Oct. 18, 1955 N. SILVER ET AL 2,721,304

VOLTAGE REGULATOR

Filed June 21, 1954 2 Sheets-Sheet 1

FIG. 1

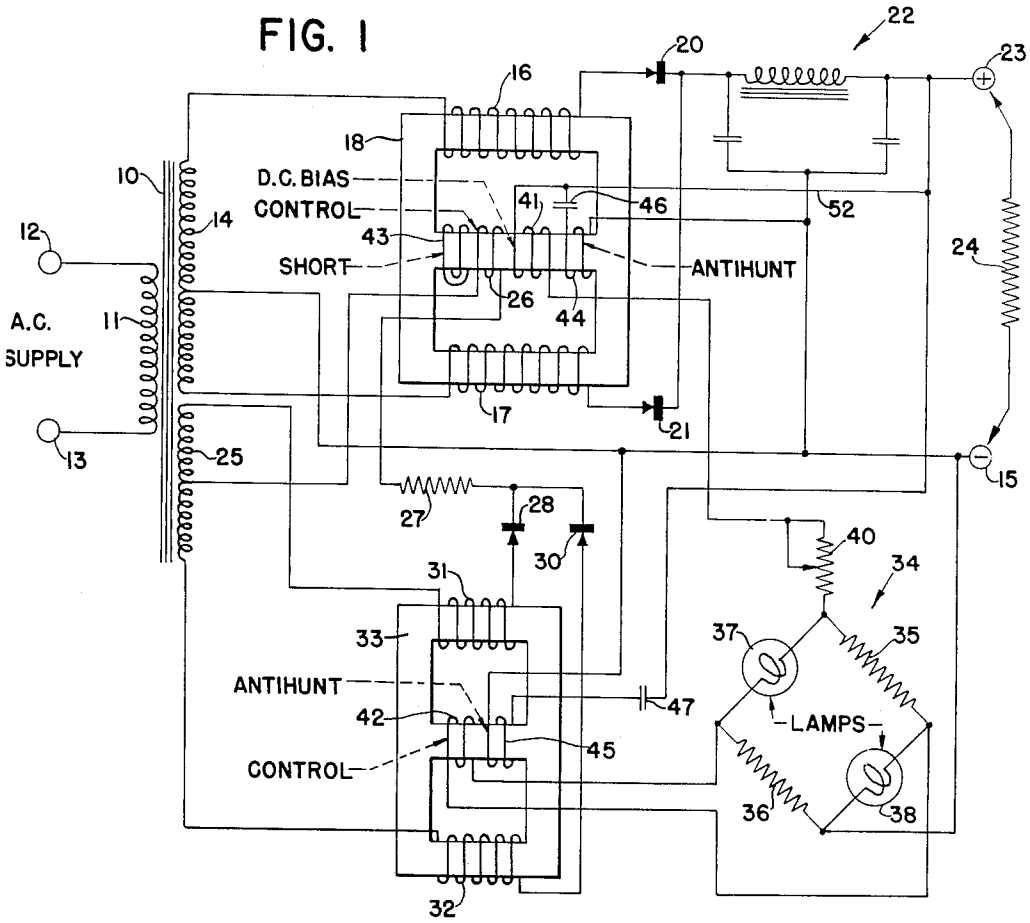


FIG. 2

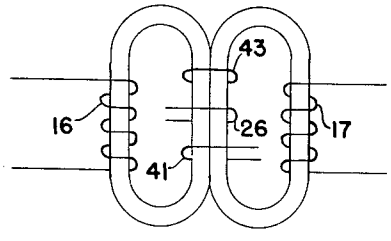
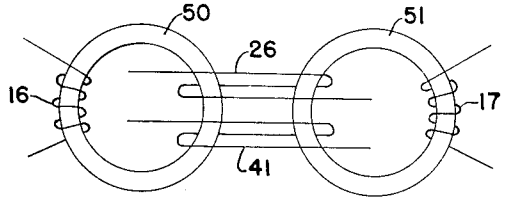


FIG. 3



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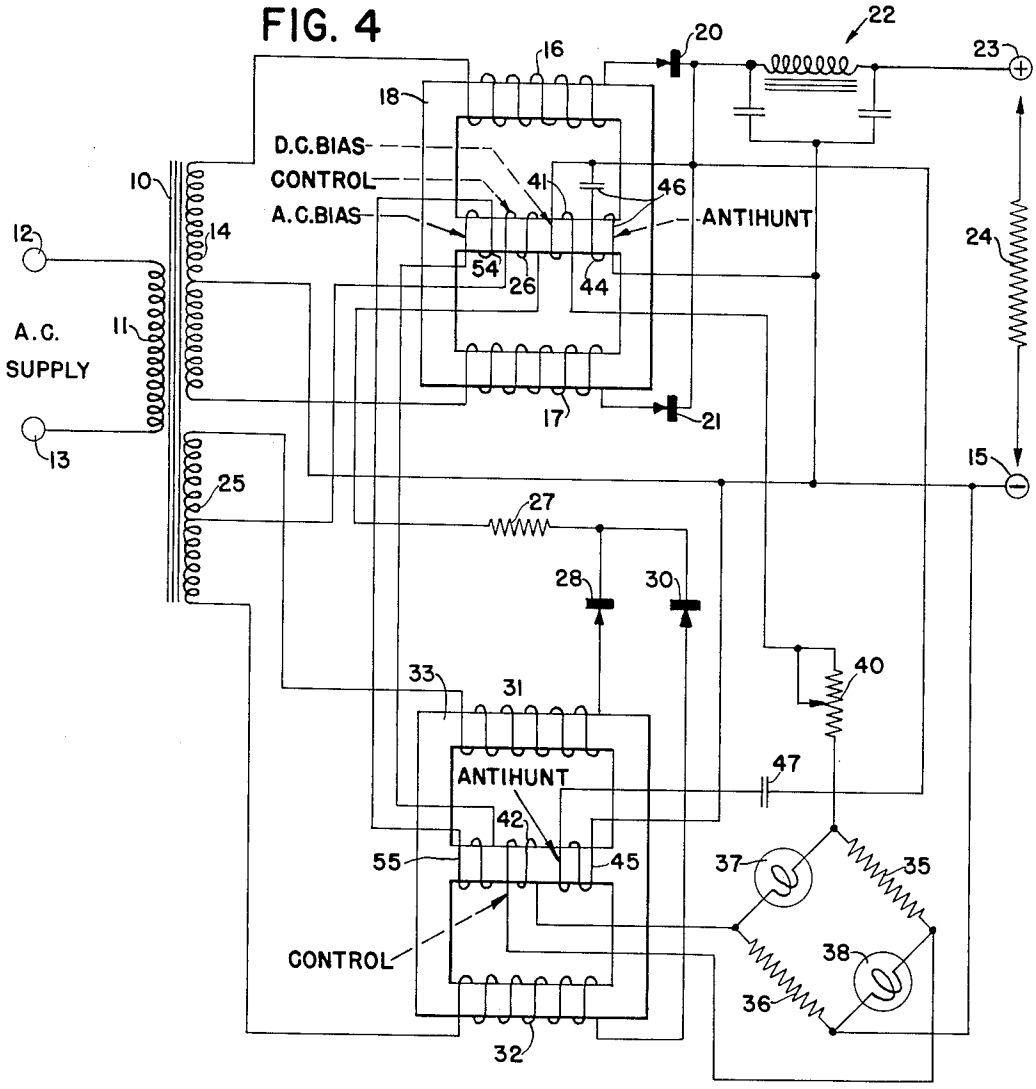
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FIG. 4



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VOLTAGE REGULATOR

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4 Claims. (Cl. 321—19)

This invention relates to voltage regulators for alternating current supply lines which are rectified to produce a regulated direct current voltage. It has particular reference to voltage regulators which do not employ electron discharge devices. The invention has further reference to voltage regulators which employ two saturable reactors which work in combination to produce a constant direct current voltage across a load when the alternating current supply line varies over a wide range of voltage values.

Many types of voltage regulators have been designed and used which employ electron discharge devices such as triodes and pentodes in amplifier circuits in order to produce a control current which can be applied to a saturable reactor and vary the impedance in a series or parallel circuit to control the output voltage. Other voltage regulators use a single transformer arrangement, the core of which is partially saturated, for voltage regulation without the use of amplifier circuits. These latter regulators have not produced good regulation, the output voltage varying several percent when the input voltage is varied over a range of plus or minus ten percent. The present invention employs two transformers, the core in each being operated at a value of magnetic flux which partially saturates the core. The use of two transformers produces a regulation across the load which is a considerable improvement over the prior art and the absence of electron discharge devices eliminates the failure due to broken filaments, short circuited elements within the tube, and loss of vacuum.

One of the objects of the invention is to provide an improved voltage regulator which avoids one or more of the disadvantages and limitations of prior art arrangements.

Another object of the invention is to provide an accurate voltage regulator which will have long life and not be subject to the failures which are generally inherent in regulators containing electron discharge devices.

Another object of the invention is to provide a voltage regulator which is able to withstand considerable vibration and mechanical shock without changing its operating characteristics.

Another object of the invention is to simplify the construction and assembly of voltage regulators.

The invention comprises an alternating current supply for two saturable core transformers. One transformer transmits power to a load circuit through two rectifier units, the amount of power transmitted depending upon the reactance of the power windings and the saturation of the core within these windings. The magnetic saturation is controlled by four control windings, one of which is a control winding which is connected to the second or control transformer. A direct current bias winding is employed to maintain the average steady magnetic flux at a partially saturating value. A third winding is coupled through a capacitor to the output terminals and eliminates hunting. A fourth winding is connected

directly to a winding on the control transformer and constitutes an alternating current bias control. This winding effectively controls the magnetic impedance of the core which holds the four control windings. Variations of output voltage are sensed by a four-armed Wheatstone bridge which contains two resistors in opposite bridge arms each having a resistance which does not vary with applied voltage and two tungsten filament lamps also in opposite arms, each producing a resistance which varies considerably with the applied voltage. The output of this bridge is applied to a control winding in the second transformer. The second transformer contains two current transmitting windings which are connected in series with rectifier units and the control winding on the first transformer. The second transformer also includes an anti-hunt winding which is coupled to the output circuit through a capacitor.

An alternate arrangement of the voltage regulator described above includes the components as described except that the alternating current bias winding is replaced by a short circuited winding which effectively eliminates the alternating magnetic flux from the middle portion of the transformer core.

For a better understanding of the present invention, together with other and further objects thereof reference is made to the following description taken in connection with the accompanying drawings.

Fig. 1 is a schematic diagram of connections of one embodiment of the invention.

Fig. 2 is a partly schematic drawing showing an alternate arrangement of the core material for either one of the two transformers shown in Fig. 1.

Fig. 3 is another alternate arrangement of core material.

Fig. 4 is another schematic diagram of connections similar to Fig. 1 but showing an alternate circuit arrangement.

Referring now to Fig. 1 a supply transformer **10** includes a primary winding **11** having terminals **12, 13** which are to be connected to an alternating current supply line which may vary considerably in voltage. A secondary winding **14** includes a tap at its mid-point which is connected to the negative terminal **15** of the load circuit. The terminals of winding **14** are connected to two power windings **16** and **17** which are placed on two portions of a shell type transformer core **18**. The other ends of windings **16** and **17** are connected in series with rectifier units **20** and **21**, the negative terminals of these rectifiers being connected together and to a filter circuit **22** which is designed to eliminate the pulsating components of the rectified power so that only direct current may be available at terminals **23** and **15** which are to be connected to an external load **24**.

A second secondary winding **25** is also part of transformer **10** and has a tap at its mid-point which is connected in series with a winding **26** on the center leg of core **18**. This winding **26** is the control winding and variations of current in this winding change the saturation of the core **18** and produce a varying reactance value in winding **16** and **17** thereby controlling the output voltage across load **24**. The other end of winding **26** is connected through a resistor **27** and two rectifier units **28** and **30** which in turn are connected in series with windings **31** and **32** on two legs of a second core **33**. The other ends of windings **31** and **32** are connected directly to the ends of secondary winding **25** on transformer **10**.

The sensing portion of this circuit comprises a Wheatstone bridge **34** which includes two resistors **35** and **36** and two lamps **37** and **38**. The bridge is supplied with power from the load terminals **15—23**, the negative terminal **15** being connected to the bottom of the bridge and the top of the bridge being connected through an adjust-

able resistor 40 and a direct current bias winding 41 to the positive terminal 23. Since the output voltage is regulated and is substantially constant the current through the above mentioned circuit is also constant and the amount of magnetic flux induced in the middle core is constant. The other two terminals of the bridge 34 are connected to a control winding 42 on the middle section of core 43, this winding comprising the point of application of a control current due to a change in output voltage across the load circuit.

For reasons that will be explained later it is desired that no alternating flux be present in the middle section of core 18 and to insure that this condition exists a short circuited winding 43 is put on this portion of the coil. Winding 43 may be an actual winding of three or four turns of heavy copper wire or it may be a conductive sleeve having only one turn and extending for the entire length of the core portion.

The circuit described above is actually two stages of a magnetic amplifier working from a bridge sensing circuit. In its usual embodiment the circuit is very sensitive to small variations in the load circuit and since there is a slight time delay because of the inductances involved the circuit would hunt if some provision were not made to counteract the tendency. For this reason an anti-hunt winding 44 and 45 is placed on the central portion of each core 18 and 33. These windings are each in series with a capacitor 46 and 47 which effectively eliminates the direct current available at the output terminals. Windings 44 and 45 together with their capacitors 46 and 47 are connected across the output terminals and receive only the sudden variations which are present at the output terminals when the impedance of the load 24 is changed abruptly. The direction of the flux produced by windings 44 and 45 is in the opposite direction to the flux produced by winding 26 on core 18 and winding 42 on core 33 and therefore large transient values of flux which otherwise would cause hunting are eliminated.

Fig. 2 shows one arrangement of cores which can be used by either one of the transformers in Fig. 1. Windings 16 and 17 can be positioned on the outside core portions while windings 43, 26 and 41 are mounted on the other two legs which have been clamped together. The results will be the same as those obtained by core 18.

The cores shown in Fig. 2 do not have to be clamped together and the arrangement shown in Fig. 3 may be employed where two circular cores 50 and 51 are used. The only connections between these cores are the windings such as 26 and 41 which enclose both cores.

The operation of the circuit shown in Fig. 1 is as follows: with an average voltage impressed on terminals 12, 13 and an unvarying load 24 the power secondary winding 14 delivers current through windings 16 and 17 to the two rectifiers 20 and 21, thereby applying a direct current voltage through filter circuit 22 to the load circuit 24. Also secondary winding 25 applies a similar but much smaller current through windings 31 and 32 in series with rectifier units 28 and 30 to winding 26 on the central portion of core 18. The current through this winding produces an unvarying magnetic flux in core 18 which partially saturates it, also the current from the positive terminal 23 over conductor 52, through coil 41, through the bridge circuit 34, to the negative terminal 15 also contributes magnetic flux which helps to maintain core 18 in a partly saturated condition. The short circuit winding 43 eliminates any alternating flux components which may be introduced by winding 26. As long as there is no change in the output voltage there will be no current through either one of the anti-hunt windings 44 and 45 and because of the unvarying output voltage there will be no change in the bridge circuit and therefore no change of magnetic flux in core 33 due to winding 42.

Now let it be assumed that the load 24 is varied in value so as to cause an increase in voltage across terminals 15, 23. This action causes an increase in saturation of core 18 because of the increase of current through windings 16 and 17. Also the saturation of core 33 is increased because of current increase in coils 31 and 32, this increase in current communicated to winding 26 on core 18 and causing a further increase of saturation in that core. The voltage of the output terminals is momentarily increased and this action causes more current to flow over conductor 52, through coil 41, through the bridge 34, and back to the negative terminal 15. The lamp bridge 34 is normally unbalanced and a small current flows from the bridge through winding 42 on the center leg of core 33 and inducing a steady flux in the core. This flux due to winding 42 is opposed to the flux produced by windings 31 and 32. In a similar manner the current through winding 26 produces a steady flux which is opposed to the flux produced by winding 41 in series with the bridge circuit.

When the current is increased through the bridge circuit there is no appreciable change of resistance in resistors 35 and 36 but the resistance of lamps 37, 38 increases considerably and unbalances the bridge to a still greater extent sending a large increase in current through coil 42 thereby lowering the saturation of core 33 and increasing the reactance values of windings 31 and 32 and decreasing the current through these coils and rectifier units 28 and 30 and thereby lowering the current through winding 26 by a considerable amount. This action causes a decrease in saturation of core 18 and an increase in the reactance values of windings 16 and 17 thereby increasing the voltage drop across these windings and lowering the output voltage to its previous regulated value.

A decrease of the alternating current supply voltage produces changes in currents and voltages which are opposite to the changes described above, the result being that the saturation of core 18 is increased, the reactance value of cores 16 and 17 are decreased, and the output voltage is raised to the desired regulated value.

The load capacity of core 18 and its associated load windings 16 and 17 are considerably increased by the use of winding 41 which may be described as a direct current bias coil. When normal current is flowing through windings 16 and 17 the magnetic flux produced by them is sufficient to cause saturation of the core 18. The current through coil 41 and the bridge circuit counteracts this flux and eliminates part of the saturating action. As described above the short circuited winding 43 effectively eliminates alternating magnetic flux from the center leg of the transformer core. The actions of the two anti-hunt circuits 44 and 45 have been previously described.

The above description has been applied to shell type cores as illustrated in Fig. 1. However, any type of core such as those shown in Figs. 2 and 3 may be employed since the flux which is induced by coil 16 lasts for only half of the alternating current cycle because this winding is in series with rectifier 20. The same is true of winding 17 in series with rectifier 21, therefore the fluxes produced by these two coils cannot occur at the same time and do not interact with each other.

The circuit shown in Fig. 4 is similar to the circuit shown in Fig. 1 except that the short circuited coil 43 of Fig. 1 has been replaced by an A. C. bias coil 54 which is connected to a similar coil 55 on the center leg of core 33. Coil 54 is employed to reduce the alternating current flux in the center leg of core 18 by current derived from coil 55 on the center leg of coil 33, this control of alternating flux resulting in an improved regulating action and a more flexible system as compared to the short circuited winding. The other operations connected with the circuit shown in Fig. 4 are the same as those described above in connection with Fig. 1.

The following flux values may be used in the circuit

shown in Fig. 1 and are illustrative of a specific application of the invention. A constant value of 24 ampere turns is applied by winding **42** on core **33** due to the unbalanced condition of the lamp bridge **34**. The current through winding **26** on core **18** appiles a variable flux to this core, the value of which may range from 10 to 60 ampere turns. This magnetizing action opposes the action of coil **41** which applies 24 ampere turns to the core.

While there have been described and illustrated specific embodiments of the invention, it will be obvious that various changes and modifications can be made therein without departing from the field of the invention which should be limited only by the scope of the appended claims.

We claim:

1. A voltage regulator for an alternating current supply circuit comprising; a first magnetic core having two windings, each coupled to the supply circuit and each in series with a rectifier which is connected to one terminal of a load circuit; a connection between a second terminal of the load circuit and a center voltage tap coupled to the supply circuit; a second magnetic core having two windings, each coupled to the supply circuit and each in series with a rectifier which is connected to one side of a control winding on the first magnetic core, the other side of the control winding connected to a center voltage tap coupled to the supply circuit; a sensing circuit for determining voltage changes on the output terminals comprising a four arm bridge, two of said arms comprising resistors whose resistance values do not vary with the current, and two of said arms comprising metallic filament lamps whose resistance varies considerably with the current; two opposing junction points on the bridge connected to the output terminals in series with a winding on the first magnetic core; and two other opposing junction points on the bridge connected to a control winding on the second magnetic core.

2. A voltage regulator for an alternating current supply circuit comprising; a first saturable magnetic core having two power windings, each coupled to the supply circuit and each connected in series with a rectifier which is connected to one terminal of a direct current load circuit, the voltage of which is maintained at a constant predetermined value; a connection between a second terminal of the load circuit and a center voltage tap coupled to the supply circuit; a second saturable magnetic core having two windings, each coupled to the supply circuit and each connected in series wtih a rectifier which is connected to one end of a control winding on the first magnetic core, the other end of the control winding connected to a center voltage tap coupled to the supply circuit, the current through said control winding for varying the saturation of the first saturable core and varying the reactance value of the two power windings on the first core; a sensing circuit for sensing voltage changes on the load terminals, said sensing circuit including a four arm bridge, two of said arms comprising resistors whose resistance is invariable with the current, and two of said arms comprising metallic filament lamps whose resistance varies with the current through them; said resistors connected opposite to each other in the bridge circuit, and said lamps also connected opposite to each other; two opposing junction points on the bridge connected to the load terminals and the other two junction points connected to a control winding on the second magnetic core for causing variations in saturation of that core.

3. A voltage regulator for an alternating current supply circuit comprising; a first saturable magnetic core having three legs, a first and second leg of which are provided with power windings, each of said power windings coupled to the supply circuit and each connected in series with a rectifier which is connected to one terminal of a direct current load circuit; a connection between a second terminal of the load circuit and a center voltage tap coupled to the supply circuit; a second saturable magnetic core having three legs, a first and second leg of which are provided with windings which are coupled to the supply circuit and each connected in series with a rectifier which is connected to one end of a control winding on the third leg of the first magnetic core, the other end of the control winding connected to a center voltage tap coupled to the supply circuit; a sensing circuit for sensing voltage changes on the load terminals, said sensing circuit including a four-arm bridge, two of said arms comprising resistors whose resistance is invariable with the current, and two of said arms comprising metallic filament lamps whose resistance varies with the current through them; said resistors connected opposite to each other in the bridge circuit, and said lamps also connected opposite to each other; two opposing junction points on the bridge connected to the load terminals and the other two junction points connected to a control winding on the third leg of the second magnetic core for causing variations in the saturation of that core when the output voltage varies.

4. A voltage regulator for an alternating current supply circuit comprising; a first saturable magnetic core having three legs; a power winding on two of said legs, each of said power windings coupled to the supply circuit and each connected in series with a rectifier which is connected to one terminal of a direct current load circuit; a connection between a second terminal of the load circuit and a center voltage tap coupled to the supply circuit; a second saturable magnetic core having three legs; a winding on two of said legs, each of said windings coupled to the supply circuit and each connected in series with a rectifier which is connected to one end of a control winding on the third leg of the first magnetic core, the other end of the control winding connected to a center voltage tap coupled to the supply circuit; a sensing circuit for sensing voltage changes on the load terminals, said sensing circuit including a four-arm bridge, two of said arms comprising components whose resistance is substantially independent of the current passing through them, and two of said arms comprising components whose resistance varies by a substantial amount when the current passing through them is changed, two opposing junction points on the bridge connected to the load terminals and the other two junction points connected to a control winding on the third leg of the second magnetic core for causing variations in the saturation of the second core when the output voltage varies.

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