Dec. 1, 1931. E. F. NORTHRUP 1,834,725

EXTERNAL FIELD ELIMINATOR

Filed Feb. 18, 1928 3 Sheets-Sheet 1

Fig. 1.

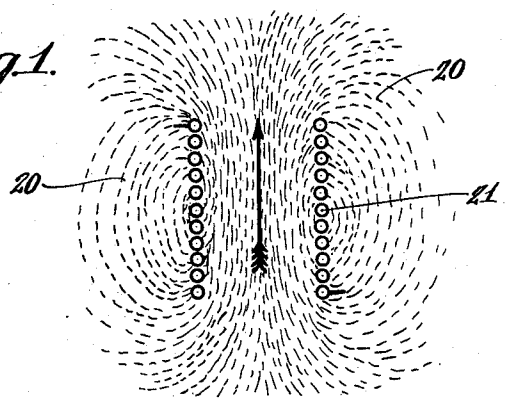


Fig. 2.

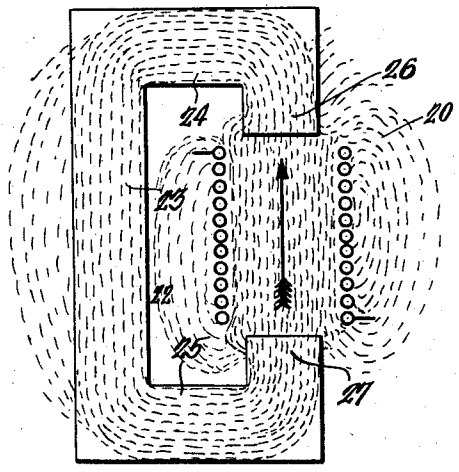


Fig. 3.

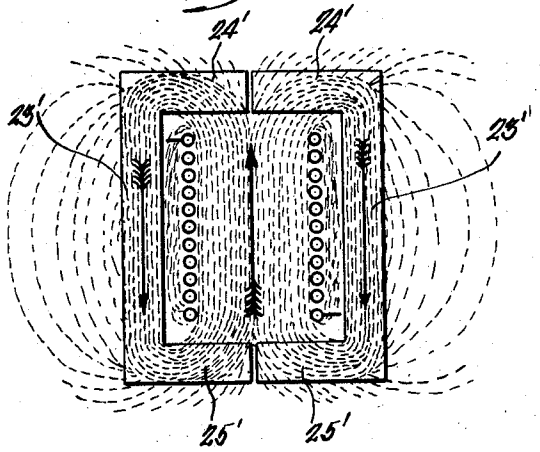
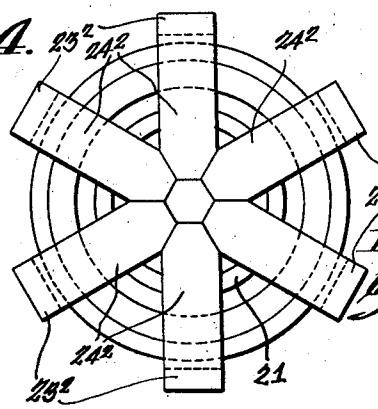


Fig. 4.



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Dec. 1, 1931. E. F. NORTHRUP 1,834,725

EXTERNAL FIELD ELIMINATOR

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Fig. 5.

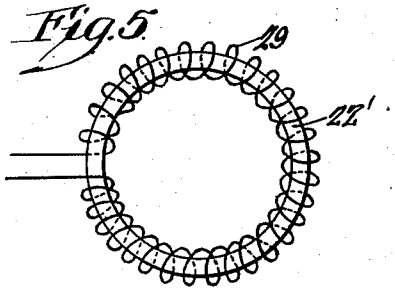


Fig. 6.

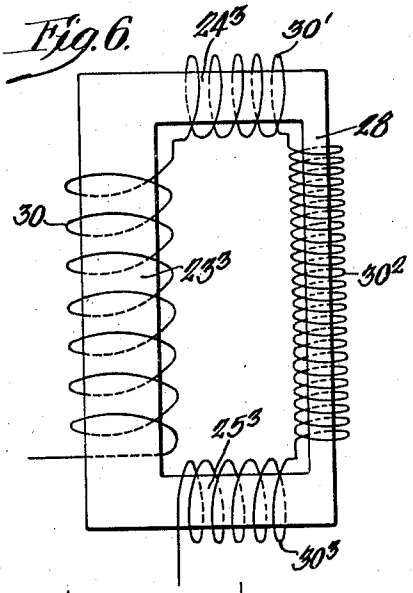


Fig. 7.

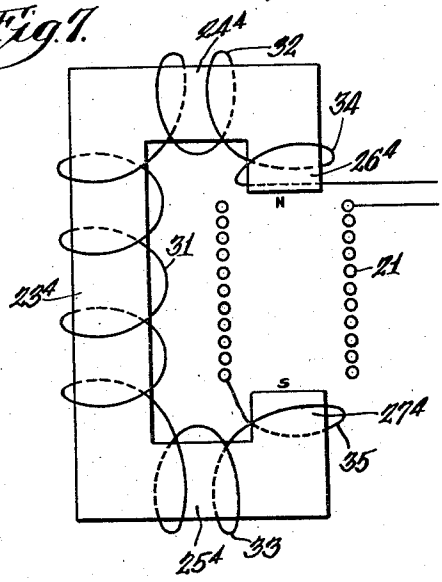


Fig. 9.

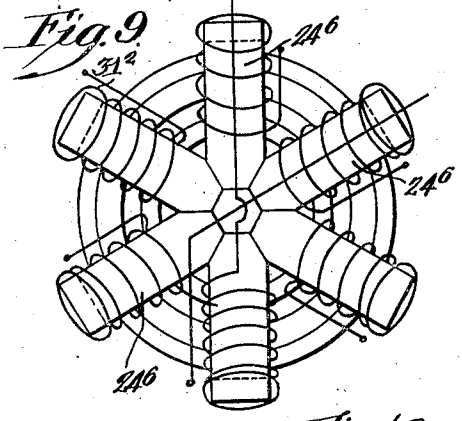


Fig. 8.

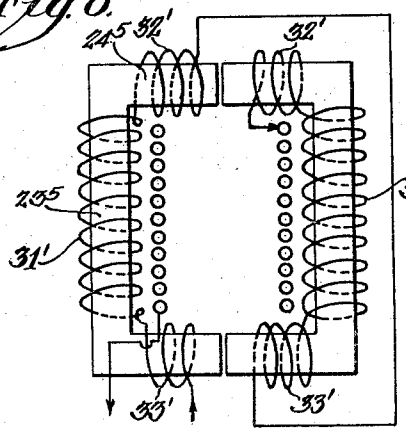
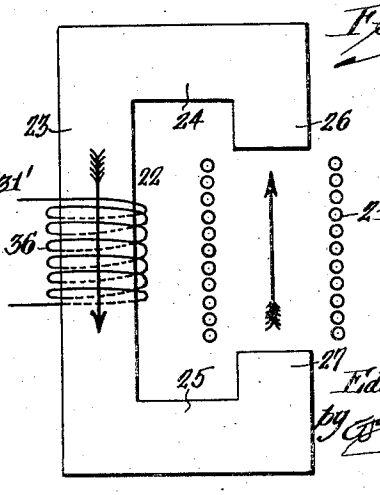


Fig. 10.



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Dec. 1, 1931. E. F. NORTHRUP 1,834,725

EXTERNAL FIELD ELIMINATOR

Filed Feb. 18, 1928 3 Sheets-Sheet 3

Fig. 11.

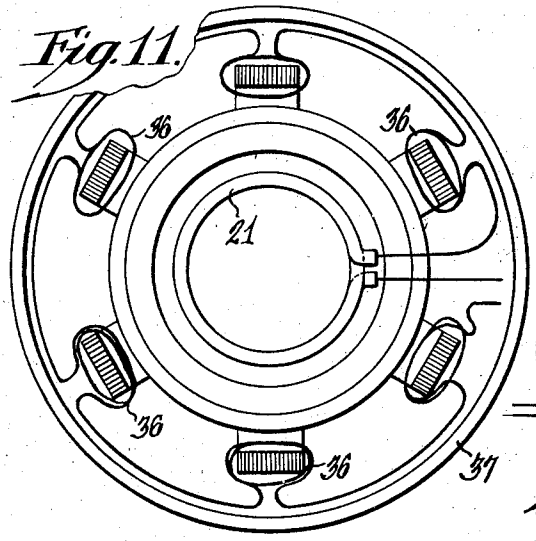


Fig. 15.

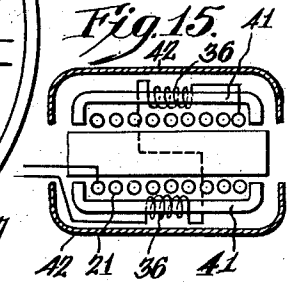


Fig. 13.

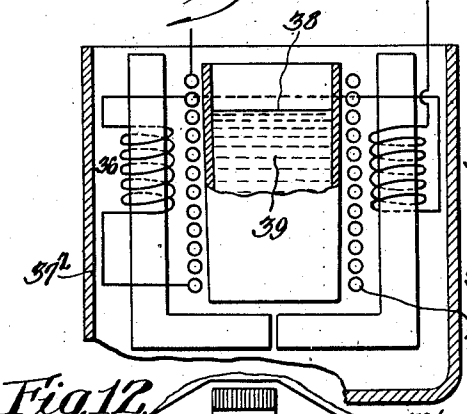


Fig. 14.

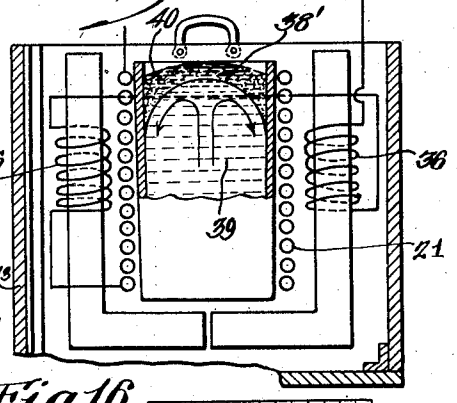


Fig. 12.

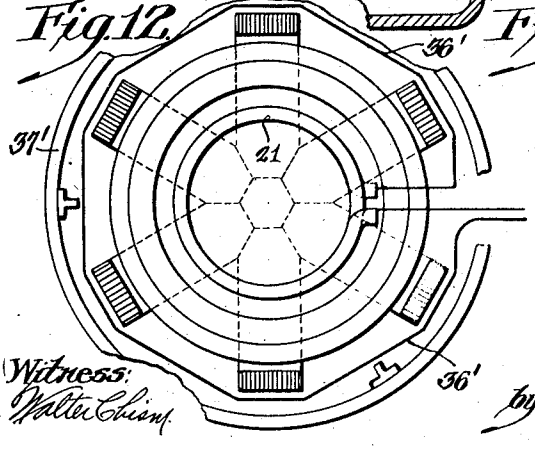
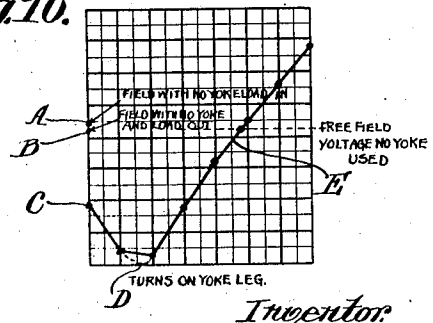


Fig. 16.



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Patented Dec. 1, 1931 1,834,725

UNITED STATES PATENT OFFICE

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EXTERNAL FIELD ELIMINATOR

Application filed February 18, 1928. Serial No. 255,248.

My invention relates to electric furnaces of the so-called coreless type in which a furnace inductor surrounds the charge being melted or heated and in which the magnetic circuit is not completed through the inductor.

One of the purposes of my invention is to substantially eliminate the stray magnetic field about a furnace inductor coil free from interthreading of transformer iron.

A further purpose is to provide a return magnetic circuit for a coreless furnace, permissibly without but preferably with excitation of the return circuit corresponding with the lines of force which are intended to flow through it.

A further purpose is to provide a return magnetic circuit for a coreless furnace with a magnetizing coil or magnetizing coils helping to control the direction of the magnetic return flux of the furnace.

A further purpose is to provide a return magnetic circuit for a furnace inductor having a multiplicity of parts and to so proportion them and the compensating windings upon them as to make the induced lines equal the total stray lines for which return is to be provided and minimize the average length of the return circuit.

A further purpose is to permit the use of iron strengthening and supporting frame structure freely in furnace construction without objectionable effect upon it by stray magnetic field.

A further purpose is to so far improve the magnetic return circuit of the field produced as to greatly improve the power factor and thus reduce the condenser capacity required to correct it.

A further purpose is by the improvement of power factor to increase the energy component of the current through a furnace coil and thus increase the concentration of energy in the charge as compared with the same quantity of current passing through the inductor.

A further purpose is by improvement of power factor and concentration of the returning lines of force at the bottom of the furnace to greatly improve the stirring effect.

A further purpose is to utilize greatly increased stirring effect obtained to produce more effective and quicker intermixing of treating or alloying ingredients and quicker slagging than is otherwise available.

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

My invention relates to the methods involved as well as to certain apparatus by which these methods may be carried into effect.

I have preferred to illustrate my invention diagrammatically by one main form only among many forms in which it may be presented, selecting a form which is simple, practical, efficient, reliable and inexpensive, and which at the same time well illustrates the principles of my invention.

Figure 1 is a purely diagrammatic sectional elevation of the inductor coil of a coreless induction furnace omitting power factor correction and current supply for it, but showing in one plane the general shape of the effective and stray magnetic fields produced in all planes through the axis of the coil.

Figure 2 is a diagrammatic sectional elevation corresponding generally with Figure 1 but showing the effect upon the stray field of a magnetic return circuit.

Figure 3 is a diagrammatic sectional elevation similar to Figure 2, but in which the magnetic return circuit is shown on both sides of the coil.

Figure 4 is a diagrammatic top plan view of a form corresponding generally to Figure 3 but in which the magnetic return circuits have been shown as increased in number and radiating from the coil.

Figure 5 is a diagrammatic side elevation of a circular or anchor ring uniformly wound.

Figure 6 is a diagrammatic side elevation of a rectangular ring approximating the magnetic conditions of Figure 5 except in so far as it has portions of different cross section and of different spacing of the winding.

Figure 7 is a diagrammatic sectional elevation of a rectangular ring but with a furnace inductor coil free from interthreading

of transformer iron interposed instead of part of the wound magnetic circuit. The magnetic circuit corresponds generally with that in Figure 2.

Figure 8 is a diagrammatic sectional elevation of a structure having the yoke wound and having a yoke circuit corresponding with the magnetic return circuit of Figure 5.

Figure 9 is a diagrammatic sectional elevation corresponding generally to Figure 8 except that the return circuit is shown as including a multiplicity of wound legs. The magnetic circuit is comparable in effect with that of Figure 4.

Figure 10 is a diagrammatic sectional elevation corresponding with Figure 7 except that it shows the winding for the magnetic circuit as concentrated upon the side of the return circuit yoke leg shown.

Figure 11 is a diagrammatic top plan view showing the form of Figure 9 except that the tops of the legs have been omitted and the winding has been concentrated upon each leg of the yoke as in Figure 10.

Figure 12 is a diagrammatic top plan view of a figure corresponding generally with Figure 11 but showing a modification of the electric circuit.

Figure 13 is a diagrammatic sectional elevation corresponding generally with Figure 12 but showing a crucible in place with a non-magnetic content in the crucible.

Figure 14 is a diagrammatic sectional side elevation showing the surface of the crucible as covered by a slag and lifted by the stirring operation.

Figure 15 is a diagrammatic longitudinal section of a heating furnace.

Figure 16 is a diagram illustrating my invention.

In the drawings similar numerals indicate like parts.

There is a great advantage in electric furnaces in having the inductor coil directly surround the charge without necessity for interthreading of transformer iron through the coil. Such furnaces, with the furnace inductor coil directly surrounding all or a part of charge, unthreaded by furnace iron are for convenience called coreless furnaces.

Coreless furnaces have been quite successful in smaller sizes but unless they can be strengthened externally by steel or metallic casings of frame work they are more difficult to build in large sizes. Where these furnaces are to be used for heating as distinguished from melting operations (as in the case of ingots, blooms, billets, etc.) their usefulness may be reduced because of the lack of strength and ruggedness of the furnace construction. In the past the use of metal and particularly magnetic material in casings and in structural reinforcement about or in very large coreless induction electric furnaces has not been permissible because of the excessive stray magnetic field which these furnaces have had.

This stray field has been due to the absence of magnetic return circuits for the lines of force induced in the furnaces. This same stray magnetic field has been objectionable also for the reason that it has affected other machinery and apparatus in the neighborhood of furnaces, requiring greater spacing of the coreless furnaces from other apparatus than would otherwise have been required and unduly otherwise restricting the equipment of the furnaces.

The heating of outside metal objects of the stray field has not been objectionable because of the damage done and restrictions imposed alone but calls for an excessive magnetizing current through the coils, lowering the furnace efficiency.

The stray field of the furnace is highly objectionable for another reason, in that it lowers the power factor of the furnace and reduces the power input per ampere turn in the coil of the furnace inductor thus limiting the output of any given furnace.

I have discovered that all of the objections above can be overcome and that the objectionable stray field can be taken care of substantially in its entirety by simple magnetic and, electromagnetic means which not only provides substantially complete paths of return for the magnetic lines but utilizes the paths effectively, to concentrate the return magnetic circuit and to greatly increase the stirring of the furnace. This increase in the stirring opens up greater possibilities of treatment of molten content such, for example, as rapid introduction and thorough inter-mixtures of chemical elements either directly within the content or indirectly by slagging.

In coreless induction furnaces as heretofore constructed the magnetic field 20 of an inductor coil 21 takes substantially the form indicated by broken lines in Figure 1 as in any straight solenoid.

That this is true most of the time notwithstanding that the induction furnace may operate upon iron, steel, nickel or other magnetic materials or alloys will be evident from the fact that during a large part of the time of operation of the furnace even upon those metals the temperature of the charge will be high enough for the charge to have lost its magnetic properties. At temperatures below this point (the recallescence point in steel) the magnetic properties may be ignored for our purpose or compromised or adjusted by the return circuit winding because the general character of the stray field remains notwithstanding that its value has been somewhat changed.

The field outside the inducing coil serves no useful purpose (whether the content be magnetic or non-magnetic) and may intro-

duce serious heating and energy losses in solid conducting material in the surrounding medium especially in magnetic materials; with the result that it is impractical to protect such furnaces by enclosing them in closely fitting metal casings as above.

If the furnace is to approach its full usefulness and be free from size limitations due to the stray field above noted, this field must be substantially eliminated. I have discussed in my further figures methods and means by which this elimination can be accomplished.

I have found by tests that the stray field may be greatly reduced by a return circuit 22 outside of the inductor coil of low magnetic reluctance (resistance) consisting of thin sheets (laminations) of transformer steel or other highly permeable materials having sides 23, top and bottom portions 24, 25 and end portions 26, 27 around the inductor coil, as in Figure 2. The stray field 20′ is also altered in position by this return as shown in the figure.

The uniformity of the return and the path of return are greatly improved by dividing the circuit on opposite sides of the inductor as shown in Figure 3, reducing the cross sections required for sides 23′ and tops and bottoms 24′, 25′. The end pieces 26, 27 have been omitted in this figure as they seem to affect the result but little. The return is further improved by increasing the number (and permissibly reducing the cross section) of these radially disposed return circuits as shown in top plan view in Figure 4, the theoretical permeance preferred of course being reached when the magnetic circuit forms a shell completely surrounding the coil. A very close approximation is reached with the radially divided return circuit shown in Figure 4, having sides 23^2, tops 24^2 and corresponding bottoms not shown.

It is well known that when a ring core of magnetic material and of uniform cross-section is uniformly wound, a current through the coil will produce a large number of magnetic lines within the ring and yet be free from stray or external field. The apparent reason for this is that each portion of the winding independently provides magnetomotive force to supply the requisite flux lines of its own portion of the length of the magnetic circuit. Such an arrangement is shown in the iron ring and winding of Figure 5.

Subject to such qualifications as might be due to variations in permeability, a very close approximation to freedom from external field is secured even when the cross-section of the magnetic circuit is varied as in Figure 6, provided the winding be varied so as to make the ampere turns per unit length of each section of the ring vary according to the reluctance of that portion of the ring. In Figure 6 where the ring has been shown of varying cross-sections at 23^3, 24^3, 25^3 correspondingly different numbers of turns are shown about the different cross-sections.

Because the current through the different windings must be in phase, the winding should be in series and the number of turns will vary inversely with the cross-section.

As compared with the circular form of Figure 5, the rectangular forms of Figures 2, 3, 4, 6 and 7 form very close approximations, the differences being negligible in practice.

In the diagrammatic illustration there has been no intention to make the number of lines of force induced by the coil 29 in Figure 5 equal those induced by the coils 30, 30′, 30^2, 30^3, nor those induced by the coils used in the other figure, but merely to indicate that in any given magnetic circuit, for the best results the winding should be uniform for uniform reluctance and that where the cross-section is not uniform the closest approach to freedom from external magnetic field is secured by winding each portion of any given circuit with turns to give throughout the circuit the same number of lines of force through the cross-section, whatever the section. Where the section of permeable material is uniform, as at 23^4, 24^4, 25^4, 26^4, 27^4, in Figure 7, the closest approach to freedom from external field is to be secured by uniformly spaced windings as in Figure 5.

Let us assume in Figure 6 that in place of the core section and coil 28, 30^2, an inductor coil 21 having an air gap be substituted as shown in Figure 7. The inductor coil will have a content equivalent magnetically to an air core since non-magnetic material would act as air would and even magnetic material would normally be treated in a heating or melting furnace at a temperature above that at which it would lose its magnetism.

Evidently an air gap inductor coil could be made to take the place of part of the magnetic circuit of Figure 7, provided the ampere turns of the winding be such as to produce the same number of lines of force within this portion of the magnetic circuit as are produced by the windings of the other parts of the circuit.

Putting this the other way, and applying to the problem at hand, a magnetic circuit with the current about it in phase with the current through the inductor coil may be so selected as to produce the same number of lines of force through the magnetic circuit as are produced by the solenoidal inductor winding, with the result that nearly all of the flux through the inductor is returned through the magnetic circuit and outside or stray magnetic field from the inductor coil is substantially eliminated. The windings are shown at 31, 32, 33, 34 and 35.

Just as the permeable material on one side of and above the inductor coil in Figure 2 can be replaced to advantage in taking care

of nearly all of the magnetic lines of force by the construction of Figure 3, and more completely by the construction of Figure 4, so also the single electro-magnetic return path of Figure 7 can be improved by placing the permeable material upon opposite sides of the inductor coil as in Figure 8 (dropping the portions 26 and 27 and windings 34 and 35), and still further improved by distributing the electro-magnetic return circuits about the circumference of the inductor as in Figure 9. The windings are shown at 31′, 32′ and 33′ in Figure 8 winding 31^2 only shows in Figure 9.

I have found that it makes very little difference in the magnetic circuit whether the winding be uniformly distributed or whether it be grouped as in Figure 10 and, as it is very much more convenient to group the windings at a small part of the length of the magnetic return circuit I prefer to use a group or localized winding.

The grouping or localizing of the winding shown at 36 in Figure 10 is of course not advantageous in that form alone; but is equally advantageous where the return magnetic circuit is divided up into many parts as in Figures 8 and 9. This localization of winding is applied to the divided magnetic circuit in Figures 11–14.

For convenience in the manipulation of furnaces built upon this principle, the magnetically permeable top legs of magnetic material 24, 24′, 24^2 (Figures 2–4), 24^3, 24^4, 24^5 and 24^6 (Figures 6–10) are preferably omitted as in Figures 11, 12, 13 and 14 and the increased ampere turns due to this increase in magnetic reluctance in this part of the circuit are to be provided by the furnace inductor coil.

This omission of the top legs produces a stray field at the top of the furnace. However, tests have established that no objectionable results follow and in fact that a positive advantage is obtained in certain cases in that the stray field assists in melting down the charge where the charge has been piled up above the furnace top.

Whatever stray field there is in this form is limited to a comparatively short space immediately above the furnace and about its upper end where there is no encasing structure and where little damage can be done to surrounding metal parts.

I have found that a close approximation to the localized windings of the compensating coil in Figures 11, 13 and 14 can be obtained without the necessity for winding these compensating coils individually about the legs. In Figure 12 I have shown the compensating windings at 36′ as localized and as surrounding the group legs of the return magnetic circuit as distinguished from surrounding the individual legs. Each form has its advantages but the simplicity of the form of Figure 12, the smaller furnace width required by it and the fact that the lines of force set up by it affect the space between the legs as well as the actual area occupied by them suit this Figure 12 form better than the individual windings to general use.

In Figures 11–14 my invention is applied diagrammatically to an induction furnace of the melting type in which as a rule it is desirable to lift the furnace bodily for tilting purposes or to transfer it bodily from the position of melting to the position of pouring. In either event increasing furnace sizes bring strains upon the furnace which cannot be taken care of to the best advantage without steel or other metal casings, supports or reinforcements for the furnaces. In these figures I have variously illustrated the strengthening or reinforcing steel at 37, 37′, 37^2, 37^3, intending the illustration to be purely diagrammatic and omitting the intermediate connecting furnace structure and refractory. Though the casings shown in these figures are preferably of shell form it is not the intention to indicate that any such restriction attaches to these casings, supports or reinforcements as the freedom from stray field leaves the designer free to utilize any form of fabricated or other metal reinforcement or support which may suit his purpose.

The capability of thus properly supporting the furnace or without regard to stray magnetic field is an important feature of my invention.

It is also not the intention in the furnaces shown to indicate that the container 38 shall necessarily be a crucible or other preformed container as my invention is wholly free from limitations of this character, permitting the melting to be performed in a preformed container, or in a bed or shell formed in the sand or other surrounding insulating material itself by the heat of the melt as is frequently done at the present time.

The marked improvement in the return magnetic circuit for the lines of force produced by the furnace inductor coil reduces the size of the magnetizing component of the current through the furnace coil, thus relatively increasing the energy component and correspondingly improving the power factor.

For the same coil winding this reduction in the percentage of the magnetizing component of the current permits a larger energy component of the total current through the coil if the combined current be kept the same, giving more rapid and effective heating and very noticeably increased stirring of the moltent content.

As compared with the furnace when not in action, the metal surface is flat at 38 on the upper surface of the content 39. I find that the pinch circulation is so much increased as to secure a high crowning of the center of the metal as at 38′ when the current is turned

on. In some tests made to determine this the center was higher than the edges to an extent approximating the radius of the melt.

The metal comes up the center and down along the sides as in the usual pinch circulation but to a more marked degree than I have been able to secure without the present invention. This is due not only to the excellence of the magnetic side path of return but to the positioning of the bottom of the magnetic return directly beneath the charge and close to it.

The improved pinch circulation is effective to very much increase the speed of mixing of added ingredients to the metal and to correspondingly increase the speed of "slagging" the metal by any slag covering such as is shown at 40 in Figure 14.

The discussion has been made general and the figures have been made diagrammatic for the reason that it is recognized that the above invention is applicable to any type of coreless induction furnace whether it contain a crucible or not and whether it melt or merely heat metal.

It is recognized that in some locations, particularly in heaters where the metal is not to be melted, such as in re-heaters for ingots, it is desirable to have the bottom of the furnace open as well as the top. Such a furnace is shown diagrammatically in Figure 15 with an ingot in place. The field-eliminator yoke used here differs slightly from that used in the melting furnaces in that there is no bottom and that the ends of the laminated legs 41 are shown as slightly turned in about the coil for the purpose of protecting the coil against injury from the ingot or other content which is being heated as well as to improve the magnetic return circuit. The furnace is externally protected by a steel jacket 42. The furnace is shown as horizontal for the purpose of permitting feeding of the ingot in at one end and out at the other. In so far as the coil is intended to heat or treat a charge longer than itself the same advantage is found as in the case of charges extending above the inductor coil in the other figures.

Experiments have been performed to gain some idea of the benefit secured by the use of the field-eliminator yokes. The experiments amply verify the statements made that my various departures from the conditions of the closed ring with uniform permeability and uniform winding cause so little stray field—and that localized above the furnace—as to maintain very close total approximations to perfect return conditions.

These experiments give a fair general idea of the results to be obtained by the use of my return magnetic circuit without and with the compensating coils. They show that the laminated sheets alone secure a considerable advantage even without the windings and that increasing strength of compensating windings continues to improve conditions up to a point of equalizing the return field and with further increase in the number of turns the windings cause an increasing stray field which finally becomes worse than that at the beginning. The amount of the stray field was determined by exploratory coils.

I find that there was a slight difference between the stray field when no yoke was used and the charge was in the furnace as compared with that when no yoke was used and the furnace was without charge, other conditions remaining the same. Field strengths appear at A and B respectively in the curve comprising Figure 16 in which the ordinates represent comparative strengths of stray magnetic fields and the abscissæ represent the number of turns of compensating winding utilized on the yoke.

When the magnetic return was used without passing any current through the coils the stray field dropped from B to C. With current through a progressively increasing number of turns on the yoke the stray field reduced as will be seen nearly to zero indicating a probable zero curve position at some such point as D. With increasing number of turns the stray field increased from the low points represented on both sides of the point D up to and finally beyond the initial stray field when no yoke was used, the stray field in the portion E of the curve representing that due to the excess magnetization from the turns of the yoke beyond the strength of the stray field due to the inductor coil.

It will be seen that the experiments plotted in the curve amply confirm the claims as to reduction of stray field by the construction indicated. This makes it possible to entirely disregard the stray field in the design of the furnace using iron or steel casing and structural iron without regard to its direction of extension or to its continuity about the furnace.

The improvement of the path of return for the magnetic flux in addition to substantially eliminating the stray field, so far reduces the magnetic reluctance of the entire circuit as to greatly increase the power factor. In experiments which were made the power factor was improved 25 percent.

The improvement in power factor also secures important advantages in that less corrective capacity is required for a given size and output of furnace. Also, since the heat transfer to the charge is limited by the amount of current that can be passed through the furnace inductor coil without excessive heating, the reduction in magnetizing current component permits a larger percentage and hence a larger amount of energy component of the current to pass through the inductor coil. As the input of heat into the furnace is proportionate to the square of the energy component of the current the improvement

in the power factor causes a disproportionately greater improvement in the heating and hence in the output of the furnace.

The effect of my field-eliminator yokes is just as if I had provided a magnetic return path of zero reluctance; yet with little current cost. The number of compensating turns is very small, much smaller than suggested by the figures, one or a very few turns being sufficient in larger furnaces.

Because of the small number of turns required it may be desirable to shunt part of the circuit about the compensator coil or coils so as to get the effect of fractional turns, either a part of a turn or an intermediate position between adjoining numbers of full turns. The shunt must be designed so as not to vary the phase of the current through the compensating winding. The same method can be used to effect an adjustment of the compensation required for non-magnetic and magnetic charges respectively, shifting from one compensation to the other as the charge becomes magnetic or ceases to be magnetic, or to secure a fixed compromise compensation which shall reasonably approximate the exact compensation estimated for each.

It will be apparent that with the disappearance of the stray magnetic field the problem of forming a return magnetic circuit for a solenoid free from interthreading with transformer iron has been solved; that a highly desirable means of power factor improvement has been applied to solenoidal circuits and that a new means of increasing the output, efficiency and stirring effect of solenoidal inductor furnaces has been secured.

Each of these marked advances in the art might be considered as a by-product of one or more of the others, according to the direction of approach; and each of the advantages in itself would well justify the return magnetic circuit by which it is secured.

It will be seen that the advance in each of these features is due to elements of process as well as to the structure elements involved; and that all cooperate toward a unitary result.

For the reasons above indicated my invention is applicable to furnaces almost without regard to their size for improvement of power factor; to furnaces dependent largely upon their intended use for improvement in the output and the stirring effect; and to large furnaces for all of these advantages and also to permit utilizing magnetic material freely in the stiffening and strengthening of the furnace structure.

In view of my invention and disclosure variations and modifications to meet individual whims or particular need will doubtless become evident to others skilled in the art, to obtain part or all 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. The process of assisting in the return of magnetic flux from a furnace coil which consists in electro-magnetically producing a flux external to the furnace coil, additional to the flux from the furnace coil and tending to assist in the return in direction of the flux.

2. The process of substantially eliminating the stray magnetic field about a furnace inductor coil free from interthreading of transformer iron, which consists in providing an easier path of return for the magnetic flux than the path through the air about the coil and assisting the passage of the lines of force through the easier path by surrounding it with a magnetizing current.

3. The process of substantially eliminating the stray magnetic field about a furnace inductor coil free from interthreading of transformer iron, which consists in providing an easier path return for the magnetic flux than the path through the air about the coil and assisting the passage of the lines of force through the easier path by surrounding it with a magnetizing current, the magnetic lines of force induced by the current being substantially equal to those produced by the furnace coil and in direction tending to assist the return of the magnetic lines of force from the furnace coil.

4. The process of eliminating the stray field from a furnace inductor coil free from interthreading of transformer iron, which consists in providing a yoke return circuit of magnetizable material about the inductor coil and a compensating winding about it in series with the furnace coil and so connected as to assist in returning the flux of the magnetic return circuit.

5. The process of eliminating the stray field from a furnace inductor coil free from interthreading of transformer iron, which consists in providing a yoke return circuit of magnetizable material about the inductor coil and a compensating winding having its current in series with current of the inductor coil, so connected as to assist in the flow of the magnetic return circuit and the compensating coil being so adjusted as to induce a magnetic flux through its length of return magnetic material substantially equal to the magnetic flux induced by the inductor coil through the furnace itself.

6. The process of reducing the magnetizing component, increasing the energy component and thus improving the power factor of a current through a coreless furnace inductor coil, as compared with the total current through the coil, which consists in providing magnetic return for the lines of force

induced by the inductor about the furnace coil and in inducing lines of force in said return in phase with the lines of force induced by the furnace inductor coil and having the same direction as the return circuit of the lines of force from the inductor.

7. The process of improving the stirring of a melting furnace inductor free from interthreaded iron, which consists in providing permeable paths of return for the magnetic lines of the circuit about the side and beneath the bottom of the coil and electro-magnetically setting up in these magnetic paths flux in the direction of the return flux from the coil.

8. A hollow charge-surrounding inductor furnace coil and a return electro-magnetic circuit for the flux caused by the coil.

9. A hollow charge-surrounding inductor furnace coil and a coil outside the furnace coil in series with it, the coil outside the furnace being so located as to assist by its flux in returning the flux caused by the inductor coil.

10. An inductor furnace coil, a magnetic return for the flux produced by the operation of the coil, comprising a return path of permeable material and a winding thereon as an inductor coil adapted to produce flux through the return magnetic circuit assisting the flux from the coil.

11. A furnace inductor coil and a magnetic return circuit for the coil extending along the sides and throughout the greater part of the radial extent of the bottom of the coil and electro-magnetized to assist in flow of the return flux from the furnace coil.

12. An inductor furnace coil, a return magnetic circuit for the flux caused by the coil comprising a plurality of yoke legs extending longitudinally of the furnace outside of the furnace and a compensating winding for the yoke legs surrounding all of them and connected to receive current in phase with the current through the inductor coil.

13. An inductor furnace coil, a return magnetic circuit for the flux caused by the coil comprising a plurality of yoke legs extending longitudinally of the furnace outside of the furnace and a compensating winding for the yoke legs looped outside of all of the legs and in series with the inductor coil.

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