

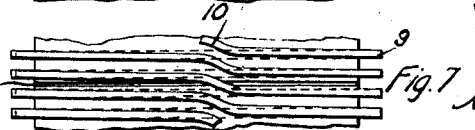
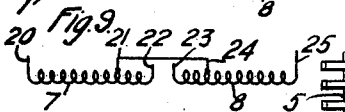
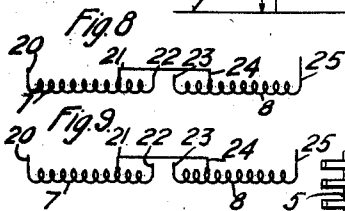
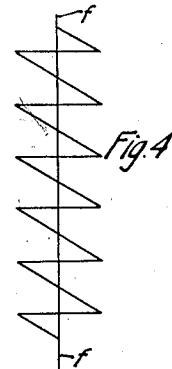
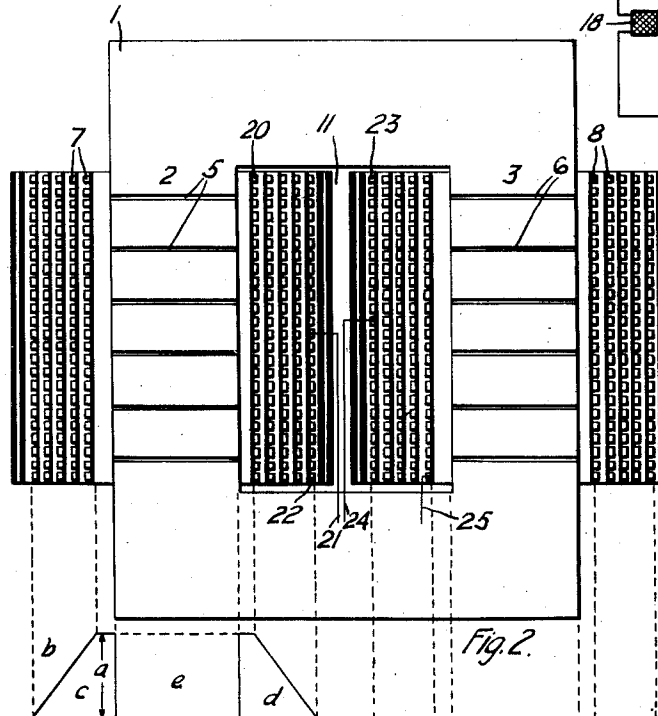
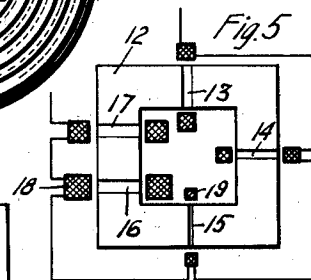
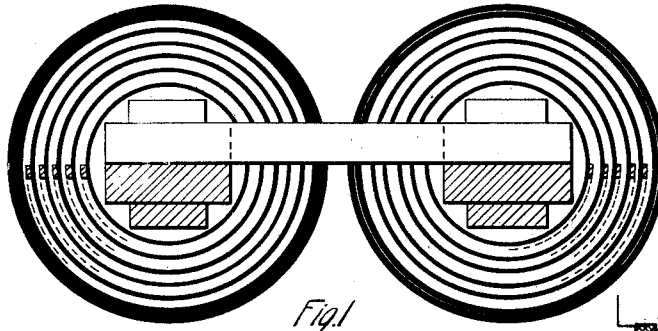
Sept. 11, 1923.

1,467,771

V. E. ALDEN

CURRENT LIMITING REACTANCE COIL

Filed Nov. 20, 1917



WITNESSES:

J. T. Wurm.

Geo. W. Hansen.

INVENTOR

Vern E. Alden.

BY

Wesley E. Carr
ATTORNEY

UNITED STATES PATENT OFFICE.

VERN E. ALDEN, OF WILKINSBURG, PENNSYLVANIA, ASSIGNOR TO WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY, A CORPORATION OF PENNSYLVANIA.

CURRENT-LIMITING REACTANCE COIL.

Application filed November 20, 1917. Serial No. 203,035.

To all whom it may concern:

Be it known that I, VERN E. ALDEN, a citizen of the United States, and a resident of Wilksburg, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Current-Limiting Reactance Coils, of which the following is a specification.

My invention relates to inductive-reactance coils and it has special relation to current-limiting devices which serve to limit the currents that may flow in an associated power circuit to safe values when abnormal circuit conditions, such as short circuits, heavy overloads and the like, obtain therein.

More particularly, my invention relates to current-limiting devices that are adapted for use with electric furnaces, in which capacity they may serve to limit the maximum values of the current, under very unfavorable conditions, to substantially four or five times the normal values.

In its broadest aspect, my invention relates to inductive-reactance coils in which leakage fluxes, that have heretofore been present in all such coils of economical design, are substantially minimized, whereby the eddy-current and other internal stray losses in the coils resulting from these leakage and nonuniformly distributed fluxes may, to all intents and purposes, be reduced to negligible quantities.

It is desirable to have current-limiting reactance coils possess straight line characteristics, within limits, in order that the reactance offered by them under normal conditions may be substantially negligible and, under abnormal conditions, sufficiently high to ensure adequate protection. Coils conforming to these qualifications may be made with air cores, but such coils are necessarily of relatively large size and require the use of standard conductors in order to eliminate the high internal stray losses which are manifested by the heating of the conductors comprising the coils and which are the result of the large magnetic-leakage fluxes. In current-limiting coils comprising magnetizable core portions of iron, it is necessary to form one relatively long air gap in the core member in order that the coil may possess a substantially straight-line characteristic which is desired of coils of this character. In such

coils, as heretofore provided, the leakage fluxes were extremely high, as well as non-uniformly distributed, which resulted in the coils having very high internal stray losses. To reduce these losses to a more satisfactory value it was necessary to employ stranded conductors of extremely large cross sectional areas. Therefore, this coil was highly uneconomical to construct.

The coil of the present invention employs a magnetizable core member having a suitable number of air gaps formed therein, whereby a comparatively straight-line characteristic, within limits, is imparted to the coil. It is, of course, desired that, when normal currents traverse the coil, the inductive reactance offered by it will be negligible or relatively small. As the currents increase in value, the reactance of the coil should increase proportionately in order to limit the value of the currents that may obtain in the associated circuit, under abnormal conditions. When a short circuit is impressed on a system which is protected by a reactance coil of the present invention, it is intended that the reactance of the coil shall be sufficiently high to preclude the development of dangerously high currents. To economically secure these results, it is necessary that the magnetizable core member of the coil shall be provided with air gaps in order that the characteristic of a coil having an air core only may be reproduced fairly accurately. The magnetizable core member of the present coil is, therefore, provided with spaced air gaps in order that the reluctance of the total magnetic circuit of the coil may be increased to a sufficiently high degree.

It is customary to associate the use of iron cores that are worked at satisfactorily high flux densities with high internal stray losses which obtain as a result of eddy currents induced in the coil conductors, as well as the core by the leakage magnetic flux lines. Other losses are the result of the hysteresis losses in the iron cores but the eddy-current losses in the current-carrying conductors comprising the coils may be equal to, and, frequently, are considerably greater than, the I^2R losses.

In the coil of the present invention, I confine the portions of the magnetic circuit of the coil that possess high magnetic reluc-

tances to certain regions thereof and dispose the current-carrying winding or conductor comprising the coil in certain relation to these portions of high magnetic reluctances, whereby the internal stray losses of the coil may be substantially minimized; while, at the same time, the active material of both the core member and the current-carrying conductor are utilized to a very high degree, ensuring the production of a highly economical power-limiting reactance coil in which an iron core member is employed.

It is obvious that my method of disposing the exciting winding of an inductive coil in certain definite relation to the air gaps provided in the associated magnetic core member may be applied to other electrical devices that comprise a source of magnetizing force and a core acted thereupon which contains portions of relatively high and relatively low reluctance.

For a better understanding of the nature and scope of my invention, reference may be had to the following description and the accompanying drawing in which Figure 1 is a plan view, partially in section, of a current-limiting reactance coil constructed in accordance with my invention; Fig. 2 is a view, partially in elevation and partially in section, of the reactance coil shown in Fig. 1; Figs. 3 and 4 are diagrams respectively showing graphically the distribution of the leakage component magnetic flux parallel to the axes of the coils of Fig. 2 and the leakage component magnetic flux perpendicular to the axes of the coils; Fig. 5 is a schematic diagram to more clearly illustrate the features of my present invention; Fig. 6 is an enlarged front view of a portion of the coil shown in Fig. 2; Fig. 7 is an enlarged rear view of the portion of the coil shown in Fig. 6; and Figs. 8 and 9 are diagrams illustrating the electrical connections of the current-carrying winding shown in the power-limiting device of Figs. 1 and 2.

Referring to Figs. 1 and 2, a hollow rectangular magnetizable core member 1 of a cruciform cross-section has its two opposite legs 2 and 3 provided with a plurality of spaced air gaps 5 and 6, respectively. The air gaps 5 and 6 are substantially equal in length and are spaced from one another equal distances. Moreover, they are correspondingly positioned in their respective core legs. It is important that the air gaps be sufficiently short to preclude the development of large fringing fluxes at the exposed sides of the core member immediately adjacent to the air gaps. Of course, fringing of the magnetic fluxes through the air gaps cannot be completely eliminated, but, by making the air gaps sufficiently small, for instance, $\frac{1}{8}$ inch, the fringing of the fluxes will not be serious. The current-carrying winding of the reactance coil comprises a plurality of

cylindrically wound coils 7 and 8 that embrace the core legs 2 and 3, respectively. The cylindrical coils are preferably wound of a strap conductor having its broader face parallel to the axis of the coil. Moreover, the coils are uniformly wound and of such length that the same number of ampere-turns is disposed on each side of each of the air gaps 5 and 6. It will also be observed that the magnetizing ampere turns associated with each air gap are immediately adjacent to the air gap, as well as symmetrically disposed thereabout, as mentioned above.

By referring to Figs. 6 and 7, it will be observed that a strap conductor 9 is wound in the form of a helix, the convolutions of which lie in planes substantially parallel to the air gap 5. In order that the major portion of the conductor comprising each convolution may lie in a horizontal plane, it is necessary that the strap conductor 9 be bent at certain portions, such as at 10 of Fig. 7, in order that the helical form of the coil may not be departed from. The air gap 5 is shown, for the purpose of illustration only, as being subtended by four convolutions of the strap conductor 9, two convolutions being disposed immediately adjacent to, and on each side of, the air gap. This relation between the air gap 5 and the magnetizing turns comprising the conductor 9 is maintained in connection with all of the air gaps 5 and 6 of the coil shown in Fig. 2. The upper and lower air gaps 5 and 6 are shown as having two convolutions of each cylindrical coil disposed immediately adjacent to their outer faces. For convenience, it may be assumed, therefore, that each of air gaps 5 and 6 is associated with the same number of ampere turns of the exciting winding which are symmetrically disposed around them.

Since the air gaps 5 and 6 are of equal length, as well as equally spaced from one another, the cylindrical coils 7 and 8 may be uniformly wound and of proper length to ensure the proper disposition of the magnetizing turns with reference to each of these air gaps.

By referring to Figs. 3 and 4, a proper understanding may be had of the distribution of the leakage fluxes in the reactance coil. The leakage flux through the coil may be resolved into two components, one parallel to the axis of the coil and one perpendicular thereto. The maximum density of the leakage flux parallel to the axis of the coil may be kept low by having a relatively long dimension parallel to the axis of the coil for an opening 11 in the core member 1. From the mechanical design of the coil, the maximum density of this leakage flux may be calculated and is represented by an ordinate a of Fig. 3. The variation in the den-

sity of the leakage flux, by reason of the five cylindrical coils 7 embracing the core member 1, may be represented by the slanting line *b*. The total leakage flux arising from the coils 7 may be represented by two areas *c* and *d*, and the total flux threading through the core leg 2 is proportional to the area *e*, the proportionality factor depending upon the permeability of the iron. A corresponding leakage-flux diagram may be constructed for the coils 8.

Knowing the shorter dimension of the opening 11, the component leakage fluxes passing through the coils, in planes perpendicular to the axes of the coils, may be calculated. It is obvious that the maximum value of the leakage flux is coincident, in space, with the center of each of the air gaps and that the minimum value is coincident, in space, with points centrally located between the spaced air gaps. Fig. 4 may, therefore, be constructed to represent graphically the component leakage fluxes perpendicular to the axes of the coils. The areas included between the zig-zag lines of Fig. 4 and the central axis *f* represent the total horizontal-component leakage flux of the core leg 3.

By winding the coils 7 and 8 of strap conductor, in the manner mentioned above, and by nesting these coils very closely to one another, the eddy currents induced in the conductors comprising the coils by reason of the component magnetic fluxes parallel to the axes of the coils, may be substantially reduced and retained at a sufficiently low value to prevent the strap conductors from becoming unduly heated. It is apparent also, that, by making the dimension of the opening 11 that is parallel to the axis of the coil sufficiently large, the component leakage fluxes may be further reduced in value. Again, the maximum value of the component leakage fluxes that are perpendicular to the axes of the coils may be limited by using the proper number of air gaps, since the maximum value of this leakage-flux component is proportional to the total number of ampere turns contained in the winding divided by the total number of air gaps formed in the core member.

While the component leakage fluxes represented in Fig. 4 may be further reduced in value by increasing the number of air gaps in the core member and individually decreasing their length, the component leakage fluxes represented in Fig. 3 may not be reduced correspondingly because the longer dimension of the opening 11 cannot be reduced beyond a reasonable length on account of the dimensions of the coils. It is important, therefore, to present the thin edges of the strap conductors to the leakage magnetic fluxes of larger value in order that the resulting eddy currents may be minimized.

In Fig. 5, I have shown a more general application of the principles embodied in the current-limiting device of Fig. 2. Herein, the core member 12 is provided with a plurality of air gaps 13, 14, 15, 16 and 17, that are of different lengths. Of course, it is understood that the length of none of them is such as would be conducive to the formation of extremely large fringing fluxes near the outer edges of the core member. Each of these air gaps is subtended by a winding, the turns comprised therein being directly proportional to the length of the air gap. For instance, the air gap 16 having the greatest length is subtended by a source of magnetizing force or a magnetizing coil 18 having the largest number of turns. The coil 18 is symmetrically disposed immediately adjacent to the air gap 16 in order that its ampere turns may be effective in overcoming the reluctance of the air gap 16 only. A coil 19, comprising the smallest number of ampere turns, is placed immediately adjacent to the air gap 15 of least length. In a corresponding manner, all of the air gaps formed in the core member are immediately subtended by sources of magnetizing force, the intensities of which are proportional to the air gaps which they severally subtend. It is, of course, presumed that the iron portions of the core member 12, as well as the core member 1, are of zero magnetic reluctance or, at least of negligible reluctance. By arranging the magnetizing windings immediately adjacent to the air gaps formed in the core member, the external magnetic fields which are usually present in inductive coils heretofore constructed has been substantially eliminated. In consequence thereof, the internal stray losses of the coil are reduced to very low and sometimes negligible quantities while the active material, such as the iron portion of the core member and the copper conductor constituting the winding are operated at higher densities than has heretofore been possible under like conditions.

In Figs. 8 and 9, I have illustrated, in the usual manner, the method of interconnecting the coils 7 and 8 of the current-limiting device of Fig. 2. In Fig. 8, the coils 7 and 8 are connected in series relationship to each other. In Fig. 9, corresponding portions of the coils 7 and 8 are shown disconnected from circuit but the balanced condition of the coil is not disturbed because of the positioning of taps 21 and 24.

While I have shown and described one embodiment of my invention, it will be understood that many modifications may be made therein without departing from the spirit and scope of the appended claims.

I claim as my invention:

1. An electrical device comprising a magnetizable core member provided with a plu-

ality of spaced air gaps, and a current-carrying winding embracing said core member, said winding being divided into portions corresponding in number to the air gaps and each of said winding portions being disposed immediately adjacent to one of said air gaps.

2. An electrical device comprising a magnetizable core member having a plurality of spaced portions of relatively high magnetic reluctance, and an exciting winding therefor comprising a corresponding number of portions that are severally placed immediately adjacent to the high-reluctance portions of said core member.

3. An electrical device comprising a magnetizable core member having a plurality of spaced air gaps, and a source of magnetizing force for said core member disposed adjacent to said air gaps to distribute the intensity of said force over said core member in proportion to the magnetic reluctance of said air gaps.

4. An electrical device comprising a magnetizable core member having a plurality of spaced air gaps, and a source of magnetizable force for said core member disposed adjacent to said air gaps to distribute said force over said core member, whereby said air gaps are impressed with a magnetizing force that is substantially proportional to its own magnetic reluctance.

5. An electrical apparatus comprising a magnetizable core member provided with a plurality of spaced air gaps, and windings surrounding said core member and said air gaps, each portion of said core member being surrounded by a winding whereby a magnetomotive force is generated therein which is directly proportional to the magnetic reluctance of the immediately adjacent air gap.

6. An electrical device comprising a magnetizable core member having a plurality of spaced air gaps and a current-carrying winding therefor, said winding being disposed symmetrically on said core member with respect to each of said air gaps.

7. An electrical device comprising a magnetizable core member having a plurality of spaced air gaps and a current-carrying winding therefor, said air gaps being severally embraced by portions of said winding that comprise ampere-turns which are directly proportional to the magnetic reluctance of the air gaps.

8. An electrical device comprising a magnetizable core member, the magnetic circuit of which is provided with alternate portions of relatively high and relatively low magnetic reluctance, and a current-carrying winding therefor serving as a source of magnetizing force, the current-carrying winding being distributed over the said core member in accordance with the magnetic reluctance

of the said several portions of relatively high and relatively low magnetic reluctance.

9. An inductive coil comprising a magnetizable core member provided with a plurality of equally spaced air gaps of equal magnetic reluctance, and current-carrying windings disposed substantially in the planes of the air gaps, the winding being uniformly wound in order to generate magnetic forces of equal magnitude.

10. A current-limiting reactance coil comprising a current-carrying winding, and an iron core member furnishing a closed magnetic path therefor, the portion of said core member embraced by said winding being provided with a plurality of air gaps of equal magnetic reluctance and the said winding generating an equal magnetizing force immediately adjacent to each of said air gaps.

11. A current-limiting reactance coil comprising a hollow rectangular core member, at least one leg of which is provided with a plurality of spaced air gaps of equal magnetic reluctance, and a current-carrying winding embracing said leg that is provided with the air gaps, said winding comprising a strap conductor, the longer side of which is parallel to the axis of the coil and said winding being positioned to separately provide an equal number of ampere turns immediately adjacent to each of the air gaps.

12. A current-limiting reactance device comprising a hollow rectangular iron core member, at least one leg of which contains a plurality of spaced portions of relatively high magnetic reluctance in order to impart a substantially straight-line characteristic to said current-limiting device, and a current carrying coil embracing said core leg and being wound so that the magnetizing action immediately adjacent to each of said core portions of high magnetic reluctance is proportionate, in intensity, to the magnetic reluctance of the respective portions.

13. A current-limiting reactance device comprising a hollow rectangular magnetizable core member, two opposite legs of which are severally provided with a plurality of spaced air gaps of relatively small length, and a winding for each of said core legs which generates a magnetomotive force adjacent to each of said air gaps that is directly proportional to the magnetic reluctance of the air gap.

14. A current-limiting device comprising a magnetizable core member forming an approximately closed circuit and having a plurality of relatively short and equally spaced air gaps of equal magnetic reluctance formed in at least one leg thereof, and a uniformly wound cylindrical current-carrying coil embracing said core leg, the said coil being so proportioned that each of

said air gaps is subtended by equal portions of said coil in order to impress equal magnetizing forces on said air gaps.

15 15. A current-limiting reactance device comprising a magnetizable core member forming an approximately closed circuit and having n relatively short and equally spaced air gaps of equal magnetic reluctance formed in at least one leg thereof, and a uniformly wound current-carrying
10 coil embracing said core leg, the said coil being so arranged that $\frac{1}{n}$ portion of its ampere-turns is disposed immediately adjacent to each of said air gaps.
15

16. An inductive device comprising a magnetizable core member having n spaced portions of relatively high magnetic reluctance of substantially equal value, and a
20 current-carrying winding therefor, $\frac{1}{n}$ portion of said winding being symmetrically

disposed immediately adjacent to each of said spaced portions of high magnetic reluctance.

17. An electric device comprising an iron core of a hollow rectangular form, the two longer legs thereof being provided with n correspondingly placed and equally spaced air gaps of equal magnetic reluctance, a
30 cylindrical, uniformly-wound current-carrying coil embracing each of said longer legs, the length of each coil being so proportioned that $\frac{1}{n}$ portion of the number of
35 convolutions thereof is symmetrically arranged about each of said air gaps, and means for connecting said coils in series relation.

In testimony whereof, I have hereunto
40 subscribed my name this 30th day of Oct., 1917.

VERN E. ALDEN.