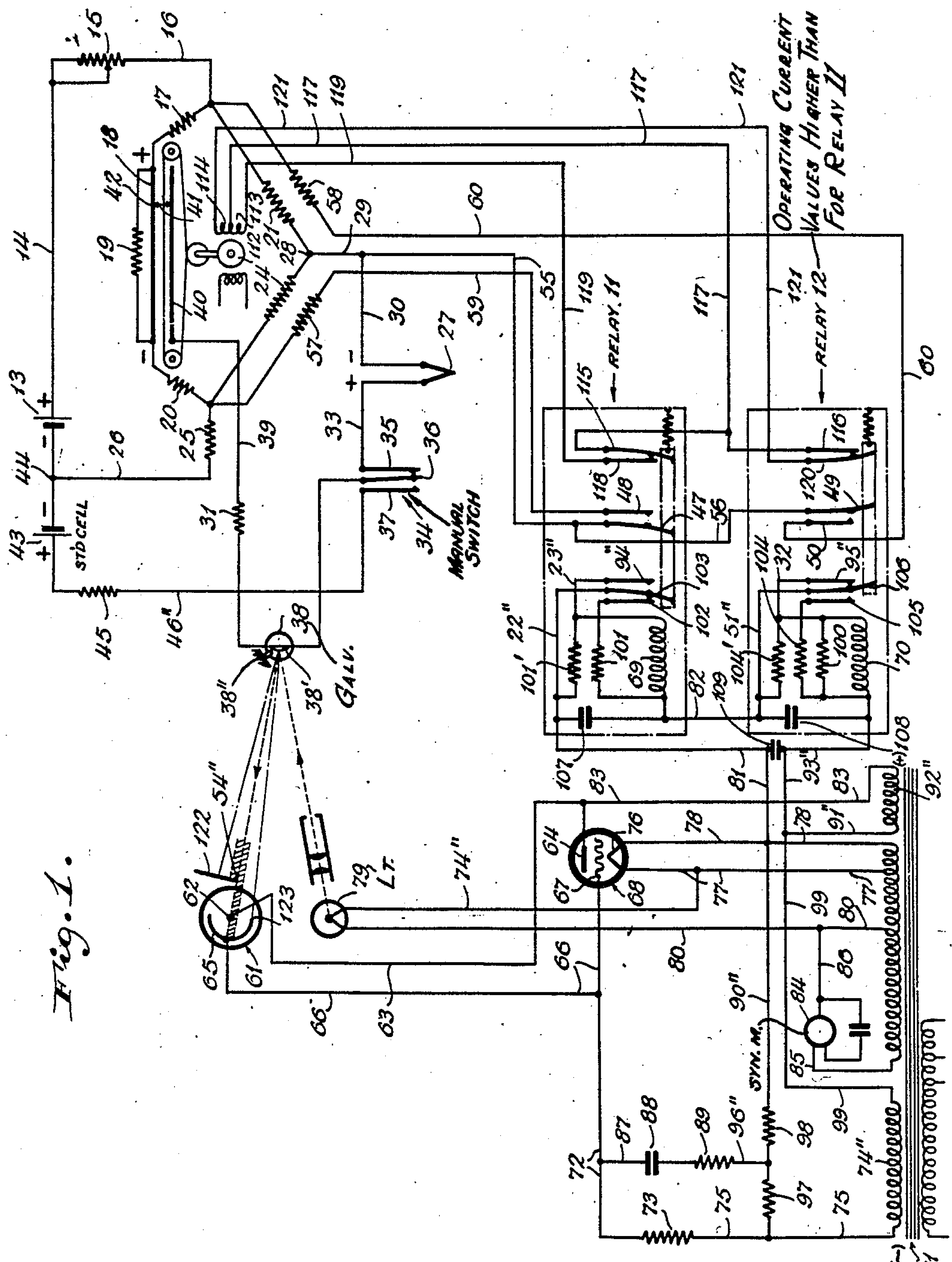

Fig. 1.

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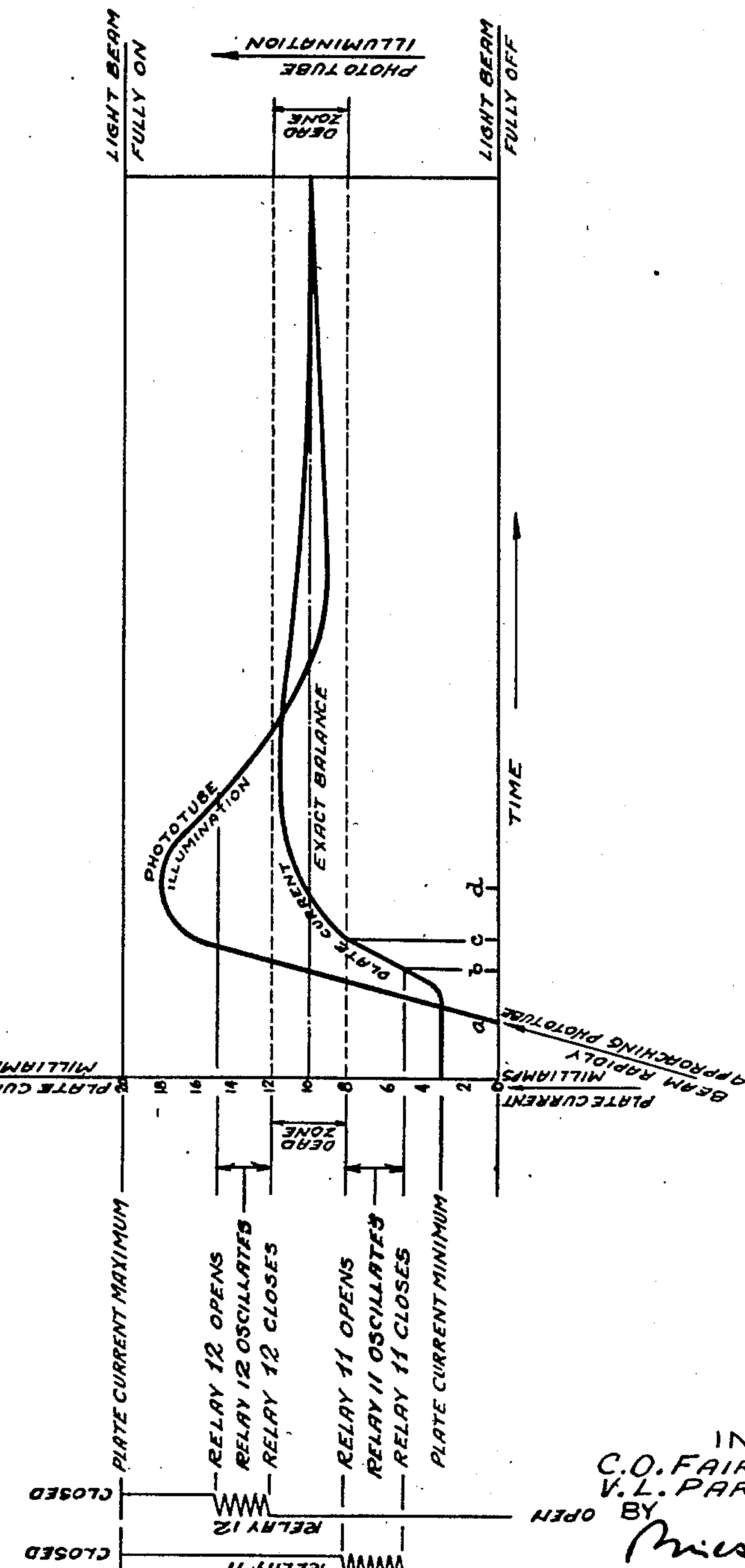
CONTROLLING SYSTEM

Filed April 17, 1937 2 Sheets-Sheet 2

Fig. 2.



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Patented Dec. 23, 1941 2,267,682

UNITED STATES PATENT OFFICE

2,267,682

CONTROLLING SYSTEM

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Application April 17, 1937, Serial No. 137,588

21 Claims. (Cl. 171—95)

This invention relates to controlling systems, particularly of the type described in the Fairchild Patent 1,970,559, granted August 21, 1934, which type includes a light source, a phototube (or other photoelectric receiver), a mirror galvanometer, and associated controlling circuits. It also relates to improved instruments of the class including recording and controlling and, as in page 1, column 1, lines 20–28 of said patent, a recording or registering device or an accurate control may be made effective in accordance with the position of a final controlled element of the system. This application covers improvements on the controlling system of Fairchild, Serial No. 131,843, filed March 19, 1937, to which reference is made to show the state of the art. A particular object of the present invention is to provide a simpler, more sensitive, and more stable electric system than others which have been heretofore described for the purpose for which this invention is suitable.

The present invention consists in a modification of the electrical control system according to the aforementioned application characterized by the use of a capacitor and an associated resistor or resistors permanently connected in the relay circuit pertaining to the governing circuit to secure different rates of response in the governing circuit for determining the rate of restoration of the current therein, without the intervention of any relay-controlled contacts.

As in the system described in the aforementioned application, the beam of light from the galvanometer mirror in the system of the present invention is focused upon the plane of a "controlling edge" of the photoresponsive receiver and moves in correspondence with variations of a controlled quantity, swinging to and fro across the edge, and, through its effect on the receiver, operates relays which control a reversing motor, this motor being used for driving any suitable final control element for actuating a measuring or controlling device. As before, the phototube is not a calibrated element but serves only to detect displacement of the light beam with reference to the controlling edge and, in cooperation with the rest of the circuit, to drive the reversible motor in one direction or the other during a displacement, and to hold the motor against rotation when the light beam is in a normal position corresponding to no deflection from its so-called zero position.

It will be evident from the following description that the performance of the instrument of the aforementioned application is improved upon. As before, included in the amplifier circuit are two relays, one of which is adjusted to close at a different value of current from that required by the other, these two relays having electric contacts connected to a reversing motor which contacts are so arranged that when one relay is closed and the other open the motor stands still, and when both relays are closed or both open the motor runs respectively one way or the other, both relays being open when the light beam does not shine upon the receiver and both closed when all of the beam, or a sufficient part of it, does shine on the receiver, and one relay will be closed and the other open when a smaller fraction of the beam falls on the receiver, the beam in this case being split by the controlling edge. These relays carry additional contacts, generally as before, for the application of an advancing E. M. F. to the galvanometer, the utility of which is also explained in the Fairchild application mentioned above.

This invention differs from that described in the abovementioned application by (1) the elimination of relay-operating contacts from the amplifier grid circuit, (2) the arrangement of this circuit to provide a varying time-constant, (3) the use of higher opening than closing relay currents which causes the balancing to be finished by a series of extremely short steps and makes possible such steps in detecting small departures from a balance, independently of the galvanometer period, and (4) the addition of resistors of appropriate magnitudes so cooperating with relay contacts that the relay operation does not undesirably affect the plate current. The selection of the particular magnitudes of the resistors of (2) and their cooperating capacitor needed to provide the variable time-constant of item 2 is an important feature of the invention and since they have a critical bearing upon the operability of the system described, are adequately disclosed herein.

Thus, the chief object of our invention is to provide improved methods of and means for causing a sensitive galvanometer to accurately and most rapidly return to a definite balancing point.

These and such other objects of our invention will appear to those skilled in the art from the accompanying drawings and specification, in which are illustrated and described a specific embodiment of our invention. It is our intention to claim all that we have disclosed which is new and useful.

In the figures, like characters of reference indicate like parts throughout and are generally as in the aforementioned Fairchild application, differences in sense being shown by the use herein of the double-prime: Fig. 1 is a diagram of our electrical measuring circuit together with the improved phototube circuit with the amplifier, relays and lamp, with which it cooperates; and Fig. 2 graphically illustrates the variation of plate current with phototube illumination; both being plotted against time as the illumination is suddenly increased.

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In the normal condition of balance, the potential of the thermocouple 27, whose temperature is to be measured, corresponds with that of the point 42 of contact of the sliding contact 41 and its slidewire 18 and there is consequently then no current flowing through galvanometer 38 which is connected with both thermocouple 27 and the sliding contact 41 through contacts 35 and 36 which are kept closed during ordinary operation and only opened manually during standardizing of the potentiometric circuit when contact 36 is closed with contact 37. In its balanced (zero-current) condition, the galvanometer directs its reflected light beam so that the beam is half on the phototube as shown in Fig. 1.

A departure from the latest steady temperature causes the galvanometer to move to alter the illumination of the phototube 61 in the opposite direction from the change of temperature, i. e., upon a fall of temperature the galvanometer swings the beam in a counterclockwise direction onto the phototube and vice versa.

A change in the illumination of the phototube 61 affects the photoelectric current in the same direction which similarly affects the potential of the governing grid 67, i. e., an increase of illumination and of the photoelectric current act through the *ir* change in resistor 73 to correspondingly raise the grid potential.

Two time-constants for the grid potential are provided to cause it to change rapidly with a first small fixed time-constant immediately after a sudden change of illumination and then very slowly relatively with a second much larger fixed time-constant. This double time-constant is produced by capacitor 88 and its shunting and series resistors 73 and 89 respectively.

In this arrangement, a sudden increase, e. g., of the photoelectric current in effect shorts out capacitor 88 initially so that the *ir* change due to the photoelectric current in its divided path through resistors 73 and 89 would cause an instantaneous rise in the grid potential if it were not for the small distributed capacity, e. g., 5 $\mu\mu$f. of the circuit connecting the amplifier grid 67 and the phototube cathode 65 with one end of resistor 73 and with one side of capacitor 88. The effect of this small distributed capacity is to cause this circuit to have a definite though very small time-constant so that the initial potential change is 90% complete in less than 1/1000 second and the plate (64) current in the coils 69 and 70 of the relays responds very rapidly also in spite of the appreciable impedance of these coils. The second time-constant is due to the storage of current in capacitor 88 which builds up a potential across the capacitor that causes an increasing current to flow through resistor 73 due to its *ir* drop until resistor 73 carries substantially all of the photoelectric current and capacitor 88 carries substantially none of it, at which time the capacitor is normally charged and conditions are steady. For the purpose of the above explanation in this paragraph, it has been assumed that the galvanometer has first been held steady for awhile in its normal position for directing the beam as shown in Fig. 1 but with the light 79 out, and that suddenly the light was turned fully on. In other words, the actions of the relays, motor 112 and galvanometer have been disregarded in the foregoing description to better bring out the characteristics of the circuit itself.

It is seen that the permanently connected capacitor in the highly sensitive governing circuit produces a double time-constant therein but without requiring the additional relay-operated contacts used in momentarily connecting an additional capacitor into the governing circuit, a change which is seen to be a considerable improvement in that it permits the initial response to be nearly complete in 1/1000 second instead of having to wait for the relays to act which takes of the order of ten times as long. This change makes possible a much faster balancing action than was possible with the device of S. N. 131,843.

Instead of relying for a stepping action upon the response of the galvanometer to the removal of a large advancing E. M. F., this function is better handled by providing the relays 11 and 12 respectively with resistors 101 and 100 which cause them to oscillate by making their opening current values higher than their closing current values (referring to the plate current). Capacitors 107 and 108 cooperate in timing the relay oscillations.

The relays 11 and 12 are provided with back-contacts which close when the relays are open, i. e., with their armatures most distant from their coils (both armatures being continuously mechanically biased toward their open positions), to then insert resistors 101' and 104' respectively in the plate circuit to thus keep the impedance of the plate circuit substantially constant for all extreme positions of both relays.

The Potentiometric Circuit

Fig. 1 shows a potentiometer circuit generally similar to that shown in the aforementioned Fairchild application, and in which current from a battery 13 flows through a conductor 14, a manually-adjustable rheostat 15, conductor 16, to a divided or bridge circuit having in one arm resistor 17, slide-wire 18 shunted by resistor 19, and resistor 20, and in the other arm resistors 21 and 24 when the circuit is balanced, then to resistor 25, conductor 26 and back to battery 13. Conductor 30 is permanently connected through conductor 29 to connection 28, with which only two pairs of relay contacts respectively 47, 48 and 49, 50 are connected. The potential of 28 is lowered by shunting resistor 24 with resistor 57 through conductors 59, 55 and 29 and contacts 48 and 47 when both relays 11 and 12 are open, or is raised by shunting resistor 21 with resistor 58 through conductors 60, 29, 55, 56 and contacts 50 and 49 when both relays are closed. By properly choosing the values of resistors 57 and 58 the potential of 28 can be changed by any amount required. Provided the resistance of slide-wire 18 and its shunt 19 are not too large in comparison with the resistances of galvanometer 38, thermocouple 27 and resistor 31, the effect of this potential change on the deflection of the galvanometer will be sufficiently constant while 41 moves across the slide-wire, being least when 41 is in the middle and greatest when 41 is at either end. It is not essential to have an exactly constant effect. It will be shown in the description following the operation of relays 11 and 12 is such that resistors 24 and 21 are not both shunted at the same time by resistors 57 and 58, but only one at a time. It will be apparent that the arrangement is such that the potential of point 28 takes only three fixed values, the intermediate one corresponding with a balanced condition of the potentiometer with relay 11 closed and 12 open and two others, when both relays are closed or both open. The slide-wire 18 is calibrated with reference to the center normal value of the potential of the point 28.

The current through the slide-wire is standardized by manually throwing switch 34 to the reverse direction from that shown, to connect the standard cell 43 opposed to the battery, by the connection 44 through resistor 45, contacts 37 and 36 of switch 34, galvanometer 38, resistor 31, conductor 39, bar 40, contacts 41 to the point 42 on slide-wire 18, when 42 is at a predetermined position selected for convenience. While the above description is adequate for the present purpose, this is also explained in the Fairchild Patent No. 2,207,344, granted July 9, 1940.

THE GOVERNING CIRCUIT

In Fig. 1, the balancing power-circuit or governing circuit is shown to be electrically independent of the potentiometer-circuit, and to include the phototube 61, connected with its anode 62 through conductor 63 to plate 64, and its cathode 65 through conductor 66 to grid 67, of triode 68. Transformer 71 is used to supply the various voltages of this circuit, no auxiliary rectifiers being used for the two tubes. Grid 67 of tube 68 is connected through conductors 66 and 72, resistor 73, conductor 75 to what is commonly called the "negative terminal" of the secondary of the transformer 71. Filament 76 of tube 68 is connected through conductors 77 and 78 to a low voltage section of the secondary. Lamp 79 is also connected to a low voltage section in the secondary through conductors 74'', 77 and 80. Plate 64 is connected to the so-called "positive terminal" of the secondary through conductor 83. Synchronous motor 84 may be connected if required, as for driving a record chart, to the transformer through conductors 85, 86 and 80. Grid 67 is also connected through conductors 66, 72, 87, capacitor 88, resistor 89 and conductor 96'' (capacitor 88, resistor 89 and conductor 96'' being shunted by resistors 73 and 97), and thence through resistor 98, and conductors (hereinafter "leads") 90'' and 78 to filament 76.

Capacitor 88 with its net-work of resistors 73, 89, 97 and 98 is permanently connected in the governing system to provide said system with a double time-constant as regards the response of the grid potential to a change of the illumination of the phototube. For purposes of the present analysis, it may be considered that the circuit which includes the phototube cathode 65 and the amplifying-tube grid 67 has a distributed capacity of 5 $\mu\mu$f. between line 72 and line 75. Adopting the convention of the polarity illustrated on Fig. 1, line 75 is at the lowest potential and line 83 and anode 62 of the phototube are at the highest positive potential.

Suppose the mirror galvanometer be held steady so that the light beam would split shielding edge 54'' for the phototube if the light 79 were turned on, but it is assumed that light 79 has been turned off for a long enough time so that the conditions of the governing system and of the relays and driving motor 112 are also steady. In other words, both relays are open and slider 41 is moving upscale (to the right in Fig. 1) at the full speed of the motor.

Now suppose that the light 79 is suddenly turned fully on to give half-beam illumination of the phototube. Instantly the photoelectric current of a few micro-amperes flows through wires 66 and 72 so that there is a suddenly-applied flow of current through a split circuit which consists essentially of capacitor 88 and resistor 73 in parallel. During the sudden change of the current, the impedance of capacitor 88 is momentarily negligible. Consequently at this instant, the relative flows through resistor 73 and capacitor 88 depend primarily on the relative values of resistance of 73 and that of 89 which is in series with capacitor 88, the resistance of 89 being relatively so low that most of the current then flows through it. Thus, when the light first strikes the phototube and starts an instantaneous flow of photoelectric current which proceeds as though capacitor 88 were shorted, there is an instantaneous *ir* change across the resistance 89 which would cause the grid potential to be instantaneously raised but for the small associated distributed capacity of, e. g., 5 $\mu\mu$f. aforementioned which causes the circuit to then have a definitely fixed initial time-constant of a far different order (i. e., one giving a much higher rate of response) than that due to capacitor 88 and its associated resistors after this initial effect has been exhausted. As later described more fully, the initial very rapid change of the grid potential causes a corresponding change of the relay current to cause relay 11 to close and thus stop the motor and slider.

As soon as the initial jump of the grid voltage is over, a much more gradual further change occurs in the same direction and the net time-constant for the circuit (from then on as long as the illumination remains constant) may be considered to be due to the building up of a potential in consequence of the storage of the photoelectric current in the capacitor 88 and the accompanying driving of the photoelectric current through resistor 73 as the potential across capacitor 88 builds up.

It takes less than $1/1000$ second for 90% of the initial sudden change to occur with the initial time-constant due to the effect of the distributed capacity of 5 $\mu\mu$f., while it takes more than 4 seconds for 90% of the remaining change to occur with the time-constant due to the effect of 0.02 μf. capacity of 88. Where the time-constants are of such different orders, it is clear that they may be considered separately and additively. In other words, in effect, the circuit has unquestionably a small fixed time-constant initially giving a very rapid rate of change followed by a much larger effective time-constant which produces a much lower rate of change of the grid potential in response to changes of the illumination of the phototube. In spite of the appreciable impedance of the relay coils, the initial response of the current in the relay coils to a change of the illumination of the phototube is at a very rapid rate and well within a half-cycle of the usual A. C. supply, such response-time being, of course, considerably less than the operating time of the relays.

The various values used in the design of the complete governing circuit are so selected that, upon a sudden swing of the light beam fully onto the phototube from a position in which it is fully off the phototube, the effect on the grid potential of the initial *ir* change across resistor 89 (i. e., during the initial sudden response while the first time-constant is effective) is sufficient to raise the value of the current in the relay coils above the closing value for relay 11 but to still leave it at a value below that for closing relay 12. The current subsequently changes so slowly that if the galvanometer had been allowed to overswing its normal position (instead of being held fixed as above stated), the

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further response of the said current value due to said overswing is so retarded that both the galvanometer and the motor have time to come to rest before the relay 12 could possibly operate, due to such overswing. Cooperating with this slower response are: the removal, by the closing of relay 11, of the advancing E. M. F. which caused the galvanometer to lead the sliding contact enough to provide time for both to come to rest, and the self-generating oscillations of relay 11 which cause the forward movements of the sliding contact to be small on the near side of the dead-zone surrounding the balancing position.

Relays 11 and 12 are connected in the plate circuit between the transformer lead 91″ and filament 76. The path of the current, when the two relays are open, is from transformer lead 91″, lead 93″, relay coil 70 shunted by resistor 100, lead 32, contacts 95″ and 106, lead 51″, lead 82, relay coil 69, lead 23″, contacts 94″, 103, lead 22″, leads 81, 78 to filament 76. When the relays are both closed, the current flows from leads 91″, 93″, and divides; part of it proceeds through coil 70 and its shunt resistor 100 to resistor 104′, to lead 82; and the other part proceeds through resistor 104, contacts 105, 106, lead 51″ and also to lead 82. The whole current continues through lead 82 and is again divided between two paths; one part through relay coil 69, resistor 101′ to lead 81; and the other part through resistor 101, contacts 102, 103, lead 22″ also to lead 81; the whole current then continues through leads 81, 78 to filament 76. It is evident that, in the open position, resistors 104′ and 101′ are shorted by contacts 106, 95″ and 103, 94″ respectively. Fig. 1 shows the relays in the balanced position, i. e., with relay 11 closed and relay 12 open.

Resistor 101′ is in series with coil 69 of relay 11. However, in the open-relay position, resistor 101′ is shorted, rendering it ineffective, through lead 23″, contacts 94″, 103 and lead 22″. When relay 11 closes, contacts 94″, 103 break, thus unshorting resistor 101, and decreasing the plate current; and the relay current is further reduced by the insertion of resistor 101 as a shunt to relay coil 69 and series resistor 101, through contacts 102, 103 and lead 22″.

Similarly coil 70 of relay 12 is in series with resistor 104′; but in the open-relay position, resistor 104′ is shorted through leads 32, contacts 95″, 106, and lead 51″. When relay 12 closes; contacts 95″, 106 break, the current flows through coil 70 and resistor 104′; and resistor 104 shunts coil 70 and resistor 104′ (which are in series) through contacts 105, 106, and lead 51″. Resistor 100, when used, reduces the current through coil 70 at all times, i. e., regardless of whether relay 12 is open or closed

Resistors 101 and 101′ are so chosen that when the relay 11 closes, the current through coil 69 is sufficiently reduced to allow the relay to open at any desired value of total plate current, but the net electrical impedance between leads 82 and 81 is maintained nearly the same. This prevents any significant change of plate current because of the relay operation. Resistors 104 and 104′ are likewise so chosen that when the relay 12 closes, the current through coil 70 is reduced and relay 12 may open again at any desired value of total plate current. Similarly the net impedance between leads 82, 93″ is maintained nearly constant so that no significant change of total plate current occurs when this relay operates.

In order to prevent the relays from chattering because of the half-wave rectification of triode 68, relay 11 with its resistors is shunted by capacitor 107, and relay 12 with its resistors is shunted by capacitor 108, and the two are shunted by capacitor 109 connected to conductors 81 and 93″. These three capacitors serve to smooth out the intermittent direct current and the variable magnetic flux in the relays, and to absorb quick surges of plate current, thus tending to greatly increase the stability of relay operation. In the succeeding paragraphs referring to the functioning of the transformer secondary circuit, all voltage references pertain to the R. M. S. voltages at the instant when the plate lead 83 is most positive relative to grid lead 75.

The potential of plate 64 relative to filament 76 varies from about 160 volts to about 80 volts as the plate current increases.

Grid 67 potential is maintained negative, relative to filament 76, by means of the transformer secondary 74″ and by the potential drop across relays 11 and 12 which are in series with transformer secondary 74″. The negative voltage source is from filament 76 through leads 78, 81, relays 11 and 12, leads 93″, 99, transformer secondary 74″, to lead 75. The voltage of transformer secondary 74″ is constant, but the potential drop through the relays increases with increasing plate current.

Resistors 97, 98 shunt the negative potential source from filament 76, leads 78, 90″, resistors 98, 97 to lead 75, and a desired negative voltage may be chosen by proper ratios of resistors 97, 98. Proper negative potential at grid 67 is maintained by a proper choice of resistor 73 and also of capacitor 88 and resistors 89, 98. At any instant the potential drop from filament 76 to grid 67 plus the potential drop across resistor 73 equals the potential drop from filament 76, through relays 11, 12 and transformer secondary 74″ to lead 75. Also at the same instant, the potential drop from filament 76 to grid 67 plus the potential drop across capacitor 88 resistor 89 lead 96″ equals the potential drop across resistor 98. The order of the magnitudes of the various resistors, including 97 and 89 and of their cooperating capacitors including 88 provides satisfactory operation in most industrial applications.

Resistor	97	25,000	ohms	± 50%
Resistor	98	5,000	ohms	± 50%
Resistor	89	2	megohms	± 50%
Resistor	73	75	megohms	± 50%
Resistor	101	7,000	ohms	± 20%
Resistor	101′	10,000	ohms	± 20%
Resistor	104	6,000	ohms	± 20%
Resistor	104′	9,000	ohms	± 20%
Resistor	100	12,000	ohms	± 20%
Capacitor	107	3 mfd.		+200% or −50%
	108	1 mfd.		+200% or −50%
	109	2 mfd.		+200% or −50%
	88	0.02 mfd.		+300% or −50%

Relay coils 69 and 70, impedance at 60 cycles 50,000 ohms+or−20%, resistance 5,000 ohms+or−20%.

Transformer voltages for 60 cycles

Leads 75—99 100 volts } ± 10%
91″—83 200 volts }

The phototube 61, when dark, has very large resistance and in effect acts as an open circuit. When illuminated, its effective resistance decreases proportionately with the illumination and 100 megohms is the order of its magnitude with the light fully on the phototube as used in this instrument. Its anode 62, connected through lead 63 to plate 64, is maintained positive relative to its cathode 65 connected through lead 66 to grid 67. The phototube may then provide a path for electron flow between grid 67, lead 66, phototube 61, lead 63 to plate 64, thus in effect applying a positive potential to the grid varying with illumination and superposed upon the negative bias supplied by the secondary 74''. The phototube current through lead 66 is supplied by electron flow through resistor 73, through resistors 97 and 89, capacitor 88 and leads 87, 72. The negative potential of grid 67 relative to filament 76 can vary only as fast as the potential variation of leads 72 relative to filament 76. Similarly, the grid bias varies directly with a change in potential across resistor 98, lead 96'', resistor 89, capacitor 88 to leads 87 and 72. The tube capacitances of triode 68 are relatively small and therefore cause very little delay in change of grid potential with change of illumination. But capacitor 88 is of relatively larger capacity and hence may delay grid potential changes considerably.

At the instant the phototube 61 is illuminated there occurs a surge of current (see Fig. 2) through resistor 89 and capacitor 88. The immediate change of potential drop across resistor 89 causes a quick change of plate and relay current. The potential across capacitor 88, however, varies more slowly as it is charged or discharged, attaining its ultimate value much more slowly. The potential of grid 67 relative to filament 76, first receives a quick change and then a more gradual one, this latter condition continuing until capacitor 88 has attained its final charge for the particular value of illumination of the phototube. This quick and slower change in grid potential causes a corresponding quick and slower change of plate current through the relays. The amount of quick change and the rate of slow change of the plate current are controlled by the values given to resistor 89 and capacitor 88. Resistor 73 allows the capacitor to discharge, whenever the illumination of the phototube 61 decreases, at a rate depending upon the value of this resistor and capacitor 88.

The nature of this quick and slower change is illustrated in detail by Fig. 2. One curve shows the increase of illumination as the beam is suddenly moved onto the phototube. With only very slight delay, the plate current jumps to a higher value than when the phototube was dark, after which it increases sufficiently slowly to allow the galvanometer to attain its balance in a manner soon to be described. Normally the light beam, in returning to the balance point, will swing beyond the controlling edge because of the time delay in the increase of plate current and the closing of relay 11, and because of galvanometer momentum. It is necessary that relay 11 shall close as quickly as possible, but that the plate current shall be sufficiently delayed behind the illumination value to prevent relay 12 from closing too quickly while the galvanometer finds its dead zone of stable balance.

Fig. 2 illustrates that the plate current at no illumination remains, e. g., at approximately 3 m. a. When the phototube is quickly illuminated by the beam, this current immediately jumps to approximately 8 m. a., which is sufficient to close, and maintain closed, relay 11. This current value corresponds to the sudden increase of voltage drop across resistor 89. Thereafter, the plate current increases more slowly, corresponding to the slower potential change of capacitor 88, so that although the instantaneous value of phototube illumination corresponds to a current value considerably higher than the closing of relay 12, the plate current increases so slowly that the closing current of relay 12 is not reached before the light beam has returned to within the dead zone. This figure shows that our circuit, without contacts and switches in the grid circuit, has successive rates of change of the plate current (with a sudden change of illumination) of the distinctly different magnitudes required.

It is found that the use of relays 11 and 12, connected in series with transformer secondary 74'' as shown in Fig. 1 to supply a common path to the plate and grid circuits, results in increased ratio of plate current change to change in phototube illumination, that is, the circuit is more sensitive to deflections of the galvanometer.

The Motor Circuit

The main purpose of the relays is to operate motor 112, indicated as a shaded-pole motor having a main coil connected to the line and having two shading coils 113 and 114 for reversing the motor. Contact 115 on relay 11 and contact 116 on relay 12 are connected through conductor 117 to both coils 113 and 114 of the motor. Contact 118 on relay 11 is connected through conductor 119 to coil 113, and contact 120 on relay 12 is connected through conductor 121 to coil 114. The arrangement is such that motor 112 is braked to a standstill when relay 11 is closed but runs contact 41 downscale when both relays are closed and in the other direction when both relays are open.

Description of Operation

The following résumé of the principal parts of the electrical circuits and their functions is included here for ready reference in reading the detailed description of operation and appended claims; first taking up, under A—D, that which has been earlier disclosed in the aforementioned patent and applications and then, under E—G, describing that which we believe to be new in this general combination:

A. *Potentiometer circuit*

The slide-wire potentiometer circuit includes a thermocouple 27 and mirror galvanometer 38 connected in series between the movable contacts 41 and point 28, the galvanometer being permanently connected to said contacts as described in previously mentioned Fairchild Patent No. 2,207,344. The potential of the point 28 is altered by relay operation as explained in the next paragraph. A decrease in temperature of the thermocouple moves the galvanometer-reflected light beam in a direction to increase the illumination on the phototube.

B. *Means for advancing the phase of the galvanometer*

In the balanced condition of the potentiometer, i. e., with the galvanometer at its normal position with no current flowing through it, relay 11 is closed and relay 12 open, the light-beam being split by the controlling edge. In this position of the relays, point 28 is at its normal potential. When the relays are both open, or

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both closed, the potential of point 28 is lowered or raised respectively, changing this potential in each case so that the galvanometer deflection is less than it would be without cooperation with the relays. These changes in the potential of point 28 result in an advance of the position of the galvanometer with reference to that of the moving contacts 41, as both move towards the balance point.

C. *Reversible motor circuit*

A shaded-pole reversible motor has its shading coils 113, 114 respectively connected to the contacts 115, 118 and 116, 120 of relays 11 and 12. In the balanced condition, both coils are short-circuited by said contacts and the motor is stationary. When both relays are open, only coil 114 is shorted thus driving contacts 41 upscale; and when both relays are closed, only coil 113 is shorted thus driving contacts 41 downscale.

D. *Photoelectric and amplifier circuit*

This includes the phototube 61, amplifier tube 68, light source 79, transformer 71 and relays 11 and 12. The circuit is not electrically connected with the potentiometer or reversible motor circuits but cooperates with these through relay contacts. An increase in the phototube illumination tends to increase the current in the relays to cause them to close.

E. *Grid circuit of amplifier*

The grid circuit of the amplifier includes, in special arrangement, capacitor 88 and resistor 89, the two in series being shunted by resistors 73 and 97. The grid return connection traverses the relay circuit through conductors 99, 93″ and 81 to the filament. This circuit is so designed that sudden illumination of the photocell results in a sudden change of grid voltage and hence of plate current to a predetermined value within the dead zone of balancing, followed by a slow rise. It may be parenthetically noted that the inclusion of the relays in the grid return circuit increases the amplification of the photoelectric current.

F. *Relay opening currents greater than closing currents*

This means that if a current between the opening and closing values flows through the relay coils, the relays will oscillate. This is accomplished by shunting coil 69 of relay 11 with resistor 101 and coil 70 of relay 12 with resistor 104, these resistors being connected across series resistors as described. The periods of oscillation are controlled by shunting capacitors 107 and 108, being chosen in any particular case in relation to the impedances of the relay coils and series and shunting resistors according to the requirements such as scale range, galvanometer sensitivity and reversible motor speed.

The condition of the relays 11 and 12 for various plate current values is shown diagrammatically in Fig. 2. It will be seen that, for example, a current of 5 m. a. is sufficient to close relay 11 but, as soon as the relay is closed, the shunt resistor 101 cuts the current through the relay down to such an extent that the relay opens again. This closing and opening of the relay (oscillation) will occur in the illustrated embodiment as long as the plate current is within a range from 5–8 m. a. but above 8 m. a. the relay will remain closed as the shunt resistance is selected so that it does not cut down this (or a higher) value of current far enough to cause opening of the relay. The same action occurs with the relay 12 except that its opening and closing currents and oscillation range are all at higher values as indicated.

G. *Stabilizing plate circuit during relay operation*

Additional resistors 101′ and 104′ on relays 11 and 12 cooperate with back contacts 94″ and 95″ to maintain the impedance of the plate circuit constant during relay operation. It may be noted here that mirror 38′ of galvanometer 38 is provided with stop 38″ which keeps the image from passing off of phototube 61 when the beam is swung in a counterclockwise direction.

Approaching balance point, light off phototube, both relays open

Having identified and described the essentials of the circuit, let us suppose that the E. M. F. of thermocouple 27 is considerably more than the difference in potential between points 28 and 42 in the potentiometer, that the galvanometer 38 is deflected proportionately to this difference in potential, and that the beam of light is off phototube 61 on the far side of the controlling edge 54″ of shield 122, up in Fig. 1. With no light on phototube 61, grid 67 assumes a sufficiently high negative bias, and the relays are both open. Contacts 115, 118, connected to the shading coil 113 are open, allowing the still-shorted shading coil 114 to cause the motor 112 to turn in such direction as to move the contacts 41 upscale (to the right in Fig. 1) towards a new balance point. Also contacts 47, 48 are closed and resistor 57 shunts resistor 24, lowering the potential of point 28 and reducing the galvanometer deflection.

The contacts 41, 42 are now moving rapidly towards a new position and the galvanometer is approaching its undeflected position under the influence of the restoring torque of its suspensions and of the decreasing potential difference between point 28 and the moving point 42. At any instant during this return movement, the galvanometer, because of the retarding effect of its back E. M. F., would ordinarily lag behind the position corresponding to that of point 42. Instead, the advancing E. M. F. imposed by the change in potential of point 28 puts the galvanometer either exactly in phase with point 42 or ahead of it. The galvanometer should ideally lead the contact sufficiently that despite the time involved in relay operation, the overrun of the motor and the accompanying movement of point 42, both the galvanometer and point 42 find exact balance on the one stopping of the motor.

As the light beam rapidly approaches the controlling edge 54″, illumination of the phototube begins at *a* and the plate current increases as shown in Fig. 2. The rapidly-increasing phototube current causes an initial quick increase of plate current from its minimum value to a value sufficiently high to close relay 11 and stop the motor.

At the instant when the relay current just begins the closing of relay 11 (point *b* in Fig. 2), the illumination has already passed the intensity for exact balance (Fig. 2) and is still rapidly increasing, the motor 112 is traveling at full speed, contact 41 is slightly behind the point of final balance, and the galvanometer is traveling at full speed beyond the balance point under the influence of the temporary advancing E. M. F. and of the moving point 42. At the instant after the closing of relay 11, contacts 115, 118 close and the motor 112 and contacts 41 begin to stop; contacts 47, 48 open to break the circuit of resistor 57 and restore point 28 to its original potential, and the galvanometer will then quickly stop under the combined influence of its back E. M. F. and the restoring torque of its suspensions, both opposing its momentum. At the instant when the motor 112 stops, contacts 41 will be at least approximately at the point 42 required for exact balance with the thermocouple E. M. F. plus the normal potential of point 28, but the galvanometer, although stopping or fully stopped, is well past the point of exact balance and the illumination of the phototube is at the moment considerably higher than the illumination corresponding with exact balance. It is necessary then to sufficiently delay the operation of relay 12 until the galvanometer has returned from its overswing to the point of exact balance under the restoring torque of its suspensions, again opposed by its back E. M. F.

Fig. 2 shows that the illumination increases rapidly from point *a* when the light beam reaches the photocell at edge 54″. There is a correspondingly rapid increase of plate current up to and beyond the closing current value of relay 11 so that relay 11 does not oscillate under these conditions. The illumination continues to increase rapidly as relay 11 is closing, but the plate current can increase only slowly because of the slower charging of condenser 88, as stated before. Soon after relay 11 is closed, the stopping galvanometer quickly decreases the rate of increase of illumination; this illumination reaching its maximum well above the corresponding closing current for relay 12 and slowly decreasing as the galvanometer returns to its exact balance. In this manner, before the plate current can reach the closing current value for relay 12, the illumination will have decreased to a point well within the dead zone, and both galvanometer and contact 41 will stably balance within a very narrow dead zone.

It will be seen that at initial illumination, the plate current quickly rises to a value at *c* just above the opening current of relay 11 so that, even though the opening current of relay 11 is considerably higher than its closing current, the relay will not be able immediately to open again once it has closed. In other words, the time, represented by the distance *b* to *c*, on Fig. 2 is smaller than the predetermined time of closing and opening again of relay 11.

In practice, it is in many cases found practicable to advance the galvanometer to such an extent that it is considerably ahead of contacts 41 as they both move towards the balance point. Then when the beam reaches the controlling edge, the relay 11 will close and stop both motor and galvanometer as before. But the contacts 41 will not have reached the point of exact balance so that, when the galvanometer begins to return from its first-stopped position beyond the dead zone, it is brought back to the low-current side of the dead zone, and relay 11 opens but quickly closes again, causing the motor and contacts 41 to take a short step forwards, this being repeated as necessary until exact balance has been reached.

Approaching balance point, light fully on phototube, both relays closed

When the thermocouple E. M. F. is lowered, the light beam is deflected onto the phototube from the latest steady value at which the instrument was balanced with relays 11 and 12 respectively closed and open and both the galvanometer and the motor stationary, relay 12 also closes (so that both relays are then closed) thus opening contacts 116, 120 for the shading coil 114 and allowing the motor to move contacts 41 downscale towards a new balance, and closing contacts 49, 50 so that resistor 58 shunts resistor 21 and raises the potential of point 28 thus decreasing the galvanometer deflection. The curves of Fig. 2 may be inverted about the center line of the dead zone, to substantially illustrate the decrease of plate current which occurs when the light beam approaches the balance point from a deflection fully on the phototube. When the beam reaches the dead zone, the plate current experiences a first quick and then a slower decrease, quickly opening relay 12 but delaying the opening of relay 11 until the galvanometer has found exact balance.

Leaving balance point, momentary opening of relay 11

Assume now that the galvanometer and relays are at exact balance and that the thermocouple E. M. F. is increasing very slowly. The galvanometer experiences a small deflection off the photocell, and the illumination and plate current decrease slowly until the opening current of relay 11 has been reached. Relay 11 then opens, but since the plate current is at that instant higher than its closing current it immediately closes again. This opening and very quick closing make possible a very short step of the motor 112 and contacts 41 upscale. Also during this short step, because of the momentary change of potential of point 28 in the previously described manner, the galvanometer receives a quick impulse in a direction back towards its normal position. This makes possible very short steps, each discrete and positive, with a high enough frequency to follow as rapid a change of thermocouple E. M. F. as occurs in practice.

Leaving balance point, momentary closing of relay 12

A similar action occurs when the thermocouple E. M. F. slowly decreases. The illumination and plate current slowly increase until the closing current of relay 12 has been reached. The relay then closes, but since its opening current is considerably higher it will open again immediately, allowing only a very short step of contacts 41 downscale. Again with each step, the galvanometer is given an impulse back so that undesirable relay "hunting" oscillation is avoided.

The application of the method of control which is disclosed here is not limited to the use of a reflecting galvanometer, source of light and photoresponsive receiver, nor to the use of two electromagnetic relays operating at different currents defining a zone of insensitivity. In a broad sense, we have shown here a system of control in which the dead zone is more of the nature of a trap than of a zone or span limited by fixed barriers or real bars. In a mechanical sense, the dead zone does not have stationary limits because, when the measuring element enters it, the near side has a tendency to oscil-

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late and does so if the entrance is slower than at a predetermined rate; and the far side in a sense "stretches" while the said element passes beyond the normal position and returns to it, the controlled means (contacts 41) having been stopped (perhaps momentarily) by the passage of said element through the near side. It is presupposed that the action is dependent for its success on advancing the phase of said element with reference to said controlled means, for otherwise the latter would pass its balancing position and a reverse action would have to come into play, in which case nothing would be accomplished by permitting the far side of the dead zone to "stretch," that is, not act immediately. It is readily apparent that said means must not be permitted to pass the balancing position else the measuring element will not return until the far side of the dead zone has acted to reverse the control.

A similar action could be accomplished with any means which is forced into electrical contact or mechanical engagement at the near side of a dead zone, while the far side is not permitted to act as soon as the element reaches it but is inactive or even removed until the element has had time to return to the normal position. Again, it is supposed that the governed means lags behind the measuring element. Alternatively, also, the abovementioned electric contacts or mechanical engagements can be used to operate any known type of relays. The system, or method, disclosed is essentially a relay system in which the governed means travels continuously towards the balancing position so long as the measuring element is deflected from its normal position, the speed of travel being of an independent and predetermined value.

While there may be some question of the logic of describing the action as a stretching of the far side of the dead zone, rather than as a slowing of response which presents a reaching of the far side; actually however, there is no fundamental difference, because the measuring element does reach and even pass the normal place or value of the far side of the dead zone. The "stretching" may be conceived as between illumination and plate current in a photoelectric method, and a more strict mechanical equivalent would be a flexible and temporary seizure of the measuring element within the dead zone while the governed means stops. It is apparent that, in the latter instance, there is a definite maximum speed beyond which it would not be possible to seize the measuring element or member before it passed the dead zone.

The terms and expressions which we have employed are used as terms of description and not of limitation, and we have no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described and portions thereof, but recognize that various modifications are possible within the scope of the invention claimed.

Where the word "system" occurs in the claims, and especially where a governing system is referred to, this is for the means stated to operatively connect the sensitive member with a final controlling element which final element operates to perform a function related to the value of the member-sensed variable and may be either an exhibiting means such as an indicator, a pen or other marking device or may be a sliding contact, a variable controlling-resistor or any equivalents. Where the expression "physical variable" or the like occurs in the claims, it refers to such a physical quantity or condition as temperature, pressure, potential or the like.

When a plurality of time-constants is referred to in the hereinafter appended claims, such term defines consecutively different magnitudes of a damping effect. The "time-constant" refers to an effect, regardless of how it is produced, instead of to a cause. In other words, it is the time-constant of a response of a condition such as, by way of example, a relay current to a change of illumination of a phototube, instead of being limited to a product or ratio of values of resistance, inductance and capacitance. The term "time-constant" of response has its usual meaning: a rate of change of the response per unit of the yet-unfulfilled portion of the response or, alternatively, the time it would take the response to be complete if continued at the rate of change of the response at the instant considered. Mathematically expressed, for the response of current i to a sudden change of illumination to have a single time-constant K, the current i must have the following exponential relation with time t:

$$i=i_0\, e^{-t/K}$$

where i_0 is the ultimate current change and e is the Naperian base. While conventional instruments may be considered to have a plurality of time-constants of response, these are not limited to damping but simultaneously, instead of consecutively, include either at least a second time-constant or a harmonic function, due to the inertia of the instrument, having a generally unstabilizing effect.

We claim:

1. In the art of measuring and controlling, the steps in the method of stably rebalancing a governing system which is sensitive to an independent physical variable and includes an electrical circuit and a member which is deflectable from a balancing position upon a change in the value of the variable, which steps comprise, acting within an operating range of positions of the member varying the electrical condition in the circuit in response to deflections of the member, continuously but sharply altering the effective time-constant of response of the condition to produce a rapid initial response directly following a sudden change in the position of the member within said range and a much lower final rate of response, and governing the rebalancing of the member to its balancing position in accordance with the value of the damped electrical condition.

2. In the art of measuring and controlling, the steps in the method of stably governing a system according to the position of a light beam from a galvanometer relative to a phototube to produce a current ultimately corresponding with such position over a range of phototube-illuminating positions of the galvanometer in a circuit including the phototube, which steps comprise continuously acting in accordance with an independent variable to affect the position of the galvanometer relative to a normal position in which the light beam is only partially on the phototube, continuously but sharply altering the effective time-constant of the circuit to produce a rapid initial current response following a sudden change in the position of the galvanometer within said range and a lower final rate of response with a different order of magnitude of the effective time-constant, and substantially

continuously acting upon the galvanometer in accordance with the value of the damped current to bring the light beam to rest substantially at its normal position.

3. The method of stably controlling a final element in correspondence with the value of an independent physical variable which is to be measured, which comprises altering the position of a member from a normal position in accordance with changes in the value of said variable, varying the value of a physical condition of a governing system to ultimately correspond with the stated deflection of the member, sharply but continuously altering the time-constant of response of the governing system following any sudden change in the position of the member near its normal position to abruptly reduce the rate of change in the condition after there is a substantial initial jump of the response, governing the position of a final element in accordance with the responsive value of said physical condition but without correspondence of the last named position with the last named value, and reacting upon the member in accordance with the position of the final element to restore both the position of the member to a normal position and the value of the responsive condition to a normal value which ultimately corresponds with said normal position and to bring the position of the final element into correspondence with the value of the independent variable.

4. In an instrument of the measuring and controlling class, in combination, a circuit, a member which is deflectable from its normal position in response to changes in the value of a variable which is to be measured or controlled to vary an electrical current in said circuit in response to its deflection, said circuit including permanently connected elements that continuously alter the effective time-constant of the circuit to very sharply reduce the rate of an initially rapid and appreciable response thereof directly following a sudden change in the deflection of the member, and means governed by the thus-modified current in the circuit for returning said member to its normal position.

5. In an instrument of the measuring and controlling class, the combination of a member having a fixed natural period and positioned in response to the difference between an independent variable to be measured or controlled and a balancing variable, a governing system including an electrical circuit and a means in said circuit sensitive to said member to alter the value of an electrical condition in the circuit in response to changes in the position of the member, said circuit being constructed to have a longer natural period than that of the first named means, an electroresponsive means for rebalancing the member, and relay means connected with the electroresponsive means and with the governing circuit and constructed to operate at predetermined current values which include a dead-zone of non-operation of the electroresponsive means and to generate self-continuing oscillations of the relay means of a shorter period than that of the member when the current supplied to the relay means is between fixed limits which predetermine oscillating ranges surrounding said dead-zone, whereby the action of the relay means causes intermittent operation of the balancing means and hence operates said member toward a stable balancing position in steps.

6. In a measuring or controlling system including a reversible motor, an electrical measuring circuit having a fixed point and including a slide-wire, and a slide-wire contact movable by said motor for varying the E. M. F. of said movable contact relative to that of said fixed point; a mirror galvanometer and a source of independently variable E. M. F. connected between said fixed point and said movable contact in response to changes in said independently variable E. M. F. and the E. M. F. of said movable contact, said mirror galvanometer having a normal position corresponding to no current flow therethrough, a source of light, and photoresponsive means so arranged that a light beam reflected by said mirror is directed towards said photoresponsive means, a stop on said galvanometer arranged relative to said mirror to prevent the deflection of its reflected beam beyond said photoresponsive means on one side only; means for amplifying the current from said photoresponsive means, and two relays connected by an amplifier circuit with said amplifyng means and operable at different values of the amplified current, said relays having contacts for controlling said motor and other contacts for altering the potential of said fixed point for affecting the relation between the movements of said galvanometer and said motor; the combination with said amplifier circuit of: means including a permanently connected capacitor and substantially constant cooperating resistors included in said amplifying means to give a quick substantial change of current response of the amplifying means following a sudden large increase of said illumination of the photoresponsive means to trap the response at a predetermined value intermediate to those corresponding to the operating values of said relays and to maintain said predetermined value for an interval of time greater than the stopping times of said motor and said movable galvanometer; and additional contacts and associated capacitors and resistors for said relays which cause the latter to oscillate when said amplified current remains at a value intermediate to the opening and closing values of either relay and to predetermine the operating values of both relays, the oscillations being timed by the relay characteristics and the values of said resistors and capacitors connected to said last named contacts to have a shorter period than the natural period of oscillation of the system.

7. In an instrument of the measuring and controlling class, in combination, a member displaceable from a normal zero position in accordance with the value of a physical condition to which it is responsive, an electrical circuit network including a means sensitive to the position of the member and in which the current value in a portion of said network is modified in response to a change in the position of the member to cause said current value to ultimately correspond with any stationary position of the member, relay means electrically connected to such portion of the circuit and constructed and arranged to operate at a predetermined value of said current, means operatively connected to said member and governed by said relay means to cause the movement of said member toward its normal zero position, and a resistor for said relay means operatively connected thereby to said circuit to maintain a substantially constant impedance value in said portion of the circuit so that the current therein is not appreciably affected by the operation of said relay means.

8. A governing system for a controlled device comprising, in combination, a governing circuit which is connectable with a source of current sup-

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ply, means connected with the circuit for modifying from a normal value the current in the circuit in response to changes in the value of a physical variable, a means for controlling said device to restore said current to substantially its normal value at least operatively connected with the circuit and responsive to the current therein, and means permanently connected with the circuit for permitting an appreciable jump of, and then damping the response of, the current upon a sudden one of the stated changes to cause said circuit to have a double time-constant of said response by very sharply reducing an initially high responsiveness by abruptly changing from an initial small time-constant to another having a different and very much larger order of magnitude, whereby a sudden change in the value of said variable is directly followed by a rapid and appreciable initial current response which tends to effect a prompt controlling operation of the controlling means, and the rate of the current response is suddenly reduced so that the initial rapid response is followed after such reduction by a much lower rate of response which gives the controlled device time to respond to an initial controlling action to strongly tend to restore the first named means to substantially its normal condition which, if steadily held, restores said current to substantially said normal value before the controlling means operates to further control the device.

9. In an instrument for measuring or controlling an independent physical variable and connectable to a source of said variable, the combination of a damped member having appreciable inertia and continuously sensitive to the difference between the independent variable and a balancing variable, a means for controlling the balancing variable, and a governing system operatively connecting the sensitive member with the controlling means to govern the balancing, said governing system including a current-modifying means sensitive to the position of said member, a circuit network connected to the current-modifying means whereby the current in the network is altered in accordance with the position of said member, relay means connected in the network and to the controlling means and operative in accordance with the value of said current to cause the operation of said controlling means when the current is outside of a normal dead-zone ultimately corresponding with a substantially balanced position of the damped member, and means permanently connected in said circuit network to cause the network to have a double time-constant of response to provide an initial rapid, and a subsequent slow, rate of response of the current in said circuit network, said permanently connected means including elements to cause so large an initial jump of the current upon the member's departure at a high velocity from its normal dead-zone when starting substantially at the balancing position as to provide an immediate operation of the relay means and a consequent immediate initiation of the rebalancing action of the means controlling the balancing variable and, upon the member's re-entry of the dead-zone, following a substantial departure therefrom, at a high enough velocity to otherwise overshoot the normal position of the far edge of the dead-zone, to provide an immediate operation of the relay means to stop the controlling means for the balancing variable, and said permanently connected means also including elements to cause damping of said current accompanying the second or delayed response which is greater than the damping of said damped member whereby, following such re-entry of the dead-zone, the stated relatively high damping at least in effect displaces the far edge of the dead-zone in the direction of motion of the member and farther than the travel of the member in that direction and to subsequently reduce the displacement of said far edge toward its normal position more slowly than the return of said member to within the normal dead-zone to then prevent a further operation of the relay means which would tend to keep the damped member from coming to rest.

10. In an instrument of the measuring and controlling class having a circuit attachable to a source of a variable electrical condition to be measured or controlled, a galvanometer connected with said circuit, together with a light source, a mirror, and a phototube, all arranged to position the reflected image of said light source relative to an edge of said phototube so that the phototube current corresponds with the galvanometer position over an operating range in which at least part of the beam illuminates the phototube, and an electrically-responsive means for rebalancing the galvanometer, the combination of: an amplifier circuit connected with the phototube and with the rebalancing means and constructed to amplify the phototube current in a portion of said amplifier circuit which is connected with the rebalancing means to govern such means in accordance with the value of the amplified current and hence with the position of the galvanometer, and means permanently connected with said amplifier circuit to cause it to have a double time-constant of response to provide an initial rapid, and a subsequent slow, rate of response of the amplified current in said amplifier circuit portion when said phototube edge is reached by said image in traveling onto or off from said phototube following a sudden change in the value of said variable electrical condition and hence in the position of said galvanometer.

11. In an instrument of the measuring and controlling class and including a motor control system having a circuit connectable to a source of a variable electrical condition to be measured or controlled, and also having a galvanometer connected with said circuit, together with a light source, a mirror and a phototube, all arranged to position the reflected image of said light source relative to an edge of said phototube so that the phototube current corresponds with the galvanometer position over an operating range in which at least part of the beam illuminates the phototube, and electrically-responsive relay means controlled by said phototube and means governed by said relay means for rebalancing the galvanometer, the combination of: an amplifier circuit connected with the phototube and with a portion of the relay means and constructed to amplify the phototube current to create a corresponding amplified current in said relay means portion to govern the stated rebalancing in accordance with the value of the amplified current and hence with the position of the galvanometer, and elements permanently connected with said amplifier circuit providing a double time-constant of response for the amplified current to provide an initial rapid, and a subsequent slow, rate of response of the amplified current in said amplifier circuit portion to a sudden change of illumination occurring when said phototube edge is reached by said image in traveling onto or off from said phototube following a sudden change

in the value of said variable electrical condition and hence in the position of said galvanometer, said relay means being two in number and including two relay coils carrying at least a part of the amplified current and having contacts operative at different values of the amplified current, a series and a shunt resistor for each of said relay coils, said contacts being arranged to operatively include both of said resistors in said amplifier circuit when the associated respective relay means is closed and to operatively exclude both when the associated respective means is open.

12. In an instrument of the measuring and controlling class, the combination of a member whose position is responsive to a change in the value of a physical condition to be measured or controlled; an electrical governing system including a circuit network, a means sensitive to the position of the member and connected with the circuit to modify the value of a current in a portion thereof from a normal value in accordance with such position, and means including a capacitor connected in another portion of said circuit, and two substantially constant resistors which are permanently connected to said capacitor respectively in shunt and in series therewith; and an electroresponsive means connected with still another portion of said circuit in which the current is modified by the last named means and operative in accordance with the value of a current in such portion to restore the value of the modified current to said normal value; said capacitor and resistors being of relative magnitudes which produce an appreciable and rapid initial current response in the last named circuit portion with a very small time-constant directly after a sudden change in the position of the member and with a sharp and great increase in the time-constant soon afterwards to produce a slow gradual further response of said current.

13. An instrument of the measuring and controlling class, comprising, in combination, a member whose position is sensitive to the difference between the values of a physical variable to be measured or controlled and of a balancing physical variable; an electrical circuit and means therein which is operatively connected with the member to modify an electrical condition of one portion of the circuit and hence the value of the current therein in ultimate correspondence with the position of the member; an electroresponsive means controlling the value of the balancing variable; relay means connected with another portion of the circuit and with the controlling means to govern the balancing operation of the latter, said relay means being constructed and arranged to fix limiting values of said current and hence positions of the member which predetermine a dead-zone as regards the stated balancing operation; and means permanently connected in a portion of the circuit intermediate of the other stated portions and constructed and arranged relative to said circuit to act independently of the operation of the relay means to permit an appreciable current response at a very low effective time-constant of the circuit directly after a sudden change of the position of the member and very soon afterwards to be very sharply increased, whereby the response of said current, upon a re-entry of the member's dead-zone by the member, is first large and rapid so that the operation of the relay means surely occurs and then slow so that both the sensitive member and the controlling means have time to come to rest within the member's dead-zone before the current can be changed enough to leave the dead-zone with the result that the current attains and tends to stay between its said limiting values.

14. The combination set forth in claim 13 in which the member is continuously sensitive to the stated difference and the combination is provided with an additional means for modifying the balancing variable independently of said electroresponsive means and operatively connected with the relay means to be governed by the operation of the latter.

15. An instrument of the measuring and controlling class comprising, in combination, a member whose position is sensitive to the difference between the values of a physical variable to be measured or controlled and of a balancing physical variable; an electrical circuit and means therein which is operatively connected with the member to modify an electrical condition of one portion of the circuit and hence the value of the current therein in ultimate correspondence with the position of the member; an electroresponsive means for controlling the value of the balancing variable; a means for modifying the balancing variable independently of said electroresponsive means; and two relay means connected with another portion of the circuit and operatively connected with the variable controlling and modifying means to govern their respective operations, each of said relay means including a coil connected with the circuit, contacts and a resistor connected by the contacts with the coil to cause a higher opening than closing current value whereby one of the relay means oscillates its contacts when the value of the current is between the opening and closing values of either relay means, said relay means also having a resistor connected therewith to cause one relay means' oscillating range to be at a higher current value than that of the other whereby a dead-zone of operation of the controlling and modifying means is set up between the oscillating zones.

16. An instrument of the measuring and controlling class comprising, in combination, a member whose position relative to a normal balancing position is sensitive to the difference between the values of a physical variable to be measured or controlled and of a balancing variable; an electrical circuit and means therein which is operatively connected with the member to modify an electrical condition of the circuit and hence the value of the current therein in accordance with the position of the member; an electroresponsive rebalancing means for controlling the value of the balancing variable; another rebalancing means operatively connected with said member to advance it towards its normal balancing position to cause an earlier rebalancing than that caused by said electroresponsive means and operative independently of said electroresponsive means; two relay means connected with said circuit and operatively connected with both of said rebalancing means to govern their operation, each of said relay means being constructed to have a higher opening than closing current value whereby one portion of the relay means oscillates when the value of the current is between the opening and closing values of either relay means, said relay means also being constructed to have the oscillating range of one relay means at a higher current value than that of the other whereby a dead-zone of operation of both rebalancing means is set up between the oscillating zones, and each of said relay means includes means for

preventing the operation of the relay means from directly appreciably affecting the current in the circuit; and means permanently connected in a portion of the circuit intermediate of the other stated portions and constructed and arranged relative to said circuit to act independently of the operation of the relay means to alter the time-constant of the current response to upon a sudden change of the position of the member to be small directly after such change and very soon afterwards to be very sharply increased.

17. A governing system for a motor comprising, in combination, a governing circuit which is connectable with a source of current supply, photo-responsive means connected with the circuit for modifying the current therein in response to changes in its illumination, a motor-controlling means at least operatively connected with the circuit and responsive to the current therein, and means permanently connected with the circuit for permitting an appreciable jump of, and then damping, the response of the current to a sudden one of the stated changes to cause said circuit to have a double time-constant of said response by very sharply reducing an initially high responsiveness by abruptly changing from an initial small time-constant to another having a different and very much larger order of magnitude, whereby a sudden change in the value of said variable is directly followed by a rapid and appreciable partial initial response which tends to effect a prompt controlling operation of the motor-controlling means, and the rate of current response is suddenly reduced so that the initial rapid response is followed after such reduction by a much lower rate of response which gives the motor time to respond to an initial controlling action before the controlling means operates to further control the motor.

18. In an instrument of the measuring and controlling class and including a circuit connectable with a source of a variable electrical condition to be measured or controlled, and also having a galvanometer connected with said circuit, together with a light source, a mirror, and a phototube, all arranged to position the reflected image of said light source relative to an edge of said phototube so that the phototube current corresponds with the galvanometer position over an operating range in which at least part of the beam illuminates the phototube, and an electroresponsive means for rebalancing the galvanometer, the combination of: an electronic amplifier including a plate, a grid, a filament and circuits connected thereto and to said phototube and to an alternating current supply, and two relay means connected in the plate and grid circuits in common and to the filament, said relay means being constructed to operate at different current values and including contacts which are connected to said electroresponsive means to balance said galvanometer in accordance with the operation of said relay means.

19. The combination set forth in claim 18, in which one of said relay means includes a coil, a resistor permanently shunting said coil, a resistor permanently connected in series with said shunted coil, a resistor connected only when said relay means is closed to shunt said coil and its series resistor, and means connected by said relay means when said relay means is opened to short said series resistor, whereby the relay means and hence the electro-responsive means is caused to intermittently operate to cause rebalancing by steps for slow changes of the value of the variable electrical condition.

20. In an instrument of the measuring and controlling class which includes a motor control system; a circuit connectable to a source of an electrical variable to be measured or controlled, and including a mirror galvanometer for directing a light beam relative to a photoresponsive means affected thereby, an electronic amplifier of the current from said photoresponsive means, said amplifier including a control grid, and a circuit connecting said amplifier with said photoresponsive means, means for rebalancing the galvanometer, and means connected with the last named circuit and including a motor for actuating the rebalancing means in accordance with the amplified current from the amplifier, the combination of a capacitor and a resistor permanently connected in series in only the control grid circuit of the amplifier circuit, and a high substantially constant resistance leak permanently shunting such series-connected capacitor and resistor, the values of said series capacitor-and-resistor and of the shunting leak being such that a sudden change to a new level of the current from the photoresponsive means causes a sudden appreciable change in the control grid voltage and hence renders the motor control system highly responsive to sudden changes of the position of the galvanometer followed by a gradual change for stabilizing the instrument.

21. In an instrument of the measuring and controlling class having a relay-governed system, the combination of a circuit, a member which is deflectable from a normal position upon a change of an independent variable to be measured or controlled and influencing the system, and said member being operatively connected to said circuit to alter the value of an electrical condition therein in response to the deflection of the member, said circuit including means permitting an initial substantial jump of the stated response and for altering the effective time-constant of the circuit and continuously effective to sharply reduce an initially rapid rate of response of said condition when the response thereof approaches its final value, a final movable element reacting upon said member, and means including relay means operatively connected to said circuit and to said element to move said element in accordance with the value of the electrical condition in the circuit to return the member toward its normal position following a deflection therefrom.

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CERTIFICATE OF CORRECTION.

Patent No. 2, 267,682. December 23, 1941.

CHARLES O. FAIRCHILD, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, second column, line 64, after "following" insert --that--; page 4, first column, lines 45 and 48, for "101," read --101',--; page 8, second column, line 45, claim 1, strike out the word "acting"; page 9, second column, line 29, claim 6, for "substantially constant cooperating" read --cooperating substantially constant--; line 68, claim 7, for "to" first occurrence, read --in series with said relay means in--; page 12, first column, line 8, claim 16, before "upon" strike out "to"; and second column, line 27, claim 20, after "of" insert a colon; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 10th day of February, A. D. 1942.

Henry Van Arsdale,
(Seal) Acting Commissioner of Patents.