May 26, 1936. D. D. KNOWLES 2,042,181

CONTROL CIRCUIT

Filed July 30, 1932

Fig. 1.

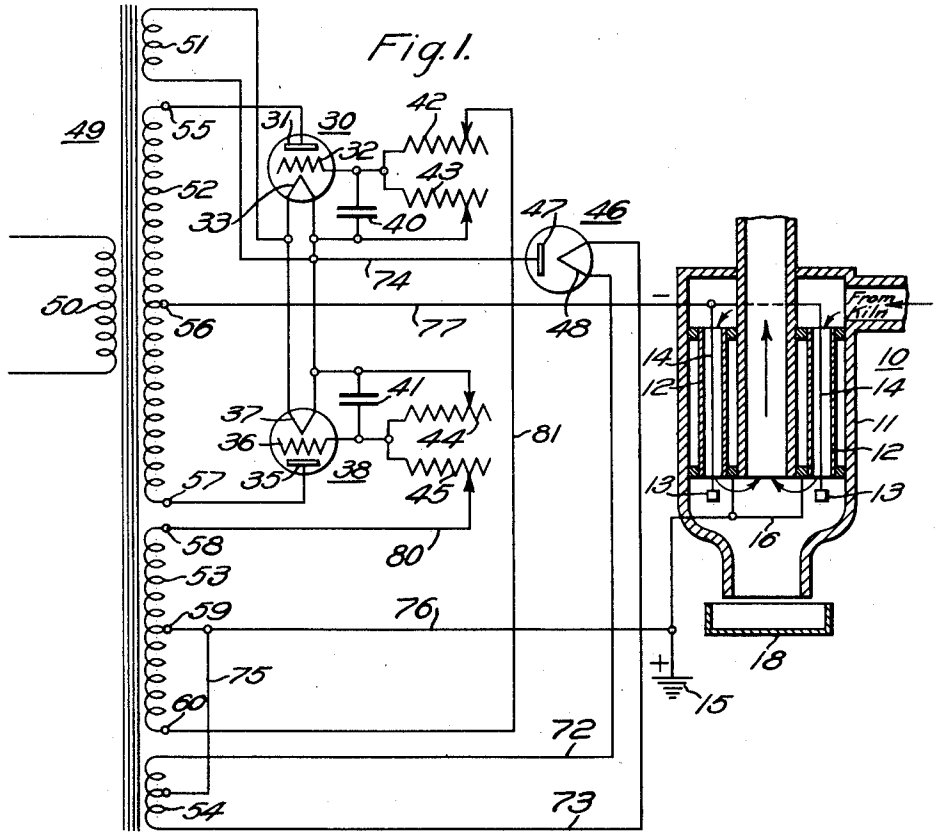
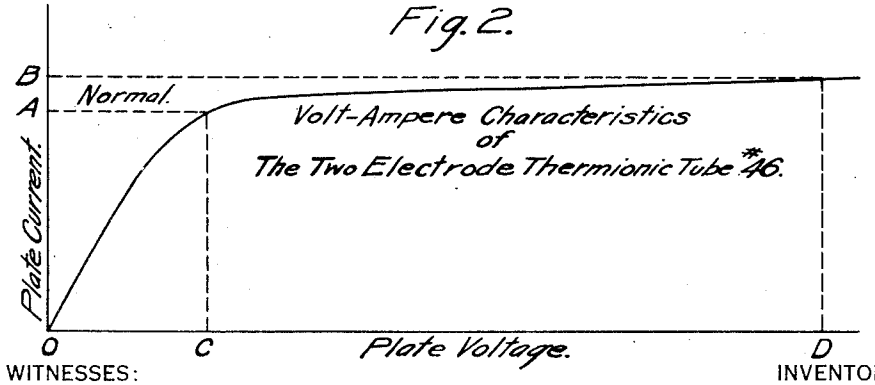


Fig. 2.



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CONTROL CIRCUIT

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10 Claims. (Cl. 183—7)

My invention relates in general to precipitating devices for smoke stacks and the like, and more particularly to the electrical circuits for supplying a uni-directional current of a relatively high voltage to the precipitating device.

In control circuits for precipitating devices employing high-voltage rectifying tubes to supply a uni-directional current of relatively high-voltage, it is imperative, to protect the rectifying tubes, that the load current be immediately reduced to a predetermined safe value just as soon as an overload condition or a flashover occurs in the precipitating device.

Whenever the density of the smoke varies during the course of the operation of a precipitating device or should dust and other foreign particles collect and build up in the precipitating device, flashovers may occur in the precipitating device. These flashovers give rise to surges in the control circuits and principally the rectifying tubes. If the flashovers are not prevented, they will eventually ruin the rectifying tubes in the course of a relatively short period of operation. When a short-circuit condition or a flashover occurs in the precipitating device, the rectifying tubes, if not protected, must absorb substantially all of the energy of the short-circuit. In other words, the rectifying tubes cannot supply the heavy current demand during a short-circuit condition, because their emission is limited to the value of the saturation current that corresponds to the temperature of the filament. As a result, the potential between the plate and the filament of the rectifying tubes increases very rapidly until substantially the full potential of the supply is applied between the plate and the filament of the rectifying tubes. The plate is then bombarded by electrons which have acquired a velocity equivalent to the full supply potential, and unless the short-circuit condition or flashover is immediately removed, the plate may melt, or, because of the high temperature of the plate, the filament may be destroyed by back bombardment of the electrons from the plate on the other half cycle or both plate and filament may be destroyed. Consequently, the very frequent flashovers incident to the operation of a precipitating device makes the question of short-circuit protection a very important consideration, because of its direct bearing on the life of the rectifying tubes.

Heretofore, mechanical means have been employed to trip or disconnect the rectifying tubes from the supply source. As is obvious, such mechanical devices are too slow in their operation, both from the standpoint of adequately protecting the rectifying tubes and of insuring efficient operation of the precipitating device. All of these mechanical means may be manifestly classed as remedial measures because they operate to remove a short-circuit condition and not to prevent it.

Therefore, it is an object of my invention to provide preventive measures rather than remedial measures to make it substantially impossible for flashovers to occur in a precipitating device under any operating condition.

Another object of my invention is the provision of a control circuit of the class indicated that shall be simple and reliable in operation and be economically manufactured and installed.

A further object of my invention is to provide for changing alternating current to uni-directional current and delivering the uni-directional current to a precipitating device, and for maintaining the uni-directional current at a substantially predetermined selected value.

It is also an object of my invention to provide for regulating the current flowing through a grid-controlled rectifying tube in accordance with a negative blocking bias that is responsive to the said current passed by the rectifying tube.

A further object of my invention is to provide for causing the regulating action of the grid-controlled rectifying tubes to be of any predetermined rate or sensitivity.

Other objects and a fuller understanding of my invention may be had by referring to the following description taken in connection with the accompanying drawing, in which:

Figure 1 is a diagrammatic view of a control system embodying the features of my invention, and

Fig. 2 is a curve representing the volt-ampere characteristics of a two-electrode thermionic tube which I employ in the illustrated control circuit of Fig. 1.

With reference to the drawing, my invention in general comprises a precipitating device **10**, a transformer **49** having a primary winding **50** and a plurality of secondary windings **51**, **52**, **53** and **54**, a pair of grid-controlled rectifying tubes **30** and **38** for changing the alternating-current to a uni-directional current, and a two-electrode thermionic tube **46**, in combination with condensers **40** and **41** and with adjustable resistors **42**, **43**, **44**, and **45**, for regulating the current flowing through the grid-controlled rectifying tubes **30** and **38**.

The electrical precipitating device **10** comprises an enclosure **11** that surrounds the base portion

of a smoke stack for steel mills and the like. Mounted within the enclosure 11 and surrounding the smoke stack are positioned a nest of vertically disposed pipes 12. Disposed axially and extending through each of the vertically disposed tubes 12 is a conductor 14. The vertically disposed tubes 12 are generally referred to as collecting tubes or electrodes, and the conductors 14 as discharge electrodes, and will hereinafter be referred to as such. For the purpose of maintaining the discharge electrodes 14 taut, weights 13 are suspended from the lower ends thereof.

As illustrated, the smoke or gases enter the upper portion of the enclosure 11 from the right and thence are forced downwardly through the nest of vertical collecting electrodes 12 and then upwardly through the smoke stack to the atmosphere. When the electrical precipitating device is in operation, the discharge electrodes 14 are charged with a uni-directional current of extremely high negative potential relative to the collecting electrodes 12, which may be connected to the ground 15. In actual practice, the potential may vary from 30,000 to 75,000 volts, depending upon the design of the installation.

The removal of the particles suspended in the smoke or gas as it passes downwardly through the vertically disposed collecting electrodes 12 is accomplished by the utilization of a strong electrical field that is established around each of the discharge electrodes 14. Such a strong field causes ionization of the gas and is accompanied by the familiar corona discharge. When the gas is ionized, the negative electrons of the molecules are separated from the positively charged nuclei or positive ions. These electrons may remain free or may unite with other neutral molecules to form negative ions.

The ions and electrons become attached to the suspended particles in the air and thereby cause the suspended particles to become negatively charged. Hence, the negatively charged particles then behave in accordance with the law of electrostatic traction, and, in consequence, are repelled by the negatively charged discharge electrodes 14 and attracted by the positively charged collecting electrodes 12. Just as soon as the particles are attracted to the inner sides of the collecting electrodes 12, they immediately fall by means of gravity into a hopper 18, which may be periodically cleaned out by an attendant as the said particles collect in the hopper. Therefore, as the gas enters the bottom of the smoke stack, it is freed or cleaned of dust and other foreign particles and the gas is emitted to the atmosphere as substantially pure and clean gas.

It is found that the best precipitating results are obtained when the discharge electrodes 14 are of a negative polarity. This is because the speed of the electrons is much higher than the speed of the positive ions, and, as a result, more effective ionization by the collision of the electrons with the suspended particles is obtained.

For the purpose of supplying uni-directional current to the discharge electrode 14 of the precipitating device, I employ two high-voltage rectifying tubes 30 and 38 connected in circuit relation with the secondary transformer winding 52 to effect a full-wave single-phase rectification. The rectifying tubes 30 and 38 are similar in construction and operation, the former having a plate 31, a grid 32 and a filament 33, and the latter having a plate 35, a grid 36, and a filament 37. In a rectifying thermionic tube suitable for precipitating devices, the container is exhausted to a high degree of vacuum and the electrodes are well insulated and protected to withstand the high-voltage to which they are connected. As illustrated, the filaments 33 and 37 of the rectifying tubes 30 and 38 are electrically heated by the secondary transformer winding 51.

The grids 32 and 36 are connected in circuit relation with the secondary transformer winding 53, the grid 32 being connected to the lower terminal 60 of the secondary transformer winding 53 through means of the adjustable resistor 42 and a conductor 81, and the grid 36 being connected to the upper terminal 58 of the secondary transformer winding 53 through the adjustable resistor 45 and a conductor 80. Hence, the potential of the grids 32 and 36 may be maintained at any predetermined selected positive value with respect to the potential of their respective filaments 33 and 37. In this manner, the rectifying tubes 30 and 38 are normally disposed to pass a predetermined amount of current for charging the discharge electrodes 14 of the precipitating device 10.

For the purpose of regulating the current flowing through the rectifying tubes 30 and 38, I utilize a two-electrode thermionic tube 46, in combination with capacitors 40 and 41 and adjustable resistors 42, 43, 44, and 45.

The thermionic tube 46 comprises a plate 47 and a filament 48, the latter of which is connected by means of the conductors 72 and 73 to a secondary transformer winding 54. The mid-tap of the secondary transformer winding 54 is connected by means of a conductor 75 to the mid-tap 59 of the secondary transformer winding 53. By means of this connection, if it were not for the opposing voltage of the secondary transformer winding 53, the potential of the grids 32 and 36 of the rectifying tubes 30 and 38 would be substantially the same as the potential of the filament 48 of the thermionic tube 46.

The volt-ampere characteristic of the two-electrode thermionic tube 46 is illustrated in Fig. 2, the plate current being plotted as ordinates and plate voltage as abscissæ. As illustrated in Fig. 2, when the plate current exceeds a predetermined normal value O—A, the corresponding change in plate voltage is very rapid, because of the saturation characteristics of the tube. Therefore, in accordance with one of the objects of my invention, I utilize this rapid change in plate voltage as a negative blocking bias to immediately increase the effective impedance of the rectifying tubes 30 and 38. As a result, just as soon as the plate current of the two-electrode thermionic tube 46 slightly increases above a predetermined normal value, the rectifying tubes 30 and 38 function to reduce the value of the plate current until it again becomes stabilized at the predetermined normal value.

In explaining the operation of my control circuit, let it be assumed that the primary winding 50 of the transformer 49 is energized from a suitable source of alternating-current. Under this condition and during the positive half of the cycle, current flows from the upper terminal 55 of the secondary transformer winding 52 through the plate 31 and the filament 33 of the rectifying tube 30, conductor 74, the plate 47 and the filament 48 of the two-electrode thermionic tube 46, the conductors 72 and 73 in parallel to the mid-tap of the secondary transformer winding 54, conductors 75 and 76 to the collecting electrodes 12 of the precipitating device 10, thence to the

discharge electrodes 14, and a conductor 77 to the mid point 56 of the secondary transformer winding 52. During the positive half-cycle of the alternating-current, the rectifying tube 38 is inoperative and, accordingly, passes no current.

During the negative half-cycle of the alternating-current, current flows from the bottom terminal 57 of the secondary transformer winding 52 through the plate 35 and filament 37 of the rectifying tube 38, conductor 74, the plate 47 and the filament 48 of the thermionic tube 46 and thence, through the same circuit as just previously traced for the positive half-cycle, to the mid-tap 56 of the secondary transformer winding 52. So long as the smoke or the gases passing downwardly through the collecting electrodes 12, or as the dielectric strength between the discharge electrodes 14 and the collecting electrodes 12 remains at a normal value, the rectifying tubes 30 and 38 will pass a normal predetermined value of current. Under the normal operating condition, the plate voltage of the two-electrode thermionic tube 46 is represented by the value O—C of Fig. 2, which means that if it were not for the opposing voltage of the secondary transformer winding 53, the grids 32 and 36 of the rectifying tubes 30 and 38 would be negatively charged with respect to their filaments 33 and 37 by an amount equal to O—C. However, under the normal operating conditions of the precipitating device, the positive biasing voltage of the secondary transformer winding 53 is greater than the drop of potential across the thermionic tube 46 by an amount sufficient to cause the rectifying tubes 30 and 38 to pass to normal current.

However, should the density of the smoke increase to cause a corresponding decrease in the dielectric strength between the discharge electrodes 14 and the collecting electrodes 12 of the precipitating device or as a result of any other condition to cause the dielectric strength to decrease, the rectifying tubes 30 and 38 tend to pass more current in order to meet the demands of the precipitating device 10. Just as soon as the current exceeds the predetermined normal value, for instance a value O—B of Fig. 2, the plate voltage of the thermionic tube 46 increases to a value O—D, which may be in the order of ten to fifteen times the normal value O—C. The increase of the plate voltage of the thermionic tube 46 to a value O—D opposes and greatly exceeds the positive biasing effect of the secondary transformer winding 53, with the result that the grids 32 and 36 of the rectifying tubes 30 and 38 are highly negatively charged with respect to their filaments 33 and 37. This means that the effective impedance of the rectifying tubes 30 and 38 is materially increased, which, accordingly, opposes any increase of the load current above the normal predetermined operating value. Therefore, by means of the thermionic tube 46 which provides the negative blocking bias to regulate or limit the current passing through the rectifying tubes 30 and 38 to a predetermined low safe value, the lives of the respective tubes are materially lengthened since the system prevents surges and flashovers.

In order to make the regulating action of the biasing effect of the thermionic tube 46 gradual and free from too quick a change, the combination of the capacitor 40 and the adjustable resistors 42 and 43 are connected in circuit relation with the grid 32 of the rectifying tube 30, and the combination of the capacitor 41 and the adjustable resistors 44 and 45 are connected in circuit relation with the grid 36 of the thermionic tube 38. The adjustable resistors 42 and 45 predetermine the rate at which the respective capacitors become charged when the load current exceeds the predetermined normal value, and the adjustable resistors 43 and 44 predetermine the rate at which the respective capacitors discharge when the load current is decreased below the predetermined normal value. In other words, the rapidity at which the rectifying tubes 30 and 38 respond to offset any change of the load current from the normal value, is somewhat dampened or delayed in order to give a smooth and continuous regulating effect.

Since certain changes in my invention may be made without departing from the spirit and scope thereof, it is intended that all matters contained in the foregoing description and shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. In an electrical control system for electrical precipitators having a collecting electrode, a discharge electrode disposed in space relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the combination of a grid-controlled rectifying tube for supplying uni-directional-current of relatively high voltage to the discharge electrode, a source of electrical energy, means for connecting the rectifying tube in circuit relation with the discharge electrode and the source of electrical energy, means for normally biasing the grid of the rectifying tube to cause a predetermined amount of current to flow therethrough, a two-electrode electronic tube, and means for so interconnecting the rectifying tube and the electronic tube that, when the current flowing through the said tubes exceeds the said predetermined amount, the electronic tube provides a negative blocking bias to oppose and exceed the action of the normal biasing means to thus decrease the current flowing through said tubes.

2. In an electrical control system for electrical precipitators having a collecting electrode, a discharge electrode disposed in space relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the combination of a grid-controlled rectifying tube for supplying uni-directional-current of relatively high voltage to the discharge electrode, a source of electrical energy, means for connecting the rectifying tube in circuit relation with the discharge electrode and the supply of electrical energy, means for normally biasing the grid of the rectifying tube to cause a predetermined amount of current to flow therethrough, a two-electrode electronic tube, and means for so interconnecting the rectifying tube and the electronic tube that, when the current flowing through the said tubes exceeds the said predetermined amount, the electronic tube provides a negative blocking bias to oppose and exceed the action of the normal biasing means to thus decrease the current flowing through said tubes, and means for predetermining the rate of decay of the said current when it exceeds the said predetermined normal value and for predetermining the rate of building up when it falls below the said predetermined normal value.

3. In an electrical control system for electrical precipitators or the like having a collecting electrode, a discharge electrode disposed in space

relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the combination of a rectifying tube having a plate, a filament, and a grid for supplying a uni-directional-current of relatively high voltage to the discharge electrode, a two-electrode electronic tube associated with the rectifying tube, a transformer having a primary winding and a plurality of secondary windings, means for connecting the plate and the filament of the rectifying tube and the two-electrodes of the electronic tube in circuit relation with the discharge and the collecting electrodes and one of the secondary windings of the transformer, means including another secondary winding of the transformer for normally biasing the grid of the rectifying tube relative to the filament to cause a predetermined amount of current to flow through said tubes, means for so interconnecting the two-electrodes of the electronic tube in circuit relation with the filament and the grid of the rectifying tube that, when the current flowing through the said tubes exceeds the said predetermined value, the increase in potential between the two-electrodes of the electronic tube causes a negative blocking bias to oppose and exceed the action of the normal biasing means to thus decrease the current flowing through the said tubes.

4. In an electrical control system for electrical precipitators having a collecting electrode, a discharge electrode disposed in space relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the combination of a rectifying tube having a plate, a filament, and a grid for supplying uni-directional-current of relatively high voltage to the discharge electrode, a two-electrode electronic tube associated with the rectifying tube, a transformer having a primary winding and a plurality of secondary windings, means for connecting the plate and the filament of the rectifying tube and the two-electrodes of the electronic tube in circuit relation with the discharge and the collecting electrodes and one of the secondary windings of the transformer, means including another secondary winding of the transformer for normally biasing the grid of the rectifying tube relative to the filament to cause a predetermined amount of current to flow through said tube, means for so interconnecting the two-electrodes of the electronic tube in circuit relation with the filament and the grid of the rectifying tube that, when the current flowing through the said tubes exceeds the said predetermined value, the increase in potential between the two-electrodes of the electronic tube causes a negative blocking bias to oppose and exceed the action of the normal biasing means to thus decrease the current flowing through the said tubes, a capacitor connected between the filament and the grid of the rectifying tube, a resistor connected in series circuit relation with said capacitor to predetermine the rate at which the said capacitor builds up, and a second resistor connected in parallel circuit relation with said capacitor to predetermine the rate at which the said capacitor discharges.

5. A control system for supplying a uni-directional current of relatively high potential to a load comprising, in combination, a source of alternating current, a load circuit that is disposed to operate on a uni-directional current, a grid-controlled rectifying tube connected between said source and said load to convert alternating-current to uni-directional current, an electronic tube associated with the rectifying tube and responsive to the uni-directional current delivered to the load, the characteristics of the electronic tube being such that, when the uni-directional current exceeds a predetermined value, the increase in voltage across the said tube causes a negative blocking bias to regulate the rectifying tube.

6. A control system for supplying a uni-directional current of relatively high potential to a load comprising, in combination, a source of alternating current, a load circuit that is disposed to operate on a uni-directional current, a grid-controlled rectifying tube connected between said source and said load to convert alternating-current to uni-directional-current, means for normally biasing the grid of the rectifying tube to cause the said tube to pass a predetermined amount of uni-directional current, an electronic tube associated with the rectifying tube and responsive to the uni-directional-current delivered to the load, the characteristics of the electronic tube being such that, when the uni-directional-current exceeds the said predetermined value, the increase in voltage across the said tube causes a negative blocking bias to oppose and exceed the action of the normal biasing means to regulate the rectifying tube.

7. A control system for supplying a uni-directional current of relatively high potential to a load comprising, in combination, a source of alternating current, a load circuit that is disposed to operate on a uni-directional current, a grid-controlled rectifying tube connected between said source and said load to convert alternating-current to uni-directional-current, means for normally biasing the grid of the rectifying tube to cause the said tube to pass a predetermined amount of uni-directional current, an electronic tube associated with the rectifying tube and responsive to the uni-directional-current delivered to the load, the characteristics of the electronic tube being such that, when the uni-directional-current delivered to the load exceeds the said predetermined value, the increase in voltage across the said electronic tube causes a negative blocking bias to oppose and exceed the action of the normal biasing means to regulate the rectifying tube, and means including a capacitor and resistor to cause the regulating action of the rectifying tube to be of any predetermined rate.

8. A control system for supplying a uni-directional current of relatively high potential to a load comprising, in combination, a source of alternating current, a load circuit that is disposed to operate on a uni-directional current, a plurality of grid-controlled rectifying tubes connected between said source and said load to convert alternating current to uni-directional-current, means for normally biasing the grid of the rectifying tubes to cause the said tubes to pass a pre-determined amount of uni-directional current, an electronic tube associated with the rectifying tubes and responsive to the uni-directional current delivered to the load, the characteristics of the thermionic tube being such that, when the uni-directional current exceeds a pre-determined value, the increase in voltage across the said tube causes a negative blocking bias to regulate the rectifying tubes, and means including a capacitor and resistors to cause the regulating action of the rectifying tubes to be of any predetermined rate.

9. In an electrical control system for electrical precipitators having a collecting electrode, a discharge electrode disposed in space relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the

combination of a plurality of rectifying tubes each having a plate, a filament, and a grid for supplying a uni-directional current of relatively high voltage to the discharge electrode, a two-electrode electronic tube associated with the rectifying tubes, a transformer having a primary winding and a plurality of secondary windings, means for connecting the plate and the filament of the rectifying tubes and the two-electrodes of the electronic tube in circuit relation with the discharge and the collecting electrodes and one of the secondary windings of the transformer, means including another secondary winding of the transformer for normally biasing the grids of the rectifying tubes relative to their filaments to cause a predetermined amount of current to flow through said tubes, means for so interconnecting the two-electrodes of the electronic tubes in circuit relation with the filaments and the grids of the rectifying tubes that, when the current flowing through the said tubes exceeds the said predetermined value, the increase in potential between the two-electrodes of the electronic tube causes a negative blocking bias to oppose and exceed the action of the normal biasing means to thus decrease the current flowing through the said tubes.

10. In an electrical control system for electrical precipitators having a collecting electrode, a discharge electrode disposed in space relation with said collecting electrode, and means for passing a gas through the region of said electrodes, the combination of a rectifying tube having a plate, a filament and a grid for supplying a uni-directional-current of relatively high voltage to the discharge electrode, a source of electrical energy, means for connecting the plate and the filament in circuit relation with the discharge electrode and the source of electrical energy, and a two-electrode electronic tube connected in series circuit relation with the filament and plate of the rectifying tube to regulate the bias of the grid of the rectifying tube, the characteristic of the electronic tube being such that a small change in the current flowing between the two-electrodes causes a relatively large change in the grid bias.

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