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[54] **CURRENT DEPENDENT FILTER INDUCTANCE**
3 Claims, 5 Drawing Figs.

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 [51] Int. Cl. **H01f 29/00,**
H02m 1/14
 [50] Field of Search **321/10;**
323/1, 6; 336/165, 178

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ABSTRACT: A current dependent variable inductance having a winding and flux coupled magnetic core portion with cross-sectional areas that vary between maximum and minimum values in planes perpendicular to the flux path. Current flow of greater than a given magnitude in the winding causes saturation of the minimum core area and generation of fringing flux in an adjacent auxiliary airgap. The lengths of the fringing flux lines and accordingly of the auxiliary airgap vary directly with the saturation current in the winding. Thus, the value of inductance provided by the winding varies inversely with that current.

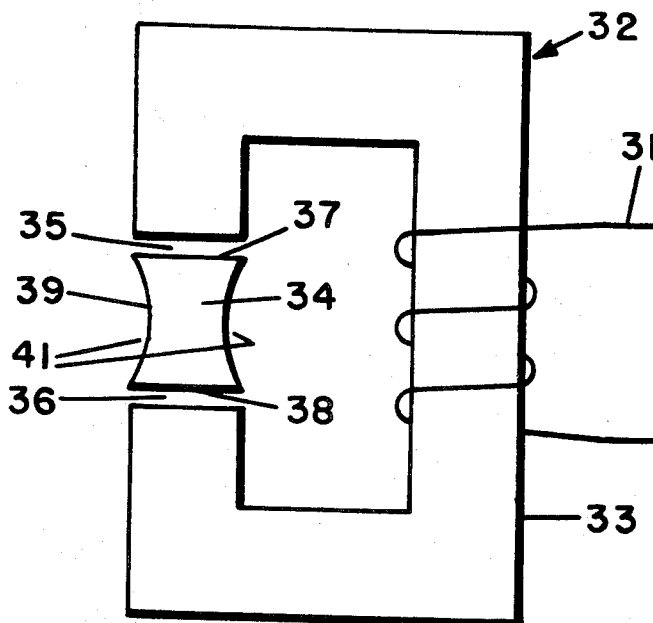


FIG. 1.

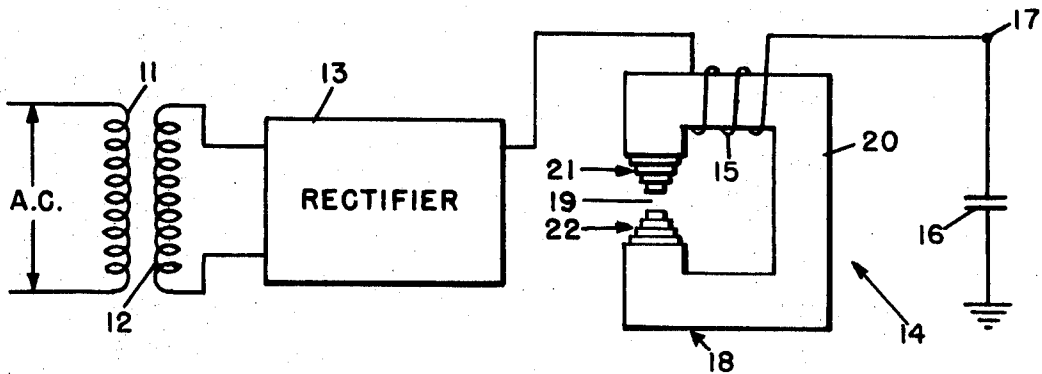


FIG. 2.

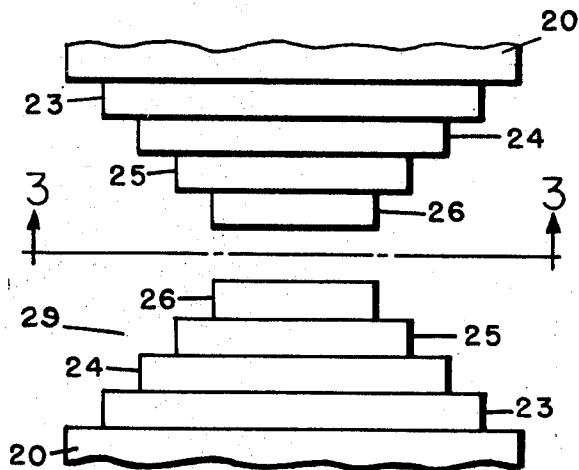


FIG. 3.

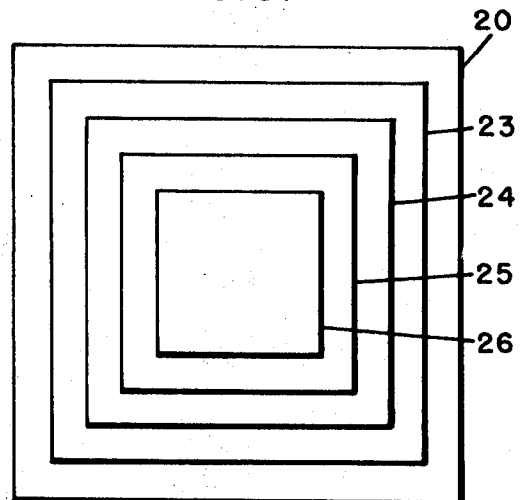
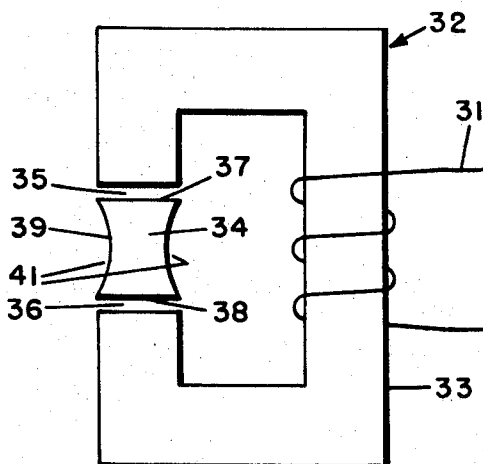


FIG. 4.



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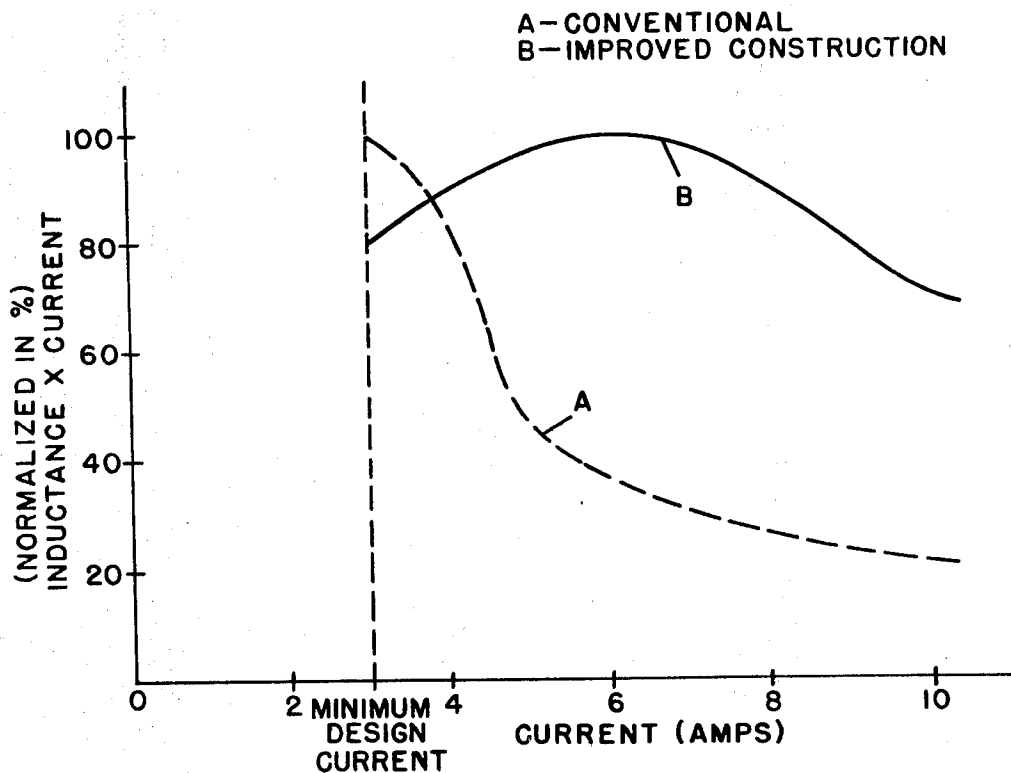
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FIG.5.



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CURRENT DEPENDENT FILTER INDUCTANCE

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to a current dependent variable inductance and is specifically suited for use as an inductive element in input filter chokes of AC or DC power supplies.

In the design of filter circuits for AC-DC power supplies, it is customary to minimize the value of inductance so as to reduce the weight and cost of the inductance element required. Optimum performance in the way of regulation, however, is realized only if the inductance value is equal to or greater than the circuit's critical inductance. This is the inductance value required to prevent current from decreasing to zero during any part of the cycle. Critical inductance (L_c) is a well-known phenomenon discussed in Reference Data for Radio Engineers (3rd ed.), pages 183-185, 1949, Knickerbocker Printing Company, N.Y., N.Y., and for a particular configuration is equal to K/I_0 where K is a constant and I_0 is the DC output current. Thus, L_c is a variable having a maximum value determined by the minimum level of output current and corresponding to the minimum inductance value required for optimum filter circuit performance. Conversely, the inductance element's current-carrying requirements which also effect weight and cost must be determined by the maximum value of DC output current. Because of these designs criteria, the typical nonvariable inductance element of an input choke filter provides an unnecessarily large value of inductance for high output current levels and an unnecessarily large current rating for low output current levels.

Attempts to alleviate the above problem have resulted in many types of variable inductances for which inductance values vary inversely with current. Examples of such inductances include swinging chokes that utilize the characteristic B-H slope of an iron core to establish the desired variation in inductance, iron-cored inductances that include an independently energized control winding that selectively controls inductance by varying the level of magnetic flux produced, and various types of mechanically adjusted inductances in which inductance values are altered either by switching mechanisms that modify the circuit relationship between plural coils or by relative physical displacement of either inductance coils or magnetic cores. All such previous elements suffer from certain disadvantages. For example, core material may not be available with a B-H loop that will provide a swinging choke with the particular operating characteristics desired for a particular application. Externally controlled variable inductances, although offering wide ranges of operation, entail the sometimes undesirable use of separate control windings and circuits. Finally, the time delays inherently required by mechanically controlled variable inductances to effect switching or mechanical displacements are not acceptable in all applications.

The object of the invention, therefore, is to provide an improved variable inductance for use in input choke filter circuits of AC-DC power supplies.

SUMMARY OF THE INVENTION

The invention is characterized by the provision of a current-dependent variable inductance that is suited particularly for use as an inductive element in choke input filters of AC-DC power supplies. The inductance comprises a winding on a magnetic core with pole pieces that define a primary airgap and establish therewith a magnetic flux path. The core further includes a longitudinal portion of reduced cross section and including cross-sectional areas in planes perpendicular to the

flux path that vary between maximum and minimum values. Current flow through the winding at levels above a predetermined value induces saturation of the longitudinal core portion at the reduced cross section thereby generating fringe flux in an auxiliary gap adjacent thereto. By utilizing cross-sectional areas in the longitudinal core portion that vary in a uniform sense between the maximum and minimum values, the length of the fringe flux lines and correspondingly of the auxiliary airgap vary directly dependent upon the level of current flow in the winding above the predetermined value. Consequently, the inductance values provided by the inductance element varies inversely with current flow through its winding.

According to a featured inductance element embodiment of the above type, the varying cross section of the longitudinal core portion is selected so as to provide an inductance value substantially equal to K/I_0 over a predetermined current operating range; where K is a constant and I_0 is the value of DC output current from a choke input filter. According to this arrangement, and inductance element having a core with a selected variation in cross section can provide a current dependent variable inductance substantially equal to the input filter's critical inductance over a predetermined operating range.

Another feature of the invention is provision of an electrical inductance of the above type wherein the longitudinal core portion of reduced cross section includes pole sections on opposite sides of the primary airgap and with areas of minimum cross section directly adjacent thereto. In this case the auxiliary airgap produced by saturation of the core is parallel to the primary airgap.

Another feature of the invention is the provision of an electrical inductance of the above types wherein the pole sections of reduced cross section are formed by a plurality of magnetic laminations stacked in planes perpendicular to the flux path. The employment of stacked magnetic laminations of different size establish the variations in cross-sectional area in a simple construction and eliminates problems that would be introduced, for example, by attempts to produce the desired variable cross section by machining. Also, the thin laminations reduce eddy current losses, particularly in high-frequency applications.

DESCRIPTION OF THE DRAWINGS

These and other objects and features of the invention will become more apparent upon a perusal of the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic circuit diagram of an AC-DC power supply employing a preferred inductance element embodiment of the invention;

FIG. 2 is an enlarged view of the pole pieces shown on the inductance core of FIG. 1;

FIG. 3 is a view of one of the pole pieces shown in FIG. 2 looking in the direction of arrows 3-3;

FIG. 4 is a schematic illustration of another inductance element embodiment of the invention; and

FIG. 5 is a graph illustrating performance characteristics of a conventional inductance and of the inductance embodiment shown in FIGS. 1-3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Shown in FIG. 1 is a transformer having a primary winding 11 connected to a source of AC power and a secondary winding 12 connected to a rectifier 13. The DC output of the rectifier 13 is applied to a filter circuit 14 including an inductance winding 15 and a capacitance 16. Appearing on output terminal 17 is the filtered DC output of the filter circuit 14. Supporting the inductance winding 15 is a horseshoe magnetic core 18 that provides with primary airgap 19 a path for magnetic flux generated by current in the winding 15. The core 18 includes a main section 20 that terminates with longitudinally spaced pole pieces sections 21 and 22 disposed on opposite sides of the primary airgap 19.

As shown more clearly in FIGS. 2 and 3, each of the pole pieces 21 and 22 is formed by a plurality of symmetrically stacked, square magnetic laminations 23-26 of different size. Thus, cross-sectional areas of each of the pole pieces 21 and 22 in planes perpendicular to the magnetic flux path vary between maximum and minimum values. The maximum value is established by the cross-sectional area of the main core section 20 while the minimum value is established by the smallest laminations 26 located directly adjacent the primary airgap 19. Furthermore, the laminations 23-26 are stacked in order of size so as to provide each of the pole pieces 21 and 22 with cross-sectional areas that vary in a uniform sense between the maximum and minimum values.

During operation of the power supply shown in FIG. 1, the flow of a given minimum magnitude of current through the winding 15 induces saturation of the smallest magnetic laminations 26 shown in FIG. 2. Further increases in the winding current generates fringe flux in an annular auxiliary airgap 29 surrounding the pole pieces 21 and 22 and parallel to the primary airgap 19. As the value of saturating current flow increases the length of the fringe flux lines also increase as does the effective length of the auxiliary gap 29. For example, after initial saturation of the laminations 26, the predominant portion of the fringe flux lines terminate at the edges of the laminations 25 so that the spacing therebetween establishes the length of the auxiliary gap 29. At higher saturation levels, fringe flux lines also extend between the more distantly spaced laminations 23 and 24 so as to extend the effective length of the auxiliary airgap 29. Thus, the effective length of the auxiliary airgap 29 is directly dependent upon the current flowing in the winding 15.

The value of inductance provided by the winding 15, however is inversely dependent upon the total airgap length which in this case includes both the primary airgap 19 and the auxiliary airgap 29. Consequently, the inductance value exhibited by the filter circuit 14 is inversely dependent upon the magnitude of current flowing in the winding 15 at levels above that required to saturate the minimum sized core portion 26. With appropriate analytical, empirical or experimental methods, relative sizes for laminations 23-26 can be determined so as to provide an arbitrary relationship between the circuit inductance (L) provided by the filter 14 and the DC current output (I_o) flowing through the winding 15. Preferably, the relative dimensions of the laminations 23-26 are selected to establish a relationship such that L is substantially constant over the range of output current values desired at the output terminal 17. In that case relatively uniform ratio exists between the actual inductance provided by winding 15 and the critical inductance L_c required by the filter circuit 14. This is possible because, as noted above, the critical inductance L_c also varies inversely with current flow through the inductance winding. Because of the substantially constant ratio, the value of inductance provided by the winding 15 need not be greater than necessary at high-current values. The above-described design criteria are therefore altered and the requirement for an oversized inductance element is eliminated.

FIG. 4 illustrates another variable inductance embodiment of the invention. As shown, a winding 31 is coiled on a magnetic core 32 that includes a main C-shaped section 33 and a longitudinal portion 34 of reduced cross section. Separating the longitudinal portion 34 from the C-shaped section 33 are a pair of primary airgaps 35 and 36. Again, the cross-sectional area of the spool-shaped core portion 34 varies between maximum and minimum values. The maximum value exists at its terminal faces 37 and 38 directly adjacent the airgaps 35 and 36 and the minimum value exists at its midsection 39.

The operation and construction of the embodiment shown in FIG. 4 is similar to that described above in connection with FIGS. 1-3. However, in this case an auxiliary gap 41 is formed in the annular volume surrounding the spool-shaped core piece 34 in response to current magnitudes in the winding 31 that saturate the core portion corresponding to the reduced cross section at the midsection 39. Thus, in this embodiment the auxiliary airgap 41, that accommodates fringe flux

emanating from the spool-shaped core piece 34 is in series with the primary airgaps 35 and 36 rather than in parallel therewith as in the embodiment of FIGS. 1-3.

FIG. 5 is a graph comparing normalized performance characteristics of a conventional nonvariable inductance (curve A) and of a current dependent inductance according to the invention (curve B). Current through the inductance is plotted on the abscissa axis and a normalized value of current x inductance value provided by the winding is plotted on the ordinate axis. Both curves A and B begin at a current value corresponding to the initial saturation of the longitudinal core portion's minimum cross-sectional area 26 (FIG. 2). As shown by curve A, the conventional inductance experiences an 80 percent variation in inductance value over the indicated current operating range. Curve B, however, indicates only a 40 percent variation in the value of inductance for an inductance according to the present invention. Thus, a substantial improvement is made toward the desired objective of an inductance that provides a current dependent value of inductance equal to K/I .

Alternative embodiments of the invention also are possible. For example, the desired saturation of the reduced cross-sectional core portion can be induced by externally controlled and isolated signals. Additionally, different portions of a core can be constructed of materials possessing different saturation levels or B vs. H curves to achieve various desired effects.

What I claim is:

1. An electrical inductance comprising:

a magnetic core having a pair of spaced-apart pole forces defining an airgap;

an elongated spool-shaped auxiliary magnetic core section separate from said magnetic core and disposed in said airgap to provide a pair of primary airgaps as defined between said pole faces and the ends of said elongate auxiliary magnetic core section,

said magnetic core with said magnetic core section and said primary airgaps providing a magnetic flux path;

auxiliary airgap means defined by said auxiliary magnetic core section with the cross-sectional areas of said magnetic core section residing in planes perpendicular to the flux path varying between a maximum value at its end to a minimum value intermediate its ends with the annular volume surrounding the spool-shaped core section constituting an auxiliary airgap in series with said primary airgaps;

a winding on said magnetic core with terminals adapted for connection in an electrical circuit;

said minimum value of cross-sectional area selected to saturate at magnetic flux levels produced in said flux path by electrical currents in said winding above a given value so as to generate fringe flux in said auxiliary gap in direct dependence upon the values of current in said winding above said given value.

2. A power supply comprising:

a rectifier means adapted for connection to a source of AC power;

a filter means connected to receive the output from said rectifier means;

a current-responsive variable inductance means comprised by said filter means, said inductance means comprising;

a magnetic core having a pair of spaced-apart pole face defining an airgap;

an elongate spool-shaped auxiliary magnetic core section separate from said magnetic core and disposed in said airgap to provide a pair of primary airgaps as defined between said pole faces and the ends of said elongate auxiliary magnetic core section,

said magnetic core with said magnetic core section and said primary airgaps providing a magnetic flux path;

auxiliary airgap means defined by said auxiliary magnetic core section with the cross-sectional areas of said auxiliary magnetic core section residing in planes perpendicular to the flux path varying between a maximum value at its

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end to a minimum value intermediate its ends with the annular volume surrounding the spool-shaped core section constituting an auxiliary airgap in series with said primary airgaps;

a winding on said magnetic core with terminals adapted for connection in an electrical circuit;

said minimum value of cross-sectional area selected to saturate at magnetic flux levels produced in said flux path by electrical currents in said winding above a given value so as to generate fringe flux in said auxiliary airgap in direct dependence upon the value of current in said winding above said given value,

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said auxiliary airgap means defined by said varying cross-sectional areas providing a variable inductance value which is equal to or greater than the critical inductance of said filter means.

3. The invention as described in claim 1,

wherein said auxiliary airgap means defined by said varying cross-sectional areas provides a variable inductance substantially equal to K/I over a predetermined current operating range of said power supply wherein K is a constant and I is the value of DC output current from said filter means.

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