Aug. 24, 1965 P. J. WOODING 3,202,751

APPARATUS FOR SUPPORTING AND CONDUCTING ELECTRIC CURRENT TO A LOAD

Filed April 2, 1963

3 Sheets-Sheet 1

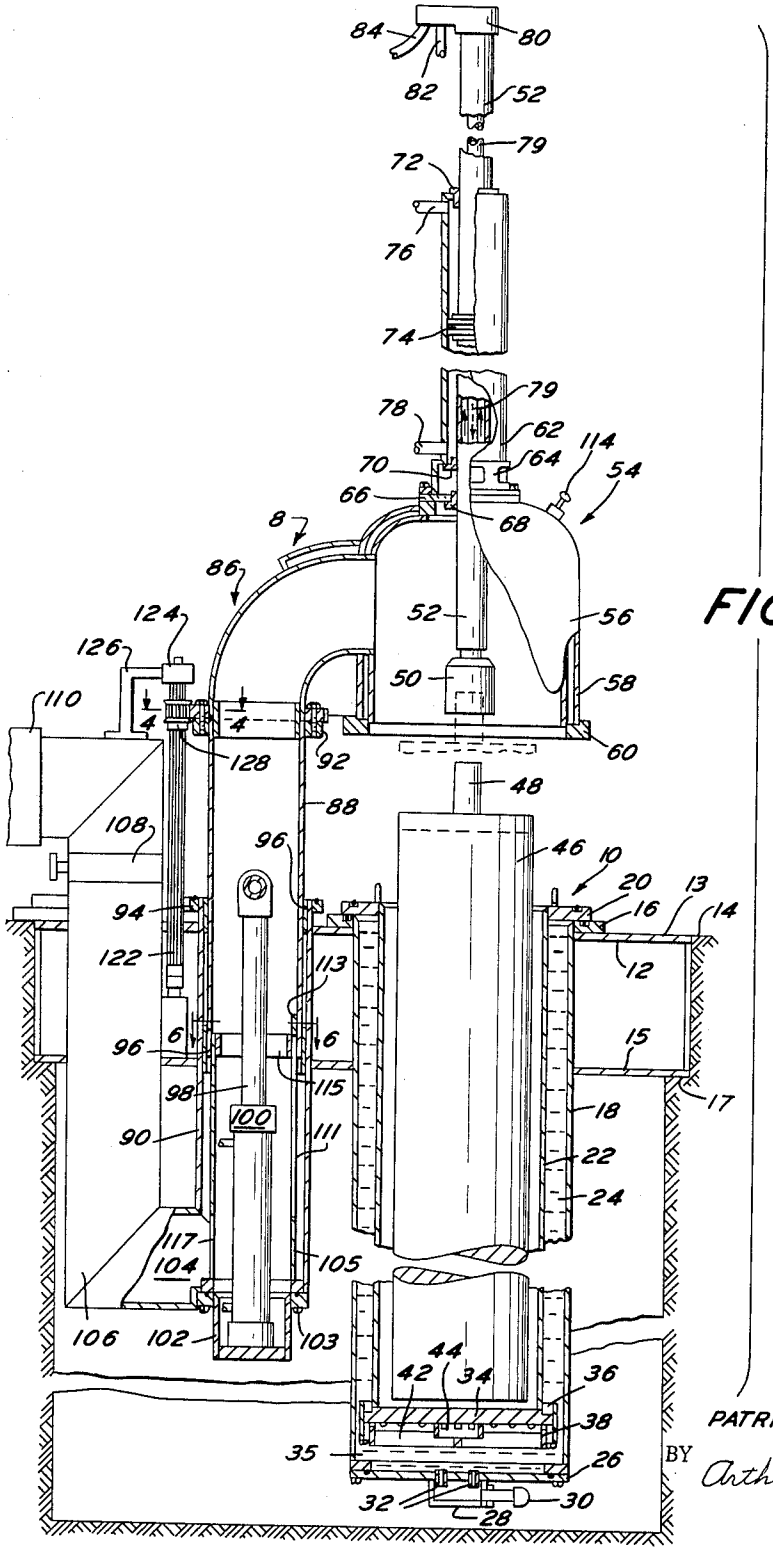


FIG. 1

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FIG. 2

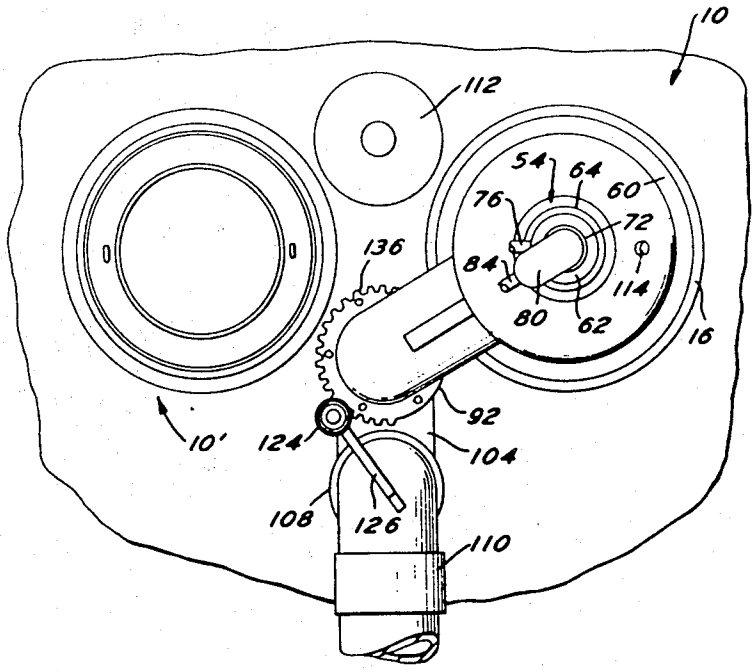


FIG. 4

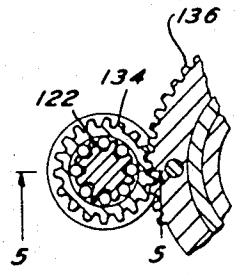


FIG. 6

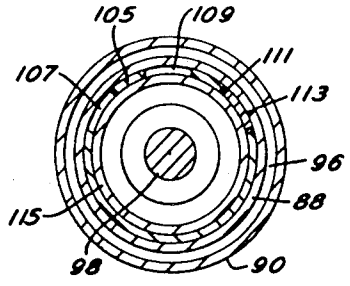
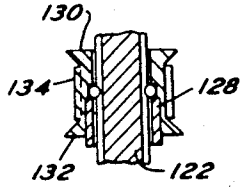


FIG. 5



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Filed April 2, 1963 3 Sheets-Sheet 3

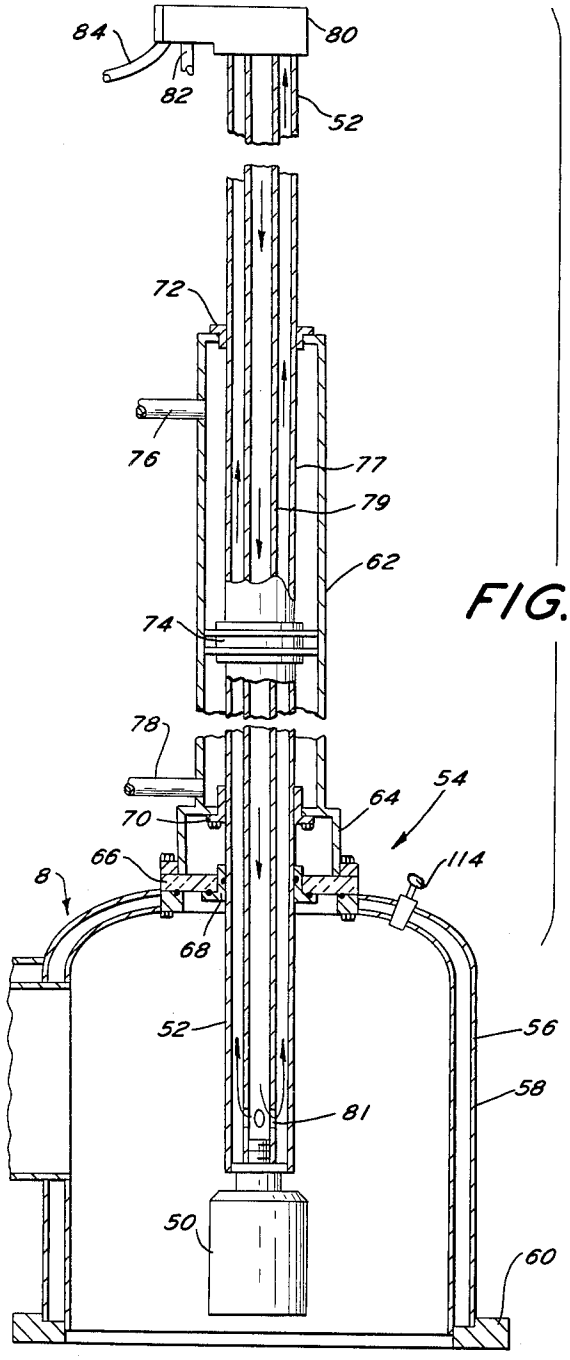


FIG. 3

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3,202,751

APPARATUS FOR SUPPORTING AND CONDUCTING ELECTRIC CURRENT TO A LOAD

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Filed Apr. 2, 1963, Ser. No. 270,027
10 Claims. (Cl. 13—31)

This invention relates to improved apparatus for supporting a load and conducting electric current to the load. More particularly, the apparatus described herein is intended to support and conduct current to a consumable electrode within an electric arc furnace, particularly a furnace of the type described in my copending application Serial No. 270,026, filed on April 2, 1963, and entitled "Consumable Electrode Vacuum Arc Furnace." The furnace therein described is designed particularly for forming ingots of metal such as titanium, zirconium and the like or superalloys and high temperature stainless steel.

In the consumable electrode vacuum arc melting furnace, a metal electrode is melted by means of a high current, low voltage arc to form an ingot in an evacuated water-cooled copper crucible. For reactive metals, the crucible can be cooled by other means, such as sodium potassium liquid metal. For some grades of metal, for example high temperature stainless steel, the furnace may be flooded with an inert gas such as argon before, during or after melting the electrode. This is done to preserve the alloy composition in cases where one or more constituents vaporize at pressures above the levels normally used for vacuum melting.

The direct current arc is struck between the tip of the electrode and the bottom of the crucible and is maintained during melting between the electrode tip and the molten top surface of the ingot being formed. Normally, this melting process takes place at pressure levels between .001 and 1.0 millimeter of mercury with the vacuum system working continuously to remove the evolved gases.

The electrode to be melted carries a heavy electrical current to support the arc, and the electrode is fed into and consumed by the arc. Commonly, the electrode is elongated and suspended by one end and fed downward. Under this method of creating heat and ultimately of melting the desired metal, some difficult problems are encountered. The electrode must be physically connected within the furnace to a supporting structure and must be electrically connected to a power supply. The electrical connection, moreover, must be sufficiently conductive to carry a heavy electrical current efficiently within the high temperature environment.

The consumable arc furnace of the type shown in the above-mentioned patent application utilizes electrodes of finite length. The electrodes employed to produce heavy ingots are necessarily long and cumbersome, and difficulty has been encountered in previous furnace designs in obtaining correct alignment and smooth and efficient control of the lowering action so that proper arcing and melting conditions may be maintained in the furnace.

In order to achieve a homogeneous ingot free of pipes and axial discontinuities, it is necessary to maintain the arc length at a minimum without causing short-circuiting. Under these conditions, the length of electrode burn-off minus the length of ingot build-up in the crucible equals the distance traveled by the electrode. It can readily be seen that as the diameter of the ingot is smaller than the crucible, the electrode will always be traveling downward. The speed of travel will depend upon the diameter of the electrode with respect to the diameter of the crucible. For example, in one practical embodiment of the present invention wherein the electrode was 26 inches in diameter and the crucible approximately 30 inches in diameter, the speed of travel of the electrode at a metallurgically acceptable melt rate was approximately .03 inch per minute.

The information above is merely illustrative of the problem solved by the present invention. That is, the electrode movement must be extremely accurately controlled during the melting operation, while still being capable of high speeds during set-up operations. That is, when the electrode is initially positioned, it must be done so at reasonably fast speeds so that little time is lost between operations.

Therefore, it is the general object of this invention to avoid and overcome the foregoing and other difficulties of the prior art practices by the provision of a new and better apparatus for supporting and conducting electric current to a load.

A further object of this invention is to provide a new and better apparatus for supplying electric current to a consumable arc electrode while accurately positioning the same.

A still further object is to provide a better and more simple consumable arc electrode support which utilizes the current carrying rod as a hydraulic piston for accurate positioning of the electrode.

Another object of this invention is the provision of a new and simpler apparatus for controlling the movement of an electrode in a consumable arc furnace which eliminates the need for complicated mechanical and electrical apparatus on the housing.

Another object of the present invention is the provision of a new and better apparatus for providing electric current to a consumable arc electrode while accurately positioning the same wherein the apparatus is mounted for rotative movement so that it can be utilized with two or more crucibles.

Other objects will appear hereinafter.

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.

FIGURE 1 is a vertical sectional view of the furnace in accordance with the present invention.

FIGURE 2 is a top plan view of the furnace in accordance with the present invention.

FIGURE 3 is a vertical sectional view of the head of the furnace shown in FIGURE 1.

FIGURE 4 is a sectional view taken along the lines 4—4 in FIGURE 1.

FIGURE 5 is a sectional view taken along the lines 5—5 in FIGURE 4.

FIGURE 6 is a sectional view taken along the lines 6—6 in FIGURE 1.

Referring to the drawing in detail, wherein like numerals indicate like elements, there is shown in FIGURE 1 a consumable electrode electric arc furnace designated generally as **8**. The furnace **8** includes a head adapted to be alternatively and sequentially used with a pair of crucible units **10** and **10'**. The units **10** and **10'** are identical. Accordingly, only the unit **10** will be described in detail.

The crucible units **10** and **10'** extend into a pit and are supported in depending relationship from a frame **12**. Frame **12** is a prefabricated unit with cut out holes to receive the crucible units and other elements of the furnace **8**. Frame **12** includes plates **13** and **15** supported by ledge **17** in the pit. The frame **12** facilitates ease of installation since it is the core of a prefabricated unit comprising other elements to be described hereinafter. An annular water jacket flange **16** having a water jacket **18** depending therefrom is supported by but is not secured to the frame **12**. A crucible flange **20** having a

crucible 22 depending therefrom is supported by but not secured to the flange 16. An O-ring seal is provided between the flanges 16 and 20.

Water or other coolant medium is adapted to be circulated in the space 24 between the crucible 22 and the water jacket 18. The crucible 22 is made from copper and provided with a taper of approximately three-fourths of an inch from top to bottom to facilitate ingot stripping. The crucible 22 is provided with a copper base 34 which is spaced from and substantially parallel to the bottom plate 26 on the water jacket 18. A housing 28 is secured to the bottom plate 26. Water or other coolant medium is introduced through conduit 30 into the housing 28 and through sleeve 32 into the space 35 between the base 34 and plate 26.

The lowermost end of the crucible 22 terminates in a stainless steel ring 36. The base 34 is removably coupled to the ring 36 by bolts which extend through a spider ring 38. The spider ring 38 is provided with spiders 42. Each spider arm 42 has a centrally disposed notch within which is disposed a spider hub 44. The uppermost surface of the ring 38 and hub 44 are notched so as to provide for maximum circulation of water or other coolant adjacent the base 34.

An electrode 46 is adapted to be remelted within the crucible 22. It will be noted that the diameter of the electrode 46 is smaller than the diameter of the crucible 22 so as to provide a vacuum gap as is well-known in the art. The electrode 46 is preferably provided with a stub 48 which cooperates with a clamp 50 to suspend the electrode 46 within the crucible 22. For the purposes of the present invention, the clamp 50 may be any one of a wide variety of conventional clamps. Preferably the clamp 50 is of the type disclosed in copending patent application Serial No. 253,220 filed on January 22, 1963 and entitled "Electrode Stub Clamp."

The clamp 50 is connected to a water-cooled current carrying ram 52 which is supported by a head 54. The head 54 includes a hollow water-cooled body 56 having a coolant chamber 58 in the walls thereof. The body 56 is provided with a radially outwardly directed flange 60 adapted to mate with the flange 20 in the lowermost position of the body 56 as will be made clear hereinafter. The head 54 also includes a cylinder 62. The cylinder 62 has a base 64 coupled to the body 56 with an electrical insulation material 66 disposed therebetween thereby electrically isolating the cylinder 62 from the body 56.

The ram 52 extends through a vacuum seal 68, through the cylinder 62, and extends thereabove. In passing through the cylinder 62, the ram 52 extends through guide seals 70 and 72.

The ram 52 has an outer hard chrome-plated steel sleeve 77 to carry the weight of the electrode 46. A piston 74 is fixedly secured to the outer peripheral surface 77 of the ram 52 in any conventional manner such as by welding. The piston 74 is adapted to be reciprocated within the cylinder 62 by selectively introducing a hydraulic fluid medium into the cylinder 62 by way of conduits 76 and 78.

A current carrying copper tube 79 is disposed within the ram 52 and spaced inwardly from the chrome-plated steel sleeve 77. The uppermost end of ram 52 terminates in a head cap 80. One or more current carrying cables 82 extends through the head cap 80 and is coupled to the current carrying copper tube 79. Also, one or more coolant carrying conduits 84 and 85 extends through the head cap 80 to introduce coolant down through the copper tube 79 and remove coolant which passes through suitable openings 81 at the base of tube 79 from the space between the outer peripheral surface of the tube 79 and the inner peripheral surface of the sleeve 77. Water-cooled current carrying electrical conduits 82 and 84 are utilized to introduce both the cooling water and the current to the ram 52 and carry the cooling water away from the ram in a series circuit. The conduits 82 and 84 are flexible hose-covered cables which allow ram 52 to reciprocate in an upright direction without interference.

Thus, the ram 52 is adapted to extend vertically upwards to become the piston rod of a double-acting hydraulic cylinder 62 mounted directly above the furnace head 56. The piston 74 is arranged for friction-free movement in the cylinder, is welded to the ram 52, or piston rod, and extends through the top 72 of the double-acting cylinder to facilitate power and water pickup.

Thus, it is possible to adapt a fully automatic well-proved hydraulic system to handle the movement of the electrode during all its modes of operation. The system permits the application of sufficient power to raise or lower the heaviest electrode, and is sufficiently compact so that the natural frequency of the over-all hydraulic suspension system permits extremely fast regulator response. Thus, it is able to regulate the lowering of the electrode at speeds as low as .005 inch per minute under manual melting conditions and even less under automatic conditions.

The hydraulic system discussed above is operative during the six different modes of operation of the furnace. That is, during manual handling, it is capable of high speeds for raising and lowering and creep speeds for raising and lowering. Additionally, during melting, the hydraulic system may be used manually, semi-automatically, or as part of an automatic system. Further, if control power or a hydraulic component fails, the operator can complete a melt using a hand pump and needle valve in a truly manual operation.

This type of hydraulic system has a number of advantages over existing electro-mechanical differential suspension systems. The most important of these advantages are an improvement of at least 3/1 in response time, fewer moving parts, and simplification of the over-all furnace maintenance requirement since one basic hydraulic system can be utilized for all the motions of the furnace.

The head 54 is suported for reciprocation toward and away from the crucible unit 10 and for rotation through an arc of approximately 120°, as illustrated in FIGURE 2, by means of a conduit 86 which is the main element through which the crucible 22 is evacuated during melting. The conduit 86 includes a first conduit section 88 telescopically coupled to a second conduit section 90. Section 88 is provided with a radially outwardly directed flange 92 adapted to cooperate with a radially outwardly directed flange 94 on the upper end of conduit section 90 when flange 60 is mated with flange 20.

Flange 94 is perferably provided with an O-ring seal or the like on its upper surface. Conduit section 88 is guided for reciprocation with respect to conduit section 90 by a single centrifugally cast bearing 96 shrunk into the housing 90. There is no vacuum seal between the conduit sections 88 and 90 except for the seal provided when the flanges 92 and 94 are juxtaposed to and engaging one another. Hence, the telescopic arrangement between sections 88 and 90 is materially simplified since the necessity for having a rotary and/or sliding vacuum seal has been eliminated.

One end of piston rod 98 is coupled to conduit section 88. The other end of piston rod 98 is coupled to a piston (not shown) disposed within cylinder 100. The lowermost end of cylinder 100 is connected to dirt bucket 102 which in turn is removably coupled to the stationary conduit section 90 by bolts 103. Motive fluid may be conveniently introduced into the cylinder 100 by conventional flexible conduits connected externally of the vacuum system to the bottom flange of cylinder 100 which is also the bottom flange of bucket 102. A conduit elbow 104 is coupled to conduit section 90 adjacent the lowermost end thereof to facilitate and cause the flow of removed vapors to make a 180° turn. Hence, elbow 104 is coupled to conduit section 106 which extends substantially parallel to conduit section 90.

The conduit section **106** may be provided above floor level with a selectively operable vacuum valve **108**. A vacuum pump or the like **110** is coupled to the conduit **106** to facilitate evacuation of the crucible **22** during melting.

As shown more clearly in FIGURES 1 and 6, a cylindrical sleeve **105** is supported at its lower end by the elbow **104**. Sleve **105** has a diameter which is less than the diameter of conduit section **88**. Sleeve **105** is provided with longitudinally extending slots **107**, **109** and **111** extending downwardly from the upper edge thereof and spaced approximately 60° apart. The conduit section **88** is provided with a radially inwardly directed projection **113** which is adapted to be disposed in one of the slots **107**, **109** and **111** when the head **54** is in its lowermost position.

When the projection **113** is disposed within the slot **111**, the head **54** is disposed over the crucible **10**. When the projection **113** is disposed within the slot **109**, the head **54** is disposed over the change station **112**. When the projection **113** is disposed within the slot **107**, the head **54** is disposed over the crucible unit **10'**. The slot **109** may be omitted if the head **54** is not to be lowered at change station **112**.

The upper end of the sleeve **105** is reinforced internally by a ring **115**. When the head **54** is not disposed over the crucible units **10** or **10'** or the change station **112**, the upper end of the sleeve **105** will be in contact with the lower surface on the projection **113** thereby preventing descent of the head **54**. This provides a precautionary feature to enable workmen to work on the head **54** with confidence that the same will not descend. The lowermost end of the sleeve **105** is provided with an opening **117** providing communication between elbow **104** and the interior of sleeve **105**.

A motor means is provided to selectively rotate the head **54** and conduit section **88** relative to the crucible units when the head **54** is in its uppermost position so that projection **113** clears the upper end of sleeve **105**. Such motor means includes a motor **120** supported by the plate **15** of the frame **12**.

The motor **120** is provided with an output splined shaft **122** which extends upwardly through a hole in plate **13** of the frame **12**. The upper end of the shaft **122** is provided with a bearing **124** which in turn is supported from the conduit **106** by a standard **126**. A ball nut **128** surrounds the shaft **122** and is disposed for reciprocal movement therealong. The ball nut **128** includes a plurality of balls which partially extend into the splines on the splined shaft **122**. While the ball nut **128** may reciprocate along shaft **122**, the ball nut **128** will transmit any rotary motion imparted to the shaft **122** by the motor **120**.

As shown more clearly in FIGURES 4 and 5, the ball nut **128** is provided with a top flange **130** and a bottom flange **132** and a pinion **134** between the flanges. The pinion **134** is in meshing engagement with the outer periphery of a gear **136**.

The gear **136** is fixedly secured to the flange **92** on the conduit section **88**. The top flange **130** is adapted to overlie the gear **136**. The bottom flange **132** is adapted to be juxtaposed to the lowermost surface of the gear **136**. Accordingly, the ball nut **128** will reciprocate with the gear **136** and yet be capable of rotatingly driving the gear **136** when the pinion **134** is closely supported by bearing **124** at the upper end of travel.

The frame **12**, conduit sections **88**, **104**, **106**, cylinder **100**, motor **120**, shaft **122**, etc., may be shipped as a prefabricated unit capable of being inserted into the pit. This feature enables the installation of a furnace to be accomplished more rapidly. Thereafter, the remaining components may be provided in the orientation illustrated by means of lift hooks or the like.

A complete description of the furnace and the manner of rotation of the head **54** is shown in my copending application Serial No. 270,026 filed on April 2, 1963 and entitled "Consumable Electrode Vacuum Arc Furnace."

The operation of the furnace **8** is as follows:

With the head **54** disposed over the change station **112**, an electrode **46** may be positioned within the water jacket **18**, as illustrated, by means of an overhead crane. By means of motor **120**, the head **54** will be rotated to a disposition over the electrode. By introducing a motive fluid through conduit **76**, the ram **52** may be caused to descend to a position wherein the clamp **50** will be coupled to the stub **48**. Thereafter, motive fluid will be introduced into cylinder **62** through conduit **78** and removed through conduit **76** to facilitate raising of the ram and the electrode to the phantom position illustrated in FIGURE 1. Prior to raising the electrode, the electrode will have been centered with respect to the crucible so that proper orientation will be attained during the melting.

Thereafter, the motive fluid in cylinder **100** maintaining head **54** in its elevated position will be slowly removed, thereby causing the head **54** to descend to a position wherein the flanges **60** and **20** will be juxtaposed to one another and in sealing contact. At the same time, the lowermost end of the electrode will be spaced from the base **34**. Valve **108** may now be opened and the space between the electrode and the crucible evacuated by pump **110** by way of the body **56** and the conduit **86**. When the desired controlled atmosphere is attained, electrical power may be coupled to the electrode by way of pipe **79**, clamp **50** and stub **48** to strike an arc between the lowermost end of the electrode and the base **34**.

By means not shown and conventional in the art, the arc gap may be sensed and the ram **52** caused to descend by introducing a motive fluid through conduit **76** as the electrode is consumed. Eventually, the electrode will be consumed until only a short stub indicated by the dotted line at the upper end of the electrode in FIGURE 1 remains. This condition may be detected and signaled by any convenient means. The consumed electrode is permitted to remain within the crucible **22** for a sufficient period of time so as to permit cooling of the ingot until the molten pool at the top end of the ingot has fully solidified. As a general rule, the head **54** will remain sealed to the crucible until a chilled skin has formed on the surface of the molten pool. At this point, the power is shut off and valve **108** may be closed. Thereafter, the vacuum seal is broken and the head **54** is raised by means of cylinder **100** and piston rod **98** to a point where projection **113** clears the upper end of sleeve **105**. Since the head moves relative to the molten pool, the molten pool will not be disturbed and the chilled skin will protect the pool from contamination. If the molten pool is disturbed before it is solidified, a substantial portion of the ingot may be wasted.

The head **54** is then rotated to a position so that the stub is above the change station **112**. At the change station **112**, the stub **48** is separated from the clamp **50**. While the head **54** was supporting the electrode being melted in unit **10**, a crane will have previously provided a new electrode and crucible in unit **10'**. Hence, the head **54** may be rotated to a position over the new electrode in unit **10'** and the above operation repeated. As soon as the previously formed ingot has solidified, it may be removed by a crane and a new crucible and electrode substituted therefor.

If it is desired that the controlled atmosphere within the crucible during melting be inert gas rather than vacuum, the inert gas may be introduced through conduit **86**. Hence, the inert gas or other gas may be introduced into the furnace body by way of conduit **86** and removed therefrom by means of an exhaust valve on the body **56**. To facilitate rapid equalization of pressure prior to raising the head **54**, the body **56** may be

provided with a manually operable exhaust valve 114. If desired, auxiliary tangential coolant inlets may be provided in water jacket 18 to increase the coolant velocity at the outer surface of the copper crucible 22. If desired, the support provided by ring 38, spider 42 and hub 44 may be eliminated if the base 34 is dish-shaped.

In order to provide for ease of maintenance, the pit is of sufficient depth so as to enable the cylinder 100 to be maintained. In order to accomplish this, the bolts 103 will be removed. With the head 54 in its lowermost position, motive fluid will be supplied to the cylinder 100 in an attempt to raise the head. Since the lowermost end of the cylinder is no longer coupled to the elbow 104, the cylinder 100 and receptacle 102 will descend. Thereafter, any dirt or contaminant in receptacle 102 may be removed and the necessary maintenance operation is performed.

The frame 12 will be provided with the necessary lifting eyes or the like to facilitate manipulation by a crane. Also, a convenient entry way will be provided to facilitate the entry of a person into the pit for maintenance purposes and the like. Suitable bracing is provided between the plates 13 and 15 of the frame 12 to provide a box girder with sufficient strength to withstand dead-load forces. For added strength and support, it will be noted that the bearing 96 lies in the planes of the plates 13 and 15 of the frame 12.

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.

I claim:

1. In an electric arc melting furnace comprising a head having an electrically conductive water-cooled ram, said head including a main body having an open bottom portion adapted to cooperate with a crucible to define a chamber within which an electrode may be melted under controlled atmosphere conditions, atmosphere controlling means in communication with said chamber for controlling the atmosphere in said chamber, support means for moving and controlling the placement of said head with respect to said crucible, said head having a cylinder mounted on said main body, said electrically conductive water-cooled ram passing through said cylinder, said ram having a piston integral therewith in said cylinder, hydraulic means for controlling the movement of said piston to raise and lower said ram, electrical supply means and water coolant supply means connected to said ram at a point outside of said cylinder and immediately above said cylinder, said ram extending through said cylinder into said body, and an electrode clamp mounted on said ram in said chamber and in electrically conducting relation with said ram.

2. The furnace of claim 1 wherein said support means is adapted to raise and lower said head and additionally is mounted for rotative movement.

3. The furnace of claim 1 wherein said electrically conductive water-cooled ram includes a first cylinder adapted to carry the weight of an electrode, said ram additionally including a second copper tube running the length of said ram and having its surface spaced from the surface of said first cylinder, said water supply means being adapted to supply water within said first cylinder and said copper tube to cool said copper tube, said electrical supply means being adapted to supply electrical current to said copper tube.

4. The furnace of claim 3 wherein said first cylinder is axially aligned with said copper tube and has a greater inner and outer diameter than said copper tube, said piston being welded to the outer surface of said first cylinder, said hydraulic fluid means being adapted to supply fluid to the top and bottom of said cylinder to control the movement of said piston in said cylinder and thereby control the movement of said ram.

5. The apparatus of claim 6 wherein said electrical supply means includes a flexible conduit having an electrical conductor therethrough and said coolant fluid supply means includes a fluid conduit about said electrical conductor to form said flexible conduit.

6. Apparatus for supporting and conducting electric current to a load comprising a cylinder having first and second ends, a ram extending through said first and second ends, said ram having a first end extending through said first cylinder end and being adapted to be connected to a load, said ram having a second end passing through said cylinder second end and being adapted to be connected to a source of electric current, said ram being electrically conducting along the length thereof, said ram having a hollow portion, said ram second end being adapted to be connected to a source of coolant fluid to be supplied to said ram hollow portion to cool said ram, a piston integral with the surface of said ram in said cylinder, and hydraulic means connected to said cylinder for controlling the movement of said piston and thereby controlling the movement of said ram, said ram including a copper tube extending from said ram first end to said ram second end to conduct electrical current therebetween, said ram additionally including a steel sleeve axially in line with said copper tube and having a greater inner diameter than the outer diameter of said copper tube to form a channel between the outer surface of said copper tube and the inner surface of said steel sleeve, said steel sleeve extending between said ram first end and said ram second end, said steel sleeve being adapted to support a load connected to said first end, said coolant supply means being adapted to supply coolant fluid within said copper tube and within the chamber between said copper tube outer surface and said steel sleeve inner surface.

7. The furnace of claim 2 wherein said support means is adapted to rotate said head about an axis parallel to and spaced from the axis of said water-cooled ram.

8. Apparatus comprising a head having an open bottom, a cylinder supported by the head, a hollow ram in said cylinder with a first end of the ram extending out of one end of the cylinder and the second end of the ram extending out of the other end of the cylinder, seal means between said ram and the ends of the cylinder, a piston in said cylinder and connected to said ram, hydraulic conduit means associated with said cylinder for moving said ram, electrode support means mounted on said second end of the ram, an electrical conductor in said ram and electrically coupled to said support means, and a vacuum seal between said head and a portion of said ram between the piston and said second end of the ram.

9. Apparatus in accordance with claim 8 wherein an electrical conductor is hollow, conduit means for introducing coolant through said ram first end into said hollow conductor.

10. Apparatus in accordance with claim 8 including means electrically isolating said ram and cylinder from said head.

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