April 12, 1955 W. B. FLETCHER 2,706,271

VOLTAGE REGULATORS

Filed Oct. 31, 1951 2 Sheets-Sheet 1

FIG. 1

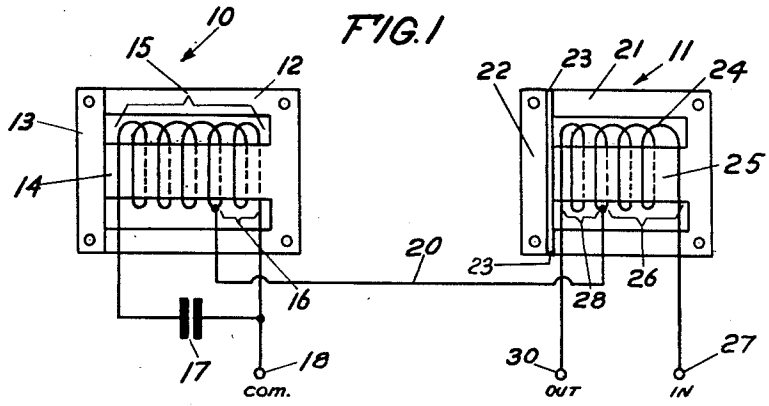


FIG. 2

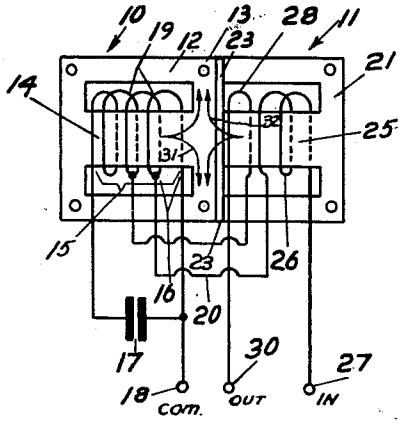


FIG. 3

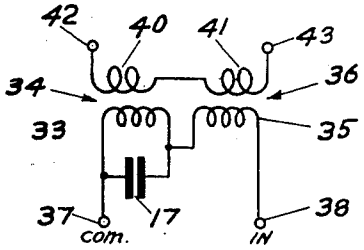


FIG. 4

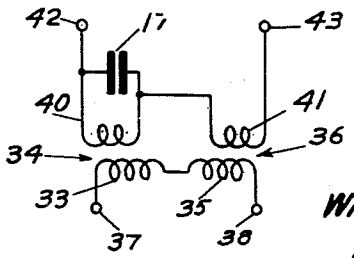


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FIG. 5a

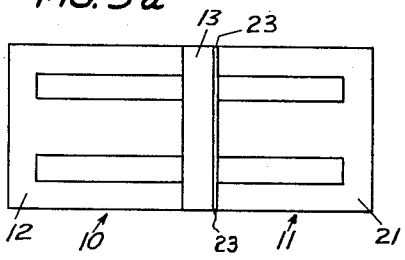



FIG. 5b

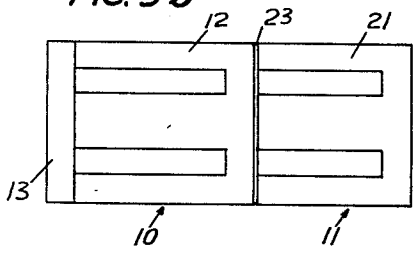



FIG. 5c

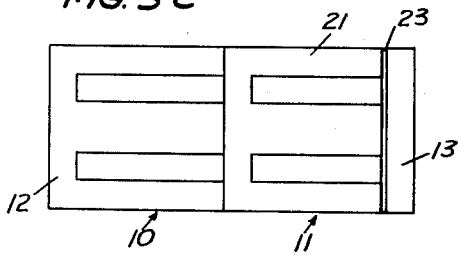



FIG. 5d

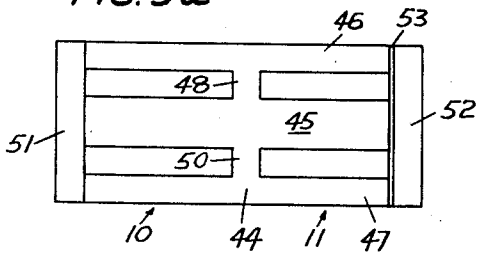



FIG. 5e

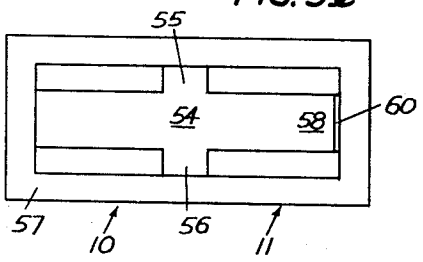



FIG. 5f

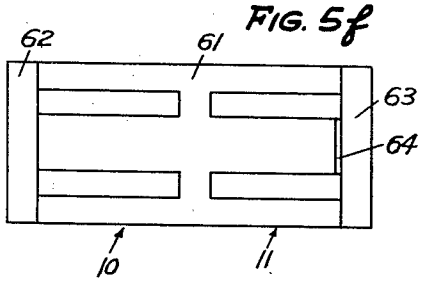
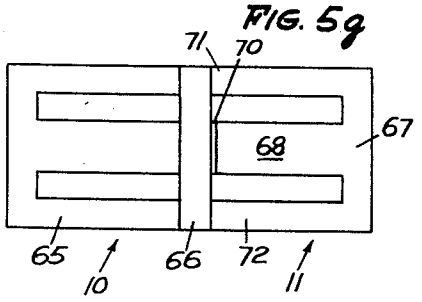



FIG. 5g

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2,706,271

# VOLTAGE REGULATORS

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Application October 31, 1951, Serial No. 254,013

6 Claims. (Cl. 323—48)

This invention relates to voltage regulators of the type using a transformer and choke and more particularly to such a regulator with the transformer and choke windings on the same core, and to configurations of the core for such a device.

One form of alternating current stabilizer utilizes two transformers wound on separate cores; one core during operation becomes saturated, and the other remains unsaturated, due to the presence of an air gap in the magnetic circuit. The primaries of both transformers are connected in series as are the secondaries. A capacitor is connected across the secondary of one of these transformers. Such an arrangement is shown and described in United States Patent No. 1,985,634, issued December 25, 1934, in the name of Wilfred K. Fleming.

In such a regulator circuit excellent voltage regulation is obtained. However, the output contains a considerable percentage of energy at the harmonics of the fundamental frequency, and material for two separate transformer cores is required.

By providing a common core for both transformers according to the present invention, a certain amount of iron is saved over a two core form designed to handle the same amount of power and give the same degree of regulation.

In addition, the regulator of the invention produces less output energy at harmonic frequencies, as the harmonics produced in the two sections of the core are cancelled in the common core, while the fundamentals are combined in quadrature. The design of the invention also results in amplitude and form factors for the device more closely approaching those of a sine wave than those of prior designs. Certain economies in production are attained by the unitary construction of the invention as compared with the separate core construction of the older design.

Other and further advantages of this invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of an existing form of voltage regulator circuit;

Fig. 2 is a schematic diagram of a voltage regulator constructed according to the invention;

Fig. 3 is a schematic diagram of the electrical circuit of another voltage regulator constructed according to the invention;

Fig. 4 is a modification of the electrical circuit of Fig. 3; and

Figs. 5*a*, *b*, *c*, *d*, *e*, *f*, and *g* show various ways in which the core of the voltage regulator of the invention may be assembled.

In Fig. 1, the reference numeral **10** designates generally a first transformer, and the reference numeral **11** designates generally a second transformer. The first transformer core comprises an E-shaped section **12** and a straight section **13** composed of laminations of sheet steel of a type suitable for transformer core construction. The central arm **14** of the E-shaped section carries an autotransformer winding **15**. The portion **16** of the winding **15** constitutes the primary of the transformer **10**. The entire winding constitutes the secondary. A capacitor **17** is connected across the secondary **15**. One side of this capacitor **17** and one end of the winding **15** are connected to a terminal **18** designated as common. The other end of the portion **16** of the winding **15** is connected by a wire **20** to the second transformer **11**. This second transformer **11** comprises a core with an E-shaped section **21** with straight section **22** mounted across its open end with a gap **23** of non-magnetic material between the sections.



A winding **24** is wound on the central arm **25** of the E-shaped section **21** of the core. A portion **26** of this winding constitutes the primary of the transformer **11**. One end of this primary winding **26** is connected to an input terminal **27**. The wire **20** is connected to the other end of this primary. Thus, the two primaries **16** and **26** are connected in series between the common terminal **18** and the input terminal **27** to which the line voltage is applied.

The secondary of the transformer **11** comprises a portion **28** of the winding **24**. One end of this winding **28** is connected to an output terminal **30**. The other end of the winding **28** is connected by the wire **20** to the winding **16** of the transformer **10**. The secondary **28** of the transformer **11** is thus connected in series with the winding **16** on the transformer **10**. The output voltage of the regulator appears between the terminals **18** and **30**.

By the principles set forth in the cited Fleming patent, the transformer **10** is operated near the knee of the B—H curve. This is accomplished by proportioning the ampere turns of the winding **15** to the cross-sectional area and length of the magnetic circuit of the transformer **10**.

The magnetic core of the transformer **11** is prevented from saturating by the gap **23**. The saturation of the transformer **10**, the association of the capacitor **17** in its circuit, and the unsaturated condition of the transformer **11** results in the stabilizing effect of the device as described in the Fleming patent. However, the harmonics generated by the nonlinear operation of the saturated transformer **10** may be undesirable in certain applications.

Fig. 2 shows how the two core structures of Fig. 1 may be combined merely by placing the E-shaped section **21** of transformer **11** in juxtaposition to one side of the core at transformer **10**, preserving, however, the gap **23**. The electrical circuit may be the same as that shown in Fig. 1. However, in the modification shown in Fig. 2, the winding **15** is provided with an additional section **19** and the winding **24** of Fig. 1 is replaced by two separate windings **26** and **28**. One end of section **19** of the winding **15** is connected to one end of the winding **28**, whose other end is connected to the output terminal **30**. The other end of section **19** is connected to one end of the winding **26**. The other end of this winding is connected to the input terminal **27**. This modification is useful to maintain the output voltage high when the input voltage is excepitonally low. For example, the circuit of Fig. 1 will maintain the output at 115 volts when the input voltage drops as low as ninety volts. With the circuit of Fig. 2, the output voltage may be maintained at 115 volts with the input dropping below seventy volts. The effect of the change is to increase the transformation ratio of the transformer **10**.

Irrespective of whether the circuit of Fig. 1 or of Fig. 2 is used with the novel core structure of Fig. 2, the magnetic flux from both transformers now passes through the common straight section **13**. The windings on the transformers are wound in such relative directions that, if the currents which flow in them are in phase, with each other, the fluxes which pass through the common return **13**, at a given instant, flow in the direction shown by the arrows **31** and **32**, that from transformer **10** flowing in the direction shown by the arrows **31**, and that from the transformer **11** flowing in the direction shown by the arrows **32**. As before, the core of transformer **10** is operated near the knee of its B—H curve and saturates while the core of transformer **11** is prevented from saturating by the gap **23**. The voltage applied to the winding **15** under the influence of the condenser **17** is substantially in quadrature with the voltage applied across winding **26**. Hence, since the currents which flow as a consequence in turn respectively lead and lag their applied voltages, such currents are substantially in phase opposition to each other. This is likewise true of the fluxes generated by such currents. As a result the fluxes **31** and **32** add directly, as indicated by the corresponding arrows in Fig. 2. The resulting high flux density in

section 13 increases the saturation of said section and consequently generates harmonic voltages in the secondary windings of transformer 11. Thus we see that, merely by the combining of the transformer cores, such harmonic voltages are introduced into the transformer 11. It is to be noted that this effect is not dependent upon an increased saturation of section 13 although such increase is quite desirable. It is sufficient that the reluctance of section 13 be substantially higher than the reluctance of the section 21. These harmonic voltages are in phase opposition to the similar harmonic voltages generated in the secondary winding 19 of transformer 10. As these windings are connected together in the output circuit, they effectively reduce the harmonic voltages appearing in the output of the stabilizer.

Figs. 3 and 4 show modifications of the electrical circuit that may be used with the magnetic core arrangement of Fig. 2 to obtain the same effect.

In Fig. 3, the capacitor 17 is connected across the primary 33 of a first transformer 34 serving the purpose of the transformer 10 of Fig. 2. This primary 33 is connected in series with the primary 35 of a second transformer 36, serving the purpose of the transformer 11 of Fig. 2, across the input terminals 37 and 38. The secondaries 40 and 41 of the transformer 34 and 36 are connected in series across the output terminals 42 and 43.

The circuit shown in Fig. 4 differs from that shown in Fig. 3 by the fact that the capacitor 17 is connected across the secondary 40 of the transformer 34 instead of across the primary 33 of this transformer, as shown in Fig. 3.

Figs. 5*a, b, c, d, e, f,* and *g* show various ways in which the consolidated core may be constructed. In Fig. 5*a*, the E-shaped portions 12 and 21 of the cores of the transformers 10 and 11 face each other, and the common straight portion 13 closes the opening in the E-shaped portions leaving an air gap 23 on the side of the E-shaped portion 21. The joint between the straight portion 13 and the E-shaped portion 12 may be of tight butt, or laced construction, or a slight gap may be left at the joint, depending upon the desired characteristics of the magnetic circuit of transformer 10.

The laced joint construction introduces less reluctance into the magnetic circuit and is generally more desirable. However, the tight butt construction may be easier to use in production in certain cases. A slight gap in the magnetic circuit between sections 12 and 13 tends further to reduce the harmonic content of the output voltage of the regulator at the expense of requiring more copper or more iron to obtain the same regulation and power-handling capacity.

In Fig. 5*b*, the E-shaped portions 12 and 21 of the cores of the transformers 10 and 11, respectively, face the same direction, in this case to the left. The straight portion 13 closes the opening in the E-shaped portion 12 and is joined to it by either butt or laced joints, or a slight gap may be left at these joints if desired. An air gap 23 is left where the arms of the E-shaped portion 21 of the transformer 11 meets the back of the E-shaped portion 12 of the core of the transformer 10.

In Fig. 5*c*, the E-shaped portions 12 and 21 face to the right. The E-shaped portions are joined with either a tight butt joint, or with a slight gap. The straight portion 13 is positioned to close the openings in the E-shaped portion 21 leaving an air gap 23 as before.

In addition to the standard E-shaped and straight sections, the core may be constructed of straight and H-shaped sections as shown in Fig. 5*d*. The H-shaped section 44 is formed with a central straight portion 45 and two narrower straight portions 46 and 47 arranged parallel to it. All three portions are joined by two lateral sections 48 and 50. The openings at either end are closed by straight portions 51 and 52, respectively. The straight portion 51 in the core of the transformer 10 is joined to the H section 44 by either a laced or butt joint, and may have a slight gap. The straight portion 52 is positioned across the othed end of the H section leaving a narrow gap 53.

A lower external magnetic field may be obtained by constructing the consolidated core, as shown in Figs. 5*e, f* and *g*. In the construction shown in Fig. 5*e*, the central section 54 is in the form of a cross with a long central section and two short arms 55 and 56. The arms 55 and 56 and one end of the central section are joined to a hollow rectangular outer portion 57 with tight butt joints. The other end 58 of the central section 54, the right end as seen in Fig. 5*e*, forms a gap 60 with the outer portion 57 of the core.

With the tongue construction illustrated in Figs. 5*e, f* and *g*, it is desirable to have the cross-sectional area of the central tongue portion less than twice the cross-sectional area of the outer portion 57. The result is that the perimeter of the core has a relatively low flux density, while the central tongue 54 has a high flux density. The low density in the outer portion 57 keeps it below saturation and this reduces the external field. It also increases the efficiency of the stabilizer by reducing the core loss in the outer portion 57.

The central tongue construction with a continuous outer portion can also be achieved by the arrangement shown in Fig. 5*f*. For this construction the H section of Fig. 5*d* slightly modified is used to form the central section 61. The open ends of the H section 61 are closed by straight sections 62 and 63. The corner joints are laced. The central piece 61 forms a tight butt joint with the end piece 62 of the first transformer core. The other end of the central piece 61 is shortened to leave an air gap 64 between it and the other end piece 63.

The advantage of the continuous outer magnetic circuit may be obtained with standard E and I laminations slightly modified by the use of the construction shown in Fig. 5*g*. In this construction the left-hand section is formed of E-section 65 and I-section 66 with laced joints. The right-hand section is formed of an E-shaped section 67 with a central arm 68 shortened to leave a gap 70 between it and the left-hand section. This E-shaped section 67 is joined to the left-hand section by either butt or laced joints at the end of the outer arms 71 and 72 of the E-shaped section 67.

The sections referred to may either be built up of laminations, or of powdered metals, or oxides, such as the material known as Ferroxcube, the choice depending upon the frequencies involved and other design factors.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In a voltage regulator, a magnetic circuit with a first and second section having a portion of the circuit common to both sections, said common portion having a reluctance greater than the rest of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, primary windings on a single leg each of the first and second sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, and secondary windings wound on the same legs of the first and second sections as the primary windings connected in series opposition so that the induced voltages at the frequency of the applied voltages in the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.

2. In a voltage regulator, a magnetic circuit with a first and second section having a portion of the circuit common to both sections, said common portion having a reluctance greater than the rest of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, primary windings on a single leg of each of the first and second sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, said means comprising a capacitor coupled to the primary on said first section, and secondary windings wound on the same legs of the first and second sections as the primary windings connected in series opposition so that the induced voltages at the frequency of the applied voltages in the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.

3. In a voltage regulator, a magnetic circuit with a first and second section having a portion of the circuit common to both sections, said common portion having a reluctance greater than the rest of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, primary windings on a single leg of each of the first and second

sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, said means comprising a capacitor inductively coupled to the primary on said first section, and secondary windings wound on the same legs of the first and second sections as the primary windings connected in series opposition so that the induced voltages at the frequency of the applied voltages in the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.

4. In a voltage regulator, a magnetic circuit with a first and second section having a portion of the circuit common to both sections, said common portion having a reluctance greater than the rest of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, a gap in said second section, primary windings on a single leg each of the first and second sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, and secondary windings wound on the same legs of the first and second sections as the primary windings connected in series opposition so that the induced voltages at the frequency of the applied voltages in the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.

5. In a voltage regulator, a magnetic circuit with a first and second section each comprising a central leg and four legs forming a hollow rectangle about the central leg with one of the four surrounding legs common to both sections, said common portion having a reluctance greater than that of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, primary windings on the central leg of the first and second sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, and secondary windings on the central legs of each section connected in series opposition so that the induced voltages at the frequency of the voltages applied to the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.



6. In a voltage regulator, a magnetic circuit with a first and second section each comprising a central leg and four legs forming a hollow rectangle about the central leg with one of the four surrounding legs common to both sections, the cross-sectional area of the central legs being less than twice that of the surrounding legs other than the common leg, said common portion having a reluctance greater than that of the second section, the first section designed to saturate during operation producing harmonics of the applied voltage, primary windings on the central leg of the first and second sections connected in series, means for causing the current flowing in the primary on the first section to lead the voltage applied thereto, and secondary windings on the central legs of each section connected in series opposition so that the induced voltages at the frequency of the voltages applied to the primaries add while the induced voltages at harmonics of the input frequency combine in phase opposition to substantially cancel.

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