June 10, 1958 E. D. SPIERER 2,838,716

PHOTOELECTRIC CONTROL SYSTEM

Filed April 20, 1955

Fig. 1.

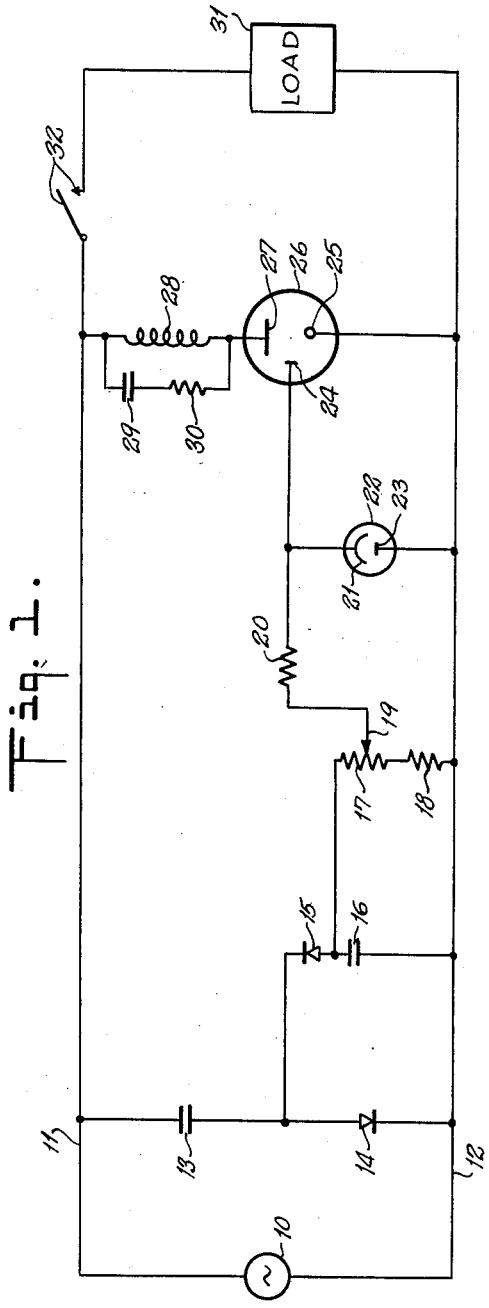
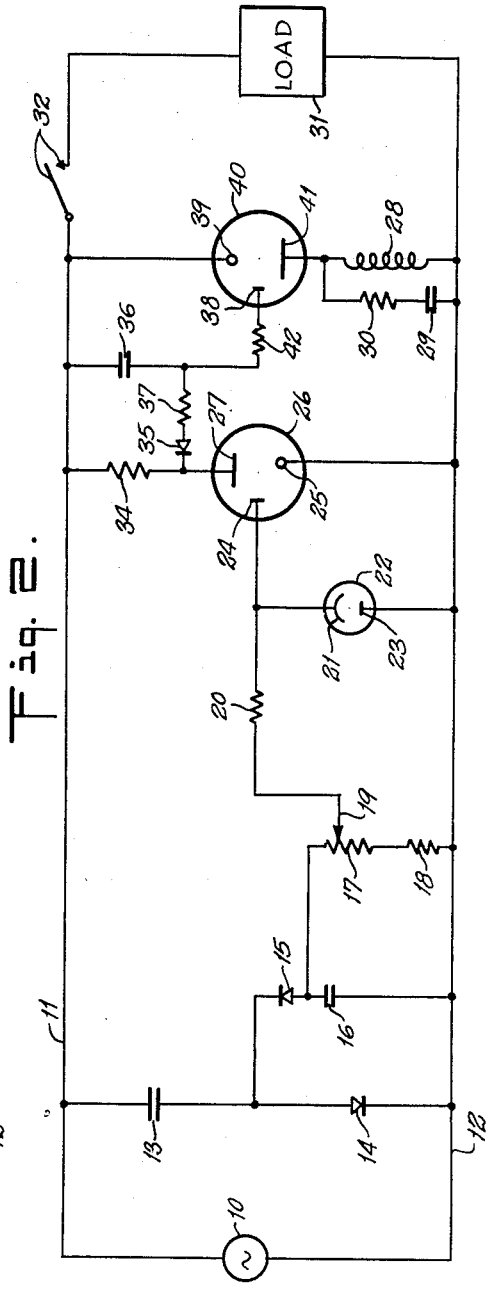


Fig. 2.



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PHOTOELECTRIC CONTROL SYSTEM

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The present invention relates to electronic control circuits and, particularly, to such circuits in which the control operation is initiated and terminated by the value of light energy falling upon a photo-tube or like type of light sensitive cell.

Photo-tubes have been widely used to initiate or terminate a control operation in dependence upon the value of light energy falling upon the tube. These arrangements usually include a load resistor in series with the tube to develop from the tube current a unidirectional control voltage varying in value with the incident light energy. This developed voltage has been conventionally amplified by a direct-current form of amplifier, and the amplified voltage is then used to control a relay or other like electrical circuit control device. While the amplifier may increase the sensitivity of the control system by decreasing the range of light values required to effect control action, these prior arrangements have the important disadvantage for many applications that it is nevertheless difficult to attain and maintain a consistently steep control operating characteristic by which the control action changes sharply and precisely from on to off, or vice versa, with only a small change of incident light energy. They also involve relatively complex and expensive constructions and require appreciable standby power consumption in operation.

In an attempt to avoid at least in part the disadvantages last mentioned, it has been proposed that the control system be simplified by coupling the photo-tube directly to the control electrodes of a gas-filled type of control tube and by energizing both tubes from an alternating current supply source. This arrangement, however, has the disadvantage that adjustment of the system for operation at selectable values of light intensity inherently becomes interrelated with and varies the point in the alternating current cycle at which the gas-tube becomes conductive. It accordingly becomes difficult precisely to establish and maintain preselectable ranges of light intensity control action, and the sensitivity of control is inherently poor.

Applicant in his United States Patent No. 2,606,274, granted August 5, 1952, points out that sensitivity of control action is greatly enhanced, in an arrangement of the type last described, if the alternating current which is used to energize the gas discharge tube is peak rectified to develop a negative energizing potential for the photo-tube circuit and by so utilizing this derived potential to control a tetrode type glow-discharge device that the tube becomes conductive with increasing negative values of the control potential. While this form of control provides high control sensitivity, it requires a relatively large series resistor between the photo-tube and the control electrode of the glow-discharge tube since the latter operates on the principle of transfer current which is comparatively small. When the glow-discharge tube becomes conductive it does not effect removal of voltage across the photo-tube due to the isolating action of the last-mentioned resistor, and over a small range of light

values there results a tendency to develop an unstable condition of operation in which the glow-discharge tube tends to "flutter" between on and off. This operation is not objectionable for many applications, but there are certain applications where high control sensitivity is desired yet instability of operation of the type mentioned cannot be tolerated. Rather these applications require highly sensitive yet positive control action as between on and off control conditions.

It is an object of the present invention to provide a new and improved photo-tube control system of simple and inexpensive arrangement yet one possessing high sensitivity and positive control action.

It is a further object of the invention to provide a novel photo-tube control system which requires negligibly small stand-by power consumption in operation.

It is an additional object of the invention to provide a photo-tube control system of high sensitivity yet one exhibiting appreciable insensitivity to undesired short duration light changes even though of large magnitude.

Other objects and advantages of the invention will appear as the detailed description proceeds in the light of the drawings forming a part of this application, and in which:

Fig. 1 represents a circuit diagram of a photo-tube control system embodying the present invention in a particular form; and

Fig. 2 is a circuit diagram of a modified form of the invention.

Referring now more particularly to Fig. 1, the photoelectric control system there shown is energized from a source of alternating current **10** through conductors **11** and **12** and includes a voltage doubling rectifier arrangement for deriving a negative unidirectional bias potential. To this end, a condenser **13** is connected through a rectifier **14** across the source **10**, and a rectifier **15** and a condenser **16** are connected in series across the rectifier **14** with the rectifiers **14** and **15** having opposed directions of conduction with respect to the source **10** as indicated. The rectifier voltage thus developed across the condenser **16** has negative polarity with respect to the source conductor **12**, and is applied to a potentiometer **17** and series resistor **18**.

A selectable value of bias voltage, depending upon the setting of a movable contact **19** of the potentiometer, is applied through a relatively large resistor **20** of the order of 100 megohms to the cathode **21** of a photosensitive device or photo-tube **22** having an anode **23** connected to the source conductor **12**. The resistor **20** and photo-tube **22** together essentially comprise a voltage divider providing a ratio of voltage division depending upon the electrical conductance of the photo-tube **22** which in turn depends upon the light energy incident thereon at any given time. The potential drop developed across the photo-tube **22** is applied directly between a glow-discharge control electrode **24** and a cathode **25** of a triode form of glow-discharge device **26**. The latter includes a main discharge anode **27** which is connected through a relay winding **28** to the energizing source conductor **11**, and the cathode **25** of the tube **26** is connected to the source conductor **12**. A condenser **29** and series resistor **30** are conventionally connected across the relay winding **28** for purposes of holding the relay closed during negative portions of the alternating current cycle when tube **26** is non-conducting. A load **31** to be controlled by the control system is connected across the source conductors **11** and **12** through the relay contacts **32**.

Considering now the operation of the control system described, it will be noted that a negative bias potential is applied to the glow-control or discharge initiating electrode **24** of the glow-discharge device **26**. The value of

this bias is initially established by adjustment of the potentiometer contact 19, and varies thereafter with the electrical conductance of the photo-tube 22 which, as earlier mentioned, comprises in conjunction with the resistor 20 a voltage divider. Thus assuming that appreciable light energy falls on the photo-tube 22, substantially to increase its electrical conductance, the negative bias constituted by the potential drop across the photo-tube 22 and applied directly to the control electrode 24 and cathode 25 of the glow-discharge tube 26 is relatively small due to the large value of voltage drop produced across the resistor 20 by the appreciable space current of the photo-tube 22. This small negative bias applied to the control electrode 24 is not sufficiently large to initiate discharge between the anode starter electrode 24 and cathode 25 of the tube 26.

If it now be assumed that the intensity of the light incident upon the photo-tube 22 decreases, the electrical conductance of the latter thereupon decreases with the result that the potential drop across the tube 22 correspondingly increases. As the light energy on the tube 22 continues to decrease, the negative bias voltage developed across the tube 22 eventually becomes sufficiently large that the glow-discharge device 26 rather abruptly becomes fully conductive and thereupon energizes the relay 28 to effect closure of the relay contacts 32 and energization of the load 31. The abrupt change of conductivity of the device 26 is considered to be premised upon the breakdown voltage of the starter electrode 24 to cathode 25, the breakdown occurring quite abruptly and being sharp and well defined. Once discharge between the starter electrode and cathode occurs, it immediately transfers over to the main electrode 27 and cathode.

Applicant has found that this abrupt change of state of the discharge device 26 from its nonconductive to its fully conductive condition is greatly enhanced by the use of a negative bias potential on the glow-discharge electrode 24. Thus the sensitivity of the control action is exceptionally high since only a small range of light values is required to render the device 26 either conductive or nonconductive. In this regard, it may be pointed out that device 26 remains conductive for the remainder of the positive half cycle of the source 10 during which it became conductive, but the control electrode 24 is able to regain control of the conductive state of the device 26 during the ensuing negative half cycle of the source 10. The level of light energy at which the discharge device 26 changes from its nonconductive to its conductive state is determined at any given time by the setting of the potentiometer contact 19 to establish the initial value of the bias potential applied to the voltage divider 20, 22.

It may be noted that since the negative bias potential is derived by rectification of the alternating potential of the source 10, changes in the peak amplitude of the latter which ordinarily tend to render the device 26 conductive either earlier or later for a given value of bias potential applied to the control electrode 24 are counteracted in large degree by the fact that the magnitude of the derived bias potential also changes with the peak amplitude of the source 10. The change in this regard is in the proper sense to render the operation of the device 26 more consistent and less sensitive to such amplitude changes of the source 10.

Due to the relatively large value of the resistor 20, selected to be about twice the resistance of the photo-tube 22 at the light level which causes the discharge tube 26 to become conductive, the microampere or so of current flowing in the control electrode 24 when the discharge device 26 does become conductive produces a sufficiently large potential drop across the 100 megohm resistor 20 as very substantially to decrease the potential applied to the photo-tube 22. This has the important effect that once the discharge device 26 becomes conductive the effective sensitivity of the photo-tube 22 is appreciably decreased so that it loses the sensitive control action which it previously possessed over the discharge tube until the latter again becomes nonconductive. This further enhances the precision and stability of the desired control action since it reduces any tendency of the system to turn on and off at a rapid rate or "flutter." The overall result is a rather sharp triggered control over the energization of the load 31.

The relay 28 may be of the type having a delayed operation, as for example one employing a bimetallic element associated with a heater through which the discharge current of the tube 26 flows, if it is desired that the system operation should be insensitive to short duration large amplitude changes of light intensity in the region of the level of light energy at which control action is effected.

Fig. 2 is a circuit diagram representing a modified form of the invention, which is essentially similar to that of Fig. 1 and similar elements are designated by similar reference numerals. This modified form of system provides a highly precise control over the time delay operation of the system for brief changes of light energy incident upon the photo-cell 22. To this end, the anode 27 of the discharge device 26 is connected to the alternating source conductor 11 through a load resistor 34, and the potential drop produced across this resistor when the device 26 becomes conductive is rectified by the rectifier 35 to charge a condenser 36 through a resistor 37. The rectifier device 35 is so poled as to develop a negative potential across the condenser 36 with respect to the conductor 11, and this potential is applied as a negative control bias through a resistor 42 to the control electrode 38 and the cathode 39 of a second triode form of glow-discharge device 40. The anode 41 of the latter is connected through the relay winding 28 to the circuit conductor 12 for control of the relay energization in accordance with the conductive state of the discharge device 40.

Considering the operation of the Fig. 2 arrangement, when the discharge device 26 becomes conductive under control of the photo-tube 22 the condenser 36 begins to charge through the resistor 37 and rectifier device 35. The rate at which the condenser charges is dependent upon the value of the condenser 36 and the value of the resistor 37 as is well known. These values are so selected that the time interval required for the condenser 36 to charge to a potential at which the discharge device 40 is rendered conductive provides the desired time delay between the moment when the first discharge device 26 becomes conductive and the time when the second discharge device 40 becomes conductive to energize the load 31 by closure of the relay contacts 32. This delay action greatly reduces the sensitivity of the system to short duration large amplitude changes of light intensity incident upon the photo-tube 22. The discharge device 40 is also maintained conductive for a short interval after the discharge device 26 becomes nonconductive, this delay being provided by the time interval required for the condenser 36 to be discharged through the resistor 42 by the conductive action of the glow-discharge control electrode 38.

The result of this delay form of control action is that the control system when turning either on or off is insentitive to even large amplitude short duration changes of light energy incident upon the photo-tube 22. The change of light intensity accordingly must maintain an average value for a preselected interval before the conductive state of the discharge device 26 is effective to render the discharge device 40 conductive or before the nonconductive state of the device 26 is effective to terminate the conduction of the device 40.

It will be noted that both of the discharge devices 26 and 40 operate under control of negative bias potentials applied to their respective glow-discharge or starter electrodes 24 and 38, thus preserving the highly sensitive trigger control action which is characteristic of the control system operation.

While not intended to limit the scope of the invention, the following component values have been found suitable for representative embodiment of the invention:

Condensers **13** and **16**	0.1 microfarad.
Condenser **29**	1.0 microfarad.
Condenser **36**	0.25 microfarad.
Rectifiers **14** and **15**	Selenium type.
Rectifier **35**	Type IN34.
Potentiometer **17**	5 megohms.
Resistor **18**	5 megohms.
Resistor **20**	100 megohms.
Resistor **30**	820 ohms.
Resistor **34**	2,000 ohms.
Resistor **37**	100,000 ohms.
Resistor **42**	20 megohms.
Photo-tube **22**	Type 5653.
Discharge tubes **26** and **40**	Type 5823.
Resistance of relay **28**	2,500 ohms.

It will be apparent from the foregoing description of the invention that a photoelectric control system embodying the invention is of relatively simple and inexpensive arrangement, and is one which requires negligibly small standby power consumption during operation. The system exhibits high sensitivity and positive control action, and readily permits the provision of operating delays which enable the system to have appreciable insensitivity to undesired short duration changes of control light intensity even though these changes be of large magnitude.

What is claimed is:

1. A photoelectric control system comprising, means including a triode form of glow-discharge device for developing a control effect dependent upon the state of conduction of said device, said device having glow-discharge control and cathode electrodes, a photo-sensitive device having a value of electrical conductance varying with the light energy incident thereon and including two electrodes directly connected to individual ones of said control and cathode electrodes, an alternating current energizing circuit for energizing said discharge device with an alternating potential, and means for deriving from said alternating potential a unidirectional negative bias potential and for applying said bias potential through a relatively high value of resistance to said control electrode and the connected one of the electrodes of the photo-sensitive device so as to bias said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device.

2. A photoelectric control system comprising, a glow-discharge device having glow-discharge control and cathode electrodes and having an anode energized through an anode load impedance, means including a source of unidirectional bias potential and a photo-sensitive device coupled to said electrodes for biasing said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device, a time-constant circuit including in series a condenser and a rectifier coupled across said load impedance for charging said condenser during the conductive state of said discharge device, and control effect developing means including a second glow-discharge device having glow-discharge control and cathode electrodes coupled across said condenser to control the state of conductivity of said last-mentioned device by the potential developed across said condenser.

3. A photoelectric control system comprising, a glow-discharge device having glow-discharge control and cathode electrodes and having an anode energized through an anode load resistor, means including a source of unidirectional bias potential and a photo-sensitive device directly connected across said electrodes for biasing said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device, a time-constant circuit including in series a condenser and a rectifier coupled across said load resistor for charging said condenser during the conductive state of said discharge device, and control effect developing means including a second glow-discharge device having glow-discharge control and cathode electrodes coupled across said condenser to control the state of conductivity of said last-mentioned device by the potential developed across said condenser.

4. A photoelectric control system comprising: a glow-discharge device having glow-discharge control and cathode electrodes and having an anode energized through an anode load resistor; an alternating current energizing circuit for said discharge device; means including a rectifier system coupled to said energizing circuit for deriving a unidirectional bias potential and including a photo-sensitive device coupled to said electrodes for biasing said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device; a time-constant circuit coupled across said load resistor and including in series a condenser, a resistor, and a rectifier for charging said condenser during the conductive state of said discharge device; and control effect developing means including a second glow-discharge device having glow-discharge control and cathode electrodes coupled across said condenser to control the state of conductivity of said last-mentioned device by the potential developed across said condenser.

5. A photoelectric control system comprising, a glow-discharge device having glow-discharge control and cathode electrodes and having an anode energized through an anode load resistor, means including a source of unidirectional bias potential and a photo-sensitive device coupled to said electrodes for biasing said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device, a time-constant circuit including in series a condenser and a rectifier coupled across said load resistor for charging said condenser during the conductive state of said discharge device, and control effect developing means including a second glow-discharge device having glow-discharge control and cathode electrodes coupled across said condenser to bias said last-mentioned control electrode negatively with respect to its associated cathode and thereby control the state of conductivity of said last-mentioned device by the potential developed across said condenser.

6. A photoelectric control system comprising, a glow-discharge device having glow-discharge control and cathode electrodes and having an anode energized through an anode load resistor, means including a source of unidirectional bias potential coupled through a relatively large resistor to a photo-sensitive device having electrodes connected directly in shunt to said first mentioned electrodes for biasing said control electrode increasingly negative with respect to said cathode for decreasing values of conductance of said photo-sensitive device, a time-constant circuit including in series a condenser and a rectifier coupled across said load resistor for charging said condenser during the conductive state of said discharge device, and control effect developing means including a second glow-discharge device having glow-discharge control and cathode electrodes coupled across said condenser to bias said last-mentioned control electrode negatively with respect to its associated cathode and thereby control the state of conductivity of said last-mentioned device by the potential developed across said condenser.

7. A photoelectric system comprising an alternating voltage line, means including a triode form of cold cathode glow discharge tube for developing a control effect dependent on the state of conduction of said tube, said tube having an anode and a cathode respectively connected

to opposite sides of the line and having a starter electrode effective on being adequately biased negatively of the tube cathode to initiate conduction of the tube, a photo-sensitive device with cathode and anode electrodes directly connected respectively to the starter electrode and the tube cathode, a voltage rectifying circuit coupled to the line to derive therefrom a unidirectional negative potential, and a resistive connection between said circuit and the cathode of said device to apply negative potential to the latter cathode and via the direct connection from the latter cathode to the starter electrode to impress the starter electrode with negative bias potential increasing to tube conduction initiating value upon diminution of the light energy on said device to a low level, said resistive connection having a resistance substantially greater than that of said device at said low level of light energy, whereby starter electrode current flow occurring upon initiation of tube conduction will produce a potential drop across said resistive connection such as to make the cathode of the photo-sensitive device appreciably less negative and thus reduce sensitivity of the device to an increase in light energy above said low level.

8. An electrical system comprising a glow discharge trigger tube having glow discharge control and cathode electrodes and having an anode energized through an anode load impedance, an alternating current energizing circuit for said tube, signal responsive means for applying triggering potential to said control electrode to initiate conduction of the tube, a time-constant circuit coupled across said load impedance and including, in series with a resistor and rectifier, a condenser charged during the conductive state of said tube, and control effect developing means including a second glow discharge trigger tube energized by said alternating current circuit and having glow discharge control and cathode electrodes coupled across said condenser to control the state of conductivity of the second tube by the potential developed across the condenser.

9. An electrical system comprising an alternating voltage line, a first gaseous discharge trigger tube having anode and cathode and control electrodes, a load impedance connected in series with said tube across the opposite sides of the line, a control circuit for applying triggering potential to said control electrode to initiate conduction of said first tube, a second such tube having its anode coupled to the same side of the line as the cathode of the first tube and its cathode coupled to the side of the line to which the anode of the first tube is connected, whereby the first and second tubes may be conductive respectively during opposite phases of the alternating voltage on the line, and means for controlling conduction of the second tube by the first tube comprising a time-delay circuit coupled across said load impedance and including, in series with a rectifier and a resistor, a condenser connected to the control electrode of the second tube and charged during conduction of the first tube to develop a triggering potential on the control electrode of the second tube to initiate its conduction.

10. An electrical system comprising an alternating voltage line, a first gaseous discharge trigger tube having anode and cathode and control electrodes, the cathode being connected to one side of the line, a load impedance connecting the anode to the opposite side of the line, a control circuit for applying a triggering potential to said control electrode to initiate conduction of the first tube, a second such tube having its anode and cathode coupled to the line in inverse relation to the first tube whereby the first and second tubes may be conductive respectively during opposite phases of the line voltage, and means for controlling conduction of the second tube by the first tube comprising a time-delay circuit coupled across said load impedance and connected to the control electrode of the second tube and including in series a condenser and resistor and rectifier of which the condenser is charged during conduction of the first tube to develop a delayed triggering potential on the control electrode of the second tube for initiating its conduction after a time delay dependent on the time constant of said delay circuit.

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