219-121
CROSS REFERENCE SEARCH ROOM

Aug. 22, 1967 S. W. H. YIH ETAL 3,337,676

ELECTRON BEAM MELTING APPARATUS

Filed April 2, 1964 3 Sheets-Sheet 1

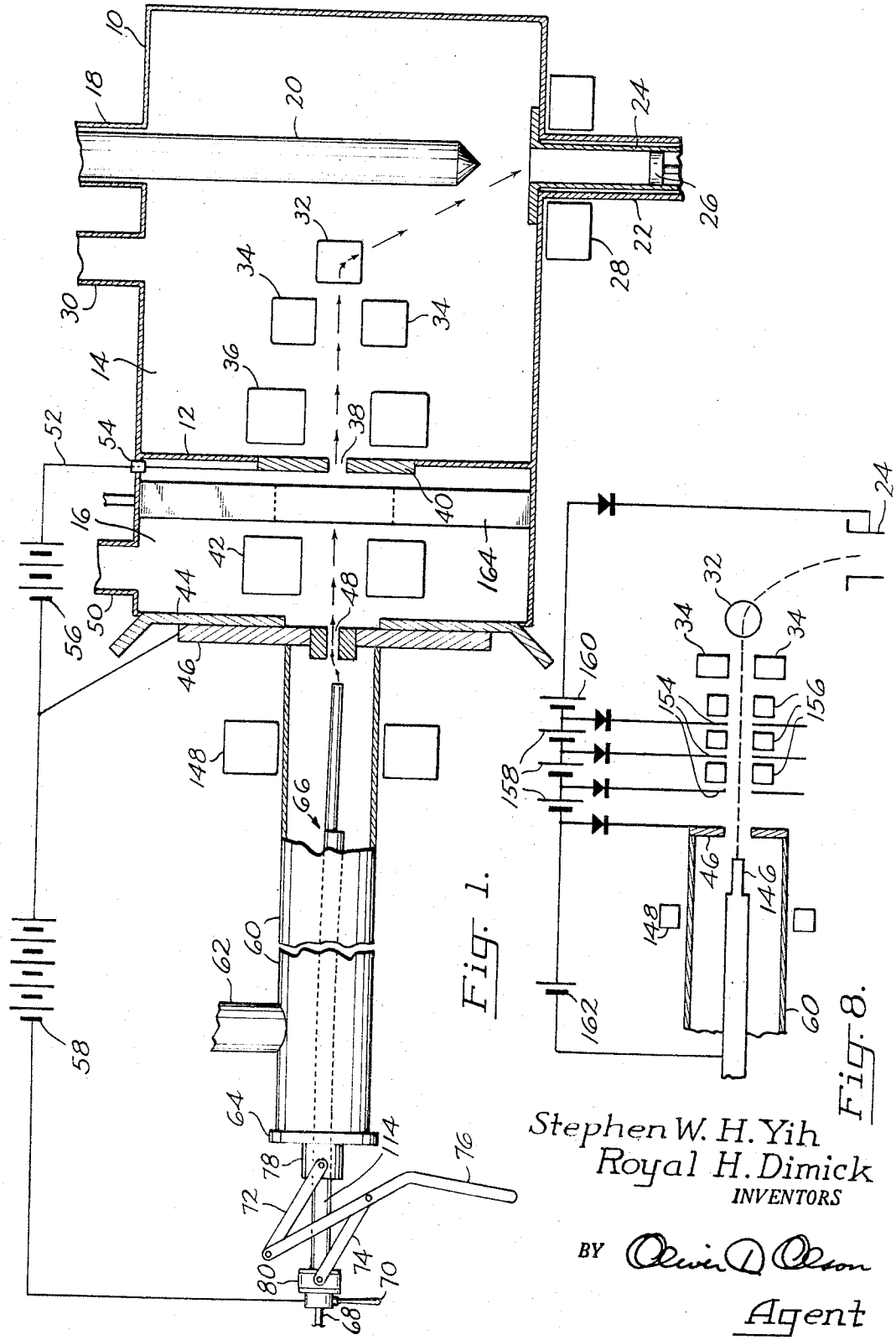


Fig. 1.

Fig. 8.

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Filed April 2, 1964 3 Sheets-Sheet 2

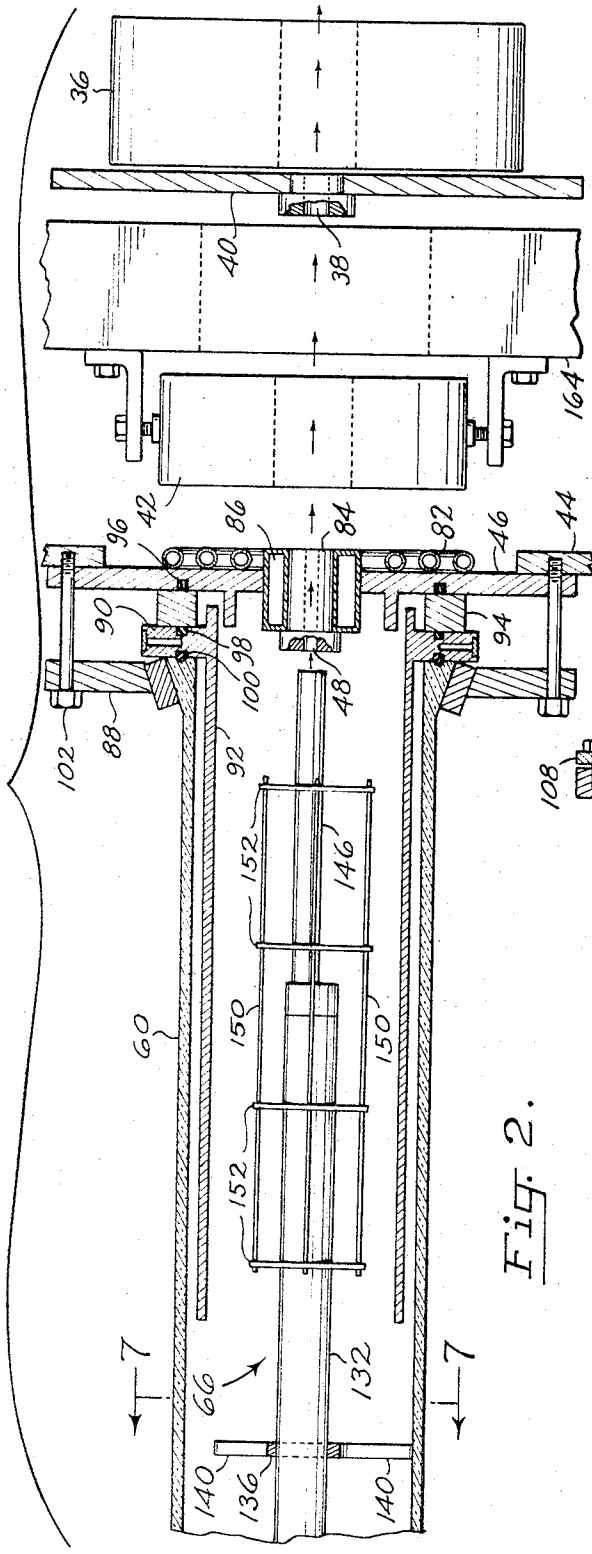


Fig. 2.

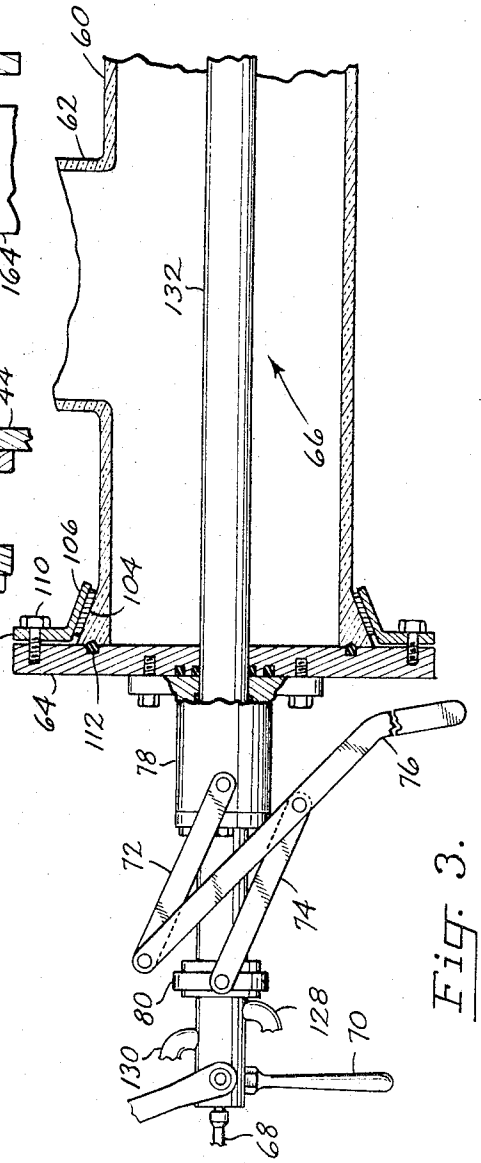


Fig. 3.

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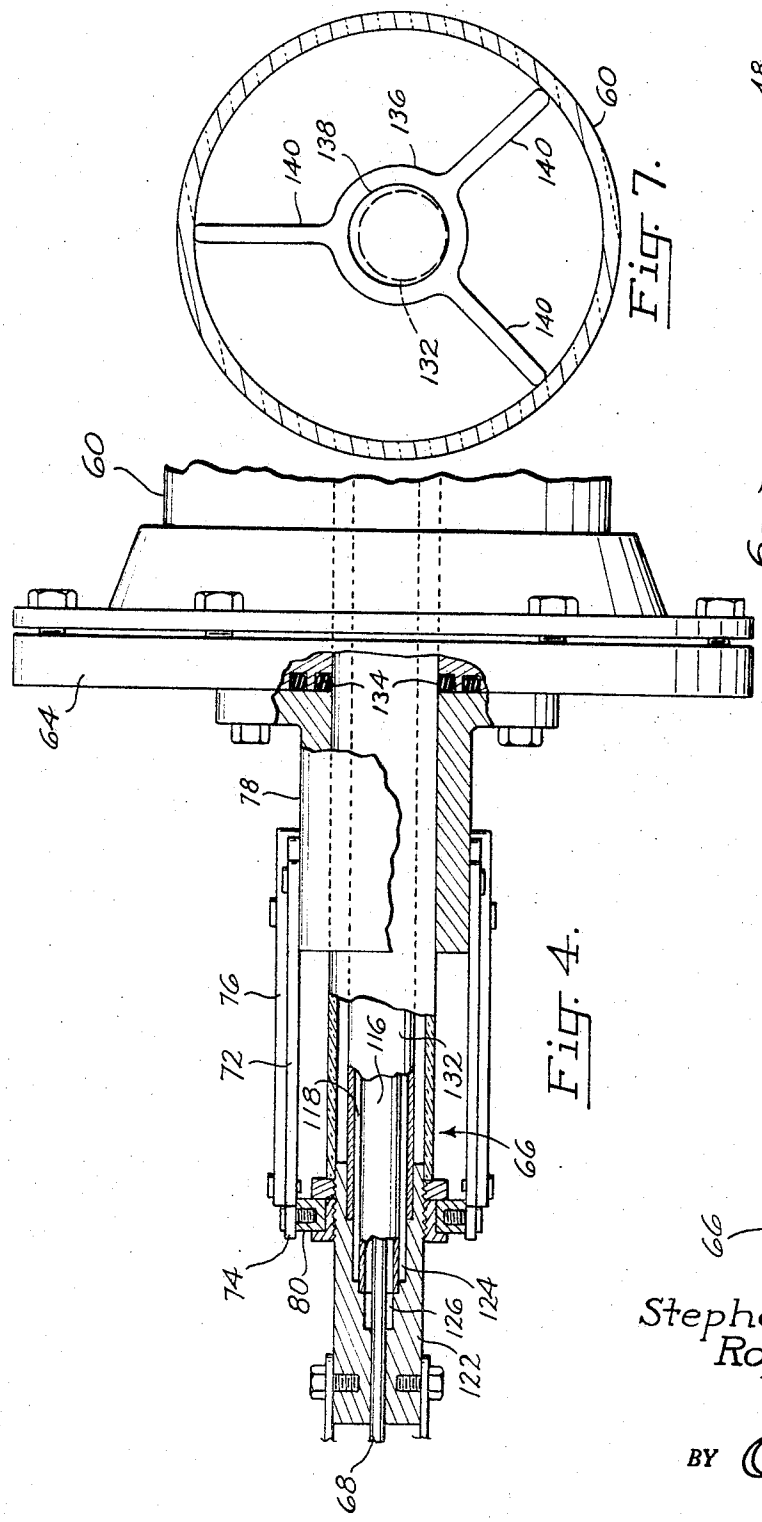


Fig. 4.

Fig. 7.

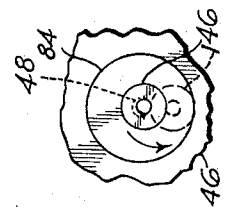


Fig. 6.

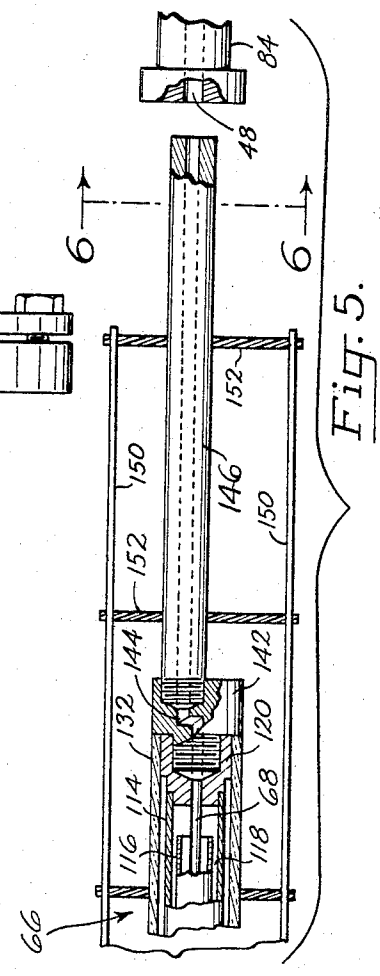


Fig. 5.

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ELECTRON BEAM MELTING APPARATUS

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6 Claims. (Cl. 13—31)

This invention relates to apparatus for melting materials by electron bombardment in a vacuum, and has for its primary objective the provision of such apparatus which is characterized by affording greater economy and efficiency of operation by reducing the requirements of the vacuum pumping system, by the protection of the high voltage power supply against insulation breakdown, by extending the life and reducing the maintenance of the electron source by protection against spatter and other contamination, and by affording operation under a wider latitude of control conditions, as compared with corresponding apparatus of the prior art.

Another important object of the present invention is the provision of apparatus of the class described in which a plasma gun is utilized as a rich source of electrons.

The foregoing and other objects and advantages of this invention will appear from the following detailed description, taken in connection with the accompanying drawings in which:

FIG. 1 is a foreshortened fragmentary view in side elevation, partly in section, showing schematically an electron beam melting apparatus embodying the features of the present invention;

FIG. 2 is a fragmentary view in side elevation, partially sectioned, showing details of construction of the plasma gun and deflection assembly of FIG. 1;

FIG. 3 is a fragmentary view in side elevation, partially sectioned, showing details of construction of the plasma gun control mechanism of FIG. 1;

FIG. 4 is a fragmentary view, partially sectioned, of the plasma gun control mechanism as viewed from the top in FIG. 3;

FIG. 5 is a fragmentary view in side elevation, partially sectioned, showing further details of construction of the plasma gun component;

FIG. 6 is a sectional view taken along the line 6—6 in FIG. 5 and illustrating the manner of adjustment of the plasma gun;

FIG. 7 is a sectional view taken along the line 7—7 in FIG. 2; and

FIG. 8 is a schematic representation of a modified form of electron control.

Referring principally to FIG. 1 of the drawings, the apparatus is shown to include a housing **10** provided with an intermediate transverse wall **12** dividing the housing into a melt chamber **14** and an electron acceleration chamber **16**. An opening **18** is provided in the top of the melt chamber for the passage downwardly therethrough of an elongated rod **20** of stock material to be melted. It will be understood that appropriate sealing means (not shown) is interposed between the opening and the melt stock to provide a vacuum type seal therebetween. In addition, conventional means (not shown) is provided for rotating the rod **20** on its longitudinal axis during melting.

Vertically below the melt stock opening is an opening **22** in the bottom wall of the housing, mounting therein an elongated hollow crucible **24** for receiving the material melted from the melt stock. The crucible preferably is provided with a retractable piston **26** by which to provide for the continuous collection of melted material in the crucible, as is well known in the art. A deflecting coil **28** preferably surrounds the crucible adjacent the bottom wall of the housing, for the purpose of directing an electron beam into the crucible.

A conduit **30** communicates the melt chamber with vacuum pumping equipment (not shown) capable of reducing the pressure in the chamber to a value below the glow discharge condition within the chamber.

Also supported within the melt chamber, by any suitable electrical insulation means, is a pair of laterally spaced vertical deflection plates **32**, a pair of vertically spaced horizontal deflection plates **34** and a focusing coil **36**. These are all arranged symmetrically with respect to a common horizontal axis which extends through the small opening **38** in an electrically conductive orifice plate **40** supported by the partition wall **12** but isolated electrically therefrom.

The electron acceleration chamber **16** of the housing contains the focusing coil **42** supported therein by any suitable electrical insulation means and arranged concentrically on the common horizontal axis previously mentioned. The outer end wall of the chamber **16** is formed in part by the plate **44** of electrical insulation material which, in turn, supports the orifice plate **46**. The orifice **48** of this plate also is arranged concentrically about the common horizontal axis previously mentioned.

A conduit **50** communicates the electron acceleration chamber with vacuum pumping equipment (not shown) capable of reducing the pressure within the chamber to at least about 5×10^{-4} torr.

The orifice plate **40** is connected through the electrical conductor **52**, suitably insulated from the housing at **54**, to an appropriate source **56** of high voltage, low amperage electric supply. Exemplary of such supply is 10,000 volts at from zero to 500 amperes.

The orifice plate **46** is connected to a suitable source **58** of low voltage, high amperage electric supply, for example 30 volts at 100 to 500 amperes.

The vertical and horizontal deflection plates and focusing coils are connected in conventional manner to appropriately controlled sources of electric supply, as will be apparent to those skilled in the art.

Projecting outwardly from the acceleration chamber **16** and enclosing the orifice **48** therein, is an elongated plasma gun housing **60**. A conduit **62** communicates said housing with vacuum pumping equipment (not shown) capable of reducing the pressure within the housing from atmospheric down to about 5×10^{-5} torr. The rear end of the housing is closed by a plate **64** which slidably receives therethrough an elongated tubular member **66**. This member terminates at its forward end in spaced relation to the orifice **48** and extends rearwardly through the plate **64**. A conduit **68** extends through the tubular member and communicates at its rear end with a source (not shown) of argon or other suitable inert gas under pressure. The tubular member is made of electrically conductive material and is connected to the negative side of the electric supply **58** for the orifice plate **46**.

For the purpose described in detail hereinafter, means is provided for moving the tubular member **66** longitudinally and rotationally relative to the orifice **48**. In the embodiment illustrated, the means for moving the tubular member rotationally comprises a handle **70** secured to the tubular member and projecting radially therefrom. The means for moving the tubular member longitudinally comprises a pantograph assembly of the parallel links **72** and **74** which are connected together pivotally at one of their opposite ends by means of the control lever **76**. One of the links **72** is connected pivotally to a hub extension **78** on the sealing plate **64** of the housing **60**, and the other link **74** is conected pivotally to a collar **80** mounted for rotation in a longitudinally fixed position on the tubular member **66**.

Certain perferred structural details of the assembly described hereinbefore are illustrated in FIGS. 2–7. Refer-

ring particularly to FIG. 2, the orifice plate **46** is cooled by the circulation of cooling liquid through the tube **82** mounted in surface contact therewith and arranged spirally about the orifice member **84** which provides the orifice **48** described hereinbefore. The orifice member **48** is mounted in an annular cooling member **86** supported by the orifice plate **46** and arranged for the circulation of cooling liquid therethrough.

The housing **60** for the plasma gun comprises an elongated glass or other electricaly non-conductive and non-magnetic tube supported at its forward end on the orifice plate **46** by means of the assembly of the clamping ring **88**. Interposed between the forward end of the glass tube **60** and the orifice plate **46** is the annular flange **90** of a tubular magnetic shield **92** of copper or other suitable material. The annular flange **90** is hollow, for the circulation of cooling liquid, and is spaced from the orifice plate **46** by means of the annular insulating block **94** of glass or other suitably non-conductive and non-magnetic material. These abutting surfaces are sealed for high vacuum by means of the interposed annular seals **96, 98, 100**. The foregoing assembly is held together by means of the clamping screws **102**.

The rearward end of the glass tube **60** is closed by the plate **64** (FIG. 3) which is secured across said open end by means of the annular centering wedge joints **104, 106** on the glass tube **60** and clamping collar **108**, respectively, the latter being secured to the end plate by means of the screws **110**. A vacuum tight seal between the abutting surfaces of the glass tube and end plate is provided by the annular sealing ring **112**.

The tubular member **66** of the plasma gun includes a pair of concentrically arranged tubes **114** and **116** (FIGS. 4 and 5) of copper or other non-magnetic material supported in spaced relation to provide an annular chamber **118** therebetween for the passage of cooling liquid. The outer one **114** of these pairs of tubes supports at its forward end a plug **120** provided with an axial bore in which the forward end of the gas supply tube **68** is supported. The rearward end of the outer tube **114** is sealed to a plug **122**, as is the rearward end of the inner tube **116** of the pair. A stepped bore in the plug **122** provides a forward annular chamber **124** communicating with the space **118** between the pair of tubes, and a rearward chamber **126** communicating with the interior of the inner tube **116** of said pair.

Conduits **128** and **130** (FIG. 3) communicate said forward and rearward chambers in the plug **122** to a supply and drainage, respectively of a source of cooling liquid. The forward end of the inner tube **116** terminates rearwardly of the forward plug **120**, to provide for communication of the annular space **118** between the pair of tubes with the interior of the inner tube **116**, to accommodate said circulation of cooling liquid. The forward end of the inner tube **116** terminates rearwardly of the forward plug **120**, to provide for communication of the annular space **118** between the pair of tubes with the interior of the inner tube **116**, to accommodate said circulation of cooling liquid.

The outer tube **114** of the plasma gun is shielded by the encircling tube **132** of glass or other non-conductive and non-magnetic material. The tube is supported at its forward end by reception over the forward plug **120**.

The tube **132** extends slidably through the closure plate **64** at the rear end of the glass tube housing **60** for the plasma gun, and a vacuum tight seal is provided therebetween by means of the annular seal **134**. The rearward end of tube **132** is supported on the forward end of the plug **122**. Thus, the assembly of tubes **114, 116** and **132** may be moved longitudinally and rotationally with respect to the closure plate, by means of the controls previously described.

A spider member **136** (FIGS. 2 and 7), having a central opening **138** freely receiving the glass tube **132** therethrough, is provided with a plurality of radiating fingers **140** which engage the glass tube housing **60**, for supporting the forward portion of the plasma gun assembly.

The forward plug **120** is counterbored inwardly from its forward end and threaded for reception of the threaded shank of the adapter plug **142**. The forward end of the adapter plug is provided with a tapped bore disposed off center with respect to the axis of the plug and this tapped bore communicates through the offset bore **144** extending rearwardly through the adapter plug, with the gas supply tube **68**. The tapped bore in the adapter plug receives the threaded end of the elongated stinger tube **146** which extends forwardly toward the orifice member **84**.

The purpose of the offset tapped opening in the adapter plug **142** is to provide adjustment of the bore of the stinger tube **146** relative to the bore **48** of the orifice member **84**. Thus, referring to FIG. 6, rotation of the plasma gun assembly by means of the control handle **70** causes rotation of the bore of the stinger tube in a circle whose center is offset from the axis of the bore **48** in the orifice member, as indicated by the arrow. The degree of offset of the bore of the stinger tube thus may be varied to control the electron flow through the orifice. In this regard, electrons are produced by causing an electric arc discharge between the forward end of the stinger tube and the orifice member, to effect ionization of the inert gas being forced through the tube **68**.

An electron emission control coil **148** surrounds the housing **60** of the plasma gun, adjacent the forward end of the stinger tube **142**, and is connected to a controlled source of electric potential for focusing the beam through the aperture **48**, as is well known.

The forward portion of the plasma gun assembly is provided with an electric shield in the form of a plurality of circumferentially spaced rods **150** supported by the longitudinally spaced rings **152** supported freely on the plasma gun tube assembly.

In the operation of the apparatus described hereinbefore, let it be assumed for purposes of illustration that an elongated cast ingot **20** of a refractory metal projects downwardly into the melting chamber **14**, as illustrated in FIG. 1, and is driven in rotation preparatory to melting. A control valve (not shown) for the inert gas is manipulated to provide a flow of the gas through tube **68** in the forward end of the stinger tube **146** and the vacuum pumping equipments are activated to reduce the pressures within the associated chambers, as previously described. Further, the appropriate sources of electric supply are activated to provide the proper potentials to the orifice plates, emission control coil, focusing coils and deflection plates.

By manipulation of the pantograph control assembly, the plasma gun is moved longitudinally relative to the orifice plate **84** until an electric arc discharge therebetween is achieved. Ionization of the inert gas results in the flow of electrons through the orifice **48**, and this beam may be adjusted by appropriate adjustment of lever **70** and coil **148**. The electrons are focused and accelerated through the orifice **38** and then again focused and deflected appropriately by proper control of the vertical and horizontal deflection plates **32** and **34**, respectively. The electron beam thus is deflected toward the collecting crucible **24** while simultaneously intercepting the path of the rotating melt stock **20**. The lower end of the melt stock thus is heated to a temperature above the melting point of the stock, whereupon the molten metal falls by gravity into the crucible.

The electron beam also impinges upon the metal in the crucible, thereby maintaining a molten pool at the surface thereof. Thus, as the piston **26** is lowered continuously during the accumulation of molten metal in the crucible, non-volatile impurities are caused to remain selectively in the molten pool while volatile impurities are exhausted through the vacuum system, in manner well known in the art.

Adjustable control of the flow of electrons to the melting chamber may be achieved by various means other than the rotational adjustment of the stinger tube **146**. For example, the stinger tube may be aligned axially with an orifice member provided with an iris type opening which may be adjusted in diameter over an operating range. Another form of control is illustrated in FIG. 8, wherein the stinger tube **146** is aligned axially with the orifice **48** as well as with a plurality of longitudinally spaced coaxial accelerating orifices **154** and focusing coils **156**, with each successive orifice forwardly of the orifice plate **46** being connected to progressively increasing sources of potential **158**. The crucible **24** is connected to a source **160** of still higher potential, and the orifice plate **46** is connected to source **162** of lowest relative potential.

The plasma gun operates in the mode of complete space charge neutralization, and therefore minimum radio frequency oscillations in the plasma is generated. Accordingly, insulation breakdown in the power supply is substantially eliminated.

The high voltage component of the apparatus is isolated and protected from gas bursts which frequently occur in the melting chamber, thus eliminating the necessity for controlling such bursts while simultaneously eliminating damage to the high voltage component.

The source of electrons, being isolated from the melting chamber, remains clean and maintenance free since it is not subject to the deleterious effects of spatter and other contamination which heretofore has necessitated frequent rebuilding or replacement of components of the electron source. Accordingly, the plasma gun remains operable over much longer periods of time as compared with electron sources of the prior art.

The apparatus of this invention is capable of operation under unlimited conditions of power, since operation does not depend upon the former requirement of a plasma column around the melt stock. The present invention utilizes a plasma gun merely as a rich source of electrons, and the melting chamber constitutes a field free space, whereas apparatus of the prior art utilizes the plasma of the melt at the electron source and the crucible to neutralize the space charge and increase the electron beam current.

The apparatus of the present invention also has the advantage of being capable of operation at higher pressures, and thus requires smaller and less expensive vacuum pumping equipment than apparatus of the prior art.

It will be apparent to those skilled in the art that various changes may be made in the details of construction described hereinbefore. For example, a gate valve **164** may be provided between the orifice plate **38** and coil **42** for releasably sealing the acceleration chamber **16** from the melting chamber **14**, to facilitate maintenance of the components in the latter without losing the vacuum in the acceleration chamber. A plurality of plasma guns and associated deflection systems may be arranged concentrically about the melt stock rod **20**, if desired. The melt stock rod may be fed in from the side rather than from the top, as shown, and means may be provided for feeding powder or other particulate material. These and other changes and additions may be made without departing from the spirit of this invention and the scope of the appended claims.

Having now described our invention and the manner in which it may be used, what we claim as new and desire to protect by Letters Patent is:

1. Electron beam melting apparatus, comprising

(a) a housing adapted to be evacuated to sub-atmospheric pressure and arranged to contain a material to be melted, the housing including a receptacle for receiving the melted material,

(b) conduit means communicating the housing with a source of inert gas,

(c) electric arc discharge means in the housing remote from and independent of the receptacle and melted material therein for providing an electric discharge arc in the path of inert gas emitted from the conduit means whereby to effect ionization of the inert gas and consequent production of electrons, and

(d) electron control means in the housing for controlling the number of electrons to the material to be melted.

2. Electron beam melting apparatus, comprising

(a) a melting chamber adapted to be evacuated to sub-atmospheric pressure and arranged to contain a material to be melted,

(b) a gas tube housing adapted to be evacuated to sub-atmospheric pressure,

(c) an electrically conductive orifice member having an opening therethrough communicating the housing with the melting chamber,

(d) an electrically conductive tube in the housing terminating at one end adjacent the orifice member and adapted for connection at its opposite end to a source of inert gas under pressure,

(e) means connecting the orifice member and tube in series in an electric circuit of a source of electric potential with the orifice member being positive with respect to the tube, for providing an electric discharge arc between said orifice member and tube whereby to effect ionization of the inert gas and consequent production of electrons, and

(f) means for directing said electrons in a beam through the opening in said orifice member and onto the material to be melted.

3. The apparatus of claim **2** wherein the melting chamber includes a receptacle vertically below the material to be melted for receiving the melted material, and the directing means includes deflection means for directing the electrons in the beam into said receptacle along a path of interception of the material to be melted.

4. The apparatus of claim **2** including control means operatively associated with the orifice member and gas tube for adjusting the gas number of electrons in the electron beam.

5. The apparatus of claim **2** including movable support means for the gas tube for moving the latter longitudinally and laterally with respect to the opening in the orifice member for adjusting the number of electrons in the electron beam.

6. The apparatus of claim **2** wherein the opening in the orifice member communicates the housing with the melting chamber through an electron acceleration chamber adapted to be evacuated to sub-atmospheric pressure, the acceleration chamber communicating with the melting chamber through an opening in a second orifice member connected to a source of electric potential which is positive with respect to the tube.

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