

Aug. 10, 1926.

1,595,970

J. M. WEED

INDUCTION FURNACE

Filed Dec. 29, 1921

3 Sheets-Sheet 1

Fig. 1.

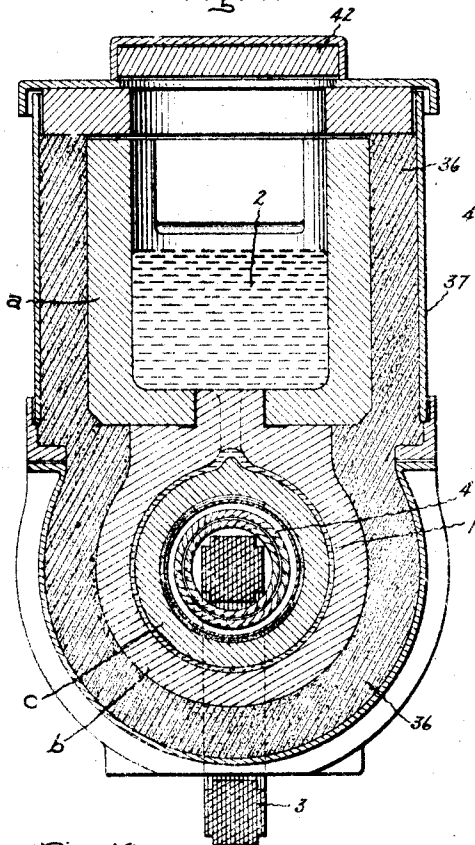


Fig. 2.

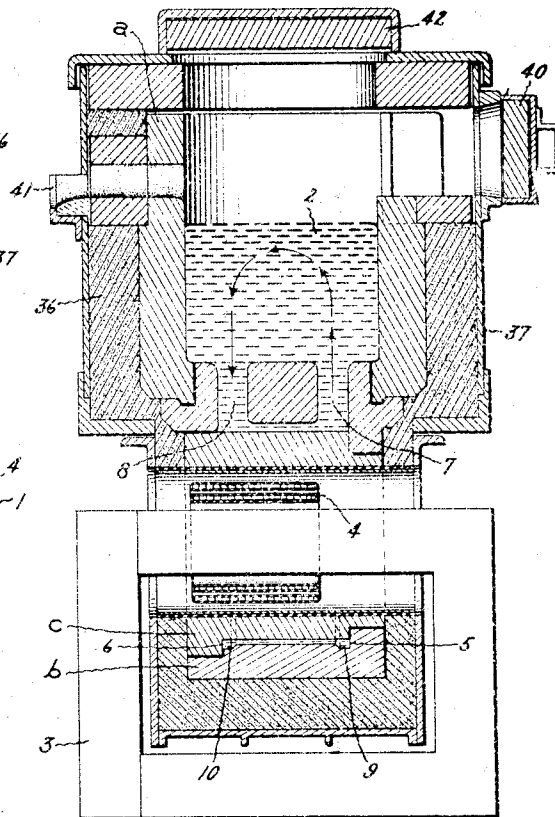


Fig. 10.

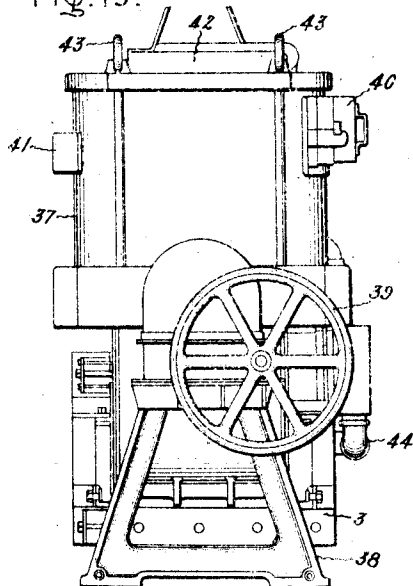
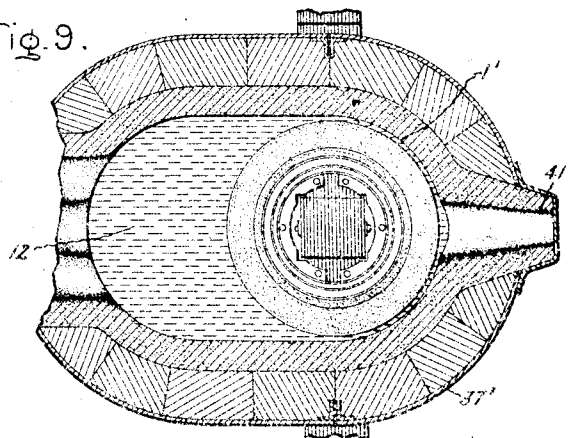


Fig. 9.



Inventor:
James M. Weed,
by *Alfred B. Davis*
His Attorney.

Aug. 10, 1926.

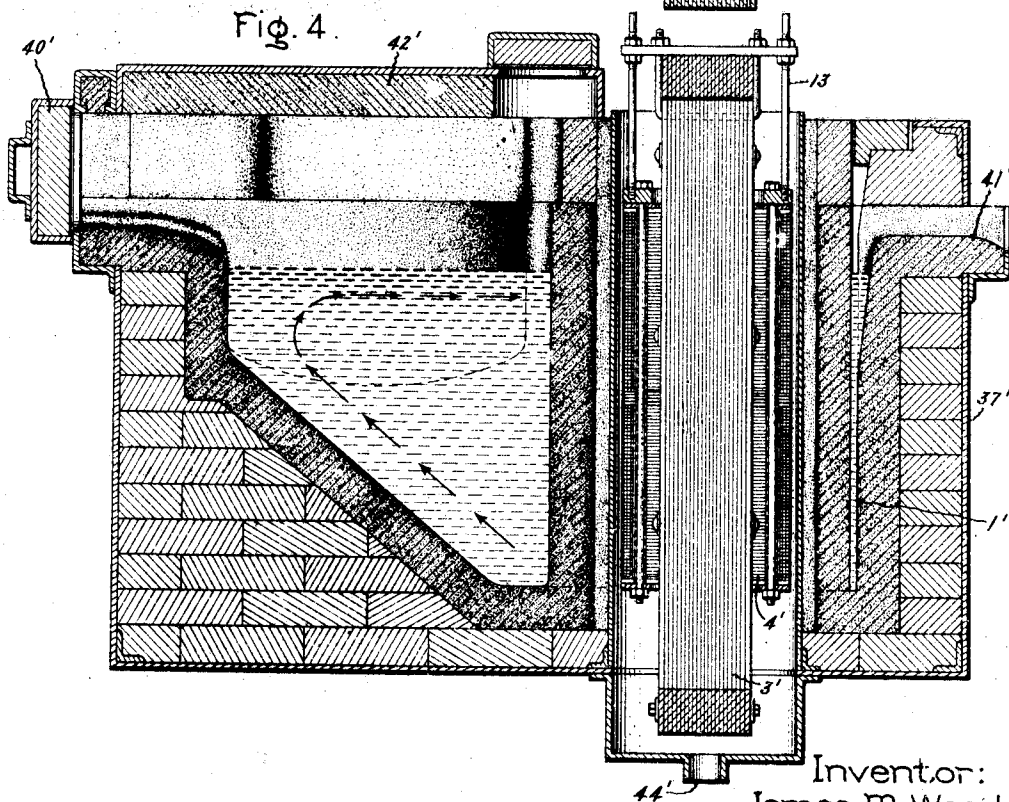
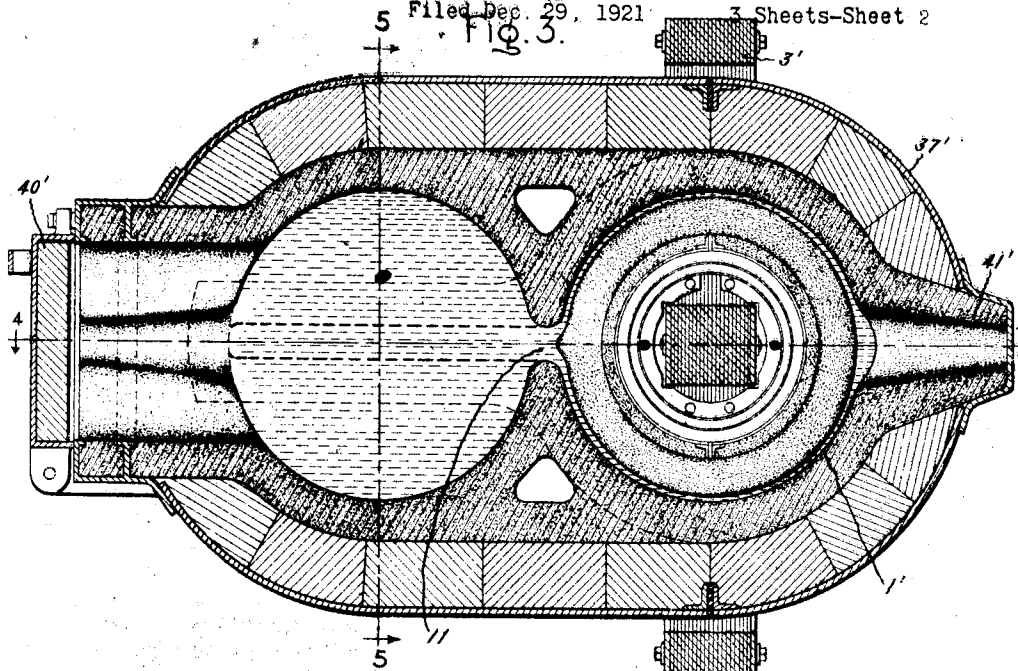
1,595,970

J. M. WEED

INDUCTION FURNACE

Filed Dec. 29, 1921

3 Sheets-Sheet 2



Inventor:
James M. Weed,
by *Alfred H. Davis*
His Attorney.

Aug. 10, 1926.

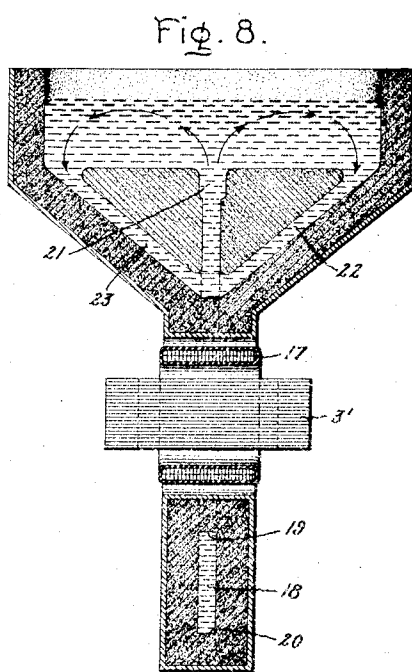
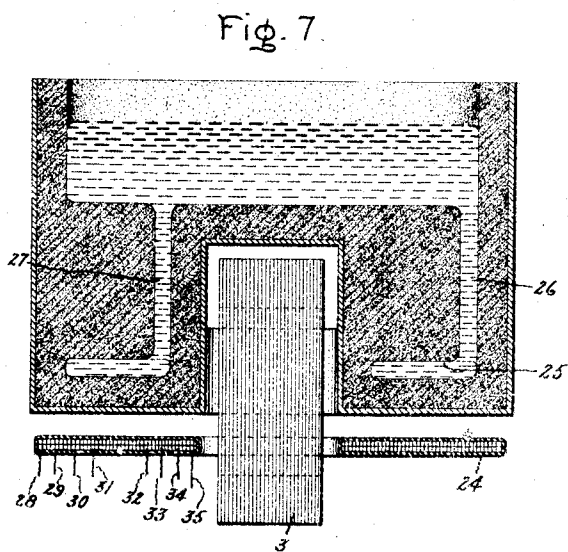
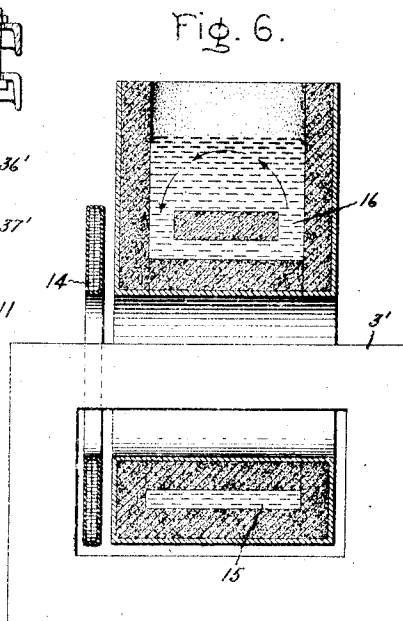
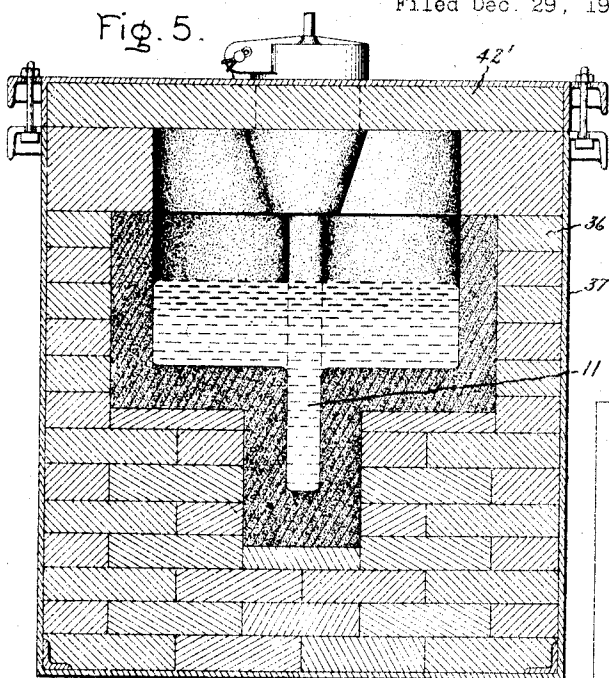
1,595,970

J. M. WEED

INDUCTION FURNACE

Filed Dec. 29, 1921

3 Sheets-Sheet 3



Inventor:
James M. Weed,
by *Allen H. Davis*
His Attorney.

Patented Aug. 10, 1926.

1,595,970

UNITED STATES PATENT OFFICE.

JAMES M. WEED, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INDUCTION FURNACE.

Application filed December 29, 1921. Serial No. 525,630.

My invention relates to electric induction furnaces and in particular to the class of furnaces in which the receptacle for the charge comprises an annular or looped portion of relatively small cross section within which the charge acts as secondary, and in communication therewith, a chamber or reservoir for increasing the furnace capacity for charge.

10 It is the object of my invention, which includes a new method as well as a new apparatus, to provide a furnace with more advantageous and controllable circulation of charge between the reservoir and looped portions of the receptacle than heretofore obtained. For this purpose I utilize a principle not previously used in induction furnaces, namely, the electromagnetic reaction between primary and secondary, these being so disposed as to give differences of fluid pressure between different parts or regions of the secondary. I make at least two such regions of different pressures, preferably those adjacent to the two most widely separated opposite bounding surfaces of the container for the secondary, to open into or communicate through respective ducts with different parts of the reservoir, so that the pressure difference can act in producing a desired circulation of the charge.

A more detailed description of my invention is given in the following specification taken in connection with the accompanying drawings, in which Figs. 1 and 2 are vertical sections taken at right angles to each other of a preferred embodiment of my invention; a modification is illustrated in Fig. 3 by a horizontal section, and in Figs. 4 and 5 by vertical sections taken at right angles to each other; Figs. 6, 7 and 8 are vertical sections of other modifications of my furnace; Fig. 9 is a horizontal section of another modification; and Fig. 10 is a perspective view of the form of my furnace shown in Figs. 1 and 2.

The furnace shown in Figs. 1 and 2 comprises a refractory receptacle constituted by a looped portion 1 of relatively small cross-section, and a reservoir of greater cross-section adapted to contain a pool 2 of fluid charge, a magnetic circuit or core 3 interlinked with the looped portion, and a primary winding 4 mounted on the core 3. The charge in the looped portion, which in this case is cylindrical in form, constitutes a

secondary with respect to the primary winding 4. Conveniently, the crucible or receptacle for the charge, is constituted by pre-formed members of suitable refractory material, for example, fused magnesia, which may be dried and fired before being assembled in the furnace. These refractory members *a*, *b* and *c* are cemented together at the joints when assembled in the furnace.

The two most widely separated opposite bounding surfaces of the secondary 1 are those at the ends of the cylinder, designated as 5 and 6. With the co-axial arrangement of primary and secondary illustrated in Figs. 1 and 2, in which they are offset or displaced from each other in an axial direction, the maximum fluid pressure in the secondary due to the repulsion of the primary is found near 5, the end of the cylinder most remote from the primary, while minimum pressure is found near 6, the end nearer the primary. Communicating ducts 7 and 8, respectively, are therefore provided between these regions of maximum and minimum pressure and different parts of the reservoir to permit circulation of molten charge in the direction indicated in Fig. 2 by the arrows.

The amount of the pressure difference which produces this circulation, and consequently the rapidity of the circulation, may be varied or adjusted by changing the geometric relation of the primary winding with respect to the secondary. Assuming that the position of the primary 4 shown in Fig. 2 gives maximum circulation, the circulation will be reduced by shifting the primary to the right. When primary and secondary are of the same axial length, as in the present case, and are flush with each other in an axial direction, the circulation will practically cease. If the primary is shifted still further, resulting in displacement in the reverse direction, the direction of circulation will be reverse. It is thus possible to control both the strength and the direction of the circulation of the molten charge in the furnace of Figs. 1 and 2 by adjusting the position of the primary winding in an axial direction.

The circulation within those portions of the secondary which are not on the same side of the cylinder with the ducts 7 and 8, is facilitated by the annular enlargements 9 and 10 at the ends of the cylinder 1 con-

stituting the secondary. The enlargement 10 in Fig. 2 distributes the molten material coming in through duct 8 more or less uniformly around the left hand end of the cylinder 1, while the enlargement 9 re-collects the material and leads it to the outgoing duct 7. Within the body of the cylinder 1, between its two ends, the general trend of the circulation will be in an axial direction, from left to right. A free continuous circulation is thus maintained between the secondary and the reservoir, which passes throughout the entire secondary cylinder, thus avoiding all danger of hot spots; and thus maintaining an almost uniform temperature throughout the molten charge within the entire crucible. The refractory crucible 1, 2 is surrounded by a layer 36 of suitable heat insulating material, for example, the commercial product known as Sil-O-Cel, and an outer shell 37 of steel or other suitable metal, so constructed to avoid a conductive circuit about the core in which a secondary current would be induced.

In Fig. 10 is shown in side elevation a complete furnace of the form shown in section by Figs. 1 and 2. The furnace is mounted upon a pedestal 38 in such a way as to permit tilting for pouring the charge. This is done by means of the hand-wheel 39. The charge is introduced by a door 40 and poured from the spout 41. A pivoted cover 42 permits access to the furnace interior for various purposes. The furnace as a whole can be lifted by eye bolts 43. Air for cooling the primary winding is supplied by a pipe 44.

The modified furnace illustrated in Figs. 3, 4 and 5 differs from that in Figs. 1 and 2, chiefly, first, in the relative positions of the reservoir and the annular secondary-containing portions of the crucible, and second, in replacement of the ducts 7 and 8 by a single opening or channel of communication. In the form of furnace shown in Figs. 1 and 2 the secondary is beneath the reservoir with its axis horizontal, while in the modification shown in Figs. 3, 4 and 5, they are beside each other, the axis of the secondary being vertical. The circulation of the molten charge is controlled in the latter case by movements of the primary winding in a vertical direction. With the primary winding positioned as shown in Fig. 4, maximum pressure due to the repulsion of the primary will be found at the bottom of the secondary, and minimum pressure at the top. This difference in pressure will result in a flow of the molten charge from the bottom of the secondary to the reservoir, and from the reservoir back to the top of the secondary, as indicated by the arrows. Parts in Figs. 3 to 9 corresponding to similar or identical parts of Figs. 1 and 2 have been indicated by the

same numerals with the addition of a "prime" mark.

Assuming that the primary winding in Fig. 4 is in a position giving maximum velocity of circulation, the circulation will be reduced by lowering the position of the primary relative to the secondary, and will be reversed in direction when the primary passes through the position of symmetry with respect to the secondary cylinder. The position of the primary coil 4' may be adjusted to vary the circulation by turning the nuts upon the frame 13.

With a free passage 11 between the secondary and the reservoir, extending from the point of maximum pressure to that of minimum pressure, a flow will naturally be produced from the secondary to the reservoir at the point of maximum pressure and from the reservoir to the secondary at the point of minimum pressure, while the charge will be stagnant in that part of the channel opening into the secondary at points of neutral pressure. It is clear, therefore, that the principle of operation, so far as the production of circulation is concerned, is the same whether separate ducts are used for connecting the secondary with the reservoir, as in the furnace in Figs. 1 and 2, or whether the wall between these ducts is eliminated, forming one common channel, as in the furnace of Figs. 3, 4 and 5.

Since there is no definite limit to the width or thickness of the channel 11, it is clear that it might be increased, if desired, to the full diameter of the secondary, or full width of the reservoir, thus causing the reservoir to become, in effect, a mere enlargement of one side of the secondary, as illustrated for instance at 12, in Fig. 9.

My invention may be embodied in various other forms of furnaces, all involving the same general principle. Three other modifications have been illustrated in simplified form in Figs. 6, 7 and 8, respectively.

The modification shown in vertical section in Fig. 6 is similar to the one of Figs. 1 and 2 except for the form and position of the primary winding. This winding 14 is disc shaped instead of cylindrical in shape, and is located at one end of the secondary cylinder. The circulation of the molten charge in this furnace will be similar to that of the furnace illustrated in Fig. 2, entering the reservoir by a duct 15 and leaving by a duct 16.

In the modification illustrated in Fig. 8, the primary winding 17 is cylindrical in shape, while the secondary-containing annular part 18 of the crucible is disc shaped. The two most widely separated, opposite bounding surfaces of this secondary are the inner and outer circumferential surfaces 19 and 20. With the symmetrical concentric arrangement of primary and secondary here

shown, the secondary surrounding the primary, the maximum fluid pressure in the secondary due to the repulsion of the primary, is found nearer its outer circumferential surface 20, while minimum pressure is found near the inner circumferential surface 19. Communicating ducts are therefore provided between these regions and different parts of the reservoir. Duct 21 serves the region of maximum pressure, while for purposes of symmetry, the region of minimum pressure is here served by two distinct ducts 22 and 23.

In the modification shown in Fig. 7, both the primary winding 24 and the secondary 25 are disc shaped, and they are located in parallel planes perpendicular to their common axis. The secondary communicates with the reservoir through ducts 26 and 27, the former leading from a region near the outer periphery and the latter from a region near the inner periphery of the secondary 25. The total primary winding is of greater radial extent than the secondary, its internal diameter being smaller and its external diameter being larger. This winding, however, is provided with terminal leads 28 and 35, and in addition with tap leads 29 to 34, making it possible to excite one portion of the winding, while other portions are left unexcited. If now primary connection is made to leads 31 and 35, exciting an inner portion of the primary winding, the outer portion being unexcited, circulation will occur from the secondary to the reservoir through duct 26, and from the reservoir to the secondary through duct 27. If connection is made to leads 30 and 34 instead of 31 and 35, the circulation will be in the same direction as before, but with reduced velocity. If connection is made to leads 29 and 33, the direction of the circulation will be reversed. And finally, if connection is made to leads 28 and 32, this reverse circulation will be increased in velocity. The modification shown in Fig. 7 thus differs from those shown in the other figures, not only in the fact that both primary and secondary are disc shaped, but also in its modification of the method illustrated in some of the other figures for controlling the direction and the velocity of the circulation. Where, in other cases, this control is effected by shifting the physical position of the primary winding without changing its excitation, in this case it is effected by a change in the portion of the winding which is excited, the position of the winding as a whole being unchanged.

A better understanding of the origin and location of the pressure difference producing circulation in my furnace may be obtained as follows: Concentrating attention upon the particular form shown in Fig. 6,

we will consider the contents of the cylindrical secondary in this furnace as subdivided into a number of annular parts by parallel planes, which are perpendicular to the common axis of primary and secondary. The magnetic leakage field between primary and secondary in this case is in a generally radial direction, and parallel to the above-mentioned planes. The density of this field is maximum within the region between the primary 14 and the left-hand (nearest) end of the secondary 15, but it extends throughout the space occupied by the secondary itself, with density gradually diminishing from the left-hand end (nearest to the primary) to the right-hand end (farthest from the primary). A stress exists in any magnetic field in the form of pressure exerted in directions at right angles to the direction of the field. The magnitude of this stress at any point is proportional to the field density at that point. Within any section of the field at right angles to its direction, the magnetic stresses at different points react upon each other, and only make themselves felt mechanically between points of different density, where the opposing magnetic stresses are unequal.

Considering now the action of the magnetic leakage field which has been described upon a given annular portion of the secondary, we find that the pressure upon the left-hand side of the annular portion (nearest to primary) is greater than the opposing pressure upon the right-hand side (farthest from the primary). The difference between these pressures will therefore be transmitted mechanically as a fluid pressure from the portion of the secondary under consideration to the next adjacent part on the right (further from the primary). Going from the end of the secondary cylinder nearest to the primary to the end farthest away, this unbalanced pressure in each part is added to that which is transmitted to it from the preceding portion. The maximum fluid pressure, therefore, is found at the end of the secondary farthest from the primary, where the density of the magnetic leakage field is minimum, while minimum fluid pressure is found at the end nearest to the primary where the density of the field is maximum.

The considerations thus outlined with respect to the form shown in Fig. 6 may be applied directly to the form of Fig. 8 by merely observing that the magnetic leakage field between primary and secondary is in a generally axial direction in the latter case instead of radial. Maximum pressure in this case is found near the outer periphery of the secondary, which is farthest from the primary, and where the density of the magnetic leakage field is minimum, while minimum pressure is found

near the inner periphery which is nearest the primary and where the density of the field is maximum.

In the forms shown in Figs. 1 to 5, the directions of the magnetic leakage field are not radial, nor yet axial, but more or less diagonal. Only the radial component is effective in the production of pressure differences between the two ends of the secondary cylinder. It is found that the density of this component is minimum, and therefore, the pressure is maximum at the end which is farthest removed from the primary as a whole.

In the form shown in Fig. 7 also, the direction of the magnetic leakage field is more or less diagonal, and in this case only the axial component is effective in producing the pressure difference found between inner and outer peripheries of the disc shaped secondary.

A characteristic of my invention, which may be seen in all the described furnace modifications, consists in a disposition of primary and secondary such that the secondary may be divided by imaginary surfaces, parallel to the direction of flow of secondary current, into complete circuit current carrying elements or parts, of varying inductive relationships with the primary, with provision for direct communication between a part of relatively high inductive relationship and an auxiliary charge containing reservoir, and also between a part of relatively low inductive relationship and the reservoir. A circulation of charge, from the part of the secondary of lower inductive relationship to the reservoir, returning from the reservoir to the part of higher inductive relationship, is generated by a difference in fluid pressure due to the electromagnetic repulsion between primary and secondary, this fluid pressure being greater for those parts of the secondary which are in lower inductive relationship with the primary.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. The method of operating an induction furnace in which the charge constitutes a closed secondary, which consists in inducing an electric heating current in the secondary by an alternating electromagnetic field, applying said field so that a difference of fluid pressure is created between different regions of said secondary by electromagnetic repulsion, thereby producing a unidirectional flow of charge through said secondary, and allowing return flow of said charge through a region external to said secondary.

2. An induction furnace comprising a crucible providing a reservoir for the charge and a cylindrical chamber in which a portion of the charge forms a closed secondary, said chamber communicating with said reservoir at axially spaced points of said cham-

ber, and a primary winding associated with said secondary arranged to produce a circulation of charge between said reservoir and chamber by electromagnetic repulsion.

3. An induction furnace comprising a crucible providing a looped channel in which the charge forms a closed secondary, and a primary winding associated with said secondary disposed to produce a flow of charge from one region of the channel to another region thereof, said crucible providing a path connecting said regions for return flow of said charge.

4. An induction furnace comprising the combination of a primary winding and a receptacle constituted by a reservoir and a communicating looped portion inductively related with said primary winding for containing a portion of the charge constituting the secondary, the primary winding and said looped portion being so arranged with respect to each other that the fluid pressures in said portion due to electromagnetic repulsion differ at separate regions where junction is made with said reservoir, thereby producing a uni-directional circulation of the charge.

5. An induction furnace constituted by the combination of a magnetic core, a primary winding thereon and a receptacle comprising a reservoir and a looped portion containing a secondary interlinked with the core, said reservoir communicating with said secondary at places between which may pass an imaginary surface perpendicular to the axis of said secondary, and dividing said secondary into two parts, one of said parts, as a whole, being at a greater distance than the other from the primary winding as a whole.

6. An induction furnace constituted by the combination of a magnetic core, a primary winding thereon and a crucible comprising a reservoir and an annular member containing a secondary interlinked with the core, said reservoir communicating with said secondary at places in remote extremities of said secondary between which may pass an imaginary surface parallel with the direction of flow of the secondary current, and dividing said secondary into two parts each of which constitutes a complete current-carrying element, one of said elements being in closer inductive relationship with the primary winding than the other turn.

7. An induction furnace comprising the combination of a magnetic core, a primary winding thereon, a crucible providing an annular portion adapted to contain a charge constituting a secondary, interlinked with said core, and a reservoir communicating with the said annular portion at points spaced apart in an axial direction, the annular portion of said crucible and the primary winding being displaced with respect

to one another along their longitudinal axes thereby causing circulation of charge between the annular portion and the reservoir by the repulsive force between primary and secondary currents.

8. An induction furnace comprising a primary winding, and a crucible comprising a reservoir and a cylindrical chamber containing a portion of the charge constituting a secondary, said chamber communicating at both ends with said reservoir and being so positioned with respect to the primary winding that one end is more remote from the primary than the other whereby the charge is caused to flow from the remote end of said chamber to the reservoir and from the reservoir to the other end.

9. An induction furnace comprising the combination of a continuous annular refractory container elongated in an axial direction, a reservoir communicating therewith and a magnetic core extending through said annular container, a primary winding on said core displaced in an axial direction with respect to said container to exert a repulsive force on a conductive charge in said container whereby said charge is caused to circulate between said reservoir and said container.

10. An induction furnace comprising the combination of a magnetic core, a primary winding thereon, and a refractory crucible comprising a reservoir adapted to contain a pool and a communicating annular portion adapted to contain a secondary, the primary winding and the annular portion being geometrically arranged with respect to each other to cause circulation of charge between the reservoir and annular portion of the crucible by electromagnetic repulsion, and means for adjusting the effective position of the primary to regulate said circulation.

11. An induction furnace comprising the combination of a magnetic core, a crucible providing an annular portion interlinked with said core and a communicating reservoir, a primary winding interlinked with said core and surrounded at least in part by said annular portion of the crucible while being longitudinally displaced from the primary winding as a whole to cause circulation of charge by electromagnetic repulsion, and means for adjusting the position of the primary winding to regulate the circulation.

12. An induction furnace comprising the combination of an annular refractory container elongated in an axial direction, a magnetic core interlinked with said container, a primary winding on said core, said winding and container being relatively displaced in an axial direction, and a reservoir communicating with said container at points spaced apart in an axial direction

whereby flow of charge is caused in said chamber and return flow through said reservoir due to electromagnetic repulsion.

13. An induction furnace comprising the combination of a charge-containing receptacle having a looped portion and a reservoir in communication with each other, and a primary winding arranged to induce a heating current in the charge in said looped portion, and to cause a circulation through said looped portion of the receptacle with a unidirectional flow by the expulsion of charge from said looped portion to the reservoir at one place of communication and the admission of charge from the reservoir to said looped portion at another place of communication.

14. An induction furnace comprising a containing crucible providing a chamber in which the charge constitutes a closed secondary, and a primary winding for inducing an electric current in said charge so positioned with relation to said secondary that fluid pressures are set up in said chamber due to electromagnetic repulsion between said primary and secondary producing flow of charge through said chamber mainly in a direction transverse to the direction of the electric current induced therein, and means for permitting return flow external to said chamber.

15. An induction furnace comprising a containing crucible providing a reservoir for the charge and an annular chamber communicating therewith in which a portion of the charge constitutes a secondary, and a primary winding so positioned with relation to said secondary that fluid pressures varying in an axial direction are produced in said chamber due to electromagnetic repulsion between said primary and secondary, causing unidirectional flow of charge in said chamber in an axial direction and return flow through said reservoir.

16. An induction furnace comprising a magnetic core, a primary winding on said core, a crucible comprising a reservoir and a looped chamber having oblong transverse sections interlinking said core containing a portion of the charge constituting a secondary, said chamber communicating with said reservoir at opposite ends of such transverse sections and being so positioned with respect to the primary winding that the fluid pressure due to electro-magnetic repulsion between primary and secondary is greater at one end of said sections than the other, whereby circulation of charge is produced between said chamber and reservoir.

17. An induction furnace comprising a primary winding, and a crucible providing a reservoir and a looped chamber having an oblong transverse section containing a portion of the charge constituting a secondary, said chamber communicating with the

reservoir at opposite ends of such transverse section and being so disposed with respect to the primary that one end of such section is farther from the primary than the other.

- 5 18. An induction furnace comprising a crucible providing a reservoir for the charge and a chamber in which a portion of the charge constitutes a closed secondary, said chamber and reservoir communicating with
10 each other at their extremities, and a primary winding associated with said secondary producing unidirectional circulation of charge through said chamber and reservoir.

- 15 19. An induction furnace comprising a crucible providing a reservoir for the charge and a chamber in which a portion of the

charge constitutes a closed secondary, said chamber communicating with said reservoir at opposite sides of certain axially perpendicular transverse sections of said chamber, and a primary winding so disposed with relation to said secondary that one side of a transverse section of said secondary is more remote than the other from the primary whereby a charge is caused to flow from the side of said section more remote from the primary to the reservoir and from the reservoir to the other side of said section.

In witness whereof, I have hereunto set my hand this 28th day of December, 1921.

JAMES M. WEED.