

Jan. 1, 1935.

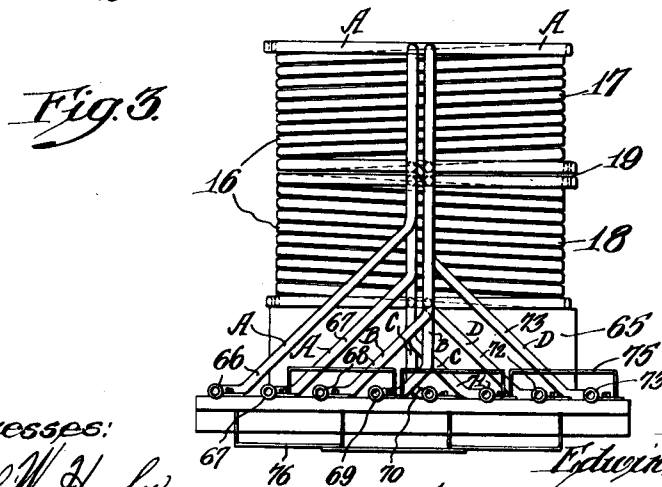
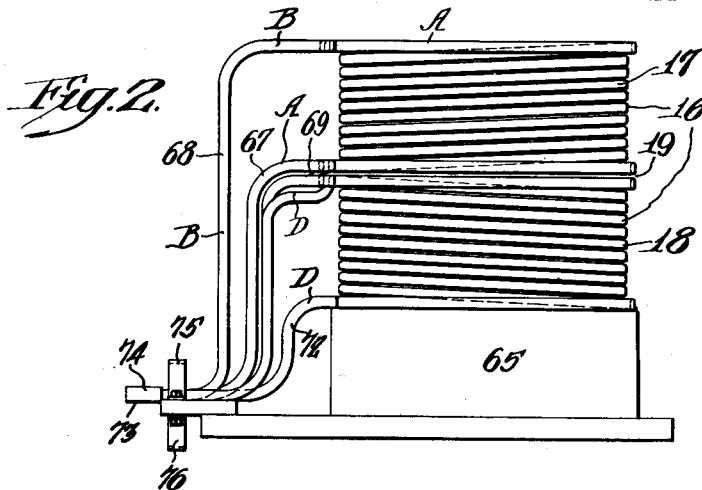
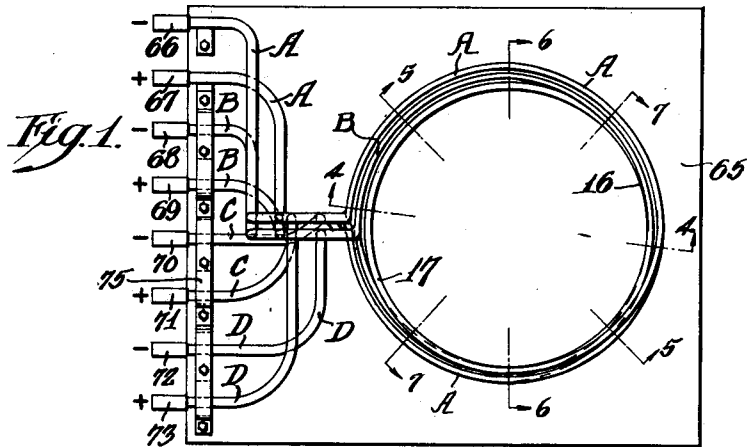
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1,986,353

INDUCTION FURNACE METHOD AND APPARATUS

Filed Sept. 21, 1931

5 Sheets-Sheet 1



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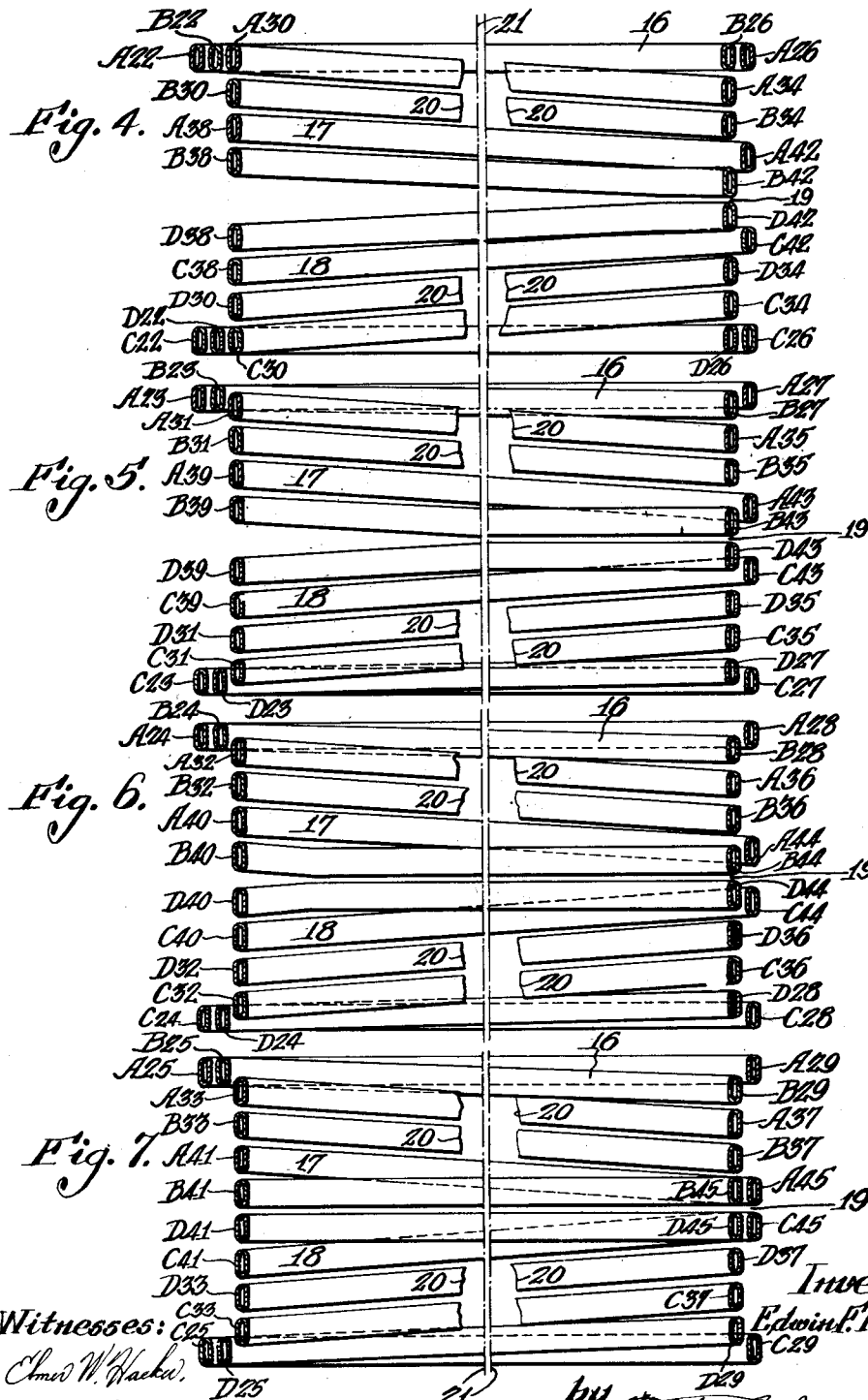
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INDUCTION FURNACE METHOD AND APPARATUS

Filed Sept. 21, 1931

5 Sheets-Sheet 2



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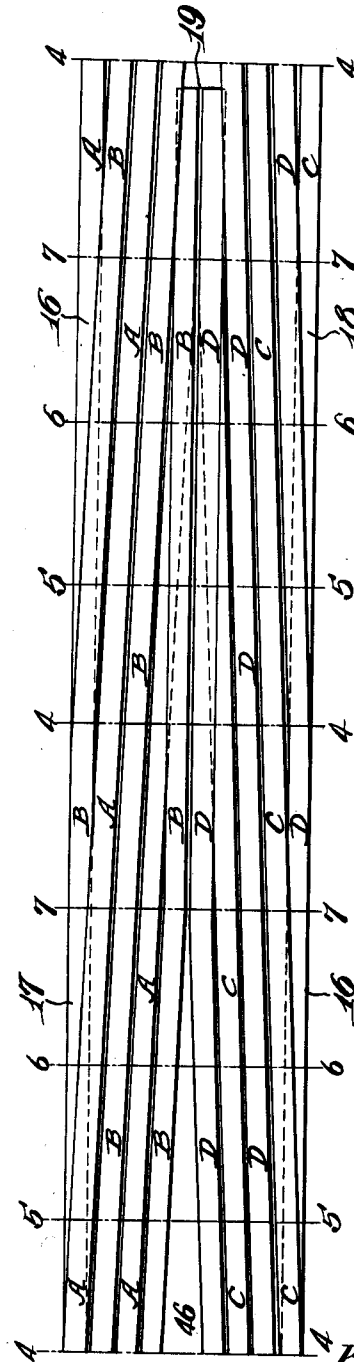
1,986,353

INDUCTION FURNACE METHOD AND APPARATUS

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5 Sheets-Sheet 3

Fig. 8.



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INDUCTION FURNACE METHOD AND APPARATUS

Filed Sept. 21, 1931

5 Sheets-Sheet 4

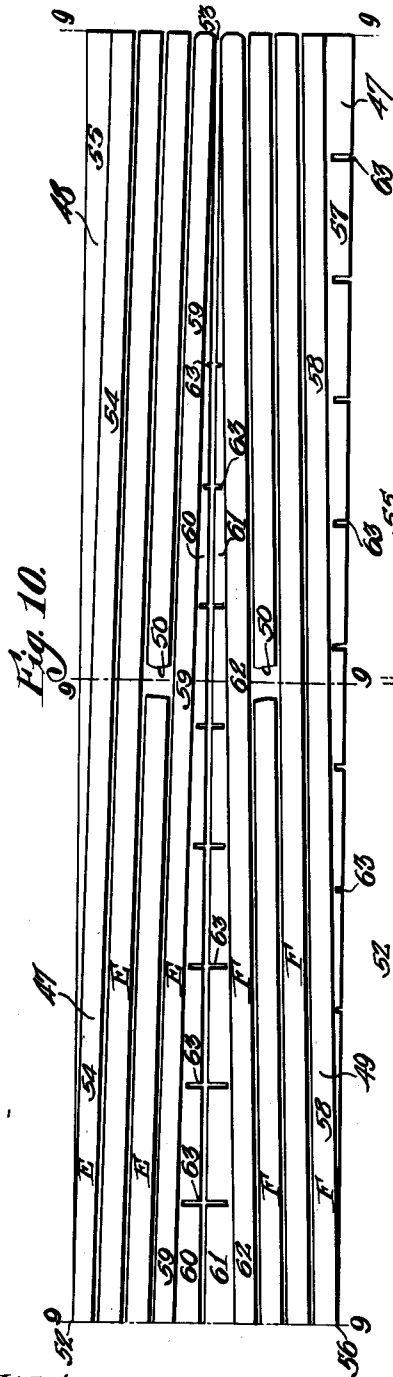


Fig. 10.

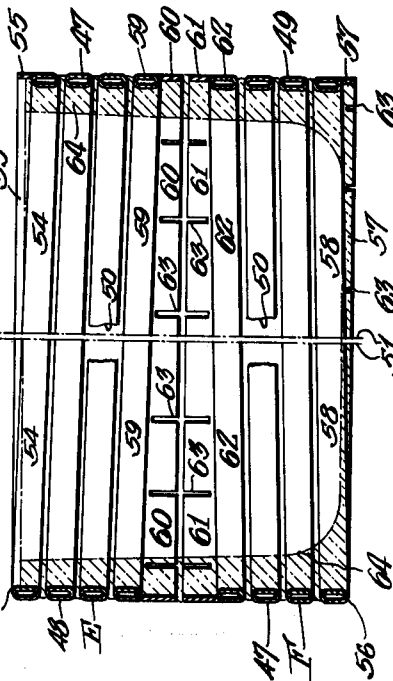


Fig. 9.

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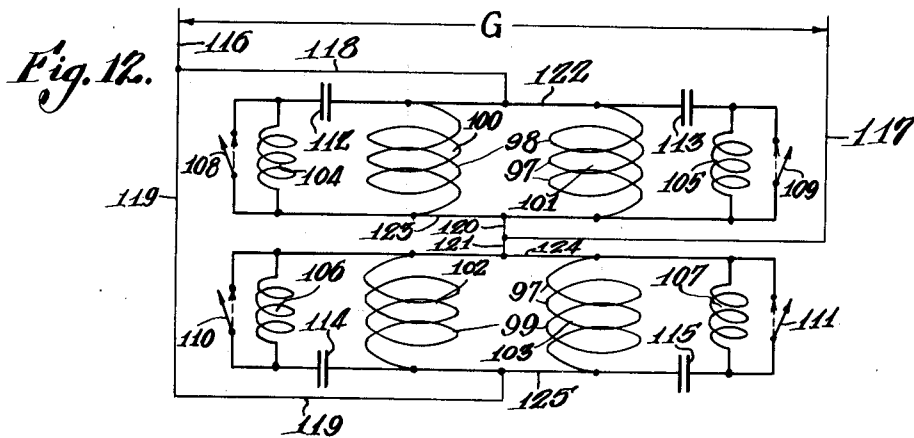
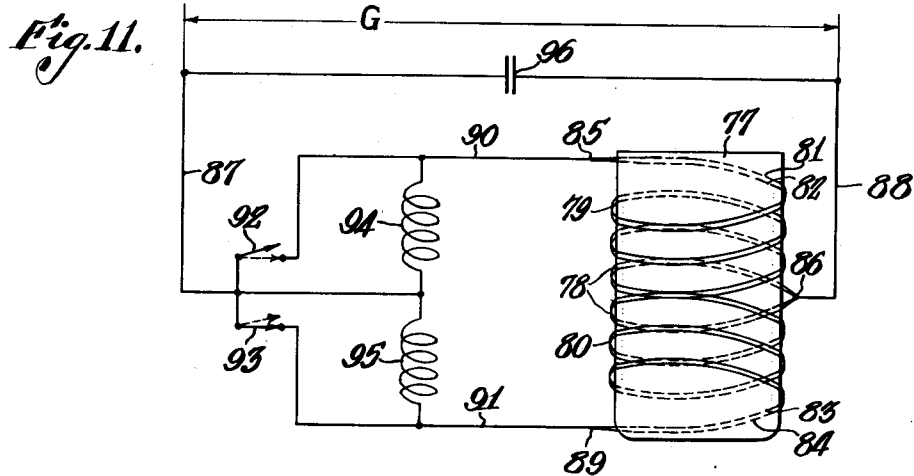
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INDUCTION FURNACE METHOD AND APPARATUS

Filed Sept. 21, 1931

5 Sheets-Sheet 5



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UNITED STATES PATENT OFFICE

1,986,353

INDUCTION FURNACE METHOD AND APPARATUS

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Application September 21, 1931, Serial No. 563,949

34 Claims. (Cl. 219—13)

My invention relates to inductors, and more particularly to the inductors of coreless induction electric furnaces, comprehending both the methods or processes involved and furnace constructions by which these methods or processes may be practised.

A purpose of my invention is to fill gaps in the inductor coil of an induction electric furnace with electrically conducting material.

10 A further purpose is to improve the coupling between an inductor coil and a furnace charge by filling the available inductor coil space about the charge more uniformly with conductors having the diameter which gives the best coupling.

15 A further purpose is to construct an inductor coil in a more symmetrical form, reducing or eliminating the discontinuities or gaps heretofore existing in such coils, especially at the ends, due to the pitch of the winding, and at intermediate points where the direction of winding has been changed.

20 A further purpose is to form a portion of an inductor coil from a plurality of conductors, preferably connected electrically in parallel, and to interweave, radially overlap, cross, change the pitch and change the diameter of winding of these conductors as occasion may require, to permit axial crowding of one or more electrical turns and to fill discontinuities or gaps which would otherwise exist in the coil at the diameter giving best coupling, due to the pitch and to the width of an electrical turn.

25 A further purpose is to construct a helical inductor coil having an end perpendicular to the coil axis.

30 A further purpose is to interwind a plurality of conductors into a helical inductor coil portion, preferably making up the inductor coil of a plurality of such portions, one of which is oppositely wound with respect to another.

35 A further purpose is to wind one of the conductors of an inductor section with a diameter other than that giving best coupling, at a point adjacent to an end or at an intermediate point on the coil, and also desirably to change the pitch of that conductor to permit placing conductors more uniformly around the charge at the diameter giving best coupling.

40 In a furnace inductor having clockwise and counter-clockwise windings leaving a band or gap between, a further purpose is to serve with current the bulk of the heretofore unserved band at the middle.

45 A further purpose is to fill a gap in an inductor coil, either at the end or at an intermediate point,

by inserting a metal strip in the gap, preferably tapering the strip and securing it longitudinally along an edge of the gap, and desirably transversely slitting the strip to reduce heating of the strip.

5 A further purpose is to reduce or eliminate inductance in taps of induction furnace coils, by placing those taps which instantaneously carry currents in opposite directions adjacent to, and generally parallel with, one another.

10 A further purpose is to construct oppositely wound inductor coil portions of a plurality of conductors for each portion, and also to connect all the conductors of a given portion electrically in parallel, supplying current to the respective portions instantaneously in opposite directions.

15 A further purpose is to control the stirring in an electric induction furnace by passing current about the same portion of the furnace charge through a plurality of conductors and by varying the proportions or the total quantity of the currents flowing through these conductors, preferably by changing the inductance of a part of the circuit including one or more of the conductors, but permissibly by varying the reactance of that part.

20 A further purpose is to separately resonate inductor coil portions, one or more of which consists of a plurality of conductors, and preferably also to separately resonate the conductors of a given portion.

25 Further purposes appear in the specification and in the claims.

30 My invention relates both to the methods involved and to the apparatus employed.

35 In the drawings I illustrate two only of numerous inductor coil constructions in which my invention might be embodied, choosing the constructions shown because of their simplicity, convenience in illustration and satisfactory operation. Likewise I illustrate a very few only of numerous possible diagrammatic circuits, referring the reader for other examples to my earlier patents and articles.

40 Figure 1 is a top plan view of a furnace construction embodying my invention, omitting all features not here material, such as the furnace lining or crucible, the furnace casing and the lateral coil support.

45 Figure 2 is a side elevation of the furnace of Figure 1.

Figure 3 is a left end elevation of the furnace of Figure 1.

50 Figure 4 is an enlarged fragmentary condensed 55

section of the inductor coil of Figure 1 upon line 4—4.

Figure 5 is a view corresponding generally to Figure 4, the section being taken upon line 5—5 of Figure 1 at a position approximately one-eighth of a turn removed from that of Figure 4.

Figure 6 is a section upon line 6—6 of Figure 1, corresponding generally to Figure 4, but taken in a plane approximately one-fourth of a turn removed from that of Figure 4.

Figure 7 is a section upon line 7—7 of Figure 1, corresponding generally to Figure 4, but taken in a plane approximately three-eighths of a turn removed from that of Figure 4.

Figure 8 is a reduced interior development of the coil of Figures 4 to 7, cut upon line 4—4, and showing the positions of the sections of Figures 4 to 7.

Figure 9 is a fragmentary condensed section of a somewhat different embodiment of my invention, the section being taken at lines 9—9 of Figure 10.

Figure 10 is a reduced condensed interior development of the coil of Figure 9, cut at the left of Figure 9.

Figure 11 is a diagrammatic view of a circuit which I may use.

Figure 12 is a diagrammatic view of a somewhat different circuit embodying my invention.

In the drawings similar numerals refer to like parts.

Induction electric furnaces depend for efficient operation upon close coupling between the inductor coil and the charge. For this reason the inductor coil is placed as near to the charge as possible, making reasonable allowance for the space occupied by heat insulation and refractory materials, if these be necessary.

To inductively heat a charge, the primary current must be conducted through a path near one or more of the surfaces of the charge. In the ordinary case, such as the heating of a solid bar or rod or of a charge to be melted in a crucible, only the outer side surfaces of the charge are available, and all heating must take place by passing current around the charge close to these surfaces.

It is highly desirable that all parts of the outer side surfaces of the charge be uniformly heated, and with this end in view the energy input from each unit interior area of the inductor coil must be the same. Not only is uneven heating often harmful to the charge, but, in the case of a molten charge, it is accompanied by uneven stirring. Still more important, if the energy input from one portion of the inductor coil be high and that from another portion be low, the portion of the inductor coil having a high energy input will have a high current density and will be correspondingly difficult to cool. The current density of an inductor coil is limited by the capacity of its cooling system, so that, if the energy input be uneven, the coil may be operating with an excessive current density at one point and with a low current density at another point. The coil may thus be overloaded and still heat very inefficiently.

The most extreme case of uneven energy input from an inductor coil is that in which the coil is not continuous, surrounding only part of the charge. If the inductor coil is to heat the whole charge, including that portion adjacent to the discontinuity or gap, the current density must be higher than if the coil completely surrounds all parts of the sides of the charge, without discontinuities or gaps.

In the past, helical inductor coils have inevitably contained discontinuities or gaps due to the pitch of the winding and the axial dimension of the conductors. For example, the end of the coil has sloped with respect to the perpendicular to the coil axis, the amount of slope depending upon the pitch angle. The end of the coil has sloped progressively toward the endmost portion of the winding. The axial length of the coil measured at the circumference has frequently varied from one circumferential position to another, and correspondingly the energy input has varied near the extremities of the coil.

In all helical coreless induction electric furnace windings there has been, therefore, a discontinuity or gap between the actual sloping end of the coil and a plane passed through the endmost point of the coil perpendicular to the axis of the coil, and this has given rise to uneven energy distribution.

Likewise, where a furnace inductor coil has been constructed from a number of conductors, in the past there have been discontinuities at points where conductors have been withdrawn from the coil or other conductors have been led into the winding. This condition has existed where the winding has been tapped for local control of the power input to certain parts of the coil.

However, an even more pronounced example of a gap at an intermediate point in a winding has occurred where the inductor coil comprises portions oppositely wound with respect to one another. In this case, opposite to the point at which the direction of winding has been changed, and to some extent all around the coil adjacent to the locality of change in direction of winding, a pronounced discontinuity or gap has existed.

It will be evident that I use the words "discontinuity" and "gap" in a very general sense, including any space in the coil not served by primary current, other than the normal small insulating spacings between conductors, and specifically including the space at the end between the last conductor and a plane passed through the endmost point of the coil perpendicular to the axis, as well as the space near where the direction of winding is changed or where taps enter or leave the coil.

While gaps have been undesirable in the past, the condition has not been more serious because many of the furnaces heretofore built have been small, and correspondingly their inductors have had many turns and the axial dimension of an individual turn, which ordinarily determines the maximum axial dimension of any gap in the inductor coil due to that turn, has been small.

When, however, larger furnaces have been built, the number of inductor coil turns has decreased, and the axial dimension of each turn has correspondingly increased. This has been done to keep the coil losses within bounds, according to the principles explained in my United States Letters Patent No. 1,694,791, and No. 1,694,792, both granted December 11, 1928.

In coils having a large pitch the loss from gaps is increased two fold. Because of the pitch there are but few turns. For the same reason the gaps in the coils have occupied an increasing axial dimension. This increased axial dimension thus forms a larger proportion of the total coil space.

That the gaps to which I refer are substantial in size may be appreciated when I point out that the gap existing at the end of a helical coil in

the prior art has a circumferential area equal to one-half of the product of the circumference of a turn multiplied by the axial width of an electrical turn. If the same condition exists at both ends of the coil, as has been the case in the prior art, the total gap due to the pitch of the winding at the ends is the equivalent of an entire electrical turn of the winding.

The discontinuity or gap produced by change in the direction of winding has been equal in circumferential area to the product of the circumference of a turn and the axial width of an electrical turn. Therefore, in a coil having oppositely wound portions, the loss through discontinuities or gaps has been equivalent to at least two electrical turns, one at the middle and one divided between the two ends.

Furthermore, in this latter case, the loss of one turn takes place at the middle of the coil, which is the most important point of the winding from the standpoint of efficient heating.

As I have pointed out, the loss of an electrical turn or even two turns of the winding in a small furnace, while in some cases quite serious, is ordinarily not a matter of great consequence because of the large number of electrical turns used in small furnaces and because of the small axial widths of individual electrical turns. Where, however, a furnace of large size is being constructed, the situation is very different. In such large furnaces, only a very few electrical turns are employed and each electrical turn has a correspondingly great axial dimension. The loss of two turns due to gaps means that a wide band of the inductor coil is entirely dead, and that a wide circumferential strip of the charge is not receiving its share of energy input.

A further serious practical difficulty caused by gaps in a furnace inductor coil is that refractory and heat insulating materials are frequently packed against the coil and cannot be supported properly unless the coil be reasonably continuous. The placing of ordinary supporting materials close to the inductor coil to fill a gap and hold a refractory or insulating lining is out of the question because of the heat, of the current, and of presence of the magnetic field close to the coil.

My invention eliminates or greatly reduces the sizes of discontinuities or gaps in the inductor coils making it possible to build inductor coils substantially without gaps, having ends perpendicular to the coil axis and having intermediate portions closely wound and of the diameter giving best coupling.

My broad invention includes a variety of different ways of filling an inductor coil gap, of which I will describe two only in detail. The form which I will describe first and my preferred form involves the use of one of the conductors of the winding itself to fill a gap. I will also describe a second method, employing a separate member for filling a gap, which is very satisfactory in some instances.

When employing my first method, I construct an individual portion of the inductor coil from a plurality of conductors which are interwound. Thus each electrical turn of the coil portion in question consists of a plurality of conductors, which may be wound one beside another or radially overlapping, depending upon whether it is desired to spread out or narrow down the axial dimension of an electrical turn at a given point.

Where a gap would otherwise occur at an intermediate point, as for example due to change in the direction of winding, I wind one or more

of the conductors with a small enough diameter to fill the gap, overlapping the other conductors of the electrical turn upon those wound into the gap.

The inductor coil 16 shown in Figures 1 to 8 is of the type having portions 17 and 18 oppositely wound above and below an intermediate point 19. For this reason it is particularly desirable to illustrate my invention, since it shows in a single embodiment the correction of discontinuities at the ends of a coil and also at the middle of the coil. However, it will of course be understood that gaps at one or more ends of a coil may be corrected without filling spaces at intermediate points, that one or more spaces at intermediate points may be filled without altering the slopes of the ends or that both corrections may be made in a single coil.

To illustrate this, while avoiding duplication of drawings, the turns in Figures 4 to 7 have been broken at points 20, indicating that correction of the slope at the end of the coil ceases at the breaks and therefore that correction may be applied to any coil, without regard to its form on the opposite side of one of the breaks. Likewise, the breaks 20 indicate that the correction of a gap at an intermediate point may be applied, no matter what the form of the ends of the coil.

Of course any number of turns may exist between the ends of the breaks 20, and therefore the breaks may indicate the removal of turns at these points and the axial shifting of the remaining portions of the coil to make the opposing ends of the breaks cooperate. Likewise I conventionally show by broken lines 21 that the diameters of the coils in Figures 4 to 7 are not in proportion with respect to the other figures.

In Figure 8 the broken lines have been omitted for the sake of clearness.

The coil 16 of Figures 1 to 8 comprises four conductors, A, B, C and D, two of which, A and B, form the upper portion 17, and two others of which, C and D, form the lower portion 18. It will of course be understood that the number of conductors in a given coil portion need not be two, provided a plurality of conductors be used, and that the conductors in one portion need not be different from those in another portion.

The upper portion 17 of the winding in the present instance is wound clockwise, while the lower portion 18 is wound counterclockwise. Where oppositely wound portions are to be used, it is of course immaterial whether the upper portion be clockwise or counterclockwise, providing the lower portion be opposite to the upper portion.

In the broad aspects of my invention, the question of whether the coil be oppositely wound in parts or not is immaterial, since gaps and discontinuities may be corrected equally well by my method at the ends or other parts of coils wound continuously in one direction.

Consider first the top of the inductor coil, where the two conductors A and B, forming the upper inductor coil portion 17, enter the winding. The construction may best be understood by observing portions of individual conductors at positions circumferentially removed approximately one-eighth of a turn from one another, as seen in Figures 4 to 7.

The conductors A and B first enter the winding at A22, B22, Figure 4, at which position conductor A completely radially overlaps conductor B, so that the electrical turn formed by conductors A

and B has its minimum axial dimension. At A22, B22 the overlapped conductors A and B also fully radially overlap the next turn of conductor A, indicated as A30. Since, at A22, B22, conductors A and B take no additional axial space beyond that already occupied by conductors A30, B30 of the next electrical turn, just radially inside of A22, B22, it may properly be said that at A22, B22 conductors A and B occupy none of the circumferential space of the inductor coil.

In position A23, B23, Figure 5, conductors A and B still fully radially overlap one another, but they no longer fully overlap conductor A at A31, since the latter conductor has moved downward slightly. As the inner conductor, B, at B23, partially radially uncovers conductor A at A31, conductor B, although still wound with a somewhat larger diameter than the diameter giving best coupling, is more effective in inducing current in the charge than when conductor B radially covered conductor A at A30. It is to be noted that the uncovered portion of conductor B at B23 is opposite what, in the prior art, would be a dead space or gap at the end of the coil.

Between positions A23, B23, Figure 5, on the one hand, and positions A24, B24, Figure 6 and A25, B25, Figure 7, the extent of overlap of conductors A and B on the next turn of conductor A at A32 and A33 progressively decreases; and finally, at A26, B26, Figure 4, the next turn of conductor A, at A34, has moved down far enough so that it is no longer overlapped, and conductors A and B at A26 are wound with smaller diameters to improve their coupling. At this position conductor B is wound with the minimum internal diameter of the coil and conductor A is wound with a diameter slightly larger than the external diameter of conductor B.

Conductor A fully overlaps conductor B at A26, B26, Figure 4. The extent of radial overlap of conductor A on conductor B progressively decreases at A27, B27, Figure 5; A 28, B28, Figure 6; A29, B29, Figure 7, until at A30, B30, Figure 4, conductor A is beside conductor B. Between A29 and A30 the diameter of winding of conductor A is decreased, so that at A30 conductor A is wound with the diameter giving best coupling.

Referring to Figures 1 to 8, it is seen that the normal manner of winding is with one conductor axially beside another, as shown in my United States Letters Patent, No. 1,694,791, granted Dec. 11, 1928, especially Figures 4 and 5, and the normal form of connection is with all conductors of a given portion electrically in parallel.

Effectively what has happened during the travel of conductors A and B (which together in one turn comprise one electrical turn) around the coil for one turn, is that the axial dimension of an electrical turn has changed from a minimum at A22, B22, to a maximum A30, B30. This has been accomplished by changing the form of winding of conductors A and B from radially overlapping to one beside another. This appears very clearly in Figure 8, where it is seen how the conductors change their pitches to complete the symmetry of the end of the coil, fanning outwardly until they are one beside another.

Since the gap produced at the end of the inductor coil by the downward travel of the conductors comprising an electrical turn, as they follow the pitch of the coil has non-parallel sides, one side being formed by a plane passed perpendicular to the coil axis through the endmost point of the winding, it is quite desirable that the change

from overlapping to side-by-side winding be made progressively as shown in the drawings.

Regarding now the end of the winding as a whole, it is seen that conductors A and B cease to be wound with the minimum internal diameter of the coil at different points on the circumference of the coil. Conductor B departs from the diameter giving best coupling between B26 and B25, while conductor A does so between A30 and A29. This is an important feature of my invention, since, by dividing an electrical turn into a plurality of conductors each having a smaller axial dimension than that of an electrical turn in which all of the conductors are wound side-by-side, I may largely avoid the loss in inductive heating heretofore resulting when a conductor has been led away from the coil, and I need not withdraw any conductor from the coil until by normal winding it reaches a position close to the plane which I wish to make that of the end of the coil.

The interwinding or interfitting of the conductors (which terms have for the present purpose the same meaning) is of considerable value in the present invention, because it makes possible the axial crowding of the conductors of a given electrical turn as the end of the winding is approached, while it permits me to pass similar currents instantaneously in the same direction through all of the conductors of an electrical turn, as for example by connecting the conductors in parallel.

As previously noted, at A30, B30, Figure 4, conductors A and B are wound side-by-side. Until axial crowding is required, side-by-side winding is continued, treating conductors A and B much the way a single conductor having the combined axial dimension of all of the conductors of the electrical turn (the axial width of conductor A plus the axial width of conductor B plus the axial space between conductors A and B when they are side-by-side) would be treated, and insulating the conductors of the same electrical turn from one another or not as desired. Even when conductors A and B are connected in parallel I prefer that they be insulated from one another, as slight potential differences, due to slight differences in inductance at corresponding points, may exist between them.

In contradistinction to A30, B30, where the conductors are axially expanded, these same conductors are axially crowded at A26, B26.

Between the respective positions A30, B30, Figure 4; A31, B31, Figure 5; A32, B32, Figure 6; A33, B33, Figure 7; A34, B34, Figure 4; A35, B35, Figure 5; A36, B36, Figure 6; A37, B37, Figure 7; etc., conductors A and B follow the normal course of the winding, travelling toward the axial center of the coil along the ordinary pitch angle selected for the winding.

The formation of the bottom of the coil is preferably accomplished according to the same principles used in constructing the top.

The lower portion 18 of the coil is constructed from interwound or interfitted conductors C and D. These are wound one beside another at C37, D37, Figure 7, and the side-by-side form of winding proceeds normally through positions C36, D36, Figure 6; C35, D35, Figure 5; C34, D34, Figure 4; C33, D33, Figure 7; etc., to and including C30, D30, Figure 4. In position C30, conductor C has reached the end of the coil. Therefore, between position C30, Figure 4 and position C29, Figure 7, conductor C moves radially outward to allow conductor D to travel toward the end of

the coil as indicated at D29, Figure 7, where conductor C partially overlaps conductor D.

From C29, D29, Figure 7, to C26, D26, Figure 4, the extent of radial overlap of conductor C upon conductor D progressively increases until, at C26, D26, conductor C fully covers conductor D.

Between positions C26, D26, Figure 4, and C25, D25, Figure 7, the diameters of winding of conductors C and D are increased and conductor C at C33, Figure 7, moves toward the end of the coil until it is partially radially overlapped by conductors C and D at C25, D25.

The extent of overlap of the next turn of conductor C increases in positions C24, D24, Figure 6, and C23, D23, Figure 5, until, in position C22, D22, Figure 4, conductors C and D fully radially overlap the next turn of conductor C at C30.

Thus between positions C37, D37, Figure 7, and C22, D22, Figure 4, conductors C and D change from a full side-by-side form of winding to a full overlapping type, in which both conductors overlap the next turn of conductor C. This change takes place in two steps, first by the departure of conductor C from the diameter giving best coupling, taking place between positions C30, Figure 4, and C29, Figure 7, where the overlapping form of winding begins, and second by the departure of conductor D from the minimum internal diameter of the coil, occurring between positions D26, Figure 4, and D25, Figure 7.

It will of course be understood that the question of whether conductor A radially overlaps conductor B or whether conductor B overlaps conductor A, and the question of whether conductor C radially overlaps conductor D, or whether the reverse is the case, are largely immaterial. It will thus be clear that widely variant coil ends may be constructed by the use of the broad principles of my invention, by changing a side-by-side form of winding into an overlapping form, or vice versa.

Up to this point the elimination of discontinuities at either end of a coil has been considered. The filling of a gap at an intermediate point on the coil involves the same general problem. The most usual cause for the formation of a gap at an intermediate point on an inductor coil is change in the direction of winding. Such a gap is difficult to fill by ordinary methods because its sides are not parallel but are diverging or converging.

My invention is particularly desirable for eliminating a gap of this sort. In the example, starting at a position at which the conductors A and B are wound one beside another, such as A37, B37, Figure 7, the conductors are continuously wound side-by-side at A38, B38, Figure 4; A39, B39, Figure 5; A40, B40, Figure 6; A41, B41, Figure 7. At position A42, Figure 4, conductor A is wound with a larger diameter to allow conductor B to bend under conductor A. This begins the process of axial crowding of the component parts of the electrical "turn", by departing from the diameter giving best coupling and changing the pitch of one or both of the conductors. The extent of radial overlap of conductor A upon conductor B increases at A43, B43, Figure 5, and at A44, B44, Figure 6, until, at A45, B45, Figure 7, conductor A fully overlaps conductor B.

Between the positions A37, B37, Figure 7, and A45, B45, Figure 7, conductors A and B move axially closer together, and the axial dimension of an electrical turn is shortened, so that con-

ductor B at B45 is in juxtaposition with the next turn of conductor B at B37.

Between the position A45, B45, Figure 7, and the position at the left of Figure 4, conductors A and B are led away from the coil. Conductors A and B depart from the minimum internal diameter of the coil at two different circumferential points, conductor A doing so between A41, Figure 7, and A42, Figure 4, and conductor B doing so between B45, Figure 7, and the position at the left of Figure 4.

When conductors C and D first enter the coil near C45, D45, Figure 7, conductor C fully overlaps conductor D. The extent of overlap progressively decreases at C44, D44, Figure 6; C43, D43, Figure 5; and C42, D42, Figure 4; until, at C41, D41, Figure 7, conductors C and D are wound one beside another. This side-by-side form of winding continues in positions C40, D40, Figure 6; C39, D39, Figure 5; etc.

Regarding the center of the coil as a whole, it is evident, as best seen in Figure 8, that the extent of the gap 46 produced by change in the direction of winding has been greatly decreased. Its circumferential area is roughly equal to the product of the axial dimension of one conductor and three-eighths of the circumference, while in the prior art the gap area has been equal to the product of the axial dimension of one electrical turn (two conductors side-by-side) and the circumference. In other words, in this particular instance the central gap area is about three-sixteenths that of the prior art, and it can be reduced still further by making up an electrical turn of a greater number of conductors than two. As seen in Figure 7, conductors B37 and D37 are spaced by the axial dimensions of only two conductors, rather than the axial dimensions of four conductors, as would be the case if both electrical turns, at A45, B45 and C45 and D45, were wound with the maximum axial widths.

By thus describing the structure of my winding in detail, I do not wish to give the impression that the particular arrangement here shown need be employed in order to obtain advantage from my invention, since it will of course be apparent that the number of interwound conductors used to make up a given portion of the coil, whether two or more than two, the places at which the conductors are wound side-by-side, the places at which the conductors are overlapped, the number of conductors overlapped at any particular point, the extent of overlap, the steepness or gradualness of the overlapping, and other similar features, depend entirely upon the extent of the discontinuity or gap to be filled and upon the physical size and electrical requirements of the particular installation.

It will be evident that I employ one or more of several co-operating steps in the method just outlined for making the coil of Figures 1 to 8. In the first place, I construct the winding of a plurality of interwound or interlapped helical conductors. Therefore an electrical turn consists of at least two conductors, and it can be widened by winding the conductors axially one beside another, narrowed (axially crowded) by radially overlapping the conductors, given any intermediate width by partially radially overlapping them, or given any particular shape by progressively varying the extent of overlap, that is, by radially covering or uncovering another conductor.

Furthermore, not only may I depart with a single conductor from the diameter giving best

coupling, which in the case of a coil surrounding a charge is the minimum internal diameter of the coil, but I may increase the diameter of winding of all of the conductors of an electrical turn, so that they lie radially outside of another conductor.

In both of these instances, I freely increase or decrease the pitch of winding of an individual conductor or of an individual electrical turn to overlap or underlap another conductor or electrical turn, or to lie perpendicular to the coil axis at the end of the coil.

In effect, I radially interwind conductors to improve the symmetry of the coil by eliminating gaps or discontinuities at its ends or at intermediate points. Thus I can produce a coil whose axial length is the same at all circumferential points, as seen in Figure 8.

When, as in the normal use of my invention, all of the interwound conductors of a given coil portion are connected electrically in parallel, there are as many electrical turns in a coil portion as there are turns in one of its single conductors, the adjacent turns of different conductors which are at corresponding longitudinal distances from the ends of the respective conductors comprising a single electrical turn.

Another important feature of my invention is the ease with which I cool the material which fills the gaps of the inductor coil. In the form of Figures 1 to 8 I preferably make the conductors of hollow tubing having high heat conductivity, such as copper, through which a suitable refrigerating medium, such as water, is circulated. Since the gaps are filled by the conductors themselves, the cooling of the gap-filling material is just as efficient as the cooling of other parts of the coil.

I illustrate hollow, flattened flat-wound tubing in Figures 1 to 8. It will of course be evident that the conductors used may be of any suitable cross section, of which a wide variety are shown in my patents. Likewise, while I show the inductor coil conductors flat-wound, it will be understood that they may be wound in any suitable manner, either entirely flat-wound, entirely edge-wound, entirely round-wound; or flat-wound, edge-wound or round-wound at particular points and wound in some other manner along other parts of the inductor coil. Since flat-winding, edge-winding, and round-winding are well known in the art, and are not particularly material to the present invention, I have merely illustrated flat-winding, which is the most satisfactory for obtaining wide axial spread of an electrical turn of the coil.

It will be evident that the inductor of Figures 1 to 8 is well suited to hold in place refractory or heat insulation packed against the coil, since all gaps have been reduced or eliminated. This is especially important where, as in many melting furnaces, the inductor coil is supported at a few points only around its outer circumference, and where the inductor itself is the effective retaining support of the furnace lining and heat insulation. At the present time there is a tendency to use sintered linings instead of crucibles, and my invention assists this by readily holding the lining material before it is sintered.

Of course my invention is highly desirable also in heating without melting, whether or not refractories or heat insulation be used.

In Figures 9 and 10 I illustrate an alternative form of my invention which, while not preferable to the form of Figures 1 to 8 for large fur-

naces, is nevertheless highly desirable, and which has certain advantages over the form of Figures 1 to 8, particularly in smaller furnaces where the inductor coils have reasonably large numbers of turns.

The coil 47 of Figures 9 and 10 comprises oppositely wound upper and lower portions 48 and 49, the upper of which consists of a single conductor E, wound clockwise, and the lower of which consists of a single conductor F, wound counterclockwise. The coil is broken at points 50 to indicate that the top, the bottom and the middle portions may be considered as separate embodiments of my invention, and also to indicate that any desired number of turns may be considered to have been omitted between the ends of the breaks, and that, if this be true, the portions of the coil are axially compressed in the views until the edges at the break are physically close together. I have likewise conventionally indicated at 51 that the proportions of the coil are not necessarily the ones which would be used.

The upper portion 48 of the inductor coil is wound in a normal helical manner from the top at 52 to the middle at 53, at which point conductor E is led away from the inductor coil. Due to the pitch of the helical winding, the uppermost turn 54 slopes, and, unless special precautions to be taken, leaves an uneven coil end.

To prevent this unevenness, I insert a tapered helical electrical conductor 55 to fill the gap at the top of the inductor. The conductor 55 is secured to the endmost turn 54 of the winding, preferably by brazing or welding. The conductor 55 is longitudinally (i. e., along their adjacent edges) in contact with the endmost turn 54, and therefore is electrically in parallel with it, so that current passing through the endmost turn 54 can spread out laterally and flow through the conductor 55.

By reason of its tapering shape, the electrically conducting strip 55 closely resembles a fin attached to the coil.

The lower inductor coil portion 49 is preferably oppositely wound with respect to the upper portion 48, and consists of a single conductor F wound helically from the middle point 53 to the lower end 56 of the coil.

The tapering gap at the bottom of the coil is preferably filled in the same manner as that at the top, by securing a tapering electrically conducting strip 57 to the lowermost turn 58 of the coil, with contact along the adjoining edges of the strip and coil.

At the middle of the coil, the gap due to change in the direction of winding is best filled by two fins, one extending from each of the inductor coil portions 48 and 49. I fasten to the lowermost turn 59 of the upper inductor coil portion a circumferential metal strip 60 which, like the other strips used, follows the contour of the winding. The strip 60 preferably fills less than half of the gap, so that it does not touch the strip 61, longitudinally secured to the uppermost turn 62 of the lower inductor coil portion 48. The conductors 60 and 61 are tapered, in contact along their edges with the coil edges and likewise electrically in parallel with their adjacent inductor coil turns, respectively 59 and 62.

The fins 55, 57, 60 and 61 are all preferably made of material having high heat conductivity, such as copper, in order that heat may be conducted from them rapidly through the walls of the adjacent inductor coil turns and into the cooling

medium passing through the interior of the inductor coil. The fins are subjected to heating from the charge, by RI^2 heating from conduction of current through the fins themselves and by inductive heating in the fins. Where the cooling capacity is adequate, there are certain advantages in having current spread out laterally and flow in part through the fin, as it will then assist the adjacent conductor in inducing current in the charge. This will take place in the case of fin 58, which is electrically in parallel with inductor coil turn 54.

Where, however, the cooling capacity is not more than ample, I may reduce heating in the fins due to conduction and induction by laterally slitting the fins, as at 63. While this will not wholly prevent the conduction of current through the fins, it will confine the bulk of the current to the inner edges of the fins, which can be most easily cooled, and will prevent the building up of excessive induced currents in the fins. On the other hand, the slits 63 will reduce but not greatly interfere with conduction of heat through the fins, since practically all conduction is axial to the cooling medium of the adjacent inductor coil turn.

The filler strips are very effective in retaining refractory and/or heat insulation in place. In Figure 9 I illustrate skeletonized refractory material 64 placed within the inductor coil and supported by the fins at gaps in the coil.

Thus it is seen that my fins operate efficiently to fill gaps in the inductor coil, so that refractory material may be supported by the coil, and also, where desired, serve to permit spreading out of current at the gaps, acting as parallel-connected conductors in much the same way as the conductors shown in Figures 1 to 8.

The fins may be cooled almost as efficiently as the conductors of Figures 1 to 8, since there is a high thermally conducting path from the fins to the cooling medium at the interior of the inductor coil.

The conductors of Figures 1 to 8, and the conductors of Figures 9 and 10 may be regarded as alternative means for filling inductor coil gaps, each having peculiar advantages of its own. In Figures 1 to 8 an electrical turn comprises more than one conductor, so that, where a furnace must have a large number of turns, this form is not as advantageous as the form of Figures 9 and 10, in which a given portion of the inductor coil is made up of a single conductor. On the other hand, as previously noted, the gap-filling conductors of Figures 1 to 8 are more readily cooled than those of Figures 9 and 10.

Aside from the construction of the inductor coil proper, there are many features of my invention which are highly advantageous. In Figures 1 to 3 I illustrate an inductor coil, mounted upon a base 65, to which are secured suitable taps from the coil. The taps comprise the ends of the conductors A, B, C, and D, which make up the winding, and are desirably hollow water-cooled tubes. There is, however, no theoretical reason why the taps may not be separate conductors electrically connected to the conductors of the coil.

In the past the arrangement of the taps has been rather haphazard. While this has caused little difficulty in small furnaces, I find that it is not desirable in large installations on account of the inductance of the taps. For example, in an inductor having four turns only in the upper portion and four turns in the lower portion, the inductance of the taps may be as large as

that of one or more turns, unless some precautions are taken to reduce the inductance of the taps.

I reduce or eliminate the inductance of the taps by placing two taps, instantaneously carrying similar currents in opposite directions, adjacent to and parallel with one another.

To accomplish this, I could, of course, place taps from different conductors which carry currents instantaneously in opposite directions one beside another. This is subject to the disadvantage, however, that some difference in magnitude may exist between the currents in different conductors. I therefore prefer to associate in parallelism the opposite ends of the same conductor. Hence the conductors must of necessity instantaneously carry current in opposite directions.

I therefore lead tap 66 of conductor A generally parallel with tap 67 of conductor A. Taps 68 and 69 of conductor B are generally parallel to one another and side by side, and the same is true of taps 70 and 71 of conductor C and of taps 72 and 73 of conductor D.

Likewise, in arranging the taps I place tap 67 of conductor A, which is instantaneously carrying current in one direction, next to tap 68 of conductor B, which is instantaneously carrying current in the opposite direction. In the same way, tap 69 of conductor B is next to tap 70 of conductor C, which instantaneously carries an opposite current to that of tap 69, and tap 71 of conductor C is next to tap 72 of conductor D, which instantaneously carries an opposite current to that of tap 71. The directions of the currents at any instant alternate in the respective taps, as shown by the plus and minus signs in Figure 1. Of course all polarities will change with each reversal of the alternating current.

It will be evident that the mutually inductive effects of taps 66 and 67 of conductor A upon one another will balance, since the taps are, at any instant, carrying equal currents in opposite directions along adjacent generally parallel paths. Likewise, the mutually inductive effects of taps 67 of conductor A and 68 of conductor B upon one another will partially or entirely balance, since the taps are generally parallel and since the currents in conductors A and B are of the same order of magnitude and are instantaneously flowing in opposite directions.

For the same reasons as above, taps 68 and 69 of conductor B are noninductive, and tap 69 of conductor B is noninductive with respect to tap 70 of conductor C.

The same canceling of inductances takes place throughout all of taps, so that the taps add little or no inductance to their circuits nor to the entire circuit of which they form parts.

By the alternate placing of tapping conductors, instantaneously carrying opposite currents, in parallelism adjacent one another, and particularly by the alternate placing of opposite ends of the same conductor in parallelism close together, I find that I entirely avoid difficulty with the inductance of the taps.

The cooling medium is preferably introduced and withdrawn from the conductors of the inductor coil through fittings 74 at the ends of the respective taps.

For connecting the conductors A, B, C and D electrically in parallel I provide bridging bars 75 and 76. Bar 75 is connected to taps 67, 69, 71 and 73, while bar 76 makes contact with taps 66, 68, 70 and 72.

My invention is applicable in a wide variety of electric induction furnace installations. In Figures 11 and 12 I show by way of illustration two circuits to which my invention is particularly well suited.

In melting furnaces, especially where metallurgical operations are to be performed, such as oxidation of impurities, degassing, alloying, slagging, and other similar processes, control of the stirring is highly desirable. To accomplish this I have previously suggested that the current in the inductor coil above a particular point in the charge be varied with respect to the current below that point.

Thus, if the current passing through the inductor coil portion surrounding the upper part of a molten charge be substantially the same as that passing through the inductor coil portion surrounding the lower part of the charge, the stirring will be general throughout the charge and will increase throughout with increase of current and decrease throughout with decrease of current. If the current surrounding the upper part of the charge be greater than that surrounding the lower part of the charge, the stirring will be concentrated in the upper portion of the charge, producing high crowning at the top of the charge, and maintaining a relatively quiescent condition near the bottom of the charge. However, if the current passing around the lower part of the charge be greater than that passing about the upper part of the charge, stirring will be concentrated near the bottom of the charge, while the meniscus will be relatively flat.

I have discovered that, particularly in large furnaces, the stirring may be controlled more effectively if the inductor coil surrounding an individual part of the charge be formed from a plurality of conductors connected electrically in parallel. In this way an electrical turn can be made quite wide without the use of an excessive width of conductor, and the currents carried by the individual inductor coil portions, or by an individual conductor within the group of conductors making up an inductor coil portion, can be varied with respect to one another to regulate the stirring in the furnace.

In Figure 11 I illustrate a conventional furnace structure 77 surrounded by an inductor coil 78, comprising upper and lower portions 79 and 80 oppositely wound with respect to one another. The upper portion 79 consists of a group of interwound helical conductors 81 and 82 and the lower portion 80 consists of a group of interwound helical conductors 83 and 84.

The conductors 81 and 82 of one group are connected electrically in parallel, joined at 85 and 86, and are supplied with current from an alternating source G through connections 87 and 88. The conductors 83 and 84 are connected electrically in parallel, joined at 86 and 89, and are supplied with current from the source G through connections 87 and 88.

The upper inductor coil portion 79 is placed in parallel with the lower inductor coil portion 80 by means of the connections 90 and 91, connection 88, and their common juncture 86. The portions 79 and 80 are oppositely wound (or wound in the same direction and oppositely connected) so that the fluxes from both coil portions produced in the charge will instantaneously have the same direction.

In the connections 90 and 91 to the respective inductor coil portions 79 and 80 I locate switches 92 and 93, which, when closed, shunt reactances

94 and 95. The reactances 94 and 95 are preferably inductance coils, although resistance can be used, though much less desirably.

In order to resonate the circuit I place capacity 96 in shunt with the inductor coil as an entirety.

In operation, when both switches 92 and 93 are closed, current will normally be supplied equally or in any predetermined ratio to the upper and lower inductor coil portions 79 and 80. Stirring will be general but not localized at this time. If, however, the upper switch 92 be opened, to the position shown in full lines in Figure 11, retaining the lower switch 93 closed as there shown, the increase in the reactance of the circuit branch including the upper inductor coil portion 79 will cause a reduction in the current through the portion 79 with respect to that through the lower portion 80, concentrating the stirring in the lower part of the charge and maintaining a relatively flat meniscus on the top of the charge.

If, on the other hand, the switch 92 be now closed, and the switch 93 be opened, the condition will be reversed, since a relatively high current will flow about the upper part of the charge and a relatively low current will surround the lower part of the charge, with resulting concentrated stirring in the upper part of the furnace and high crowning at the surface; and little stirring at the bottom of the charge.

In Figure 11 I vary the currents through a plurality of conductors surrounding a given portion of the charge by inserting reactance (inductance) in a portion of the circuit common to the conductors, and I resonate the paths through all of the conductors and through all of the groups of conductors by means of capacity common to all.

In Figure 12, on the other hand, I illustrate a circuit generally similar to Figure 11, but in which I show reactance individual to each conductor for varying the current through that conductor, and also an oscillation circuit individual to each conductor containing capacity for tuning the individual conductor.

For convenience in illustration, the inductor coil 97, having upper and lower portions 98 and 99, is shown with the respective conductors 100, 101 and 102, 103 placed side-by-side rather than interwound as would actually be the case. Each of the conductors 100, 101, 102 and 103 has in its local oscillation circuit one of the reactances 104, 105, 106 or 107, shunted by one of the switches 108, 109, 110 or 111. Likewise each of the individual oscillation circuits contains a capacity 112, 113, 114 or 115.

Thus it is evident that the oscillation circuit of the individual inductor coil conductor 100 includes the capacity 112 and the switch 108 (shunting the inductance 104), when that switch is closed, and includes the capacity 112 and the inductance 104, when the switch 108 is open.

The oscillation circuits of the other conductors are similarly constituted.

Current is supplied to the inductor coil from the alternating source G through leads 116 and 117 each of which divides into branches 118, 119 or 120, 121, to place the upper and lower inductor coil portions respectively in parallel, and each of which includes two connections 122, 123 or 124, 125, for placing the individual conductors of the inductor coil portions in parallel.

From the standpoint of stirring control the form of Figure 12 has certain advantages. By opening the switch 108, closing all of the other switches, it is possible to reduce slightly the stirring in the upper part of the charge, with respect

to that when all of the switches are closed. By opening both of the switches 108 and 109, it is possible to place inductance in both of the oscillation circuits of the conductors 100 and 101 in the upper inductor coil portion 98, thus still further reducing the stirring in the upper part of the charge.

Likewise, the degree of stirring at the bottom of the charge may be decreased in two steps, first by opening one of the switches 110 or 111, while maintaining all other switches closed, and second by opening the other also of the switches 111 or 110 (that is, having both switches open) while keeping all other switches closed.

This gradual variation in the stirring in either the top or the bottom of the charge is not possible with the form of Figure 11, where the stirring in the upper or in the lower part of the charge must be either maximum or minimum, and no intermediate gradation is possible.

A further advantageous feature of the form of Figure 12 is that the capacities 112, 113, 114 and 115 may be individually suited to the winding of the inductor coil conductor which they are to tune.

Thus, if there be some variation in the inductances of the respective inductor coil conductors, this may be taken into account and compensated for by variation in the individual capacities used in tuning.

It will be evident that the capacities 112 and 113 are individual to the upper inductor coil portion 98, while the capacity 112 is individual to the conductor 100 of that portion. Therefore, in Figure 12 I have oscillation circuits individual to the coil portions and also individual to given conductors. Of course I could, if desired, have all my capacity in one branch, using a single resonated path for both conductors of a given inductor coil portion.

For reducing the current in an individual conductor or inductor coil portion, I may if desired, use resistance, rather than inductance, although to somewhat less advantage.

It will be evident that the form of coil having a plurality of conductors in one group surrounding one portion of the charge and a plurality of conductors in another group surrounding another portion of the charge is highly desirable, as it lends itself to control of the currents in individual conductors for the purpose of regulating stirring and to resonance of the individual conductors, or to both, as desired.

I believe that I am the first to form part of a furnace inductor coil of a plurality of conductors and to wind them in such a way as to fill gaps in the coil.

I likewise believe that I am the first to employ electrically conducting material, electrically in parallel with other parts of an inductor coil, to fill gaps in a coil.

I further believe that it is novel to reduce or balance the inductance of induction electric furnace taps.

I further believe that I am the first to control the stirring in an electric induction furnace by means of an inductor coil having a plurality of portions, in which each portion consists of a plurality of conductors electrically in parallel.

In view of my invention and disclosure variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain all or part of the benefits of my invention without copying the structure shown, and I, therefore, claim all

such in so far as they fall within the reasonable spirit and scope of my invention.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:—

1. In an induction electric furnace, an inductor coil having a gap and an electrical conductor following the curve of the coil and filling the gap.

2. In an induction electric furnace, an inductor coil having a gap and an electrical conductor electrically in parallel with an adjacent turn of the coil, following the curve of the coil and filling the gap.

3. In an electric furnace inductor coil, a plurality of adjacent helical conductors wound with varying pitches, and for this reason presenting a gap in the circumferential surface, radially interwoven to fill the gap.

4. In a coreless induction electric furnace, an inductor coil comprising a plurality of mechanically interfitted helical conductors, axially side by side at one part of the coil and radially overlapped at another part of the coil, a source of alternating current and connections from the source to the conductors placing them electrically in parallel.

5. A coreless electric furnace inductor coil, comprising a plurality of conductors of helical form wound axially side by side in part of the coil, in which one conductor is radially overlapped upon another at a circumferential point on the coil to axially crowd the turns.

6. A coreless electric furnace inductor coil, comprising a plurality of conductors electrically in parallel wound into generally helical form and having a portion of one of the conductors wound with the same diameter but with a different pitch from an adjacent conductor.

7. A coreless electric furnace inductor coil, comprising a plurality of conductors of helical form wound one beside another in part of the coil and having a portion of one of the conductors wound with an inside diameter greater than the outside diameter of the next turn to permit bringing adjacent turns of the same conductor axially closer together.

8. A coreless electric furnace inductor coil, comprising a plurality of conductors of interfitted helical form wound axially one beside another in part of the coil, in which one conductor is wound with a larger diameter and radially overlaps another at a circumferential position on the coil and the number of conductors wound with the smaller diameter varies at different circumferential positions around the coil.

9. A furnace inductor coil, comprising a plurality of conductors wound into a generally cylindrical form, having a portion of one of the conductors wound with a diameter other than giving best coupling, said portion at least partially radial covering another conductor at one point on the circumference of the coil, said portion progressively varying in extent of radially covering between that point and another point on the circumference of the coil.

10. A furnace inductor coil, having portions oppositely wound with respect to one another, one portion of which is constructed of a plurality of interfitted helical conductors.

11. A furnace inductor coil, having one portion made up of a plurality of interwound clockwise helices and another portion made up of a plurality of interwound counterclockwise helices.

12. In an electric induction furnace, an inductor coil having one portion formed of a plu-

- ality of interwound clockwise helices and another portion formed of a plurality of interwound counterclockwise helices, a source of alternating current, connections from the source to one coil portion for passing current instantaneously in one direction through its helices in parallel and connections from the source to the other coil portion for passing current instantaneously in the opposite direction through its helices in parallel.
13. In an electric induction furnace, a source of alternating current supply, an inductor coil having portions, each of which comprises a plurality of interwound conductors, the portions being oppositely wound with respect to one another, connections from one side of the source to the ends of the conductors which are nearest together and connections from the other side of the source to the conductors at the outer extremities of the inductor coil portions.
14. In an electric induction furnace, a source of alternating current supply, an inductor coil having adjoining portions, each of which comprises a plurality of interwound conductors, the portions being oppositely wound with respect to one another, connections from one side of the source to the conductors at the point of change in direction of winding, oscillation circuits complete for each inductor coil, inductance in each oscillation circuit, means for varying the inductances and connections from the conductors at each extremity of the inductor coil to the other side of the current source.
15. A furnace inductor coil having adjoining portions oppositely wound with respect to one another, each portion comprising a plurality of interfitted helical conductors, and one conductor of each portion being displaced radially at the point at which the direction of winding is changed to reduce the gap thereabout.
16. A furnace inductor coil having adjoining axially spaced portions oppositely wound with respect to one another, each portion comprising a plurality of interfitted helical conductors in parallel, and one conductor of each portion being overlapped upon another conductor of the same portion and same electrical turn adjacent the point of change in the direction of winding to reduce the gap produced by change in the direction of winding.
17. In an electric induction furnace, an inductor coil having portions oppositely wound with respect to one another, each portion comprising a plurality of interfitted helical conductors, and the conductors of each individual portion being wound with different diameters where the direction of winding is changed, to axially crowd the turns, a source of alternating current, connections from the source to one portion for passing current instantaneously in one direction through its conductors in parallel and connections from the source to the other portion for passing current instantaneously in the opposite direction through its conductors in parallel.
18. In an induction electric furnace, an inductor coil having an uneven end and electrically conducting material filling out the end of the coil to make it flat.
19. A furnace inductor coil having a plurality of interwound helical conductors one of which is overlapped upon another at one end of the coil, whereby the end is perpendicular to the coil axis notwithstanding that the coil is helical.
20. A furnace inductor coil having a plurality of interwound helical conductors, in which individual conductors depart from the minimum interior diameter of the helix at a plurality of points at the end of the coil and the end is perpendicular to the coil axis.
21. A furnace inductor coil having portions oppositely wound with respect to one another, each portion comprising a plurality of interfitted helical conductors one of which is overlapped upon another at each end of the coil to reduce the slope of the winding at the ends.
22. A coreless electric furnace inductor coil having adjoining portions oppositely wound with respect to one another, each portion comprising a plurality of interfitted helical conductors, one conductor of each portion being overlapped upon another at an end of the portion to reduce the slope of the winding at the ends and one conductor of each portion being overlapped upon another adjacent the point of change in direction of winding to make the coil more continuous where the direction of winding is changed.
23. In an induction electric furnace, an inductor coil having a gap and a metal strip filling the gap and secured to a longitudinal edge of a conductor of the coil at one side of the gap.
24. In an induction electric furnace, a helical inductor coil having a tapering gap, a tapering metal strip fitting the gap and longitudinally secured to a conductor of the coil on one side of the gap, and refractory surrounding the coil and partially retained in place by the strip.
25. In an induction electric furnace, an inductor coil having an uneven end and a tapered metal strip secured to the end of the coil and making the end even.
26. In an induction electric furnace, a helical inductor coil having a gap at a point of change of spacing of conductors intermediate between its extremities, and a tapering metal strip longitudinally secured to a conductor of the coil adjacent the gap.
27. In an induction electric furnace, an inductor coil having a gap and an electrical conductor fitting the gap, and having transverse slots in the conductor to reduce heating therein.
28. The method of filling a non-continuous gap in an inductor coil of an electric induction furnace wound from a conductor which consists in inserting electrically conducting material into the gap and in connecting it in parallel with a conductor in the coil.
29. The method of filling a gap in an inductor coil of an electric induction furnace which consists in widening the axial dimension of an electrical turn of the coil adjacent the gap with respect to that of another electrical turn on the coil.
30. The method of forming an inductor coil of a coreless induction electric furnace which consists in winding part of the coil from a plurality of conductors arranged axially one beside another, in radially overlapping the conductors, and in circumferentially carrying the conductors in overlapped condition.
31. The method of forming an inductor coil of a coreless induction electric furnace which consists in winding part of the coil from a plurality of conductors electrically in parallel arranged axially one beside another, in radially overlapping the conductors, and in circumferentially carrying the conductors in overlapped condition.
32. The method of forming an inductor coil which consists in winding part of the coil from a plurality of conductors arranged axially one beside another, in radially overlapping one conductor upon another and in progressively in-

creasing the axial extent of overlap with circumferential travel of the overlapping conductor around the coil.

5 33. The method of forming an inductor coil which consists in winding an electrical turn of the coil from a plurality of conductors electrically in parallel having different diameters at one circumferential point on the coil and the same diameter at another such point.

10 34. The method of forming an inductor coil of

a coreless induction electric furnace which consists in winding an electrical turn of the coil from a plurality of conductors electrically in parallel and radially overlapping, and in decreasing the diameters of the conductors until the innermost conductor has the same interior diameter as that of all of the conductors of the next electrical turn in the coil. 5

EDWIN FITCH NORTHRUP. 10