

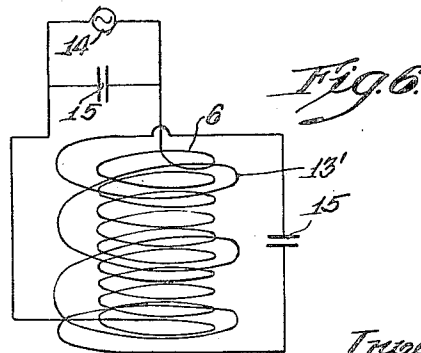
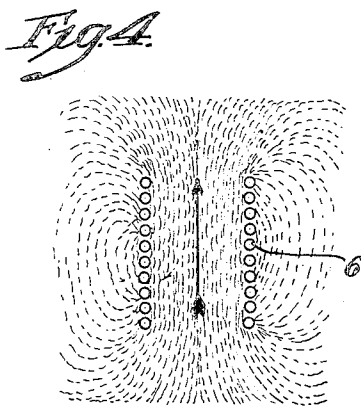
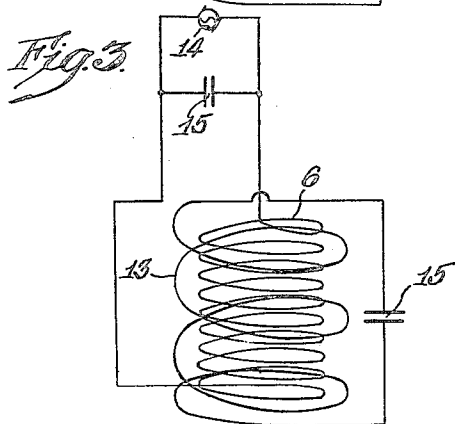
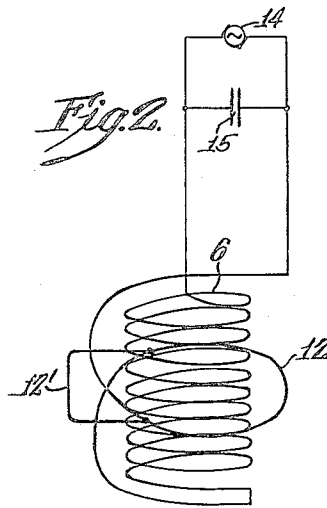
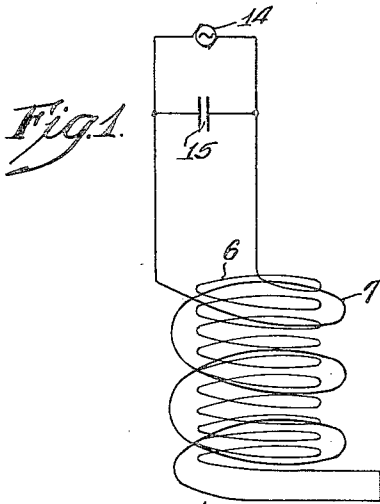
Jan. 28, 1930.

E. F. NORTHRUP

1,744,983

INDUCTOR FURNACE

Filed Aug. 2, 1928



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UNITED STATES PATENT OFFICE

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INDUCTOR FURNACE

Application filed August 2, 1928. Serial No. 296,936.

My invention relates to electric induction furnaces free from interthreading with furnace or transformer iron and in which a stray electromagnetic field is caused by the furnace inductor.

The main purpose of my invention is to protect the outer part of the furnace against the stray magnetic lines of force so as to permit magnetizable casings, shells or frames to be used freely in supporting and strengthening the furnace reinforcement without interference of the stray field with this magnetizable metal.

A further purpose is to set up at predetermined distance outside of the primary inductor coil an electromagnetic flux which will eliminate any desired outside stray field flux.

A further purpose is to surround the primary inductor coil by a coil in which a current of electricity is set up by the inductor current supply, by induction or by a separate source, using the outside coil to assist the passage of lines of force between it and the furnace inductor and to shield from passage of magnetic flux beyond the outside coil.

A further purpose is to provide a short-circuited secondary coil about a primary inductor furnace coil and to use the current induced in the secondary coil to assist flux between this induced current and the inductor coil and to eliminate, or retard the flow of magnetic lines of force outside the secondary circuit.

A further purpose is to balance the magnetic flux from an auxiliary coil about a furnace inductor against stray inductor field by selection or adjustment of its resistance and number of turns with added condenser capacity so as to cause the flux produced to equal within the field selected the stray field to be eliminated.

A further purpose is to provide a compensating coil outside of a furnace inductor coil with current from the inductor source of supply or with induced current and added capacity in its circuit.

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

My invention relates to the processes in-

volved as well as to apparatus by which the processes may be carried out.

I have preferred to illustrate my invention by a few furnaces only among the many in which it may appear, selecting furnaces which are practical and efficient and which at the same time well illustrate the principles involved.

Figures 1, 2, 3 and 6 are diagrammatic illustrations, showing inductor furnaces to which my invention is applied.

Figures 4 and 5 are diagrammatic illustrations intended to assist in explanation of the theory of my invention.

In electric furnaces of the inductor type in which the inductor surrounds the furnace charge, usually a furnace pool, and in which the inductor is not interthreaded with furnace nor transformer iron, the lines of magnetic force caused by the current in the inductor thread through the inductor primary in some such manner as is shown diagrammatically in Figure 4, passing up through the center of the inductor coil and returning about the entire outside section of the coil.

The external magnetic circuit requires for its production considerable magnetizing current in the inductor circuit which lowers the power factor of the circuit. It is undesirable also from another standpoint. It interferes seriously with the use of iron or steel in the furnace.

The reduction in power factor can be fully compensated for by the use of additional condenser power factor correction and is, therefore, not very serious; but as the size of the furnace increases the need of shells of iron or steel for cheap and effective construction of the furnace itself increases and the injurious effects of stray current upon any iron or steel used becomes a serious problem, heating up the iron or steel used needlessly, wasting the energy that is used and by the heat generated interfering with the proper use of the furnace.

The present application improves the power factor of the furnace—thus somewhat reducing the capacitive power factor correction required—but finds a much greater usefulness in negative stray magnetic field which

would otherwise interfere with the use of magnetizable materials in the furnace support or equipment.

The latter use is more important both because the power factor correction can be taken care of very fully and easily by condensers and because a much smaller current through my auxiliary coil is effective to protect against stray field outside of it than is required to completely take care of the magnetizing current otherwise needed for the return flux within.

If the inductor coil 6 in Figure 4 be energized, lines of force will pass through it in some such manner as indicated and these lines of force will at any given moment pass up, let us say through the body of the coil and down about the outside of the coil to form the return magnetic circuit for flux through the coil. These are the directions assumed in the figures, though the directions at intervening times, of course, will be exactly opposite.

If now the coil 6 of Figure 4 be applied about a body of non-magnetic metal (or of iron or steel heated until it has lost its magnetism) to be heated, melted or treated, the lines of force through the interior of the coil will pass through the charge as through an airspace and the magnetic return circuit will circulate in some such manner as is shown in Figure 4 in vertical planes about the outside of the coil.

It has not been deemed necessary to show the charge nor the refractory or other heat insulating materials, in view of the diagrammatic character of the showing. If the coil 6, of Figure 1, be now connected with a surrounding coil 7 and the current be passed through the coil 7 opposite in direction and corresponding in phase with the current through the coil 6, and we consider the effect of the current in coil 7, a magnetic flux will be set up within the coil 7 corresponding in direction to the return magnetic flux shown in Figure 4 in that it will pass downwardly through the interior of the coil 7. Its return circuit will pass upwardly about this coil.

Turning to Figure 5 which shows the direction of flux at a given instant in a single turn of each of the coils we find that the magnetic lines 8, 8' due to turn 10 of coil 6 pass upwardly through the interior of the coil and return downwardly about the coil. On the other hand the magnetic lines 9, 9' caused by turn 11 of the coil 7 pass downwardly through the interior of the turn 11 and upwardly about the outside of the coil.

Obviously, therefore, the lines 9 passing down the inside of the turn 11 and 8 passing down the outside of turn 10 but within turn 11 assist each other, so that coil 11 reduces the magnetomotive force necessary to pass the lines 8 downwardly between the spaced turns 10 and 11. On the other hand lines 8' of the

return flux from coil 6 which tend to return about the outside of turn 11 are opposed by the lines 9' which form the return magnetic circuit from the coil 7, nullifying this return magnetic circuit. The effects of the two coils are merely the summations of the effects of their turns.

If the coil 7 be in series with the coil 6 and reversely wound its current will be in phase with that of the coil 6, and its included magnetic circuit will assist the return magnetic circuit of the coil 6 to a maximum degree.

Where elimination of stray field is sought the diameter of the coil 7 is selected as the diameter beyond which the elimination is considered desirable. This diameter is of importance because it determines by the spacing of the coil from coil 6 to proportion of the return magnetic circuit from coil 6 which tends to return outside of the coil 7 and which must be eliminated. The larger the auxiliary coil the smaller the current required to eliminate the outside field. For any given diameter of auxiliary coil 7 the number of ampere turns through the coil 7 exists at which the return magnetic circuit caused by the current through the coil 7 and passing outside of that coil will exactly balance and hence neutralize that part of the return magnetic circuit due to the current through the inductor coil 6 which returns outside of said coil 7. This condition of exact balance or a sufficient approximation for any given purpose can be determined with greater ease experimentally by the use of exploration coils to determine the field outside coil 7 due to uncompensated lines from coil 6 or overcompensation by coil 7 than by computation, and moreover can be checked at any time and can be averaged for any desired condition of operation of the furnace. Fractional ampere turns can be secured by shunting part of the current as in Figure 2.

When the return magnetic circuits outside of coil 7 due to current through the two coils 6 and 7 balance each other the stray magnetic field from the inductor coil has been eliminated so far as it lies outside of the coil 7, permitting strengthening of the container for the molten metal by any desired casing or framework or other structure of magnetizable material to be used outside of this coil 7, with freedom of interference by the magnetic circuits.

At the same time that the coil eliminates the stray magnetic field outside of the position of the coil—and hence, outside of any predetermined coil path—the coil is effective, as is seen, in assisting the passage of that part of the return magnetic circuit from the inductor which returns between the two coils, reducing the magnetizing part of the current required to pass through the inductor to supply this return circuit and assisting

in maintenance of a full return circuit for the magnetic flux.

For the reason previously stated that the stray field elimination is less easily taken care of otherwise than the improvement of the power factor, the number of turns of coil 7 will ordinarily be selected with a view to the stray field elimination rather than the improvement of the power factor. It ordinarily requires a fraction only of the turns required for the main inductor circuit stray field equalization.

For large furnaces the ampere turns needed for stray field elimination are not great, particularly if there be liberal spacing between the auxiliary coil and the main coil. Figure 2 is intended to illustrate the complete flexibility of my invention. Whereas Figure 1 illustrates any plural number of turns of auxiliary coil, Figure 2 illustrates a means by which the ampere turns can be reduced below those equivalent to the inductor coil ampereage through one turn, the reduction being effected by a shunt 12'.

The series arrangement of the two coils in Figures 1 and 2 conveniently insures that the currents in the two coils are in phase and maintains a fixed relation between the currents in the two coils even where the shunt makes the coil currents unequal.

In Figures 3 and 6 the auxiliary coils 13 and 13' are inductively coupled with coils 6.

The inductor coils are all supplied with current from generators 14 and are corrected by condensers 15 shown as shunted across the lengths of the coils. This is a conventional showing only. The present invention does not interfere in the least with proper power factor correction for the inductor coil but does reduce the amount of it required.

In the form shown in Figure 3 the auxiliary coil is provided with means of adjusting the magnetizing effect of the coil by the condenser 15' in series with the coil.

In the forms of Figures 3 and 6 the number of turns, the diameter, the resistance of the individual turns and the condensers afford four means of adjustment of the current in the auxiliary coils 13 and 13' in order to secure the proper number of ampere turns to eliminate or substantially eliminate the stray field outside the coil, and as in the series coils of the other figures, the diameter of the auxiliary coil 13 or 13' determines the limits of position of the stray magnetic field from the inductor circuit, permitting this elimination to be controlled by any predetermined distance from the inductor.

In Figures 1 to 3 the auxiliary coils used are concentric with the inductor. This would be the normal position of the coils. However, access to the pouring spout of the furnace or other reason may make it quite desirable to have the auxiliary coil eccentric as in Figure 6; and I find that a very fair approxi-

mation can be obtained with this eccentric coil to the results in stray field elimination which are obtained by concentric coils. The eccentricity need not be regular.

The condenser-compensated coils 13 and 13' will react slightly upon the inductor coil to improve the power factor of the inductor and to reduce the amount of power factor corrective condenser capacity which is needed for the inductor coil circuit.

My invention is applicable to the complete or partial elimination of stray fields of inductors generally whatever the use to which the inductors are put whether for furnaces or for other purposes, and, if for furnaces, whatever the character of the charge or the operation performed upon it, and without regard to the detail of inductor construction, such, for example, as the system of cooling if any.

Whether the compensation for or assistance to stray field be calculated or found experimentally, the operation of determining it need not be repeated for other furnaces of the same general character.

In all of the forms shown the auxiliary (compensating) coil is shown as slightly longer than the inductor coil. The coils are shown as of the same height at the top in order not to complicate charging and pouring operations but the compensating coil may extend below the inductor coil if desired for the purpose of additionally protecting against straying of the rather concentrated flux present at both ends of the inductor as seen in Figure 4, but which cannot be taken care of so conveniently at the upper end of the inductor. This is an additional feature which has an advantage and can be used where desired, but is not vital to operation of my main invention.

It is desirable that the length of the auxiliary coil be not more than $\sqrt{2}$ times the length of the inductor coil.

The auxiliary induced current coil will have maximum ampere turns if it substantially fill the axial length of the auxiliary coil space, a smaller number of turns representing a nearly correspondingly larger ampereage.

In operation all of the forms alike utilize the auxiliary coil current whether in series with the inductor or induced thereby to neutralize all of any desired proportion of the stray field about the outside of the auxiliary coil and to assist the return flux caused by the inductor coil and which passes between the two coils. In all of them the diameter of the auxiliary coil limits the range of the stray field about the inductor to predetermined position of the coil and in all of them also the radial distance of the auxiliary coil from the inductor coil along with the spread of the return field determine how nearly the auxiliary coil flux necessary to eliminate stray field induction outside of it also equals, in-

side this coil the return field there set up by the inductor.

If the auxiliary coil be placed radially far from the inductor coil there will be but little stray field flux induced by the inductor coil which would pass beyond the auxiliary coil location even if there were no coil there. The auxiliary coil, therefore, need set up but little flux to compensate for and neutralize this stray field radially beyond it and will correspondingly but little assist in the passage between the two coils of return lines of force of the inductor flux.

On the other hand if the auxiliary coil be wound radially closer to the inductor coil the strength of stray inductor field beyond the auxiliary coil to be compensated will be increased and the strength of stray inductor field between the two coils will be relatively reduced. The larger magnetomotive force required to be exerted by the auxiliary coil under these circumstances of winding closer to the inductor will, therefore, be more effective in assisting the smaller number of lines of force from the inductor passing between the coils.

Keeping in mind these relations of larger magnetic flux required from the auxiliary coil current with closer winding of the auxiliary coil to the inductor and of greater proportionate effect of the closely wound auxiliary coil in helping the return flux from the inductor, it will be seen that the stray field eliminator may be made to give much or little assistance to the return flux due to the inductor coil current.

With reducing distance between the two coils there will evidently be a diameter and auxiliary coil strength at which the auxiliary coil may be made to eliminate the stray return magnetic flux and at the same time relieve the inductor coil of the necessity of furnishing the magnetizing current for its external field.

I have thus provided means by which any predetermined part or all of the stray field outside of an assumed position may be eliminated and whereby the eliminator is effective to assist in the return of magnetic flux through the inductor coil to an extent determined upon the flux eliminated.

It will be obvious that in determining the questions of extent of flux elimination outside of the auxiliary and of assistance given in return of that part of the inductor flux passing within the auxiliary coil, account must be taken of that part of the primary current energy which is used to pass current through an auxiliary in series to induce current through the secondary coil which would otherwise be induced in the charge.

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 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 method of stray field elimination about an inductor, which consists in providing a path for current about the inductor, inducing current therein to set up a stray field outside the auxiliary path opposite in direction to the stray return field set up by the inductor and in equalizing the stray field from the induced current approximately to that outside of it from the inductor by selection of the constants of the auxiliary path.

2. The method of stray field elimination about an inductor coil free from interthreading with transformer iron which consists in providing a path for current about the inductor, inducing current therein to set up an opposite stray field about the auxiliary path and in equalizing the stray field from the induced current to that outside of it from the inductor and at the same time assisting in power factor correction of the inductor current by the use of capacity in the induced circuit to adjust the current therein.

3. In an inductor furnace free from interthreading of transformer or furnace iron, a furnace inductor and a short-circuited coil surrounding the inductor and adapted to receive induction from it to counteract by the stray field of the short-circuited coil that part of the stray field of the inductor outside of the short-circuited coil.

4. In an inductor furnace free from interthreading of transformer or furnace iron, a furnace inductor and a short-circuited coil surrounding the inductor and adapted to receive induction from it to counteract by the stray field of the short-circuited coil that part of the stray field of the inductor outside of the short-circuited coil and added capacity in the circuit of the short-circuited coil.

5. In an inductor furnace free from interthreading of transformer or furnace iron, a furnace inductor and a short-circuited coil surrounding the inductor and adapted to receive induction from it to counteract by the stray field of the short-circuited coil that part of the stray field of the inductor outside of the short-circuited coil balancing the stray field of the one circuit against the stray field of the other.

EDWIN FITCH NORTHROP.