Inventors,
Howard T. Jones,
Joe St. Nuckolls,
by Sidney Greenberg
Their Attorney.
CONSTANT CURRENT REGULATOR WITH MOVING COIL TRANSFORMER
Howard T. Jones, Flat Rock, and Joe A. Nuckolls, Hendersonville, N.C., assignors to General Electric
Company, a corporation of New York.

No. 674,079

U.S. Cl. 323—6

Claim...

ABSTRACT OF THE DISCLOSURE

Current regulator device comprises a moving coil transformer having a main secondary winding connected to an illuminating load and an auxiliary secondary winding associated with the main secondary winding, and phase control means connected to the auxiliary secondary winding for controlling the current therein and thereby the current in the main secondary winding and the load, the phase control means comprising controlled rectifier switching means and an actuating circuit connected to a stable primary voltage source for controlling the operation of the switching means. The regulator is used in lighting circuits to control lamp brightness. The regulator can be operated from a remote location.

The present application is a continuation-in-part of co-pending application Ser. No. 594,910 filed Nov. 16, 1966, now abandoned, and assigned to the same assignee as the present application.

The present invention relates to constant current regulators, and more particularly to such regulators used in lighting circuits for supplying selected levels of current to lamps for controlling their brightness.

Among lighting circuits of the above type in which the invention may advantageously be employed are those used for lighting airport runways and in which the lamp brightness is controlled in accordance with visibility conditions at the airport.

It is an object of the invention to provide an improved constant current regulator for electrical devices in which the current to the load may be controlled to predetermined levels in continuous or stepless manner.

It is a particularly objects of the invention to provide a constant current regulator of the above type in a lighting circuit for controlling the brightness of the lamps energized by the circuit.

It is still another object of the invention to provide an improved constant current regulator of moving coil transformer type which is readily adjustable in continuous manner to enable desired variation in the level of constant current supplied to the load.

Another particular object of the invention is to provide a constant current regulator of the above type which incorporates a moving coil transformer in which the load current is varied by means of auxiliary primary and secondary coil circuits associated with the moving coil transformer.

It is still another object of the invention to provide a constant current regulator of the above type which is adapted to be adjusted by either local or remote control means.

A further object of the invention is to provide a remote control arrangement for a constant current regulator of the above type which is of low voltage, low current type and provides satisfactory operation even at long distances from the regulator device.

Still another object of the invention is to provide a constant current regulator of the above type which is relatively low in cost, is compact and lightweight, and is reliable in operation.

Other objects and advantages will become apparent from the following description and the appended claims.

With the above objects in view, the present invention, in a preferred embodiment, relates to a current regulator device comprising a moving coil constant current transformer having main primary and secondary windings and having terminals connected to the main primary winding for connection to a source of alternating current, load means connected to the main secondary winding, control circuit means associated with the main secondary winding for varying the level of current supplied to the load means comprising an auxiliary secondary winding adjacent the main secondary winding, and phase control means including variable resistance means connected to the auxiliary secondary winding for controlling the current in the latter winding and thereby the current in the main secondary winding and the load means in circuit therewith, and auxiliary primary voltage supply means for providing a stable primary voltage to the phase control means. The latter auxiliary supply means may in one embodiment comprise an auxiliary primary winding arranged adjacent the main primary winding and connected to the phase control means.

The invention will be better understood from the following description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a circuit diagram of a constant current regulator arrangement in accordance with the present invention;

FIGURE 2 is a circuit diagram of a remote control arrangement which may be employed with the constant current regulator arrangement of FIGURE 1; and

FIGURE 3 is a circuit diagram of a modified constant current regulator in accordance with the invention.

Referring now to the drawings, particularly to FIGURE 1, there is shown a circuit arrangement energizing at a constant current a load 1, such as an illuminating means. The illuminating means may be constituted by one or more lamps, such as incandescent, gaseous discharge or fluorescent-type lamps. The circuit includes a movable coil constant current transformer 3 comprising a main primary winding 3e connected to terminals 2 of a source of alternating current and a main secondary winding 3b across which load 1 is connected. In such a movable coil transformer 3, either primary coil 3e or secondary coil 3b may be made movable on the core relative to the other. As will be understood from the art, such a transformer is a variable impedance device that provides a constant output current to a range of load impedances throughout a limited variation in the primary supply voltage, and corrects any variations in output current by changing the variable impedance in series with the load. In such a device, the output current is constant at a particular level depending on the structure of the core and coils and the ampere-turn relationship of the coils. In the regulator circuit employed in the invention, a control device is incorporated for varying in stepless fashion the level of the constant output current which would otherwise be fixed. The control device as shown in FIGURE 1 comprises an auxiliary secondary winding 4 adjacent main secondary winding 3b and in fixed spatial relation thereto. Connected across auxiliary secondary winding 4 is a controlled rectifier switching circuit 5 which serves to provide a phase controlled current of desired amount in winding 4 to thereby vary the ampere-turns of main secondary coil 3b, and thus resulting in the desired adjustment of the constant current supplied to load 1. Controlled rectifier circuit 5 includes a paralleled pair of oppositely poled con-
3,440,520

By suitable adjustment of variable resistance 10, which may be employed as a manually operated local control means for the lighting circuit, the current circulating in auxiliary secondary coil 4 may be varied by means of the described SCR phase control device. The change in current thus produced in coil 4 results in variation of the amper-turns in that coil, which subtract from the amper-turns in main secondary coil 3b, thus effecting a change in the load current in the latter circuit.

The voltage supplied from the auxiliary secondary coil 4 to the actuating circuit 23 is synchronized with the current through the SCR’s since the latter are connected across coil 4. However, as the current through the SCR’s varies during their alternate operation, the current also varies conversely in the load circuit. The voltage across coil 4 therefore also drops, causing the actuating circuit 23 to change the firing angle of the SCR circuit 5 and even to stop operating if the voltage is insufficient to trigger the SCR’s.

In order to overcome these difficulties, there is provided in accordance with the invention an auxiliary circuit 20 associated with the main primary coil 3a of transformer 3 for the purpose of providing a relatively stable source of potential to actuating circuit 23 to ensure proper operation of SCR switching circuit 5. Auxiliary circuit 20 comprises an auxiliary primary coil 21 adjacent and in fixed relation to main primary coil 3a. Thus, if main primary coil 3a is movable, auxiliary primary coil 21 will move together with main primary coil 3a. Auxiliary circuit 20, in the embodiment shown, also comprises transformer 22 and phase-shifting means comprising series-connected capacitor 24 and resistor 25 connected across the secondary of transformer 22. Transformer 22 is used to step-up the voltage to the desired level, e.g. 200 volts which is then reduced to about 75 volts across resistor 25 by the phase-shifting network.

In those cases where a voltage step-up is not necessary, transformer 22 may be dispensed with, in which case capacitor 24 and resistor 25 are simply connected in series with auxiliary coil 21. Phase-shifting means other than that shown could be used, such as a reactor and resistor combination.

Circuit 20 is connected as shown to a voltage divider network comprising resistors 29 and 30 by means of which the voltage output from auxiliary secondary coil 4 is sampled. The relative resistances of resistors 29, 30 are selected to provide the desired level of voltage to be added to the voltage supplied from auxiliary circuit 20 and to synchronize the phase control voltage with the voltage developed across the auxiliary secondary of the circuit. Generally, optimum conditions are obtained when the voltage across resistance 30 is about equal to that across resistance 25. The combination of the auxiliary circuit 20 and voltage divider network 29, 30 compensates for variations in voltages and wave-shapes in the auxiliary primary and auxiliary secondary circuits and results in providing a relatively constant voltage fed into the phase control circuit.

To limit the variations in the voltage supplied by auxiliary circuit 20, a voltage clamping means such as a double Zener diode 26 is connected, as shown, across a portion of resistor 25. A fixed resistor 27 is preferably placed in series with variable resistance 10 so as to provide a minimum in resultant resistance in the event event variable resistance 10 is adjusted to such low resistance that there would be a risk of short circuiting.

The constant current regulator thus described is particularly applicable to airport runway lights where brightness levels of the lamps must be adjusted in accordance with visibility conditions. For such application, the quick and reliable adjustment of the lamp brightness from a remote location is essential. FIGURE 2 shows a remote control circuit arrangement which may be readily combined with the FIGURE 1 circuit.
The remote control circuit includes a pair of conductors 31 and 32 to which is connected an adjustable resistor 33, conductors 31, 32 being as long as necessary to enable adjustable resistor 33 to be placed in a remote location such as the control tower for operating the regulator device of FIGURE 1 at the desired distance. The remaining components of the FIGURE 2 remote control circuit described below are preferably arranged in proximity to the components of the FIGURE 1 regulator circuit. The FIGURE 2 circuit is connected by means of terminals 34, 35 to terminals 36, 37 in the auxiliary circuit 20 of the FIGURE 1 regulator circuit for connecting the remote control circuit across primary auxiliary coil 21 so as to provide a source of potential for the remote control circuit. Variable resistor 38 which is arranged in conductor 32 in series with adjustable resistor 33 serves to compensate for the length of conductors 31, 32. Connected across terminals 34, 35 is a voltage clamping device such as Zener diode 39 for providing a fixed voltage supply to the remainder of the remote control circuit. Resistor 40 is used to limit the current passing through Zener diode 39.

Incandescent lamp 41 is connected across adjustable resistor 33, so that the degree of its brightness may be varied by selective adjustment of resistor 33. The initial brightness level of lamp 41 may be set by means of variable resistor 42 arranged in supply line 31. A light sensitive device 43, such as a cadmium sulfide photoelectric cell, is located adjacent incandescent lamp 41 and preferably enclosed therewith in a light-tight box 44. Photoelectric cell 43 is connected by means of terminals 45, 46 to terminals 47, 48 of variable resistor 10 of the FIGURE 1 regulator device, so that photoelectric cell 43 is connected in parallel with variable resistor 10. Variable resistor 49 in the photoelectric cell circuit may be used to set the level of response of photoelectric cell 43.

In the operation of the remote control circuit, e.g., in an airport lighting system, adjustable resistor 33 is adjusted for the purpose of changing the brightness of lamp load 1. By such adjustment, the current through incandescent lamp 41 changes, thus changing the brightness of the latter lamp. This in turn varies the resistance of photoelectric cell 43, and since the latter is connected across variable resistor 10 it affects the operation of actuating circuit 23 of the regulator circuit in substantially the same manner as if variable resistance 10 itself were adjusted, as described above, and accordingly the constant current supplied to lamp load 1 is changed to a different level in the manner explained in connection with the FIGURE 1 regulator circuit.

The remote control circuit shown in FIGURE 2 provides a number of advantages. It is a low-cost, static circuit device which operates on low voltage and low current, thus avoiding risks of high voltage to operating personnel and being fully operable even with the use of long connecting conductors. The arrangement is such that the FIGURE 1 regulator circuit is effectively isolated from the adjustable remote control resistor, thus avoiding false triggering and the effect of the resistance and capacitance of the connecting leads or faults therein which might adversely affect the operation of the phase control unit or other parts of the regulator circuit.

In a typical regulator circuit of the described arrangement used for airport runway lighting, terminals 2 are connected to a voltage supply of about 2400 volts A.C., auxiliary primary winding has about 60 volts induced therein, transformer 22 steps up to the voltage to about 200 volts, phase shifting network 24, 25 reduces this to about 75 volts, and the combination of these voltages are supplied to the actuating circuit 23. As resistor 10 is variable from resistance to minimum resistance, the current through coil 4 would vary from zero amperes to about 80 amperes, and the current through load 1 would vary from about 6.6 amperes to about 2.8 amperes.

The following components in such a circuit would typically have the indicated values:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistor 10</td>
<td>50K ohms</td>
</tr>
<tr>
<td>Resistor 26</td>
<td>2.2K ohms</td>
</tr>
<tr>
<td>Capacitor 11</td>
<td>0.1 mfd</td>
</tr>
<tr>
<td>Capacitor 13</td>
<td>0.15 mfd</td>
</tr>
<tr>
<td>Resistor 25</td>
<td>1K ohms</td>
</tr>
<tr>
<td>Capacitor 24</td>
<td>1 mfd</td>
</tr>
<tr>
<td>Resistor 30</td>
<td>1K ohms</td>
</tr>
<tr>
<td>Resistor 31</td>
<td>5.6K ohms</td>
</tr>
<tr>
<td>Capacitor 14</td>
<td>1 mfd</td>
</tr>
<tr>
<td>Resistor 15</td>
<td>33 ohms</td>
</tr>
<tr>
<td>Resistor 40</td>
<td>200 ohms</td>
</tr>
<tr>
<td>Resistor 42</td>
<td>500 ohms</td>
</tr>
<tr>
<td>Resistor 33</td>
<td>1K ohms</td>
</tr>
<tr>
<td>Resistor 38</td>
<td>200 ohms</td>
</tr>
<tr>
<td>Resistor 49</td>
<td>10K ohms</td>
</tr>
</tbody>
</table>

FIGURE 3 shows a modified control circuit arrangement for the constant current regulator. As shown in this embodiment, in which like numerals designate components corresponding to those of the FIGURE 1 circuit, the regulator's 50 of an auxiliary alternating current source are provided for supplying a stable voltage to actuating circuit 23, which source may be the same as the source to which terminals 2 are connected or any independent voltage source which provides a peak voltage compatible with the voltage applied to main primary coil 3a. One lead 51 from the auxiliary voltage source 50 is connected to actuating circuit 23. The other lead 52 is connected to a tap on auxiliary secondary coil 4 which serves to synchronize the trigger pulse voltage for firing controlled rectifier switch means 54 to the auxiliary winding voltage phase angle over a wide load operating range. The magnitude of voltage thus tapped from auxiliary winding 4 should be sufficient to provide reliable synchronization, and in practice the tapped voltage is normally about 25% of the source voltage.

Also incorporated in the FIGURE 3 embodiment is a feedback circuit 53 to provide complete readjustment in the secondary load current due to changes in the impedance of load 1 during operation. Circuit 53 includes current transformer 54 arranged in the secondary load circuit, an adjustable voltage divider (55, 56 in a vicinal) connected across the secondary of current transformer 54, and series-connected incandescent lamp 56 and current limiting resistor 57 connected to voltage divider 55. Lamp 56 is arranged in a light-tight enclosure 58 adjacent to photoelectric cell 60 so that the latter operates in response to the light level of lamp 56. Voltage divider 55 may be adjusted to control the amount of current in feedback circuit 53 and hence the range of light levels of lamp 56. Resistance 57 serves to protect lamp 56 from excessive current. Resistance 59 is connected across the secondary winding of current transformer 54 to provide a voltage output that is directly proportional to the primary current, for the purpose of generating a linear error signal which can be utilized by actuating circuit 23 to effect automatic self-regulation.

Photoelectric cell 60 is connected across variable resistor 10 which in combination with series-connected charging capacitor 11 serves to control the time of firing SCR switching circuit 5a via actuating circuit 23.

The feedback arrangement described operates as follows. In the event the current in the secondary load circuit increases, such as from burning out of lamps in load 1, current transformer 54 develops a higher voltage across voltage divider 55, causing a brightening of incandescent lamp 56 and resulting in a decrease in the resistance of photoelectric cell 60. This effectively decreases the net charge Q in series with capacitor 11, causing SCR switch 5a to be fired earlier, and thereby increasing the current in the circuit of auxiliary secondary winding 4 and effecting a proportional decrease.
in the current in the main secondary winding circuit, as explained above. It will be understood that other sensing and feedback means could be used in place of current transformer 54 if desired.

Also shown in the FIGURE 3 embodiment is a circuit branch comprising series-connected resistance 61 and capacitor 62 connected across charging capacitor 11 and serving to provide increased gating energy over a longer period of time, which may be desirable in order to produce stable firing of large SCR's which may be used with switch circuit 5a.

Switching circuit 5a may also be modified as shown in FIGURE 3 by using series-connected resistance 63 and capacitor 64 connected across SCR's 7 and 8, for limiting the rate of voltage rise across the SCR's, and providing holding current once the SCR's are fired. In addition, a voltage limiting device 65 such as a voltage sensitive resistor (varistor) is connected between the control electrodes 7', 8' of SCR's 7 and 8 to provide protection for the SCR's against open circuit conditions by limiting the high voltage appearing across the SCR's through non-destructive firing of the latter. Varistor 65 also thereby eliminates the need for high voltage insulation in the secondary and circuitry of transformer 3 to protect open circuit voltage conditions.

In further modifications, small capacitors 66 and 67 are arranged in the gate circuit of the SCR's as shown in FIGURE 3 to block the reverse gate direct current during turn-on, bias the gate for a more positive turn-on, and provide buffering allowing varistor 65 to positively trigger the SCR's when a high voltage appears across them and thus provide the protective function described. Resistors 68, 69 connected across the SCR gate circuits as shown provide a low impedance level to prevent false firing of the SCR's resulting from stray fields or noise.

The prior disclosure of the invention is shown in FIGURE 4 of a current regulator, variable resistor 10 along with photovoltaic cell 60 and associated components of feedback circuit 53 may be placed at the desired remote location if desired.

Although not shown, means such as current transformers may be provided, if desired, in the main secondary circuit to monitor the load current therein for the purpose of operating such devices as an ammeter and an open circuit voltage protector of known type. Also, a three-position switch (not shown) may be suitably incorporated in the described circuit to enable the circuit to be alternatively operated with local control resistor 10, or remote control resistor 33, or to be switched to an off position.

While the described constant current regulator device has been disclosed particularly with respect to its use in an airport lighting system, it will be understood that it may also be found useful for control of other lighting equipment or of other types of apparatus which it is desired to operate at adjustable levels of constant current, as for example electric ovens and other heating devices. Other forms of sensing and feedback may be incorporated if desired, e.g., the use of a relative humidity sensor which changes its resistance and causes an increase in the current thereby automatically lightening the lights during rain or fog conditions.

While the present invention has been described with reference to particular embodiments thereof it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the spirit and scope of the present invention. Above all it is understood that we intend herein to cover all such modifications as fall within the true spirit and scope of our invention.

What we claim is:
1. Current regulator device comprising, in combination, a moving coil constant current transformer having main primary and secondary windings, and having terminals connected to said main primary winding for connection to a source of alternating current, load means connected to said main secondary winding for energization thereby at a substantially constant current, control circuit means associated with said main secondary winding for varying the level of constant current supplied to said load means comprising an auxiliary secondary winding adjacent said main secondary winding, and auxiliary primary voltage supply means for providing a primary voltage to said control circuit means.
2. A device as defined in claim 1, said control circuit means comprising phase control means connected to said auxiliary secondary winding and to said auxiliary primary voltage supply means for controlling the current in said auxiliary secondary winding.
3. A device as defined in claim 2, said auxiliary primary voltage supply means comprising an auxiliary primary winding arranged adjacent said main primary winding and connected to said phase control means.
4. A current regulator device as defined in claim 3, including voltage divider means connected across said auxiliary secondary winding and to said phase control means for supplying to said phase control means a predetermined ratio of the voltage in said auxiliary secondary winding combined with the primary voltage provided by said auxiliary primary voltage supply means.
5. A device as defined in claim 4, said auxiliary primary voltage supply means including phase shifting means connected in series with said auxiliary primary winding.
6. A device as defined in claim 5, said auxiliary primary voltage supply means further comprising step-up transformer means connected between said phase shifting means and said auxiliary primary winding.
7. A device as defined in claim 6, said phase shifting means comprising a capacitor and resistor in series, and voltage control means connected in parallel with said resistor for limiting the voltage supplied by said auxiliary primary voltage supply means.
8. A device as defined in claim 2, said phase control means comprising bi-directional conducting controlled rectifier means connected across said auxiliary secondary winding and being normally non-conductive to block current flow through said auxiliary secondary winding and having control electrode means to render it conductive in either direction depending on the polarity of the alternating current supply, and means for applying a control signal to said control electrode means including a capacitance and a resistance connected in series, and voltage sensitive switch means and transformer means connected across said capacitance in series discharge relation therewith.
9. A device as defined in claim 2, said auxiliary primary voltage supply means being connected to said auxiliary secondary winding for synchronizing the operation of said phase control means with the voltage phase of said auxiliary primary voltage supply means.
10. A device as defined in claim 2, including feedback means connected to said load means and to said phase control means for controlling the operation of the latter means in response to changes in the operation of said load means.
11. A device as defined in claim 10, said feedback means comprising current sensitive means connected to said load means, light producing means connected to said current sensitive means and having variable light output in response to variations in current in said current sensitive means, and photosensitive means responsive to said light producing means, and control means for controlling the operation thereof in response to the light output of said light producing means.
12. A device as defined in claim 8, said controlled rectifier means comprising a pair of paralleled oppositely poled controlled rectifiers each having a control electrode, and voltage sensitive resistance means connected between the control electrodes of said pair of controlled rectifiers for limiting the voltage appearing across said rectifiers.
13. A device as defined in claim 8, including a capacitor and a resistor connected in series across said controlled rectifier means for limiting the rate of voltage rise across the same.

14. A device as defined in claim 8, including resistance means connected across said control electrode means for preventing inadvertent operation of said controlled rectifier means.

15. A device as defined in claim 8, including a capacitor and a resistor connected in series across said capacitance for increasing the energy applied to said control electrode means for operating said controlled rectifier means.

16. A current regulator device as defined in claim 2, having connected thereto a remote control device comprising a remote adjustable resistor connected across said auxiliary primary voltage supply means, light producing means connected in parallel with said adjustable resistor and being variable in brightness in accordance with varying adjustment of said remote adjustable resistor, photosensitive means arranged in exposure to the light produced by said light producing means, and means connecting said photosensitive means to said phase control means for controlling the operation thereof in accordance with varying adjustment of said remote adjustable resistor.

17. A device as defined in claim 16, including voltage limiting means connected in parallel with said light producing means and said remote adjustable resistor.

References Cited

UNITED STATES PATENTS

1,339,793 5/1920 Smith -------- 336—115 X
2,265,980 12/1941 Berger -------- 323—48 X
2,779,897 1/1957 Ells -------- 323—21 X
3,079,546 2/1963 Koba ----------- 323—50
3,102,226 8/1963 Borkovitz ------- 323—24 X
3,184,675 5/1965 Macklem ------- 323—48 X
3,222,572 12/1965 Powell ------- 323—21 X
3,249,807 5/1966 Nuckolls ------- 315—199

OTHER REFERENCES


JOHN F. COUCH, Primary Examiner.
A. D. PELLINEN, Assistant Examiner.

U.S. Cl. X.R.
323—21, 24,36, 48, 53; 315—139, 194, 278