ELECTRON BEAM MULTICHAMBER HIGH VACUUM FURNACE

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FIG. 1

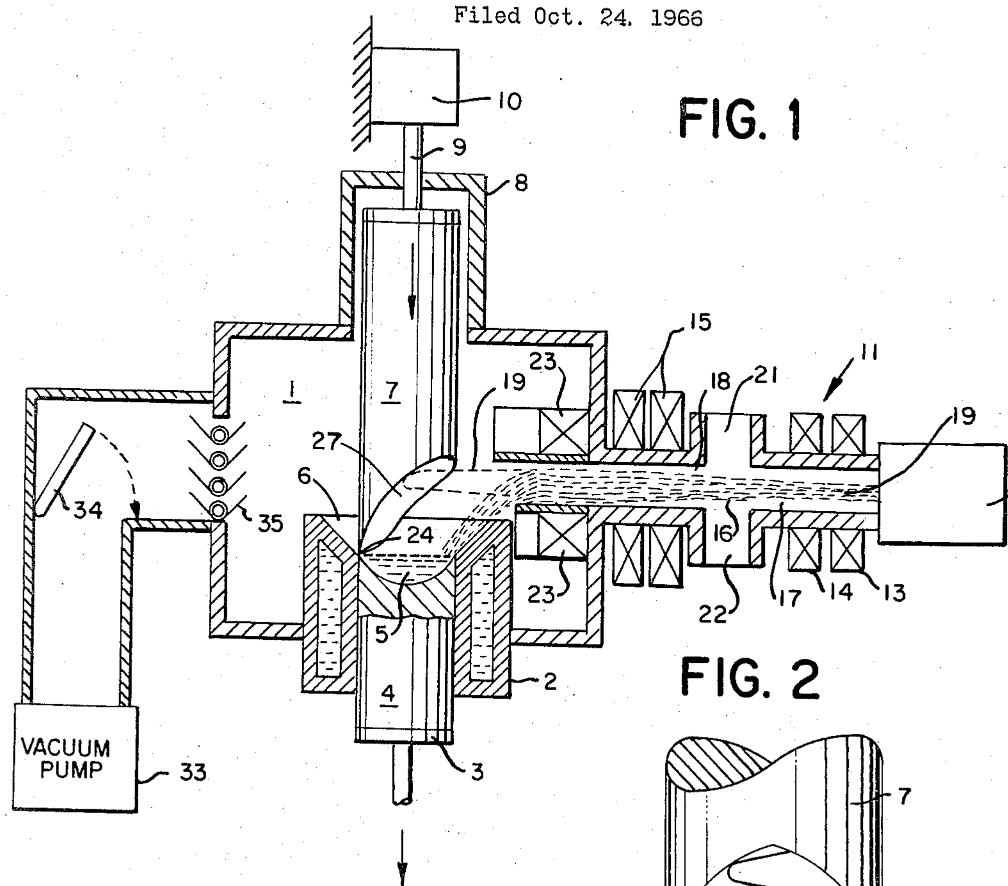


FIG. 2

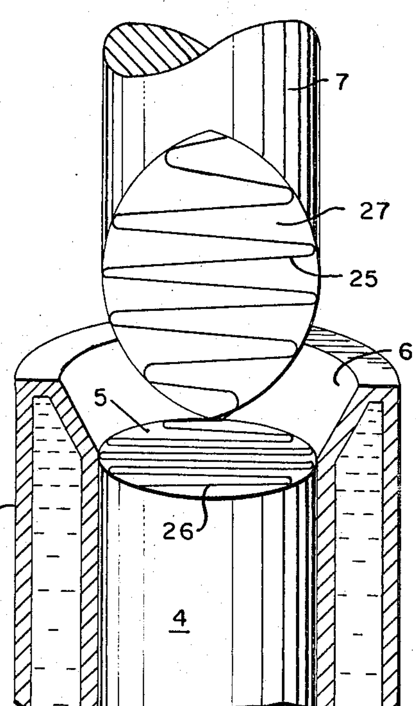
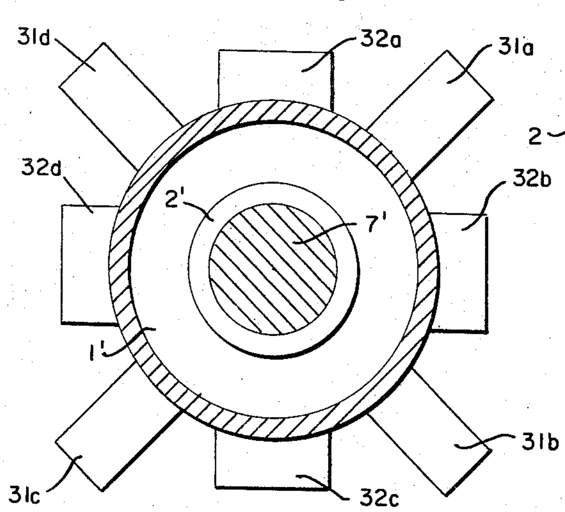


FIG. 3



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ELECTRON BEAM MULTICHAMBER HIGH VACUUM FURNACE

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The present invention relates to an electron beam multiple chamber furnace for melting under high vacuum.

Electron beams are utilized in a multitude of applications among which is the heating of material such as in a multichamber furnace. An electron beam multichamber furnace is used principally for the melting of metals which are reactive and which have high melting points. Steel in blocks weighing several tons may be melted by recently developed systems utilizing electron beams. In one system, the electron-emitting cathode is concentrically positioned around and surrounds the melting stock. The cathode is usually of directly heated type. The system is deficient because the cathode becomes highly vaporized, so that it rapidly becomes useless. Flat beam electron guns or traverse guns are utilized in attempts to overcome such deficiency. The electron beam is deflected almost 180° or more by a constant magnetic field. The cathode is not exposed to either vaporization or to stray metal from the melt. In another system, the cathode is concentrically positioned around and surrounds the melting stock and an annular anode is positioned around and surrounds the cathode thereby shielding said cathode from vapor and stray metal from the melt.

In many of these systems, melting is produced in a field-free chamber. The electron beam is initially applied in substantially conical configuration around a rod of the melting stock and is applied from a relatively great distance. These systems are deficient because the pressure is the same at the cathode and in the melting chamber, since the electrodes and components of the system are all positioned in the same chamber. When the pressure increases more than 2×10^{-4} mm. Hg, the high potential breaks down and glow discharges occur between the various electrodes and points at ground potential. In an attempt to overcome the foregoing deficiencies, another system utilizes determined surface rotation-symmetrical cathodes and focused for powerful electron beams. The electron beams are focused by magnetic lenses over extended distances of 1 to 2 meters and are maintained at a small diameter. Gas flow impedance thus may be positioned between the electron gun and the melt chamber, which chambers are evacuated separately from each other. An electron beam source may thus utilize several pressure stage chambers evacuated independently from each other. The pressure is the melt zone, area or chamber may increase to 10^{-2} mm. Hg between the cathode chamber and the melt area, while the pressure in the electron beam source chamber does not exceed 10^{-4} mm. Hg.

Electron beam directing assemblies utilizing an electron beam source which may be independently evacuated, may be utilized in two systems. In one system, the melting stock is fed in from the top and a plurality, such as 3 to 5, electron beam directing assemblies are positioned at the top in oblique attitudes. In such system, the electron beam power output may be up to 1000 kilowatts. In another system, the melting stock is fed substantially horizontally and a plurality of electron beam directing assemblies are utilized. Despite the utilization of several electron beam directing assemblies, when the melting stock is of large size having large dimensions, such as a large diameter, of 0.5 meter or greater, for example, the energy distribution in the melt is non-uniform. It is extremely important to have a uniform distribution of energy when melting alloys, and thus when melting steels. To overcome the non-uniformity of energy in the melt, in the melting of large size material, the material may be fed in substantially horizontally and only one electron beam directing assembly may be utilized. The electron beam is moved in a determined pattern through the melt or melt pool and over the melting stock. The electron beam is directed substantially vertically from the top of the equipment into the melting chamber. The electron beam is periodically deflected in a manner whereby said electron beam follows a circular or elliptical path, so that the melting stock is struck by said electron beam during each period or cycle of deflection. The deficiency of the foregoing arrangement is that the diameter of the melting stock must be considerably smaller than the diameter of the ingot formed by the solidfying and solidified melt or ingot. Furthermore, the diameter of the melting stock should be smaller than ⅔ the diameter of the crucible. In a large scale operation, in which the weight of the ingot is more than 10 tons, the movement or feeding of the melting stock into the equipment during melting creates an excessive expense.

The principal object of the present invention is the provision of a new and improved electron beam multichamber high vacuum furnace. The electron beam furnace of the present invention overcomes the deficiencies of known systems and operates efficiently, effectively and reliably and without excessive expense. The electron beam furnace of the present invention may utilize a crucible having a diameter larger than 0.5 meter. The electron beam furnace of the present invention produces an ingot having a diameter which is equal to the diameter of the melting stock and a uniform distribution of energy in the melt pool and over the melting stock. The electron beam furnace of the present invention produces an ingot of very large diameter weighing over 10 tons. The electron beam power outputs of the electron beam furnace of the present invention are as great as 6000 kilowatts. The electron beams of the electron beam furnace of the present invention may be controlled in accordance with determined deflection programs.

In accordance with the present invention, an electron beam multiple beam chamber furnace comprises a melting chamber having a top, bottom and sides. A fluid-cooled crucible is positioned at the bottom of the melting chamber. A support feeds melting stock substantially vertically downward into the crucible from the top of the melting chamber. The melting stock and the crucible have substantially the same cross-sectional configuration. The melting stock has an axis. An electron beam producing and directing assembly positioned in a side of the melting chamber produces and directs an electron beam onto the lower area of the melting stock in a determined periodical deflection program thereby melting the melting stock to produce a melt pool in the crucible and directing the electron beam over the surface of the melt pool in a determined periodical deflection program. The electron beam producing and directing assembly comprises an axially symmetrical electron gun positioned to supply an electron beam at an angle of 50 to 90 degrees with the axis of the melting stock and electromagnetic deflection means for deflecting the electron beam onto the melting stock and onto the melt pool in the crucible. The periodical deflection program of the electron beam on the melt pool is adjustable separately from the periodical deflection program of the electron beam on the melting stock in a manner whereby the time that the electron beam is on each point of the melting stock and on each point of the melt pool is adapted by the periodical deflection programs to the amount of heat required. The electron beam forms a cavity in the lower area of the melting stock. The periodical deflection programs for the melting stock and for the melt pool merge at the area of smallest separation between the melting stock and the melt pool. Vacuum pumping means evacuates the melting chamber and the electron beam producing and directing assembly for maintaining a high vacuum in the melting chamber and the electron beam producing and directing assembly.

In order that the present invention may be readily carried into effect, it will now be described with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic diagram, partly in section and partly in block form, of an embodiment of the electron beam multichamber high vacuum furnace of the present invention;

FIG. 2 is a perspective view, partly in section, of the upper part of the crucible and the lower part of the melting stock of the electron beam furnace of the present invention, including the track of the electron beam; and

FIG. 3 is a plan view of another embodiment of the electron beam furnace of the present invention.

The electron beam multiple chamber furnace for melting under high vacuum of the present invention provides a very high power output of more than 1000 kilowatts and is especially adapted to melt steel on a large scale. In FIG. 1, a melting chamber, zone or area **1** houses a water or fluid-cooled crucible **2**. The crucible **2** has a movable bottom **3**, which may be moved in axial directions and which supports a block or ingot **4** formed by solidified and solidifying melt or melt pool **5**. The melt pool **5** is produced at the upper part of the ingot **4** at the lower periphery of the mouth **6** of the crucible **2**. The melt pool **5** is formed by the melting of the melting stock or material to be melted **7** and is maintained by melted material continuously dripping into said melt. The melt pool **5** is the upper part of the ingot **4** which is maintained in molten condition.

The melting stock **7** to be melted has the same cross-sectional area as the ingot **4**. The melting stock **7** is fed into the melting chamber **1** from the top via an extending portion **8** of said melting chamber. All the components in the melting chamber **1** are under the same pressure. A support member **9** supports the melting stock **7** and is gradually moved in axial direction toward the crucible **2**. The speed or rate of movement of the melting stock **7** is determined and adjusted in accordance with the amount of melting stock **7** which is to be melted. The support member **9** may in turn be supported by any suitable supporting and moving means such as, for example, a pulley or crane device **10** in an evacuated housing.

One or a plurality of electron beam directing assemblies **11** is or are provided in the sides of the melting chamber **1**, between the upper and lower parts of said melting chamber. The electron beams are thus supplied to the melting chamber **1** in horizontal or substantially horizontal direction. The electron beams supplied to the melting chamber **1** are at an angle of from 50° to 90° with the vertical. The multichamber electron beam directing assembly **11** comprises an electron gun **12**, a plurality of magnetic lenses **15** and pressure gradient chambers **16** and gas flow impedances **17** and **18**. The multichamber electron beam assembly produced a focused and directed electron beam **19**.

The electron beam **19** passes through the gas flow impedance **17** into the pressure gradient chamber **16**. The pressure gradient chamber **16** has projecting conduits or nipples **21** and **22** for connection to vacuum pumps (not shown in FIG. 1). The electron beam **19** passes from the pressure gradient chamber **16** through the gas flow impedance **18**, the magnetic last lense **15** and a magnetic deflection system **23** for the electron beam **19** into the melting chamber **1**. The magnetic deflection system **23** comprises four electromagnet windings, two of which are shown in the view of FIG. 1, and two of which are positioned in a plane at right angles to the plane of the two which are shown and are not shown in FIG. 1. The electron beam directing assembly **11** thus permits the pressure in the melting chamber **1** to be independent from the pressure in the electron gun **12**.

The gas flow impedances **17** and **18** and the pressure gradient chambers between the electron gun and the melting chamber **1** compensate for pressure differences which may occur in the melting chamber **1** due to the eruption of gases from the melting stock **7** or from the melting pool **5**. Thus, the pressure in the melting chamber **1** may increase to 10^{-2} mm. Hg, for example, while the pressure in the cathode chamber is limited to the 10^{-4} mm. Hg.

The magnetic deflection system **23** comprises four electromagnetic coils, as mentioned, which are positioned and current-controlled in a manner which permits said coils to deflect the electron beam **19** in different, independently adjustable, periodical or cyclical movement patterns on the melting stock **7** and in the melt pool **5**. The beam deflection system **23** deflects the electron beam **19** to any desired point on the melting stock **7** and to any desired point in the melting pool **5** and maintains the electron beam at the desired point in accordance with the necessary melting conditions and in accordance with the movement pattern.

The independently adjustable movement patterns of the electron beam **19** for the melting stock **7** and for the melt pool **5** join each other at the lowest part or edge **24** of said melting stock. The lowest edge **24** of the melting stock **7** is positioned in the crucible **2** and is almost in contact with the melt pool **5** in said crucible. The movement patterns of the electron beam **19** for the melting stock **7** and for the melt pool **5** are adjusted to provide a melting surface on said melting pool in the shape of a conical cavity. It is thus preferable to utilize soft magnetic ferrite material as the pole pieces of the magnetic lenses, as the cores and, as necesary, as the magnetic circuit components of the electron beam deflection system **23**.

FIG. 2 illustrates the tracks or movement patterns of the electron beam. FIG. 2 shows, on an enlarged scale, part of the crucible **2**, part of the melting stock **7** and the melt pool **5**. The electron beam **19** (not shown in FIG. 2) strikes the melting stock **7** and moves along the lower surface of said melting stock in a movement pattern **25** and strikes the melt pool **5** and moves through said melt pool in a movement pattern **26**. The movement patterns **25** and **26** and the thickness of the electron beam are independently determined and are periodically or cyclically repeated until the melting process is completed. The electron beam movement patterns **25** and **26** are controlled by the current supplied to the coils of the beam deflection system **23** or by the voltage applied to said coils.

The amount of energy applied to the melting stock **7** and to the melt pool **5** is dependent upon the thickness of the electron beam **19** and the speed of deflection of said electron beam. The movement pattern **25** is substantially sinusoidal with a variable frequency which is relatively low, higher, highest, lower and low as said pattern moves from top to bottom of the lower part of the melting stock **7**. The movement pattern **26** is the same as the movement **25**, but moves from side to side of the melt pool **5**. The energy applied by the electron beam **19** in the movement patterns **25** and **26** is thus most concentrated in the central portion of said patterns and is gradually less concentrated from the central portion to each end portion. The movement pattern **25** forms a cavity **27** of conical configuration in the lower part of the melting stock **7** as the electron beam **19** melts said melting stock. The conical cavity **27** formed in the melting stock **7** has many technical advantages.

The advantages of the conical cavity **27** include the formation of a large angle between the melting stock **7** and the axis of the electron beam **19** striking said material and the prevention of the electron beam from striking the mouth **6** of the crucible **2**. The utilization of two indepedent movement patterns **25** and **26**, which join each other in the area of the lowest edge **24** (FIG. 1) of the melting stock **7** permits said melting stock to have a diameter which is considerably smaller than the inner diameter of the crucible **2**. Furthermore, the cross-section of the melting stock **7** may be other than circular, due to the independent movement patterns **25** and **26**.

The mouth **6** of the circuible **2** permits the electron beam **19** to strike the melt pool **5** at any point of its surface including the peripheral edge thereof. In the electron beam multi-chamber high vacuum furnace of the present invention, although vapor is produced at the melted surface of the melting stock **7** in directions substantially perpendicular to such surface, the conical cavity **27** configuration of such surface prevents most of such vapor from reaching the gas flow impedances **17** and **18**, so that very little vapor reaches said gas flow-impedances. Furthermore, most of the vapor produced at the surface of the melt pool **5** is prevented from reaching the gas flow impedances **17** and **18**, so that very little vapor from said melt reaches said gas flow impedances.

A plurality of electron beam directing assemblies **11** (FIG. 1) may be utilized in the electron beam furnace of the present invention. Each of the electron beam directing assemblies is independently or separately adjusted or controlled to provide a movement pattern, but the movement patterns are determined by the electron beam deflection systems **23** of said electron beam directing assemblies in determined relation to each other. FIG. 3 discloses an embodiment of the electron beam furnace utilizing a plurality of electron beam directing assemblies in determined relation to each other. FIG. 3 discloses an embodiment of the electron beam furnace utilizing a plurality of electron beam directing assemblies.

In FIG. 3, four multichamber electron beam directing assemblies **31*a***, **31*b***, **31*c*** and **31*d*** are positioned in the sides of the melting chamber **1**[1] and are equidistantly and equangularly spaced from each other in a horizontal plane. Four vacuum pumps **32*a***, **32*b***, **32*c*** and **32*d*** are positioned between the electron beam directing assemblies **31*a***, **31*b***, **31*c*** and **31*d*** equidistantly and equiangularly spaced from each other and from said electron beam directing assemblies in a horizontal plane. The crcible **2**[1] and the melting stock **7**[1] are shown in FIG. 3.

In the embodiment of FIG. 1, a vacuum pump **33** is utilized to evacuate the melting chamber **1** and may be positioned close to the crucible **2**. The vacuum pump **33** may comprise any suitable oil diffusion pump. The vacuum pump **33** cooperates with and operates via a valve **34**, which valve may be part of an oil diffusion pump. A plurality of water or fluid-cooled sheets **35** are provided in spaced linear relationship to each other between the melting chamber **1** and the valve **34** of the vacuum pump **33**. The sheets **35** are spaced from each other at equal distances which prevent heat, vapor and stray metal from the melt pool **5** from reaching the valve **34** or the pump **33**. The sheets **35** thus protect the valve **34** and the pump **33** from stray metal, vapor and heat in the melting chamber **1**. If the vacuum pump **33** comprises an oil diffusion pump, the sheets **35** function as a condensation trap for the oil vapor of such a pump, so that said sheets avoid the need for an oil trap.

While the invention has been described by means of specific examples and in specific embodiments, we do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electron beam multiple chamber furnace, comprising a melting chamber having a top, bottom and sides; a fluid-cooled crucible at the bottom of the melting chamber; support means for feeding melting stock substantially vertically downward into the crucible from the top of said melting chamber, said melting stock and said crucible having substantially the same cross-sectional configuration, said melting stock having an axis;

electron beam producing and directing assembly means positioned in a side of said melting chamber for producing and directing an electron beam onto the lower area of said melting stock in a determined periodical deflection program thereby melting said melting stock to produce a melt pool in said crucible and for directing said electron beam over the surface of said melt pool in a determined periodical deflection program, said electron beam producing and directing assembly means comprising an axially symmetrical electron gun positioned to supply an electron beam at an angle of 50 to 90 degrees with the axis of said melting stock and electromagnetic deflection means for deflecting said electron beam onto said melting stock and onto said melt pool in said crucible, said periodical deflection program of said electron beam on said melt pool being adjustable separately from said periodical deflection program of said electron beam on said melting stock in a manner whereby the time that said electron beam is on each point of said melting stock and on each point of said melt pool is adapted by said periodical deflection programs to the amount of heat required, said electron beam forming a cavity in the lower area of said melting stock, the periodical deflection programmed patterns of said electron beam for said melting stock and for said melt pool merging at the area of smallest separation between said melting stock and said melt pool; and

vacuum pumping means for evacuating said melting chamber and said electron beam producing and directing assembly means for maintaining a high vacuum in said melting chamber and said electron beam producing and directing assembly means.

2. An electron beam multiple chamber furnace as claimed in claim **1**, wherein the cavity formed in the lower area of said melting stock is of substantially conical configuration.

3. An electron beam multiple chamber furnace as claimed in claim **1**, wherein the electromagnetic deflection means of said electron beam producing and directing assembly means comprises magnetic lenses and magnetic deflection means having poles and coil cores of soft magnetic ferrite material for focusing and deflecting said electron beam.

4. An electron beam multiple chamber furnace as claimed in claim **1**, further comprising valve means interposed between said vacuum pumping means and said melting chamber and baffle plate means comprising a plurality of spaced fluid-cooled sheets positioned between said melting chamber and said valve means.

5. An electron beam multiple chamber furnace as claimed in claim **1**, wherein said electron beam producing and directing assembly means comprises a plurality of axially symmetrical electron guns equiangularly positioned from each other in the sides of said melting chamber, the periodical deflection programs of said electron guns being separately adjustable from each other.

6. An electron beam multiple chamber furnace as claimed in claim **5**, wherein the periodical deflection programs of said plurality of electron guns are coordinated with each other.

7. An electron beam multiple chamber furnace as claimed in claim **5**, wherein said vacuum pumping means comprises a plurality of vacuum pumps each positioned between adjacent ones of said electron guns in the sides of said melting chamber.

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