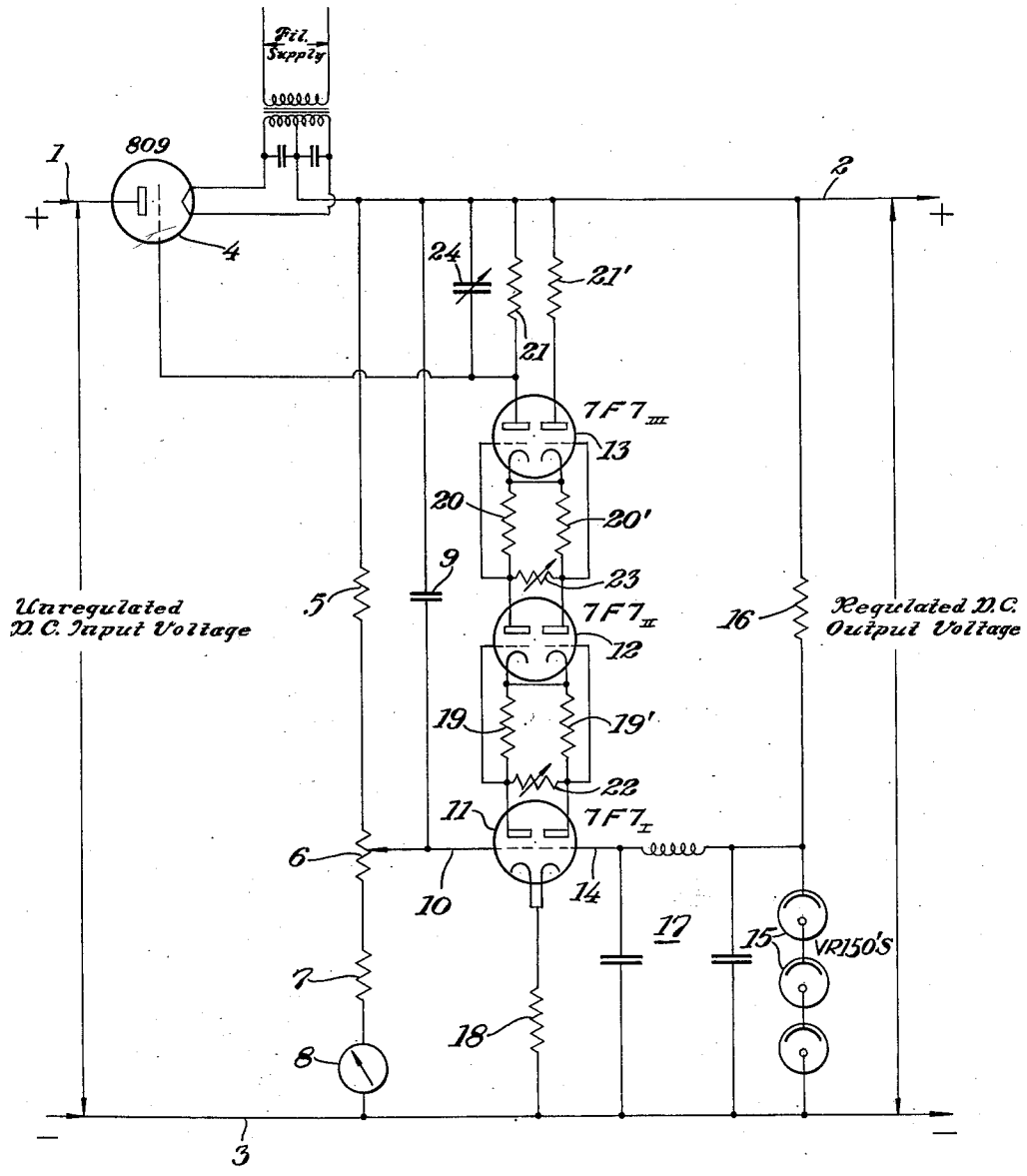
Feb. 2, 1954 E. J. GROTH, JR 2,668,272

VOLTAGE REGULATOR

Filed March 1, 1946



INVENTOR.
Edward J. Groth Jr.
BY
Robert A. Saunders

Patented Feb. 2, 1954 2,668,272

UNITED STATES PATENT OFFICE

2,668,272

VOLTAGE REGULATOR

Edward J. Groth, Jr., Woods Hole, Mass., assignor, by mesne assignments, to the United States of America as represented by the United States Atomic Energy Commission

Application March 1, 1946, Serial No. 651,286

3 Claims. (Cl. 323—22)

1

This invention relates to voltage regulators of the type wherein variations of the output voltage from a desired value are detected, amplified, and then employed to control a variable resistive element in series with the source voltage.

In such voltage regulators there are two standards of performance, namely its rapidity of response characteristic and its long time stability characteristic. It is ordinarily desired for the regulator to have a very rapid response characteristic in order that small rapid fluctations in the source voltage be promptly suppressed and not appear in the output voltage. This rapidity of response characteristic is determined by the time constant of the regulator, the rapidity of response being increased by a decrease in the time constant. It is also ordinarily desirable for the regulator to have an extremely good long time stability characteristic such that the output voltage will remain constant over a long period of time and have little or no tendency to drift. This long time stability characteristic is determined by the gain of the amplifying system of the regulator such that the long time stability characteristic is improved by an increase in gain.

In the design of prior regulators, ordinarily one of these characteristics had to be sacrificed at the expense of the other, that is, if it was desired to design a regulator having a very rapid response, it was ordinarily necessary to sacrifice good performance of the regulator with respect to its long time stability characteristic, and conversely, if it was desired to provide a regulator which would have very little tendency to drift over a long period of time, it was necessary to sacrifice the performance of the regulator with respect to its rapidity of response. When it was desired to provide a regulator having particularly good performance with respect to both of these characteristics, complicated, expensive, and cumbersome designs had to be resorted to.

The principles of the present invention permit the design of a simple regulator having extremely good characteristics both with respect to rapidity of response and long time stability. Moreover, adjustable means are provided within the regulator for increasing the rapidity of response at the expense of the long time stability characteristic, and also for improving the long time stability characteristic at the expense of the rapidity of response.

These beneficial characteristics of the present regulator are obtained by the provision of a novel high gain extremely stable amplifying system consisting of a plurality of series-connected

2

amplifying stages connected across the regulated output voltage of the regulator.

Also, in the prior art devices designed for a maximum output voltage of the order of four thousand volts or so, a direct potential of two or three thousand volts generally appears across one of the tubes in the regulator amplifier. Such a large potential across one tube is undesirable from the standpoint of continuity of operation. The present design eliminates the necessity for such a large potential appearing across any one tube in the amplifying system.

Accordingly, the primary object of the present invention is to provide a simple high voltage regulator having a wide adjustable range of output voltages.

Another object of the present invention is to provide a regulator having at the same time an extremely rapid response to small rapid fluctuations in the source voltage and very little tendency for its output voltage to drift over a long period of time.

Still another object of the present invention is to provide a regulator including adjustable means for controlling both its rapidity of response characteristic and its long time stability characteristic.

Still another object of the present invention is to provide a regulator including adjustable means for controlling both its rapidity of response characteristic and its long time stability characteristic.

Another object of the invention is to provide an extremely stable high gain electronic amplifier particularly adaptable for use in a voltage regulating system.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawing wherein one embodiment of the invention is illustrated.

Referring to the single figure of the drawing, there is shown a wiring diagram of a regulator embodying the principles of the present invention and particularly designed to provide a continuously adjustable output voltage of a range from perhaps one thousand five hundred volts to about four thousand volts. In this diagram, the unregulated input voltage to the reuglator from the direct current source appears at the extreme left between positive lead 1 and negative lead 3, and the regulated output voltage from the regulator is produced at the extreme right between positive lead 2 and negative lead 3. As in conventional regulators, a three element thermionic vacuum tube 4, preferably type 809, is

inserted in series between input lead 1 and output lead 2 such that the internal resistance of the tube is in series with the source voltage. As a result the regulated output voltage is at all times equal to the unregulated source voltage minus the voltage drop across this tube. As shown, the filament may be heated by any suitable alternating current supply through a transformer. Also in accordance with conventional regulator design, the potential of the grid of tube 4, and therefore the voltage drop across the tube, is controlled in such a way, as will later be described in detail, that the output voltage appearing between leads 2 and 3 is maintained substantially constant at its desired value irrespective of variations in load current or in source voltage.

Across output leads 2 and 3 there is connected a voltage divider network consisting of a primary voltage divider resistor 5, a potentiometer 6, a smaller resistor 7, and an ammeter 8. Since the total resistance included in this voltage divider network is constant, the current flowing therein depends upon, and is proportional to, the output voltage of the regulator. Accordingly ammeter 8 provides an indication of this output voltage.

An adjustable portion of the total output voltage of the regulator is picked off on the slider of potentiometer 6, and this voltage is connected by lead 10 to the left hand or control grid of vacuum tube 11, shown as a duotriode type 7F7. A condenser 9 is connected between leads 2 and 10. It will be apparent that if this condenser were omitted the potential applied to the control grid of tube 11 would always be a definite percentage of the output voltage, as determined by the position of the slider of potentiometer 6. The condenser 9, however, operates as a short circuit around resistor 5 for extremely rapid fluctuations in the output voltage. Such rapid fluctuations therefore appear in undiminished amplitude upon the control grid of tube 11, thereby tending to increase the sensitivity of the regulator in suppressing any rapid fluctuations which might tend to be produced upon the output voltage.

The right hand or standardized grid of tube 11 is maintained at a constant standard voltage by being connected by lead 14 to the positive side of three series-connected gas-filled tubes 15, preferably type VR 150. These gas filled tubes 15 are energized from the output voltage of the regulator through the resistor 16. As is well known, the voltage drop across such gas-filled tubes remains extremely constant over a wide range of tube currents. Accordingly, the potential of the standardized grid of tube 11 remains constant at a known value independently of any variations in the output voltage of the regulator. An inductance-capacitance filter arrangement, indicated generally by reference numeral 17, is inserted between the positive side of the series arrangement of gas-filled tubes and the standardized grid of tube 11 in order to prevent any small fluctuations in the output voltage from being reflected upon the standardized grid.

The amplifying system essentially comprises two inter-connected symmetrical parallel paths both of which are connected across the output voltage of the regulator. One of these parallel paths is provided by the left hand portions of three series-connected amplifying tubes 11, 12 and 13, all of which may be type 7F7 duo-triodes. The other parallel path is provided by the right hand portions of these tubes. The left and right hand cathodes of each of these tubes are connected together. Tube 11 has its cathode resistor 18 connected to the negative output lead 3. The respective plates of tube 11 are connected to equal plate resistors 19 and 19' respectively, and thence to the common cathode of tube 12. The respective grids of tube 12 are connected to the respective plates of tube 11. A gain control potentiometer 22 is connected between the plates of tube 11. Similar connections are made between tubes 12 and 13, equal resistors 20 and 20' comprising the respective plate resistors for tube 12, and potentiometer 23 comprising the gain control for this stage. Equal resistors 21 and 21' are connected between the positive output lead 2 and the respective plates of tube 13. Shunted across resistor 21 is a variable condenser 24 which may be employed to control the time constant, and therefore the rapidity of response, of the regulator. The output of the whole amplifying system is taken as the voltage across plate resistor 21, one side of this resistor being connected to the cathode of tube 4 and the other side being connected to the grid of tube 4.

The direct action of the regulator system is to maintain the potential of lead 10 equal to the standard potential of lead 14, as will hereinafter be described in detail. Since the regulator output voltage between leads 2 and 3 is a direct multiple of the voltage appearing between leads 10 and 3, and since the magnitude of this multiple may be controlled by the position of the slider of potentiometer 6, this potentiometer provides a control for the value at which the output voltage is maintained constant by the regulator.

Variations of the regulator outut voltage with respect to its desired voltage will effect corresponding variations in the potential of the control grid of tube 11, while the potential of the standardized grid of this tube will remain constant. This difference, or unbalance, between the potentials of the two grids of tube 11 may be considered as the input signal to the amplifying system. This difference between the potentials of the two grids of tube 11 will appear as an amplified variation in the voltage across resistor 21. A large change will therefore result in the voltage drop across tube 4, this change being in such direction as to return the regulator output voltage to its desired value.

The operation of the regulator will now be more particularly described assuming that the regulator output voltage should tend to rise for any reason. It will be considered for the present that gain control potentiometers 22 and 23 and time constant condenser 24 are omitted. If the output voltage should rise, the potential of the control grid of tube 11 would rise proportionately, thereby allowing a greater electron current to flow to the left hand plate of this tube. This increased current flow through cathode resistor 18 raises the potential of the cathode of tube 11, thereby decreasing the potential of the standardized grid with respect to the cathode. The circuit constants are of such values that the increase of potential of the control grid with respect to the cathode is substantially the same as the resulting decrease of potential of standardized grid with respect to the cathode. Accordingly, there results a decrease in the plate current of the right hand side of tube 11 substantially equal to the increase in the plate current of the left hand portion of that tube. Accordingly, the total current flowing through tube

11 is substantially constant regardless of the input signal to the amplifying system.

The effect of the unbalance which has occurred in the left and right hand portions of tube 11 is to cause a greater amount of current to flow through plate resistor 19 and to cause a smaller amount of current to flow through the plate resistor 19'. The potential of the left hand plate of tube 11 is thereby reduced while that of the right hand plate is increased. Since these plates are respectively connected to the left and right hand grids of tube 12, a corresponding amplified unbalance signal is thereby produced across the grids of the second tube.

In a similar manner, this signal is again amplified in tubes 12 and 13 so that a much larger current flows through plate resistor 21 than would flow if zero signal were received on the grids of tube 11. Accordingly, the potential of the grid of tube 4 is correspondingly reduced with respect to its cathode, and the internal resistance of that tube is increased, thereby increasing the voltage drop across the tube, and bringing the voltage output of the regulator back down to its normal value.

Conversely, if the regulator output voltage should tend to decrease for any reason, the potential of the grid of tube 4 will be automatically increased, thereby decreasing the voltage drop across this tube, and tending to bring the output voltage back up to its constant desired value.

The purpose of potentiometers 22 and 23, respectively connected between the respective plates of tubes 11 and 12, is to control the gain of the amplifier arrangement. If these resistors were not present at all, that is, if there were an open circuit between the plates at these points, then the amplifier would operate exactly as has been previously described. However, if the two plates of any of the amplifying tubes were short-circuited, it will be seen that any unbalance of plate currents resulting from a voltage signal being impressed upon the grids would completely equalize through the short circuit, and that the grids of the succeeding tube would therefore be at equal potentials. In effect then the gain of the amplifier would be zero, since the signal would have disappeared. Obviously with various adjustments of potentiometers 22 and 23 intermediate to the extreme conditions of open circuit and short circuit just described, there would be corresponding degrees of gain. Either potentiometer 22 or 23 would in itself be sufficient to control the gain, and therefore the long-time stability characteristic, of the regulator. The provision of two such gain control potentiometers serves merely to increase the degree of manual control provided. If desired, a similar gain control potentiometer could be connected between the respective plates of tube 13 to provide a manual control of the gain of the amplifier stage associated with that tube.

The effect of variable condenser 24 connected between the cathode and grid of tube 4 is to vary the time constant, and therefore the quickness of response of the regulator. It will be appreciated that if this condenser were completely omitted, that is, if the capacitance had a value of zero, any variation in the voltage drop across plate resistor 21 would immediately appear between the grid and cathode of tube 4, whereas, if this capacitance were to have a very large value, a considerable time would be required to charge or discharge the condenser to a different voltage, and the response of the regulator system would therefore be slower. Various degrees of rapidity of response can therefore be obtained by suitably adjusting the value of this condenser.

If it is desired that the regulator have a very good long time stability characteristic, the resistance of potentiometers 22 and 23 should be increased to a very high value in order to increase the gain of the amplifier arrangement as much as possible. However, as the gain is increased, it may be found necessary to increase the capacitance of variable condenser 24 in order to correspondingly increase the time constant of the circuit to a point where the system will not oscillate.

On the other hand, if it is desired that the regulator be especially sensitive to rapid fluctuations in the source voltage, the capacitance of variable condenser 24 should be made as small as possible in order to reduce the time constant of the circuit. In this case, the gain of the amplifier arrangement may have to be correspondingly cut down by decreasing the value of the resistance provided by potentiometers 22 and 23 in order to prevent the circuit from oscillating.

It will be understood that it is not necessary to employ duo-triodes for the three stages of the amplifier, as shown. If desired, two ordinary three element vacuum tubes could be substituted for any or all of these duo-triodes. However, an advantage is obtained by using duo-triodes in that variations in the filament supply voltage for any of the amplifier stages, or variations in the tube characteristics, will be equally reflected into both parallel paths of the amplifying system. Since the input signal and the output signal of the amplifying system appear solely as an unbalance between these two parallel paths, equal variations in the characteristics of both paths simultaneously will have no effect upon the overall gain of the amplifying system. In this way, by employing duo-triodes as shown, the long time stability characteristic of the regulator is increased, variations in the tube characteristics and variations in the filament supply voltages having substantially no effect upon the system.

The principles of this regulator may be adapted to produce a maximum output voltage of the order of ten kilovolts or so, and the number of tubes in the amplifier will be determined by the maximum permissible voltage drop across each tube. It has been found that a drop of about a thousand volts across each tube is all that is permissible for steady operation. If more tubes are used in the amplifier for a particular application the gain of each tube may have to be limited so as to prevent oscillation. This limiting may be accomplished by the use of time constant condensers or plate to plate resistors, or both. It will be understood that since the various tubes in the amplifier arrangement are operating at different potentials, separate well insulated filament transformers (not shown) will be required for each.

The range of adjustment of the output voltage is determined by the range of current that may be tolerated in the voltage regulating tubes. It was found that this range may be stretched to about four to one as a limit. The range of adjustment of the regulator voltage for any particular application therefore is about four to one.

Since many changes could be made in the above construction and many widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matters contained in the above

description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In a voltage regulating system of the type wherein a variable resistive element, connected in series with the positive side of an unregulated input voltage supply, is automatically varied to produce a regulated output voltage supply, in combination, two normally balanced symmetrical interconnecting parallel amplifying channels connected across said regulated output voltage supply; each of said channels comprising a plurality of thermionic amplifying tubes, each tube having at least a cathode, a grid, and an anode, the tubes of each channel being arranged in series with the anode of one tube being connected to the cathode of the succeeding tube through a resistance, respective resistive connections from the anode of the last tube of each channel to the positive side of said regulated output voltage supply, a common resistive connection from the cathode of the first tube of each channel to the negative side of said regulated output voltage supply, respective connections between the cathodes of the corresponding tubes of each channel, respective connections from the grid of each tube, except the first tube of each channel, to the anode of the preceding tube; a voltage divider connected across said regulated output voltage supply; means associated with said divider for applying a percentage of the regulated output voltage between the grid of the first tube of one of said channels and the negative side of said regulated output voltage supply; circuit means also connected across said regulated output voltage supply, and including a voltage regulating tube, for deriving a constant voltage; means for applying said constant voltage between the grid of first tube of the other of said channels and

the negative side of said regulated output voltage supply; and means for controlling the value of said variable resistive element in accordance with the voltage signal existing between the anode of the last tube of one of said channels and the positive side of said regulated output voltage supply.

2. Apparatus, as claimed in claim 1, further including a variable condenser connected across the two points between which said last-named voltage signal exists to provide a control for the quickness of response of said regulating system.

3. Apparatus, as claimed in claim 1, further including a variable resistor connected between the anode of one tube of one of said channels and the anode of its opposite number tube in the other of said channels to provide a control for the sensitivity of said regulating system.

EDWARD J. GROTH, JR.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,796,375	Kent	Mar. 17, 1931
2,075,966	Vance	Apr. 6, 1937
2,085,488	Woodward et al.	June 29, 1937
2,133,891	Soller	Dec. 6, 1938
2,210,393	Braden	Aug. 6, 1940
2,226,233	Doba, Jr.	Dec. 24, 1940
2,312,934	Shook	Mar. 2, 1943
2,318,644	Tubbs	May 11, 1943
2,329,073	Mitchell et al.	Sept. 7, 1943
2,424,893	Mansford	July 29, 1947

OTHER REFERENCES

Publication, Radio Service Encyclopedia, Mallory Yaxley Co. Control Circuits 77 to 103, page 120, January 1937.