

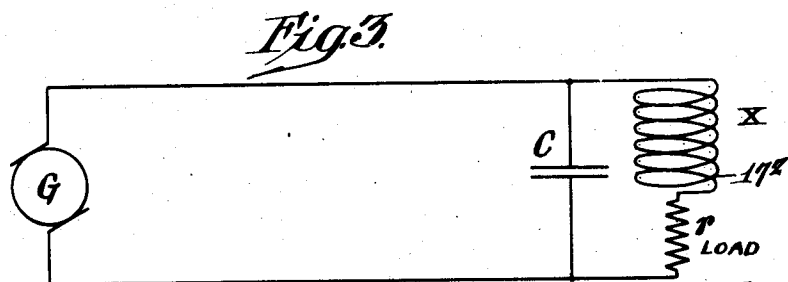
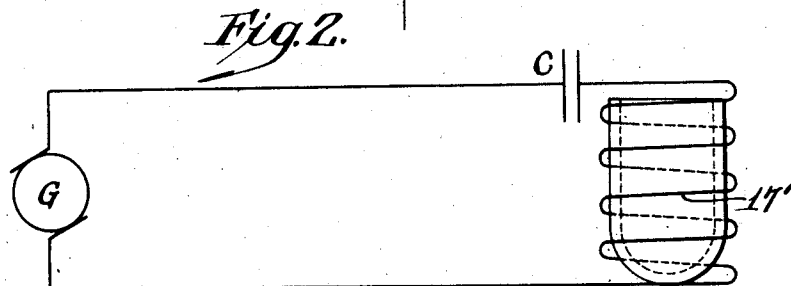
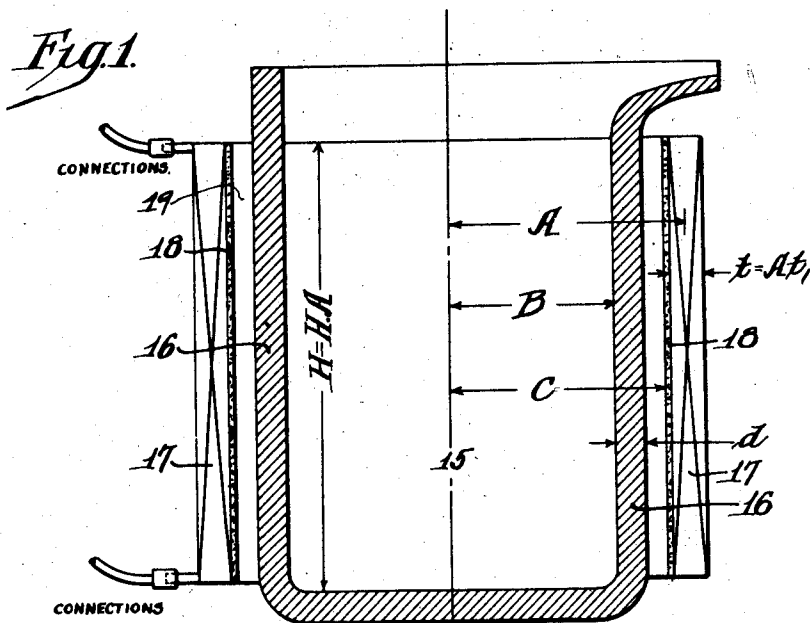
Dec. 11, 1928.

1,694,791

E. F. NORTHRUP
INDUCTION ELECTRIC FURNACE

Filed Feb. 14, 1925.

2 Sheets-Sheet 1



Witness:
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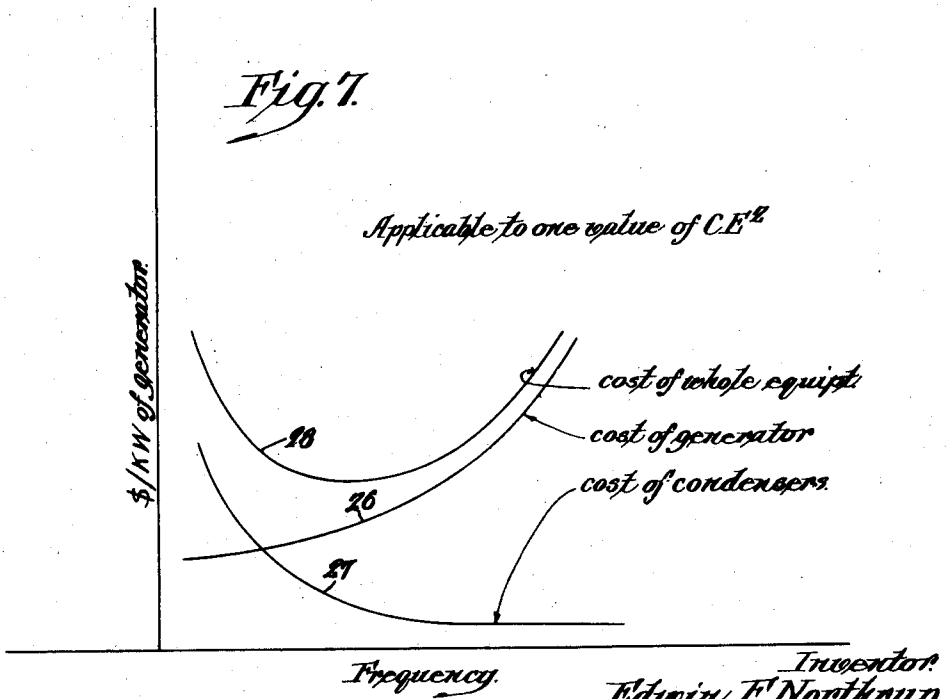
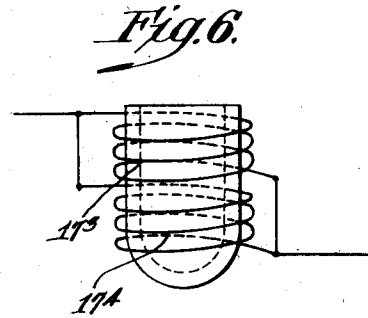
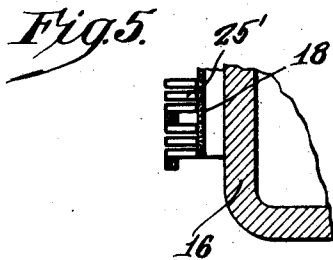
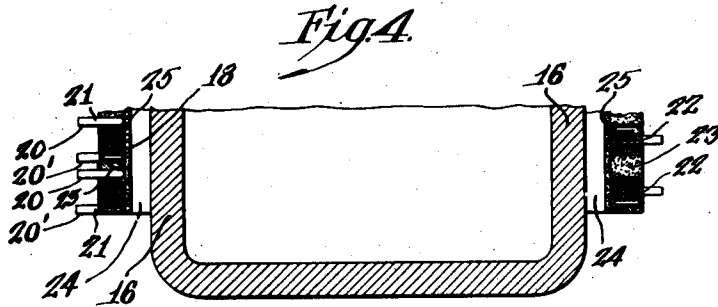
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E. F. NORTHRUP
INDUCTION ELECTRIC FURNACE

Filed Feb. 14, 1925

2 Sheets-Sheet 2



Witness:
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UNITED STATES PATENT OFFICE.

EDWIN F. NORTHRUP, OF PRINCETON, NEW JERSEY, ASSIGNOR TO AJAX ELECTROTHERMIC CORPORATION, OF TRENTON, NEW JERSEY, A CORPORATION OF NEW JERSEY.

INDUCTION ELECTRIC FURNACE.

Application filed February 14, 1925. Serial No. 9,312.

My invention relates to high temperature electric furnaces for inductive heating of non-magnetic materials.

The purpose of my invention is to provide a high temperature inductive furnace of large enough diameter to convert into heat substantially all of the electromagnetic energy supplied by the inductor before the axis of the furnace is reached, which is adapted to heat non-magnetic conducting materials to high temperatures and to heat-treat steel and iron above the recalescence point or to melt them, by the application of alternating current supplied from multipolar alternators of standard design.

A further purpose is to connect the inductor of a high temperature furnace free from transformer iron in series with an alternating current dynamo of standard construction and of frequency commercial or within the lower range of high frequency currents.

A further purpose is to maintain an interrelation between the size of the furnace, the frequency and the ampere turns applied to make the size large enough to adapt it to operate on frequencies available from rotary alternators and small enough to operate on their voltages.

A further purpose is to increase the frequency as compared with frequencies in common use to such a high frequency that the increasing cost of production of standard generators balances against the reducing cost of condensers to correct power factor securing minimum cost for the entire equipment.

A further purpose is to so interrelate features of structure and physical and electrical constants as to adapt the ironless induction furnace to vary much lower frequencies than had previously been believed to be possible.

A further purpose is to adjust the current automatically so as to pass it through a portion of the coil corresponding to the depth of the charge.

A further purpose is to use edgewise windings in multiple to secure maximum cooling for a turn of conductor having considerable extent parallel to the axis of the coil.

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

I have preferred to illustrate my invention diagrammatically in a single form, whose dimensions are subject to wide modification,

and diagrammatically show two of the ways in which it may be applied to a commercial circuit, selecting a form of furnace and ways of connecting which are practical and efficient and which at the same time well illustrate the principles involved.

Figure 1 is a sectional elevation, largely diagrammatic, of a furnace embodying my invention.

Figures 2 and 3 are diagrammatic views illustrating different ways of applying the invention to a commercial circuit.

Figure 4 is a fragmentary section showing preferred edge-wound inductor structure with multiple path water cooling.

Figure 5 is a corresponding section showing air cooled edge-wound coils.

Figure 6 is a diagrammatic view of an inductor having automatic adjustment of primary current flow to depth of charge.

Figure 7 is a diagrammatic view illustrating by curves the frequency-cost relation existing with respect to condensers and generators.

In the drawings similar numerals refer to like parts.

Describing in illustration and not in limitation and referring to the drawings:—

Prior to my present invention, I have applied high frequency induction to the melting of electrically conducting metals but without full appreciation of the fact that the frequency could be reduced to come within the range of direct supply from generators of standard multipolar construction in application to non-magnetizable metals or to magnetizable metals at temperatures above their recalescence point. Prior proposals to use induction coils surrounding the bath with frequencies of a lower order had so far failed to teach the conditions essential to their successful use as never to have been practical and to have led to the belief that a lower order of frequency could not be used commercially for such a purpose.

I have discovered that this belief of the inadaptation of a lower order of frequency to the heating of non-magnetic materials to high temperatures and iron and steel above the recalescence point has been due to a lack of conception of the true inter-relations of dimensional, physical and electrical constants of the furnace and circuit with a consequent

misapprehension of any experiments with frequencies too low for the size of charge.

I have discovered that increase in the linear dimensions of a furnace capable of use upon high frequency induction is quite an important factor in adapting the furnace to operation upon a much lower order of frequency.

The linear dimensions of a high frequency ironless induction furnace are relatively small and when it has been sought to operate a furnace of this character upon materially lower frequencies than that for which it is adapted there have been such a falling off in furnace efficiency and drop in power factor as have led to the belief of an utter inadaptation of the lower order of frequencies to heat non-magnetic material to high temperatures without inter-linkage of transformer iron.

I have found that the power factor of a furnace of this character apparently rapidly drops away with any extension of the magnetic induction beyond the center of the charge, and that if the furnace is to maintain a power factor approaching its best power factor there must be such inter-relation between the impressed frequency and the resistivity and diameter of the charge as will prevent this extension of the magnetic induction across the center.

It is readily shown that the ratio between the reactance and the resistance of an inductor solenoid of the form shown in Figure 1 is a direct function of the product A^2N where A is the radius (or other linear dimension) of the inductor and N the frequency of the impressed current.

The effective inward extension of the magnetic induction in centimeters into the charge can be shown to approximate $25,000 (\rho/N)^{1/2}$ which is about four times what is known technically as "depth of penetration". This is that extent of penetration of the induced current into the mass which with the same current density existing at the surface would give the same total current as exists in the mass. Its numerical value is from one-third to one-fifth as great as the actual distance of induction penetration beneath the surface of the material.

For a theoretical discussion of "depth of penetration" consult "Transient Electric Phenomena and Oscillations", Chapter VII, by Steinmetz.

If the conducting material being heated has a diameter suggested, equal to or greater than twice the distance of effective inward penetration of the induction, that is, equal to or greater than about $50,000 (\rho/N)^{1/2}$, and the inductor resistance be very low as compared with its reactance, the power factor should approach its best value.

Figure 1 illustrates a desirable form of ironless inductive furnace. The conducting mass 15 to be heated having radius B , height

$H=H_1A$ and resistivity ρ , is surrounded and supported by a crucible 16 of wall thickness d . This in turn is surrounded by the inductor 17. A thin electrically insulating sheet 18 and a space 19 filled with a heat insulating substance are shown between the crucible and the inductor.

The inductor is most desirably of single layer winding, preferably edgewound and has a radius A , a radial depth $t=At_1$ and an average diameter preferably equal to the height $H=H_1A$. It is desirable to have $H_1=2$ and $H=2A$.

The coupling ϕ between the material 15 heated within the crucible and the inductor will vary both with the area ratio B^2/C^2 where C is the inside radius of the inductor, and somewhat with the ratio of H to A . When the crucible is charged to depth such that $H=2A$, a normal full charge, the coupling factor closely approximates a value $0.8B^2/C^2$.

The inductor space 17 is partially occupied by electrical insulation and cooling provision, of which the most effective is water and only a certain proportion f of the total volume of the space 17 is occupied by the copper of the conducting element. The resistivity of the conducting element within the inductor is ρ_1 and the element has n turns of total resistance R . The voltage is proportional to the number of turns (n) and can be kept down by reducing n . This becomes of more importance in the larger furnaces.

Under these conditions it is readily shown that the volume of the inductor is $4\pi t_1 A^3$; that the direct current ohmic resistance R equals $\rho_1 \pi f^{-1} t_1^{-1} n^2 A^{-1}$; that the $i^2 R$ loss within the inductor is equal to $\rho_1 \pi f^{-1} t_1^{-1} (ni)^2 A^{-1}$; and finally that the $i^2 R$ loss per unit volume within the inductor is $(1/4) \rho_1 f^{-1} t_1^{-2} A^{-4} (ni)^2$. When the coil carries alternating current the direct current resistance is somewhat increased due to "skin effect" but this increase does not affect the general principles here set forth, though it may somewhat affect the final value which must be assigned to the furnace efficiency.

I find usual values for ρ_1 and desirable values for f and t_1 to be respectively 2×10^{-6} , $1/2$ and $1/6$, and with these values the $i^2 R$ loss in the inductor becomes $75.4 \times 10^{-6} (ni)^2 A^{-1}$, and the $i^2 R$ loss per unit volume within the inductor becomes $36 \times 10^{-6} A^{-4} (ni)^2$.

The power input in a final analysis is limited alone by my ability to extract heat from the coil by water flow as fast as it is generated; a far off limit.

In practice the permissible power input as regards the heating is greatly increased by the use of cooling fluid, the intensity of heating the inductor, as measured by the $i^2 R$ loss per unit volume within the inductor being then limited by what might be called the specific

power to cool it as measured by the maximum rate at which each unitary volume may be cooled.

This specific power to cool the inductor, as measured by how many heat units per unit volume of the inductor may be removed each unit of time, will depend somewhat on circumstance and mechanical facilities, yet it may without undue error be taken as approximately independent of the actual volume or sectional area of the inductor (provided the furnace proportions above expressed are maintained) within such limits as are likely to be met in usual practice, that is, be taken as a constant independent of the size of the inductor and of the frequency of alternation of the voltage impressed upon the inductor. This constant will be the maximum i^2R loss per unit volume of the inductor that can be adequately removed by cooling the inductor. The i^2R loss per unit volume has been shown to be measured by $A^{-4}(ni)^2$.

The heat developing within the inductor per unit volume of the inductor for a given form of furnace is thus shown to be measured by $A^{-4}(ni)^2$, so that any number of furnaces similar otherwise, but variant with respect to size and with respect to the frequency of the alternating voltage impressed upon the inductors, should normally at full load operate with the same value for $A^{-4}(ni)^2$.

Considering these similar furnaces, I find from mathematical analysis that if $A^{-4}(ni)^2$ has the same value in all, that then the respective values of A^2N in the different furnaces may be taken as measuring the respective intensities of heat input into the different charges; also that when these values are multiplied by a suitable constant they may be taken as measuring the respective ratios between reactance and resistance of the respective inductors; also that by dividing the respective values of A^2N by the respective resistivities of the different charges values are obtained which determine in each case the ratio of the distance induction is penetrating into the charge to the radius of the charge.

It is thus clear that furnaces operating with the same values of $A^{-4}(ni)^2$ under conditions giving equivalent values of A^2N in the respective furnaces, should pour heat into their respective charges with equal intensities; i. e., the heat absorption per unit volume of charge should be the same in all the furnaces; also, that in all the furnaces there should be the same ratio between the inductor reactance and inductor resistance; also if the furnaces are charged with the same material or with different materials having equal resistivities, then the ratio between the distance induction penetrates beneath the surface of the charge and the radius of the charge will be the same in all.

If the furnaces differ in size, as is here presumed to be the case, the frequencies of the

smaller furnaces will be relatively very much higher than in the larger furnaces, while conditions with respect to power factor, furnace efficiency and intensity of heat delivery should be approximately the same in all.

A small furnace operating on a frequency of 50,000 cycles should operate in the same way as a furnace having ten times its diameter and operating on a frequency of 500 cycles, the charge and requisite power for the larger furnace being however 1000 times that of the smaller.

Consider the effect of endeavoring to operate the smaller furnace upon 500 cycles instead of 50,000. The current, limited by the permissible heat withdrawal from the inductor coil will be the same in each case. The heat loss in the inductor will have substantially the same value as for 50,000 cycles, while the heat delivered to the charge, even were it possible to maintain the same power factor, would drop to 1% of its former value. The power factor however would also drop away, both from fall in the reactance of the inductor and from the induction spreading across the center of the charge, so that the power usefully converted into heat would become quite insignificant.

It is little wonder, in view of the foregoing, that it has hitherto been believed by those skilled in the art that commercial frequency induction and high frequency induction within the reasonable range of multiple pole generators of standard type (i. e., within the range of direct generation by increasing the speed and the number of poles of standard types of multipolar generators) and frequency changers were utterly unadapted to heating conducting non-magnetic materials.

It is obvious that the larger furnace above is adapted to operate on frequencies much higher than 500 cycles. Subject to increase in R due to skin effect there may be a considerable gain in electrical efficiency and in intensity of heating though unfortunately with little improvement in power factor and with the requirement for increased voltage, or if the voltage be limited, fewer turns in the inductor, approximately in accord with a relation $E \propto An$.

If we operate the larger furnace upon 50,000 cycles instead of 500 cycles the intensity with which heat is poured into the melt will be increased very nearly a hundred fold, but with corresponding increase in the power required and in the voltage to maintain the same current. It should be noted that the electromagnetic induction will be converted into heat within a relatively small outer shell only of the metal, losing the advantageous generation of the heat throughout the mass which is obtained when the depth of the electromagnet induction extends nearly or quite to the center.

The larger furnaces are thus adapted to op-

erate upon much wider ranges with respect to intensity of heating and therefore are adapted to operate with reasonable efficiency upon much wider and higher ranges of temperature and frequency than the smaller furnaces. Also the larger furnaces should be better adapted to operate equally well upon a wider range of materials (i. e., materials in which there is a greater range of resistivity variation) than the smaller furnaces.

Comparing the two furnaces of different size for the same voltage the smaller furnace normally will have a larger number of turns and a higher frequency with which the induction, we will say, reaches but does not effectively cross the center of the charge, while the larger furnace for the same kind of material and same kind of heat absorption will have a smaller number of turns and lower frequency.

For the same values of $A^{-4}(ni)^2$ and A^2N the frequency for the most desirable operation of different furnaces will vary inversely as the square of the radius, or if the same frequency be maintained the rate of input varies directly with the square of the radius.

In considering the question of size we must not overlook the fact that size cannot be increased indefinitely.

A natural relation exists between voltage, number of turns and radius for furnaces having A^2N equal and $A^{-4}(ni)^2$ equal—that is, operating at the same intensity of heat input and efficiency the values of E/An will be equal. From this we see that the voltage varies directly as the radius and directly as the number of turns. Any limitation or preference in voltage therefore can be taken care of by adjustment of the number of turns.

In the operation of any furnace reduction of frequency below the value of $N_1 = A^2N/A_1^2$ will result not only in less intensive heating but also in a drop in power factor by reason of the induction flowing across the center of the charge. With increase in frequency without a corresponding increase in voltage, there will of course be a reduction in the current through the inductor with corresponding reduction in power.

My invention is well adapted for electric furnaces without the use of transformer iron within the coil and for direct supply of current from rotor generators of standard multipolar type and at voltages available from such generators.

Though I prefer not to use either transformers or frequency changers, I recognize that both are adjustable by static apparatus, the voltage through condensers and the frequency through one or more frequency changers, successively doubling the frequency, though with corresponding successive reductions in the energy available. I have not considered it necessary to illustrate either of these devices in my diagrammatic showing

as their use will be clear from the above description.

Diagrammatic Figure 2 illustrates capacity in the form of condensers C in series between the generator G and the inductor 17 about the crucible 16', increasing the voltage at the inductor terminals.

In Figure 3, the capacity (condensers) C is placed across the line in parallel and the coil 17² is in series with the generator, the load resistance being separately indicated at r. In each of these cases the current in the line to the generator will be substantially in phase with the generator voltage.

As above indicated, in either of these cases the voltage or frequency could be adjusted to that required by transformers or frequency changers, the furnace coil being fed from the transformer or frequency changer or both.

I have indicated the inductor space rather than the inductor coil in Figure 1 to emphasize the fact that some features of my invention are independent of details of character as to the inductor which fills the space; for example, as to whether it be water-cooled or air-cooled, edge wound or otherwise, whether the different "turns" be in series or parts in parallel and whether each turn represents a single conductor or a plurality of conductors in multiple.

Because of the desirability in large furnaces of having a small number of turns with a considerable vertical space occupied by the turns and the necessity for a high rate of heat withdrawal from the inductor, I have illustrated in Figure 4 both the edgewise winding and the water cooling which is so desirable where the rate of heat withdrawal must be a maximum. I have also included in this figure the multiple grouping of edgewise wound conductors by which a "turn", in cross section extending over a distance parallel to the axis greater than its radial depth may still be edgewise wound and water-cooled. These features fit in with the multiple flow of cooling fluid applied by me in other furnaces.

In Figure 4 the individual conductors 25' or 25 (which may be air or water cooled) are edgewise wound and are shown as water cooled. In the fragmentary Figure 5 these conductors are shown as edgewise wound solid and air-cooled.

Both the water-cooled and air-cooled conductors are shown as connected in multiple, the unit of multiple shown being three, so that each set of three conductors is electrically connected in multiple to comprise one turn, the diagrammatic connections being shown at 20 and 20'. The cooling water is supplied through insulating tubes to inlets 21 and is vented to discharge at 22, the several inlets and discharges being not connected turn by turn in the illustration but obviously being adapted to have as many inlets and as many outlets, electrical and fluid, for the entire coil as may be preferred.

Because the individual conductors are grouped in sets the conductors of each set require no insulation from each other, greatly increasing the unit volume of copper per unit length axially of the inductor space; but the turns, comprising a number of conductors each, are insulated from each other as at 23. Air cooling space is shown at 24 and a heat insulating and electrical insulating lining 18 is placed between the coil and the crucible, preferably against the coil.

In Figure 6 I show automatic regulating mechanism for adjusting the input of electric energy proportionally to the axial extent of the charge, which in the case of a crucible becomes the depth of charge.

In this figure the inductor coil is divided into a plurality of sections shown in the illustration as two; these sections of inductor being connected in multiple with the current supply and, if water cooled, also preferably with multiple water passages and the usual tube insulation from the connecting pipes. Obviously the number of such sections electrically in multiple can be increased without varying from the theory of my invention though necessarily with practical limits as to the expediency.

The inductor coil sections 17³ and 17⁴ which are in parallel will operate precisely as the series coil when on full charge, except that their parallel connection will correspondingly increase the current flow. However, the current flow in each section is limited by the impedance of the section, and there will be a very much reduced impedance within the section when it surrounds a conducting charge. As a result with a depth of charge equal to half the furnace depth the impedance of the lower coil 17⁴ would be substantially reduced by reason of the charge whereas the reactance of the upper coil 17³ would remain a maximum. There would result from this a natural automatic adjustment of the current by which a relatively small current only would flow through the coil 17³, whereas the coil 17⁴ would take a large current.

The current is thus automatically much restricted to the portion of the coil surrounding the charge, greatly improving the coupling and reducing the *i*²*r* inductor loss. At the same time the power factor will be improved and the efficiency will be increased.

Subject to requirements of simplicity and strength the conditions of intended use as they affect the depth of furnace charge must be considered largely in determining the number and size of sections or sub-divisions of the inductor coil in each given case.

In Figure 1 it is of course apparent that the crucible itself may be the heating element, the crucible walls being then of conducting material. Either conducting or non-conducting material would then be heated within the crucible.

Throughout the discussion, the resistance of the inductor has been taken constant whereas to a certain extent it will be a function of frequency.

It was shown by me in the General Electric Review Nov. 1922, p. 663, that the power absorbed by the mass is approximately expressed by the Equation (10) on that page,

$$P = \frac{0.636\phi E^2}{x(\phi^4 + 2 - 2\phi^2)} \quad (1) \quad 75$$

where P is the power in watts, the coupling factor, E the volts at inductor terminals and *x* the reactance of the inductor when empty. We can thus write

$$P \propto \frac{E^2}{x} \quad (2) \quad 80$$

It is well established that for complete corrections of the power factor,

$$x_c = X \quad (3) \quad 85$$

when the condenser is in series with the load, and

$$x_c = \frac{R^2 + X^2}{X} \quad (4) \quad 90$$

when the condenser is in shunt to the load.

In Equations (3) and (4)

$$x_c = \frac{1}{2\pi NC} = \text{negative reactance}, \quad 95$$

R = the equivalent resistance of the load and X = the equivalent reactance of the load. C is the capacity in farads of the condenser. It was shown by me in the General Electric Review, Nov. 1922, p. 662, that

$$X = \frac{x(2 - \phi^2)}{2} \quad (5) \quad 105$$

Since ϕ , the coupling factor is constant, we can write,

$$X \propto x \quad (6) \quad 110$$

Hence, when the condenser is series connected (which is the more simple case to consider),

$$X \propto x \propto x_c \quad (7) \quad 115$$

for complete power factor correction.

Hence, we can write from relation (2),

$$P \propto \frac{E^2}{x} \propto NCE^2 \quad (8) \quad 120$$

or

$$CE^2 \propto \frac{P}{N} \quad (9) \quad 125$$

It follows from relation (9) that the CE² rating of a condenser required for correcting power factor varies directly as the power absorbed, but inversely as the frequency used.

From a commercial or economic standpoint this is a very vital conclusion. It sets a high

premium upon the advantage of inductive heating with high frequency current.

While it is true that condensers are now priced as proportional to their k. v. a. rating, namely,

$$\S \propto \frac{2\pi NCE^2}{1000} \quad (10)$$

and that the k. v. a. of condenser required to correct the power factor of a certain load is independent of the frequency, nevertheless, condensers for use on the higher frequencies are costly to construct in proportion to their CE^2 and not their k. v. a. rating. We can sustain, therefore, the statement that the cost of a condenser to correct the power factor to 100% is substantially as the relation,

$$\S \propto \frac{P}{N} \quad (11)$$

Quotations received on alternators of different capacities and frequencies prove that the cost of such alternators per k. w. output increases with the frequency they must supply. Since condensers cost less as the frequency increases and alternators cost more as the frequency increases, it is of economic importance to pick the frequency point for the minimum cost of the combination of generator and condenser which operates at unity or near unity power factor.

In Figure 7 I show in a general way by curves the cost of generators and condensers at different frequencies based upon one CE^2 output. In this figure curve 26 represents the cost of generators, which is seen to increase with the frequency, and 27 represents the cost of condensers, seen to decrease with the frequency. In both of these, particularly the condenser cost, there are factors entering into the cost which may be treated as constants and which change the curves somewhat from their purely theoretic forms. Other factors, including costs for materials, improvements in design and advances in methods of manufacture will change the values of these curves. However, at the time when any installation is contemplated the values, actual and comparative may readily be ascertained.

Curve 28 represents the sums of the ordinates of curves 26 and 27. This curve is seen to be high at both ends and to have an intermediate low section representing the range of economical equipment.

If the frequency at which two such curves give minimum combined ordinates is high enough to meet other considerations of efficient inductive heating, then this is the frequency to use. As previously shown the other considerations indicate that we should make

$$N \geq \frac{25 \times 10^8}{D^2} \quad (12)$$

If the diameter D of the mass to be heated

is a foot or more, and the resistivity of the metal is about that of molten brass, the permissible frequency will be well below that shown by application of the current as the range of frequencies for minimum combined cost of equipment.

With values at the present time I find that the lower range of minimum cost is about 360 cycles and that this range extends with little variation in the cost to somewhat over 500 cycles without the use of frequency changers. The combinations of generators of lower frequency with frequency changers, making due allowance for loss of energy in the frequency changers would give a different curve for current supply cost which is to be considered in connection with the cost of condensers in reaching conclusion as to the most advantageous equipment from the standpoint of combined costs.

By making sure that the furnace is large enough for the Equation (12) to be satisfied it is clear that we can take our frequency for most commercial quantity of production solely upon an economic basis and from data such as used in plotting the curves in Figure 7.

The curves shown in Figure 7 have been plotted for one value of power input, the same for both. There will be some variation particularly in generator costs according to the size of the equipment but it will not make much difference in the comparative cost.

Throughout the claims where I refer to the furnace coil as fed from a generator or use similar language I intend to include therein the feeding of the coil from the generator whether it be through a transformer or frequency changer as well as when connected with the generator without the interposition of any such apparatus.

In view of my invention and disclosure, variations and modifications will doubtless become evident to others skilled in the art, to meet individual whim or particular need, and I therefore claim all such in so far as they fall within the reasonable spirit and scope of my claims.

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

1. In inductive heating free from inter-threading by transformer iron, the process of efficiently using alternating currents within the range of frequency of generation by rotary multipolar generators which consists in confining the current path to a single layer of turns about the charge and in maintaining such a relation of frequency to diameter of the charge that the induced electromagnetic energy shall not penetrate substantially beyond the axis of the charge.

2. In inductive heating free from inter-threaded transformer iron, of non-magnetic charges and of magnetic charges above the

recalescence point, the process of efficiently using the current from rotary multipolar generators while maintaining the power factor which consists in making the radius of the charge not less than three times the "depth of penetration" of the electromagnetic energy into the charge.

3. In inductive heating free from transformer iron by a coil surrounding a charge, the novelty which consists in accommodating the furnace to frequencies which are not high by enlarging the charge for such a frequency to a point at which the induction induced within the charge does not substantially pass the center of the charge.

4. In inductive heating free from transformer iron of a charge surrounded by the inductor, the novelty which consists in maintaining the frequency within the range of a standard rotary multipolar generator, and in making the radius of the pool not less than three times the depth of penetration.

5. In an induction furnace, a rotary generator of multipolar type, an edgewise wound helical inductor furnace coil free from included transformer iron, fed from the generator and static capacity correcting the power factor, the relation of size of charge to frequency being such that the energy induced in the charge is substantially all converted into heat before the axis of the coil is reached.

6. In an induction furnace, a rotary generator of multipolar type, an edgewise wound water-cooled helical inductor furnace coil free from included transformer iron fed from the generator, connections for passing the cooling liquid through different parts of the conductor in multiple, and static capacity correcting the power factor, the relation of size of charge to frequency being such that the energy induced in the charge is substantially all converted into heat before the axis of the coil is reached.

7. In an inductive electric furnace, an alternating current generator of rotary multipolar type having a frequency in excess of existing commercial line frequencies, an inductor heating coil fed thereby, the diameter of the charge being sufficient at the frequency so that the energy in the secondary shall be substantially all converted into heat before the axis of the coil is reached, and capacity for power factor correction in the circuit.

8. In an inductive electric furnace, an alternating current generator of rotary multipolar type having a frequency in excess of existing commercial line frequencies, a single layer edgewise wound helical inductor heating coil fed thereby, the diameter of the charge being sufficient at the frequency used so that the energy in the secondary shall be substantially all converted into heat before the axis of the coil is reached, and capacity for power factor correction in the circuit.

9. In an inductive electric furnace, an

alternating current generator of rotary multipolar type having a frequency in excess of existing commercial line frequencies, an inductor heating coil free from enclosed transformer iron fed thereby, the diameter of the charge being sufficient at the frequency used and at the resistivity of the metal treated so that the energy in the secondary shall be substantially all converted into heat before the axis of the coil is reached, and capacity for power factor correction in the circuit.

10. In an inductive electric furnace, an alternating current generator of rotary multipolar type having a frequency in excess of existing commercial line frequencies, a single layered edgewise wound helical inductor heating coil fed thereby, and free from enclosed transformer iron, the diameter of the charge being sufficient at the frequency used so that the energy in the secondary shall be substantially all converted into heat before the axis of the coil is reached and capacity in series with the supply circuit for power factor correction in the circuit and to raise the voltage.

11. In an inductive electric furnace, a generator of rotary multipolar form having a frequency above existing commercial line frequencies and a single layer, edgewise wound, hollow, water-cooled, helical inductor heating coil fed thereby, and free from enclosed transformer iron, the diameter of the charge being large enough with respect to the frequency so that the energy in the secondary shall be substantially all converted into heat before the axis of the coil is reached.

12. In an inductive electric furnace, a generator of rotary multipolar type, an edgewise wound, helical conductor coil fed thereby and free from enclosed transformer iron, and static capacity for power factor correction of the circuit, a plurality of the edgewise wound conductors of the inductor coil being connected in multiple to form each effective turn thereof.

13. In an inductive electric furnace, a generator of rotary multipolar type, an edgewise wound helical inductor coil, free from enclosed transformer iron and static capacity for power factor correction of the circuit, the inductor coil being split up into a plurality of sections which are electrically connected in multiple with the source of current supply.

14. In an inductive electric furnace, a generator of rotary multipolar type, a furnace coil supplied therefrom, free from enclosed transformer iron, the coil having parts of its length electrically in multiple one with the other and power-factor-corrective static capacity for the circuit.

15. In an inductive electric furnace, a generator of rotary multipolar type and a furnace coil fed therefrom, free from transformer iron within the coil, the coil being edge-wound and water cooled and having parts of its length electrically in multiple

one with another and power-factor-corrective devices for the circuit.

16. In an inductive electric furnace, a generator of rotary multipolar type and a furnace coil fed therefrom, free from interlinkage of transformer iron within the coil, the coil being helical, single layer, edge-wound and water cooled and parts of the coil being in multiple with each other both electrically and with respect to the water cooling.

17. In an inductive electric furnace, a generator of rotary multipolar type and a furnace coil fed therefrom, free from interlinkage of transformer iron within the coil, the coil comprising edgewound conductors, a plurality in multiple to the single turn.

18. In an inductive electric furnace, a generator of rotary multipolar type and a furnace coil fed therefrom, free from interlinkage of transformer iron within the coil, the coil comprising edgewound and water cooled conductors, a plurality of conductors being in multiple both electrically and with respect to the water cooling to make up each turn.

19. A high frequency inductive furnace using static capacity for power factor correction, having the frequency such that the sum of the costs per generator kw. for the generator and static capacity for power factor correction shall be a minimum.

20. A high frequency inductive furnace free from interthreading of the inductor coil by transformer iron, in combination with a source of high frequency current including a generator of rotary multipolar type, and condenser power factor correction having the frequency such that the sum of the costs for the current supply and for the condensers shall be a minimum per kw. used.

21. A high frequency induction furnace free from interthreading of the inductor coil by transformer iron in combination with a source of high frequency current including a generator of rotary multipolar type, and condenser power factor correction in series with the generator and the coil of the furnace, having the sum of the costs for current supply and condensers a minimum per kw. used.

22. A high frequency induction furnace free from inter-linkage of transformer iron with the inductor coil, an inductor coil, a rotary multipolar type of high frequency generator supply for the inductor coil and power-factor-corrective condensers to maintain the power factor in the circuit, the frequency of the supply being such that the induced energy in the charge substantially has been absorbed before the axis of the charge is reached and the combined cost of generator and condensers is a minimum.

23. An inductive furnace having a coil surrounding the charge, a rotary multipolar type of generator supply therefor and power-factor-corrective condensers for the circuit in which the frequency is such that the induced energy is substantially absorbed in the secondary before the axis of the furnace is reached and the combined cost of current supply and condensers is a minimum.

24. In a commercial frequency high temperature furnace, a single layer solenoidal inductor, an alternator energizing the inductor, means for removing heat developing in the inductor, and a non-magnetic conductor surrounded and heated by the inductor and having an inter-relation between its diameter, its resistivity and the applied frequency such that the product of its diameter in centimeters into the square root of the ratio between the frequency in cycles per second and the resistivity in ohms per cubic centimeter is approximately as great as 50,000; i. e., expressing it algebraically

$$D(N/\rho)^{1/2} \cong 50,000.$$

25. In an induction furnace, a rotary generator of standard multipolar type, an edge-wise wound helical inductor furnace coil free from included transformer iron, fed from the generator and condenser correction for the power factor, the relations of size of charge to frequency and resistivity of metal treated being such that the energy induced in the charge is substantially all converted into heat before the axis of the coil is reached.

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