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MAGNETIC STIRRING DEVICE AND METHOD

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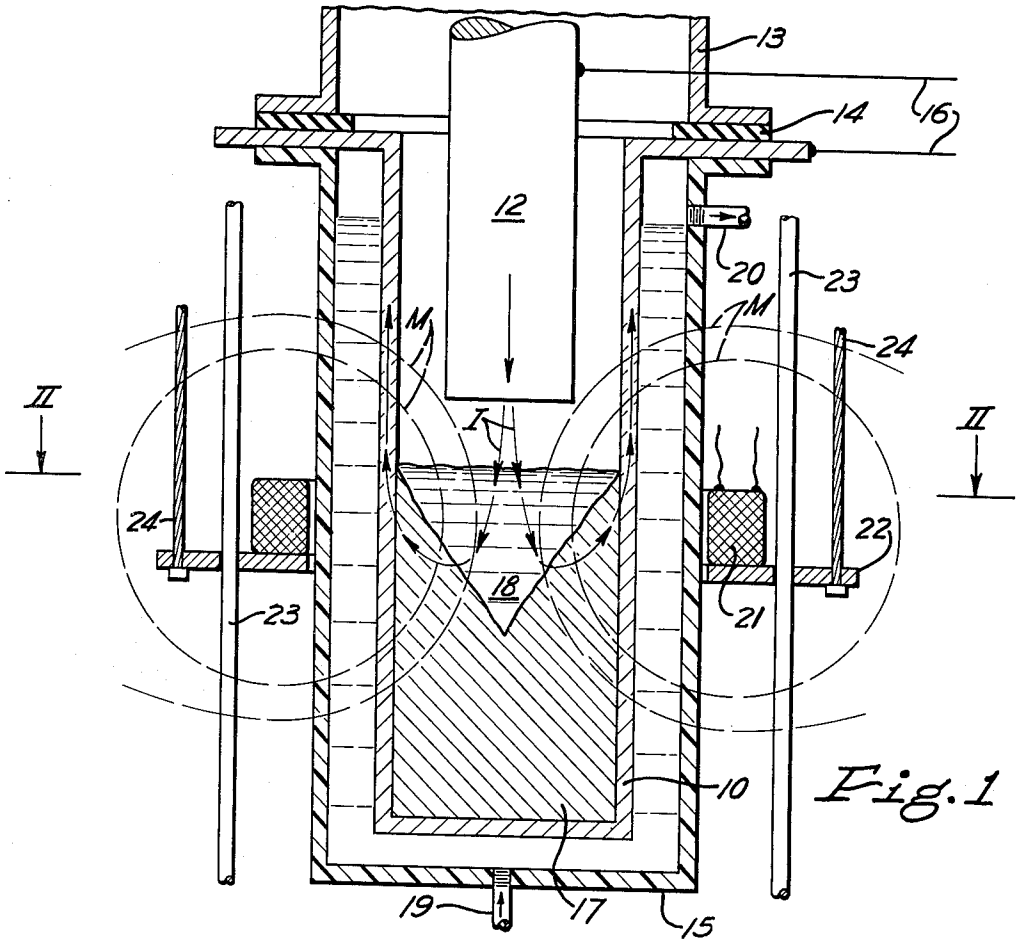


Fig. 1

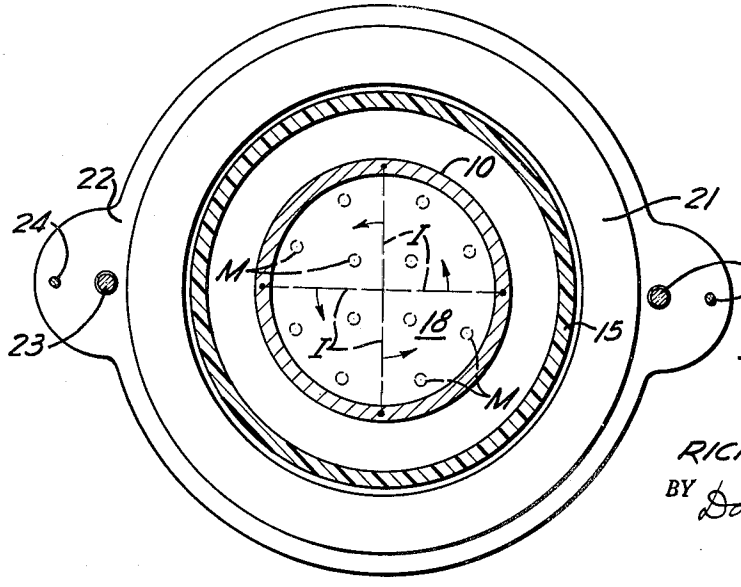


Fig. 2

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MAGNETIC STIRRING DEVICE AND METHOD

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The present application is a continuation-in-part of my earlier application Serial No. 2,691 filed January 15, 1960, and now abandoned.

The invention relates to an improved magnetic stirring device for use with a consumable electrode melting furnace and to an improved stirring method.

Conventionally a consumable electrode melting furnace includes a water-cooled electrically conductive crucible and an electrode usually of metal suspended thereabove. An electric arc is struck between the electrode and a "starting pad" of conductive material in the crucible. The electrode melts and drips into the crucible, where an ingot gradually builds up. The operation is conducted in either an inert atmosphere or a vacuum. Such furnaces have been particularly useful for producing ingots of highly reactive metals (for example, titanium or zirconium) from compacted metallic powder or sponge, but they also have application to ferrous metals and others. Examples of furnaces of this type are shown in Herres Patent No. 2,640,860, Newcomb et al. Patent No. 2,762,856, and Boron et al. Patent No. 2,798,107.

It is known that an electromagnetic coil can be placed around the crucible to stir molten material from the electrode before it solidifies. The theory is that vertical lines of magnetic force act on the radial lines of current flow through the molten material to produce a motor action which keeps the material in motion. For a detailed explanation, reference can be made to a printed publication entitled "Arcs in Inert Atmospheres and Vacuum," edited by W. E. Kuhn, copyright 1956 by John Wiley and Sons, Inc. (pages 57 to 69). However, as far as I am aware, previous magnetic stirring devices have not been successful for stirring ferrous or other magnetic metals. These devices concentrate the lines of magnetic force in the high-permeability section of the electrode, which remains at a temperature below its Curie point. Consequently, the magnetic field above the hot electrode tip fringes radially outward above the hot tip, and the arc current is diverted to the crucible sidewall. This is objectionable since the exposure of the crucible to the arc damages the crucible, electrode metal splashes against the crucible sidewall (solidifying there and giving a scaby ingot surface), and the lessening of the arc current to the pool produces an unsound and inhomogeneous ingot.

An object of my invention is to provide an improved magnetic stirring device and method which can be used for stirring magnetic materials when melted in a consumable electrode furnace.

Another object of my invention is to provide improved arc stability and ingot soundness when melting either magnetic or nonmagnetic electrodes.

A more specific object is to provide an improved magnetic stirring device in the form of a short length movable coil which surrounds the crucible of a consumable electrode furnace at a critical height below the surface of molten material therein; thereby concentrating the lines of magnetic force where they produce the most effective stirring action.

A further object is to provide an improved magnetic stirring method in which the height of the magnetic field within a crucible is continually adjusted to maintain it in a critical relation with respect to the surface of molten material therein.

In accomplishing these and other objects of the invention, I have provided improved details of structure, a preferred form of which is shown in the accompanying drawing, in which:

FIGURE 1 is a somewhat diagrammatic vertical sectional view of a consumable electrode furnace equipped with a stirring device in accordance with my invention; and

FIGURE 2 is a horizontal section taken on line II—II of FIGURE 1.

FIGURE 1 shows a conventional consumable electrode furnace which includes a crucible 10 of electrically conductive material (for example copper), an electrode 12 of material to be melted, a gas-tight cover 13 over the crucible, a gasket 14 between the crucible and cover, and a water jacket 15 surrounding the crucible. The electrode is supported by any suitable mechanism (not shown) which enables its height to be adjusted as it melts, as known in the art. The interior of the crucible and cover is evacuated, and if desired, can thereafter be filled with an inert gas, such as argon. The crucible and electrode are connected to a suitable high amperage D.C. source indicated schematically at 16. An arc forms between the bottom of the electrode and the material in the crucible and the resulting heat progressively melts the electrode. The material of the electrode drips into the crucible, where it solidifies to form an ingot 17. Molten material on top of the solidified ingot forms a pool 18 of approximately inverted conical shape. The water jacket 15 has a water inlet 19 at its lower end and a water outlet 20 at its upper end. Thus water circulates through the jacket to cool the crucible and aid in solidfying the ingot.

In accordance with my invention, I place a short length vertically movable electromagnetic coil 21 around the crucible 10 outside the water jacket 15. The coil has an axial length less than its outside diameter and a number of turns sufficient to produce a theoretical flux density of about 30 to 300 gauss at its centroid when energized with a current of 40 to 160 amperes. The term "axial length" refers to the dimension of the coil along its vertical axis or center line. Of course the wire or tubing used in the coil must be sufficiently heavy to carry safely enough current to produce the desired flux; I have successfully used copper tubing wrapped with sleeve insulation and having a 1/16 inch wall and a 1/4 inch outside diameter. The coil is mounted on a suitable support 22 which is constrained against rotation about its vertical axis, but can be raised or lowered as desired. For this purpose I have shown the support 22 slidably mounted on guide rods 23 and suspended from cables 24 which extend to suitable take-up means above the crucible, although it is apparent many equivalents are possible.

According to my stirring method, as an electrode 12 melts, I continually adjust the position of coil 21 to maintain its height in a critical relation with respect to the upper surface of pool 18. Contrary to expectations, I have found that the centroid of the coil should not be at the same height as the upper surface of the pool, but somewhat lower. The term "centroid" refers to the cen-

ter of mass of the coil as a geometric solid. The centroid of the coil should be spaced below the upper surface of the pool by a distance equal to 1/6 to 2/3, preferably 1/4 to 1/2, the mean diameter of the coil. Since I move the coil physically, each increment of adjustment can be exceedingly small, and I can maintain the coil accurately at its most effective position. Shortly after the ingot starts to form, I energize the coil with a relatively small current (for example about 40 amperes). As the ingot builds up, I progressively increase the coil current to magnitudes in the range of 80 to 140 amperes. During the tapering off period as the ingot approaches its final height, I increase the coil current in a maximum of about 160 amperes.

As the drawing shows, the lines of current flow I pass through the pool 18 in a generally radial direction, while the lines of magnetic force M pass therethrough in a generally vertical direction. Thus there is a motor action which keeps the molten material in constant motion circumferentially of the pool, but I have observed this motion also has a radial component. Turbulence is increased by flow against the conical surface of the solidifying ingot acting as a deflecting surface. I have also observed my coil generates a field which seems to focus the metal dripping from the electrode away from the side walls of the crucible toward the center of the pool. The arc remains more stable and controllable, and I can taper off the operation with an arc current as low as 3000 amperes. Thus I can eliminate the shrinkage cavity which usually forms in the top of the ingot.

Example I

As a specific example to demonstrate my invention, I loaded a conventional consumable electrode furnace with an electrode in the form of a Type 302 stainless steel bloom about 15 feet long, 10½ inches square in cross section. I placed 25 pounds of structural steel punchings in the crucible to act as a "starting pad." I evacuated the interior of the furnace to an absolute pressure of 15 mircons of mercury, which I maintained throughout the operation. I started the melt by lowering the electrode until it touched the starting pad, passing a minimum arc current therethrough and then raising the electrode about 2 inches. I maintained an arc current at 3000 amperes for about 3 minutes, an arc voltage of about 22 volts, and used the electrode as the negative pole. Later I increased the arc voltage by about 2 volts and raised the electrode to maintain an arc length of about 5 inches. I increased the arc current in steps to 7500 amperes (5 minutes), 12,000 amperes (3 minutes) and finally to 15,000 amperes, which I maintained up to the tapering-off period. The electrode melted at a steady rate of about 1.40 lb./min. per 1000 amp. and the ingot slowly built up toward its final height of 60 inches.

I surrounded the crucible with a coil made up of 81 turns of 1/4 inch outside diameter copper tubing having a 1/16 inch wall thickness and wrapped with sleeve insulation. The coil formed a cylindrical shell having a mean diameter of 36 inches, an axial length of 6 inches and a thickness of 4 inches. I energized the coil when the ingot was 10 inches tall. Initially I positioned the coil about 2 inches below the starting pad, and I raised it from time to time to keep its centroid about 9 to 15 inches below the surface of the pool. Initially I maintained a current of 40 amperes in the coil, and I increased this current to 80 amperes when ingot was 24 inches tall and to 100 and 130 amperes when the ingot reached its full height of 60 inches. As a result, the pool was stirred vigorously and continuously.

While the ingot is building up, I attain some of the more important advantages of my invention. The arc is steady and controlled throughout the melt. The crystal structure is more nearly uniform along the length of the ingot than otherwise attained, and the ingot is sounder. If no stirring or only a gentle stirring is used, a sheath of metal forms around the molten pool and shrinks away from the crucible wall. From time to time the molten pool breaks out into the space between the sheath and wall and forms a scab-type defect on the ingot. By stirring vigorously, I maintain a band of molten metal from the pool continuously washing the crucible wall and thus avoid such defects.

After the melting period, I reduced the arc current in steps in the tapering-off period while maintaining the coil energized. This tapering-off allows the molten pool to become smaller and reduces the size of the shrinkage cavity.

Example II

To further demonstrate my invention I loaded the furnace with an electrode of magnetic steel of similar cross section having the following analysis:

	Percent
C	0.46
Mn	0.79
Si	0.28
Ni	0.48
Cr	0.99
Mo	1.01
Al	0.02
P	0.014
S	0.007
Cu	0.13
Fe	balance

I operated the furnace in similar fashion to that described in Example I, and surrounded the furnace with the same electromagnetic coil maintained in the same height relation. I energized the coil when the ingot was 9 inches tall with a current of 40 amperes and then 60 and 80 amperes. When the ingot was 61 inches tall (its final height), I increased the current to 120, 140 and finally 160 amperes. All the while I attained a satisfactory stirring action and arc behavior despite the magnetic properties of the electrode.

While I have shown and described only a single embodiment of my invention, it is apparent that modifications may arise. Therefore, I do not wish to be limited to the disclosure set forth but only by the scope of the appended claims.

I claim:

1. The combination, with a consumable electrode melting furnace which includes a crucible, a water jacket surrounding the outside of said crucible, and an electrode of magnetic material suspended above said crucible, whereby the material of said electrode can melt and drip into said crucible to form an ingot having a pool of molten material at its top, of a magnetic stirring device comprising an electromagnetic coil surrounding the outside of said water jacket and being of an axial length less than its own outside diameter, means constraining said coil against rotation about its axis, and means supporting said coil for physically raising and lowering it with respect to said crucible to maintain the centroid of said coil below the upper surface of the pool, said coil producing vertical lines of magnetic force having a flux density of 30 to 300 gauss at its centroid while carrying a current of 40 to 160 amperes.

2. In a consumable electrode melting process in which an electrode of magnetic material melts, drips into a crucible, and builds up an ingot therein having a pool of molten material at its top, and in which the crucible is water-cooled around its exterior, the combination therewith of a method of stirring the pool comprising surrounding the crucible and its cooling means with an electromagnetic coil of an axial length less than its outside diameter, continually physically raising the coil as the ingot builds up to maintain the centroid of the coil lower than the pool surface by a distance equal to 1/6 to 2/3 the mean diameter of the coil, energizing the coil with

a relatively small current of about 40 amperes as the ingot starts to form, increasing the coil current to a magnitude in the range of 80 to 140 amperes as the ingot builds up, and finally increasing the coil current to a maximum of about 160 amperes as the ingot approaches its final height, thereby producing vertical lines of magnetic force within the pool having a flux density of 30 to 300 gauss.

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