

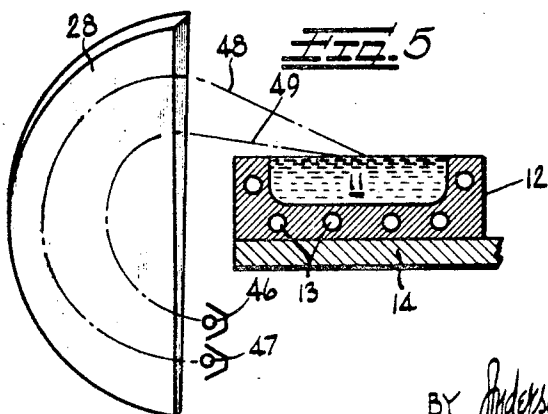
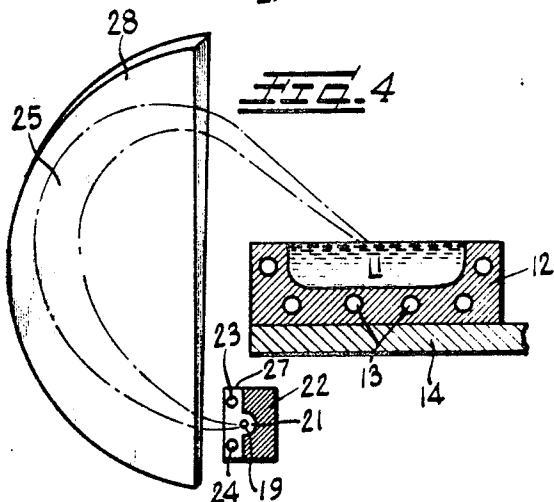
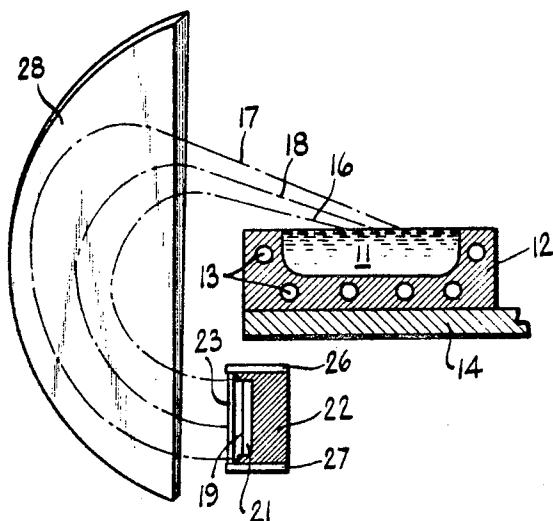
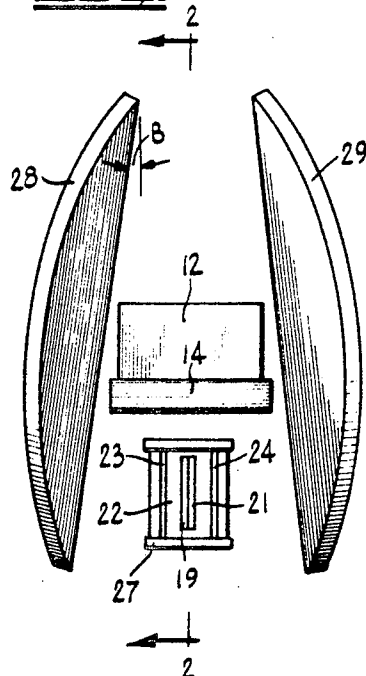
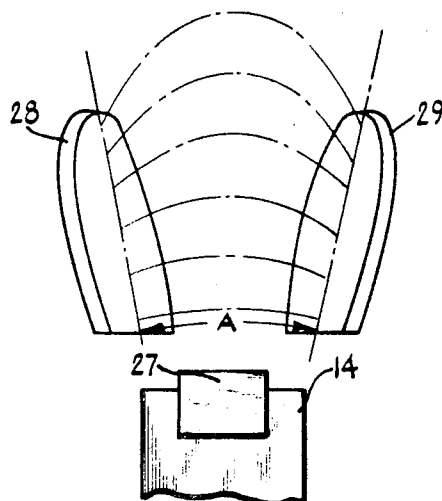
June 17, 1969

C. W. HANKS ET AL
METHOD AND APPARATUS FOR PRODUCING
AND DIRECTING AN ELECTRON BEAM

3,450,824

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FIG. 2FIG. 1FIG. 3

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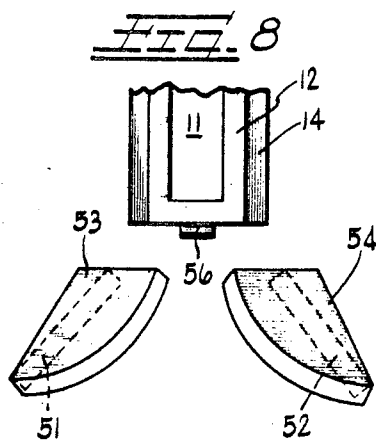
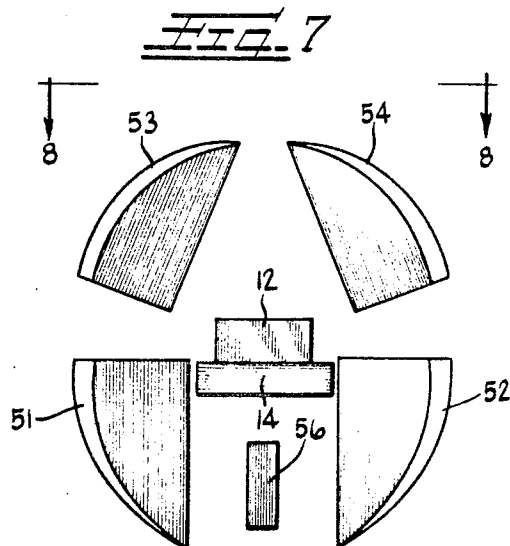
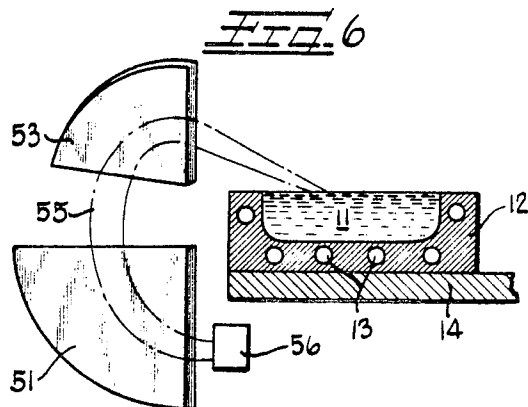
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METHOD AND APPARATUS FOR PRODUCING AND DIRECTING AN ELECTRON BEAM

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6 Claims

ABSTRACT OF THE DISCLOSURE

Apparatus for producing and directing an electron beam, which incorporates a transverse magnetic field for deflecting the beam through an arcuate path, the electrons toward the outer edge of the arcuate portion of the beam for the greater part of their path of travel passing through a weaker region of the field relative to the electrons toward the inner edge of the arcuate portion of the beam.

The present invention relates to apparatus for producing and directing an electron beam and more particularly to apparatus for focusing such an electron beam.

Electron beam furnace systems utilize one or more electron beam gun assemblies for producing and directing high energy electron beams to a target for heating the same. Electron beam gun assemblies generally comprise an electron source or emitter for emitting electrons, and suitable means for focusing the electrons into a beam. The beam of electrons is accelerated along an initial path by a suitable accelerating anode. Magnetic fields may be provided to direct the electron beam through a desired path onto the surface of a target in the furnace and to focus the beam to a desired concentration.

One type of electron beam gun assembly which offers particular advantages utilizes magnetic fields extending transverse to the direction of travel of the electrons in the beam to deflect the beam of electrons through a curving path onto the target. Deflection of the electron beam by transverse fields enables the electron source to be positioned out of a line of sight of the target. Thus the electron source is not directly exposed to materials vaporized from the target, and evolved condensible materials do not readily condense on its surfaces. A substantial decrease in the contamination of the electron source and a resulting longer life of the electron source is achieved. Moreover, the tendency for negative ions and secondary electrons to be trapped in the electron beam is substantially reduced by the use of transverse fields. This reduces space charge buildup which can detrimentally affect focusing and deflection.

One example of the use of transverse fields is in connection with the melting of material in an upright crucible. Spalling of condensed materials from cool surfaces of the vacuum enclosure, and splashing and splattering of molten material from the crucible, constitutes a potential impairment to satisfactory operation of the electron source. By positioning the electron source underneath the crucible and by deflecting the electron beam through a curving path of over 180°, contamination and shorting of the electron source are avoided and it is unnecessary to utilize splatter shields or similar devices. An electron beam gun assembly of this type is disclosed in copending application Ser. No. 464,968, filed June 18, 1965, which is assigned to the assignee of the present application.

Another example of a use for transverse fields in deflecting an electron beam is where separately pumped chambers for the target and the electron source are used and

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where a small opening communicates between the two chambers. By positioning the electron source out of a line of sight from the opening, and by deflecting the electron beam through a curving path, fewer vapor particles passing through the opening, reach the source. Furthermore, there is a reduction in the tendency for negative ions and secondary electrons to be trapped in the transverse field and impede direction and focus of the beam at the opening.

In many instances, including the two just described, it may be desirable, in addition to deflecting the electron beam through a curving path, to prevent divergence or to focus the electron beam so that the beam converges in a certain region, referred to herein as a focal region. By causing convergence of the beam into a generally round spot at a focal region which is at or just prior to the surface of the target, an efficient transfer of energy will occur between the beam and the target. By converging the beam at an opening in a wall between separately pumped vacuum chambers, or at an opening in a splatter or vapor shield, the size of the opening may be minimized for better separation or shielding.

Heretofore, methods and apparatus for producing and directing electron beams have not provided satisfactory electron beam convergence for many purposes. This has proved particularly true where deflection of greater than about 90° is desired. Deflection and convergence problems may be compounded by the use of an elongated emitter which produces a strip-like or ribbon shaped beam. Emitters of this type, however, offer some advantages over other types of emitters and it is therefore desirable that satisfactory focusing of ribbon shaped beams be attainable.

It is a principal object of the present invention to provide an improved apparatus for producing and directing an electron beam.

Another object is to provide an improved apparatus for producing and directing an electron beam, and which deflects the electron beam through a curving path and converges the beam at a focal region subsequent to the curving path.

An additional object is to provide an improved electron beam gun assembly which is adapted to be positioned to minimize contact of vapor particles with the electron source.

A still further object is to provide apparatus for converging an electron beam at the surface of a target or just prior thereto while providing transverse deflection of the electron beam through a curving path which is about 90° or greater.

Various other objects of the invention will become apparent to those skilled in the art from the following detailed description taken in connection with the accompanying drawings wherein

FIGURE 1 is a schematic elevational end view illustrating an electron beam gun assembly in accordance with the invention;

FIGURE 2 is a cross sectional view taken along line 2—2 of FIGURE 1;

FIGURE 3 is a bottom view of the apparatus of FIGURE 1;

FIGURE 4 is a schematic vertical cross sectional view of a further embodiment of the invention;

FIGURE 5 is a schematic vertical cross sectional view of a still further embodiment of the invention;

FIGURE 6 is a schematic vertical cross sectional view of still another embodiment of the invention;

FIGURE 7 is an end view of the apparatus of FIGURE 6; and

FIGURE 8 is a top view of the apparatus of FIGURE 6.

Very generally, the apparatus of the invention operates to produce an electron beam directed in an initial path. A non-homogeneous magnetic field is established transverse to the initial path. The electron beam is passed through the transverse magnetic field to be deflected hereby through a curving path. Throughout a substantial portion of the curving path of the beam, the magnetic field has a strength which generally decreases as the distance from the innermost edge of the beam increases. In this portion of the beam path, the field may be shaped so that the electrons toward the outer edge of the beam pass through a longer region of the field relative to the electrons toward the inner edge of the beam.

Turning now to the invention in greater detail, reference is made to FIGURES 1 through 3 wherein a target material 11 which is to be heated is contained within a crucible 12. A plurality of coolant passages 13 are provided in the walls of the crucible 12 and a coolant, such as water, is circulated therethrough. By cooling the crucible in this manner, the crucible is constructed of a convenient material such as copper. Because the crucible is cooled, a solid skull of the target material forms between the molten pool and the walls of the crucible to prevent any reaction between the material in the molten pool and the crucible material. The crucible is supported on a suitable base plate 14.

The target material 11 and its supporting crucible 12 are all disposed within the interior of an evacuated enclosure, not illustrated. Heating of the material 11 in the crucible 12 is accomplished by means of an electron beam. As will be explained, the electron beam is of the rectangular strip or ribbon shaped type and, in FIGURE 2, its longitudinal edges are indicated by the dash-dot lines 16 and 17. The axis of the ribbon beam is indicated by the dash-dot line 18 in FIGURE 2.

The electron beam 16-18 is produced and directed at the target material 11 by means of an electron beam gun assembly. The electron beam gun assembly illustrated in FIGURE 1 includes an elongated emitter 19 which is of a suitable material, such as tungsten, which produces free electrons when sufficiently heated. A direct current, the connections for which are not illustrated, is passed through the emitter in order to produce heating and consequent electron emission. Although not indispensable to the invention, the use of an elongated emitter provides a number of advantages in construction and operation.

The emitter 19 is disposed in the recess 21 in a shaping or focusing element 22 which is positioned alongside and behind the emitter 19. The shaping element, as well as the emitter, is maintained at a negative potential and electrons emitted by the emitter 19 are therefore directed into a rectangular strip or ribbon shaped electron beam moving out of the recess 21. A pair of grounded accelerating electrodes 23 and 24 are supported by two support plates 26 and 27 and are positioned on either side of the beam as it leaves the recess 21. Because the electrodes 23 and 24 are positive with respect to the emitter, the electrons in the beam are accelerated to a relatively high velocity. The emitter is positioned below the crucible 12 and, as a result, it is protected from splatter and vapor which may issue from the surface of the molten material in the crucible.

In order to direct the electron beam 16-18 from the emitter 19 through an arc of greater than 180 degrees to the target material 11, and in order to converge the ribbon shaped beam into a more concentrated shape at the target for better heating, the beam is passed through a non-homogeneous magnetic field which extends transversely of the path of the beam. In the embodiment of FIGURES 1-3, the transverse non-homogeneous magnetic field is established between a pair of semicircular pole pieces 28 and 29 of ferromagnetic material. The pole pieces are magnetized to be of opposite polarity by connecting the same to suitably energized solenoids or permanent magnets (not shown). The two semicircular pole

pieces 28 and 29 are supported on either side of the beam by suitable means (not shown) so that the straight edges thereof lie in a vertical plane extending transverse to the axis of the initial beam path and slant toward each other from their lower ends at an angle B from the vertical for a purpose hereinafter explained. Their lower ends are disposed below the emitter and their tops are disposed above the surface of the target. The opposed faces of the pole pieces 28 and 29 are flared outwardly with respect to each other, for a purpose described hereinafter. Suitable means (not shown) for cooling the pole pieces, is provided.

This positioning of the pole pieces 28 and 29 provides a field which decreases in intensity from the straight edges and bows outwardly toward the curved edges due to the flare of the pole pieces and which increase in intensity from bottom to top adjacent the straight edges of the pole pieces. The field deflects the beams 16-18 over about 225° through a generally planar arcuate path. The outwardly bowed flux lines prevent the electrons in the beam from diverging in a direction normal to the plane of the beam as the beam passes through the field. The electrons toward the inner edge 16 of the beam, upon entering the field and until a position adjacent their exit from the field, pass through a stronger field than the electrons toward the outer edge of 17 of the beam. However, since the path of travel of the electrons increases as their distance from the inner edge 16 increases, the electrons toward the outer edge 17 are under the influence of the field for a longer path of travel, preventing divergence or causing convergence according to the variation in path lengths.

In FIGURES 1-3, the angle of the flare of the pole pieces 28 and 29 is made such that the beam remains substantially of the same width through the greater part of its path of travel through the field. For a deflection greater than 180°, the angle of flare, as indicated by A in FIGURE 3, is preferably between about 50° and 55° to provide a constant width beam throughout most of its travel through the field. At and near the region in which the beam emerges from the non-homogeneous magnetic field, because of the angle B of the straight edges of the pole pieces, the outer edge 17 of the beam is in a stronger region of the magnetic field than the inner edge of the beam. This causes the electrons toward the outer edge 17 to be deflected more than those toward the inner edge 16, thus resulting in a convergence or focusing of the beam exiting from the field. The angle of the straight edges of the pole pieces is selected to provide the desired convergence of the beam. To provide a generally circular beam at the target, the angle B is made about 5°.

The particular arrangement utilized in the apparatus of FIGURES 1 through 3 is a convenient way for achieving convergence at the surface of the molten material 11 in an electron beam furnace system. The shape of the pole pieces is not necessarily critical to the invention, however, their relative spacing and angular relationship determines the variation of the field strength. For example, a substantially round impact area is achieved at the surface of the melt about 3½ inches from the straight edges of the pole pieces for an electron beam power of 13 kilowatts. The emitter is 4 inches long, and its center about 4½ inches below the melt surface. The upper ends of the pole pieces are separated by a 4-inch gap and diverged along the straight edges about 10° and flared about 55°. The pole pieces are 23 inches along their straight edges and the maximum width of the pole pieces 23 inches. A field strength which increases from about 10 gauss at the region of beam entry to about 20 gauss at the region of beam exit is satisfactory. Other field configurations may be established depending upon the particular beam deflection characteristics desired.

Referring now to FIGURE 4, it may be seen that the

apparatus of the invention is of advantage in a situation wherein the emitter extends transversely of the plane of the arcuate beam path, rather than lying in such plane, as was the case in the embodiment of FIGURES 1 through 3. As previously mentioned, space charges and ambient magnetic fields within the vacuum environment often produce a tendency for the electrons in the beam to diverge. This divergence can have a detrimental effect on the heating properties of the beam 25. By passing through a field of the same type as in FIGURES 1 through 3, this tendency to diverge is corrected, as illustrated by the dotted lines in FIGURE 4.

FIGURE 4 may also be taken as representative of a situation wherein a spot source of electrons, rather than an elongated source, is utilized. As is the case with an elongated source, a spot source also produces a beam wherein the tendency is for electrons to diverge. Correction of this is achieved as explained in connection with the elongated source and with reference to FIGURE 4.

Referring to FIGURE 5, it will be seen that the apparatus of the invention is of advantage in connection with two electron sources or emitters, rather than one. Occasionally, such as where substantial electron beam power is desired, it is of advantage to utilize two electron sources, rather than one. These sources are illustrated and indicated in FIGURE 5 at 46 and 47. The beams 48 and 49 produced thereby have their axes indicated by the dotted lines. It will be seen that the beams are converged into a desired relationship at the surface of the molten material 11. In addition, the magnetic field established cause convergences or focusing of the electrons in each beam as was described in connection with FIGURE 4.

Referring now to FIGURES 6 through 8, an embodiment of the invention is illustrated which, under some circumstances, provides additional versatility. Two pairs of pole pieces 51, 52 and 53, 54 are used. The electron source 56 is identical with that of FIGURES 1 through 3, providing a ribbon shaped electron beam 55. The pole pieces 51 and 52 are flared outwardly, but their straight edges are substantially parallel with each other and with the plane of the arcuate path through which the electron beam is deflected. Thus, as viewed in FIGURE 6, the strength of the field diminishes from right to left in the same direction as the path of the electrons as they leave the electron gun or source 56. The strength of the field between the pole pieces 51 and 52 is established to cause the beam to be deflected through substantially 90°.

After leaving the field established between the pole pieces 51 and 52, the beam passes across a gap and then enters the field established between the pole pieces 53 and 54. It may be noted that the pole pieces 53 and 54 not only are flared outwardly in the same manner as the pole pieces 51 and 52 but have their straight edges disposed at an angle toward each other. Thus, the radius of curvature of the electrons in the beam in the field established between the pole pieces 53 and 54 decreases as they move toward the upper ends of the pole pieces 53 and 54.

By utilizing two separate pairs of pole pieces in the manner just described, the strengths of the non-homogeneous fields established therebetween can be varied on an individual basis to select a desired relation therebetween and effect a desired deflection and focusing characteristic to the beam. Moreover, the electron source can be positioned a substantial distance below the level of the molten material 11 and the upper pair of pole pieces 53 and 54 positioned at the necessary level to deflect the beam from a vertical path onto the target.

It has been found that the utilization of non-homogeneous magnetic fields, as described herein, affords particular advantages in electron beam furnace systems. These advantages include the ability to effect a desired deflection of the beam from a source positioned below the target and a desired focusing of the beam at the surface of the molten material.

Various other embodiments of the invention, in addition to those shown and described herein, will be apparent to those skilled in the art from the foregoing description and accompanying drawings. Such other embodiments, and modifications thereof, are intended to fall within the scope of the appended claims.

What is claimed is:

1. Apparatus for producing and directing an electron beam, comprising means for producing an electron beam directed in an initial path, means for establishing a magnetic field transverse to the initial path for deflecting the electron beam through a curving path, said field establishing means including a pair of pole pieces positioned on opposite sides of the beam path, said pole pieces having surfaces oriented with respect to each other and to the initial path so the distance between said surfaces increases with the distance from said beam production means in the direction of the initial path to produce a non-homogeneous transverse magnetic field which has a strength which for a greater part of the path of travel of the beam in the field decreases in the plane of the curving path from the inner edge of the beam toward the outer edge.

2. Apparatus according to claim 1 in which said pole pieces are of sufficient size that the electron beam remains in the region directly between them throughout the curving path so that the electrons toward the outer edge of the beam pass through a longer region of the field relative to the electrons toward the inner edge of the beam.

3. Apparatus in accordance with claim 1 in which said surfaces of said pole pieces are oriented so that the distance between them increases from the outer edge of the beam to the inner edge at the exit of the electron beam from the field, whereby the field is of greater strength at the outer edge of the beam than at the inner edge at the exit.

4. Apparatus according to claim 1 in which said field establishing means comprise a pair of generally flat pole pieces positioned on opposite sides of the curving portion of the beam path.

5. Apparatus according to claim 1 in which said field establishing means comprise a pair of generally semi-circular spaced discs each having a substantially straight edge positioned toward said beam producing means, said discs having an angle of divergence along the straight edges thereof opening toward the region of entry of the electron beam into the magnetic field, and having a further angle of divergence outwardly toward the midpoint of their curved edges.

6. Apparatus according to claim 1 including means for establishing a second transverse non-homogeneous magnetic field prior to the first-named magnetic field, said second magnetic field establishing means including a pair of second pole pieces positioned on opposite sides of the beam path, said second pole pieces having surfaces oriented with respect to each other and to the initial path so that the distance between said surfaces increases with the distance from said beam producing means in the direction of the initial path such that throughout a substantial portion of the curving path of the beam the second magnetic field has a strength which decreases as the distance from the innermost edge of the beam increases.

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U.S. Cl. X.R.