

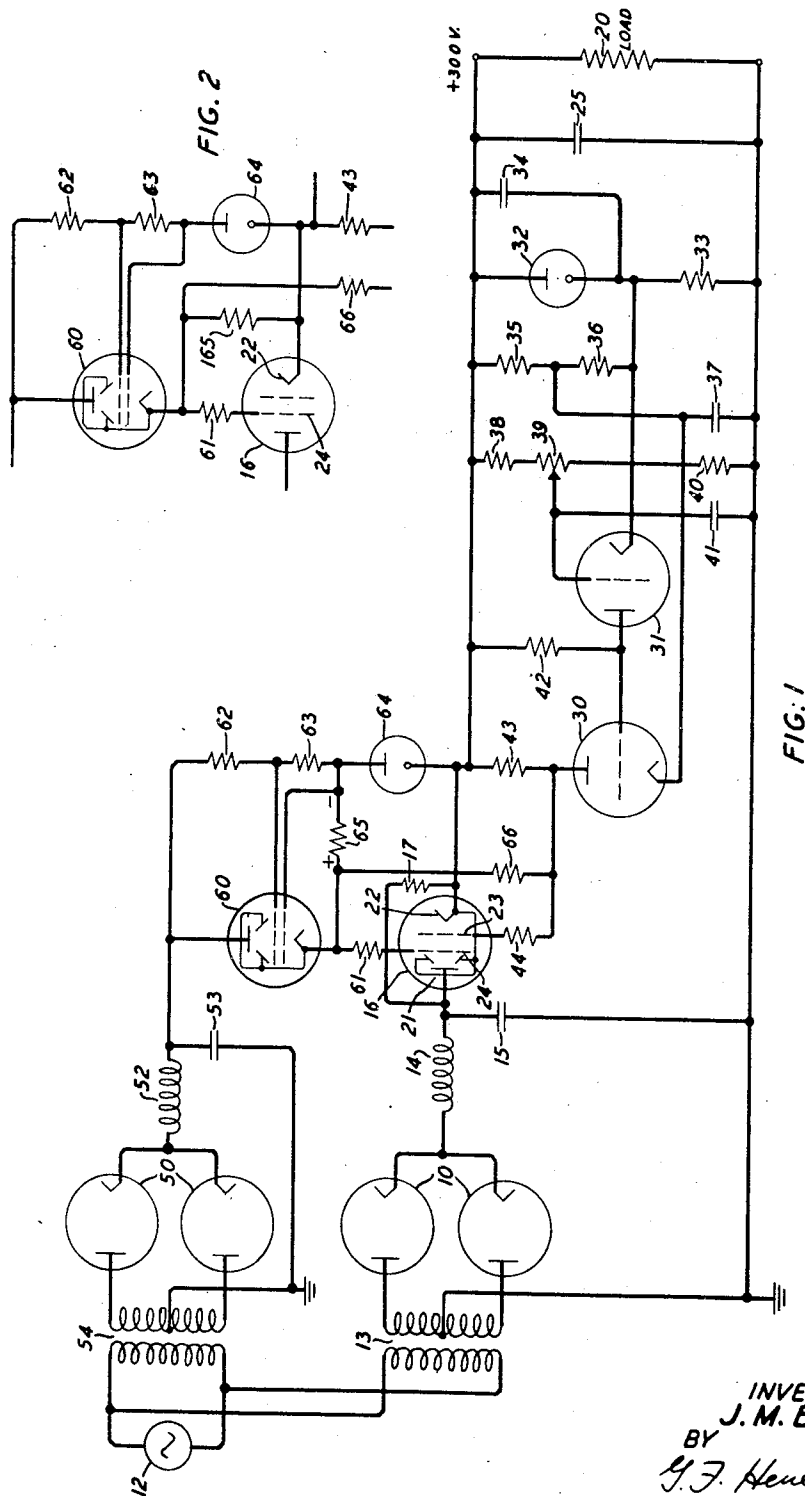
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SPACE DISCHARGE VOLTAGE REGULATION CIRCUIT

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SPACE DISCHARGE VOLTAGE
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This invention relates to voltage regulation and more particularly to novel means for controlling the impedance of a circuit through which current is supplied from a source to a load to minimize voltage changes across the load caused by load changes and by voltage changes of the source.

In voltage regulators used heretofore it has been common practice to include the space current path of a regulator space discharge tube in series with the load and to cause the resistance of the space discharge path to vary to control the current supplied to the load and thus to control the load voltage. Where the maximum current to be supplied to the load is relatively large, it is desirable that the minimum resistance of the space discharge path be low in order that the power loss introduced in the circuit by the regulator tube be kept at a reasonable low level. The power loss in the circuit for supplying current to the load can, of course, be reduced by using a regulator tube of increased size or by increasing the number of regulator tubes used, the anode-cathode paths of the tubes being connected in parallel with respect to each other. This expedient has the disadvantage of increasing the cost of the apparatus and of requiring larger space.

In accordance with the present invention there is provided an improved voltage regulating circuit employing a regulator tube, or a plurality of such tubes, having at least four elements to one of which, specifically the screen grid, is supplied a potential for reducing the anode-cathode resistance of the tube and thereby permitting increased current to be supplied to a load. The screen grid-cathode voltage is supplied from an auxiliary rectifier energized by current from an alternating current supply source which also supplies current to a main rectifier the output current of which is supplied to the load. In order that the screen grid potential may be sufficiently high to cause the anode-cathode resistance of the regulator tube to be reduced to a suitably low value when the supply voltage is at a minimum value and to prevent the screen grid-cathode voltage from exceeding a safe operating limit when the supply voltage is at a maximum value, auxiliary voltage regulating means is provided for reducing or minimizing changes of the screen grid-cathode voltage. Preferably the auxiliary regulating means comprises a circuit having the anode-cathode path of an auxiliary space discharge device and a resistor in series to which current is supplied from the auxiliary rectifier, the voltage drop across the resistor being im-

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pressed upon the control electrode-cathode circuit of the auxiliary space discharge device for increasing the anode-cathode resistance of the auxiliary space discharge device and therefore the voltage drop across the anode-cathode path in response to an increase of current flowing through the resistor. Potential changes at the cathode of the auxiliary space discharge device, and therefore at the screen grid of the series regulator tube which is connected to the cathode of the auxiliary space discharge device are thus minimized.

The invention will now be described with reference to the accompanying drawing in which:

Fig. 1 is a diagrammatic view of a current supply circuit embodying the invention; and

Fig. 2 is a diagrammatic view of a modification of a portion of Fig. 1.

In accordance with the specific embodiment of the invention shown in the drawing, there are provided a main rectifier comprising a pair of diodes 10 for rectifying current supplied from an alternating current supply source 12 through a transformer 13 and a ripple filter having a series inductance element 14 and a shunt condenser 15. The rectified and filtered current is supplied to a load 20 through a circuit having the anode-cathode path of a space discharge regulator tube 16 in one branch path and a shunt resistor 17 connected across the anode-cathode path, the negative output terminal of the rectifier and one terminal of the load being connected to ground. A filter condenser 25 is connected across the load 20. The series regulator tube 16 comprises an anode 21, connected to the ungrounded output terminal of filter 14, 15, a cathode 22 connected to the positive load terminal, a control grid 23 and a screen grid 24. While a single regulator tube 16 is shown in the drawing, a plurality of similar tubes having their anodes conductively connected to the common terminal of filter elements 14 and 15 and having their cathodes conductively connected to the positive load terminal may be used if desired. For example, there may be employed three such tubes of the type known as 6Y6-G.

A circuit comprising amplifier tubes 30 and 31 is provided for amplifying load voltage variations to set up a control voltage which is impressed upon the control electrode-cathode circuit of regulator tube 16 for varying the anode-cathode resistance of tube 16 and thereby controlling the current supplied to load 20. There is connected across the load a shunt path comprising a cold cathode, gas filled voltage regulating tube 32 of the type known as VR-150 and a resistor 33

in series. A shunt path connected across tube 32 comprises a condenser 34 and a second shunt path connected across the tube comprises resistors 35 and 36 in series. The common terminal of tube 32 and resistor 33 is connected to the cathode of amplifier tube 31 and the common terminal of resistors 35 and 36 is connected to the cathode of amplifier tube 30 and to a terminal of condenser 37, the other terminal of the condenser being connected to ground. There is also connected across the load a shunt path comprising in series a resistor 38, potentiometer 39 and a resistor 40, the variable tap of the potentiometer 39 being connected to the control grid of tube 31 and, through a condenser 41, to ground. The positive load terminal is connected through a resistor 42 to the anode of tube 31 and through a resistor 43 to the anode of tube 30. The anode of tube 31 is conductively connected to the control electrode of tube 30 and the anode of tube 30 is connected through 470 ohm resistor 44 to the control electrode 23 of series regulator tube 16.

The voltage regulator tube 32 has the characteristic that its resistance decreases as a current through the path 32, 33 increases, and vice versa, at such a rate that the voltage across the tube 32 remains substantially constant. Therefore the potential at the cathodes of tubes 30 and 31 with respect to the potential of the positive load terminal remains substantially constant. The potential at the control grid of tube 31 varies in accordance with load voltage variations. If the load voltage increases by a small amount due to an increase of line voltage or an increase of the resistance of load 20, for example, the control grid of tube 31 will become relatively more negative with respect to its cathode to reduce the anode current flowing through resistor 42. The control grid of tube 30 therefore becomes relatively less negative with respect to its cathode to cause its anode current flowing through resistor 43 to be increased. As a result the grid 23 of tube 16 becomes relatively more negative with respect to its cathode to cause the anode-cathode resistance of tube 16 to increase. The increase in load voltage is thus minimized.

It is desired that the anode-cathode path of series regulator tube 16, or of several such tubes having their anode-cathode paths in parallel, should have a low minimum resistance so that a relatively large current may be supplied to a load while maintaining the load voltage substantially constant. For this purpose, means are provided for impressing upon the screen grid 24 of series regulator tube 16 with respect to the cathode 22 a voltage which is preferably high but not higher than the maximum safe operating voltage. The screen grid-cathode voltage is derived from a direct current source of considerably higher voltage than the load voltage. As shown in the drawing the screen grid potential is supplied from an auxiliary rectifier comprising diodes 50 through a ripple filter comprising a series inductance element 52 and a shunt condenser 53, alternating current from the supply source 12 being supplied to the rectifier through a transformer 54. If the voltage across the load 20 is maintained at substantially 300 volts, for example, the output voltage of the auxiliary rectifier produced across the condenser 53 may have a minimum value of about 600 volts. The negative output terminal of the auxiliary rectifier is grounded and the common terminal of inductance element 52 and condenser 53 is connected to the anode

of a space discharge device 60 which may be a beam power tube of the type known as 6L6-GA. The cathode of the tube 60 is connected through a 47-ohm resistor 61 to the screen grid of tube 16. Where a plurality of series regulator tubes like tube 16 are used, the screen grid of each tube is connected through a resistor to the cathode of tube 60. A current path may be traced from the common terminal of inductance element 52 and condenser 53 through 5000-ohm resistor 62, 20,000-ohm resistor 63, cold cathode gas-filled voltage regulating tube 64 (VR-105) and load 20, to ground. The common terminal of resistors 62 and 63 is connected to the screen grid of tube 60 and the common terminal of resistor 63 and tube 64 is connected through 18,000-ohm resistor 65 to the cathode of tube 60. In addition to supplying anode current to amplifier tube 30 from the rectifier 10 through a circuit comprising resistor 43, anode current is also supplied thereto from the auxiliary rectifier 50 through a circuit comprising an anode resistor 66. Space current in the tube 30 is thereby increased. The control electrode of tube 60 is connected to the common terminal of resistors 63 and 65 and of tube 64. In addition to supplying energizing current to the circuit described for supplying screen grid potential to the tube 16, the rectifier 50 may also supply current to a load connected across the filter condenser 53.

When the voltage of the supply source 12 increases from its minimum value, increased current flows through the path comprising the anode-cathode path of tube 60, resistor 65 and voltage regulating tube 64. As a result, the voltage drop across resistor 65 is increased, thus making the control electrode of tube 60 more negative with respect to its cathode to cause the anode-cathode resistance of tube 60 to increase. The voltage drop across the voltage regulator tube 64 increases by only a relatively small amount because of its negative resistance-current characteristic. The increase of voltage drop across the resistor 65 is small relative to the increase of voltage drop across the anode-cathode path of tube 60 because of the increase of resistance of the anode-cathode path of tube 60 in response to an increase of current through resistor 65. Thus the voltage in the screen grid cathode circuit of tube 16, that is the sum of the voltage drop across voltage regulating tube 64 and the voltage drop across resistor 65, increases by a relatively small amount such that the safe operating screen grid voltage of tube 16 is not exceeded for any voltage of the supply source within the operating range of supply voltage.

The current supplied from the auxiliary rectifier 50 to the tube 60 and its associated circuit is relatively small. The maximum current supplied to the current path comprising resistors 62 and 63 and voltage regulating tube 64 may be of the order of 15 milliamperes, this current decreasing as the voltage of the auxiliary rectifier is reduced. When three 6Y6-G tubes in parallel are used in place of the single tube 16 shown in the drawing, the maximum current supplied from the auxiliary rectifier to the current path comprising the anode-cathode path of tube 60 and the screen grid-cathode paths of the 6Y6-G tubes is of the order of 30 milliamperes. This current decreases as the source of line voltage, and therefore the output voltages of rectifiers 10 and 50, respectively, increase due to the control grids of the 6Y6-G tubes becoming increasingly negative with respect to their cathodes.

It should be noted that the regulating action

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of the circuit comprising tube 60 tends to prevent not only changes of screen grid-cathode voltage of tube 16 due to voltage changes of the supply source 12 but changes of screen grid-cathode voltage due to any cause such as a change of screen grid-cathode resistance of tube 16. The screen grid-cathode resistance and the anode-cathode resistance of tube 16 are each changed in response to changes of control grid-cathode voltage of the tube. These changes must be relatively large to correct for load voltage changes especially when a resistor 17, as shown in the drawing, is connected in parallel with the anode-cathode path of tube 16. An increase of the supply voltage and an increase of the screen grid-cathode resistance of tube 16 resulting in a decrease of screen grid-cathode current usually occur simultaneously. Assume, however, that the supply voltage is constant and the load voltage rises due to a decrease of load. As a result the control grid of tube 16 will become relatively more negative with respect to its cathode, thereby increasing the screen grid-cathode resistance. The voltage drop across the anode-cathode path of regulator tube 60 thus decreases to cause an increase of the screen grid-cathode voltage of tube 16. This increase of voltage is minimized, however, due to the increased current flowing through the resistor 65 which causes the control grid of tube 60 to become relatively more negative with respect to its cathode and therefore causes the anode-cathode resistance of the tube 60 to increase.

Maintaining the screen grid of tube 16 at a relatively fixed potential with respect to its cathode has the further advantage that when the supply voltage and the anode-cathode voltage of tube 16 are relatively high, the anode-cathode resistance is substantially independent of supply voltage changes when the control grid-cathode voltage is fixed. If the screen grid-potential of tube 16 were permitted to increase with an increase of supply voltage, it would be necessary to produce a larger change in the control voltage applied to the control electrode-cathode circuit of tube 16 in order to keep the load voltage substantially constant than is the case when changes of screen grid-cathode voltage of tube 16 are minimized.

Fig. 2 shows a modification of a portion of the circuit shown in Fig. 1, the same numerals being used to designate corresponding elements in the two figures. Fig. 2 differs from Fig. 1 in that resistor 65 of Fig. 1 is omitted from the arrangement of Fig. 2 and in that, in Fig. 2, there is provided a resistor 165 in a path connecting the cathode of tube 60 and the cathode 22 of tube 16. If the current through resistor 165 increases, for example, due to an increase of supply voltage or to a decrease of screen grid-cathode current of tube 16, or both, the control grid of tube 60 becomes relatively more negative with respect to its cathode. The voltage drop across the anode-cathode path of tube 60 is therefore increased to cause the increase of screen grid-cathode voltage of tube 16 to be minimized.

What is claimed is:

1. Apparatus for controlling the voltage supplied to a load from a first direct current supply source the voltage of which may vary, comprising a first space discharge device having an anode, a cathode and a pair of control electrodes each for controlling the resistance of the anode-cathode path of said device in accordance with the potential thereof with respect to the potential of the

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cathode, means for connecting the anode-cathode path of said device in series with said load and said supply source, an auxiliary direct current supply source the voltage of which may vary, a second space discharge device having an anode, a cathode and a control electrode, a circuit comprising in series the anode-cathode path of said second space discharge device and a resistor to which circuit current is supplied from said auxiliary source, a circuit including said resistor connecting a first of said pair of control electrodes and the cathode of said first space discharge device for impressing upon said first control electrode a potential which is positive with respect to the potential of said cathode, a circuit including said resistor connecting the control electrode and cathode of said second space discharge device for controlling the resistance of the anode-cathode path of said second space discharge device in response to changes of the voltage drop across said resistor to minimize changes of said voltage drop, thereby minimizing changes of the potential of said first control electrode with respect to the cathode of said first space discharge device, and means for controlling the potential of the second of said pair of control electrodes with respect to said cathode of said first space discharge device for controlling the voltage supplied to said load.

2. Apparatus in accordance with claim 1 in which there is provided a circuit comprising in series a cold cathode gas-filled space discharge tube having an anode and a cathode and a resistance means to which circuit current is supplied from said auxiliary current supply source, and in which said circuit for connecting the first of said pair of control electrodes and said cathode of said first space discharge device comprises said cold cathode gas-filled tube, the cathode of said tube being conductively connected to the cathode of said first space discharge device.

3. Apparatus in accordance with claim 1 in which said second space discharge device includes a screen grid electrode and in which there are provided a circuit to which current is supplied from said auxiliary supply source, said circuit comprising in series a second and a third resistor and a cold cathode gas-filled space discharge tube having an anode and a cathode, means for connecting the common terminal of said second and third resistors to said screen grid electrode, means for connecting the common terminal of said third resistor and the anode of said cold cathode tube to the common terminal of said first mentioned resistor and said control electrode of said second space discharge device and means for connecting the cathode of said cold cathode tube to the cathode of said first space discharge device, the common terminal of said first resistor and the cathode of said second space discharge device being connected to the first of said pair of control electrodes of said first space discharge device.

4. In combination, a first space discharge device having an anode, a cathode, a control grid and a screen grid, a second space discharge device having an anode, a cathode and a control grid, a first circuit comprising in series a first impedance means, the anode-cathode path of said first space discharge device and a source of voltage for causing current to flow in said circuit, a second circuit comprising in series a second impedance means, the anode-cathode path of said second space discharge device and a source of voltage for causing current to flow in said second circuit, means for controlling the po-

tential of said control grid with respect to that of the cathode of said first space discharge device in accordance with the voltage across said first impedance means, thereby controlling the anode-cathode impedance of said first space discharge device and the voltage across said first impedance means, means for controlling the potential of the control grid with respect to that of the cathode of said second space discharge device in accordance with the voltage across said second impedance means, thereby controlling the anode-cathode impedance of the second space discharge device and the voltage across said second impedance means, a circuit connecting the screen grid and cathode of said first space discharge device including said second impedance means, thereby impressing upon said screen grid with respect to said cathode a potential for further controlling the anode-cathode impedance of said first space discharge device.

5. In combination, a first circuit for supplying current to a load, said circuit comprising in series with the load and a supply source the anode-cathode path of a first space discharge device having an anode, a cathode, a control grid and a screen grid, a resistance means, a second circuit for supplying current to said resistance means, said circuit comprising in series with the resistance means and a supply source the anode-cathode path of a second space discharge device having an anode, a cathode and a control electrode, one terminal of said resistance means being connected to said cathode of said second space discharge device, means for connecting the other terminal of said resistance means to the control electrode of said second space discharge device for impressing upon said control electrode with respect to said cathode a potential which varies in response to current variations in said second circuit, thereby reducing said current variations, a circuit including said resistance means connecting the screen grid and cathode of said first space discharge device for impressing upon said screen grid a potential which is positive with respect to the potential of said cathode, and means responsive to load voltage changes for controlling the control grid-cathode voltage of said first space discharge device to control its anode-cathode resistance and thereby to minimize said load voltage variations.

6. Apparatus for controlling the voltage across a load to which current is supplied from a first source of direct current the voltage of which may vary comprising means for supplying direct current from said source to said load through the anode-cathode path of a first space discharge device having an anode, a cathode, a control grid and a screen grid, means for supplying direct current from a second source of direct current the voltage of which may vary to a current path including the anode-cathode path of a second space discharge device having an anode, a cathode and a control electrode, means for deriving from said current path and impressing upon the screen grid with respect to the cathode of said first space discharge device a voltage for reducing the anode-cathode resistance of said first space discharge device when the voltage of said first source is relatively low, means for deriving and impressing upon said control electrode with respect to said cathode of said second space discharge device a potential

which varies in response to variations of the current supplied through the anode-cathode path of said second space discharge device to control the resistance of the anode-cathode path of said second space discharge device, thereby reducing variations of the current flowing through the anode-cathode path of said second space discharge device and variations of the screen grid-cathode voltage of said first space discharge device, and means for deriving and impressing upon said control grid with respect to said cathode of said first space discharge device a potential which varies in response to load voltage variations for controlling the anode-cathode resistance of said first space discharge device to cause a reduction of said load voltage variations.

7. Regulating apparatus for controlling the direct current supplied to a load from a main direct current source the voltage of which may vary comprising a first space discharge device having an anode, a cathode and a first and a second control electrode, means for connecting the anode-cathode path of said device in series with said load with respect to said main current source, an auxiliary direct current source the voltage of which may vary, a second space discharge device having an anode, a cathode and a control electrode, a circuit to which current is supplied from said auxiliary current source comprising in series the anode-cathode path of said second space discharge device and a resistor, a circuit comprising said resistor connecting the control electrode and cathode of said second space discharge device for causing the anode-cathode resistance of said second space discharge device to be increased in response to an increase of the current supplied to said resistor, and vice versa, thereby minimizing voltage changes across said resistor, a circuit including said resistor for connecting the second control electrode and the cathode of said first space discharge device to impress a potential upon said second control electrode with respect to said cathode for reducing the anode-cathode resistance of said first space discharge device when the voltage of said main source is relatively low and for making the anode-cathode resistance of said first space discharge device for a fixed potential on the first control electrode with respect to the cathode relatively independent of voltage changes of said auxiliary current source, and means responsive to load voltage changes for impressing upon said first control electrode of said first space discharge device with respect to said cathode a potential which varies in response to load voltage changes for controlling the direct current supplied to said load and thereby minimizing said load voltage changes.

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