April 6, 1937. J. R. WYATT 2,076,216

ELECTRIC INDUCTION FURNACE

Filed March 10, 1933 2 Sheets-Sheet 1

Fig. 1.

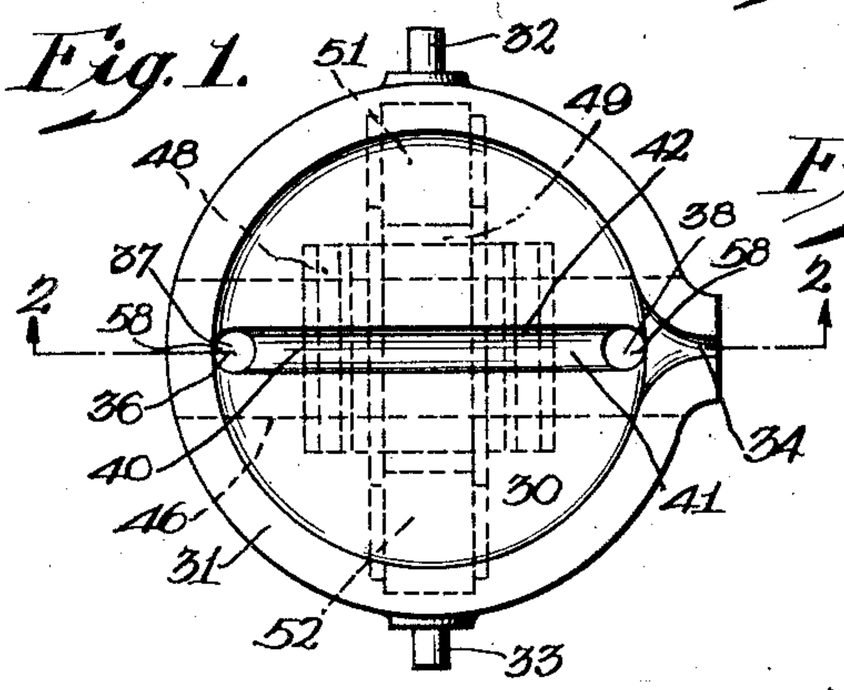


Fig. 4.

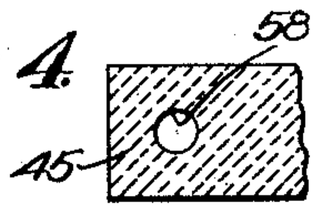


Fig. 4.a

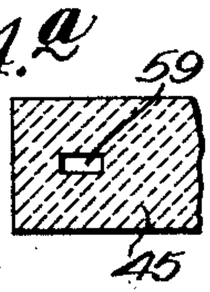


Fig. 4.b

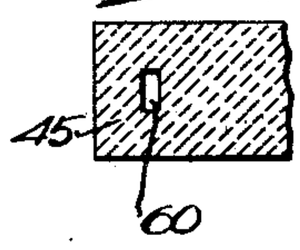


Fig. 3.

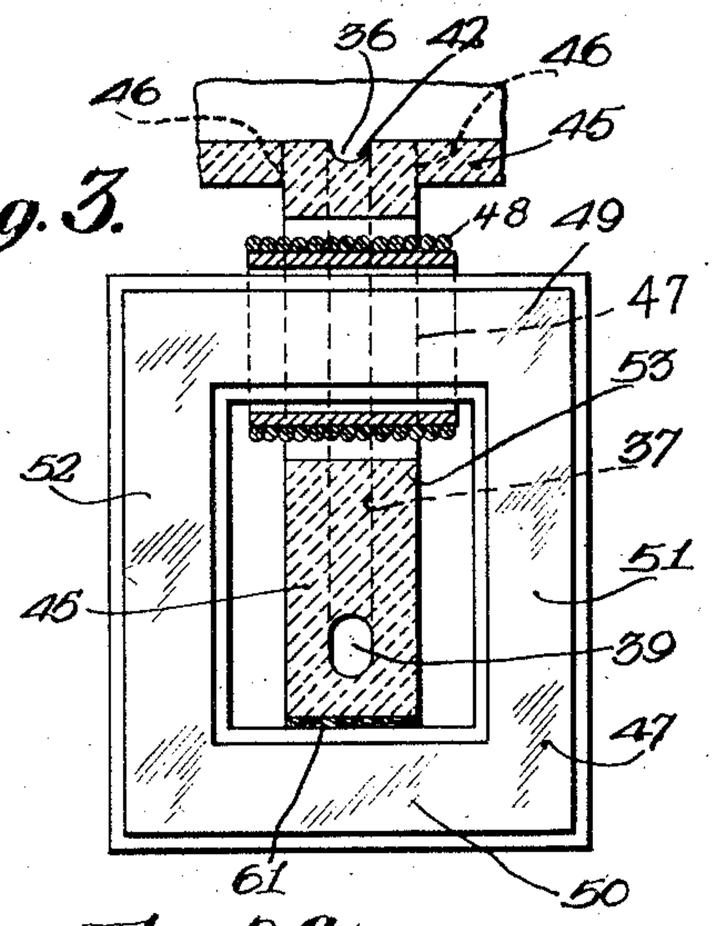


Fig. 2.

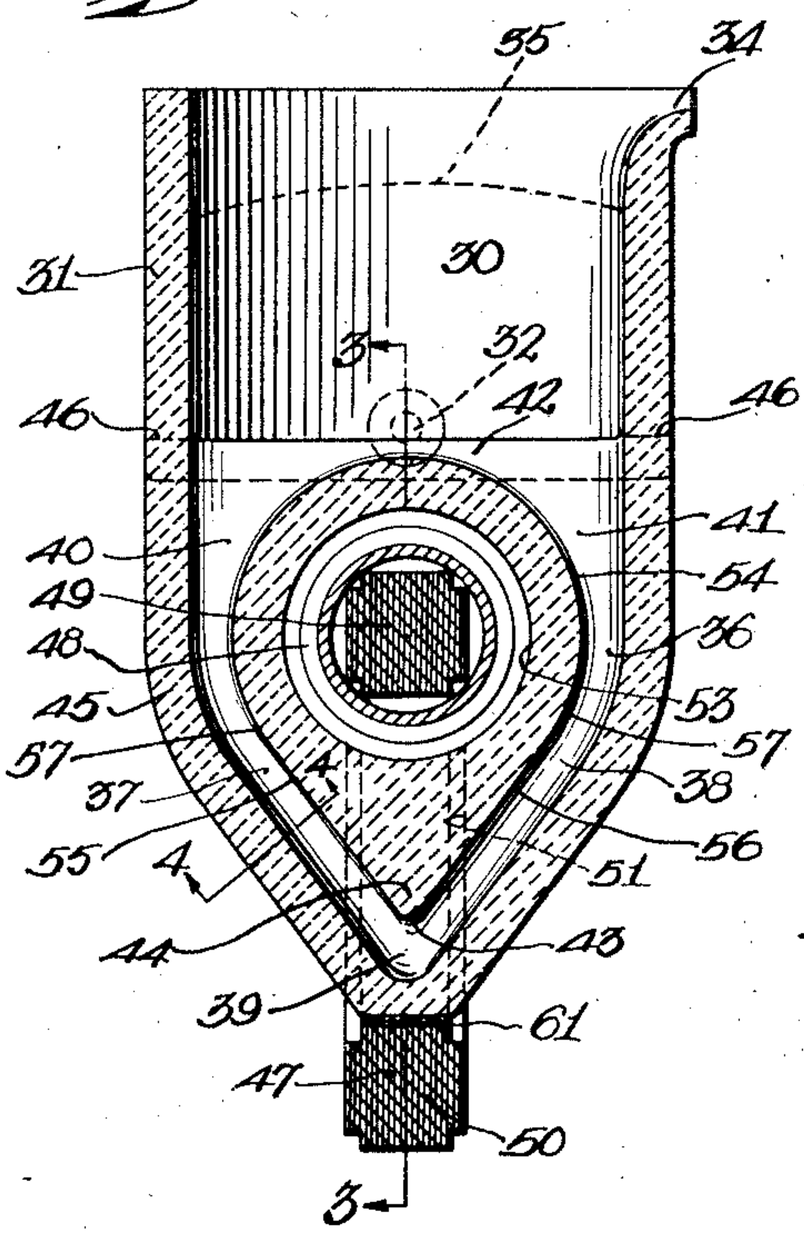
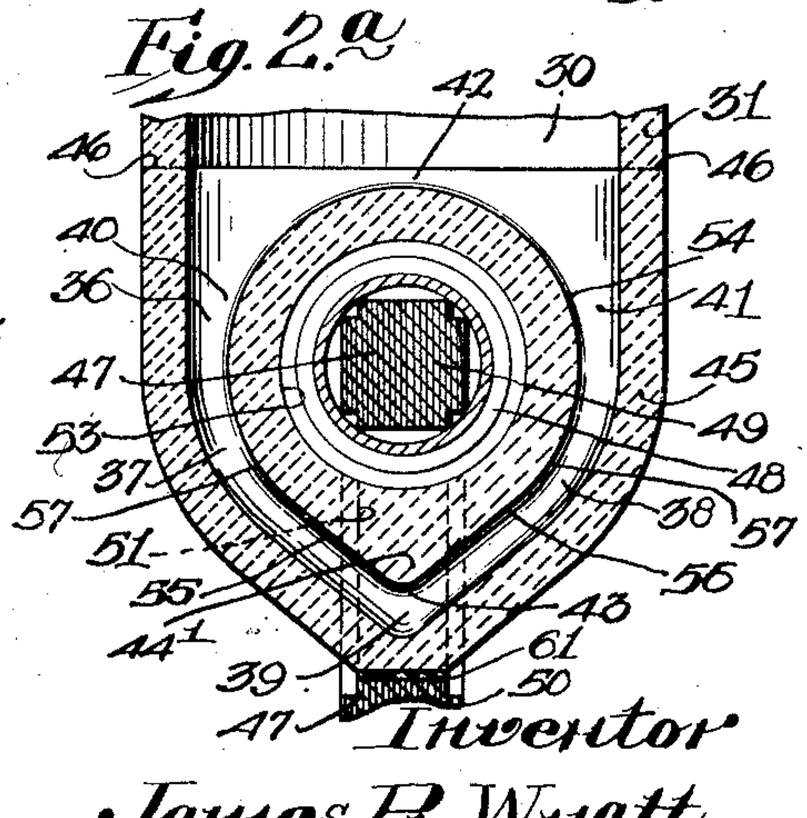


Fig. 2.a



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ELECTRIC INDUCTION FURNACE

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Fig. 9.

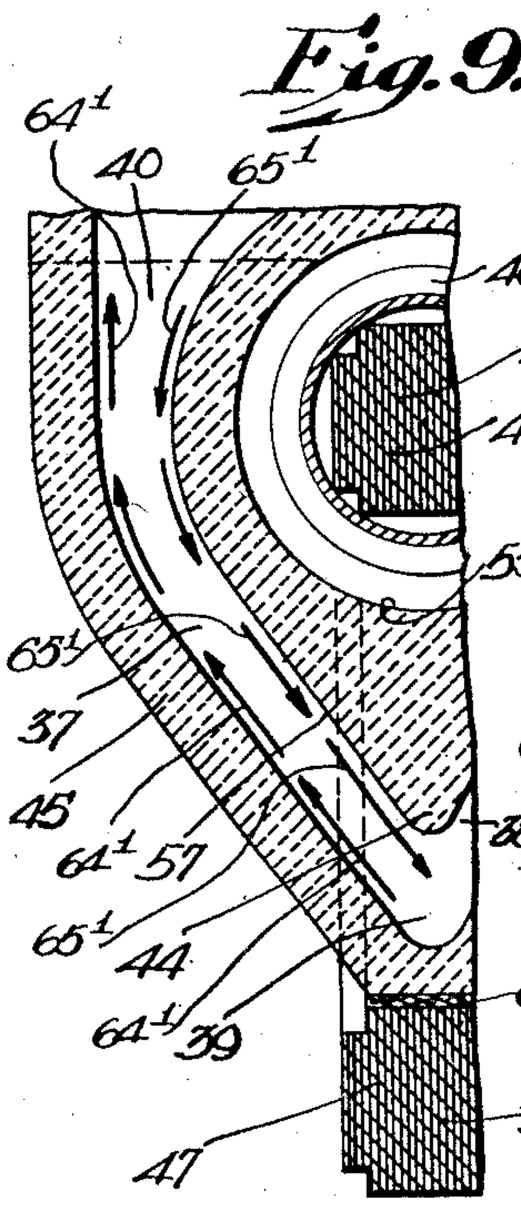


Fig. 5.

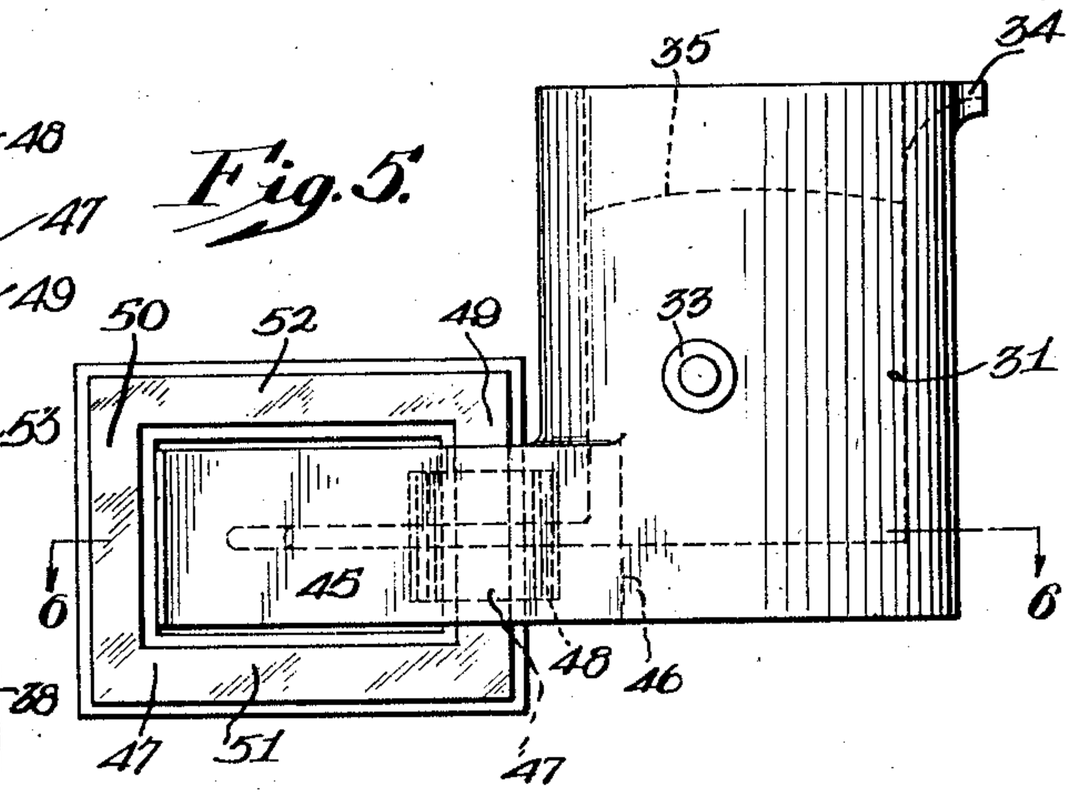


Fig. 6.

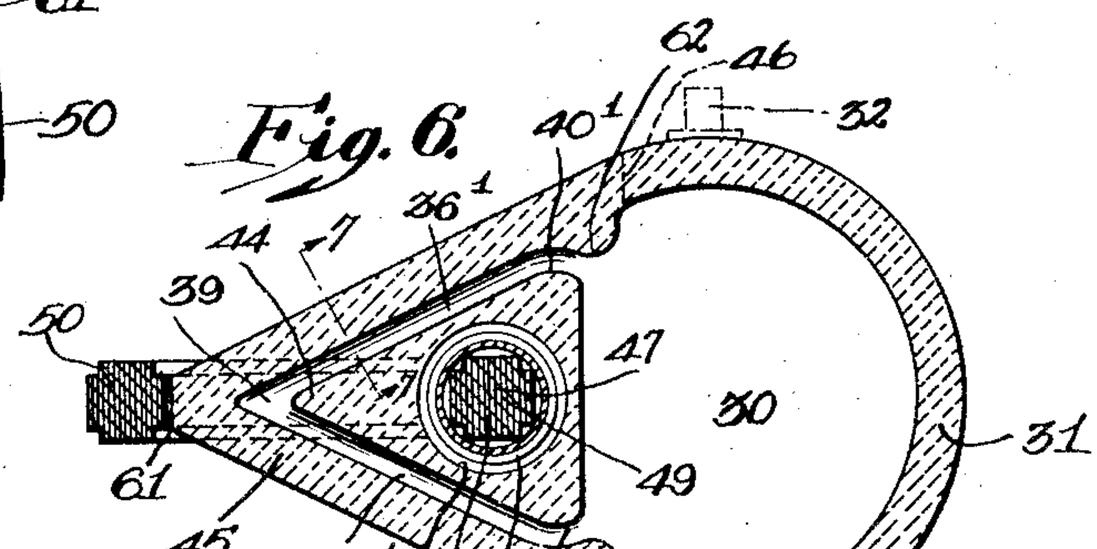


Fig. 7.

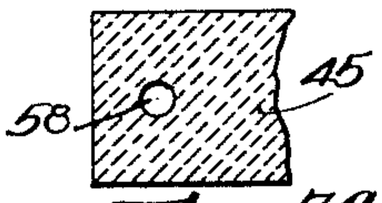


Fig. 7a

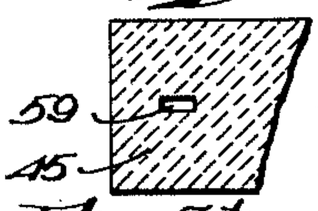


Fig. 7b

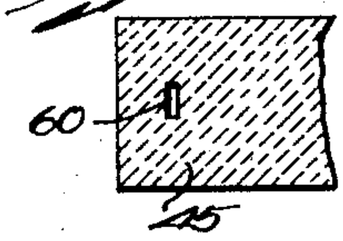
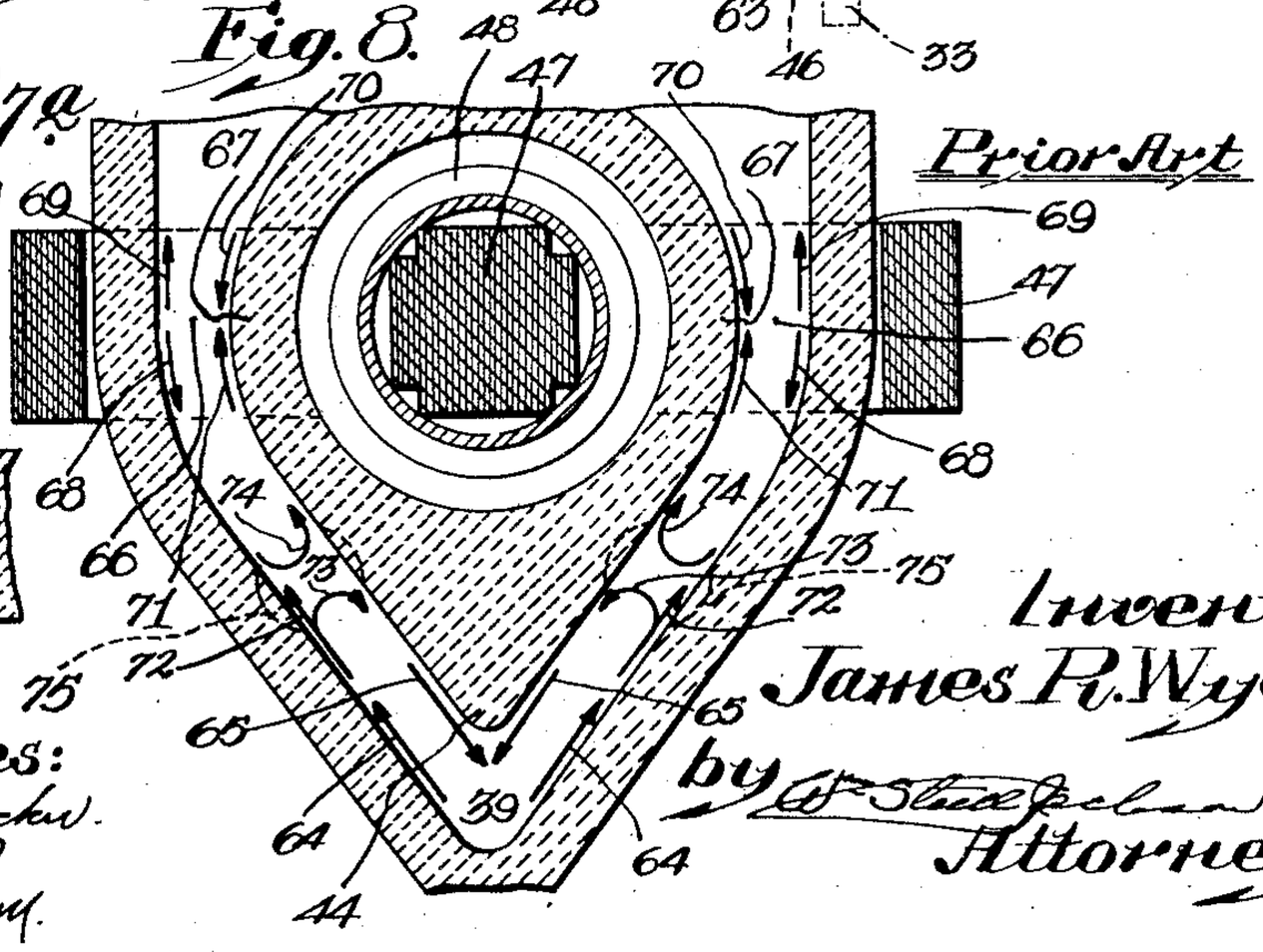


Fig. 8.



Prior Art

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Patented Apr. 6, 1937 2,076,216

UNITED STATES PATENT OFFICE

2,076,216

ELECTRIC INDUCTION FURNACE

James R. Wyatt, Camden, N. J., assignor to Ajax Electric Furnace Corporation, Philadelphia, Pa., a corporation of Pennsylvania

Application March 10, 1933, Serial No. 660,202

6 Claims. (Cl. 13—29)

My invention relates to submerged channel electric induction furnaces.

A purpose of my invention is to improve the stirring in a submerged channel electric induction furnace.

A further purpose is to eliminate some of the wear upon the refractory walls of the submerged channel of an electric induction furnace.

A further purpose is to reduce superheating in the submerged channel of an electric induction furnace.

A further purpose is to remove the magnetic damming effect from an electric induction furnace submerged channel.

A further purpose is to start primary-on-secondary stirring in the submerged channel of an electric induction furnace at the same point at which secondary-on-secondary stirring is initiated.

A further purpose is to concentrate flux at the bend of a submerged channel angle having the point of the angle directed away from an electric induction furnace pool.

In a submerged channel electric induction furnace having a V-shaped channel with the point of the V directed from the pool of the furnace, a further purpose is to place the core of a core-type transformer around the bend of the V and to locate a coil surrounding the core between the branches of the V.

Further purposes appear in the specification and in the claims.

My invention relates to the methods involved and the apparatus used to carry out the methods.

In the drawings I have illustrated the furnace of my invention diagrammatically, eliminating purely structural features, such as the outer furnace supports and tilting mechanism, and the numerous accessories used with every furnace.

I have chosen to illustrate two only of the main forms of my invention, selecting forms chiefly for the sake of clear explanation of the principles involved and convenient exemplification of the main features of my invention.

Figure 1 is a top plan view of a furnace having a depending channel, made in accordance with my invention.

Figure 2 is a central vertical section of Figure 1, taken on the line 2—2.

Figure 2*a* is a fragmentary view corresponding to Figure 2, but showing a modification.

Figure 3 is a fragmentary section of Figure 2 on the line 3—3.

Figure 4 is a fragmentary section of Figure 2 on the line 4—4.

Figure 4*a* is a view corresponding to Figure 4 and illustrating a modified channel cross section.

Figure 4*b* is a view generally similar to Figure 4, but with a different channel cross section.

Figure 5 is a side elevation of a somewhat different furnace embodying my invention.

Figure 6 is a section of Figure 5 upon the line 6—6.

Figure 7 is a fragmentary section of Figure 6, taken upon the line 7—7.

Figure 7*a* is a view similar to Figure 7, showing a different channel cross section.

Figure 7*b* is a view corresponding to Figure 7, and illustrating another variation in channel cross section.

Figure 8 is a fragmentary diagrammatic view of a prior art furnace.

Figure 9 is a fragmentary diagrammatic view of a furnace of my invention.

In the drawings, like numerals refer to like parts.

My invention relates particularly to submerged channel electric induction furnaces in which heat is developed by induction in a molten conductor, and the heat is conveyed, primarily by circulation of the molten conductor, to a pool of molten charge, to which solid charge may be added for melting if desired.

My invention is particularly applicable to submerged channel electric induction furnaces of the type shown in my U. S. Patent No. 1,201,671, Figures 1 to 6, inclusive, but may also be applied to other submerged channel electric induction furnaces which involve similar problems of circulation.

My electric induction furnaces are ordinarily used to melt metals and alloys and to heat and superheat metals and alloys which have been melted, although any charge which is electrically conducting when molten and which can be heated in much the same way as a metal or alloy, may be used in my furnaces.

Circulation is of great importance in submerged channel electric induction furnaces, not only because it is relied upon to convey heated charge to the pool of molten charge, but because, without adequate and properly controlled circulation, the charge in the molten conductor will reach an abnormally high temperature at which attack upon the refractory lining of the channel will be more rapid, at which vaporization of charge in the channel may occur and at which other undesirable effects of overheating may be observed.

In the drawings, two main types of submerged

channel electric induction furnaces are shown. The type illustrated in Figures 1 to 4*b* inclusive, commonly known in the art as the Ajax-Wyatt type, has a depending channel or a channel located vertically below the pool of molten charge (see my U. S. Patent No. 1,201,671, Figures 1 to 6, inclusive). The type illustrated in Figures 5 to 7*b* inclusive has the submerged channel placed at one side of the pool (see my U. S. Patent No. 1,201,671, Figures 7 to 10*a*, inclusive).

Referring first to the form of Figures 1 to 4*b*, inclusive, the bulk of the charge, whether molten or partially solid and partially molten, forms a pool 30 contained within a holder or crucible 31 comprising suitable refractory material. Charge may be removed from the crucible, as for example by tilting the furnace around trunnions 32 and 33 to pour from a spout 34.

While the holder or crucible has been shown as a cylindrical relatively deep vessel, filled with charge to a suitable depth, as for example, up to a level 35, it will be understood that any proper shape of crucible may be used, as best suited to the particular case, and the depth and contour of the crucible may be adjusted accordingly.

The charge is heated by a submerged channel 36 having branches 37 and 38 meeting at 39 in an angle whose point is directed away from the pool 30. The channel is markedly diverging at its ends 40 and 41, and desirably has a groove 42 joining the two branches at the ends.

Both of the ends 40 and 41 of the submerged channel communicate with the pool, so that molten charge from the pool may freely enter the channel, and likewise molten charge from the channel may readily mingle with the pool.

The channel is effectively a V, whose bend is located at 43.

The angle 44 of the V, which is the angle between the adjacent straight portions of the branches of the channel, may vary from the angle shown in Figure 2. For example, in Figure 2*a* the angle 44' of the V is an obtuse angle rather than an acute angle as shown in Figure 2, and any type of angle between an extremely obtuse angle and a very acute angle may be used, provided the angle point faces away from or is directed away from the pool, and does not reach 180° or greater for reasons later explained.

The submerged channel 36 is formed in a channel block 45 consisting of suitable refractory material such as magnesia, chrome, etc., and desirably is cemented to the crucible 31 at 46.

The transformer core 47 is preferably rectangular, and is of core-type as distinguished from shell-type, and comprises a side 49 passing through the coil 48, a side 50 parallel to the side 49 and located below and close to the point of meeting of the two branches of the submerged channel and sides 51 and 52 respectively parallel to one another and transverse to the sides 49 and 50.

The transformer core 47 will of course be made of laminated sheets of transformer iron, which are assembled by overlapping individual sheets at points of joining as in conventional transformer practice. No attempt has been made to indicate where individual laminated plates end and others begin in making up the core.

The coil 48 suitably comprises one layer of turns wrapped around the side 49 of the transformer core, and located in an opening 53 through the refractory of the channel block 45. Heat and electrical insulation of the coil have been omitted. The walls of the channel curve at 54 preferably around the same axis of curvature as that of the coil, and the straight portions 55 and 56 of the branches 37 and 38 of the submerged channel are preferably tangential at 57 to the curved portion 54.

The present invention applies to submerged channel furnaces having angles in the channels whose points are directed away from the pool, whatever the cross sectional contour of the submerged channel and the contour is therefore not specifically claimed in this application. However I have discovered and will elsewhere claim that a channel having a circular contour 58 as shown in Figure 4 is of special advantage in all angle type submerged channel furnaces, whatever the form or position of the transformer. The edge-presented contour 59 of Figure 4*a* might also be used and somewhat less desirably the flat-presented contour 60 of Figure 4*b* could be employed. It will be understood that these are examples merely, and that considerable variation can be made in the type of contour used.

The coil 48 is protected from the molten charge by the refractory walls of the channel, and may be cooled if desired by any suitable means, such as a blast of air. Likewise, the transformer core 47 is protected by the refractory material, and may be artificially cooled if this be deemed necessary. To avoid transfer of heat from the bend of the channel at 39 to the side 50 of the transformer core, a layer of heat insulating material, such as asbestos board is located at 61 between the refractory and the core material.

It will be evident at once that the form of Figures 5 to 7*b*, inclusive, is generally similar to that of Figures 1 to 4*b*, inclusive, except that in Figures 5 to 7*b*, inclusive, the submerged channel extends laterally from the pool.

Without repeating, in the description of the form of Figures 5 to 7*b*, inclusive, the parts already described in relation to Figures 1 to 4*b*, inclusive, it will be evident that the channel 36' as seen in Figure 6 need not be of exactly the same contour as the channel 36 of Figure 2. The ends 40' and 41' at which the channel joins the pool 30 may connect with the pool in any suitable way, and the direction of the channel may be somewhat changed at this point, as is true in Figure 2 also, as by baffles 62 and 63.

The essential features of Figures 5 to 7*b*, inclusive, are, however, the same as those of Figures 1 to 4*b*, inclusive. In both cases the submerged channel communicates at both ends with the pool, comprises two branches meeting in an angle whose point is directed away from the pool, and has the transformer core 47 surrounding the point 39 at which the branches meet. In both forms, likewise the coil surrounds the core and is located between the branches.

The same general variations may be made in the construction of Figures 5 to 7*b* as in that of Figures 1 to 4*b*. The angle of meeting of the branches of the channel may be varied, and the contour of channel cross section may be altered. In Figures 7, 7*a* and 7*b*, the same three channel cross sections are shown as are illustrated in Figures 4, 4*a* and 4*b*.

In the prior art, the general practice has been to construct a submerged channel electric induction furnace as illustrated in Figure 8, with the coil between the branches of the channel surrounding the middle leg of a shell-type transformer core, whose outer legs are each outside the channel.

The submerged channel is heated by electric

current induced in it from the primary coil 48. This induced current flows through the channel and through the pool from one channel end to another.

In a submerged channel having an angle whose point is directed away from the pool, a stirring tendency originates at the point 39 of meeting of the branches, due to the action of the electric current in one branch of the channel upon the electric current in the other branch. This tendency is referred to by me as secondary-on-secondary stirring, and is an effect of the repulsion of one conductor upon another. Due to the secondary-on-secondary stirring, there is a tendency to cause molten metal to flow upwardly from the point 39 along the outside of the channel in each branch toward the pool as indicated by the arrows 64, and to permit molten metal to flow by gravity down the inside of the channel from the pool as indicated by the arrows 65, to replace the upwardly flowing molten metal.

The secondary-on-secondary repulsion stirring is a very important aspect of any submerged channel induction furnace having an angle whose point is directed away from the charge, and is due to the presence of the angle. If the channel lacked the angle 44 and were circular as viewed in the plane of the length of the channel (that is, in the plane of the paper in views such as Figures 2, 2*a*, 6 or 8), the repulsion forces would be nearly balanced, completely balanced if there were a complete circle of uniform cross section and secondary-on-secondary repulsion stirring could be ignored. It is by virtue of the V or the angle having its point directed away from the pool that secondary-on-secondary repulsion is so greatly accentuated. This was shown and discussed in my U. S. Patent No. 1,201,671.

In addition to secondary-on-secondary stirring, there is primary-on-secondary stirring in an electric induction furnace of the type under discussion. Primary-on-secondary stirring tends to cause flow away from the point of concentration of the leakage field. In the prior art, where the shell-type transformer was used, the leakage field in the channel was most concentrated at some points 66 between the legs of the transformer core. This results in a tendency of the molten charge to flow in both directions (in and out) through the channel away from the points 66 of high leakage field intensity.

The primary and secondary currents are both strong and opposite (180° apart) in direction. Their fields, one clockwise and the other counterclockwise about its conductor, will therefore have the same direction at some points 67 between them and immediately inside the channel.

The reaction of one field upon the other will tend to force the molten metal charge within the channel to follow the outside of the channel in moving away from the points of high field intensity 66 which is intensified under the iron core. As a result, there is pressure causing a tendency to flow in both directions in each branch of the channel, down and up the outside as indicated by the arrows 68 and 69, and for any flow which takes place, a resulting gravity flow into this zone as shown by the arrows 70 and 71, to take the place of the molten metal removed.

The force indicated by the arrow 69 directly helps to move molten metal toward the pool, but the force represented by the arrow 68 tends to move molten metal toward the point 39 where the branches of the channel meet. This tendency is in direct opposition to the upward flow at the outside of the channel due to secondary-on-secondary repulsion indicated by the arrows 64, and would prevent upward flow were it not for the fact that the secondary-on-secondary stirring (arrow 64) is more powerful than the primary-on-secondary downwardly stirring pressure (arrow 68).

As a result of the above, some of the charge flows upwardly as indicated by the arrow 72, overcoming the tendency to flow downward indicated by the arrow 68, while another part of the charge is turned back toward the point 39 as indicated by the arrow 73. Likewise some of the downwardly flowing charge indicated by the arrow 68 is returned upwardly as indicated by the arrow 74.

While the theory above cannot be verified practically in its entirety it seems to me to be well founded and is confirmed in part, at least by the fact that excessive lateral erosion takes place in the channel at about the place where the eddy flow arrows 73 and 74 appear.

Pinch effect flow, due to the tendency of current in different parts of the same molten conductor to constrict the conductor and to cause molten metal to flow upwardly along the middle of the channel has been considered in the above discussion, but has not been discussed before nor further than is herein explained for the reason that the elimination of counter-pressures along the outer walls of the channel, provided by my invention herein, is highly beneficial whether pinch effect be weak or strong. As a rough analogy, pinch effect flow may be compared to the type of flow produced in a flexible hose when the walls are uniformly constricted from the outside. Pinch effect does not assist circulation except where there is a change in cross section. Since whatever flow there may be, whether strong or weak, merges with the flow produced by my invention herein, my invention is beneficial whatever the pinch flow.

From another standpoint also pinch effect discussion herein can be eliminated because pinch effect is a function of "tube" or channel design and the tube can be designed to take care of the pinch effect. Pinch effect is not directly affected by transformer design or position.

From Figure 8 it will be clear that the primary-on-secondary pressure of the prior art form having the shell type transformer tends to cause circulation directly counter to the secondary circulation in that part of the tube—constituting almost all of the tube—which lies below the transformer medial line and tends to cause circulation above that medial line in the same direction as the secondary-on-secondary circulation. At first glance it would appear therefore that the circulation above the medial line from primary-on-secondary pressure would be helpful. This is not wholly true as the ultimate circulation in the lower part of the channel may be so nearly stagnated before the molten metal gets up to the medial line of the transformer that the chief effect of the primary-on-secondary pressure above the medial line will be to cause local circulation from this medial line up to the pool and back again. In any event, the primary-on-secondary pressure above the medial line can be of little benefit in assisting circulation within the channel below the medial line. At most it will make circulation a little easier by clearing metal out of the way along the outer wall of the channel from a point at which circulation has already begun to be easier to effect by reason of the flaring of the channel.

In other words, whatever assistance primary-on-secondary pressure above the medial transformer line offers in clearing metal out ahead of the secondary-on-secondary flow is not effective until a point in the channel is reached at which the fluid resistance to upward molten metal flow along the outer channel wall has been reduced and is being progressively lowered by enlargement of the channel.

For the reasons above, beneficial effect of primary-on-secondary pressure upon the molten metal above the medial transformer line is much less than the injurious effect of the counter pressure in that part of the channel below the medial line.

This is true even without considering the eddy currents produced within the channel as by flow shown at **73** and **74** and becomes more pronounced when the objectionable washing effect of the counter flow is considered.

It will be evident therefore that the damming effect of the opposition to upward current flow produced by primary-on-secondary stirring in its entirety is a direct hindrance to secondary-on-secondary stirring. In other words, the shell type transformer produces a magnetic dam which reduces and alters the character of the secondary-on-secondary stirring within the submerged channel and which damages the channel not only because of the reduction in the speed of clearing molten metal, causing unnecessarily high temperature within the channel, but because of the erosion of the channel walls weakened against erosion by the higher temperature.

The magnetic damming action of the shell-type transformer has other undesirable effects in that cutting down the stirring in the channel makes the circulation of the molten metal more sluggish as it discharges into the pool reducing the mixing effect and resulting in an undesirable difference in temperature in different parts of the pool.

It will be evident that the temperature differential between the pool and the channel will be maintained whatever the temperature of the pool and cannot be equalized by merely operating the furnace longer to increase the pool temperature since molten metal flowing down from the pool at the higher temperature will again be increased in temperature by reason of the unnecessarily reduced flow of metal in the channel.

A further undesirable feature of the magnetic damming action is that, due to the high temperature differential between the submerged channel and the pool, molten metal in the channel is likely to be vaporized, particularly where a high energy input into the furnace is employed. Vaporization on account of magnetic damming gives rise to the phenomenon of "kicking", occurring in furnaces operating on brass and other zinc-containing metal. The "kicking" is due to vaporization of zinc, which breaks the electrical circuit through the submerged channel and causes momentary cessation of heating. When the vaporized zinc has passed out of the channel, molten metal flows in to fill the space which it occupied, producing a noise known as a "bump" and causing coincident shock and stress to the channel walls, with corresponding weakening of the walls and in some cases with strain or even rupture of the walls.

I have discovered that the difficulties present in the use of the shell-type construction across channels meeting in a V whose point is directed away from the pool, as shown in Figure 8, may be avoided by using a core-type transformer located about the point of meeting of the branches of the submerged channel. For such a construction, circulation lines as they appear to operate are shown in Figure 9, with upward flow indicated by the arrows **64'**, and downward flow indicated by the arrows **65'**. The upward flow (arrows **64'**) is partly primary-on-secondary and partly secondary-on-secondary stirring.

My construction gives a maximum advantage for the secondary-on-secondary stirring effect already described, both through concentration of electromagnetic effect at the V (due to the transformer position linking the V) and because of the elimination of the counter force represented in Figure 8 by arrow **68** due to primary-on-secondary force in the prior art form.

Not only is the secondary-on-secondary effect increased therefore and the magnetic dam, due to primary-on-secondary effect in the Figure 8 form, eliminated, but the primary-on-secondary pressure which previously constituted the dam is applied to assist instead of opposing the secondary-on-secondary pressure movement.

In the present invention, primary-on-secondary stirring still tends to send the charge in both directions along the channel from the point of concentration of flux, but this point is now the point **39** at which the branches of the channel meet, the same point at which the secondary-on-secondary forces are concentrated and from which they spring, and both stirring effects combine to send charge up the outside of each branch, no longer bucking one another.

In addition to the great advantage of applying this primary-on-secondary pressure beneficially, changing a "bucking" liability to an "assisting" asset to clear the channel quickly, reduce the temperature in the channel and correspondingly to reduce the temperature differential between the channel and the pool, I secure a decided benefit also in eliminating molten metal eddy currents such as are shown at **73**, **74**.

The use of core-type transformers about the points of angles in submerged channels has been attempted in which the point of the angle of the channel is directed toward the pool.

The attempt to use the core-type transformer about re-entrant angles as above has not produced the advantage nor the flow relations of my invention. The reason for this is that though the primary-on-secondary repulsion produced tends to cause flow up the inside of the outer wall of the channel, with gravity return flow down the inside of the channel—as in the present invention—the secondary-on-secondary tendency to flow is out along the inner surfaces of the inner wall of the channel passage, which are the surfaces farthest from each other at the angle. This causes secondary-on-secondary flow along the inner channel walls at the angle directly opposing gravity return flow from the primary-on-secondary circulation. Moreover, normal return flow for this secondary-on-secondary inside channel circulation is down along the inner face of the outside wall of the channel, directly in line with and opposing the primary-on-secondary flow.

It will be evident that the re-entrant angle form concentrates the flux from the core-type of transformer disadvantageously at the angle instead of advantageously and loses all of the advantages of my invention.

By explaining the theory upon which my invention is believed to operate, I do not wish to limit myself to this theory nor to make the cor-

rectness of the theory essential to the protection afforded my invention. Aside from the theory, I find that the practical results obtained by my invention are highly desirable, in quicker and more efficient heating, better stirring and much longer life of the refractory in the submerged channel. The results of the tests made upon my invention are remarkable and convince me of the commercial feasibility of the furnace of my invention, not only for alloys of lower melting point, including brass relatively high in zinc, such as red brass, copper, but also for iron and steel.

It will be evident that both of the moving forces used (primary-on-secondary and secondary-on-secondary) are motor effects.

In view of my invention and disclosure variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain all or part of the benefits of my invention without copying the structure shown, and I, therefore, claim all such in so far as they fall within the reasonable spirit and scope of my invention.

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

1. In an electric induction furnace, walls forming a holder for a molten metallic charge, walls forming a single-conduit submerged channel having converging branches each communicating at one end with the holder and meeting in an angle whose point is directed away from the holder at the other end, a closed magnetic circuit surrounding the point of meeting of the branches and a transformer coil comprising the sole energizing means for the magnetic circuit, located between the said converging branches and effective to set up lines of magnetic force in the magnetic circuit having a maximum at the angle.

2. In an electric induction furnace, walls forming a crucible for a charge, walls forming a V-shaped single-conduit channel filled with molten charge when the furnace is in operation, communicating with the crucible and having the point of the V directed away from the crucible, a closed magnetic circuit individual to the channel surrounding the point of the V and passing through the spacing between the channel walls and a primary winding upon the portion of the closed magnetic circuit between the channel walls, the transformer being free from winding in proximity to the V.

3. In an electric induction furnace, a crucible adapted to hold a molten metal charge, walls forming a single-conduit submerged channel depending from the crucible, having two branches, each communicating with the crucible at its upper end, converging one with respect to the other branch along a straight portion and meeting the other branch at its lower end in an angle whose point is directed downwardly and a transformer core passing around and linking the angle, having its sole exciting coil between the channels and part of said core outside of but close to the angle for concentrating flux at the angle in excess of that in the channel branches close to the crucible, there being but one channel per transformer.

4. In an electric induction furnace, a crucible adapted to hold a charge, walls forming a submerged channel depending from the crucible, communicating at its upper ends with the crucible and having a V-bend whose angle point is directed away from the crucible, a closed rectangular transformer core surrounding the V-bend, having a first side extending transversely of the plane of the channel above the V-bend, a second side parallel to the first below the V-bend, and third and fourth sides joining the ends of the first two sides, there being but one channel conduit within the transformer core, and electrically energized means including a coil surrounding said first side and comprising the sole energization of the core to set up lines of magnetic force in the magnetic circuit having a maximum at the angle.

5. In an electric induction furnace, a crucible, walls forming a single-conduit submerged channel extending laterally from the crucible, communicating at its ends with the crucible and having an angle whose point is directed away from the crucible and transformer means for concentrating flux at the angle including a core linking the channel with one leg adjacent the angle and a transformer coil within the angle which coil affords the sole energization for the transformer.

6. In an electric induction furnace, a crucible, walls forming a V-shaped single-conduit channel nearer to one side of the crucible pool than to the other side, communicating at its ends with the lower part of the crucible and having the point of the angle extending away from the crucible and a transformer having a rectangular core surrounding the bend of the V and having its sole excitation from a coil surrounding one leg of the core and inside the V.

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