Aug. 27, 1963

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3,101,515

ELECTRON BEAM FURNACE WITH MAGNETICALLY GUIDED AXIAL AND TRANSVERSE BEAMS

Filed June 3, 1960

3 Sheets-Sheet 1

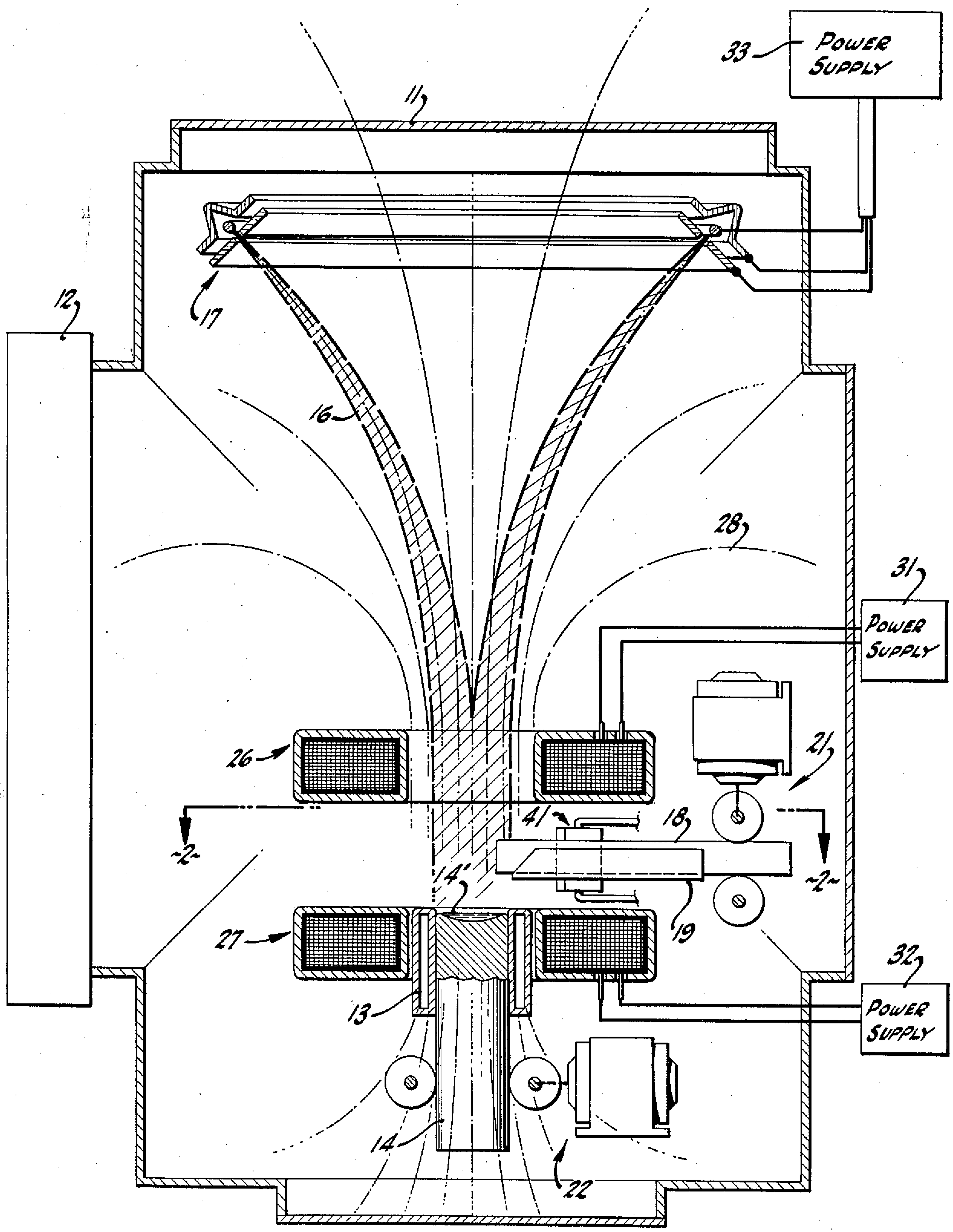

FIG-1

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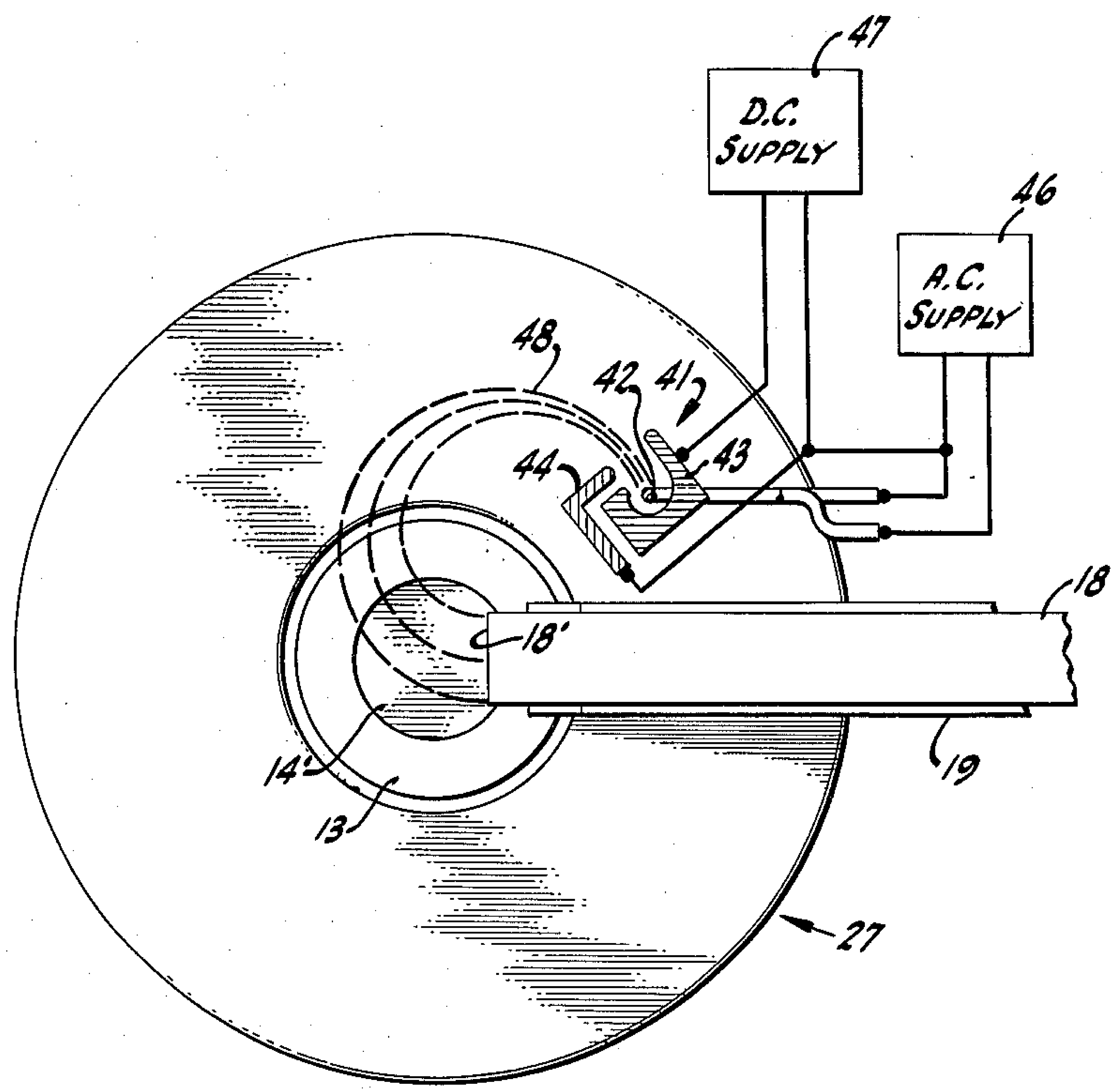

FIG-2

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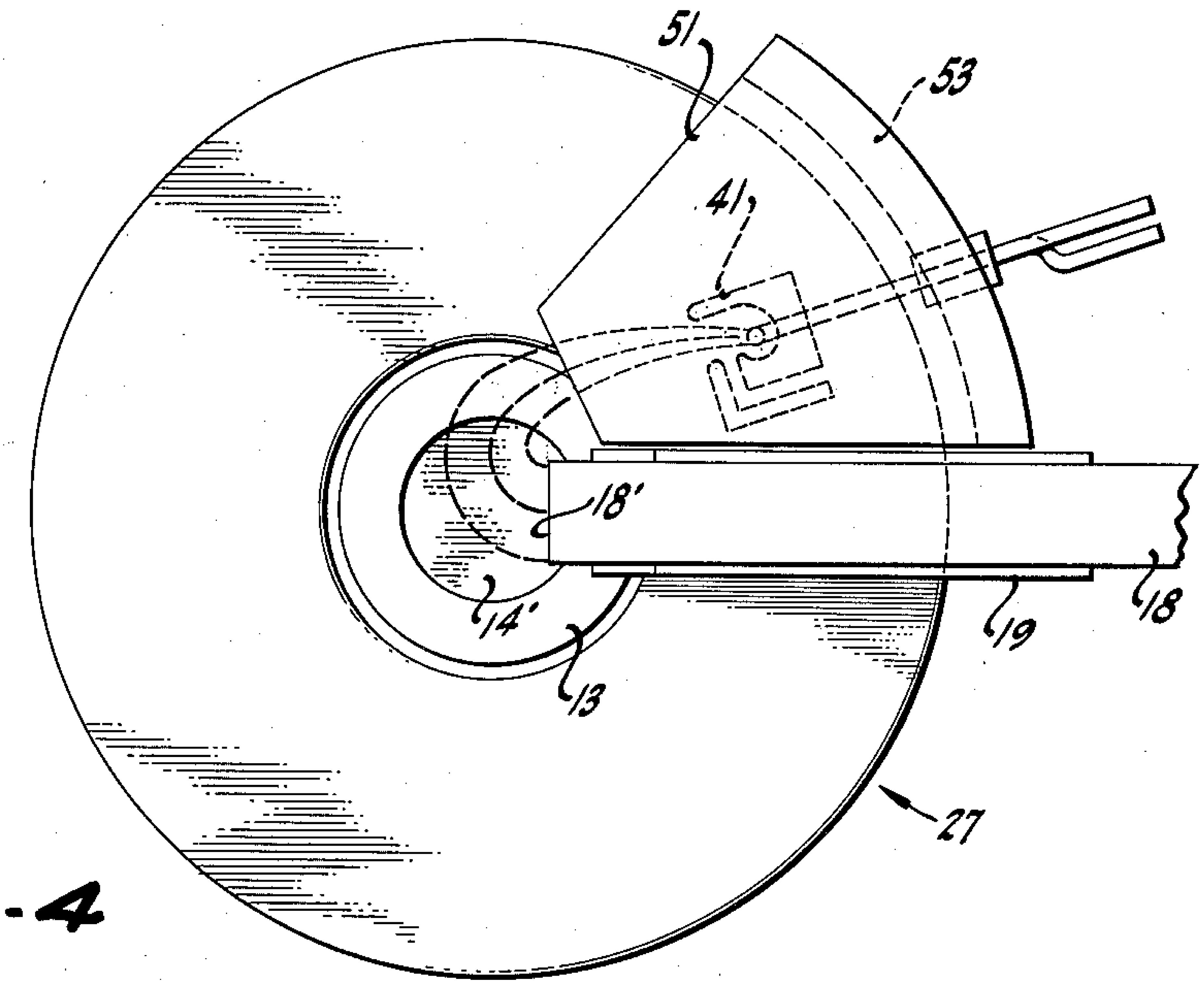

FIG-4

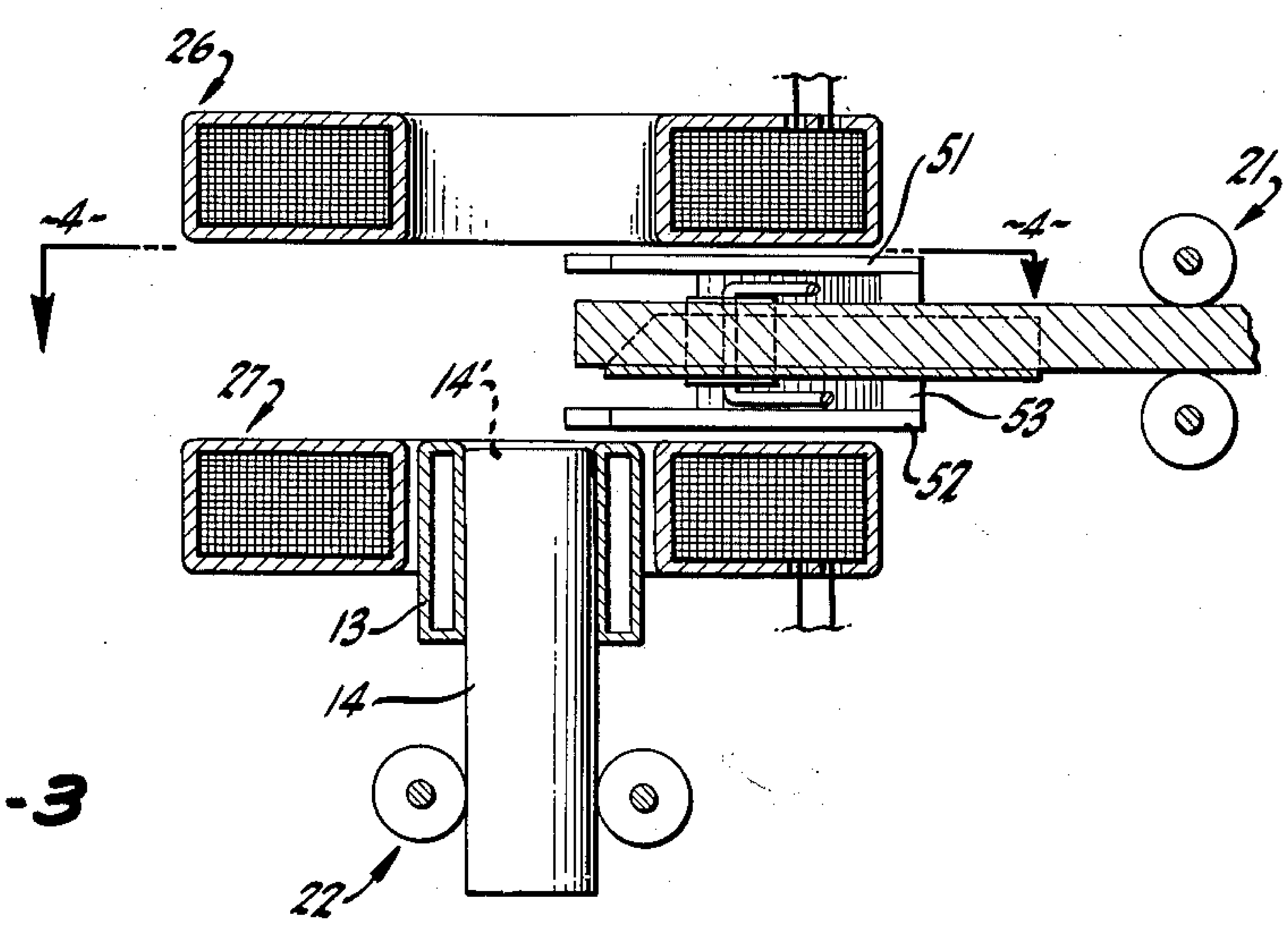

FIG-3

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ELECTRON BEAM FURNACE WITH MAGNETICALLY GUIDED AXIAL AND TRANSVERSE BEAMS

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9 Claims. (Cl. 22—57.2)

The present invention relates to an improvement in electron beam furnaces, and particularly to the improved control and utilization of electron beam bombardment therein.

It is first to be noted that an electron beam furnace generally comprises a vacuum tank having vacuum-pumping means attached thereto for continuous evacuating the interior to maintain a relatively constant low pressure therein. Within this tank there is disposed a container such as a water-cooled casting mold having an open top, and adapted to receive and contain metal, or the like, being operated upon in the furnace. One or more electron beams are directed into the upper open end of this casting mold to heat metal therein, and also, electron beams are employed to bombard and progressively melt a metal in the form of a melt stock disposed above the mold, so that such metal then drips downward into the top of the mold. Within the top of this mold, there is maintained a molten pool of metal so that, in addition to the general casting function of the furnace, there is also achieved a material purification of the metal being cast.

In connection with the electron beams employed in an electron beam furnace of the general type described above, there have been proposed various methods and apparatus for controlling and directing such electron beams to achieve maximum utility therefrom. In this respect, attention is invited to prior copending patent application of Hugh R. Smith, Jr. entitled "Electron-beam Furnace with Magnetically Guided Beam," filed in the U.S. Patent Office on May 27, 1960 with Serial No. 32,215, and assigned to the same assignee as the present application, and wherein there are disclosed magnetic guidance systems providing an improved electron beam furnace. The present invention is directed to a further improvement in this same field, and more particularly, to the provision of a separate or auxiliary electron beam source for melting the bar stock to be cast. Particular advantages are possible through the utilization of an additional or bar melt gun in that the main electron beam gun of the furnace may then deposit substantially all of the energy therefrom into the molten pool in the mold, so as to attain a maximum energy deposition therein with a minimum size gun. It is also possible, in accordance herewith, to prevent the occurrence of a relatively cooler portion of the molten pool directly below the melt stock being bombarded. This cooler portion of the molten pool is highly undesirable, and may occur from the interruption of some portion of the electron beam originally directed into the pool. This particular problem is herein overcome by decreasing the diversion of the main pool electron beam by the melt stock, and furthermore, by the addition to a particular portion of the pool of further bombarding electrons from the auxiliary or bar melt electron gun.

In accordance with the present invention, the bar stock is continuously melted to drip into the open mold by bombardment with an electron beam directed in a transverse plane to the axis of the mold, a separate main electron gun bombarding the metal within the mold. It has been found that in the melting of metal in an electron beam furnace, there are unavoidably produced gas bursts from impurities in the original material being cast therein, and furthermore, that these pressure excursions or gas

bursts extend generally normal to the melting surface of the metal. Although the interior of the furnace is at all times continuously evacuated to a low pressure, it will be appreciated that very rapid pressure excursions are possible when substantial quantities of gases and vapors are almost instantaneously evolved within the furnace. It is highly desirable to direct these gases and vapors away from the electron beam sources, for otherwise damage to the latter may occur. In the electron beam furnace configuration of the present invention, the main electron beam bombarding the molten pool of metal is wholly removed from the area of the melt stock, and is furthermore entirely out of line with the melting surface thereof. Furthermore, the auxiliary electron beam herein provided for bombarding the melt stock, is likewise maintained entirely out of alinement with the melting end of the melt stock. The configuration of the present invention provides for the substantially complete removal of all electron beam sources from any areas of substantial gas or vapor pressures, as may periodically evolve in the course of melting and casting operations within the furnace. Of particular advantage in the present invention is the utilization of magnetic guidance fields for directing the main pool electron beam into the upper surface of the mold, and the utilization of this same magnetic field for directing the auxiliary beam onto the melt stock. In accordance with the teaching of the above-noted copending patent application, there is herein employed axial magnetic beam guidance, and there is further provided herein for the utilization of this same magnetic guidance field for directing the trajectory of an auxiliary electron beam onto the desired surface of a melt stock for bombardment of same. The present invention then incorporates the advantages of the magnetic guidance systems for electron beam furnaces with the further improvement of an auxiliary electron beam for bombarding the melt stock without in any way reducing the effectiveness of the main guidance system.

Various objects and advantages of the present invention will become apparent to those skilled in the art from the prior brief description of the features of the present invention, taken together with the following description of particular preferred embodiments hereof; however, no limitation is intended by the terms of this 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 vertical, sectional view through an electron beam furnace incorporating the improvements of the present invention;

FIG. 2 is a horizontal, sectional view of the central portion of the electron beam furnace illustrated in FIG. 1, and taken in the plane 2—2 thereof to show the location of the auxiliary electron beam source of this invention;

FIG. 3 is a vertical, sectional view of an alternative embodiment of the present invention; and

FIG. 4 is a horizontal, sectional view taken in the plane 4—4 of FIG. 3.

Considering first the structural details of an electron beam furnace, as illustrated in FIGS. 1 and 2, it is noted that there is provided a vacuum tank 11 having vacuum-pumping means 12 attached thereto and encompassing a casting mold 13. An ingot 14 of cast metal is adapted to be disposed within the casting mold 13 for bombardment by an electron beam 16 from a distant electron gun 17, disposed in substantial vertical displacement above the casting mold. Metal to be cast in the furnace may be provided in the form of a bar or melt stock 18 within a laterally extending bar trough 19, above and to one side of the casting mold. Suitable feed means 21 are provided for moving the bar stock 18 laterally toward the mold above same, so that electron bombardment of the outer end of the bar stock will heat same to a melting temperature whereby the metal will drip downward into the top of the mold. This mold 13 may, for example, be formed of copper, with suitable passages for water, or the like, to remove heat therefrom, and the ingot 14 may be continuously withdrawn from the bottom of the mold as by withdrawal means 22.

Magnetic guidance is herein employed to achieve a highly advantageous direction of the main electron beam 16 downward into the open top of the mold onto the top of the ingot 14 therein. It will be appreciated that bombardment of the upper surface of the ingot within the mold will cause the metal thereat to remain molten, so as to form a pool 14′ atop the ingot. The magnetic guidance means herein employed includes a pair of identical annular magnet windings 26 and 27 disposed coaxially with the mold with the lower magnet immediately about the mold top, and the upper magnet displaced vertically upward a distance equal to the magnet radius. This particular magnet configuration approximates a Helmholtz coil arrangement so as to thereby establish a magnetic field having parallel lines of force through the annular magnets, and consequently, into the upper surface of the mold. Suitable means are provided for energizing these magnets to establish the magnetic field, herein identified by the dashed lines 28. These energizing means may, for example, comprise power supplies 31 and 32. Suitable energizing means, such as a power supply 33, are also provided for the electron beam gun 17, which will be seen to be illustrated as an annular electron source having accelerating means for directing copious quantities of high-energy electrons downward and radially inward therefrom.

To the extent previously described, the electron furnace hereof is disclosed in the above-noted copending patent application, and has been found to produce highly effective casting and purification operations. The present invention provides for a distinct improvement in the above-described electron beam furnace by the provision of a second or auxiliary electron beam source 41, disposed above the casting mold 13 and radially outward therefrom. In the particular furnace configuration illustrated, the second beam source or electron gun 41 is disposed between the two annular magnet coils 26 and 27, alongside the bar trough 19. This is best illustrated in FIG. 2, wherein it will be seen that the bar gun, as same may herein be denominated, is disposed immediately adjacent the bar trough 19 radially outward of the mold 13.

The particular configuration of the second electron gun may be varied considerably with the limitation that the gun is to produce a high-energy electron beam directed in a generally horizontal plane, somewhat inwardly toward the axis of the furnace. The electron gun illustrated includes an electron-emissive cathode wire 42, disposed within a reentrant cavity in a backing electrode 43, and having an anode electrode 44 displaced outwardly of such reentrant opening. Energization of the electron-emissive cathode 42 by suitable means, such as a power supply 46, will raise the temperature of this member to electron emission, and the application of a relatively positive potential upon the anode 44 with respect to this cathode and backing electrode 43, as by means of a further power supply 47, will cause such emitted electrons to emerge from the gun in a high-energy beam 48. It will, of course, be appreciated that electron acceleration and beam forming is produced by the establishment of relative potentials between the elements of the gun, and thus consequently ground connections may be employed as desired, as long as the anode 44 is maintained at a positive potential with respect to the other portions of the gun. The electron beam 48, established by the second gun 41, is shown as being directed generally circumferentially of the furnace configuration, and it will be seen that this electron beam is traversing a path which is perpendicular to the magnetic field 28, established by the coils 26 and 27. Inasmuch as the electron beam is traveling generally perpendicularly to the established magnetic guidance field, there is applied a deflecting force to the beam so as to deflect the trajectory thereof into a generally spiral path, as illustrated. By the utilization of suitable electron beam accelerating potentials and gun placement, the electron beam will be seen to be curved back into impingement with the forward face or surface 18′ of the bar stock 18. The magnetic guidance field, described above, and provided for the purpose of directing the main electron beam 16 into the pool of molten metal atop the ingot 14, will thus be seen to likewise herein serve to deflect the trajectory of the second electron beam 48 into direct impingement upon the leading surface of the bar stock 18.

This bombardment of the front face 18′ of the bar stock by the auxiliary or second electron beam 48, as same is deflected by the magnetic guidance field 28, serves to heat this forward face and thereby to melt same, so that the bar stock drips downwardly into the open top of the casting mold 13 to form a part of the ingot 14 therein. In this manner, the bar stock has the front face 18′ thereof maintained substantially vertical, inasmuch as relatively uniform bombardment of all of such face is achieved by the auxiliary beam 48. Consequently, gas and vapor bursts which may occur from this front face of the bar stock, will be seen to be directed laterally across the upper surface of the mold away from all electron guns in the furnace, and preferably, toward the evacuation means of the furnace. The energy employed to melt the bar stock will thus be seen to be provided by the auxiliary beam 48, rather than the main beam 16, and consequently, all energy of this main beam is thus available for maintaining a relatively even temperature in the molten pool 14′ above the ingot, so as to preclude the possibility of relatively cool spots forming in such pool. Despite the direction of the auxiliary beam 48 in a generally horizontal direction, it will be appreciated that certain portions of the beam will unavoidably traverse paths which are other than horizontal, and consequently, electrons following such paths will then be acted upon by the magnetic field to spiral downwardly into the top of the open mold 13. This further serves to provide additional bombardment of the molten pool 14′ in the casting mold, and consequently, to insure the presence of a full molten pool therein.

An alternative embodiment of the present invention is illustrated in FIGS. 3 and 4, and referring thereto, there will be seen to be provided a pair of metal plates disposed on opposite vertical sides of auxiliary electron gun 41. These plates 51 and 52 are formed of a ferromagnetic material to serve as magnetic shunts, and may each have the form of segments of a circle, as best seen in FIG. 4. Radially outward of the electron gun 41, there is provided a vertical wall 53 joining the magnetic shunt plates 51 and 52, and likewise formed of a ferromagnetic material. It will be appreciated that the magnetic shunt described above, and enveloping the auxiliary gun 41, will serve to very materially decrease the magnetic field strength in the vicinity of the gun itself. This serves the substantial advantage of decreasing the amount of electron beam curvature in the vicinity of the gun radially outward of the axis of the furnace. In this manner, it is then possible to employ a much lower accelerating potential for the auxiliary electron gun, and yet to attain the desired electron beam trajectory terminating upon the leading face of the bar stock 18. As illustrated in FIG. 4, the electron beam emerging from the gun 41 is subjected to only relatively small magnetic forces throughout the initial portion of the trajectory thereof, and, in fact, until such beam reaches the central axial portion of the furnace whereat the beam enters a very strong magnetic field normal thereto. This strong magnetic field will then deflect the beam trajectory so that the beam is, in fact, curved back around to impinge upon the leading face of the bar stock. By the magnetic shielding of the auxiliary electron gun, it is herein possible to materially reduce the requirements imposed upon this gun in order to achieve the desired electron beam trajectory therefrom.

It will be appreciated from a consideration of the location of the electron beam guns of the improved furnace of this invention that same are disposed entirely out of the area of maximum contamination, wherein gun damage may result from bombardment by ions formed in the furnace or from the deposition of vapors thereon, as evolved during the melting and casting operations. In particular, it is noted that the auxiliary gun **41** is disposed laterally outward of the ingot and mold on the same side thereof as the melt stock, so that gas bursts, and the like, occurring upon the melting surface of the latter will not direct vapors or gases toward the gun. A very substantial electron gun longevity has been realized with the furnace configuration hereinabove described, and in particular, it is noted that the auxiliary electron gun even though positioned in somewhat closer proximity to the molten metal than the main gun **17**, is likewise fully protected particularly against ion bombardment, inasmuch as the ions generated immediately above the molten pool will generally be constrained by the guiding magnetic field to move axially of the furnace, rather than radially outward as would be required for same to reach the auxiliary gun. The improved bar stock melting of the present invention is thus achieved without any sacrifice in the longevity of the furnace or any other of the advantages accuring to the improved electron beam furnace employing magnetic guidance.

It will be appreciated that the illustration of the present invention and the above description of particular preferred embodiments thereof have, in part, referred to schematic representations of particular portions of the furnace. Inasmuch as such portions form no part of the present invention, and are not novel to this particular furnace, no detailed discussions of same are herein included. With regard to operation of the furnace, same is believed to follow directly from the above description, and the teaching in prior-filed patent applications relative to electron beam furnaces of this general type. A continuous casting process may be performed with the furnace hereof by continuously withdrawing the solidified ingot **14** from the lower portion of the mold **73**, while adding molten metal to the top of the ingot to form the pool **14'** thereon, which will be seen to solidify as the ingot is slowly withdrawn downwardly through the mold. Likewise, the bar stock **18** may be continuously fed into the proper position for melting by the auxiliary electron gun **41** by an suitable means such as those schematically illustrated at **21**. It will be appreciated, in the operation of this furnace, that the feed of the bar stock **18** is adjusted to the energy deposited upon the leading edge thereof by the auxiliary gun **41**, so as to maintain the molten metal dripping downwardly into the pool within the casting mold. Control over the relative feed rates of the bar stock **18** and the withdrawal rate of the ingot **14** is left to the discretion of the operator of the particular furnace, and it will be appreciated that the rates employed are dependent, in part, upon the energy of the deposited beam and the particular material being cast in the furnace. In accordance with prior developements in this field, the electron beam furnace hereof provides not only for the improved casting of high-temperature metals, but furthermore, provides for the purification of same, inasmuch as the high vacuum maintained in the furnace tank serves to remove volatile impurities in the metal, and furthermore, the molten pool maintained atop the metal serves to float those insoluble impurities which are lighter than the metal being cast.

What is claimed is:

1. An electron beam furnace comprising a container for molten metal and having an open top with a vertical axis, means establishing a magnetic field symmetrically about said axis with lines of force converging into the open top of said container, a source of electrons disposed above said container, means for accelerating electrons independently of the container and toward same whereby the accelerated electrons are guided into the container by the converging magnetic field, means feeding a metal melt stock laterally toward said container immediately above same and below the source of electrons, an electron gun disposed laterally of the container, means for accelerating an electron beam from the gun independently of the melt stock transversely into said magnetic field whereby the beam from the gun is magnetically deflected to traverse a curved path in a substantially horizontal plane into impingement with said melt stock above the container and to melt same, means defining a single chamber encompassing at least the top of said container and said electron source and electron gun, and means continuously evacuating said chamber.

2. An electron beam furnace as set forth in claim 1, further defined by means maintaining said magnetic field substantially axial of said mold for a distance above said mold beyond said second electron beam source.

3. An electron beam furnace as set forth in claim 1, further defined by magnetic shunt means adjacent said second electron beam source and directing magnetic flux thereabout for maintaining a minimum magnetic field strength about said second source radially outward of said mold.

4. An electron beam furnace comprising a first annular electron gun disposed about a central axis therethrough and producing an intense high energy electron beam therefrom, an open-topped container disposed below said first gun in axial alinement therewith, means for accelerating the electrons from the first gun independently of the container and toward it, means coaxial with said container establishing a magnetic field having lines of force emerging axially from the open top thereof and diverging upwardly for guiding electrons from said first gun into the open container top, a second electron gun displaced laterally of and above said container and directing an electron beam transversely into said magnetic field for deflection thereby into focus above one side of the container top, the second gun being disposed below the first gun, means feeding melt stock below the first gun and laterally of said container above same into said second beam focus for bombardment and continuous melting whereby said melt stock drips into said container for further electron bombardment therein, and means for accelerating electrons from the second gun independently of the melt stock transversely into the magnetic field.

5. An electron beam furnace as set forth in claim 4, further defined by means directing said magnetic field about said second electron gun to maintain a low magnetic field strength thereat.

6. An electron beam furnace as set forth in claim 4, further defined by a pair of ferromagnetic plates disposed one above and one below said second electron gun radially outward from said container and connected by a ferromagnetic piece for shunting said magnetic field about said gun and thereby decreasing the beam acceleration required to attain focusing of same upon the metal fed laterally over the container.

7. An electron beam furnace comprising an annular electron gun having a vertical axis and directing high energy electrons downward toward such axis, a casting mold having an open top disposed coaxially with said annular gun in spaced relation beneath same, means establishing a magnetic field axially through said mold in radial divergence through said annular electron gun for guiding said high energy electrons into the open mold top, means for accelerating electrons from the annular gun independently of the casting mold and toward it, means feeding melt stock below the annular electron gun and laterally toward said axis immediately above said mold, and a laterally displaced electron beam gun disposed adjacent said last means radially of said mold directing electrons trans-

versely over the mold perpendicularly through said magnetic field for deflection in a curved trajectory onto a front face of said melt stock above the mold to melt the melt stock whereby same drips downward into the mold for further electron bombardment heating therein, means for accelerating electrons from the laterally displaced gun independently of the melt stock feeding means transversely through the magnetic field, and means evacuating a chamber encompassing said electron guns and mold top for maintaining a high vacuum therein.

8. An electron beam furnace as set forth in claim 7, further characterized by a pair of magnet pole pieces disposed one above and one below said laterally displaced electron beam gun and connected by a magnetic shunt radially outward of said gun for establishing a low magnetic field region about said electron gun and a high magnetic field region radially inward thereof for establishing said electron beam trajectory onto said metal.

9. An electron beam furnace comprising a mold having an open top, a first annular magnet winding disposed around the mold and adjacent the top of the mold, a second annular magnet winding spaced above the first and disposed around an axis passing through the mold and first winding to form a Helmholtz coil arrangement to establish parallel magnetic lines of force between the two coils and into the top of the mold, the lines of force converging inwardly and downwardly from above the second winding, a first electron beam source disposed above the second coil, means for accelerating electrons downwardly and inwardly from the first source along the converging magnetic lines of force for guidance into the open mold top, means feeding a metal melt stock laterally over said mold from a point between the two coils, a second electron beam source disposed at a level between the first and second coils and laterally spaced from the line along which melt stock is fed, means for accelerating electrons transversely into the magnetic field adjacent said melt stock for deflection by said magnetic field to bombard the leading surface of said melt stock to melt same, whereby said metal drips from said melt stock into said mold for further heating by electron bombardment therein.

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