United States Patent

Wooding et al.

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[54] **ELECTROSLAG FURNACE ELIMINATING MAGNETIC STIRRING EFFECT**

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[52] **U.S. Cl.** ....**164/250**, 75/10 C, 13/9, 13/12

[51] **Int. Cl.** **B22d 27/02**

[58] **Field of Search**........164/52, 252; 13/12, DIG. 9; 75/10 C

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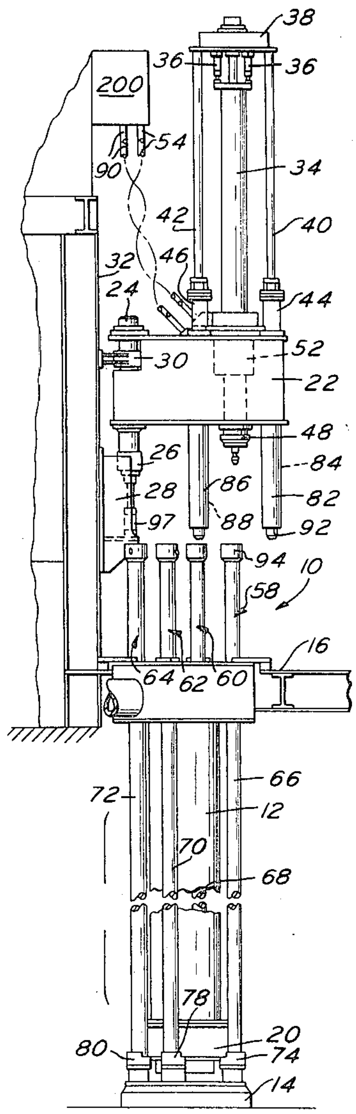
[57] **ABSTRACT**

An electroslag furnace is provided with a power connection equivalent to a coaxial conductor to eliminate the deleterious effects of magnetic fields upon the pool of molten metal.

10 Claims, 4 Drawing Figures



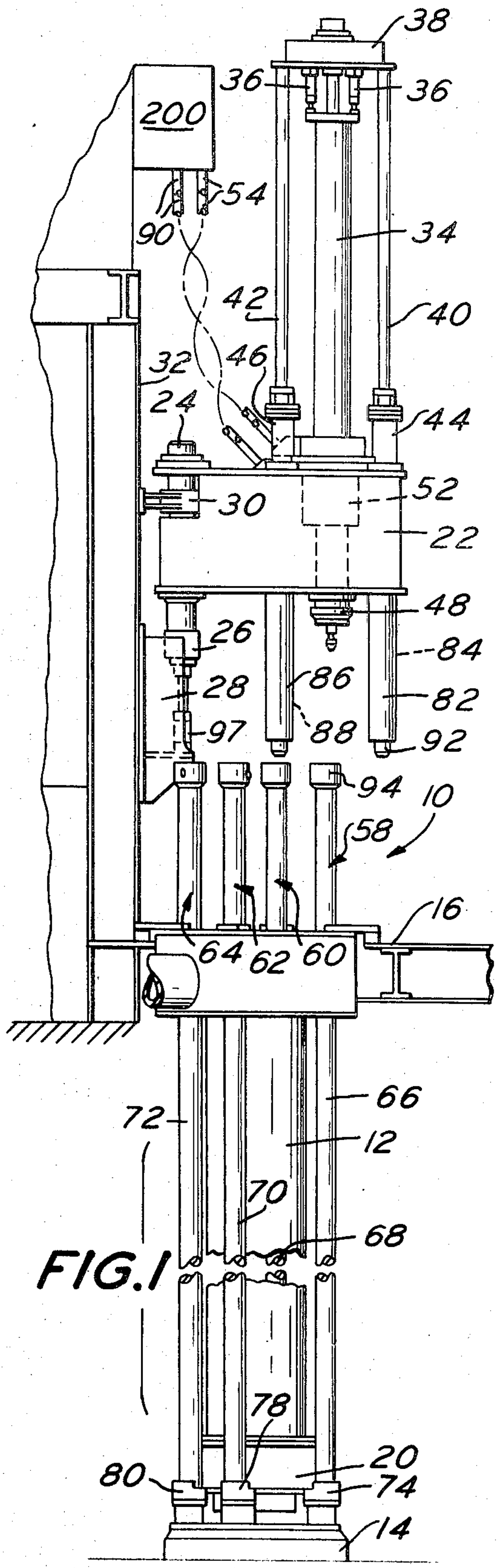


FIG. 1

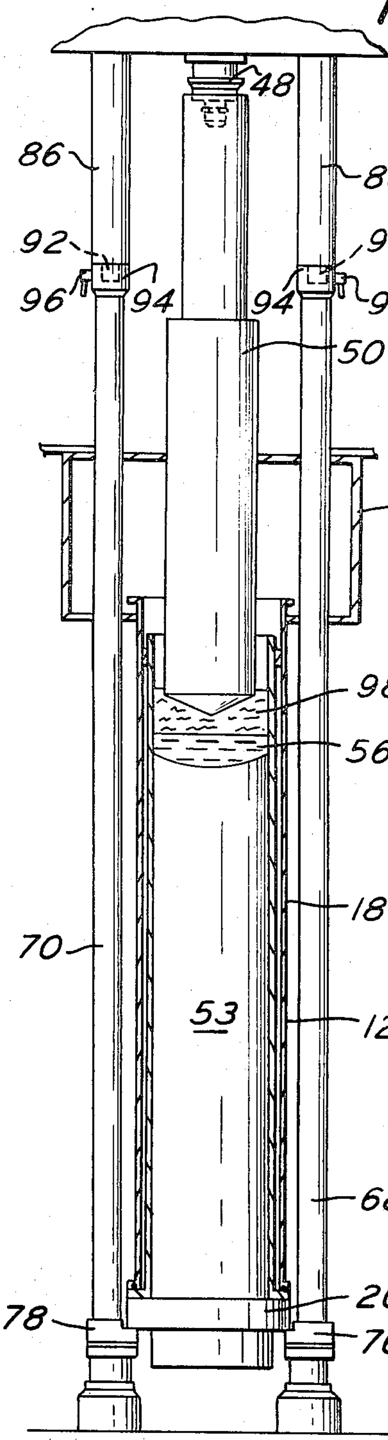


FIG. 2

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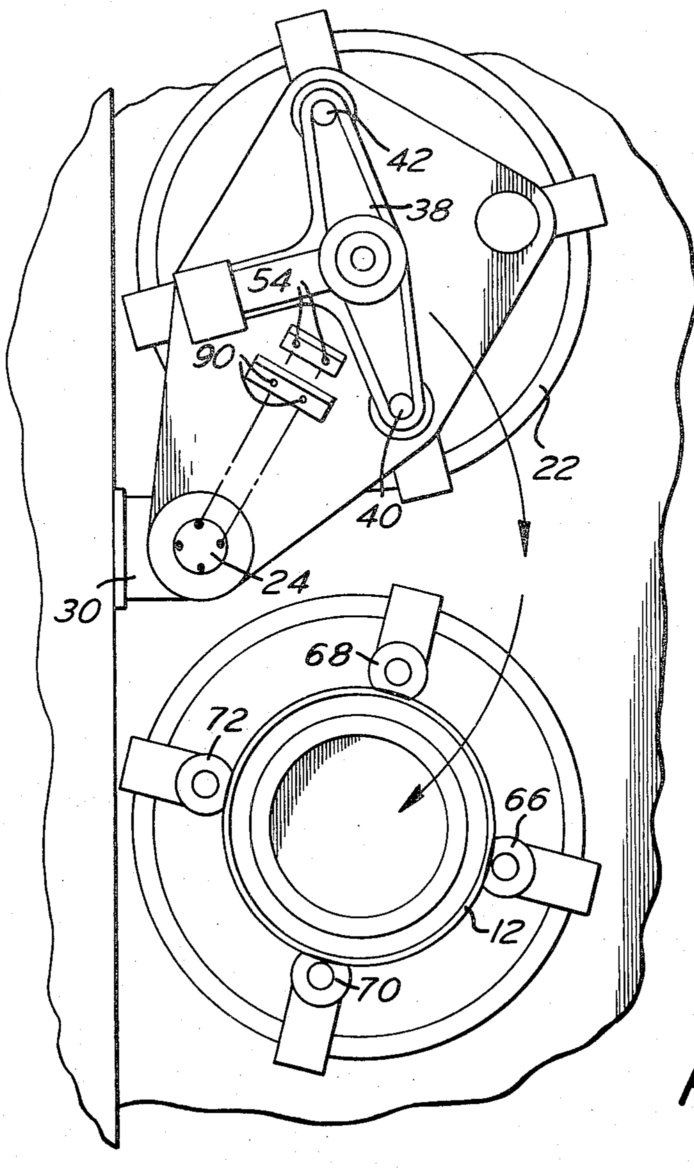

FIG. 3

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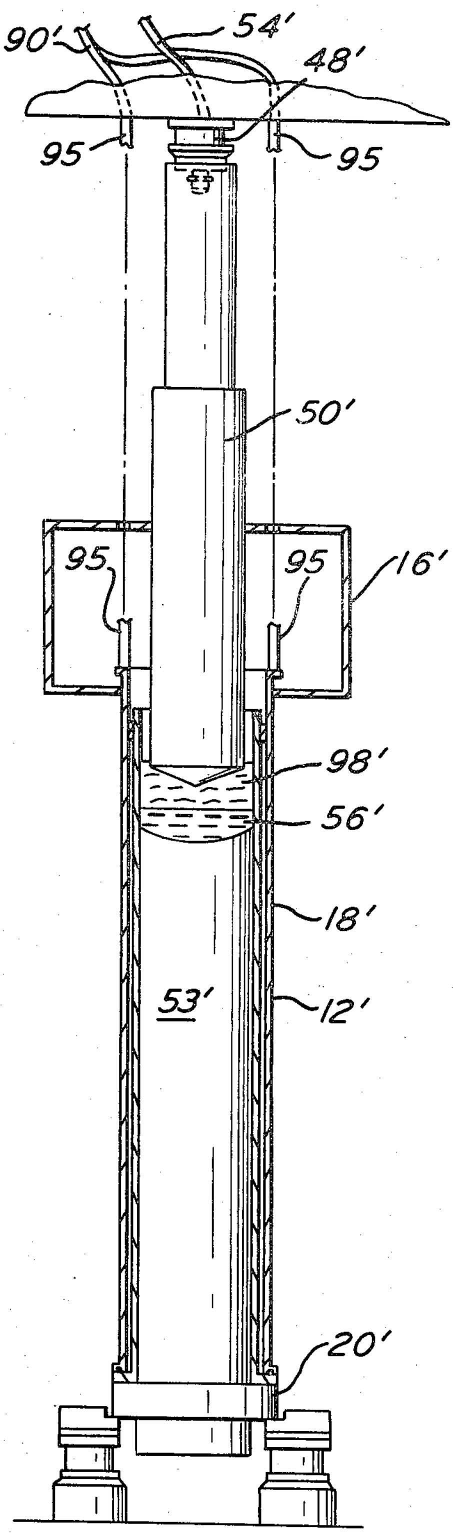

FIG. 4

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ELECTROSLAG FURNACE ELIMINATING MAGNETIC STIRRING EFFECT

This invention relates to a power connection for an electroslag furnace. More particularly this invention relates to a power connection which is the equivalent of a coaxial conductor so as to eliminate the various deleterious effects of magnetic fields.

The present invention relates principally to apparatus for distributing the current in an electroslag furnace to eliminate the stirring effects of the magnetic field on the pool of molten metal.

One of the primary advantages of consumable melting is the progressive solidification of the ingot. Thus the typical consumable electrode furnace first forms a pool of fused metal which enlarges to a determined volume and thereafter remains fairly constant while progressive solidification takes place at the bottom of the pool.

It is known that the shape of the interface between the liquid and solid metal at the top of the resulting ingot plays a very important part in determining the metallurgical quality of the ingot itself. In the electroslag process the operating conditions are chosen so that the solidification front obtained is as flat or horizontal as possible to promote the formation of an ingot of high quality.

Another factor which has been found to influence greatly the quality of the resultant ingot is the degree of stirring or agitation of the molten metal pool. It has been found that for many materials, particularly those with high alloy contents which are subject to alloy segregation, the most uniform ingot structure and the highest ingot quality are obtained when the molten metal pool is completely or almost completely quiescent.

In conventional electroslag furnaces as previously constructed, a quiescent molten metal pool has not been obtainable because of inherent magnetic stirring. This effect results from the inter-action between the horizontal components of the main process current which flow radially towards the sidewall of the crucible, and vertical components of stray magnetic fields produced by the various conductors used to carry current to and from the process. The stirring effect occurs on alternating current furnaces as well as on direct current furnaces because when AC is used the current and the stray magnetic fields reverse simultaneously and the direction of the motor force acting on the molten slag and metal pools remains the same.

There have been no known attempts to eliminate the effects of the magnetic fields in electroslag furnaces mainly because magnetic stirring was not thought to be a problem in electroslag processes. Even with the inherent stirring that occurs in conventional furnaces, the quality of the ingot produced is very high providing the correct operating conditions have been selected. It is however, one of the objects of the present invention to eliminate inherent stirring, resulting in an even higher ingot quality or alternatively resulting in the ability to obtain equivalent quality at a higher production rate.

The objects of the present invention are achieved by providing a coaxial conductor or the equivalent thereof for supplying power to an electroslag furnace. The purpose for using a coaxial conductor design can best be understood by analyzing the nature of the magnetic forces produced in a typical electroslag furnace. The

electrode which is to be melted in such a process must be smaller in diameter than the crucible which will contain the forming ingot and its associated molten slag and molten metal pool. When current is passed between the electrode and the ingot, this diameter difference inevitably results in horizontal components of current flowing radially outwards towards the perimeter of the mould or radially inward towards the electrode depending on the polarity of the applied voltage. In addition to this, the skin effect (for alternating current) is much more pronounced in the molten metal pool than in the slag pool, because of the difference in their electrical resistances. This means that the tendency of the alternating current to flow on the outside is much more pronounced in the molten metal pool than it is in the molten slag pool. Again, in flowing from the slag pool to the molten metal pool or vice versa, horizontal components of current are produced. In a conventional electroslag furnace the power connections to the top of the electrode and the base of the ingot form a large single turn inductive loop generating considerable magnetic fields. These fields generally have a pronounced vertical component in the region of the melt zone. This vertical component will react with the radial component of the electrode current to produce a circulatory motor force according to the classical left hand motor rule.

From the foregoing it is apparent that reducing the vertical component of magnetic field will reduce the deleterious stirring effects. This is accomplished by arranging that the current connection to the top of the electrode and the return conductor from the base of the ingot form a vertically orientated coaxial conductor.

It should be noted that in a conductor system which consists of a vertically orientated coaxial conductor, the magnetic field is completely confined to the space between the inner and outer conductors, and further, the orientation of this magnetic field is completely horizontal. There are no vertical components of field in such a system which could produce magnetic stirring in an electroslag process.

In practice it is difficult to achieve such an ideal coaxial condition because the electrode must be fed downward as it is consumed and because the necessity for access to the furnace prevents the use of a continuous outer return conductor normally associated with a coaxial connection.

In one embodiment of the present invention, displacement of the electrode is provided for, by the incorporation of a sliding contact system. A number of discrete conductors (preferably at least three) are used to obtain the effect of a coaxial return conductor. It has been found in practice that four or more conductors are required to give the same effect as a continuous return conductor but the use of three or even two conductors represents an improvement over the conventional system.

The confinement of the magnetic field previously mentioned results in a conductor system having an inductance much lower than that of a conventional electroslag furnace. This means, for furnaces operated with AC power, that the reactive voltage drop between power supply and the molten slag pool is relatively small and the furnace exhibits a relatively high operating power factor. A further advantage which occurs when sliding contacts are used, is that the length of the coaxial conductor remains fixed even though the electrode is being consumed or melted. This means that the reactive voltage drop is fixed for any particular current level. By contrast, in a conventional electroslag furnace the large single turn inductuve loop formed by the power connection decreases in size as the electrode is melted. This results in a decrease in the reactive voltage drop as the process proceeds, thereby necessitating a controlled decrease in the output voltage of the power supply by way of compensation in order to maintain the thermal and electrical equilibrium of the melt zone. The elimination of this complication in the present invention therefore represents an additional advantage. Yet another advantage of the confinement of the magnetic field into the space between the inner and outer conductors of the equivalent coaxial system is the substantial elimination of the eddy current heating in the steel support structure of the furnace or adjacent equipment located outside the confined loop.

The object of the present invention, therefore, is directed to providing an electroslag furnace for use with alternating or direct current having the requisite equivalent of a coaxial conductor system to eliminate deleterious magnetic stirring of the molten slag and metal pools.

A further object of the present invention is directed to providing an electroslag furnace having the requisite equivalent of a coaxial conductor system which results in a high operating power factor when used with alternating current.

Yet another object of the present invention is directed to providing an AC electroslag furnace having the requisite equivalent of a coaxial conductor system of fixed length in which the reactive voltage drop remains substantially unchanged as the electrode is consumed.

A further object of the present invention is directed to providing an AC electroslag furnace having the equivalent of a coaxial conductor system which substantially eliminates eddy current heating of the steel support structure of the furnace and adjacent equipment.

The objects and advantages of the present invention are achieved by providing an electroslag furnace with a power connection equivalent to a coaxial conductor. This is accomplished by providing a return conductor extending substantially vertically from the base of the crucible. The return conductor, which is preferably a number of discrete conductors equally spaced around the perimeter of the crucible, extends coaxially upward and surrounds the power connection to the electrode, the electrode, the molten slag pool, the molten metal pool, and the ingot so as to define over all, a coaxial configuration. The coaxial configuration is continued to a point sufficiently above the molten slag pool and the molten metal pool so that negligible vertical components of magnetic fields will be generated in the melt zone by the flexible conductors used to make an electrical connection between the coaxial configuration and the electrical power supply.

For the purpose of illustrating the invention, there is shown in the drawings a form which is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

FIG. 1 is a side elevation view of the furnace with the head rotated out of alignment with the crucible.

FIG. 2 is a partial sectional view of the furnace showing an electrode and a partially formed ingot within the furnace.

FIG. 3 is a plan view of the furnace illustrated in FIG. 1.

FIG. 4 is a partial sectional view of a second embodiment of the furnace.

The concepts of the present invention are best understood by referring to the drawings wherein like numerals designate like elements.

The drawings show a consumable electrode furnace of the electroslag type designated generally as **10**. The furnace has been greatly simplified for purposes of describing this invention. Thus, such parts as the control console, slag feeder, and process starting equipment have not been shown since they form no part of the present invention. What is shown is an electroslag furnace having a crucible **12** resting upon a base **14**. The crucible is fixed adjacent its top by a steel box frame **16**. As best illustrated in FIG. 2, the crucible **12** includes an outer water jacket **18** for cooling the walls thereof. The crucible also includes an appropriate water cooled stool **20** at its base which is conventional in such crucibles. As indicated above, appropriate means (not shown) for inserting slag into the crucible are provided

A furnace head **22** is reciprocably and rotatably supported above the crucible **12** by means of a large pin **24** extending through the head and fixed within an appropriate bearing **26** fixed to the block **28**. The pin **24** also extends through a sleeve **30** which provides additional support for the furnace head **22**. The block **28** and the sleeve **30** are supported by column **32**. The pin **24** can be lifted by hydraulic cylinder **97** to provide reciprocal as well as rotational motion of the head **22**.

A water cooled conductor **34** is supported on the head **22** by hydraulic cylinders **36** which are fixed to the plate **38**. Hydraulic cylinders **36** provide a means whereby electrical contact can be made between conductor **34** and the top of the electrode **50**.

The plate **38** is supported above the head **22** by a pair of rams **40** and **42** which are reciprocated by hydraulic pressure applied to pistons fixed at their ends within the cylinders **44** and **46**. Thus, the water cooled conductor **34** can be reciprocated with respect to the head **22**, and also the crucible **12**, by appropriate control of the position of the rams **40** and **42**.

The water cooled conductor **34** supplies current from one terminal of a power supply **200** to the electrode **50** to be remelted within the furnace. The electrode itself is supported at the end of the water cooled conductor by an electrode clamp **48**. This is best illustrated in FIG. 2 wherein the electrode **50** is shown fixed in position on the clamp **48**. Electric power is supplied to the water cooled conductor **34** by a sliding contact assembly **52** mounted within the head **22**. The sliding contact assembly **52** is connected to a power supply **200** by a pair of water cooled conductors **54**.

The electrical circuit from the power supply through the conductor **54**, sliding contact assembly **52**, water cooled conductor **34** and electrode **50** is completed through the pool of molten slag **98**, the pool of molten metal **56**, the ingot **53**, the stool **20**, and the return conductors **58**, **60**, **62** and **64**. The partially formed ingot **53** is shown below the pool **56** in FIG. **2**. Each of the return conductors **58–64** is divided into two sections. The first section is the lower or crucible section identified as **66**, **68**, **70** or **72**. Each crucible section is electrically connected to the stool **20** by means of appropriate connecting blocks **74**, **76** and **78**. The upper portion of each return conductor **58–64** is defined by one of the head sections **82**, **84**, **86** and **88**. The upper or head sections of the return conductors are fixed within the head **22** and connected to a pair of water cooled conductors **90** which in turn are connected to the power supply.

The head sections of the return conductors are shown in FIG. **1** disconnected from the crucible sections so that the head **22** can be rotated out of alignment with the crucible **12**. This is the position of the head **22** illustrated in FIG. **3**. The head is rotated to the illustrated position so that a completed ingot can be removed from the crucible **12**. This also permits removal and replacement of the crucible **12**. After the ingot has been removed, a fresh electrode is positioned within the crucible and the head **22** thereafter rotated into position over the crucible **12**. The electrode **50** is then fixed to the electrode clamp **48** so that it is properly aligned within the crucible. Thereafter, the head **22** is lowered so that each head section **82–88** mates with a corresponding crucible section **66–72** of the return conductors **58–64**. This is illustrated in FIG. **2** wherein a male fitting **92** protruding from each of the head sections **82–88** is fitted within a cup-like female fitting **94** fixed to the end of the crucible section **66–72**. Appropriate locking means **96** fix the fittings in mating relationship and provide good electrical contact. As thus fitted together, the sections of the return conductors **58–64** provide a return for completing the electrical circuit of the furnace **10**.

The return conductors **58–64** are spaced at equal distances about the circumference of the crucible **12**. Moreover, they extend upwardly parallel to the axis of the crucible **12** and are preferably kept as close to the crucible as possible. As thus positioned, they form the equivalent of the outer sheath of a coaxial cable. The water cooled conductor **34** and clamp **48** may be regarded as the internal concentric conductor. Also included in the internal conductor in an operating furnace are the molten slag pool **98**, the molten metal pool **56**, and ingot **53**. The return conductors **58–64** provide a magnetic field which is equal and opposite to the magnetic field generated by the conductor **34**, clamp **48**, electrode **50**, molten slag **98**, molten metal **56**, and ingot **53**. Thus, the magnetic field external to the furnace is cancelled. Moreover, the coaxial positioning of the return conductors **58–64** to the internal concentric conductor (**34**, **48**, **50**, **98**, **56**, **53**) eliminates all vertical components of magnetic flux and hence all stirring forces.

In the preferred embodiment four return conductors are provided. However, it should be noted that three conductors may suffice. Moreover, it may also be desirable to provide more than four return conductors. Four conductors, however, sufficiently control the magnetic field to provide the requisite equivalent of a coaxial configuration for all practical purposes.

As best illustrated in FIGS. **1** and **2**, the coaxial effect is carried well above the melt zone **56** all the way into the head **22**. It is only at the top of the head that conductors **54** and **90** are displaced horizontally with respect to the furnace. Since the conductors **54** and **90** are kept close together, that is, they are "laced" their magnetic fields produced in the region of the melt zone are mutually cancelling. The net result is that there is very little reactive voltage drop in the circuit when AC power is used for melting. Indeed, a furnace constructed in accordance with the principles of this invention will have a much better power factor than other furnaces.

As previously indicated, the water cooled conductor **34** and electrode clamp **48** are used as a means to make electrical connection to the electrode **50**. Power is supplied to the conductor **34** through the sliding contact **52**. During the operation of the furnace, the foreshortening of the electrode **50** is taken up by the displacement of the conductor **34** downwardly toward and into the crucible **12**. In view of the foregoing, the length of the current carrying internal conductor of the coaxial configuration does not decrease as the electrode **50** is melted. Since the length of the coaxial configuration remains fixed even though the electrode is being consumed, the reactive voltage drop in the entire circuit is fixed at any selected current level. Accordingly, there is no requirement for adjusting or compensating the power supply voltage to maintain thermal and electrical equilibrium in the melt zone.

Although the return conductors **58–64** define the preferred embodiment of the present invention, it should also be noted that the crucible itself can be used as a return conductor as shown in FIG. **4**.

In that Figure elements which are the same as those shown in FIG. **2** are identified by the same numeral. Hence the crucible **18'** is electrically connected to the base **20'** as well as to the head **22'**. The connection to the head may be by conductor means **95** which are coaxial with the electrode **50'**. The electrode **50'** is connected to the power supply by conductors **54'** and a sliding contact similar to contact **52** in FIG. **2**. These conductors are electrically insulated from head **22'**. The head **22** may be connected to the power supply by return conductors **90'**.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

We claim:

1. A power connection for an electroslag furnace, said furnace including a crucible, a crucible base, an electrode support and positioning means, and means to make connections to the electrode and the base from a power supply, the improvement comprising a return conductor electrically connected to the base, said return conductor being coaxially disposed around the crucible and the power connection to the electrode, the electrode, the molten slag pool, the molten metal pool, and the ingot to define a coaxial configuration, said coaxial configuration being continued to a point sufficiently above the molten slag and molten metal pools that negligible vertical components of magnetic fields will be generated in the melt zone by a conductor loop used to make an electrical connection between the coaxial configuration and an electrical power supply.

2. A power connection in accordance with claim 1 wherein said return conductor comprises a number of discrete conductors.

3. A power connection in accordance with claim 1 wherein said return conductor comprises at least three discrete conductors equally spaced around the perimeter of the crucible.

4. A power connection in accordance with claim 1 including a sliding contact for making an electrical connection to an electrode, whereby the length of the current carrying coaxial configuration does not decrease as the electrode is melted.

5. A power connection in accordance with claim 4 wherein the power connection from the coaxial configuration to the power supply is laced.

6. A power connection in accordance with claim 4 wherein said return conductor comprises at least three discrete conductors substantially equally spaced about the perimeter of the crucible.

7. A power connection for an electroslag furnace, said furnace including a crucible, a crucible base, an electrode support and positioning means; a power supply, and means to make power connections to the electrode and the base, the improvement comprising a return conductor electrically connnected to the base, said return conductor being coaxially disposed around the crucible and the power connection to the electrode, the electrode, the molten slag pool, the molten metal pool, and the ingot to define a coaxial configuration, said return conductor including first conductor means comprising three or more discrete conductors extending generally vertically upwards from said base, said conductors being equally spaced about the perimeter of said crucible, a separable head, said head supporting matching conductors defining a second conductor means to continue the return conductor vertically upwards to a first terminal point located on said head, means for connecting and disconnecting said second conductor means from said first conductor means so that said head may be displaced to permit loading or unloading of crucibles, electrodes and ingots, said electrode support and positioning means passing through said head, sliding contact means for making an electrical connection between the electrode support means and a second terminal point insulated from said first terminal point, and laced, flexible power cables for making electrical connection between said terminal points and said power supply.

8. A power connection for an electroslag furnace in accordance with claim 7 wherein said first terminal point is located on said head, and said second terminal point is positioned adjacent to said first terminal point.

9. A power connection for an electroslag furnace in accordance with claim 7 wherein said sliding contact means is located on said head.

10. A power connection for an electroslag furnace, said furnace including a crucible, a crucible base, an electrode support and positioning means, a power supply, and means to make power connections to the electrode and the base, the improvement comprising a return conductor electrically connected to the base, said return conductor being coaxially disposed around the power connection to the electrode, the electrode, the molten slag pool, the molten metal pool, and the ingot to define a coaxial configuration therewith, said return conductor including the wall of said crucible extending generally vertically upward from said base, a separable head, means for making and unmaking electrical connection between said head and said crucible wall so that said head may be displaced to permit loading and unloading of crucibles, electrodes and ingots, said head defining a second conductor means to continue the return conductor vertically upwards to a first terminal point located on said head, said electrode support and positioning means passing through said head, sliding contact means for making an electrical connection between the electrode support means and a second terminal point insulated from said first terminal point, and laced, flexible power cables for making electrical connection between said terminal points and said power supply.

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