

April 26, 1927.

1,626,485

M. UNGER

INDUCTION FURNACE

Filed Feb. 16, 1921

3 Sheets-Sheet 1

Fig. 1.

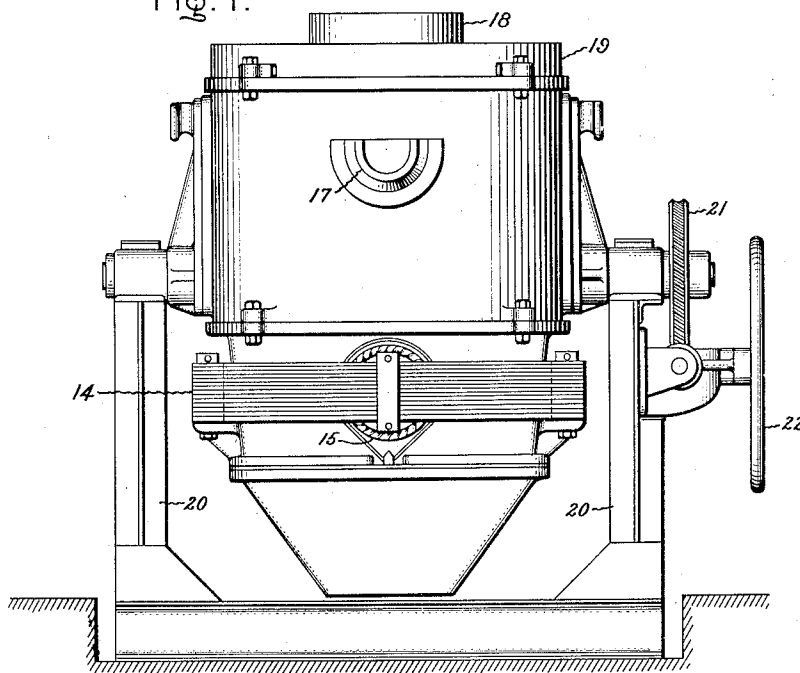


Fig. 2.

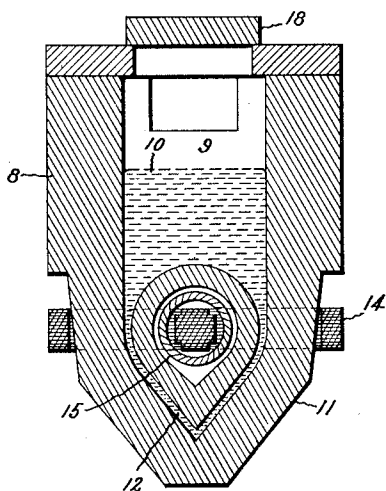
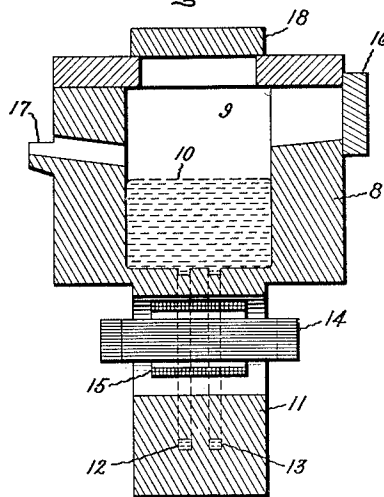


Fig. 3.



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Fig. 4.

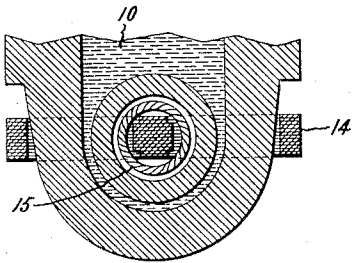


Fig. 5.

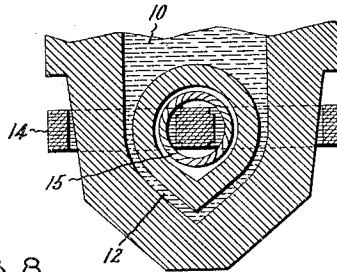


Fig. 8.

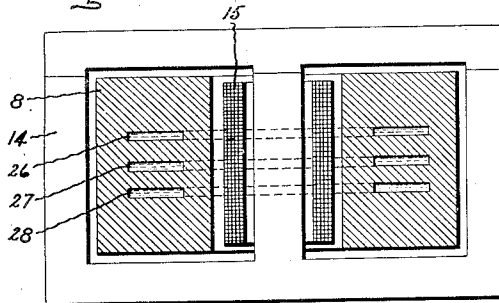


Fig. 6.

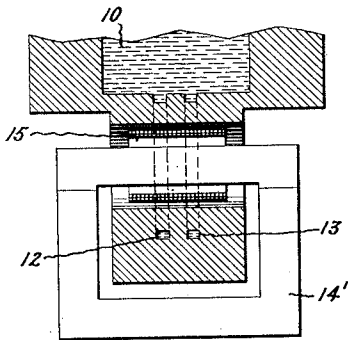
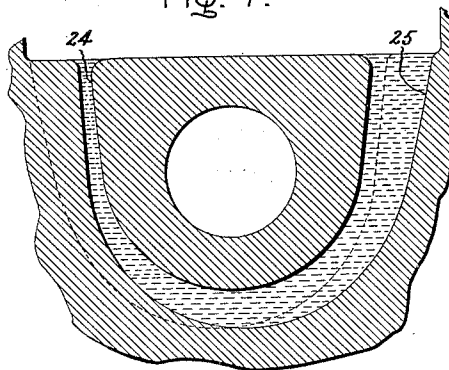


Fig. 7.



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3 Sheets-Sheet 3

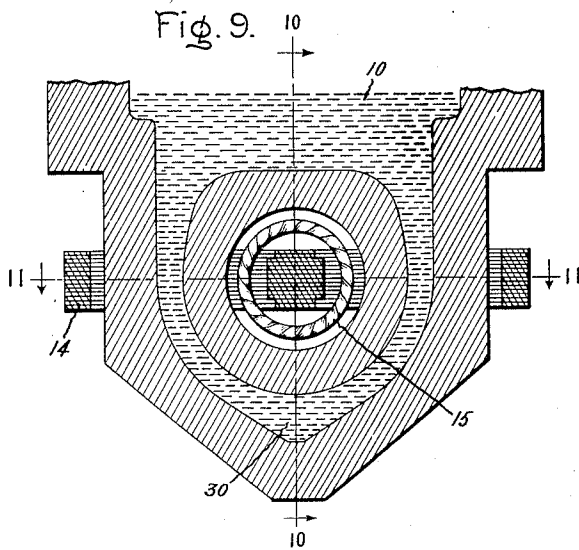
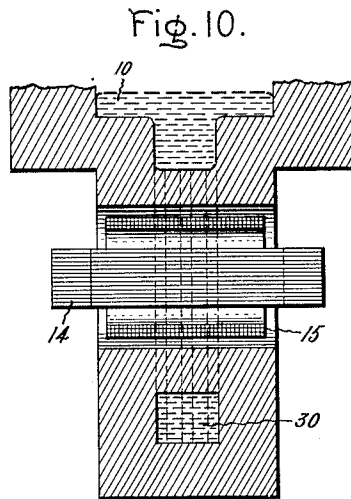
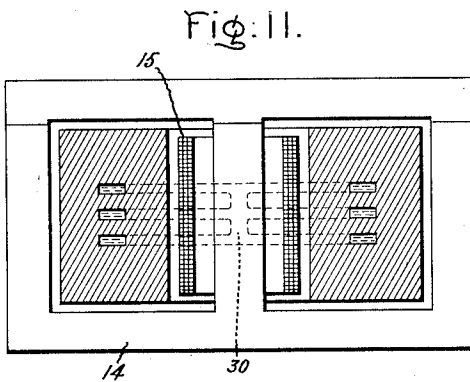
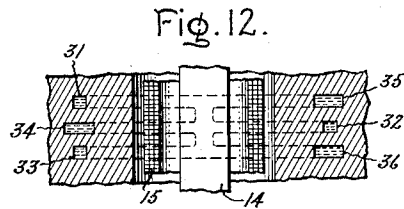
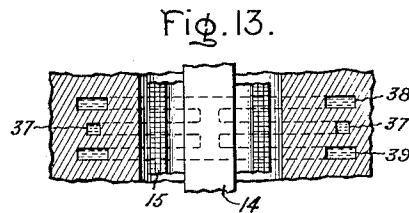


Fig. 15.

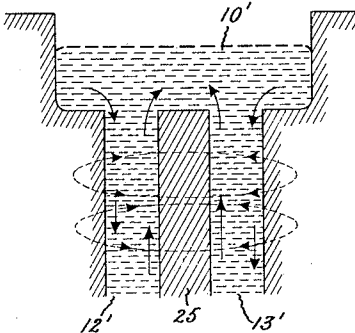
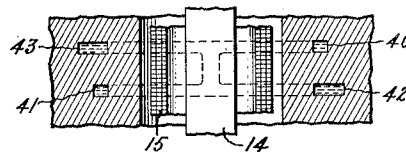


Fig. 14.



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UNITED STATES PATENT OFFICE.

MAGNUS UNGER, OF PITTSFIELD, MASSACHUSETTS, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INDUCTION FURNACE.

Application filed February 16, 1921. Serial No. 445,514.

The present invention comprises a new induction furnace which although of general utility is particularly adapted for the melting of non-ferrous metals of high conductivity, such, for example, as copper, aluminum and brass.

One of the limitations of electric furnaces of the induction or transformer type is the pinch force, that is, the compressive electrodynamic force exerted by the magnetic field upon the molten charge when it is carrying currents. At sufficiently high current density this pinch force may interrupt the continuity of the liquid conductor constituting the secondary during the operation of an induction furnace. The current interrupting tendency of this pinch force may be counteracted by subjecting the molten charge constituting the transformer secondary to a hydraulic pressure, for example, by providing a channel located in a vertical plane. The molten charge in this channel, constituting part of the secondary, is subjected to the weight of a pool of metal communicating with the upper ends of the channel. In this manner the permissible current density and hence the energy input may be increased. Nevertheless the pinch force limitation is still a serious factor in the operation of the furnace, and particularly so when it is desired to melt metal of low resistance such as copper or aluminum.

It is the main object of my present invention further to counteract the pinch force and thereby to increase the permissible power input of induction furnaces. As a result of my invention various other advantages are secured, the efficiency and the power factor of induction furnaces is improved. These advantages are secured by providing an induction furnace with a plurality of channels adapted to contain molten charge and interlinked in parallel with a common magnetic core. Even though the combined sectional area of the separate channels does not exceed the sectional area of a single channel, the permissible power input of the furnace is increased materially and greater efficiency is secured.

The novel features of my invention will be set forth with greater particularity in the appended claims. For a more detailed explanation of my invention, reference may be had to the following specification taken in connection with the accompanying drawing

in which Fig. 1 shows a side elevation of a furnace embodying my invention; Figs. 2, 4, 5, 7 and 9 are sectional views taken in a plane passing through both branches of one of the channels in different modified embodiments of my invention; Fig. 6 is a vertical sectional view of a modification of my invention having a vertical core; Figs. 3 and 10 are vertical sectional views of different forms of furnaces having a horizontal core, the view being taken substantially at right angles to planes in which the channels are located, Fig. 10 being taken on lines 10—10 of Fig. 9; Figs. 8, 11, 12, 13, and 14, are horizontal sectional views of different forms of furnaces taken through the primary winding (Fig. 11 being taken on lines 11—11 of Fig. 9); and Fig. 15 is a somewhat diagrammatic section through the junction of two channels illustrating the circulation of the charge.

A furnace embodying my invention comprises essentially a body of refractory material 8 (Figs. 2 and 3) enclosing a chamber 9 adapted to contain a pool 10 of molten charge, the furnace body having a downward extension 11 in which are formed a plurality of open looped channels 12, 13, (see Fig. 3) located side by side on a common winding axis and communicating at their upper ends with the chamber 9. These channels have been illustrated in Figs. 2 and 3 as having a uniform substantially rectangular section, but they may have sections of various other shapes. In the modification shown in Figs. 2 and 3, these channels surround the middle leg of a horizontal shell type magnetic core 14 on which is located a primary winding 15. Magnetic cores of other desired shape or design may be employed. For example, in Fig. 6, a modification of my invention is illustrated having two channels interlinked in parallel with a rectangular core 14' located in a vertical plane.

The furnace chamber 9 is provided with a charging door 16, a pouring spout 17 and a cover 18. As shown in Fig. 1, the furnace body 8 is surrounded by a shell 19 of boiler plate or the like, bolted together and hung upon trunnions 20. Suitable gearing 21 is provided operated by a hand wheel 22, or other suitable means, whereby the furnace may be tilted to pour a charge.

In the modification illustrated by Fig. 2,

the arms or sections of the channels meet at an acute angle. As shown in Fig. 5, these arms meet at an obtuse angle; in the modification shown in Fig. 4 the channel is rounded or U-shaped; and in Fig. 9 the channel at the bottom is rounded on one side and angular at the opposite side. Any of these shapes may be used in a furnace embodying my invention.

10 A circulation of metal occurs in the channels due to several forces, for example, the repulsion between the primary and the secondary, and the mutual electrodynamic attraction between independent conductors carrying current in the same direction. The circulation set up when one or both of these conductors consists of a liquid is illustrated in Fig. 15 which shows in section the upper portion of two channels 12', 13', separated by a wall 25, communicating with a pool 10' and carrying currents in the same direction. The magnetic field is indicated by dotted lines surrounding the two channel conductors. Metal in the channels 12', 13' when carrying current is forced toward the adjacent walls or faces of the channels and is thus caused to circulate upwardly into the pool along the inner or adjacent walls of the channels, as indicated by arrows.

30 Another force causing circulation is due to an unequal flux density at the bend of the lowermost part of the channels, for example, in a furnace as shown in Fig. 5. Assuming a uniform current density in the metal, the electrodynamic force at the inside of the bend is stronger than at the outside. This causes a circulation as both the current density and the flux density at the inner part of the bend are greater than at the outer part and therefore causes the metal to be forced from the inner wall of the bend to the outer wall.

Other forces may be superimposed upon these circulatory forces. For example, in some cases the two legs of the channel may be made unsymmetrical to produce a unidirectional thermal circulation.

In Fig. 7 I have illustrated in vertical section a part of a two-channel furnace in which the arm 24 of the channel is of materially smaller cross-section than the arm 25 of the same channel. The adjoining channel is similarly shaped and, as shown in dotted lines, the constricted arm of one channel is opposite the wide arm of the adjoining channel.

Various other modifications may be introduced in channel outline and section in accordance with the results desired. In Fig. 8 I have illustrated a three-channel furnace in which the channels, 26, 27, 28, are rectangular in section, the longer axis of the sections lying within a vertical plane and extending at right angles to the axis of the primary winding 15.

In some cases the several channels may to advantage be connected with each other by a conduit. In Figs. 9, 10 and 11, I have illustrated by two sectional views taken at right angles to each other, a furnace provided with a connecting passage 30, connecting the several looped channels. This construction improves the circulation of molten charge through the channels, particularly so when one of the channels, or one of the arms of one or more of the channels, is of a different diameter or section than the remaining channels or channel arms. For example, the molten charge may leave the furnace at the mouth of one channel and return through the connecting passage through another channel to the pool.

In the modification shown in Fig. 12, the arms 31, 32, 33, are smaller in cross-section than the arms 34, 35, 36. The fact that the channel arms 31, 32 and 33 are square while the arms 34, 35 and 36 are elongated, in itself will tend to produce a circulatory force even when the sectional area of the arms is the same. In the form shown in Fig. 13, both arms of the middle channel 37 are smaller in cross-section than the adjoining arms of the channels 38, 39. Here again the compact shape of the channel 37, which is square in cross-section, as compared with the elongated rectangular cross-section of the outer channels 38, 39, produces a circulatory effect. In Fig. 14, a two channel furnace is shown having the channel arms 40, 41 of lesser square section opposite the channel arms 42, 43, or greater rectangular section. As a result both of the difference of cross-section and the difference of shape and size, a unidirectional circulation of molten charge down the one channel and up another channel occurs.

In all the modifications shown in Figs. 11 to 14 inclusive, a common channel 30 connects the several channels, as best shown in Fig. 10. When one or more of the channel arms has a greater or lesser cross-section or in shape differs in some respects from the remaining channel arms so that the current density or flux distribution is unequal, the electro-dynamic force in the channel arms will differ, and unidirectional flow will result, accompanied by some incidental local circulation.

In a double channel furnace, as above described, the permissible power input is nearly twice as great as in a single channel furnace in which the channel has a sectional area equal to the combined sectional area of the two channels and hence has the same cubical capacity as the two channels combined. This fact is of particular importance when a metal of very high conductivity is to be melted, as for example, copper or aluminum.

The reason for this greatly increased en-

ergy capacity will appear when for theoretical consideration a two channel furnace is assumed in which the channels are so far apart that their mutual inductive effect is negligible. The place at which the pinch force will eventually interrupt the circuit is near the junction of the channel and the pool. At this point "X," the hydraulic pressure is the smallest, being equal only to the weight of a column of metal in the pool. The hydraulic pressure H is expressed by the equation:

$H = h \times S$ (pounds per square inch).
 h = distance in inches from point X to pool level.
 S = weight of pool material

lbs.
 cu. in.

The pinch force P when rupturing the circuit of this point in a single channel furnace at the center of the channel may be expressed as follows:

$$P = \frac{I^2}{KA} \text{ (pounds per sq. in.)}$$

I = current in amperes.

A = area of the single channel in square inches.

K = constant (approximately 45×10^6).

In a double channel furnace this pinch force (p) for each channel will be expressed as:

$$p = \frac{i^2}{Ka} \text{ (pounds per sq. in.)}$$

i = current in amperes in one channel.

a = area in sq. in. of one channel.

In a one channel furnace the pinch force will open the circuit approximately when

$$H = \frac{I^2}{KA}$$

In a two channel furnace the pinch force will open the circuit approximately when

$$H = \frac{i^2}{Ka}$$

As the furnaces under comparison are assumed to be identical except for the channels it follows that

$$\frac{I^2}{KA} = \frac{i^2}{Ka}$$

Furthermore it has been assumed that

$A = 2a$, hence

$$\frac{I^2}{K^2a} = \frac{i^2}{Ka}$$

Therefore

$$I^2 = 2i^2$$

or

$$I = \sqrt{2} i$$

or

$$1.41 I = 2i.$$

The total resistance R of the two channel furnace must be equal to that of the one channel furnace, as the combined cross-section of the two channels has been assumed to be equal to the cross-section of the single channel. As the current in the single channel furnace is I and the total current in the two channel furnace is $2i$, the heat generated in the two furnaces under comparison may be expressed as follows:

$I^2 R$ for the single channel furnace.

$(2i)^2 R$ for the two channel furnace.

As we have found the limiting condition to be $2i = 1.41I$, it follows that the power input of the two channel furnace is

$$(2i)^2 R = (1.41I)^2 R = 2I^2 R,$$

that is, the power input in the two channel furnace is twice as great as in the one-channel furnace of the same cubical capacity. The energy capacity of a furnace with a greater number of loops will be correspondingly greater.

In a practical furnace the assumed theoretical conditions will be approximated only as the channels are in close inductive relation. As this will to some extent modify the results, nevertheless it is always possible to considerably increase the power input to a furnace by designing it with two or more loops.

The power factor of a multi-loop furnace is also bound to be greater as the secondary reactance of a multi-loop furnace is lower than for a single channel furnace, the ohmic resistances being assumed to be equal, as already explained.

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

1. An electric induction furnace comprising a furnace body providing a main chamber adapted to contain a pool, a plurality of open looped channels located side by side on a common winding axis communicating at their ends with said chamber and communicating with each other at their bends, and means for inducing a heating current in a charge contained in said channels.

2. An electric induction furnace comprising a furnace body constituting a chamber adapted to contain a pool and a plurality of open looped channels having a common winding axis and communicating with said pool, a conduit connecting said channels at a point removed from said pool, and inductive means so interlinked with said channels that a current will be induced in a conductive charge in said channels.

3. An electric induction furnace comprising a furnace body constituting a chamber adapted to contain a pool and at least three channels having a common winding axis and communicating with said pool, at least one of the outermost channels having a greater

cross-section than the intermediate channel, a conduit connecting said channel at a point removed from said pool, and means for inducing a heating current in said channels.

5 4. An electric induction furnace comprising a furnace body constituting a chamber adapted to contain a pool and a plurality of channels, said channels being bent on themselves and communicating at their ends
10 with said pool, a conduit connecting said channels at the bends thereof, and means for inducing a heating current in said channels.

15 5. An electric induction furnace comprising a furnace body constituting a chamber and a plurality of looped channels communicating with said chamber, the legs of said channels differing in current-carrying

capacity, a conduit connecting said channels adjacent the bends thereof, and means for inducing a current in conductive material
20 contained in said channels.

6. An electric induction furnace comprising refractory walls providing a reservoir, a plurality of looped channels having a common axis and communicating at their
25 ends with said reservoir, the adjacent legs of said channels differing in cross-section, a conduit connecting said channels at a point removed from said reservoir and means for inductively heating a charge in said chan-
30 nels.

In witness whereof, I have hereunto set my hand this 14th day of February, 1921.

MAGNUS UNGER.