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T. A. WEIL

2,827,565

CURRENT REGULATORS

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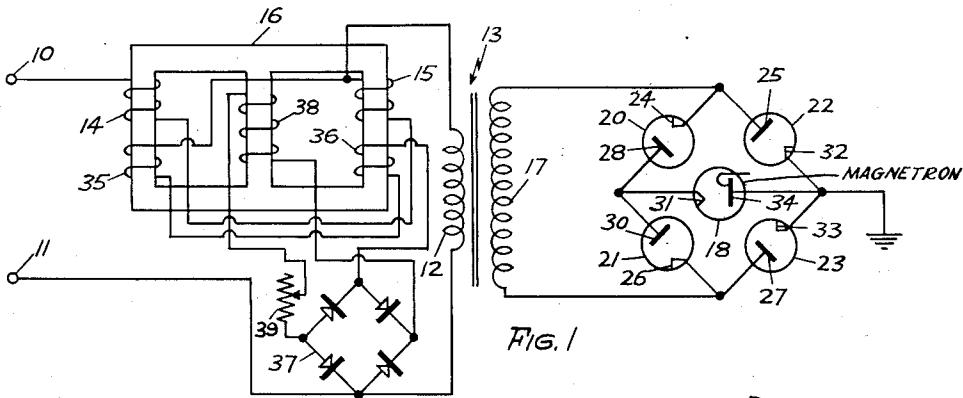


FIG. 1

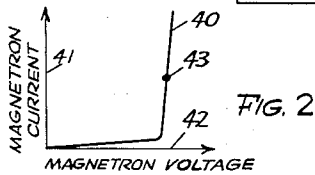


FIG. 2

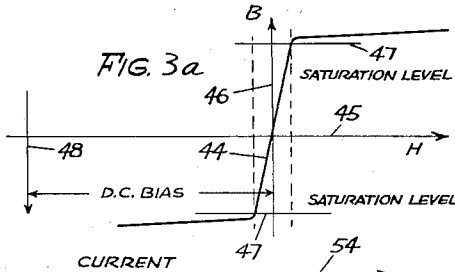


FIG. 3a

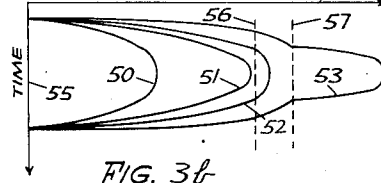


FIG. 3b

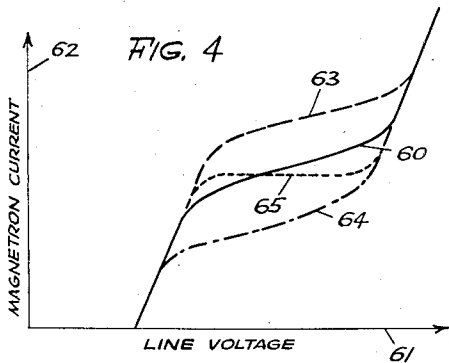


FIG. 4

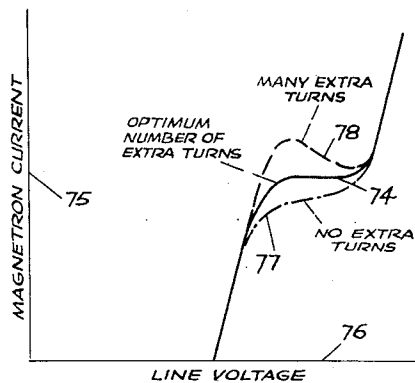


FIG. 5

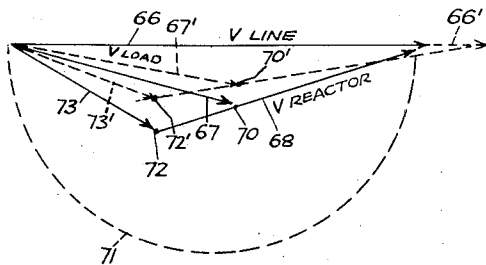


FIG. 6

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CURRENT REGULATORS

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4 Claims. (Cl. 250—27)

This invention relates to current regulators, and more particularly to current regulators of the type utilizing saturable reactors and a rectified portion of the load voltage to regulate the current applied to a load that is inherently constant voltage such as a magnetron.

In supplying power to a load, such as a magnetron, that inherently maintains the voltage across it constant over a wide current range, a small change in the applied voltage may cause the current drawn to vary widely. Usually, however, it is desirable to hold the current flowing through the magnetron close to a chosen value regardless of variations in supply voltage over some specified range. The current can be regulated to some extent by inserting a saturable reactor in the primary of the transformer supplying power to the magnetron or other load and applying a fixed value of direct current to the control winding of the reactor. By this invention, the fixed value of direct current for the control winding of the saturable reactor is obtained from the constant load voltage; in addition, the control action of the saturable reactor is greatly enhanced by obtaining the direct current for the control winding from the constant load voltage plus an additional voltage which tends to compensate for the imperfect regulating action which would be obtained with a saturable reactor having only a fixed value of direct current in its control winding. This additional voltage may be obtained most easily by the autotransformer action of added windings on the saturable reactor, or it may be obtained equally well from a separate transformer or autotransformer if desired. This method of regulating the current to a constant voltage load also permits the current to be set to different values, without loss of regulating action, by the adjustment of a resistor in series with the control winding of the saturable reactor or by other equivalent methods of varying the ampere-turns of current in the control winding. In comparison with other methods of obtaining regulation, such as those involving separate voltage or current references and usually employing feedback, a simplicity and economy of parts is obtained.

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 the circuit of the invention;

Fig. 2 is a graph of the variation of current through a representative magnetron with the voltage applied across it;

Fig. 3a is a graph of the B-H curve of a representative saturable reactor;

Fig. 3b is a graph of the variation of the current through the primary windings of a transformer supplying power to a magnetron;

Fig. 4 is a graph of the variation of the current through the magnetron with changing line voltage and various control currents applied to the saturable reactor with the desired curve shown in dotted lines;

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Fig. 5 is a vector diagram of the interaction of the various voltages involved in the control circuit of the invention; and

Fig. 6 is a graph similar to that of Fig. 4 showing the effect of different numbers of added turns in the circuit of the invention.

In Fig. 1, the reference numerals 10 and 11 designate terminals connected to a source of alternating current potential. Current from these terminals is supplied to the primary 12 of a transformer 13 through two coils 14 and 15 wound on the core of a saturable reactor 16. The particular arrangement of core and coils in Fig. 1 is shown only for illustration of the principles of this invention, and various other arrangements of cores and coils may be used in the construction of the saturable reactor as will be apparent to those skilled in the art. The secondary 17 of the transformer 13 is connected to a rectifier circuit supplying a magnetron 18 or other load having the above-mentioned inherent constant voltage characteristic. This rectifying circuit as shown comprises four diodes 20, 21, 22, and 23. The cathode 24 and the plate 25 of the diodes 20 and 22, respectively, are connected to one terminal of the secondary 17 of the transformer 13. The cathode 26 and the plate 27 of the diodes 21 and 23, respectively, are connected to the other terminal of the secondary 17. The plates 28 and 30 of diodes 20 and 21 are connected to the cathode 31 of the magnetron 18. The cathodes 32 and 33 of the diodes 22 and 23 are connected to the plate 34 of the magnetron 18. It is to be understood that other types of rectifying circuits may be used. Additional windings 35 and 36 are wound on the core of the saturable reactor 16 and are shown connected in series with the rectifier network 37 across the primary 12 of the transformer 13. The control winding 38 of the saturable reactor 16 is connected to the direct current output of the rectifying network 37 in series with an adjustable resistor 39.

The operation of this circuit can best be understood by reference to the graphs of Figs. 2 through 6. Fig. 2 shows a graph 40 of the variation of the current through a magnetron plotted vertically along the axis 41 with the voltage applied across it plotted horizontally along the axis 42. It will be noted that there is essentially no current in the region of low voltages below the operating point 43. As the voltage approaches the operating point, the current abruptly increases along a steep slope to give a large increase in current for a small increase in voltage. For a wide range of current, the voltage remains nearly constant. This is what is meant by the constant voltage characteristic of the magnetron as a load for a power supply.

Fig. 3a shows the B-H curve 44 of a representative saturable reactor. It will be seen that, as the magnetizing force H plotted horizontally along the axis 45 increases, the flux density B plotted vertically along the axis 46 increases until the saturation level represented by the line 47 is reached, after which the application of additional magnetizing force results in a negligible further increase in flux density.

The operation of the invention can best be understood if it is first assumed that a fixed source of direct current is applied to the control winding 38 of the saturable reactor 16. This will have the effect of biasing each half of the reactor with a magnetizing force represented by the line 48 in Fig. 3a. The magnetizing force due to the appropriate half cycle of the load current is represented by the curves 50, 51, 52, and 53 in Fig. 3b. These curves show the variation of current plotted horizontally along the axis 54 with time plotted vertically along the axis 55. The magnetizing force necessary for

saturation is indicated by the lines 56 and 57. It will be seen that the magnetizing force that is the resultant of the bias current and the load current represented by the graphs 50 and 51 never brings the core out of saturation and into the region represented by the space between the lines 56 and 57, while the magnetizing force represented by the graph 52 reaches this level for a limited time, and the magnetizing force represented by the graph 53 penetrates through this region into the region of saturation. When the core of the saturable reactor is saturated, the reactor presents little or no impedance to the load current. As the load current increases and the core becomes unsaturated, the impedance presented by the reactor increases, limiting the load current as shown by the rounding off of the curve 52. However, as shown by the curve 53, if the reactor is driven entirely through the unsaturated region, the reactor ceases to present appreciable impedance to the load current and it again can increase according to the operating conditions of the magnetron or other load.

Fig. 4 shows the effect of various values of control current in the control winding of the saturable reactor upon the magnetron current-line voltage characteristic curve. The graph 60 is such a characteristic curve with line voltage plotted horizontally along the axis 61 and magnetron current plotted vertically along the axis 62. It is to be understood that the magnetron current shown in Figs. 4 and 6 is the average magnetron current. With an increase in the control current, the flattened portion shifts upward to a position represented by the broken line 63 and with a reduced bias it shifts to a position shown by the dot-dash line 64. It will be seen that at best these lines 60, 63, and 64 show only a reduction in the rate of variation of the magnetron current with line voltage. What is desired is a characteristic curve having a portion in the region of expected line voltages that is substantially flat, that is, one that shows little or no increase in magnetron current with a moderate shift in the line voltage about the operating point. Such a characteristic is shown by the dotted line 65 and can be obtained by supplying the control winding with somewhat more direct current bias at low line voltage than at high line voltage.

This is accomplished by adding the windings 35 and 36 to the reactor core and connecting them in series with the rectifier 37 across the primary 12 of the transformer 13. The direct current output is applied to the resistor 39 and the control winding 38 on the reactor 16.

The effect of this arrangement is best understood by reference to the vector diagram of Fig. 5. Although the various voltages are not actually sinusoidal, the vector diagram shown is useful for descriptive purposes. The line voltage is represented by the vector arrow 66. This voltage represents the vector sum of the voltage across the load represented by the vector arrow 67, actually the voltage across the primary of the transformer 13, and the voltage across the windings 14 and 15 on the reactor 16 represented by the vector arrow 68. Because the load is not purely resistive and the reactor is not purely inductive, the vector voltages across them are not perpendicular to each other, but are approximately as shown. If they were perpendicular, their junction point 70 would fall on the dotted semi-circle 71 erected on the vector arrow 66 representing the line voltage. The voltage across the coils 35 and 36 extends the reactor voltage vector 68 to the point 72. The vector 73 drawn to this point represents the voltage that is applied to the rectifier 37 and after rectification is applied to the resistor 39 and the control winding 38 of the reactor 16. If the line voltage increases, as shown by the vector 66', the voltage across the coils 35 and 36 extends the reactor voltage vector 68' to the point 72'. This results in the voltage across the rectifier 37 represented by the vector 73' being reduced, so that less current is produced in the control winding 38,

thus retaining the magnetron current constant, as shown by the dotted line 65 in Fig. 4.

Fig. 6 shows how this result can be obtained by using the proper number of turns in the windings 35 and 36 on the reactor 16. The graph 74 represents the regulation characteristic obtained with the optimum number of such turns added, with the magnetron current plotted vertically along the axis 75 and the line voltage plotted horizontally along the axis 76. The graph 77 shows the regulation obtained without the added turns of this invention. It will be seen that this graph 77 has the shape of the curves 60, 63, and 64 in Fig. 4. The curve 78 shows the effect of using more than the optimum number of turns in the windings 35 and 36. Adjustment of the resistor 39 will cause the flat portion of the curve 74 to occur at different current levels.

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. A current regulator for an inherently constant voltage load comprising a saturable reactor, a first set of windings on said reactor connected between a source of alternating current potential and an inherently constant voltage load, a control winding on said reactor, and means for obtaining in this winding a unidirectional current proportional to the inherently constant load voltage comprising a second set of windings connected to the first set of windings and a rectifier with its input connected in series with the second set of windings across the load and its output connected across the control winding.

2. A current regulator for an inherently constant voltage load comprising a saturable reactor, a first set of windings on said reactor connected between a source of alternating current potential and an inherently constant voltage load, a control winding on said reactor, and means for obtaining in this winding a unidirectional current that varies about a value proportional to the inherently constant load voltage in a direction opposite to the variation in the potential of said source comprising a second set of windings connected to the first set of windings and a rectifier with its input connected in series with a second set of windings on said reactor across the load and its output connected across the control winding through a resistor.

3. A current regulator for a magnetron comprising a saturable reactor, a first set of windings on said reactor connected between a source of alternating current potential and a magnetron, a control winding on said reactor, and means for obtaining in this winding a unidirectional current proportional to the inherently constant voltage across the magnetron comprising a second set of windings connected to the first set of windings and a rectifier with its input connected in series with the second set of windings across the magnetron and its output connected across the control winding.

4. A current regulator for a magnetron comprising a saturable reactor, a first set of windings on said reactor connected between a source of alternating current potential and a magnetron, a control winding on said reactor, and means for obtaining in this winding a unidirectional current that varies about a value proportional to the inherently constant voltage across the magnetron in a direction opposite to the variation in the potential of said source comprising a second set of windings connected to the first set of windings and a rectifier with its input connected in series with a second set of windings on said reactor across the magnetron and its output connected across the control winding through a resistor.

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