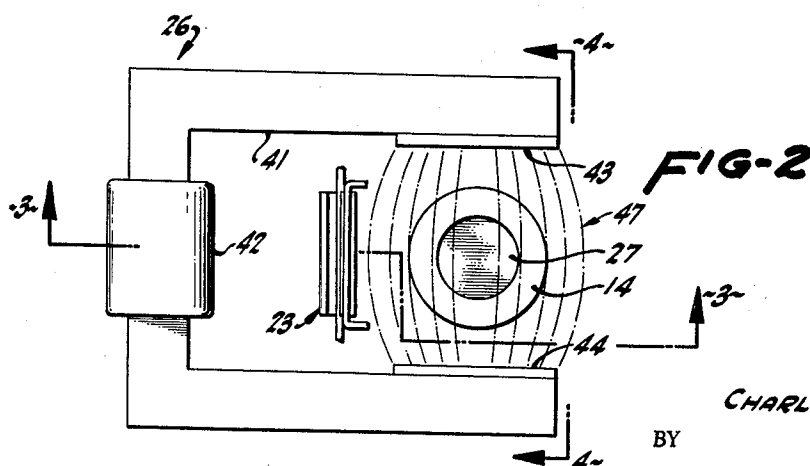


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April 13, 1965

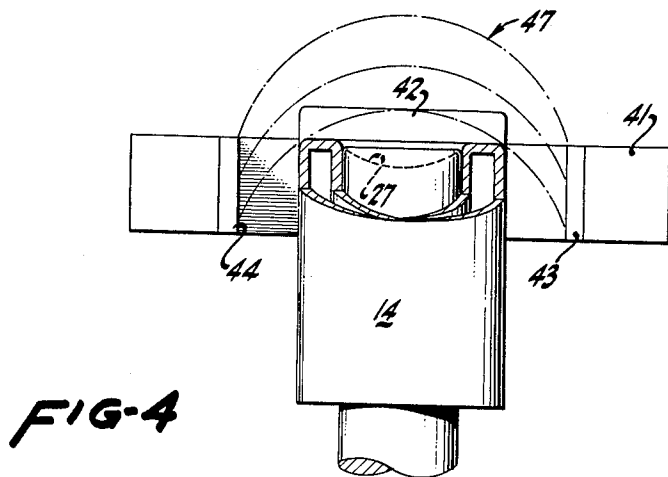
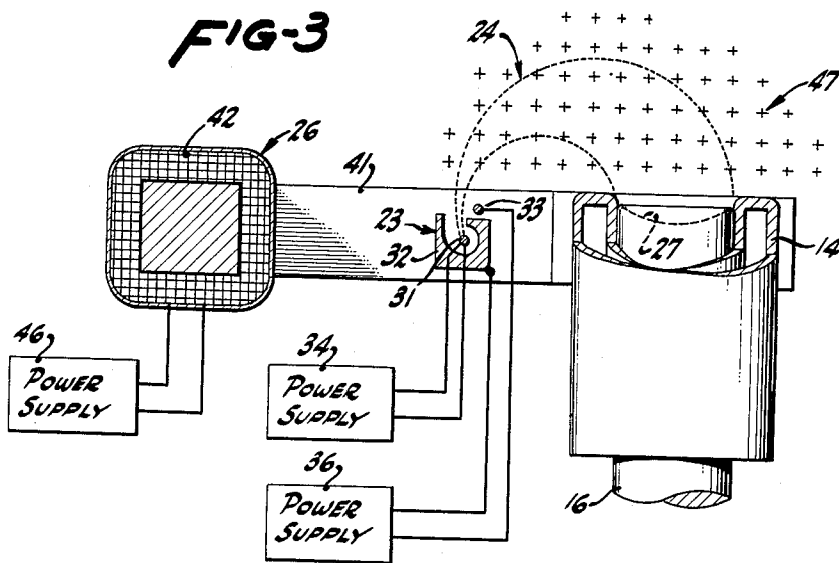
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ELECTRON BEAM FURNACE WITH LOW BEAM SOURCE

Original Filed June 21, 1960

2 Sheets-Sheet 2



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3,177,535

ELECTRON BEAM FURNACE WITH LOW BEAM SOURCE

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Continuation of application Ser. No. 37,615, June 21, 1960. This application Feb. 21, 1963, Ser. No. 260,158 8 Claims. (Cl. 22—57.2)

The present invention relates to an improvement in electron beam furnaces wherein materials are treated by electron beam bombardment in high vacuum. More particularly, the present invention is directed to an improvement in the protection of electron beam sources in furnaces, and to the improved guidance and control of electron beams employed in such furnaces for bombardment heating of materials. This application is a continuation of my prior copending U.S. patent application Serial No. 37,615, filed June 21, 1960, now abandoned.

It is first noted that an electron beam furnace of the type herein contemplated, includes an enclosure which is continuously evacuated to a high vacuum and wherein a material is treated by electron beam bombardment to melt the material. Such treatment may be employed for casting operations and for purification of metals, for example. A typical electron beam furnace may employ a water-cooled copper mold into which is dripped a material being melted by bombardment heating, and within which the material is further heated by bombardment at the open top of the mold. This latter bombardment serves to maintain a molten pool of material within the mold atop a solidifying ingot therein. By continuously withdrawing solidified material from the lower portion of the mold, it is possible to attain a continuous casting and purification process with such a furnace. Alternative applications of electron beam furnaces are also, of course, possible.

With regard to the improvement provided in electron beam furnaces by the present invention, it has been found that in order to maintain prolonged operations of such a furnace it is necessary to protect the electron beam sources, or electron guns, from vapors evolved in the course of operations. In particular, it has been found that substantial quantities of vapor rises from the surface of the molten pool within the casting mold or container of the furnace, and that such vapors tend to deposit upon the elements of electron guns, or the like, utilized for electron beam generation, and consequently to severely limit their efficiency and controlled operation. The present invention provides for overcoming this difficulty by the positioning of an electron gun for pool bombardment below the surface of the pool. It will be appreciated that vapors generated from a molten pool of material will rise therefrom, and consequently by the positioning of the bombarding electron gun below the surface of the pool, such gun is then disposed almost entirely out of the region of substantial vapor concentration.

Direction of the electron beam into the pool for bombardment heating thereof is herein accomplished by the utilization of magnetic field guidance, and the present invention provides for the disposition of such guidance means below the surface of the pool in order that vapor rising therefrom shall not deposit upon the guidance means. In many applications of electron beam furnaces, extremely large quantities of vapor and gases are evolved from the surface of the molten pool of material in the container thereof, and despite the high-speed evacuation of the furnace enclosure, such vapor will deposit upon any surface disposed immediately above the pool. This

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is highly disadvantageous in normal operations, inasmuch as such deposition of material will affect the operation of those elements upon which it deposits, and is further disadvantageous in the situation wherein the vapor is to be otherwise utilized.

The present invention provides a substantial improvement in electron beam furnaces by the disposition of the pool electron gun below the pool surface, and by the utilization of magnetic guidance to direct a high-energy electron beam from such gun onto the surface of the pool so that the volume above the pool is relatively unobstructed by furnace elements for the ready removal or utilization of the vapor rising from the pool. Although various possible objects and advantages of the present invention will become apparent to those skilled in the art from the following description of a single, preferred embodiment of the invention, no limitation is intended by the terms of such description, and instead, reference is made to the appended claims for a precise delineation of the true scope of this invention.

The invention is illustrated in the accompanying drawings, wherein:

FIG. 1 is a schematic illustration of an electron beam furnace embodying the improvements of the present invention;

FIG. 2 is a plan view of a portion of an electron beam furnace, including the pool gun and magnetic guidance means, in accordance with this invention;

FIG. 3 is a sectional view taken in the plane 3—3 of FIG. 2; and

FIG. 4 is an elevational view of the elements of FIG. 2 taken in the plane 4—4 of such figure.

Considering first the electron beam furnace in general, and referring to FIG. 1, there will be seen to be illustrated an enclosure 11 defining a chamber 12 therein, and having evacuation means 13 connected thereto. These evacuation means serve to continuously pump out the chamber 12 in order to maintain a high vacuum therein, as of the order of 1 micron of mercury. Within the furnace there may be disposed a container 14 into which material such as metal may be deposited. This container 14 may, for example, be formed of copper, or the like, with passages therein for the circulation of cooling water, so that molten material deposited within the mold will be cooled therein and may be withdrawn from the bottom thereof in the form of an ingot 16. Suitable withdrawal means 17 may be provided for this purpose in order to maintain continuous casting operations in the furnace. The material to be operated upon may be provided in the form of a melt stock or bar stock 18, disposed above the container 14 and fed toward the container by suitable feed means 19. In the instance wherein the electron beam furnace is to be employed for melting and casting of materials such as refractory metals, for example, the bar stock 18 is fed toward the container from above as by lateral or vertical feed over the top of the container for bombardment by an electron beam to progressively melt the material of the bar stock so that the same then drips downwardly into the open top of the container 14. Provision is also made for additionally heating materials dripped into the container.

Electron bombardment heating of the bar stock 18 is accomplished with at least one electron gun 21 producing a high energy electron beam 22 and like heating of the top of the material in the container 14 may be accomplished with one or more separate electron guns 23 producing a high-energy electron beam 24. In accordance with the present invention, the electron guns 21 and 23 are disposed in positions of minimum danger from vapors and gases evolved in the furnace, and mag-

netic guidance means 26 are employed to direct the electron beams into desired trajectories. Thus, as shown in FIG. 1, the pool gun 23 is located below the top of the container and of a molten pool of material 27 maintained therein by bombardment heating. The magnetic guidance means 26, described below, provides for curving the electron beam paths and such curvature may be employed to pass the beams about baffles or protective shields further inhibiting the passage of gasses or vapors directly to the guns from the molten material. There is schematically illustrated in FIG. 1 a shield 28 masking the bar gun 21 from the pool 27, as well as from the bar stock, and a further shield 29 masking the pool gun 23 from the leading edge 18' of the bar stock. These shields 28 and 29 fully isolate the guns 21 and 23 from direct line paths between the molten metal and guns, and the electron beams are curved about the shields so that maximum gun protection is achieved.

Further to the particular improvements in electron beam furnaces provided by the present invention, reference is made to FIGS. 2, 3 and 4 of the drawings wherein the electron beam gun for pool bombardment is illustrated as to relative position with respect to the container or mold of the furnace; and furthermore, the magnetic guidance means are shown as to one preferred embodiment thereof. In these figures the shield 29 is omitted for clarity. The electron gun may include an electron-emissive filament 31 disposed within a reentrant opening in a backing electrode 32. Also included as a part of the gun 23 is an anode or accelerating electrode 33, disposed without the backing electrode 32 and adjacent the opening therein. The electron gun 23 is disposed to one side of the container 14 and below the upper surface thereof. Energization of the electron gun may be conventionally accomplished by the connection of a power supply 34 across the filament 31 to thereby raise the temperature of same for electron emission, and by the connection of a further power supply 36 between the backing electrode 32 and accelerating electrode 33. Electrons generated at the electron-emissive filament 31 will thus be seen to be attracted by the electric field established between the electrodes 32 and 33 so as to be accelerated outwardly of the backing electrode, and as illustrated, the opening in such electrode is directed upwardly so that the accelerating field consequently serves to accelerate electrons upwardly from the source. There is thus produced a ribbon-shaped beam which is accelerated from the source in a direction that is perpendicular to the filament. There may also be employed alternative electron gun configurations including, for example, indirectly heated emitters wherein more precise control of beam trajectory is possible.

In order to direct the electron beam 24 into the open top of the container or mold 14 for bombardment heating of material therein, there is established, in accordance herewith, a magnetic field having flux lines extending across the top of the container 14. The magnetic guidance means 26, generating and maintaining such a magnetic field, may include a yoke 41 of magnetic material such as iron, and having a magnet winding 42 thereabout. The yoke 41 has pole pieces 43 and 44 disposed on opposite sides of the container 14, so as to define a magnet gap between such pole pieces. Suitable magnet power supply means 46 may be connected to the winding 42 for energizing same to establish a magnetic field between the pole pieces 43 and 44. As best seen in FIG. 2 of the drawings, the pole pieces are oriented so as to establish magnetic lines of force 47 transversely of the direction of propagation of the electron beam 24.

The acceleration of the electron beam 24 transversely into the magnetic field 47 will be seen to cause a deflecting force to be applied to the electrons of the beam, with such force being directed at right angles to the magnetic field and at right angles to the direction of electron travel. Employing normal conventions, it will be seen that the

magnetic field 47 should be directed into the plane of FIG. 3, in order to deflect the electrons to the right and downwardly into the pool 27. In the illustrated embodiment, the entire magnetic guidance means 26 is disposed below the surface of the molten pool 27, so that vapor arising from such pool by the bombardment heating of same will not tend to deposit upon the pole faces, yoke or any other portion of the guidance means. The actual amount of deflection of any particular electron beam into a single container in any electron beam furnace will, of course, be appreciated to be dependent upon the relationship between the strength of the magnetic field, the velocity of the electrons in the beam 24, and the relative disposition of the electron gun 23 and container 14. The amount of deflecting force, and consequently the radius of curvature of any electron beam in any field strength, may be calculated from available relationships to be found in conventional texts, and consequently no such calculations are herein included beyond the notation that same may be readily computed.

Considering further the magnetic guidance and focusing of electrons onto the material for heating, there is herein provided both an overall guidance and lateral focusing. The transverse magnetic field through which the beam travels exerts a deflecting force upon the electrons so that the beam is guided to traverse a generally arcuate path, as indicated in FIG. 3. In addition, the invention provides a warped magnetic field of decreasing intensity toward the mold so that an additional focusing action is attained. This warped field actually has a barrel shape, as generally indicated in FIG. 4, to thereby establish a vector force upon electrons toward the axis of the mold. Electrons having an initial lateral divergence in their direction of propagation from the filament are not only deflected into an arcuate trajectory, but are also directed toward the central plane of FIG. 4. The direction of the force vector acting upon these electrons is perpendicular to the field lines and to the direction of electron travel, thus urging the electrons toward a central plane through the filament and mold so that beam spreading is precluded. Actually, any electrons laterally displaced from the center of the mold are acted upon by the barrel-shaped field to thus be urged back toward the mold center. Consequently, a wide ribbon-shaped beam, as is produced by the elongate filament shown in FIG. 2, is acted upon to fold the beam edges inwardly so as to focus substantially all of the beam in the mold. Electrons at the beam edges pass through a laterally curved magnetic field which applies converging forces to these electrons and thus focuses the beam into a generally circular configuration upon the material in the mold. In this manner it is thus possible to employ straight elongate filaments and yet focus the beam therefrom upon an area of limited lateral extent.

The electron beam furnace improvement of the present invention will be seen to provide for the disposition of the electron guns entirely out of areas of high vapor concentration, and also entirely removed from positions subject to gas bursts arising from the melting of a material in the furnace. Furthermore, the magnetic guidance means of the present invention affording the requisite electron trajectory to focus electron beams upon the material being treated, are also wholly removed from critical areas wherein deposition of vapor thereupon might otherwise occur. In those instances of electron beam furnace operation wherein very substantial quantities of vapor and/or gases are generated in the furnace operation, it will be appreciated that the effects of same are quite material, particularly in furnace configurations wherein the electron guns of the furnace may be affected by such gases or vapors. The electron guns of the present invention may be quite conventional in providing for the generation of copious quantities of electrons and the acceleration of same to high energy, as of the order of 5 to 15 kv. The electron beam sources of this furnace

may be properly termed "remote guns," inasmuch as the entire electron acceleration is completed in the gun area and without regard to potentials of other portions of the furnace. This is highly advantageous in maintaining desired electron beam trajectories, for alternative arrangements allow the material being treated to influence the electron beam, particularly in regions of high gas concentration adjacent the materials.

The above-described magnetic guidance may also curve the beam through a much greater angle than that illustrated. This is highly advantageous in that the relative orientation of the electron gun or source may then be modified so as to provide even greater protection thereto. Thus, the gun 23 may be disposed to initially direct the electron beam horizontally away from the container 14 or even downwardly so that the beam is curved through an angle between 180° and 360°, for example. It is only necessary in accordance herewith to direct the beam substantially perpendicularly into a sufficiently strong magnetic field from a proper location below the top of the container to focus the beam into the container. With the gun directing the beam away from the container, it is possible to dispose the gun so that the back thereof faces the active furnace volume where gases and vapors are evolved to thus further minimize contamination of the operating gun elements.

By the utilization of remote electron guns and the positioning of same entirely out of areas of high vapor or gas pressures, as may instantaneously occur in operation of the furnace, there is afforded hereby a material advancement in electron beam furnaces. Furthermore, the magnetic beam guidance of the present invention is highly desirable in focusing the electron beam upon the material to be bombarded. This magnetic guidance means is likewise fully protected herein by the physical positioning of same below the surface of the pool of material being treated, so that almost no vapor deposition upon the guidance means occurs.

What is claimed is:

1. An electron beam furnace comprising, an evacuated enclosure adapted to contain a material which has a surface to be treated by electron bombardment, means within said enclosure adjacent the material to be treated and below the surface thereof for generating an elongated ribbon-shaped electron beam, means directing the electron beam in a path away from the surface of the material to be treated, means on opposite sides of the material to be treated for generating a magnetic field adjacent the surface of the material to be treated and in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the material to be treated, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be treated.

2. An electron beam furnace comprising, an evacuated enclosure containing a container for receiving a material to be heated, means adjacent said container and positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombardment of the material to be heated, means directing the electron beam in a path away from the surface of the material in said container, means adjacent opposite sides of said container and extending below the upper surface of said container for generating a field adjacent the open top of said container and in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the material to be heated, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be heated in said container.

3. An electron beam furnace comprising, an evacuated enclosure containing an open top container for receiving a material to be heated, means adjacent said container and

positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombardment of the material to be heated, magnetic pole pieces extending alongside and adjacent to opposite sides of said container and positioned below the upper surface of said container, means for energizing said pole pieces for generating a barrel shaped magnetic field about the open top of said container in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the material in said container, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be heated in said container.

4. An electron beam furnace comprising, an evacuated enclosure containing an open top container for receiving a material to be heated, means adjacent said container and positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombardment of the material to be heated, accelerating means for directing the electron beam in a path away from the surface of the material in said container, magnetic pole pieces extending alongside and adjacent to opposite sides of said container and positioned below the upper surface thereof, means for energizing said pole pieces for generating a barrel shaped magnetic field about the open top of said container and in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the material in said container, the barrel shaped magnetic field including a fringing portion extending toward said generating means, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be heated in said container.

5. An electron beam furnace comprising, an evacuated enclosure containing an open top container for receiving a material to be heated, means adjacent said container and positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombardment of the material to be heated, accelerating means for directing the electron beam in a path away from the surface of the material in said container, magnetic pole pieces adjacent opposite sides of said container and positioned below the upper surface thereof, said pole pieces being slightly longer than the width of said container, means for energizing said pole pieces for generating a barrel shaped magnetic field about the open top of said container in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the material in said container, the barrel shaped magnetic field including a fringing portion extending toward said generating means, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be heated in said container.

6. An electron beam furnace comprising, an evacuated chamber, means for feeding an ingot to be melted into said chamber, means for generating an electron beam for melting an end of said ingot, a casting mold beneath the end of said ingot for receiving the melted ingot, means adjacent said mold and positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombardment of the melted ingot, magnetic pole pieces extending alongside and adjacent to opposite sides of said mold and extending below the upper surface thereof, means for energizing said pole pieces for generating a barrel shaped magnetic field about the open top of said mold in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and has curving lines of flux which are concave with respect to the surface of the melted ingot in said mold, thereby causing deflection and convergence of the

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elongated ribbon-shaped electron beam onto the surface of the melted ingot in said mold.

7. An electron beam furnace comprising, an evacuated enclosure adapted to contain a material which has a surface to be treated by electron bombardment, means for generating a magnetic field adjacent the surface of the material to be treated which has curving lines of flux which are concave with respect to the surface of the material to be treated, means within said enclosure for generating an electron beam for bombardment of the material to be treated, said generating means being disposed within the magnetic field generated by said magnetic field generating means and positioned below the surface of the material to be treated, means directing the electron beam away from the surface of the material to be treated in a path transverse to the magnetic field, whereby the electron beam is focused onto the surface of the material to be treated.

8. An electron beam furnace comprising, an evacuated enclosure containing a container for receiving a material to be heated, means adjacent said container and positioned below the upper surface thereof for generating an elongated ribbon-shaped electron beam for bombard-

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ment of the material to be heated, means directing the electron beam in a path away from the surface of the material in said container, magnetic pole pieces of opposed polarity adjacent opposite sides of said container and extending below the upper surface of said container for generating a magnetic field about the top of said container in the path of the electron beam, which magnetic field is transverse to the path of the electron beam and which in the region of the apogee of the beam path has curving lines of flux which are concave with respect to the surface of the material to be heated, thereby causing deflection and convergence of the elongated ribbon-shaped electron beam onto the surface of the material to be heated in said container.

References Cited by the Examiner

UNITED STATES PATENTS

2,880,483	4/59	Hanks et al.
2,932,588	4/60	Frank.
3,046,936	7/62	Simons.

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