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APPARATUS FOR HEATING A TARGET IN AN ELECTRON BEAM FURNACE

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FIG. 1

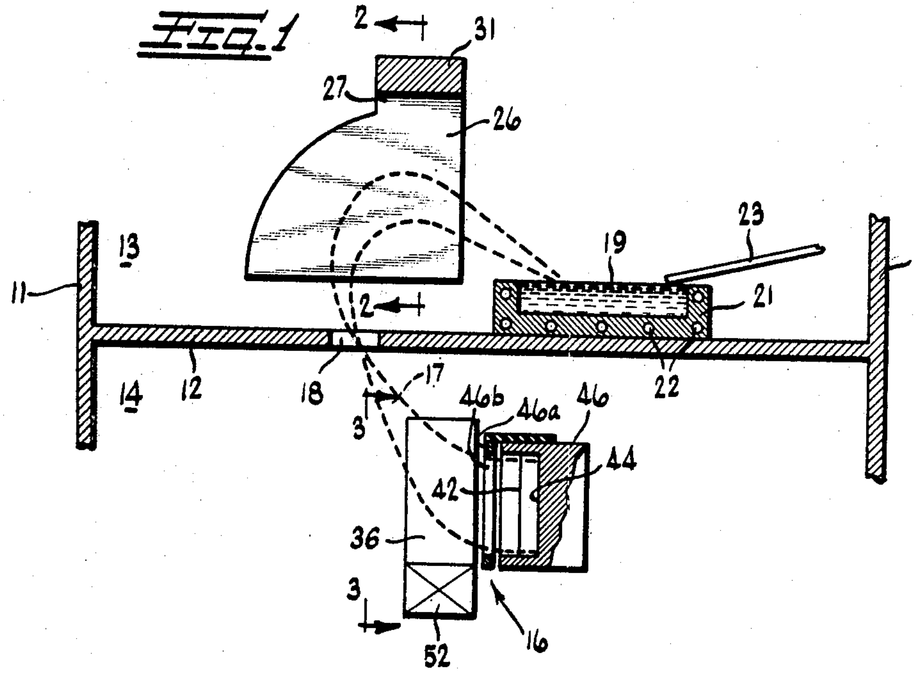


FIG. 3

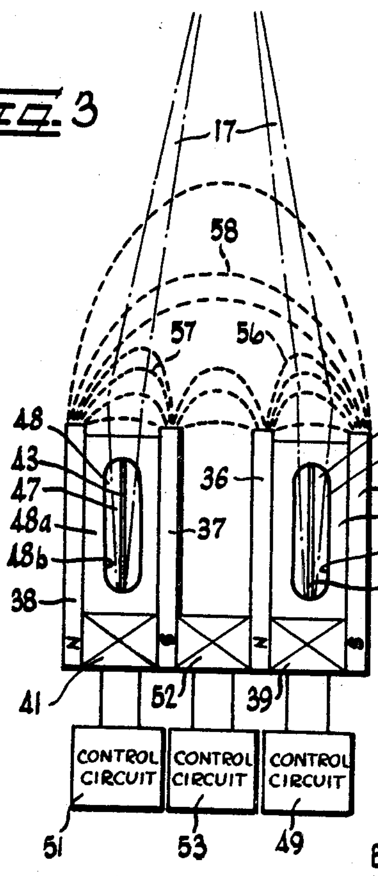
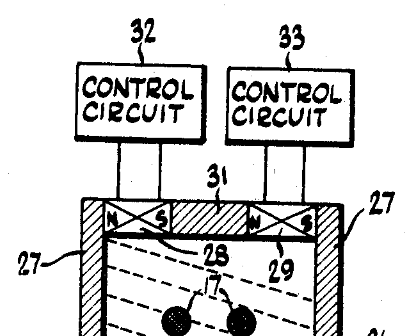


FIG. 2



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APPARATUS FOR HEATING A TARGET IN AN ELECTRON BEAM FURNACE

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U.S. Cl. 13—31 4 Claims

ABSTRACT OF THE DISCLOSURE

Apparatus for heating a target in an electron beam furnace is described, wherein at least two electron beams are produced, wherein two controllable primary transverse magnetic fields are each positioned in the path of a respective electron beam for deflecting and focusing same, and wherein a controllable secondary transverse magnetic field is positioned in the path of both electron beams for deflecting the beams and for converging the beams at a predetermined region. A tertiary transverse magnetic field may also be established for deflecting and focusing the electron beams onto the surface of the target.

The present invention relates to apparatus for heating a target in an electron beam furnace and, more particularly, to apparatus for focusing and directing a plurality of electron beams in an electron beam furnace.

Electron beam furnaces are useful in melting, casting, vaporizing, annealing, and similar heat treatment of various materials including metals, alloys, ceramics, and plastics. Such furnaces generally comprise a suitable vacuum enclosure maintained at a high vacuum, for example, less than one millimeter of mercury absolute. A target, consisting of the material to be heated, is contained within a crucible disposed within the enclosure and one or more electron beams are directed at the surface of the target. The electron beam or beams are produced by an electron beam gun assembly.

An electron beam gun assembly generally comprises one or more emitters for producing free electrons, and suitable means for shaping and focusing the electrons into an electron beam. Because of a space charge effect, electron beams exhibit a tendency to diverge. Since an excessively large area of beam impact on the target leads to certain inefficiencies, it is desirable to prevent divergence of the electron beams. Moreover, it is frequently desirable that provision be made for further focusing the electron beam to reduce the cross sectional area thereof and thereby effect a greater concentration of electrons. This leads to greater efficiencies in the heating of the target, and facilitates the passage of the electron beam through small openings in such items as vapor barriers and splatter shields. Where an elongated emitter which produces a ribbon shaped or rectangular cross section electron beam is used, as has been found of advantage in many instances, proper focusing makes it possible to shape the ribbon shaped electron beam into a more concentrated roundish cross sectional area at the target.

In addition to the desirability of focusing electron beams, in certain applications it is advantageous to effect a transverse deflection of an electron beam of up to 270° or more. Transverse deflection of an electron beam enables the emitter to be placed in a position where it is not susceptible to being splattered with molten material or to having vapor condense thereon. Transverse focusing also enables the emitter to be placed in a separate vacuum chamber from the target. This is an arrangement which is of particular advantage when material is being vaporized, since the presence of vapor at the emitter can be substantially eliminated. A further advantage of transverse deflection of electron beams accrues from the fact that negative ions and free electrons are not as readily trapped in the electron beam. Excessive amounts of such negatively charged particles in the electron beam cause divergence problems due to the consequent space charge.

In some circumstances, it is desirable to produce a plurality of electron beams for direction at a target. A plurality of electron beams provide greater power capabilities than that obtainable through the use of a single beam, and allow greater flexibility in heating certain areas on a target than in the case of a single beam. Production of several electron beams usually requires the use of a corresponding number of emitters and suitable accelerating electrodes. Focusing and deflection of a plurality of electron beams is complicated and often necessitates complex control arrangements. Moreover, some interaction between various deflecting and focusing fields for the several electron beams presents difficulties in control thereof. These deflection focusing and control problems are compounded where the beams are produced in a separate chamber from the material being heated and where it is desired to minimize the area of direct communication between the chambers necessary to permit passage of the electron beams from one chamber to the other.

It is therefore an object of the present invention to provide an improved apparatus for heating a target in an electron beam furnace by utilizing a plurality of electron beams.

Another object of the invention is to provide an improved apparatus for producing and controlling a plurality of electron beams.

Still another object is to provide apparatus for heating a target in an electron beam furnace system by utilizing a plurality of electron beams and wherein the various beams are precisely controllable with respect to their focus and direction.

It is another object to provide apparatus for heating a target in an electron beam furnace system by utilizing a plurality of electron beams, which apparatus provides good control over the beams, and is relatively low in cost and simple of operation and construction.

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

FIGURE 1 is a schematic sectional view of an electron beam furnace including apparatus constructed in accordance with the invention;

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

FIGURE 3 is a front view taken along the line 3—3 of FIGURE 1.

In accordance with the invention, first and second primary transverse magnetic fields are established, each positioned in the path of a respective electron beam for deflecting and focusing same. A secondary transverse magnetic field is established, positioned in the path of both electron beams, for deflecting the beams and for converging the beams at a predetermined region. The strength of the primary and secondary transverse magnetic fields are controllable for precise control of deflection and focusing, and of the position of the predetermined region.

Referring now particularly to FIGURE 1, an electron beam furnace in which the invention is used is shown schematically. The furnace includes a vacuum enclosure having an outer wall **11**, parts of which are illustrated. The enclosure is divided by a wall **12** into an upper chamber **13** and a lower chamber **14**. Suitable vacuum pumps (not shown) are provided for each of the two chambers.

When evaporation is taking place in the chamber **13**, the fact that the chamber **14** is separately evacuated minimizes the amount of vapor in the chamber **14**.

An electron beam gun **16** is positioned in the low vapor environment of the lower chamber **14**. The substantial absence of vapor in the lower chamber **14** facilitates the operation of the electron beam gun **16**. The electron beam gun, which is described in greater detail subsequently, produces a pair of electron beams **17**, the envelopes of which are indicated by dash-dot lines. The beams **17** are passed through an opening or openings **18** in the wall **12** into the upper chamber **13**.

The beams **17** which, as will be explained, may be converged into a single beam or which may be displaced from each other, are deflected through about 220° in the chamber **13** to impinge upon and melt target material **19** held in a crucible **21**. The particular illustrated furnace is for evaporating the target material. The crucible **21** may be provided with coolant passages **22** for cooling same to form a skull of solid material between the molten material and the crucible. A rod **23** of feed stock material is fed by a suitable mechanism, not illustrated, into the molten pool of target material **19** in order to replenish the pool for material evaporated therefrom.

Deflection of the electron beams in the chamber **13** is accomplished by means of a magnetic device consisting of a pair of pole pieces **24** and **26** (see also FIGURE 2). The pole pieces are generally shaped as disc quarters, having extensions **27** at the upper edges thereof. The extensions **27** each form a part of a low reluctance path between the pole pieces, the path being completed by a pair of iron core electromagnetic coils **28** and **29** and a joining web **31** of magnetic material. The coils are oriented so that a magnetic field is established between the pole pieces **24** and **26**. A control circuit **32** is connected to the coil **28** and a control circuit **33** is connected to the coil **29**. The control circuits **32** and **33**, which are constructed in accordance with known principles, vary the current in the coils **28** and **29** and thus vary the strength and/or the skewness of the field established between the pole pieces **24** and **26**. A similar deflection system is shown in Patent No. 3,235,647.

By changing the skewness of the lines of flux between the pole pieces **24** and **26**, which is changed by varying the relative amounts of current supplied to the coils **28** and **29** through the control circuits **32** and **33**, the beams **17** are shifted transversely with respect to the target. For example, where the flux lines are shifted from a horizontal position to the position shown in FIGURE 2, the tendency is for the beams indicated at **17** to move in the direction of the arrows adjacent thereto. By varying the overall strength of the field between the pole pieces **24** and **26**, the radius of curvature of the upper and lower edges of the beams as they pass between the pole pieces is varied to vary the longitudinal position of the impact area on the surface of the molten material **19**. This is desirable in that the beams can be swept longitudinally of the target and strike the end of the feed stock wire **23** when it is desired to increase the addition rate of the material to the molten pool.

The beams **17** are focused in the vertical direction as they pass between the pole pieces **24** and **26** to impinge upon the material **19** in a desired impact area. This results from the longer path of travel in the magnetic field of one edge of the beam with respect to that of the other edge.

Referring now to FIGURE 3, a sectional schematic view of the apparatus in the chamber **14** is seen. The indication of the beams **17** and the magnetic fields associated with the apparatus (shown by the dotted lines in FIGURE 3) are spread out upwardly in the drawing for clarity. Actually, such fields would rise upwardly and away from the paper, as may be determined from a comparison with FIGURE 1.

The electron beam gun assembly includes a pair of

pole pieces **34** and **36**, and a pair of pole pieces **37** and **38**. An iron-core electromagnet coil **39** extends between the pole pieces **34** and **36**, and an iron-core electromagnet coil **41** extends between the pole pieces **37** and **38**. The pole pieces extend on either side of the respective emitters **42** and **43**.

The emitters **42** and **43** are parallel with and spaced from each other. They each comprise a piece of elongated tungsten wire which is heated to provide free electrons in a known manner. The emitter **42** is disposed in a recess **44** in a shaping electrode **46**, and a grounded accelerating electrode plate **46*a*** having an opening **46*b*** therein is supported on the shaping electrode with insulation therebetween. The shaping electrode **46** is maintained at a negative potential and cooperates with the accelerating electrode **46*a*** to shape and direct the free electrons, produced by the emitter, out of the open side of the recess and through the opening **46*b***. The emitter **43** is disposed in a similar recess **47** in a shaping electrode **48** of identical construction and operation to the electrode **46**. Likewise, an accelerating electrode **48*a*** with an opening **48*b*** is provided. The result is that two ribbon type electron beams are produced. Although shown parallel with each other and parallel with the associated pole pieces, the emitters may be disposed perpendicular to the pole pieces and axially aligned with each other with pole pieces which are suitably designed to provide a desired deflection.

A control circuit **49** is connected to the coil **39** for energizing the same. Similarly a control circuit **51** is connected to the coil **41** for the same purpose. Energization of the coils **39** and **41** estatblishes a pair of primary transverse magnetic fields **56** and **57**. These extend between respective pairs of pole pieces as indicated by the dotted lines. The polarity of each pole piece is indicated thereon. In accordance with known principles, the electron beams produced by the respective emitters, as they pass through these transverse fields, are deflected. The direction of deflection is upwardly in the plane of the paper in FIGURE 3. It will also be noted that, beyond the ends of the pole pieces, the flux lines of the primary magnetic fields **56** and **57** are bowed outwardly. As the electrons of the electron beams pass through such bowed flux lines, they are deflected toward each other and thus are focussed. Depending upon the strength of the field, this may be used to prevent divergence of electrons in the beam or to cause them to converge on each other. In the latter case, the cross section of the ribbon beam is changed from an elongated oval to a more circular shape.

In order to provide for control over the relative positions of the two electron beams **17**, an electromagnetic coil **52** is positioned between the pole pieces **36** and **37**. A control circuit **53** is connected thereto. The coils **39** and **41** are so arranged as to establish opposite polarities in the outermost pole pieces **34** and **38**. Accordingly, a secondary transverse magnetic field **58** having bowed flux lines extending between the two outermost pole pieces is established. This is shown by suitable dotted lines in FIGURE 3. The coil **52** is wound to oppose the polarities of the pole pieces **36** and **37** and thereby controls the magnetic field **58**. When the control circuit **53** increases current in the coil **52**, the field **58** is weakened, and when the current in the coil **52** is decreased, the field **58** is strengthened.

As the electron beams **17** pass through the secondary transverse magnetic field **58**, the bowed flux lines thereof cause both beams to converge. The strength of the field may be varied to thereby vary the position of the region of convergence. Thus, the two beams may be precisely converged upon each other as they pass through the opening **18** in the wall **12**. This permits the size of the opening to be minimized, and thereby minimizes the amount of vapor which passes from the chamber **13** into the chamber **14**. Alternatively, such as in a single chamber furnace, or where two openings **18** are used, the two beams may be caused to be parallel, or even to diverge, depending upon the particular requirements of the furnace.

The various control circuits may be combined in a single circuit, depending upon the particular types of variation it is desired to effect on the beams. It has been found that apparatus as described enables extremely precise control over the position, size and intensity of the electron beams for superior furnace operation. Moreover, if three or more electron beams are produced, further secondary fields may be established in accordance with the principles developed herein. These fields may be controlled as desired to effect beam focusing, deflection, and convergence.

It may therefore be seen that the invention provides an improved apparatus for heating a target in an electron beam furnace system. Control over a plurality of electron beams is facilitated, and the apparatus is relatively simple and thereby low in cost.

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

What is claimed is:

1. Apparatus for heating a target in an electron beam furnace system comprising, means for producing at least two adjacent ribbon shaped electron beams directed in initial parallel planar paths, means for establishing a separate independent primary transverse magnetic field in the path of each electron beam, each of the independent primary transverse magnetic fields including, in the direction of travel of the electron beam, a first region having straight lines of flux generally perpendicular to the plane of the electron beam for causing the beam to be deflected in an arcuate path in its plane, and a second region having bowed lines of flux which are concave with respect to the electron beam producing means for causing the beam to be converged normal to its plane, and means for establishing a secondary magnetic field in the path of both electron beams in a region along the paths of both electron beams beyond the primary magnetic fields, the

secondary magnetic field being transverse to the planes of the beams and having bowed lines of flux concave with respect to the electron beam producing means to converge the paths of the electron beams toward one another.

2. Apparatus according to claim **1** including means coupled to said secondary field establising means for controlling the strength of the secondary transverse magnetic field, thereby permitting control of the convergence of the electron beams.

3. Apparatus according to claim **1** including means coupled to said primary field establishing means for controlling the strength of the primary transverse magnetic fields, thereby permitting control of the deflection and focusing of the beam.

4. Apparatus according to claim **1** wherein said electron beam producing means comprise a pair of elongated emitters arranged in a side by side spaced apart relationship, wherein said primary transverse field establishing means include two pairs of pole pieces each pair disposed on opposite sides of a respective one of said emitters, and coil means magnetically coupled between said pole pieces, said pairs of pole pieces being arranged in a row in spaced apart relationship with the outermost pole pieces in the row of pole pieces being of opposite polarity, and wherein said secondary transverse field generating means include coil means magnetically coupled between the outermost pole pieces in the row of pole pieces.

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