E. F. NORTHRUP.

OSCILLATION CURRENT METHOD AND APPARATUS.

APPLICATION FILED NOV. 25, 1916.

1,286,395.

Patented Dec. 3, 1918.

2 SHEETS—SHEET 1.

FIG. 1.

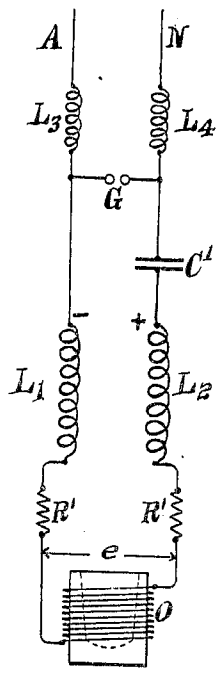


FIG. 2.

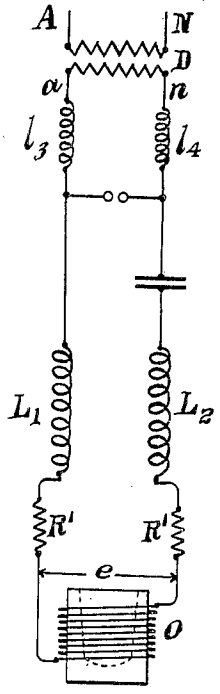


FIG. 3.

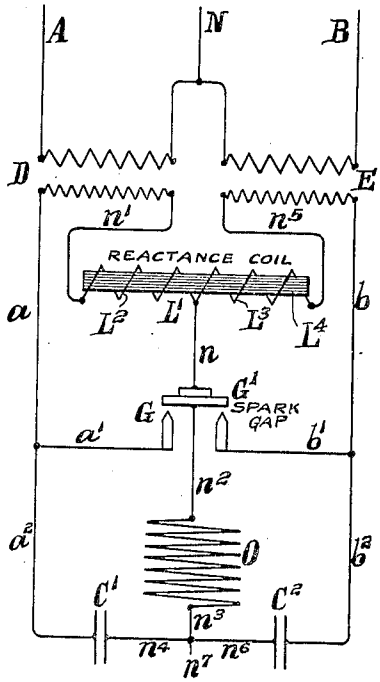


FIG. 3a.

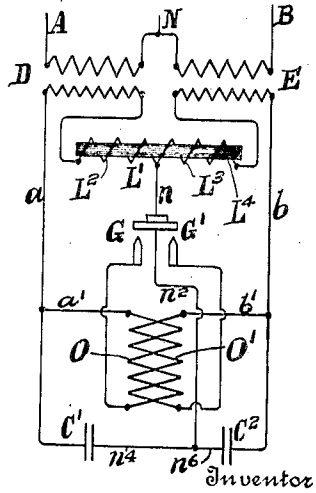


FIG. 4.

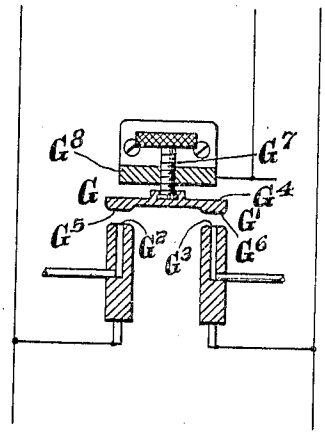
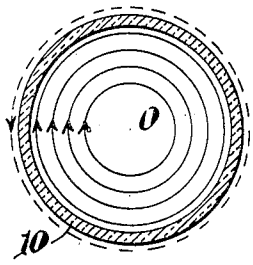


FIG. 5.



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2 SHEETS—SHEET 2.

FIG. 8.

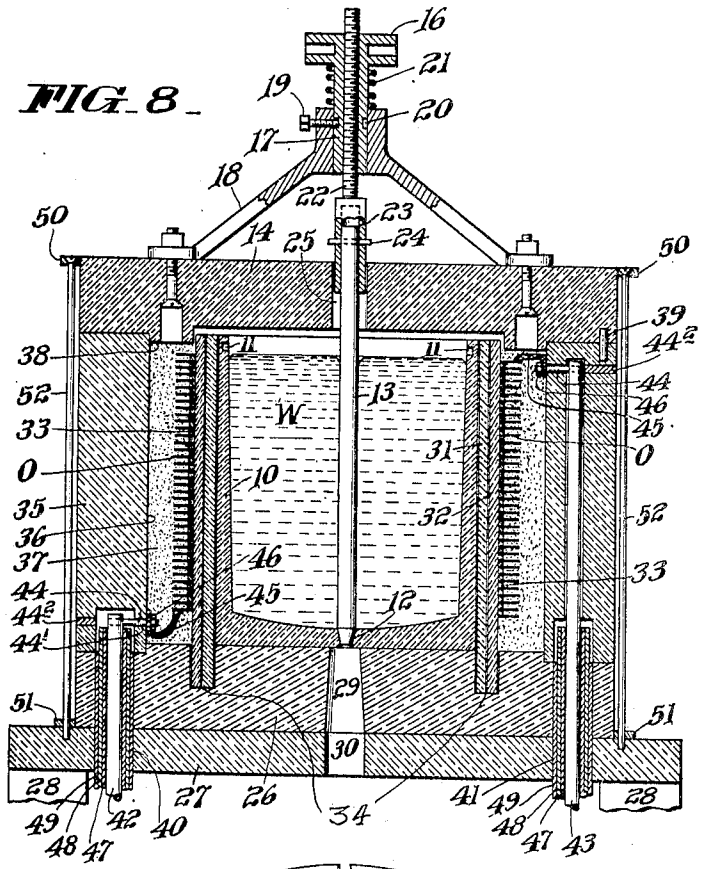


FIG. 6.

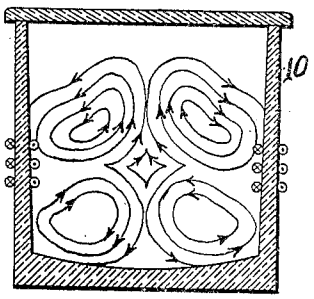


FIG. 10.

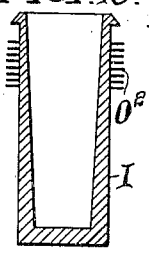


FIG. 11.

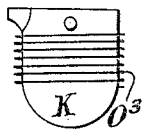


FIG. 9.

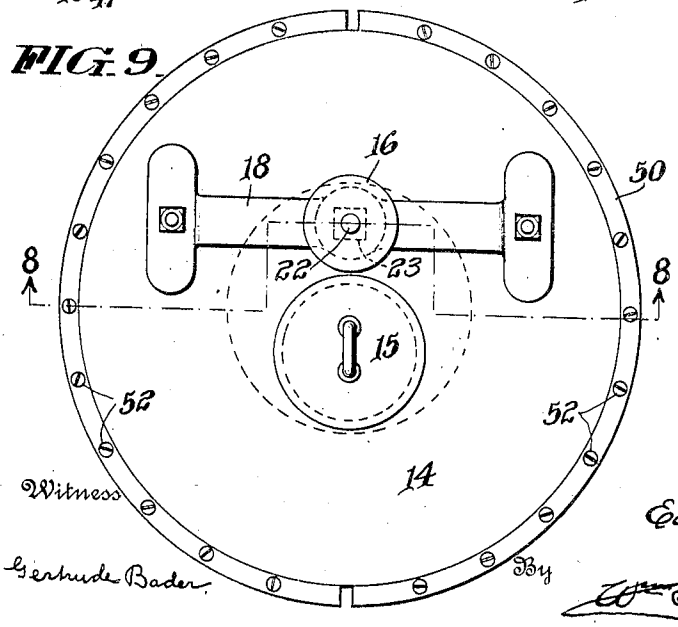
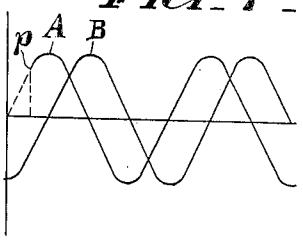


FIG. 7.



Witness

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UNITED STATES PATENT OFFICE.

EDWIN F. NORTHRUP, OF PRINCETON, NEW JERSEY, ASSIGNOR TO THE AJAX METAL COMPANY, OF PHILADELPHIA, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

OSCILLATION-CURRENT METHOD AND APPARATUS.

1,286,395. Specification of Letters Patent. Patented Dec. 3, 1918.

Application filed November 25, 1916. Serial No. 133,474.

To all whom it may concern:

Be it known that I, EDWIN F. NORTHRUP, a citizen of the United States, residing at 30 Wiggins street, Princeton, in the county of Mercer and State of New Jersey, have invented a certain new and useful Oscillation-Current Method and Apparatus, of which the following is a specification.

The purpose of my invention is to utilize the heating effect of electric currents having the natural frequency of a freely oscillating electric system from a condenser discharging through a gap is contrasted with the forced frequency directly produced by alternators.

A further purpose of my invention is to transfer energy from place to place by electrict currents having natural frequency and to transform the energy into heat at the place of intended use.

A further purpose is to make the "resistor," which is to be heated or treated or to be worked while hot the secondary of an inclosing oscillation coil primary or primaries, discharging a condenser or condensers through this primary and a discharge gap to induce currents of corresponding period within the resistor. I purpose applying my invention to the electric furnace art, among others, using the body of the pool as resistor and inducing circumferential flow of electric current about it, without the intermediation of a magnetic circuit such as is threaded through the pool or through a connecting tube in existing induction furnaces.

A further purpose is to charge condensers from multiphase currents through inductance coils having a common magnetic path, preferably a common core, protecting the generating apparatus by them from excessive current flow and through them transferring to another phase or other phases, energy which would otherwise be uselessly employed.

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

I have preferred to illustrate my invention chiefly diagrammatically, in view of the broad character of the invention, and have applied it to but one art and to but one illustration in that art, among the various arts and many forms in which it may be carried out, selecting therefor an art which is important and a form which is practical, efficient and simple, in which my invention has high commercial utility and which at the same time illustrates the principles of my invention to considerable advantage.

Figures 1 and 2 are diagrammatic views used in discussion of the principles of my invention.

Figs. 3 and 3ª are diagrammatic views of connections which may be used in applying my invention.

Fig. 4 is a mixed diagrammatic and sectional view of a portion of the circuit shown in Fig. 3.

Figs. 5 and 6 are diagrammatic views showing in a more or less hypothetical way the directions of flow of induced currents of electricity and of a molten oscillation resistor when my invention is applied to furnace operation.

Fig. 7 is a diagram used in discussing the assistance which can be given one phase from the other in two phase application of my invention.

Figs. 8 and 9 are a vertical elevation through the pool and a top plan view respectively of a structure by which I may apply my invention to induction furnace uses.

Figs. 10 and 11 are diagrammatic views showing application of my invention to ingot mold and ladle use respectively.

In the drawings similar numerals indicate like parts.

My invention applies oscillatory electric currents to the heating of conducting material performing a stirring function also by the same currents when the mass is a molten or otherwise liquid pool. My invention resides both in the general application of the principles involved and in the processes and mechanism by which these principles are utilized in the particular art from which I have taken my illustration.

The broader form of my invention is claimed by me in a co-pending application, Serial No. 192,049, filed September 19, 1917, for method and apparatus for electric heating by high frequency currents.

The introduction of inductance into the circuit of a constant speed alternator transmission line under "forced vibration" causes the current to lag in phase behind the electro-motive force, and capacity so introduced causes the current to lead in phase. The preponderance of induction over capacity

both in the line and in the coils of existing induction apparatus applying heat has reduced the power factor making it prohibitively low in otherwise desirable installations. With a relatively small amount of power available for use, this low power factor requires an equipment in proportion to the relatively large currents flowing in the line and heat is developed where it is not only not required but even injurious.

If, on the other hand, electric energy be stored in a condenser and the latter be then allowed to discharge itself through a closed circuit, the electricity oscillates back and forth like a pendulum until the energy stored in the condenser is finally dissipated in electric radiation and in heat. The inductance in such a circuit does not affect the total energy transformed, only the natural frequency, the time within which the vibrations will cease, the damping factor and the number of vibrations. In this it is comparable with the mass of a ball swinging at the free end of a spring whose opposite end is fixed. There is no dissipation of energy in this mass and its increase merely alters the natural period of the vibration, the time within which the spring comes to rest and the number of vibrations of the spring.

If the capacity and inductance be large, the fraction of energy dissipated in radiation is negligibly small. The movement of electricity in the circuit constitutes a natural, unforced or free vibration having a period

$$T = 2\pi\sqrt{LC}$$

Since T should be less than the period of the alternating current supply and in practice is therefore limited, the product of $L \times C$ must be kept within limits. This can very readily be kept within required limits for any total values of capacity and inductance by placing the condensers in multiple or splitting up the oscillation coil into parts fed from different condensers, which may be placed in multiple, by special non-inductive line construction and in other ways.

It might be noted that the currents in the oscillation resistor correspond to those in the oscillation coil in period and follow the fluctuations of the oscillatory currents even though they be not themselves of free vibration.

The only points or places in such a free oscillation circuit where heat is dissipated are where there is ohmic resistance or where there is an inductively coupled circuit having ohmic resistance, such as a solid, liquid or plastic body of conducting material or container or holder therefor forming a secondary to such a free oscillation primary.

It follows that conductors which lead from the condenser to the oscillation coil at the place where it is required to convert the energy stored in the condenser into heat may be quite long and may have considerable inductance without wasting energy objectionably in heat during this transmission, provided these conductors have small ohmic resistance. Practically, as well as theoretically, therefore, energy stored in a condenser can be transmitted a considerable distance from the location of the condensers with low heat losses, and there converted almost wholly into heat. This conversion may not take place wholly in the first oscillation, but will comprise an "integration" of the heat from the oscillation or successive oscillations in the circuit or the impulses of corresponding period and strength but opposite direction in the "oscillation resistor."

As the energy stored in the condenser is one half its capacity times the square of the voltage to which it is charged, the sole determining factors for the available energy from a single charge are the size of the condenser and the voltage applied in charging it. The power is then determined by the number of times the condenser is charged to this voltage and discharged per unit of time.

The inductance of the circuit, the resistivity of the metal constituting the secondary coupled circuit or resistor and the closeness of the coupling have no effect upon the power generated and, theoretically, no effect upon the power delivered to the metal.

Where the available voltage is sufficient to charge the condenser directly from it, no transformer is required between the supply and the condenser and I have shown such a construction in Fig. 1. The theory will be well understood from this figure. A single phase alternating current circuit is shown having sides A, N. The condenser to be charged is shown at C', the oscillation coil, through which the condenser discharges at O, the inductance of the two sides of the circuit at L_1, and L_3, and L_2, L_4 and a discharge gap at G. These inductances are intended to represent the entire inductance of each side of the circuit and are divided for convenience in the later discussion.

The energy stored at each charge is $1/2\ CV^2$. When the discharge gap G breaks down, the energy will surge in the oscillation circuit until it is all dissipated in radiation and heat, for low frequencies chiefly in heat.

The means of dissipation are as follows:

1—Dielectric loss in condenser.

2—I^2R loss in discharge gap G.

3—I^2R_1 loss in line, where R_1 is the ohmic resistance of the line possessing inductance L_1 and L_2.

4—I^2R' loss where R' is the ohmic resistance or its equivalent of that portion of circuit where it is desired to convert the energy $1/2\ CV^2$ into heat.

5—Radiation loss. This is the radiation

of energy utilized in radio telegraphy and is quite negligible for low frequencies.

6—Losses in the transformer D which feeds the oscillatory circuit.

It is indifferent whether R′ is a resistance located in the oscillatory circuit or whether it is a resistance in an inductively coupled circuit, *i. e.*, in the oscillation resistor, or the sum of these. And because the secondary circuit constitutes but a single turn within the mass and the inducing circuit has several turns, the magnitude of the current in the oscillation resistor is correspondingly great.

In speaking of the "mass" I desire to make clear that, though in some uses of my invention the oscillation coil may operate upon a thick mass, the shape may vary widely according to the application intended and may be, for example, a mere shell of cylindrical or other shape, solid, in paste form, molten or normally liquid.

It will be noted that the oscillation coil O in the illustration forms a part of two circuits. It is part of the secondary alternating circuit for charging of the condenser and also constitutes an oscillation primary in the discharging circuit for the oscillation resistor as a secondary.

In the effort to transmit the energy stored in potential form in the condenser to the conducting material heated with maximum efficiency, it is indifferent, within wide limits, what may be the natural frequency of the oscillatory circuit. The efficiency which we wish to get is

$$E_f = \frac{p}{P}$$

where p is power dissipated and held as heat in the oscillation resistor and P the power supplied at the primary terminals of the transformer.

To obtain high efficiency the following losses must be small:

1—Dielectric loss. (Low frequency of oscillation will contribute to make this loss small.)

2—I^2R_1 loss in discharge gap.

3—I^2R_1 loss in line. To make this loss small the ohmic resistance of L_1, L_2, L_3, and L_4 must be kept low.

If L_1 and L_2 are large (which does not affect power) and their ohmic resistance is negligible they will not diminish the power transmitted in the oscillation circuit while the potential drop will take place chiefly over them, so that the potential drop at the ends of the oscillation coil O, measured at *e* in Fig. 1 can be kept comparatively low. This will facilitate insulation between the coil and its secondary.

With each surge of the oscillatory current through the coil circuit, there will be a tendency of the supply current to short circuit through the ionized air across the discharge gap. This may be controlled by the inductance L_3, L_4, of the supply circuit or by other means, such as blowing out the discharge.

Since the supply of alternating current will seldom agree in voltage with that desired to charge the condenser, the circuit will more usually be as indicated in Fig. 2, where the supply circuit A, N, is transformed at D and the condenser is charged from the secondary transformer connections *a*, *n*. While the short circuiting of the supply, (here taking place in the secondary) across the discharge gap, can still be controlled by primary inductance, or by special provisions for blowing or vacuum at the discharge, it is more desirable to control it by inductance in that portion of the circuit between the discharge gap and the transformer secondary, indicated diagrammatically at l_3 l_4. The discussion of Fig. 1 is then applicable to this form also with the change in symbols from A, N, to *a*, *n*, and L_3, L_4, to l_3, l_4. In Figs. 1 and 2 the oscillation coil may be placed in the discharge gap connection, free from the charging circuit, as in Fig. 3ª if desired.

In Fig. 3 I have illustrated my invention as applied to a multiphase circuit without unbalancing the phases, selecting two phase for the illustration because it presents the simplest form and, therefore the form capable of easiest clear explanation.

Because transformers will be required usually to step-up the voltage from that available to the much higher voltage under which my invention becomes most efficient, I have shown transformers here, the system being practicable wherever two phase current may be obtained. The transformers can be omitted where the commercial current is of suitable voltage.

The two phase primary circuit has sides A and B and neutral N and supplies transformers D and E. The secondary of transformer D is connected with one side each of discharge gap G and condenser C′ by conductors *a*, *a′* and a^2, and with the other side of the discharge gap and condenser by conductors, *n′*, *n*, n^2, n^3 and n^4. Likewise the secondary of transformer E is connected with the two sides of discharge gap G′ and condenser C^2, by conductors *b*, *b′*, b^2 and n^5, n n^2, n^3 and n^6.

The windings L^2, and L^3, respectively, of a reactance coil L′ are placed in series with the discharge gaps G and G′, and their connections *n′*, *n* and n^5, n; and the oscillation coil O may be placed in the charging circuit in the common connections n^2, n^3, therefor, or coils may be placed in the discharge gap connections *a′*, *b′*, where distant location of the coils makes this desirable.

There are condenser charging expedients, at present well known, which do not require

alternating currents. Since they are in the nature of makeshifts or substitutes and, so far as they are successful, are electrical equivalents of the alternating current charging source, I desire to be understood as including them within my claims where the latter include alternating current and these substitutes can be used in the combinations stated.

Fig. 3ª shows other connections suitable to use with a local charging circuit including the condenser or condensers and the induction coil or coils and an oscillation coil or coils, the discharge gap being permissibly placed at any point in the discharge circuit.

If no transformer be needed to vary the voltage of the alternating supply circuit, the sides A, B would be connected directly to conductors *a* and *b* and the neutral to *n'* and n^5.

In the use of multiphase supply it will be noted that the discharge from different condensers will occur at different times, since they are charged by currents of different phase.

In any condenser operation, if short circuiting of an alternating current condenser charging circuit through the condenser discharge gap or gaps be prevented by the introduction of inductances in this supply (whether transformers be used or not) there is a considerable advantage in the use of multiphase currents since they make it possible to use a common core for the inductance coils in the different phases, returning to the other phase or phases energy which would otherwise be spent uselessly in the discharge gap, if the useful transfer of energy from phase to phase were not provided.

This transfer of energy from phase to phase between inductances in multiphase circuits can be used with great advantage not only in the arts in which an oscillation coil is used to apply heat to an oscillation resistor, which forms part of my invention claimed herein, but both the process and apparatus are also applicable to other arts, where the heating effect is not of importance, such, for example, as in the arts of wireless telegraphy and telephony, and this subject matter is intended to be claimed by me as broadly new.

Application of this inductance coil energy transfer between phases to the remainder of my invention herein will be clear from Fig. 3, where the two reactance coils L^2, L^3, are wrapped about a common core L^4. As a result, when the voltage in phase A, (Fig. 7), rises to some such point as *p*, charging the condenser C', the inductive action of the coil L^2, upon the coil L^3, to some extent affects the voltage, (or the phase of the voltage) being impressed by phase B, through coil L^3, upon condenser C^2. The gap G now breaks down and the secondary at D is put on short circuit through the gap G. The rush of current which tends to follow, magnetizes the core, and the energy represented by this magnetization is in part transformed to the coil L^3, hastening or retarding, (according to the relative directions of the windings on the core), the rises of voltage being impressed upon condenser C^2. The same action takes place when condenser C^2 is being charged and when gap G' breaks down.

Thus the energy stored in each transformer, is thrown into the system of circuits joined to the other transformer instead of being spent in heating at the discharge gap. This "trading" of energy causes each of these phases to assist the other, and the energy which would otherwise be dissipated in the discharge gaps is greatly reduced.

It is to be noted that the inductance represented by the windings upon coil L', will prevent all high frequency oscillation currents from finding their way back into the transformers D and E, confining them to the circuit shown in the lower part of the figure through the oscillation coil and discharge gap.

In operation, the multiphase electro-motive forces are impressed upon the primaries of the two transformers D and E and the condensers C' and C^2 are charged through reactance coils L^2 and L^3 and with the particular connections shown, also through oscillation coil O, until their capacity is reached with the discharge gap adjustment used.

As each discharge gap breaks down the oscillatory currents will surge through the oscillation coil O, acting as a primary and will induce oppositely directed current flow in the resistor W, forming the oscillation secondary, the current flow in the oscillation secondary being in substantially parallel planes or strata to that in the inducing oscillation coil.

The successive chargings of the condensers will alternate, as will also their discharges, at irregular intervals dependent upon the capacities of the condensers, the applied voltage, the separation of the discharge gap and possibly other variables, a rapid series of heating impulses which also have a stirring action proportionate to the energy input per volume of molten or liquid resistor.

The condensers are preferably of equal capacity and their capacity and break-down strength limit the power. For good glass approximately one cubic foot of glass is required per k. w.

In Fig. 4 I have shown in more extended diagrammatic form, a discharge gap adapted for use at the gaps G and G'. Here the ends at G and G' are provided with nozzles G_2 and G_3 capable of operation with either

vacuum or air pressure, to reduce the arcing, and the bar G_4 carrying contacts G_5 and G_6 is adjustable as by screw G_7 operating in a support G_8.

I have illustrated my invention by application to an electric induction furnace, and will describe its use in connection with the particular furnace shown in Figs. 8 and 9, to which the principles are well adapted, but which is described by way of illustration and not limitation.

I would expressly point out that though there is patentable novelty in the application of the broad invention to the furnace art, and to the particular furnace illustrated, electric furnace operation is one only of various uses of the broader invention.

Successful furnace operation requires rapid transfer of heat between the metal most actively heated and the remainder of the metal. This must be by conduction or by circulation or both. In existing gas and coke furnaces, conduction and Joule effect within the pool are relied upon and have proved fairly satisfactory. In the various electric induction furnaces heating the metal in channels connected with the pool, the opportunity for conduction is poor and circulation by pinch effect, motor effect or Joule effect is largely relied upon to obtain and maintain substantial uniformity of temperature. Moreover, in most at least of these channel induction furnaces, the more highly heated metal must be removed from the channel to the pool rather quickly to avoid overheating within the channel. This is particularly true with such metals, as brass, as contain easily vaporizable contents whose vaporization will vary the cross section of or break the (secondary) channel circuit and also cause a change of proportion of content. The narrow range of temperature available in such a metal may be seen from the fact that brasses melt at 940 C. and zinc begins to vaporize from brass at 1090 C.

For furnace operation my invention possesses the advantage of inducing closed currents of electricity in the furnace or crucible pool, as distinguished from utilizing a channel or other outlying path. The oscillation coil may conveniently surround the pool and lie in any desirable plane or series of parallel planes inducing current flow in the pool in planes parallel to its own. It is most convenient to place it horizontal with the crucible furnace shown.

The freedom from channels and other outlying containers of molten metal makes my furnace more nearly comparable with existing gas- or coke-heated crucible furnaces and the position of the induced current path within the metal still further helps in unifying the temperature of the pool.

Though theoretically the induced currents within the pool are distributed over a large part of the body of the pool in closed conducting lines, "skin effect" causes the current to be somewhat more concentrated in the outer portion of the pool than in other parts, heating the outer circumference most rapidly and providing its large conduction area for transfer of heat to the inner part of the pool. Joule effect is also present. The direction of current flow in the oscillation coil is indicated by the outside arrows in Fig. 5, the inside arrows indicating the direction of induced current within the pool.

The electric current flow near the circumference may be made as great as desired by the proportioning of the cross section to the current, with the result that this current flow within the oscillation resistor, can be made great enough to develop useful "pinch" contraction of the current-carrying metal, giving commercially practical stirring, which is particularly useful with the circumferential heating of the pool by the current in it or in the crucible walls. For all practical purposes "pinch" effect has previously been regarded as confined to passages of small cross section used in connection with pools.

The stirring movement is due to combined pinch and Joule effects and is quite noticeable in the molten pool when the oscillation current is passed through the surrounding coil. Its direction, however, can not be so accurately determined from observation. It probably takes places within radial planes through the coil axis, with greatest concentration at about the middle of the coil height and an inward and upward direction there, about as indicated in Fig. 6. The center of the pool lifts above its normal level, which would confirm this.

Since the metal of the pool is heated along the outside throughout the whole of its vertical height, the oscillation coil stirring effectually mixes the metal. The concentration of relatively hot metal at the center of the top of the pool obtained by this circulation, at the point where fresh charge is put in, tends also to equalize the temperature reducing the temperature difference as the charge is melted.

I have shown how effective stirring may be obtained. The question of its need is dependent so much upon the speed of heating or melting required, the heat losses planned, the heat conductivity and other characteristics of the material being heated, the quantity of fluid being handled, the shape of the pool, the range of difference in temperature permitted by the intended use and other factors determined by the character of installation that the use made of this stirring must be left to the engineer. Where the crucible is a conductor of electricity or where but a very small energy input per

volume is required, for the temperature results sought, there will be little or no oscillation stirring. On the other hand, an induction furnace, melting metals and planned to secure maximum output will utilize a large induced current density and will need and obtain corresponding stirring benefit. Obviously additional stirring can be employed if special circumstances require it, but this is neither necessary nor desirable under normal circumstances.

Though the stirring effect is secondary in my view to the heating effect of the oscillation current, and may be omitted or disregarded, as shown, in some applications of my invention, it is not for that reason unimportant, as the stirring may be proportioned to the need by varying the current density, enabling the designer to so proportion the oscillation current and volume or shape of the pool of the crucible or furnace as that the conduction, Joule effect and "oscillation stirring" will maintain substantially uniform temperature conditions throughout the body of the furnace, and I purpose claiming this "oscillation stirring" broadly as applicable not only to induction furnaces, but to the stirring of any molten or otherwise liquid electrically conducting mass.

In the furnace illustrated in Figs. 8 and 9, I have shown a crucible furnace having the crucible fixed at the time of use and with bottom outlet, because the simplicity, reliability, economy in labor and operation and low cost of this form make it the most desirable and because notwithstanding the ideal character of this furnace, induction heating has not been previously applied to it successfully.

The crucible 10 is removable for cleaning and replacement and may be removed for pouring by lifting mechanism engaging with the crucible and already known in the furnace art. This is suggested sufficiently for present purpose by holes 11. I prefer to give the crucible a bottom outlet 12 for pouring purposes, placing it off-center, in order to give as much room as possible for charging. The crucible is formed of any suitable refractory, which may be an electrical conductor or a non-conductor as suits the needs of the installation or the preference of the engineer. It is most desirably of sufficient mechanical strength to permit the metal to be chilled in it without breakage. The tapering of the sides of the interior crucible wall reduces the danger of breakage.

Where the crucible is itself a conductor, the lines of induced current flow will of course take place largely, if not exclusively in the walls of the crucible and the heating of the pool will be by conduction from these crucible walls.

The bath or pool content may be a conductor or non-conductor of electricity, normally liquid, or of paste consistency or fused, as barium chlorid, and may be under treatment itself or be used in treating other materials (as in tempering, for example).

The outlet 12 is closed by a refactory plug 13, of any suitable material, such as carbon, which I insert through the cover 14 and the body W of the pool. The outlet and plug are placed off-center so as to give room for charging through any opening in the cover, closed by a gap 15. The plug can be withdrawn for pouring purposes, and I show one means for this. The wheel 16 operates a sleeve 17 which turns within a bracket support 18 secured to the cover. Relative vertical movement is prevented by set screw 19 and annular sleeve groove 20. Lost motion is taken up by spring 21. The interior of the sleeve is threaded to engage with a screw 22 which is formed at its lower end as a socket at 23 to receive the upper end of the plug 13, the coupling being completed by a pin 24. The screw is kept from rotation by engagement of a non-circular part of the socket with the walls of a correspondingly shaped hole in the cover, as at 25.

The cover and plug-operating mechanism can thus be lifted without disturbing the plug and the crucible can be removed with nearly the same freedom as if intended to be lifted for pouring, known in the furnace art.

The crucible rests upon a heat insulating block 26 supported by a base 27 for both of which alberene stone is well suited. The block and base rest upon stone legs 28 and are cut away, as at 29 and 30, below the discharge opening 12, to allow free flow of metal through the block and base to any mold, not shown.

The removability of the crucible from the body of the furnace, whether required for pouring or not, requires that the furnace coil O shall be separately mechanically supported, and that it shall be particularly well insulated from the crucible. I have indicated the support and insulation as comprising cylinders 31 and 32, for which alberene and quartz, respectively are well suited. Oscillation coil O is preferably formed of edge-wound copper strip, nickel plated to prevent oxidation and is mounted upon or about the outer cylinder. Its windings are spaced and insulated by an asbestos cord 33.

Both of the cylinders are set within a recess or recesses shown at 34, in the block 26, and may be made removable from the base for convenience.

The cylinders and coils are placed within an outer insulating cylindrical casing 35 from which they are preferably spaced, as

at 36, to provide for a surrounding insulation 37, which I have illustrated as sea-sand and which may be loosely poured in place after the parts have been seated.

The cover 14 fits down into the outer casing as at 38, far enough to prevent it from side movement, and the intended position to bring its plug opening in line with the outlet in the crucible is fixed by a pin 39 or other keying means.

Outside current connection is best made from below, on account of the high currents intended to be passed through the oscillation coil O and I have provided for this conveniently by holes 40, 41 within which conductor rods 42, 43 are inserted, the connections with the two ends of coil being shown as formed by pins 44, threaded into holes in the rods and connected with the coil ends by conductors 45 and nuts 46. For convenient access to drill the holes 44′ through which the pins pass. I have provided holes 44^2 in the outer casing, which latter are subsequently plugged. The lower ends of the conductor rods are protected by tubing, preferably quartz, shown at 47, 48. The tubing is surrounded by a grounded casing 49 in each case.

Because of the high voltage utilized by the furnace and to avoid possibility of injury therefrom, I have grounded all of the metal parts, including the yoke or bracket at the top, and lifting mechanism for the plug rod and have surrounded the furnace with a grounded cage, comprising, as shown, top and bottom rings 50, 51 and connecting bars 52, to any one of which the metal parts and grounded casing may be connected.

The process and apparatus above generally described when applied to heating and stirring molten metal in a furnace, as will be seen from the mechanism illustrated, secure results closely approximating the "perfect" furnace.

It will be evident that the theory of operation, process and preferred structures used as illustrations herein, will suggest many and various forms in which my invention may be utilized by the public to heat or heat and stir liquids or molten metal, or for welding or forging purposes at temperatures lower than the melting point or barely reaching the melting point and without stirring; and that the application of the same or allied structures or processes to any such uses will embody my invention, whether additional inventive skill be required or not.

It is further evident that my invention has general utility in the transfer of power for various purposes utilizing the discharge from a condenser for the accomplishment of work at a considerable distance.

The metal can be chilled in the furnace without breakage, develops no cracks on melting and can be melted in place from the solid state.

The furnace is easy to fill and empty, the molten metal can be drawn off from below the level of the metal, and there need be no movable parts except the stopper plug and the mechanism by which it is moved.

There is a marked economy in the labor required.

The inductive electric heating is clean and uses no electrodes. My application of it produces no disruptive internal pressure forces and the path of the current in the molten metal cannot be interrupted. The metal cannot be subjected to contamination from gases and so large a mass of metal is in contact with the portion most rapidly heated that conduction greatly assists the circulation in preventing any considerable difference in temperature of different parts of the pool, minimizing the importance of circulation. There is no danger of vaporization of constituents having a low vaporization point, unless substantially the entire mass is overheated.

The types of the furnace otherwise best suited to carry out my invention facilitates heat insulation, so that substantially all of the heat generated remains in the metal.

The pool requires but little melted metal to operate well and can be started with turnings or even with more solid chunks of metal. The entire charge can be emptied and a new charge started with or without intermediate withdrawal of the crucible.

Commercial charging frequencies can be used and the furnace is capable of highly advantageous use on polyphase circuits, avoiding unbalancing of such circuits.

The primary voltage from the generator can be used where high voltages are available, avoiding step-up or step-down transformers.

The power factor may be maintained substantially at unity and the efficiency markedly increases with the size of the furnace.

It is particularly suited for melting precious metals where the requirements are most exacting and have not been satisfactorily met before.

Closely allied to furnace uses are those in which material in a path or pool, whether electrically conducting or nonconducting is to be maintained hot or heated, but in which no melting or ore reduction (such as might be performed in the furnace illustrated) is required, and I have shown two diagrammatic illustrations of such uses in Figs. 10 and 11.

In Fig. 10 an ingot mold I is provided with an oscillating heating coil O^2 for the purpose of keeping the metal hot at the mouth to prevent "piping" which has so seriously interfered with the use of the entire ingot in steel work. Here the heating

is intended to be local only and the stirring function may be negligible.

In Fig. 11 a pouring ladle K is shown with a heating coil O^3 for the purpose of keeping the metal in the ladle hot during the desirable "settling" after filling the ladle and before pouring from it. Some slight stirring would be helpful here.

It will be evident that the several uses suggested are but a few of the large number to which the broad principles of my invention are applicable. The transfer of energy to the distance by oscillatory currents, the trading of energy between phases of a multi-phase current and the induced heating effects from oscillatory discharge are separately useful in different as well as in many of the same arts. The heat-treatment of metal alone includes not only the furnace treatment of ore and metal, but tempering, annealing, forging, soldering, etc.

In treating liquids I believe that I am the first, moreover to usefully employ pinch from currents induced in a pool or bath itself, as distinguished from channel discharge into or through the pool or bath.

I recognize that, with the disclosures which I have made herein, others will be able to make many different uses of my invention and expressly desire to include within my claims all such uses as reasonably come within the broad scope of my invention.

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

1. Induction heating mechanism comprising an alternating current transformer, a condenser charged therefrom and adapted to be discharged, a transformer primary in the discharge circuit from said condenser and a heating coil secondary in inductive relation thereto.

2. An induction heating system comprising a primary alternating source of current, a transformer connected therewith, a condenser charged from the secondary of said transformer, a heating oscillation primary in the discharge circuit of said condenser and in inductive relation to the resistor to be heated, and an inductance coil in the secondary circuit protecting against condenser discharge.

3. In apparatus utilizing oscillatory currents, a multiphase current source, condensers charged therefrom, one for each phase, an inductance coil in series with each phase of the charging current, the coils having inductive relation to each other, and connections for discharging the condensers free from said coils.

4. In heating mechanism, an oscillation heating coil in inductive relation to the material to be heated, a multi-phase current source, condensers charged therefrom, inductance coils in series with the charging current, one in each phase and in inductive relation to each other, and a discharge gap located between the inductance coils and condensers for discharging the condensers through the oscillation coil.

5. In heating mechanism, an oscillation heating coil in inductive relation to the material to be heated, a multi-phase current source, condensers charged therefrom, inductive windings in series with the charging circuit, one in each phase and having a common magnetic core and discharge gaps between the windings and condensers for discharging the condensers through the oscillation coil.

6. In a heating system, an oscillation heating coil in inductive relation to the material to be heated, a multi-phase current source, condensers connected with the oscillation coil, discharge gaps for discharging the condensers through the coil and connections between the current source and the circuit including the coil, condensers and discharge gaps for charging the condensers, said connections having inductive windings about a common core adapted to trade energy from one circuit of said connections to another.

7. In a heating system, oscillation heating coil provision in inductive relation to the material to be heated, two condensers and two discharge gaps forming discharge circuits through the oscillation coil provision, two charging circuits, one for each condenser and passing through windings upon a common core providing inductance and adapted to trade energy and a multi-phase current source for said charging circuits.

8. In an alternating current heating system, oscillation coil heating means, a plurality of condenser and discharge gap circuits adapted to discharge therethrough, separate charging circuits for said condensers having windings in series therewith upon a common magnetic core and multiphase current supply for the charging circuits.

9. In an induction heating system, a primary source of electric current, a transformer connected therewith, a reactance coil connected in series with the transformer secondary, a condenser charged from the secondary, a discharge gap across the charging circuit between the condenser and reactance coil and a coil surrounding the resistor to be heated and included in the discharge circuit from said condenser.

10. In a heating device, an electrically conducting coil, an electrically conducting container therein adapted to hold material in liquid form and free oscillation current supply for said coil.

11. In a heating device, a source of electric current, a condenser charged therefrom, a discharge gap for the condenser and an oscillation coil through which the condenser is adapted to discharge in inductive relation to electrically-conducting material to be heated.

12. In a heating device, a source of electric current, a condenser charged therefrom, an oscillation coil adapted to surround a liquid pool and connected in the charging circuit and a discharge gap across the condenser on the far side of the coil therefrom.

13. In a heating and stirring device, a container having a draining outlet, a heating and stirring oscillation coil thereabout, and free-oscillation current supply for said coil.

14. In a heating and stirring device, a container for an electrically conducting pool and having a bottom outlet, a plug for said outlet extending down through the pool and induction means setting up closed current paths in said pool for heating the pool and stirring it.

15. In a heating device, a two-phase current supply, two condensers, one charged from each phase of the supply, two reactance coils, one in series with each phase of the charging circuits, the two coils having a common core, a container for a pool, an oscillation coil in series with each phase of the charging circuits and surrounding the pool and break-down discharge means for the condensers, discharging in each phase through the oscillation coil.

16. In a heating device, an induction coil, a crucible insertible into and withdrawable from the coil and an oscillation current supply for the terminals of the coil.

17. In a heating device, a crucible having a draining outlet and direct induction means for causing closed lines of electric current flow within the content to heat it.

18. In a heating device, a crucible having a draining outlet, a plug for closing said outlet, passing through the body of the pool, a conductor surrounding the crucible, a condenser connected with said conductor, means for charging said condenser and means for discharging the condenser through the conductor.

19. In a heating device, a furnace adapted to contain a pool and to remain fixed during use, in combination with a coil surrounding the furnace and free oscillation current supply for the terminals of said coil.

20. In a heating device, a vertically movable crucible, a hollow coil support within which said crucible is removably inserted, a substantially horizontal oscillation coil surrounding the support, insulation for said coil and condenser means for supplying current to said coil

21. In a heating device, an oscillation coil, insulation therefor, a crucible within the coil and having an off-center draining outlet and free oscillation current supply for the terminals of said coil.

22. In a heating device, a removable crucible having a draining outlet, a furnace casing from which said crucible is removable, a coil winding in said furnace casing in proximity to the crucible and connections for transmitting primary current through said coil to induce secondary current flow in the crucible.

23. In a heating device, a crucible having generally cylindrical outer contour and bottom outlet and adapted to contain a pool, a casing within which the crucible is removably supported and a cylindrical coil winding within the casing close to the opening for the pool.

24. In a heating device, a crucible, in combination with an edge-wound coil conductor surrounding the crucible.

25. In a heating device, a hollow coil support, an edge-wound oscillation coil thereabout and a crucible removably supported within said support.

26. In a heating device, a base, a refractory annular insulation removable therefrom, a coil winding upon said insulation, an outer protective casing, insulation between the annular insulation and casing and a furnace crucible removably supported within the annular insulation.

27. In a heating device, a crucible, an oscillation coil thereabout, connections for said coil, insulation about the coil and connections and a grounded metallic frame about said crucible and coil for protection against current leakage therefrom.

28. The method of heating a body of material constituting a bath or pool which consists in utilizing electrically conducting material for the walls of the container and in passing currents having free oscillation about the container to induce current flow in the container as a secondary.

29. The process of charging and discharging condensers which consists in charging the condensers in parallel through reactances in inductive relation to each other and in discharging the condensers through discharge spark gaps located between the reactances and the condensers.

30. The process of charging and discharging condensers which consists in charging the condensers in parallel from multi-phase current supply through windings having common magnetic core and giving reactance and in discharging the condensers independently and free from said windings.

31. The method of transmitting energy from place to place at a distance which consists in converting stored potential energy

into electric current having natural, as distinguished from forced frequency, in transmitting it to a distance in this condition by conductors and in transforming it at the point of use for heating purposes.

32. The method of utilizing electric potential energy at a distance which consists in storing the energy in condensers, in discharging the condensers through conductors extending to a distant point and through a conducting coil located at that point and in inductively coupling the coil and the work at the point of use for heating purposes.

33. The method of utilizing at a distance electric energy stored in a condenser which consists in charging a condenser through a local circuit at one point, in discharging it through conductors extending to a distance point and in there utilizing the oscillatory discharge from said condensers.

34. The method of utilizing at a distance electric potential energy stored in a condenser which consists in charging the condenser through a local circuit including an inductance coil and in discharging the condenser through a different circuit excluding the inductance coil and extending to a distant point, and in there passing the discharge through a transformer coil and utilizing the induction from said coil for the production of heat within a material adapted to be heated

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