June 19, 1945. C. E. SEIFERT 2,378,884

TRANSFORMER

Filed June 20, 1940 4 Sheets-Sheet 1

Fig. 1.

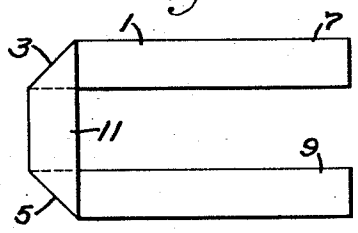


Fig. 2.

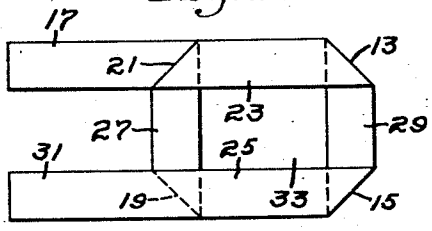


Fig. 3.

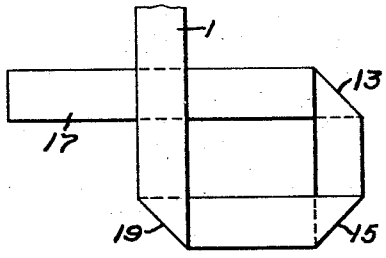


Fig. 4.

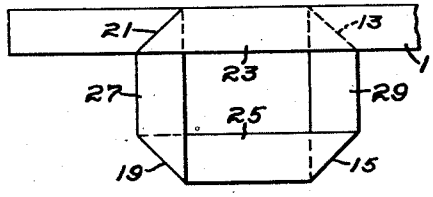


Fig. 5.

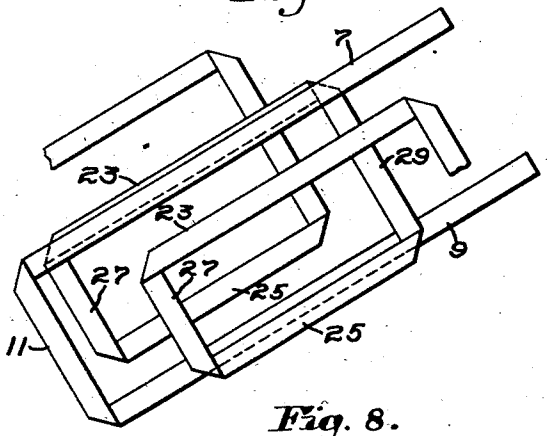


Fig. 6.

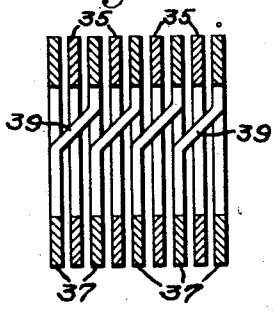


Fig. 7.

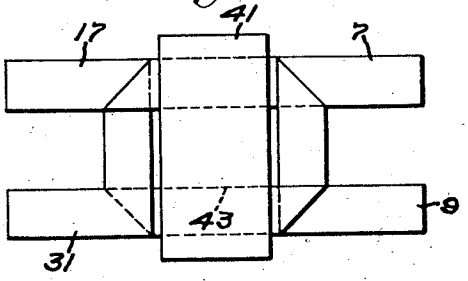
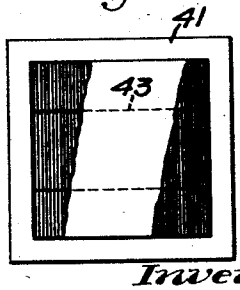


Fig. 8.



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TRANSFORMER

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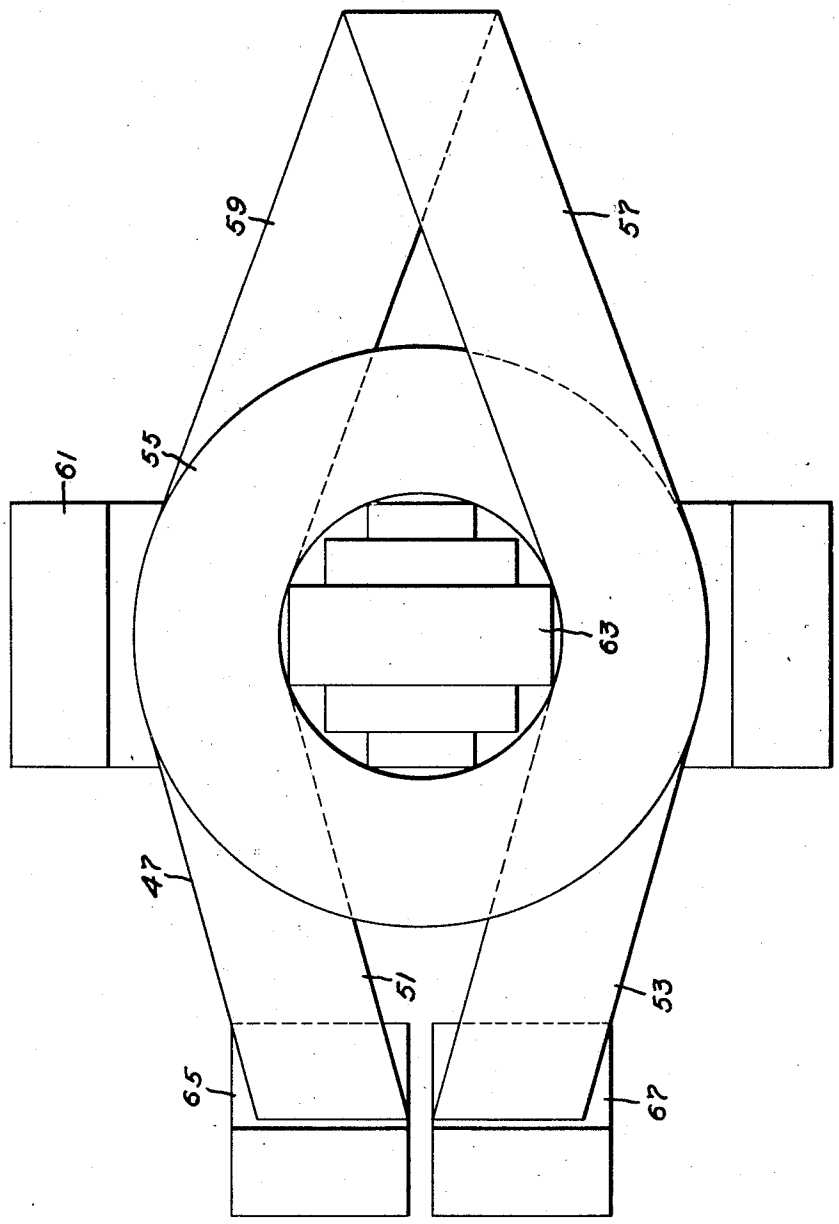

Fig. 9.

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TRANSFORMER

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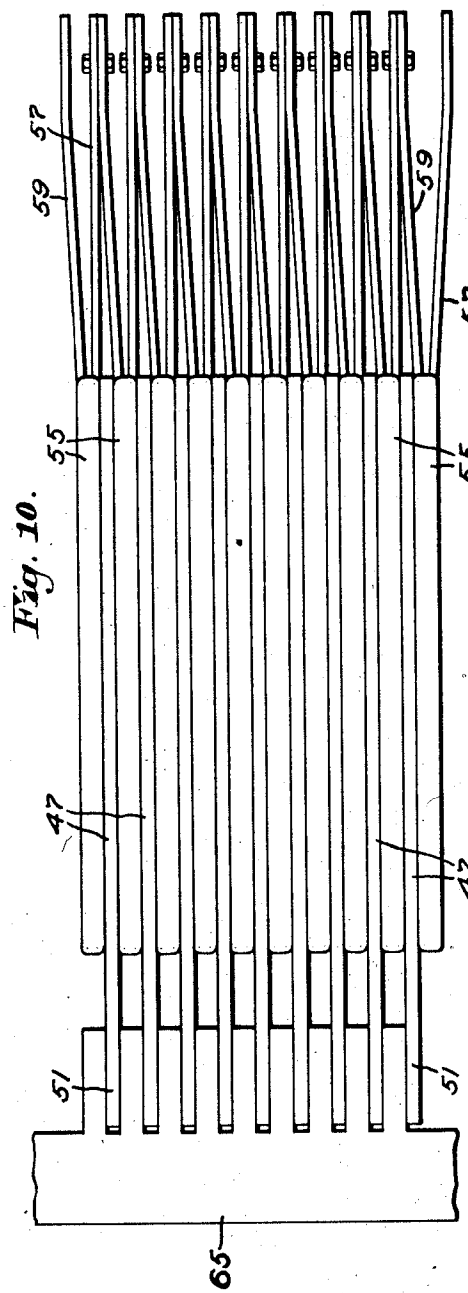

Fig. 10.

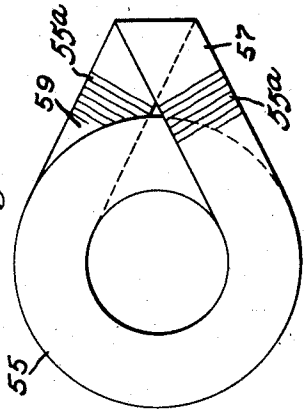

Fig. 15.

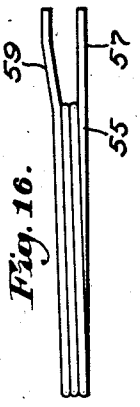

Fig. 16.

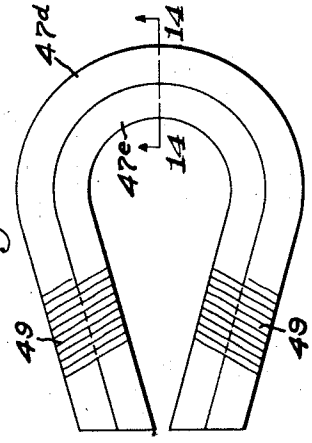

Fig. 13.

Fig. 14.

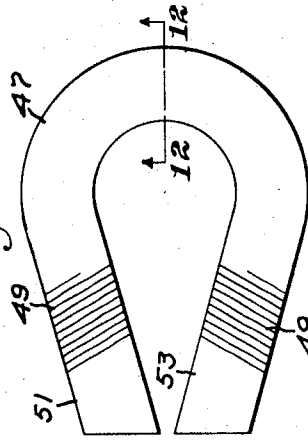

Fig. 11.

Fig. 12.

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TRANSFORMER

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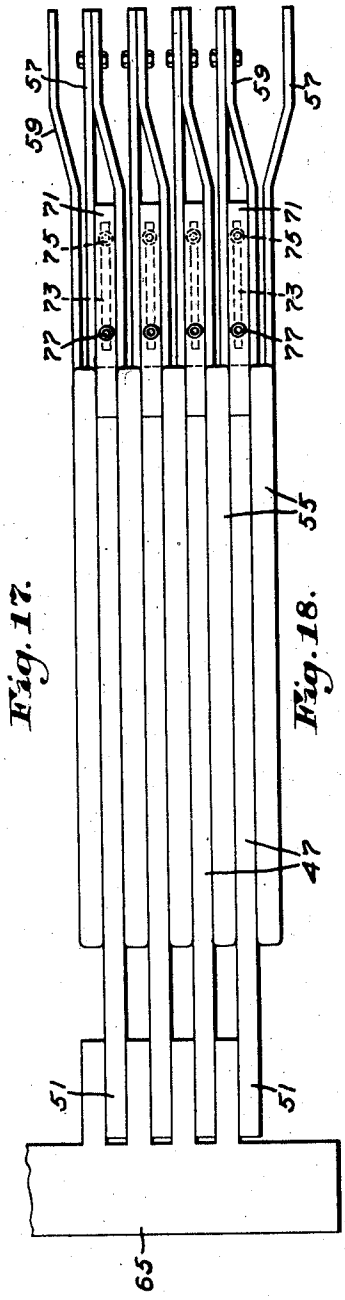

Fig. 17.

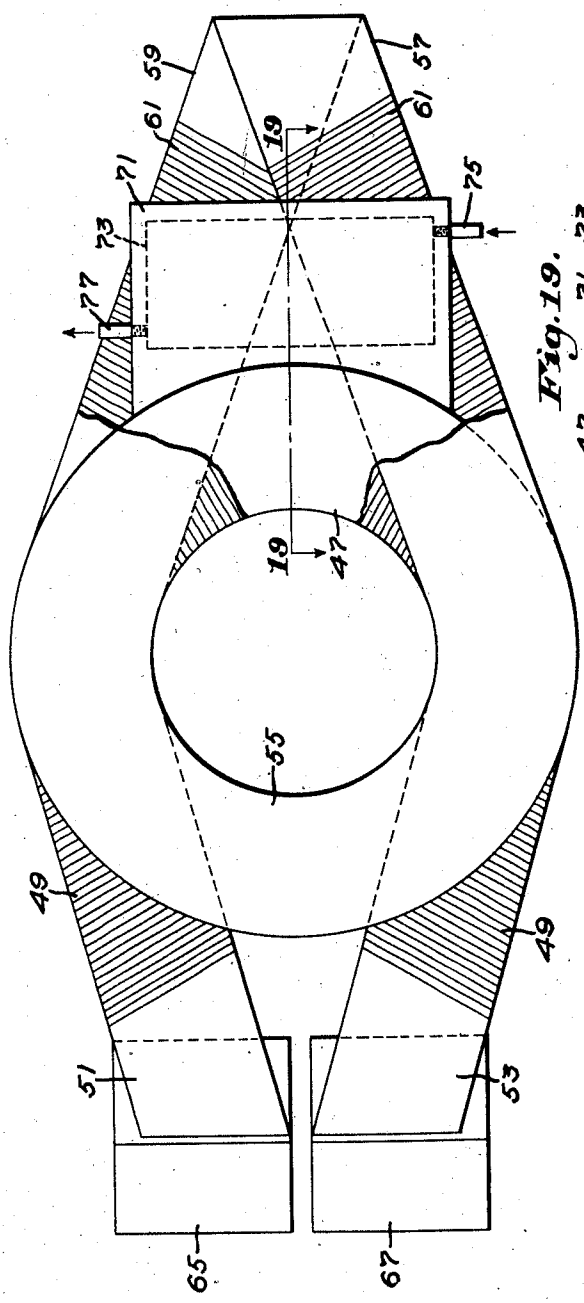

Fig. 18.

Fig. 19.

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Patented June 19, 1945 2,378,884

UNITED STATES PATENT OFFICE

2,378,884

TRANSFORMER

Charles E. Seifert, Swampscott, Mass., assignor to Thomson-Gibb Electric Welding Company, Lynn, Mass., a corporation of Massachusetts

Application June 20, 1940, Serial No. 341,489

11 Claims. (Cl. 175—356)

This invention relates to electric transformers and more particularly to those employed for resistance welding where large volumes of secondary current are required for brief intervals in the welding operations.

One object of the invention is to increase the efficiency of the transformer and to reduce the demand made on power lines from the use of such transformer, while at the same time still securing the large volumes of secondary current as are called for.

In the use of such transformers, due to the reactance of the entire circuit, the primary current input required to secure the necessary volume of secondary current is apt to be very high, causing a serious voltage drop in the power line when the welding or secondary circuit is closed. This results in wide fluctuations in the voltage in the power line which are difficult and often impractical to control at the central station.

This voltage drop is due in part to the resistance and reactance of welding circuit outside of the transformer, owing to characteristics of the welding machine which are fixed and unchangeable. The leakage reactance in the transformer itself, however, contributes materially to the reactance of the circuit as a whole and to the drop in the voltage at the terminals of the transformer when under load.

When the current flows through the primary of the transformer it magnetizes the transformer core and the pulsating flux induces a current in the secondary winding opposite in phase to that of the primary current. These opposing currents tend to set up a leakage flux, a part of which returns through the iron core of the transformer and part through the air space between the primary and secondary coils. This leakage flux materially reduces the open circuit or no-load terminal voltage of the transformer when it is placed under load.

Leakage between the primary and secondary coils, however, is not confined to the air gap between the coils but some of this leakage flux passes through the copper windings themselves. This tends to set up eddy currents in the windings, serving only to heat the copper and further increase the voltage drop on closed circuit.

The reactance in a transformer increases with the thickness in an axial direction of both the high and low voltage coils or groups of coils, with the distance in an axial direction between the centers of high and low coils or groups of coils, and also with the square of the number of high voltage turns effective in establishing leakage flux across any one leakage path.

The present invention is designed to provide the closest practical approach to an ideal condition in respect to each of these factors, bringing the reactive drop in the transformer to a minimum. This is accomplished by providing both high and low voltage coils of the maximum possible thinness, interleaved in close compact face-to-face relation to reduce the distance between coil centers, and with a minimum number of high voltage turns interleaved with each low voltage turn, which latter are connected in multiple. This makes it possible greatly to lessen the reactance and to increase the aggregate number of primary turns in inductive relation to the secondary, thereby to increase the transformation ratio and provide the required volume of secondary current with a greatly reduced input amperage. This will be evident for the amperes multiplied by the number of turns must be the same in both the primary and secondary windings, and, since there is but one effective turn in the secondary, increasing the aggregate number of primary turns reduces the needed primary amperage.

This object is secured by providing the primary windings in a plurality of serially connected sections, each section consisting of a minimum number of turns each in the form of a relatively wide thin flat conductor wound edgewise, and further providing secondary turns which may be connected in multiple, each secondary turn being also in the form of a relatively wide thin flat conductor and also wound edgewise, one secondary turn being interleaved between each two adjacent primary sections and in close compact face-to-face relation with the primary turns, separated only by the necessary intervening insulation. Both the primary and secondary windings may be wound edgewise to form windings of a generally rectangular or other polygonal shape or of a generally circular shape.

The use of relatively wide flat conductors, wound on edge, for the primary and secondary coils and arranged and interleaved as indicated not only greatly reduces the reactance, but since the intersecting flux can cut only the relatively narrow edges of the windings the eddy current losses in the windings are greatly reduced.

Another object of the invention is to provide effective cooling for the windings by availing of the peculiar characteristics which are presented by this method of forming the windings.

These and other objects of the invention will be best understood by the following description

when taken in connection with the accompanying illustrations of one or more embodiments thereof.

In the drawings:

Fig. 1 is a detail showing in side elevation the formation of one form of a secondary turn when made from a thin flat strip of conductive metal capable of being bent or folded;

Fig. 2 shows in side elevation a primary winding comprising a succession of turns as they appear when also made from a thin flat strip of conductive metal;

Fig. 3 illustrates the first step in the formation of the primary windings;

Fig. 4 illustrates the next succeeding step;

Fig. 5 is a perspective illustrating how a single secondary leg is interleaved with successive primary turns;

Fig. 6 shows the relation of the primary and secondary windings, which are here spaced apart for clarity, and with the cross-over connections between successive primary turns shown diagrammatically;

Fig. 7 is an elevation showing the transformer with the windings assembled on the core, looking in a direction transversely the windings;

Fig. 8 is an elevation of the transformer looking in a direction lengthwise the windings;

Fig. 9 shows in side elevation another transformer, embodying the same principles but in which windings are formed from heavier strips or plates of copper;

Fig. 10 is a plan view showing the relation of the windings in the transformer of Fig. 9;

Fig. 11 is a detail showing in side elevation one of the secondary legs or turns for the transformer shown in Fig. 9;

Fig. 12 is a cross-section of the secondary leg, taken on the line 12—12 in Fig. 11, where the leg is formed of several strips;

Fig. 13 shows one method of forming the secondary leg by use of inner and outer concentric strips;

Fig. 14 is a cross-section on the line 14—14 in Fig. 13, illustrating a difference in the cross-section of the inner and outer strips;

Fig. 15 shows in elevation one section of the primary windings of the transformer of Fig. 9;

Fig. 16 is a plan view of a primary winding section;

Fig. 17 shows in plan a section of the windings of a transformer similar to that of Figs. 9 and 10, but with the back of each secondary leg provided with a water cooled fin;

Fig. 18 is a side elevation showing the water cooled fin for one of the secondary turns; and

Fig. 19 is a section in plan on the line 19—19 in Fig. 18.

Referring to the drawings, and first to Figs. 1 to 8 inclusive, there is shown for illustrative purposes one embodiment of the invention in which both the primary and secondary turns are formed of relatively wide flat strips of conductive metal, such as copper, of such thinness that their flat faces are capable of being bent and folded.

In this case, the secondary legs of the transformer may each be formed, as shown in Fig. 1, by taking a suitable length of such a copper strip 1, bending it over and against itself on the diagonal line of fold 3, and again similarly on the diagonal line of fold 5, so that the strip then assumes the shape of a flat-sided thin U-shaped copper leg or turn with the projecting terminal strips 7 and 9 and the cross-connecting strip 11.

Any desired and suitable number of primary turns are formed from a similar but longer strip of flat thin copper. In forming the primary turns, one end of the strip (Fig. 3) is first bent along the diagonal lines of fold 13 and 15, as described in connection with Fig. 1, leaving an extension 17 which serves as one primary terminal. The other leg of the strip is then bent upward about the line of fold 19, as indicated in Fig. 3. Next, as shown in Fig. 4, the upstanding continuation of the strip is bent along the diagonal line of fold 21, thereby forming one complete turn of the primary winding which consists of the upper and lower strips 23 and 25 and the side strips 27 and 29.

Successive steps of this operation are then repeated over and over again, bending the continuous strip to form a series of similar turns. The primary winding, when completely formed, assumes the shape shown in Fig. 2, with the ultimate end 31 of the strip forming an extension parallel to the extension 17 to serve as the remaining primary terminal.

The primary winding when completed presents a continuous flat-sided winding on edge (Fig. 2) enclosing a polygonal and herein rectangular core space 33, the successive turns of which can be opened up or separated like the helices of a spring to permit the interleaving by insertion between successive turns of the separate secondary legs.

The windings having been thus formed, the strips constituting the secondary legs are covered with any suitable thin insulating material such, for example, as glass tape. The primary windings may be similarly insulated, but where a secondary is disposed between each two adjacent primary turns, the primary insulation may be unnecessary since the insulated secondary separates one primary turn from another.

To interleave the windings each secondary leg is inserted into the nest of primary turns, one to lie between two adjacent primary turns, the next to lie between the next adjacent primary turns, and so on. This may be accomplished by interleaving the secondary leg between two adjacent primary turns, as illustrated in Fig. 5, so that the upper strip 7 of the secondary leg lies between the strips 23 of adjacent primary turns, the lower strip 9 of the secondary between the strips 25, and the cross strip 11 of the secondary between side strips 27, but with the side strip 29 of one primary turn to the next turn passing from one side of the secondary strip 7 to the opposite side of the secondary strip 9. This leaves the side strip 29 of one primary turn crossing from one side of the secondary leg to the opposite side thereof and serves as a cross-over connection for the adjacent primary turns in the open space of the secondary leg. Each complete primary turn thus constitutes a primary winding section with a secondary turn interleaved between adjacent primary winding sections and, when finally assembled, are in close compact face-to-face relation separated only by the intervening insulation.

This interleaving assemblage of the primary and secondary windings provides one secondary turn placed face-to-face compactly between each two adjacent primary turns, with all the primary turns serially connected and with the closest possible relation between the windings. This leaves the successive primary and secondary turns in a relationship which may be diagrammatically represented in Fig. 6, but where the primary and secondary turns for clarity are shown spaced one from another, the primary turns being repre-

sented at 35, the secondary legs at 37 and the cross-over connections between successive primary turns at 39.

The windings after assemblage in a compact face-to-face relation are mounted in a laminated iron core 41 of any usual or suitable construction, having (Figs. 7 and 8) the winding core member 43 of rectangular cross-section to fit the core space 33 in the windings. The secondary turns are connected in multiple to terminal headers (not shown) by bolting or brazing all the extensions 7 of the secondary legs to one terminal head of the welding circuit and the extensions 9 to the remaining terminal head. The extension 17 of the primary winding is connected to one terminal of the line and the extension 31 to the other terminal thereof, so that all the primary windings are in series.

While the optimum condition is reached by compactly interleaving one secondary winding leg between each two successive primary turns, certain advantages of this type of transformer winding may be had by so interleaving the secondary legs that they are opposed in compact face-to-face relation each to a group of two or more serially connected primary turns.

The number of primary and secondary turns will, of course, be selected according to the ratio of transformation desired, and this ratio may be varied by dividing the serially connected primary turns into groups, which groups in turn are connected in multiple.

The described method of forming the windings may be employed where copper in strip form is used of a thickness which permits the bending and folding described. By way of example, a transformer suitable for lower capacities in welding work may be constructed by this method using copper strips for the windings from 1 to 4 inches wide and approximately .010 to .050 inch thick.

Since the thickness of the primary and secondary turns, the distance between their centers and the number of primary turns effective in establishing leakage flux across any one leakage path have been reduced to a minimum and the primary and secondary windings are presented to the intersecting flux in a most effective relation for preventing eddy current losses, the leakage reactance in the transformer is reduced to a minimum, the number of primary turns can be increased and the same current volume may be secured in the welding circuit with a reduced current volume in the primary.

In larger capacity units, welding currents of very large volume may be called for, requiring a cross-sectional area in the windings inconvenient or impracticable to secure with flexible copper strips. Or for mechanical reasons it may be impracticable to construct the primary in the form of a continuous helix. In this case substantially the same principle may be utilized by employing thicker strips of copper or other conductive metal wound or bent on edge about suitable forms or arbors, the secondary turns being formed each into a flat horse-shoe or hair-pin shape, and the primary winding being formed into separate sections each of which comprises one or more complete turns.

One transformer of this type is illustrated in Figs. 9 and 10. In this case (Fig. 11) the secondary turns 47 comprise each a relatively wide flat copper strip which, for example, might be ¼ of an inch thick and several inches in width. This is formed into a flat horse-shoe shaped leg, as shown in Fig. 11, by being bent on edge about a suitable form or arbor, after which it may be covered with thin insulating tape 49 (a portion only of which is shown), which however preferably terminates short of the projecting ends 51 and 53 of the leg so as to leave the bare metal of the latter exposed to the air.

Where the combined width and thickness of the secondary leg called for by current requirements make it difficult to bend the copper on edge as described, the secondary leg may be formed of two or more thinner copper strips 47*a*, 47*b*, 47*c*, etc., as indicated by the cross-section in Fig. 12, which are then taped together so that they act as one solid section or a composite conducting leg.

The current carrying capacity of the secondary leg may furthermore be increased, if desired, by increasing the width of the secondary leg. If the width is increased to the point where mechanical difficulties are encountered in bending the strip, the leg may be formed in two parts, as shown in Fig. 13. Here the leg is made up of an outer strip 47*d* bent about one arbor and an inner strip 47*e* bent about another and smaller arbor but closely interfitting within the outer strip. The secondary turn then comprises an inner and an outer flat strip each wound on edge and arranged concentrically one within the other. The two parts may then be taped together and function as one single section. In this case both the outer and inner strips 47*d* and 47*e* may be formed from two or more laminated copper strips, as illustrated in Fig. 12.

Where an inner strip is employed arranged concentrically within an outer strip, as illustrated in Fig. 15, the outer strip which presents the longer path to the current may be made of somewhat greater thickness than the inner strip, as indicated in Fig. 14, thereby to equalize the current flow and the heating effect of the current throughout the secondary turn.

The primary turns are also formed of thin flat strips 55 of copper of a width corresponding to the width of the secondary turns. As in the case of the secondary legs, the turns of each primary section may be formed from a single strip or made up of laminated strips face-to-face, as in Fig. 12, or built up of concentric inner and outer strips, as in Fig. 13, or the methods of both Fig. 12 and Fig. 13 may be employed, as well as the use (Fig. 14) of inner and outer turns of different thickness.

It will be observed that whether a secondary or a primary turn is formed from a single strip of conductive metal, or is of composite formation, as through the use of laminated strips, or concentric inner and outer members, any one conductive turn is not only wide, thin and flat but the part or parts of which it is composed function as a single conductor. It is accordingly intended to include within the term of wide thin flat conductive turns both those composed of a single strip and those of composite formation acting as a single conductor.

In the case of primary windings, each section is formed by bending the strip about a suitable arbor so that it assumes the helical form shown in Figs. 15 and 16, the winding being provided preferably with one or more complete turns. The strip terminals 57 and 59 are left projecting tangentially from the section, as indicated in Figs. 9 and 15, and the terminals 59 are bent laterally into such a position (Fig. 10) that a series connection from one primary winding section to another can be readily made. The helical strip

constituting each primary section is insulated as by being wound with thin insulating tape **55***a* (a short length only of which is shown), which however may be applied to leave uncovered and exposed to the air the bare metal of the projecting tails or terminals **57** and **59**.

Each section of the primary winding may be wound in a number of helical turns, but this number is preferably kept as low as practicable for each section, preference being that they should not exceed two or three turns, thereby providing a relatively large number of very thin flat primary sections, each of a low number of turns, between adjacent sections there being interleaved a single secondary turn in close compact face-to-face relation to the primary turns. In the case of the primary section illustrated in Figs. 15 and 16, the primary winding of each section has somewhat less than three complete effective turns formed from the flat coils wound on edge and compactly arranged side by side.

In the transformer, the primary sections and secondary legs are mounted in the core **61**, having the winding core member **63**, indicated in Fig. 9 but omitted for simplicity from Fig. 10. On the core they are assembled, as shown in the drawings, with one secondary leg (Fig. 10) interleaved between each two adjacent primary sections, with the broad, flat sides of each thin secondary turn in close compact face-to-face relation with the corresponding broad, flat sides of the adjacent insulated thin primary sections. If desired the insulation may be omitted from the secondary turns.

The projecting terminal ends **51** and **53** of the secondary legs project from the core in one direction, the ends of the upper legs **51** being seated and brazed in spaced recesses of one terminal head **65** of the welding circuit and the ends of the lower legs **53** similarly connected to the underlying other terminal head **67** of the welding circuit, thereby connecting all the secondary legs in multiple. The terminals **57** and **59** of each primary section project from the opposite side of the core, preferably extending for a substantial distance at one side of the transformer and clear of the compactly related secondary turns. The terminal **59** of one section is bolted or otherwise connected to the terminal **57** of the next adjacent section to provide a series connection for the entire group of primary sections. Connection to one side of the line circuit is established through the terminal **57** of the end primary section of the group and connection to the opposite side of the line circuit through connection to the terminal **59** at the opposite end of the group.

This arrangement of the primary and secondary windings, provided each with wide flat conductors wound on edge and interleaved in close compact face-to-face relation with one secondary turn between each adjacent primary section, provides a close approximation to the conditions described in connection with the transformer in Figs. 1 to 8. Furthermore, it provides a highly important condition of greatly enhanced cooling capacity for the transformer as a whole. The primary coil sections being wound in comparatively few turns, the tendency for the production of hot spots is greatly reduced since there is relatively little insulation for the heat to pass through. Copper being a good heat conductor, the heat generated in the turns can readily escape lengthwise the relatively short intervening path to the wide flat exposed extensions **57** and **59** which provide the series connections from section to section.

These extensions each presents a heat radiating or conducting surface relatively large in proportion to its cross-section, and the group as a whole, comprising two extensions or tails for each primary section, each exposed to the air, is capable of rapidly dissipating the heat conducted to them. Similarly, the bare exposed extensions **51** and **53** of the secondary windings, being also exposed to the air, contribute their effect to the further dissipation of heat.

The natural dissipation of heat from the primary and secondary extensions may be increased by forcibly blowing air or circulating other cooling medium over either or both, or by immersing them in a cooling tank suitably arranged to enclose them, or the entire transformer might be immersed in a tank of oil for cooling it. Additional cooling means might be applied to the secondary windings by circulating cooling water through passages in the terminals **65** and **67**.

In Figs. 17 to 19 inclusive there is shown an effective cooling means for the secondary turns, the use of which is facilitated by this method of arranging and interleaving the windings.

This is accomplished by attaching to the secondary leg **47**, intermediate its terminals and preferably at the mid portion of its curved back, a rearwardly projecting copper or other metallic cooling fin **71** of substantially the same thickness as that of the leg and having its attached edge curved to mate with the curved outer edge of the leg. This attachment is preferably by brazing the metal of the fin to the metal of the leg so that it becomes in effect an extension of the metal of the leg.

This fin is herein provided with an internal chamber **73** through which a cooling medium, such as cold water, may be circulated, entering through one pipe, such as the pipe **75**, at the bottom of the fin from any suitable source (not shown) and being discharged through another pipe, such as the pipe **77**, at the top of the fin. These fins may be made to present a large cross-section for heat conduction from the secondary and a broad internal area exposed to the cooling water for the effective abstraction of conducted heat. In the illustrative example they assume such a form as to provide a large rectangularly shaped cooling chamber. The heat generated in the secondary leg is rapidly conducted to the projecting fin and abstracted therefrom by the circulated cooling water or other cooling medium.

The primary and secondary turns are assembled as previously described and as indicated in Figs. 17 and 18. There is shown in Fig. 17 a group of five primary sections, but this is merely illustrative and it will be understood that any desired number of primary sections may be employed to secure the desired ratio of transformation, there being a secondary turn between each two adjacent primary sections. As before, the flat thin secondary legs are interleaved, one between each thin flat primary section, in close face-to-face compact relation. This also compacts each fin, or a large part of it, between the adjacent primary sections. The secondary turns with attached fins may be covered with thin insulation or left uninsulated, with the insulation on the primary sections to provide the required insulation between the primary and secondary turns. In the latter case, the insulation

covering for the primary turns should be carried out far enough along the primary extensions 57 and 59 to overlie the surface of the fins 71. The cooling chambers may be connected each separately to the supply source for the cooling medium, or they may be serially connected to cause the latter to pass in succession from one to another.

While there is herein disclosed by way of example several embodiments of the invention, it will be understood that wide departures from the form, relative arrangement and details of the parts as herein described may be made, all without departing from the spirit of the invention.

I claim:

1. A transformer having a plurality of serially connected primary winding sections, each section comprising one or a small plurality of turns in the form of a relatively wide thin flat conductor wound edgewise, said transformer having secondary turns connected in multiple each in the form of a relatively wide thin flat conductor also wound edgewise, there being one single secondary turn interleaved between each two adjacent primary sections and in close compact face-to-face relation thereto, separated only by intervening thin insulation.

2. A transformer having a plurality of serially connected primary winding sections, each section comprising a single turn in the form of a relatively wide thin flat conductor wound edgewise, said transformer having secondary turns connected in multiple each in the form of a relatively wide thin flat conductor also wound edgewise, there being one single secondary turn interleaved between each two adjacent primary single-turn sections and in close compact face-to-face relation thereto, separated only by intervening thin insulation.

3. A transformer having a primary winding consisting of a relatively wide thin flat strip of conductive metal, folded on itself at spaced intervals, forming an edgewise wound helical winding providing a core space of polygonal cross-section, said transformer having secondary turns connected in multiple formed each from a relatively wide thin flat strip of conductive metal, also folded on itself at spaced intervals to provide an edgewise-wound turn, there being a single secondary turn interleaved between adjacent primary turns and in close compact face-to-face relation thereto, separated only by intervening insulation.

4. A transformer having a primary winding consisting of a relatively wide thin flat strip of conductive metal, folded on itself at spaced intervals to form thereby an edgewise-wound helical winding, providing an enclosed core space of polygonal cross section.

5. A transformer having a winding, each turn of which consists of a relatively wide thin flat strip of conductive metal, folded on itself at spaced intervals.

6. A transformer having a plurality of serially connected primary winding sections, each section comprising a relatively few helical turns in the form of a relatively wide thin flat conductor wound edgewise to provide an enclosed core space, said transformer having secondary turns shaped each to provide a leg in the form of a relatively wide thin flat conductor also wound edgewise, the projecting ends of the leg being connected in multiple, there being one single secondary leg interleaved between each two adjacent primary sections and in close compact overlying face-to-face relation thereto, separated only by intervening thin insulation.

7. A transformer having a plurality of serially connected primary sections each comprising a relatively few helical turns each in the form of a relatively wide thin flat conductor wound edgewise, said transformer having secondary turns connected in multiple in the form of a relatively wide thin flat conductor also wound edgewise, there being one single secondary turn interleaved between each two adjacent primary sections and in close compact face-to-face relation thereto, separated only by interleaving thin insulation, the serially connected terminal ends of successive primary sections extending for a substantial distance at one side of the transformer and clear of the compactly related secondary turns and exposed thereat to the effect of a cooling medium.

8. A transformer having a plurality of serially connected primary winding sections, each section comprising one or more turns in the form of a relatively wide thin flat conductor wound edgewise, said transformer having secondary turns connected in multiple each in the form of a relatively wide thin flat conductor also wound edgewise, there being one single secondary turn interleaved between each two adjacent primary sections and in close compact face-to-face relation thereto, separated only by intervening thin insulation, and projecting cooling fins attached to the outer edges of a plurality of said secondary turns intermediate the terminals thereof and containing each a cooling chamber for the circulation of a cooling medium.

9. A transformer having secondary windings consisting of a plurality of separate turns connected in multiple, each turn in the form of a single relatively wide thin flat electrically unitary conductor wound edgewise and having attached to its outer edge at a point intermediate its length a projecting cooling fin containing a cooling chamber for the circulation of a cooling medium.

10. A transformer having secondary windings consisting of a plurality of separate turns connected in multiple, each turn in the form of a single relatively wide thin flat electrically unitary conductor wound edgewise and having attached to its outer edge at a point intermediate its length a projecting cooling fin of substantially the same thickness as that of the conductor.

11. A transformer having secondary turns in the form of a single relatively wide thin flat electrically unitary conductor wound edgewise, each such conductor comprising concentric inner and outer thin flat metal strips each wound on edge and closely interfitted radially and secured together to present a single conductive turn, the outer strip being substantially thicker than the inner one.

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