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[54] PLASMA ARC TORCH

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[21] Appl. No.: **409,329**

[52] **U.S. Cl.** .... **13/9,** 219/121 P
[51] **Int. Cl.** **H05b 7/18**
[58] **Field of Search** .... 13/9, 9 P, 18; 219/121 P

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Primary Examiner—R. N. Envall
Attorney, Agent, or Firm—Strauch, Nolan, Neale, Nies & Kurz

[57] **ABSTRACT**

A plasma arc remelting furnace system with improved components including mechanisms for independently vertically feeding and oscillating the metal blank through the top of the furnace. Multiple plasma arc torches (plasmatrons) are installed in a sealed chamber and adjustable operators enable angular disposition of individual torches. The torches have improved torch nozzles with heat sink construction enabling operation at higher temperatures, better stabilized plasma arcs and longer torch life. The system can utilize ingot molds of various cross section shapes, i.e., round, square, rectangular and polygonal and, depending upon mold shape, the number of torches can differ. Operating circuits are provided for use with a plurality of different numbers (up to eight) of torches, either with direct current or alternating current power sources, and possible variations of circuits will enable using a larger number of torches.

62 Claims, 20 Drawing Figures

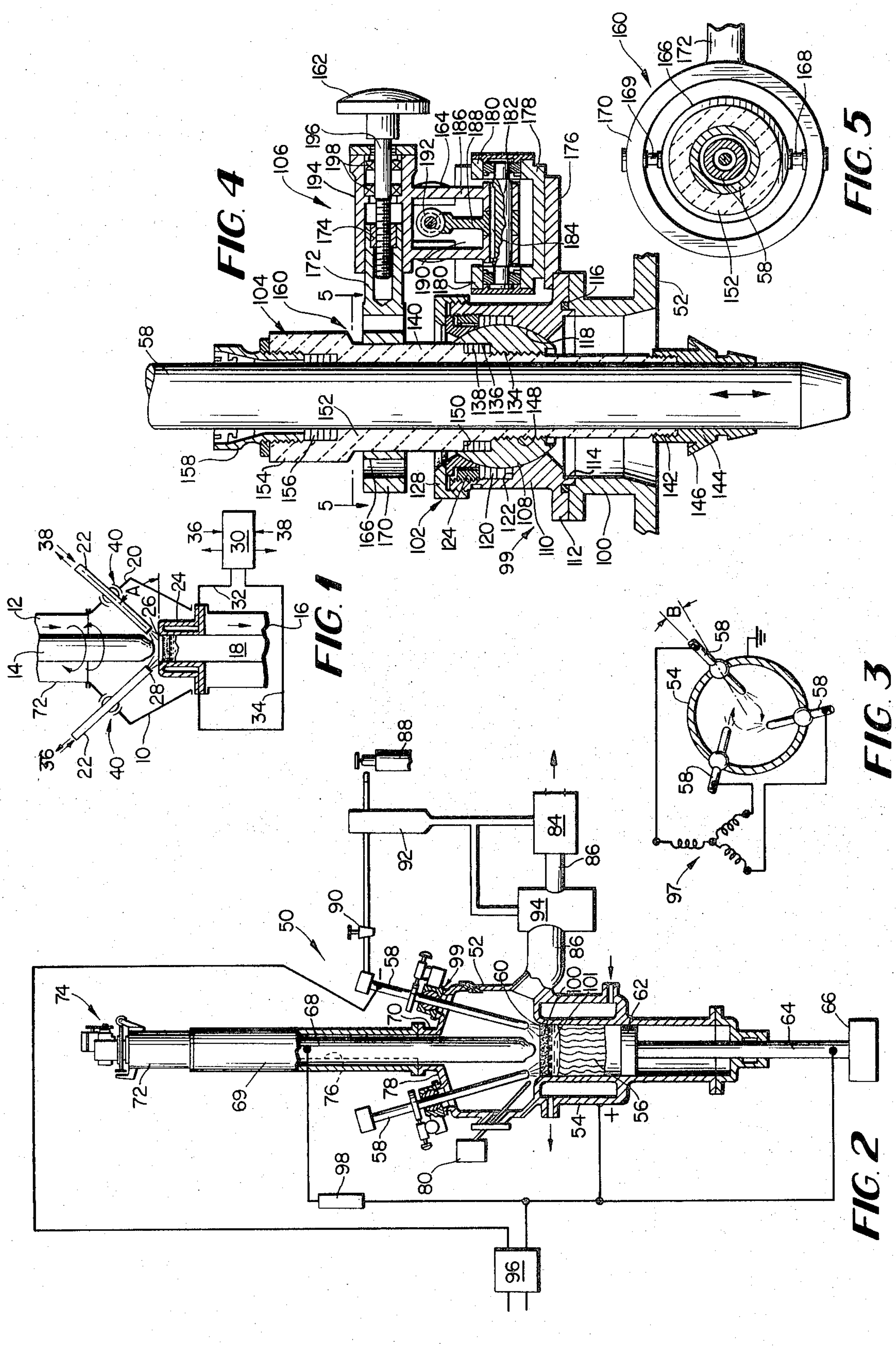
FIG. 1
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FIG. 4
FIG. 5

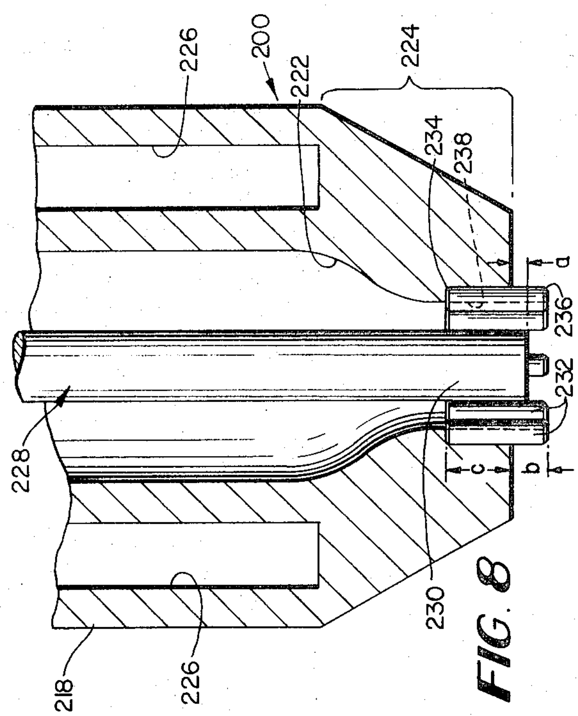


FIG. 8

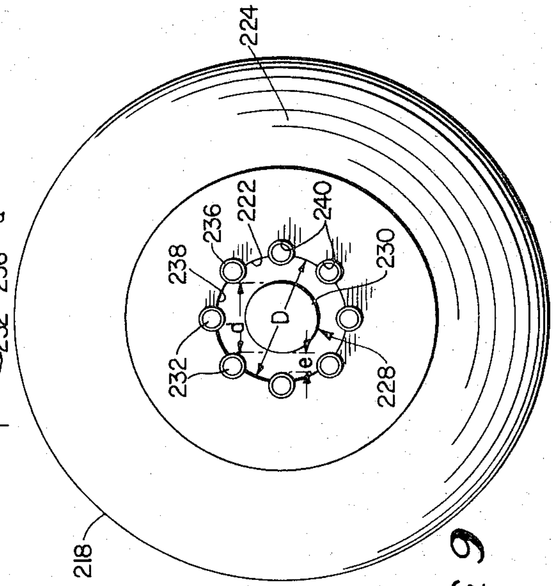
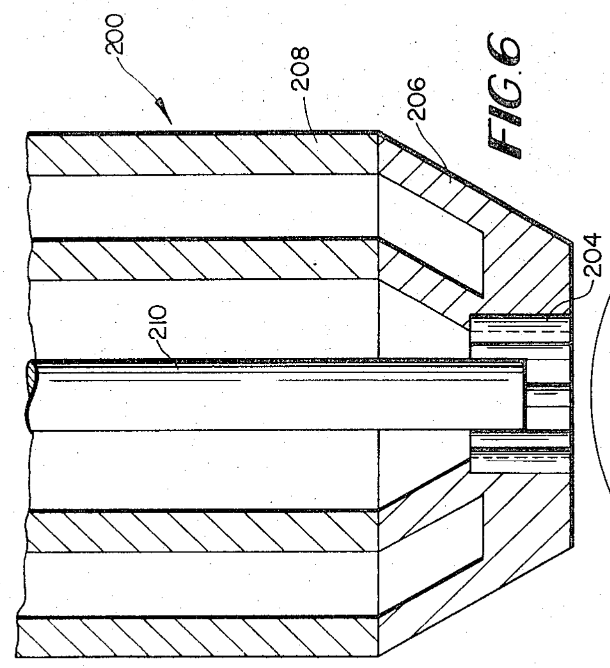


FIG. 9



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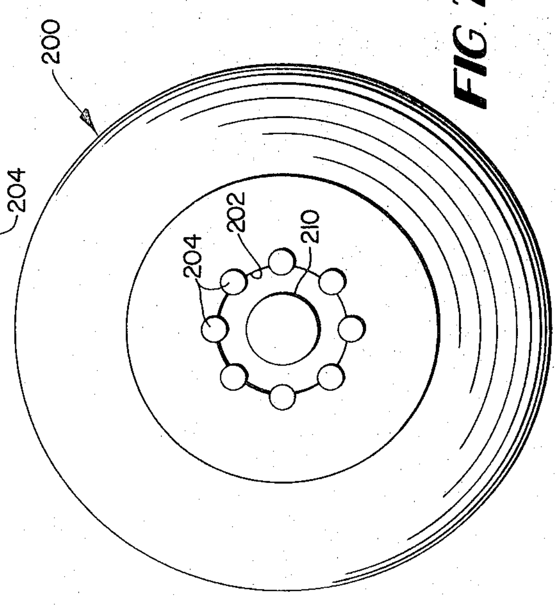

FIG. 7

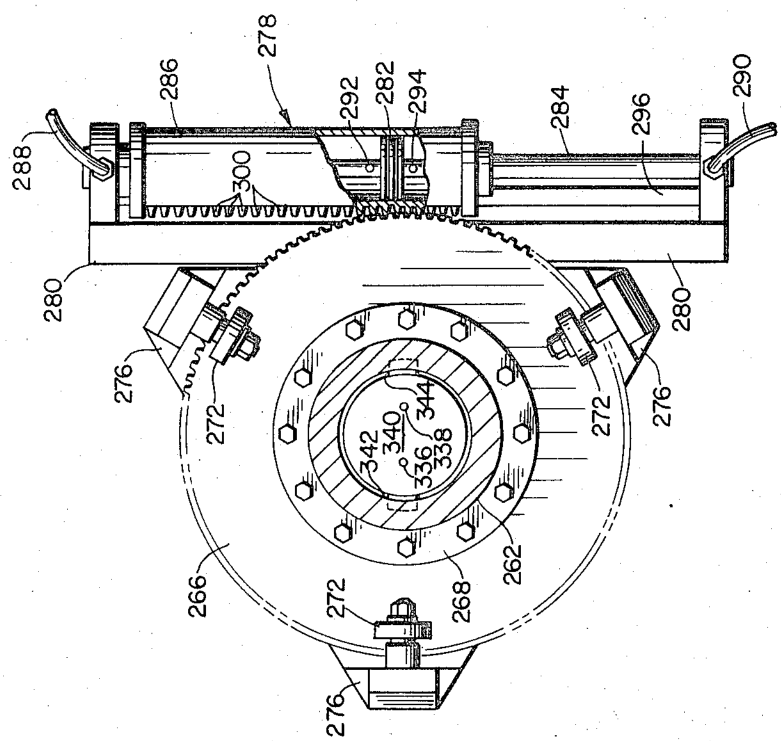
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FIG. 11

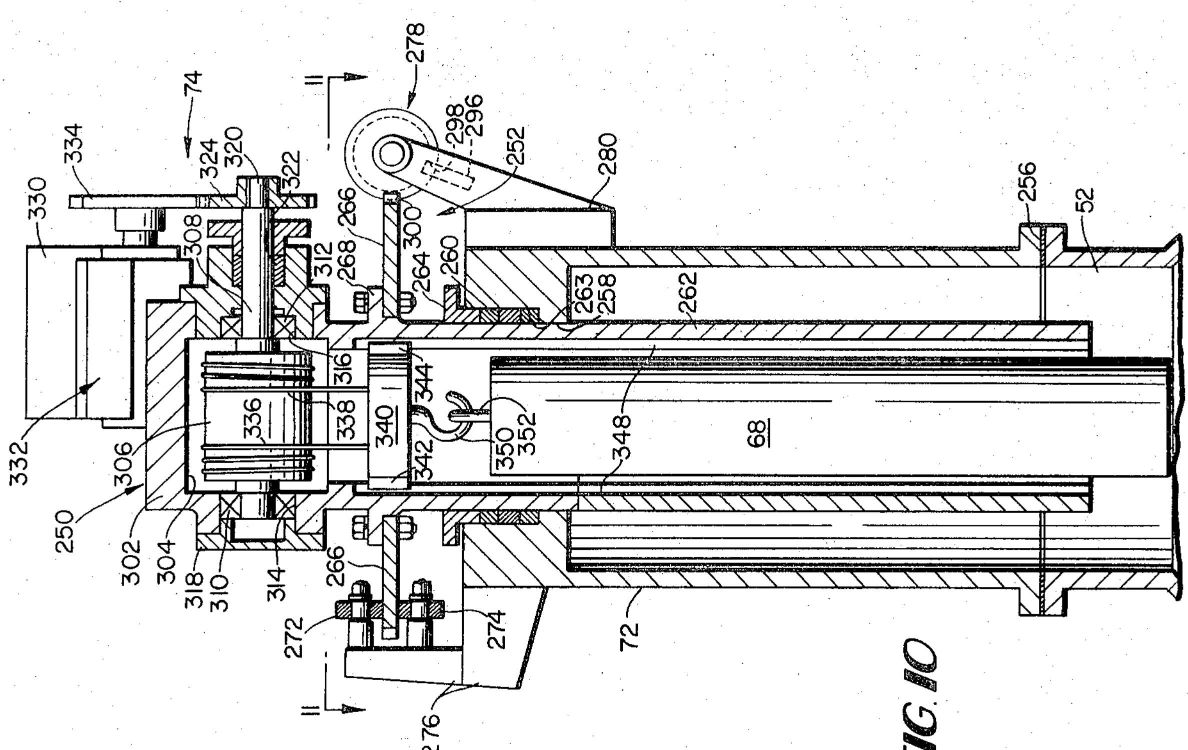
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FIG. 10

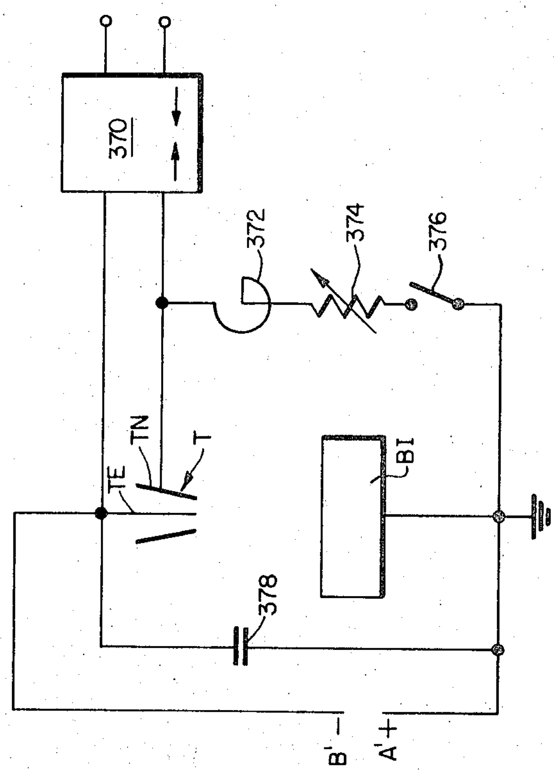
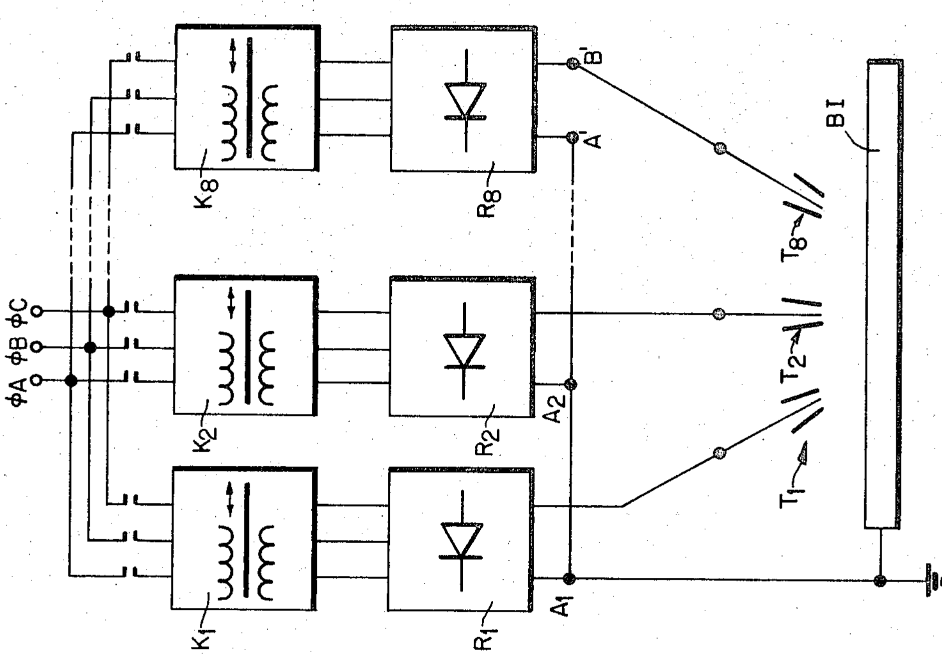


FIG. 13



1 TO 8 UNITS

FIG. 12

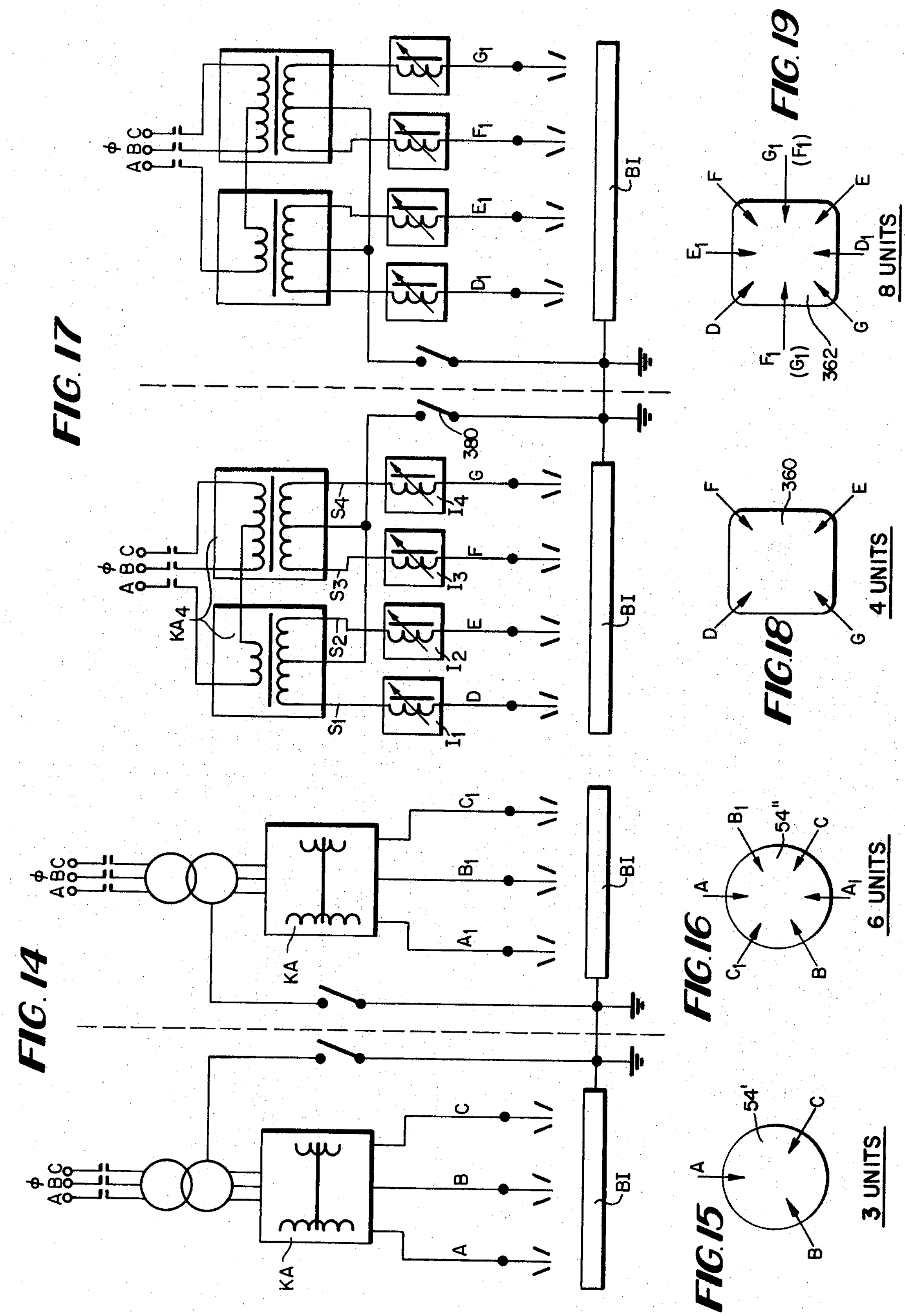


FIG. 14

FIG. 15

FIG. 16

FIG. 17

FIG. 18

FIG. 19

FIG. 20

MATERIAL DESIGNATION	HEAT CONDUCTIVITY COEFFICIENT $\lambda, \frac{cal}{cm.\ sec.\ deg}$	MELTING TEMPERATURE OF THE MATERIAL Tm, °C
GRAPHITE	0.12 — 1.0	3407 Tm, °C
TUNGSTEN	0.38 — 0.47	3200
RHENIUM	0.38 — 0.47	3150
COPPER	0.92	1083
MOLYBDENUM	0.364	2600
TANTALUM	0.195	3027
ZIRCONIUM	0.2	1860
ZIRCONIUM NITRIDE	0.08	2980
NICKEL	0.14	1452
IRON	0.12	1530
HAFNIUM	0.07	2200
ZIRCONIUM OXIDE	0.05	2760

PLASMA ARC TORCH

BACKGROUND OF THE INVENTION

The present invention was developed to provide improved operation and longer life for plasma arc remelting systems used to make metal ingots and components of such systems. Together with the improved structure the invention contemplates improvements in the methods for the operation of such systems.

Installations in the prior art used for the production of ingots in plasma arc remelting teach use of a cooled mold with a vertically movable bottom part for lowering the ingot being made. The mold is positioned within the lower portion of a hermetically sealed chamber and the installations utilize one or several plasma torches connected to a source of electrical energy. A suitable power operated mechanism connected to the bottom part provides for moving that part and extracting the formed ingot. Reference can be made to U.S. Pat. Nos. 3,147,329 and 3,496,280 for explanations of plasmatron operation and plasma arc remelting.

One known installation of this type is disclosed in British Pat. No. 1,237,155 based, in part, on prior development work of several of the applicants hereof. A serious problem encountered was that the plasma arcs frequently burned through the water cooled torches and/or the mold, thereby releasing the coolant fluid into the evacuated space of the chamber and causing serious explosions due to the presence of high temperature molten metal therein. In that installation plasma torches having a fixed position with respect to the mold were provided for melting a metal blank which was lowered into the remelting chamber. Difficulties with the thermal balance in this installation were encountered and overcome. Another problem was that the plasma arcs did not occupy the same paths between the plasma torches and the mold in successive runs. As a result the metal blank was not uniformly melted in this apparatus.

Many of these disadvantages were overcome by development of the improved system disclosed in part in a U.S.S.R. publication entitled Stahl, No. 6, 1971 which teaches top feeding and revolving of a blank in a plasmatron furnace as well as angular adjustment of at least one of several torches arranged to direct the plasma arc flame downwardly toward the lower end of the blank and against the upper end of the water-cooled mold. Those improvements enabled operation wherein at least one of the plasma arc torches is adjustably mounted via a ball and socket joint in the chamber so that the position of its plasma arc flame can be adjusted with respect to the mold and wherein the metal blank being melted can be rotated as well as lowered axially into the remelting zone within the chamber.

Radial arrangement of several plasmatrons around a crystallizer allows the placement of heat sources evenly around the molten pool, or bath, of metal which exists at the top of the ingot being formed. Precise regulation of the heating of all sections of the bath is obtained by changing the circumferential distances between the plasmatrons. It is known, that at low remelting rates, 70 to 80 percent of the heat released by the solidificating ingot is removed to the water-cooled copper crystallizer through its contact strip with the bath. In heating the bath by plasma flames placed along the periphery of the bath it is easy to obtain its flat shape. Also, at a certain inclination of the plasmatrons to the bath, one can make the liquid metal revolve, at a desired rate, around the vertical axis by using the energy of plasma jets.

The experience in operation of plasma-arc furnaces with a radial arrangement of plasmatrons around the crystallizer has shown, that through control of the heating of the bath by changing the peripheral distances between the plasmatrons, one can obtain in the same furnace (by changing only the crystallizer and priming) round, square, rectangular and other shaped ingots from the same blank, for instance, of round cross section.

Another significant advantage of the multi-plasmatron furnace with axial feed of the blank is an essential (almost 70 percent) radiation screening of the plasma jets and bath by the blank. Blanks larger than 150 mm in diameter are melted close to free surface of the bath and their melted face takes a flat or a concave form, thus causing an increase in the efficiency of the remelting process. In this case the demands put on the quality of the blanks are less rigid than on blanks used in furnaces with sidewise feed or blanks, where usually the blanks must be much thinner than the ingot and therefore their manufacture consumes more labor. Blanks for multi-plasmatron furnaces can be of round or square cross section, or they can be composed of end and side scrap of sheet. In the case of remelting a loose material in a furnace with a radial arrangement of plasmatrons, the material is fed to the middle of the bath, securing a good and complete melting of the fed material.

A non-uniform temperature field is generated during melting of a metal in a water-cooled copper crucible by intensive heat-energy flow from plasmatrons. Temperature gradients can reach 200°/cm. The non-uniform temperature field generates free-convexion macroflows, causing a stirring of the metallic bath with an intensity directly proportional to the number of plasmatrons installed in the furnace. This stirring promotes a chemical homogenization of the molten metal and accelerates the reactions which take place in the diffusion zone. Therefore, in the multi-plasmatron furances ingots of higher quality can be obtained than in single-plasmatron furnaces, not only because of the thermal conditions of the process, but also in connection with a more favorable diffusion kinetics of metal-refining reactions.

Experience gained from those previously known plasma arc remelting systems brought to light various difficulties in obtaining appropriate control over torch adjustment, operational functioning of the feed and revolving structures and emphasized the very short torch life, one of the major problems of plasma arc torches used in furnace systems for remelting metals.

The location of plasmatrons around the crystallizer of the furnace does ensure better operational conditions than in the case of axial arrangement, where the whole, or almost the whole, capacity of the furnace is concentrated in a single plasmatron. Nevertheless, to be economically feasible and acceptable, the plasmatrons used in metallurgy, whether in single or multi-torch furnaces, unlike plasma generators for welding, cutting, surfacing, etc., must possess a considerable resource in working capacity and be reliable in operation; in this respect the ablation of the tungsten cathode and the failure of the nozzle must be eliminated or reduced to a minimum. The stronger is the current of the power source, the more difficult it is to secure high working capacity of the plasmatron. Prior art plasma arc torches have been water cooled, the nozzles have been water cooled and even the center electrode has been water cooled but still the tungsten cathodes and the nozzle structures fail in a short time, often before an ingot is completed.

SUMMARY OF THE INVENTION

The present invention consists of an installation for the production of metal ingots including a hermetically sealable chamber which contains an ingot forming mold and mounted through the chamber walls are a plurality of plasma arc torches. The torches are mounted for adjustment along their axis as well as being swivelled in the chamber wall enabling precise location and shifting of the plasma arc flame issuing from the torch with respect to the other torches and with respect to the mold. Also provided are an electric power supply source for powering the torches and a device for maintaining a metal charge such as a blank arranged within the chamber to be melted in the plasma arc, the molten metal from the charge being collected and solidified in a mold to form an ingot. The torches, the chamber, the mold and even the charge maintaining device are preferably made with hollow walls and fluid cooling is provided. A mechanism for rotating a metal blank being melted is provided and can be operated simultaneously or selectively with respect to directional feed of the blank along its axis. When the metal charge being melted is in the form of metal particles, the blank feeding mechanism can be omitted.

Primary objects of this invention reside in providing an improved plasma arc remelting torch and torch nozzle construction.

A primary novel component is a plasma arc remelting torch (plasmatron) with a novel nozzle area construction which increases the stable, plasma arc producing service life of the torch electrode and the torch nozzle end, these being the critical components of the torch.

In conjunction with the preceeding, primary novel component, further objects of the invention reside in a plasmatron nozzle construction utilizing one or more of the following constructional details: smooth gas flow path profile to avoid turbulence as well as shock formations at supersonic flow; torch electrode projection (preferably 2–3 mm) from nozzle body; use of heat sink inserts within the nozzle orifice and surrounding the electrode; press-fit heat seat inserts enabling ease of replacement; projection of heat sink inserts (preferably 10–15 mm) from the terminal end of the nozzle; torch electrode and heat sink inserts both projecting from the nozzle terminal end with inserts projecting beyond the electrode; nozzle being fluid cooled but with no cooling at the terminal end; nozzle made from copper with high heat conductivity and including heat sink inserts of other material having not only a high degree of heat conductivity but also a high melting temperature; cylindrical inserts having chamfered ends; torch electrode spaced from heat sink inserts at a preferred distance of 2–7 mm, electrode diameter being at least 8 mm, and nozzle orifice having a diameter preferably within the range of 10–30 mm; and, heat sink inserts preferably being made of tungsten or other material having similar melting point and thermal conductivity properties. Each of these aspects contributes to increased torch life.

Further novel features and other objects of this invention will become apparent from the following detailed description, discussion and the appended claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

A preferred structural embodiment of this invention is disclosed in the accompanying drawings, in which:

FIG. 1 is a schematic elevation section view of the major components of a plasma arc remelting furnace and system to which the present invention applies;

FIG. 2 is a front elevation diagrammatic sketch of a plasma arc remelting system;

FIG. 3 is a plan schematic view of the positioning of the plasma arc torches in the installation of FIG. 2 and includes a schematic 3 phase AC power circuit;

FIG. 4 is an enlarged vertical cross-section view of the ball and socket connection providing projection of each torch into the furnace chamber, and shows details of the correlated torch angle positioning control members, the plasma arc torch not being sectioned;

FIG. 5 is a section view taken on line 5—5 of FIG. 4 showing the sliding collar and gimbal connection between the operating mechanism and the torch mounting sleeve;

FIG. 6 is an enlarged vertical section through the nozzle end of a plasma arc torch showing an intermediate aspect in development of the embodiment illustrated in FIG. 8;

FIG. 7 is a bottom view of the nozzle shown in FIG. 6;

FIGS. 8 and 9 are views similar to FIGS. 6 and 7 but illustrating a plasma arc torch nozzle structure according to the present invention;

FIG. 10 is a vertical section of the upper end support bell end operating mechanism for enabling introduction, feed and oscillation of the blank;

FIG. 11 is a section view taken on line 11—11 of FIG. 10 showing details of the blank oscillating structure and operator mounted in the upper end bell housing;

FIG. 12 is a schematic circuit illustrating one way of obtaining and connecting DC power to one or more plasmatrons;

FIG. 13 is a schematic circuit illustrating a starter or ignition circuit by which a plasma arc torch can be started;

FIG. 14 is another schematic circuit illustrating an AC circuit which can be used to power plural torches in multiples of three;

FIGS. 15 and 16 are diagrams, respectively of three and six torch plasma arc remelting installations with the electric connections to each torch labelled to correlate with the torch connections shown in FIG. 14;

FIG. 17 is another schematic circuit illustrating an AC circuit enabling powering for plural torches in multiples of four, particularly useful in remelting metal into molds of square or other polygonal cross-section;

FIGS. 18 and 19 are diagrams, respectively of four and eight torch plasma arc remelting installations with square cross section molds and with the electric connections to each torch labelled to correlate with the torch connections shown in FIG. 17; and

FIG. 20 is a table showing the heat conductivity coefficient and melting temperatures for several materials considered for making heat sink inserts.

GENERAL DESCRIPTION

With reference to FIG. 1, a brief general description of the plasma arc remelting installation to which this invention pertains is shown with a hermetically sealable chamber 10 having an opening 12 at the top portion thereof for accommodating a vertically positioned metal blank 14 and an opening 16 in the lower portion thereof for accommodating a solidified ingot 18. The chamber includes an outwardly downwardly inclined roof portion 20 which supports a plurality of plasma torch devices 22 which extend through the chamber roof into the vicinity of the lower end portion of the metal blank 14. A hollow wall fluid cooled mold 24 is positioned into the lower end of the chamber with its upper mouth 26 spaced closely adjacent the nozzle ends 28 of the plasma arc torches 22. A coolant system 30 is provided for supplying cooling fluid through coolant lines 32 and 34 to the mold 24 and also for providing cooling fluid for plasma arc torches 22 through dual lines 36 and 38. The walls of the chamber 10 may also be made hollow and the cooling system 30 may also be connected with the chamber 10 to provide cooling in its sidewalls thereof.

In general, the operation of a plasma arc remelting installation such as depicted in FIG. 1 is as follows. Plasma arc torches 22 are connected with a conventional source of electrical power AC or DC (not shown) which is also connected directly to the ingot 18 and mold 24. A metal blank 14 to be melted is suspended from the top of chamber 12 to a location within the upper portion of the chamber 12 in substantially the position shown in FIG. 1. The chamber is sealed and all air within the chamber is exhausted to a vacuum in the order of 10^{-2} mm. Hg and the chamber is scavaged with an inert gas such as argon. The plasma arc torches are then sequentially ignited by the use of a direct current pulse between the torch body, e.g., nozzle, and the cathode from the power supply source. A convenient method of establishing ignition or initiating DC pulse is to employ a common oscillator connected between the cathode and torch body of the torch means to be started and the mold 24. Once the plurality of torch means have been started the metal in blank 14 is progressively melted and drops into the mold 24, forming a molten metal bath on top of ingot 18. Metal blank 14 is progressively lowered as it is melted off and ingot 18 is progressively extracted from the bottom portion of chamber 16 as the molten metal pool progressively solidifies by reason of the heat extracted by the fluid cooled mold 24. Metal blank 14 is axially lowered into the remelting zone defined by the plasma arcs issuing from the plasma arc torches 22. It can also be oscillated or rotated as shown by the rotation arrow while being lowered into the remelting zone. By carefully controlling the remelting parameters and adjusting the positions of the plasma arc torches 22 with respect to the melting end of metal blank 14, the liquid level of the molten metal pool in the top of mold 24 can be maintained at a constant position within the mold to attain balanced thermodynamic conditions within the remelting zone and the molten metal bath and to produce a high quality metal ingot which is substantially free from nonmetallic inclusions, stringers, and gas bubbles. The grain pattern shown by the ingots thus produced is of the ideal herringbone formation wherein the grain patterns are directed from the center of the ingot upwardly and outwardly toward the exterior surfaces thereof.

The axial moving of metal blank 14 and the rotation thereof can be selectively used when needed, and particularly rotation of the ingot need not be used in all cases since the plasma arc torches are adjustably mounted within chamber 10.

In the schematic diagram of FIG. 1, the plasma arc torches are positioned within chamber 10 in such a manner that their longitudinal axes define an angle A with a plane defined by the horizontal top of mold 24. This angle can be varied by virtue of the adjustable feature of the plasma arc torches by reason of ball joints 40 and operating mechanisms (FIGS. 2, 3 and 4) which are secured in and to the roof portion 20 of the plasma arc remelting installation. The position of the ball joints with respect to the plasma arc torches 22 define a fixed point along the axis about which variable angular positioning of the torch is possible. It is also possible to adjust the longitudinal axial position of the torches 22, which is usually fixed for a specific furnace system, by moving them inwardly and outwardly along their axis in order to bring the plasma arc torches closer to and further away from the mouth portion 26 of mold 24. This adjustable feature of the plasma arc torches allows an existing plasma arc installation as described herein to produce a variety of cross sections of ingots 18 by inserting different molds 24 into the plasma arc chamber 10. For example, a circular cross section mold can be removed and replaced with a square or rectangular cross section mold whereupon the plasma torches will be adjusted as needed to accommodate the different size and shaped molds and hence the ingots being made. As shown the mold 24 is removable retained within the body of chamber 20. The top portion, the chamber, the mold and the lower portion are secured by interconnected flanges enabling separability of the furnace components.

The schematic diagram of FIG. 2 shows a plasma arc installation 50 equipped with operational supporting subsystems therefor. Although not depicted, the furnace components can be separable as described for FIG. 1. The hermetically sealable chamber 52 is provided with a fluid cooled mold 54 which is shown integrally constructed with respect to the remaining portions of chamber 52 and is arranged to form an ingot 56. A plurality of plasma arc torches 58 are positioned so as to direct the plasma arcs toward the upper mouth portion 60 of mold 54. The plasma arc torches are adjustably mounted and in the position shown have their axes in vertical planes which are directed at acute angles to the vertical axis of the mold 2. These adjustable torches can either extend in a vertical diametric plane of the mold or their yaw angle can be adjusted so the plasma arc has a direction with a component extending tangentially which will rotate the bath of molten metal in the mold 54. An arrangement of the torches 58 having a tangential component is diagrammatically illustrated in FIG. 3.

The mold 54 has a movable bottom or carriage 62 which is connected via rod 64 to an ingot extracting mechanism 66.

Metal blank 68 is supported to project down through the upper sleeve extension 69 on neck portion 70 in the roof of chamber 52 by a flanged end bell housing 72 and blank feeding and oscillating mechanism **74.** The power driven mechanism **74** operates to feed and to rotate or oscillate the blank during remelting. A side hatch **76** can be provided in sleeve extension **69** and/or upper neck portion **70** in order to provide for insertion of the metal blank **68** and for withdrawing of the spent stub of the blank following the melting operation, however the entire bell housing **72** and the operating mechanism can be disconnected and lifted as a unit from the chamber **52** to insert the blanks and to withdraw the spent stub.

Plasma arc torches **58** are positioned within the upper roof portion **78** of chamber **52** and are adjustably mounted therein in the manner as will be hereinafter described relative to FIG. **4.** In order to melt a metal charge in installation **50** it is not necessary to employ a solid metal blank **68.** It is also possible to add the charge by feeding metal particles, such as scrap, into the upper mold mouth **60** from a hopper **80** connected with the interior of the chamber through a feed trough **82.**

Other parts of the support system include a vacuum pump **84** connected through a pipe line **86** with the crystallizer chamber **52** which, along with plasma arc torches **58,** is supplied with plasma forming gas or gas mixtures from a gas supply tank **88** which is connected to each plasma arc torch through a gas distribution device **90** (one shown) designed to simultaneously control the gas consumption as well as the ratio of gases in the plasma gas mixture.

To assure constant pressure in the crystallizer chamber **52** during the melting cycle, provision is made for a gas recirculating circuit comprising a diaphragm compressor **92** connected to the distribution device **90** and through a system of gas filters **94,** which include a chemical purification system containing absorber devices, to pipe lines **86.**

The plasma arc remelting installation can be supplied with either a DC or AC power supply from an electrical power source through a control unit **96.** In a conventional manner, the cathodes of the plasma arc torches **58,** in a DC mode, are connected to the negative terminal of the supply source **96** while the mold **54** is connected to the positive terminal. In such case the positive terminal of the DC source may connect directly to the mold or to the ingot through the ingot withdrawing mechanism **66** or to both the mold and the mechanism **66.**

The electrical power source portion of unit **96** can be a three-phase alternating transformer having its secondary windings arranged in start form **97** (FIG. **3**) with each leg connected to a respective plasma arc torch **58** and with the star neutral point or center connector insulated from ground and from the mold **54.** In this AC circuit connection the mold **54** can be and in the normal installation is usually grounded.

Briefly stated, to start a plasma arc remelting operation, the metal blank **68** is inserted into the upper neck portion **70.** Air in chamber **52** is pumped out by vacuum pump **84** until a satisfactory low pressure is reached such as 10^{-2} mm Hg. Chamber **52** is then filled and scavaged with a neutral gas which is then recirculated with the gas recirculation equipment **90, 92** and **94.** Plasma arc torches **58** are then initiated in a manner described above and the positions thereof are adjusted in order to accommodate the particular type of cross-section of the ingot **56** being solidified within installation **50.** When a molten metal bath is obtained in the upper part of mold **54** as the result of melting of the lower end portion of metal blank **68,** the metal blank feeding mechanism **72** and the ingot extracting mechanism **66** are initiated.

Removal of nonmetal and gaseous admixtures in the molten metal bath, as well as the change of shape of the end of the metal blank **68** as a result of the fusion action and control over the drip forming process on the lower end of the metal blank can be conveniently varied within the installation **50** by adjustment of the axial positions thereof as above described without the necessity of replacing and rebuilding the entire installation **50** for each new position of the torches which is desired.

When the plasma torches **58** are positioned with a tangential component as described above with reference to FIG. **3,** the molten metal bath under the action of the plasma arcs will rotate and speed of rotation can be regulated by varying the angle B (see FIG. **3**) which the plasma torches form with the radial planes passing through the axis of the mold **54.** Also, the force of the plasma arcs and intensity of heat radiation can be additionally controlled by varying the volume of the inert gas being pumped through the torches and also by varying the current applied to the torches.

The forming of molten metal drops on the lowermost end of metal blank **68** can be additionally regulated by varying the current being supplied by electric power supply means **96** by employing modulated pulses of current having an optimal pulse shape and duration. Pulsing of the gas being delivered from the torches can also be employed.

If during the melting process a molten slag cover **100** for the molten metal bath is required for refining of the metal, slag can be added through the trough of hopper **80** as desired during the process.

The cooled mold **54** is designed to extract up to 80 percent of the heat released by the solidifying ingot through the cooling system therefor.

The molten metal pool **101** supported by the solidified ingot **56** forms a flat shallow bath in the installation **50** which has a maximum depth dimension to maximum cross-sectional dimension (diameter for FIG. **3**) of the mold of from one-fifth to one-tenth. Within this molten metal bath the temperature gradient can be up to about 200° C per centimeter by employing currents of from 500 to 5,000 amps. and voltages of from 40 to 200 volts. The operation power level of the installation **50** is from 150 to 3,000 kilowatts in order to produce ingots having weights varying from 50kg. to 5,000 kg.

TORCH ADJUSTMENT

The manner in which the plasmatrons are adjustably mounted in the walls of the crystallizer will now be described with general reference to FIG. **2** and reference to FIGS. **4** and **5** for details. Each torch **58** is an elongate, essentially tubular member, normally made from a material such as copper which has extremely good heat conductivity. The main torch body **58,** not herein described in detail, is made with hollow walls (FIG. **4**) and has provision for circulating a fluid cooling medium such as water, from an inlet at the exterior of chamber **52** down through the torch body to and around the nozzle end and then back up through the body to an outlet, as has been described in connection with FIG. **1.** Some torches also have the central electrode holder cooled by cooling fluid. Surrounding the electrode is an annular passage for introduction of inert plasma gas such as argon.

In accord with the present invention, the roof portion **78** of crystallizer chamber **52** includes a plurality of flanged apertures **100** accommodating the sealed mounting of a desired number of torches **58** through associated adjustment assemblies **99.** Each torch **58** projects through its own adjusting assembly **99** into the crystallizer and each assembly **99** has a ball and socket unit **102,** a torch to ball sleeve gland arrangement **104** and a torch swivelling adjustment mechanism **106.**

Torch **58** projects down into the crystallizer chamber **52** through a seal in the sleeve gland arrangement **104** which passes through and is secured and sealed to the ball **108,** which is secured and sealed in its socket.

The socket of the ball and socket arrangement **102** consists of several parts including a base **110** having a flange **112** by which the base is secured by suitable bolts to an associated upstanding flanged aperture **100** in the crystallizer cover. The connection between the socket base flange and the aperture flange is sealed by a spigotted construction **114** and a heat resistant seal ring **116.** Ball **108** seats in a parallel spherical seat **118** machined in the socket base **110** and multiple contoured ring seals **120,** placed in an annular recess **122** in the base and secured by a ring nut clamp **124** socket base, provide a friction tight fluid seal between the socket base and the surface of ball **108.** A ring-shaped, partially spherical ball cap **126** is disposed to extend down within the seal ring unit **124** and fit against the ball **108,** being held in its position by a threaded, seat cap clamping ring **128** screw threaded over the socket base **110.** Clamping ring **128** is tightened an amount sufficient to provide a proper seating relationship yet still enable the desired swivelling fit between the ball **108** and seat surfaces. Ring nut **124** is used to tighten the seals **120** to provide a gas tight seal between the ball and the socket.

Ball **108** is apertured with a through bore, partially threaded at **134** below an enlarged annular recess **136** within which is received a group of heat resistant seal rings **138.** A sleeve **140,** having a close sliding fit over the cylindrical body of torch **58,** is part of the sleeve gland assembly **104,** and has several external stepped portions. The lowermost terminal portion **142** of the sleeve **140** projects into the crystallizer chamber **52** and is threaded. A heat shield ring **144,** disposed with a sliding fit over the lower end of the torch, is threaded on the inner terminal end of sleeve **140** and in assembly is positioned just within the crystallizer chamber. Sleeve **140** is made from insulating material. Shield ring **144** is made of a heat resistant material, having a high melting point, and includes an inverted, frusto-conical skirt **146** which by deflecting and blocking the high temperature radiation from the plasma arc flames shields the sealed ball joint zone at the associated chamber aperture **100** from the intense heat.

A mesial threaded portion **148** of sleeve **140** screws into the internal threads **134** of the ball **108** so that a shoulder **150** abuts and compresses the seal rings **138** between the sleeve and the ball. A portion **152** of sleeve **140** external of the chamber is cylindrical and terminates in a threaded gland cup **154** which holds packing rings **156** compressed by a gland nut **158.** By loosening nut **158,** the torch **58** can be axially shifted through the gland sleeve so the torch nozzle end can be positioned the desired distance from either or both of the blank and the molten metal pool or slag bath at the upper part of the mold. When the desired axial disposition of the torch is obtained, the torch is rigidly secured to the sleeve by tightening gland nut **158,** and the torch will normally be maintained in such position throughout the remelting operation.

With the construction shown in FIG. **4,** torch **58,** sleeve **140** and ball **108** can be swivelled 15° in any direction from a coaxial axis through the associated chamber aperture **100.** The angular disposition of torch **58** can be selectively set via the adjustment mechanism **106** which connects to the torch assembly through a gimbal device **160** slidably embracing the heavy cylindrical outer portion **152** of gland sleeve **140.**

The gimbal device is shiftable in two directions normal to each other, which for convenience can be designated as movements having components in X and Y axes, by adjustable control members **162** and **164,** a part of mechanism **106.** Gimbal device **160** has an inner ring **166** slipped over the heavy outer portion **152** of gland sleeve **140** with a free sliding fit. The ring **166** has diametrical trunnions **168** and **169** (FIG. **5**) by which it is journalled to the outer gimbal ring **170** which in turn includes an integral projecting boss **172** through which adjustment control movements in both the X and Y axes are transmitted to the gimbal device. Gimbal boss **172** has an axial bore and includes, fixed within the bore, a threaded nut **174** for purposes which will presently be described.

Adjustment mechanism **106** is secured on a bracket **176** mounted as by screws or welding to the associated socket flange. A base member **178** secured to the bracket **176** has spaced bearing blocks **180** which journal a rock shaft **182** on an axis through the center of ball **108.** Rock shaft has a keyed connection **182** to and carries both a rocking arm assembly **186** and a worm wheel sector **188.** A black plate **190** integral with base member **178** provides an axially fixed bearing connection for the shaft of a worm gear **192** meshed with the worm wheel sector **188.** Both ends of the worm gear shaft will be journalled in rigid supports although only the back support plate **190** is shown. Control member **164** is a manual operating knob secured to the worm shaft so that rotation of the control member will rotate the worm and rock the rocking arm assembly **186** about an axis extending through the center of the ball **108.**

The other control member **162** is carried at the upper end of the rocking arm assembly **186** in a sleeve-like construction **192** parallel to the rocking axis and into one end of which the elongate boss **172** of the gimbal device is telescoped. The control member knob **162** is fixed to one end of a threaded shaft **196** which is rotatably journalled in an axially fixed disposition within the sleeve construction **194** via bearings **198.** The threaded end of shaft **196** is threaded into the nut **174** in the boss of the gimbal device **160,** whereby rotation of control knob **162** will move the gimbal device **160** toward and away from the rocking lever along an axis parallel to the rocking axis, providing a swivel adjustment to the torch in one direction of the aforenoted X-Y adjustment. Rocking of the rocking arm **186,** by means of control knob **164,** rocks the gimbal device in the second direction of the X-Y adjustment.

Coordinated adjustment of the two control knobs **162** and **164** will enable selective positioning of the torch in any direction up to an angle of 15° so the plasma arc path can be directed, for example, along a diametral plane through the vertical axis of the blank to impinge closer to the blank or to an greater degree down into the molten metal bath and closer to the side walls. In conjunction with such adjustment the torch can be swivelled to provide a tangential component of the plasma arc path around the vertical axis of the mold to cause a swirl of the molten metal bath. Control members are manual knobs but power actuators, selected from many available types could, if desired, be substituted for the manually operated control knobs.

More accurate control of the positioning of the torches as well as ability to selectively control the torch angles during operation enables better and more even distribution of the melting temperatures relative to the blank and the molten pool at the upper end of the mold. This becomes extremely important as higher powered longer life torches are made possible as a result of the following advantageous improvements in the torch itself.

TORCH NOZZLE CONSTRUCTION

Operational experience has taught that the weak link in a PAR system is the torch nozzle. The electrode terminal end is disposed within the reduced diameter nozzle orifice. The torch start-up arc occurs between electrode and the nozzle surface while the running or operating arc occurs from the electrode to the melt or ingot being made. During operation an undesirable cross-arcing from electrode to nozzle occurs due to non-stable flow conditions. This undesirable cross-arcing, something which has been essentially impossible to avoid, is called intermittent arcing and causes ablation of the electrode and the nozzle and often results in burn-through at the nozzle aperture. The highest tempratures, i.e., the hottest plasma exists at the torch tip. The prior art torches including nozzle tip structure are water cooled and are conventionally made from copper. The prior art nozzle structures normally include hollow walls to provide the annular chamber for fluid cooling. Nozzle constructions, known prior to this invention, due to ablation and burn-through, had an extremely short operating life, not more than several hours and often not long enough to permit making a complete ingot.

In accord with the present invention some conditions causing intermediate arcing are negated by providing a smoother gas flow pattern. Also by providing a heat sink structure at the nozzle, i.e., or controlling the location of the intermediate arcing by affording it a directed path from electrode to nozzle, the possibility of burn-through by the intermittent arcing is almost completely eliminated. To accomplish this desired function it was decided to shield the prior art hollow nozzle **200** tip with cylindrical metal inserts **204** as is shown in FIGS. **6** and **7** having good heat conductivity and high melting temperatures. Tungsten, being one material having a good heat conducting coefficient of 0.38 through 0.47 and a high melting temperature of 3,200° C., was used in the form of small cylindrical rod **204** spaced around the inner periphery of the torch nozzle orifice **202**. While a problem with tungsten is difficulty of machining, it has been determined that ground tungsten bars (cylindrical inserts) provide satisfactory heat sink inserts.

The first attempts at use of such inserts as shown in FIG. **6**, were satisfactory to increase life at lower powers, however they did not provide much increased life at the desired higher powers due to thermal shock destruction of the brittle tungsten inserts, occurring because of intermittent arcing now being confined to the inserts. Proceeding from those attempts at using inserts, the nozzle of torch **218** has been further improved, in the manner shown in FIGS. **8** and **9**, in several important respects, each of which contributes to the materially increased life of the nozzle tip and negates burn-off ablation or destruction of nozzle, electrode and heat sink insert material which, besides shortening the torch life, contaminated the ingot being made.

Referring specifically to FIGS. **8** and **9**, orifice **222** of the nozzle **220** is constructed with a smoother profile curvature of the side wall configuration so flow of plasma gas adjacent the walls remains laminar rather than turbulent. Smooth nozzle curves can be calculated from known techniques but the advantages of acquiring and using such nozzle profiles in plasma arc torches has not been previously known, used, or appreciated. Laminar flow of the plasma forming gas is essentially necessary for stability of the plasma arc in higher powered torches which use a higher velocity gas flow and provide a long plasma flame. Note: non-laminar flow which has turbulent zones can be tolerated in low powered torches, i.e., those which produce short length plasma flame.

Nozzle exit diameter can vary from 10 mm to 30 mm. It has been found through experience that high power PAR torches should have a preferred nozzle exit diameter of 25 mm while lower powered torches have been found to perform satisfactorily using a 20 mm exit diameter.

Together with the changed nozzle orifice profile, the torch tip structure **224** (FIG. **8**) is changed so that the annular cooling chamber as in the attached hollow tip **206** of FIG. **6** is omitted. In tip **224**, the fluid passages **226** in the hollow torch walls do not extend down into the tip body around the reduced diameter nozzle **222** which surrounds the portion **230** of the terminal end portion of the electrode **228** which is disposed laterally adjacent the heat sink inserts **232**. In other words, the nozzle tip **224** where the inserts are placed is solid metal (copper being preferred). Leaving out the water cooling at the nozzle tip avoids the intense thermal shock, resulting from inadvertent intermittent arcing from the electrode to the nozzle structure. In prior art nozzles, the intermittent arcing directly impinged on and resulted in rapid burn-through of the copper nozzles which were water cooled. Thermal shock of such arcing could be accommodated by the ductile property of the copper nozzles, however when tungsten inserts were added, the water cooled areas maintained the tungsten at a temperature sufficiently cool so that the thermal shock of an intermittent arcing under the high powers resulted in fracturing the brittle tungsten inserts.

Together with the above structure it has been found that by projecting the electrode terminal tip **230** slightly below the terminal end of the nozzle tip per se, as shown by distance *a* in FIG. **8**, laminar flow of the gas is enhanced, it will help maintain continuity and stability of the plasma arc flame path and it reduces wear of the electrode tip. An electrode projection distance *a* of from 2 to 3 mm below the torch tip plane has given highly satisfactory results at high powers. While the heat sink inserts **204** (FIG. **6**) were mounted wholly within the nozzle tip, they were extended down past the tip end of electrode **210** which did increase useful life by shifting the location of the arcing as well as by shielding the nozzle tip from direct arcing action. The inserts **232** (FIG. **8**) in accord with further aspects of the present invention are mounted slightly lower in the nozzle tip **224** and project from a transverse plane at the nozzle tip a distance *b* which is greater than the projection of the relocated electrode **228.** Desired projection dimensions *b* of the inserts have been found to be from **10** to **15** mm. The resulting structural relationship between the solid nozzle tip, the smoothly curved laminar flow profile of the nozzle orifice, the relocated projecting electrode terminal end and the projecting heat sink inserts each are improvements which in and of themselves increase the useful life of the torch and when all of these improvements are used in combination the resulting plasmatron is capable of a very high powered operation with an extended length, stable plasma flame has been accommodated for over a 1,000 hour life period before repair or replacement of component torch parts is necessary. It is believed that a very important aspect of this startling torch life improvement in high power operation is due to the essentially smooth walled profile **222** of the nozzle orifice and the projection of both the electrode tip **230** and the ends of inserts **232** beyond the terminal plane of the annular nozzle body per se, resulting in an annular laminar flow nozzle path whose internal wall formed by the electrode surface does not terminate prior to the termination of the outer peripheral confining wall nozzle orifice of the annular zone, and results in the controlled relocation of the zone of intermittent arcing to a position near or outside of the terminal edge of the nozzle.

The cylindrical heat sink inserts **232** provide a greater body surface to shield the copper nozzle tip **224** which has a substantially lower melting temperature than the inserts. One refinement to the inserts **232** which helps provide longer life is to chamfer **234, 236** both ends to avoid sharp corners. This feature is of particular importance at the inner ends of the inserts because it helps reduce the sharp structural break interference type of flow path interference which creates Blasius turbulence which in turn contributes to the intermittent arcing. To a lesser extent a sharp terminal edge at the exit end of the inserts can also create Blasius type of turbulence but by projecting the inserts beyond the nozzle exit, any turbulence created by their terminal edges is at a location in the flow path of the plasma flame which is outside of the nozzle where it has essentially stabilized into relatively free laminar flow so the effect of turbulence caused by the terminal end of the insert tips is negligible.

As a result of successful operations of the new plasma torches, several desired parameters have been found. Referring again to FIGS. **8** and **9**, the diameter D of the nozzle inner periphery at the nozzle outlet **238** should preferably be from 10 to 30 mm; the inserts **232** should use that nozzle diameter or a minutely larger diameter as a common mounting circle for their center axes in order to provide a cylindrical keyway **240** slightly greater than 180° for an embracing keyed interfit between insert and the keyway groove **240** into which they are pressed; the keyway interfit *c* can be up to 10 mm in length; the electrode end **230** projects a distance *a* of 2–3 mm beyond the nozzle terminal edge; the inserts **232** project a distance *b* of 10–15 mm; the distance *e* between electrode end **230** and inserts **232** is from 2–7 mm; and the circumferential spacing between inserts may be from "0" to 2 mm. Of course a zero circumferential spacing between inserts is technically impossible when a keyed groove insert mounting arrangement is used but when other insert mounting techniques are used the inserts can be placed to touch each other.

Solid electrode diameters *d* of 10–12 mm have been found satisfactory for high power (up to 2,000 Amperes) operation. Above 2,000 Amperes, multiple strand or composite electrodes up to 25 mm in diameter are satisfactory. For low power (up to 1,000 Amperes) solid electrodes of 8 mm diameter are satisfactory.

The Table of Various Metals, Alloys and Metal Oxides in FIG. **20** of the drawings shows the Heat Conductivity Coefficient and the melting temperatures for the metals. Similar values can be found for other metals, alloys and metal oxides. While various materials have been tried for heat sink insert materials, tungsten and Rhenium are presently found to be the best because of their excellent coefficient of heat conductivity and its high melting temperature. The insert material should be electrically conductive and preferably should have a coefficient of heat conductivity of 0.3 and a melting temperature above 2,500° C.

BLANK FEED AND OSCILLATING MECHANISM

This portion of the description will have general reference to FIGS. **1** and **4** and specific reference to FIGS. **10** and **11.** As briefly described hereinbefore, the PAR furnace is arranged to accommodate top feeding of a blank **68** downwardly along the vertical axis of the furnace remelting chamber **52** as shown in FIG. **2,** and feeding of the blank is accomplished by a blank feed and oscillating mechanism **74** mounted coaxially on top of chamber **52.** Mounting for mechanism **74** includes a furnace bell housing **72** which can be constructed for direct installation over a flanged central opening in the remelting chamber, as shown in FIG. **1,** or as an upwardly directed sleeve extension fastened on the upper end of a sleeve-like bell housing extension **69** such as shown in FIG. **2.**

Bell housing **72** constitutes a rigid heavy support structure for the blank feed and oscillating assembly **74** which includes blank feeding mechanism **250** as well as blank oscillating mechanism **252.** Housing **72** is a vertical sleeve-like member having lower end flanges **254** which enable the bell housing to be secured as by bolts to a mating flange on the top of the melting chamber or to the upper end of a chamber top extension. A suitable heat and vacuum seal **256** may be placed between the flanged connection. The upper end of housing **72** has a reduced diameter opening and incorporates a radial bearing **258** with a heat and vacuum seal arrangement **260** for a hollow rotatable support shell **262** which projects coaxially down through the bell housing **72.** The upper end opening of housing **72** is recessed at **263** to receive the seals **260** which are secured by a gland ring **264.** The gland ring can be threaded or otherwise adjustably secured to press the seals tight between the recess walls and the support shell **262.** The inner periphery of the gland ring and the bearing **258** below the seal recess **263** provides a radial bearing and guide to maintain the support shell **262** coaxial within the bell housing **72.**

Support shell **262** carries the entire blank feed mechanism **250,** is rotatably mounted in the upper bearing end of the bell housing, and also carries a massive large diameter spur gear **266** which serves the dual purpose of transferring oscillatory drive power to the shell and of locating and maintaining the shell **262** in fixed axial disposition on the bell housing. Spur gear **266** is bolted to an outer annular flange **268** on the shell **262** adjacent but spaced down below the top end of the hollow support shell. In turn the spur gear **266** is axially fixed in a rotatable fashion between three sets of upper and lower support rollers, **272** and **274** respectively, arranged in equiangular spacing on associated double bearing support assemblies **276,** the brackets of which are secured as by welding to the outside of the upper end of the bell housing **72.**

Oscillatory rotational movement of the support shell is accomplished by means of a double acting hydraulic motor **278** mounted via its support bracket **280** on one side of the upper end of the bell housing **72.** The exemplary hydraulic power unit has a fixed position **282** intermediate the ends of a piston rod **284** secured at each end to an ear of bracket **280.** The motor cylinder **286,** is mounted on the rod **284** and surrounds the piston **282** for reciprocation between the support bracket ears. Hydraulic fluid under pressure from a suitable source (not shown) and through a suitable automatically reversing control system (not shown) is supplied through one or the other of lines **288** and **290** which connect through suitable drilled passages in the fixed piston rod to respective internal orifices **292** and **294** on opposite sides of the piston. As in well-known double acting hydraulic motors when pressure is applied in line **288,** line **290** is automatically connected through valving to a drain or return conduit back to the source and vice versa. Automatic control of hydraulic system valving can be accomplished in any known manner, e.g., by electric motor driven rotary valving (not shown).

The reciprocable cylinder **286** is prevented from rotary movement by a suitable tracking device, e.g., a bar **296** fixed between the ears of bracket **280.** The bar **296** can slidably fit into notches **298** (see FIG. **10**) in the cylinder end plates. Rigidly fastened to or integrally formed on the outer surface and extending between the ends of cylinder **286** and parallel to its axis is a rack of gear teeth **300** which mesh with the teeth of spur gear **266.** Reciprocation of the hydraulic cylinder **286** thus causes oscillation of the spur gear **266** which in turn oscillates the blank support shell **262.**

The top end of blank support shell has an end wall **302** and is internally contoured by suitable means such as casting or machining into a cable drum chamber **304,** receiving a cable drum **306** fixed to a support axle **308.** The ends of axle **308** are journalled in heavy radial bearings **310** and **312** received in bearing recesses **314** and **316,** respectively, machined in diametrally opposed walls of the drum chamber **304.** The bearings and drum are maintained against axial shift by a bearing end cap **318.** One end **320** of the axle **308** projects to the exterior of the chamber through a heat and vacuum seal arrangement **322** and carries a spur gear **324** which is suitably drive connected to the axle as by a key and keyway or via a splined fitting.

Mounted on top of the upper end of the blank support shell **262** is a reversible electric motor **330** (or a suitable alternate kind of reversible rotary motor) which connects through a reduction gear box **332** to an output spur gear **334** meshed with the drum drive gear **324.**

Dual wrought steel cables **336** and **338** are wound around and have one of their respective ends secured to the cable drum **306.** The other ends of both cables depend in equally spaced apart diametral arrangement relative to the axis of the blank support shell and are secured in such diametral spacing to a vertically movable cross-head **340.** Cross-head **340** has diametral projecting guide ribs **342** and **344** which slidably ride in internal, vertical groove tracks **346** and **348** extending from adjacent the top of shell **262** to its bottom end. Firmly secured to and depending from the underside of cross-head **340** in the exemplary disclosure is a heavy hook **350** from which is hung a blank **68** by means of eye **352** rigidly secured in the blank and projected from the center of the blank end face. Because the cross-head is keyed to the blank support sleeve and because the cross-head hook **350** and blank eye **352** are rigidly secured to the cross-head and blank respectively, oscillatory rotation of the blank support sleeve **262** will cause oscillatory rotation of the blank **68.**

Furthermore, the blank feed mechanism **250** being wholly supported on the top of the blank support sleeve will be rotated with the sleeve so there is no interference between oscillatory movement and the gearing of the blank feed mechanism, each can be selectively operated independently of the other, oscillation does not effect feed movement and feed movement does not effect oscillation.

The reversible electric motor **330** will of course be operated from a suitable power source (not shown) and via suitable controls which can be manual or automatic to gradually lower the blank **68** into the furnace chamber **52** as the lower end of the blank is melting off during the plasma arc remelting process.

The construction of the feeding and blank-revolving mechanisms, are relatively simple and negate manufacture and servicing problems.

From past experience in operation of plasma-arc furnaces, it is known that a radial arrangement of plasmatrons around the crystallizer provides better operation through control of the heating of the bath because the peripheral distances between the plasmatrons can be changed. Thus one can obtain in the same furnace (by changing only the crystallizer and priming) round, square, rectangular and other shaped ingots from the same blank, for instance, of round cross section. Blanks need not be round, they can be of round or square cross section, or they can be composed of end and side scrap of sheet. In any event the novel nozzle construction, the improved controls for torch manipulation and positioning, and the simple rugged blank feed and turning mechanism, as has been hereinbefore described, results in more satisfactory operation as well as enabling operations not previously possible. The new nozzle tip construction may be utilized on existing torch bodies and will enable longer continuous operation at higher powers and will provide longer and hotter plasma flames. The torch positioning control (FIG. **4**) permits accurate torch manipulation and adjustment even during remelting. At higher powers the blank is remelting at a faster rate so reliable blank feeding is absolutely necessary in order to keep the blank down in position between the plurality of radially disposed torches in the furnace cover.

ROUND AND SQUARE MOLDS

Ingots made in a round mold **54, 54'** and **54''**, such as shown in FIGS. **3, 15** and **16** should use at least two torches, but can very conveniently be made by using a crystallizer with one or more torches of any number (furnaces with at least up to eight torches are feasible and the number very probably could be higher) and the torches such as A, B and C in FIG. **15** will be equally spaced around the axis of the furnace. As shown in FIGS. **1** and **2,** the blank **14** or **68** hangs down, along the furnace axis, so its lower end portion is positioned between and is radiation screening each of the torches from the plasma flames of the other torches. In circular molds, the plural plasma jets, in cooperation with radiation screening by the blank, provide a good distribution of heat over the top of the molten metal bath so its melted face takes on a flat or only a very slightly concave form and even heat disposition is easily maintained around the cooled mold wall perimeter.

The torches A, B and C in FIG. **15** are radially disposed, in plan view. FIG. **3,** shows three torches **58** equally spaced around a circular mold but having an angular disposition in plan view to cause a rotation of the molten metal bath. Blank oscillation when three torches are used should be at least in a 60°, back and forth rotation to result in even melting off of the blank tip. When more torches are used, as by adding torches A_1, B_1 and C_1 to the three torches A, B and C of FIG. **15,** the six torch pattern of FIG. **16** is obtained. Again, such torches can be radial or inclined to obtain the desired plasma flame paths but with an increased number of torches, a shorter arc of blank oscillation can be used, e.g., a 30° arc, to obtain even melting off of the blank tip.

When square or cornered molds, such as molds **360** and **362** shown in FIGS. **18** and **19,** are used, it is found to be of importance to provide at least a torch for each corner. Thus, for rectangular (including square) molds at least four torches D, E, F and G are required. The corner mounting and plasma flame direction against the blank tip intentionally results in maximum radiation of heat back into the corner areas of the molten metal bath, areas which require more heat to maintain a proper molten bath thickness because the cooled mold corner structures have disproportionate cooling of the volume of metal adjacent the mold corner wall surfaces in relation to the volume of metal adjacent the flat intermediate wall surfaces.

In polygonal cross-section molds, the torches will be increased in multiples of the number of corners of the mold, e.g., the square molds **360** (FIG. **18**) and **362** (FIG. **19**) respectively have four torches D, E, F, G or eight torches D, E, F, G and D_1, E_1, F_1, G_1. In such installations the torches are equally spaced apart. However it is understood that with irregular shaped molds the torch positioning must of course be varied to provide the best possible disposition of the heat radiation correlated with the mold cooling wall shapes.

POWER CIRCUITS

Power for the furnaces can be either AC or DC and several exemplary circuits which can be used have been shown. The power circuits are essentially well known and will only be briefly described.

FIG. **12** is a simple circuit using DC for the torches T_1, T_2, and T_8. The circuit derives AC power from a three phase input and the three phase lines connect in parallel to three phase transformers K_1, K_2, K_8. One or up to eight individual transformers can be provided depending on the number of torches used. The output of each transformer K connects to a rectifier bank R_1, R_2 or R_8. The positive output terminal A of all rectifier banks is connected to the furnace mold, ingot and hence the molten bath indicated as BI and the negative terminal of each rectifier R is connected to the electrode of an associated torch T. Equalized power can be obtained by suitable controls such as providing variable transformers K_1, K_2 . . . , K_8.

Excitation of a torch can be accomplished through circuits also known previous to this invention, one such suitable circuit being depicted in FIG. **13,** where the starting arc is struck between the torch electrode TE and nozzle body TN. The circuit is energized by oscillator **370,** and a parallel circuit consisting of a high frequency induction coil **372** variable resistor **374,** switch **376** and condensor **378.** The common ground is also connected to one side of the main power circuit and the mold, ingot bath arrangement BI.

The in-turn excitation of plural plasmatrons can be accomplished by using a common oscillator and suitable plural switching.

AC power circuits are shown in FIGS. **14** and **17.** FIG. **14** illustrates a circuit suitable for three torches or for multiples of three torches and uses three phase inputs to the primary windings of a three phase transformer KA for each set of three torches, A, B, C, the respective electrodes of which are connected to individual phase windings of the transformer secondarys.

FIG. **17** shows an AC circuit suitable for torches arranged in groups of four. The right hand circuit is a duplicate of the left hand circuit and enables powering of eight torches. Transformer KA_4 is a special wound transformer having a three phase primary winding connected to a three phase power source. Using suitable ratios of secondary windings S_1, S_2, S_3 and S_4 to the associated primary windings of transformer KA_4 four different secondary outputs of equal current valves can be obtained and all four outputs will be out of phase with each other. Each output S_1, S_2, S_3, and S_4 is connected through a respective variable inductance I_1, I_2, I_3 and I_4 to the electrode of its respective torch D, E, F and G, and the common lead from the secondary connects to a common ground with the mold, ingot bath unit BI.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by Letters Patent is:

1. A plasma arc torch with a center electrode and a nozzle end structure, said nozzle end structure comprising: an elongate, hollow body coaxially surrounding and spaced from the lower end of said electrode; a plurality of circumferentially spaced apart electrically conductive heat sink inserts mounted in the interior of said body, around and radially spaced from said electrode, each said insert having a first portion radially adjacent said electrode lower end and second portion axially disposed beyond the terminal end of said electrode; said body providing an annular nozzle orifice having end means defining a nozzle orifice with a smoothly curved, convergent profile surface within said body for providing a substantially laminar flow of plasma gas past said electrode and inserts.

2. A plasma arc torch as defined in claim **1**, wherein said smoothly curved, convergent profile surface starts at a location upstream of said inserts and merges into an essentially straight flow path adjacent the upper ends of said inserts to the terminal end of the nozzle body.

3. A plasma arc torch as defined in claim **1**, wherein at least one of said inserts has a portion axially disposed to project beyond the terminal edge of said body.

4. A plasma arc torch as defined in claim **3**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

5. A plasma arc torch as defined in claim **3**, wherein all said inserts have portions axially disposed to project beyond the terminal edge of said body.

6. A plasma arch torch as defined in claim **3**, wherein the distance of projection of said inserts beyond the terminal edge of said body is within a range of from 10–15 mm.

7. A plasma arc torch as defined in claim **1**, wherein said electrode terminal end projects beyond the terminal end of said body.

8. A plasma arch torch as defined in claim **7**, wherein the distance of projection of said electrode terminal end is within a range of from 2–3 mm.

9. A plasma arc torch as defined in claim **8**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

10. A plasma arch torch as defined in claim **1**, wherein the diameter of said electrode is at least 10 mm.

11. A plasma arc torch as defined in claim **10**, wherein the current of the arc operating power can be up to 2,000 amperes and the electrode is solid.

12. A plasma arc torch as defined in claim **10**, wherein the current of the arc operating power can be above 2,000 amperes and the electrode is of composite strand structure.

13. A plasma arc torch as defined in claim **1**, wherein said inserts are made from material having a heat conductivity coefficient of at least 0.3 and a melting temperature of at least 2,500° C.

14. A plasma arc torch as defined in claim **13**, wherein said inserts are made from tungsten.

15. A plasma arc torch as defined in claim **1**, wherein said inserts are cylindrical.

16. A plasma arc torch as defined in claim **2**, wherein at least said upper ends of said inserts are chamfered.

17. A plasma arc torch as defined in claim **16**, wherein both ends of said inserts are chamfered.

18. A plasma arc torch as defined in claim **1** wherein the shortest distance from said electrode lower end to said inserts is in a range of from 2–7 mm.

19. A plasma arc torch as defined in claim **1**, wherein said inserts are cylindrical and the lower inner peripheral portion of said body has partially cylindrical keyways which receive said inserts.

20. A plasma arc torch as defined in claim **19**, wherein said partial cylindrical keyways have cross-sections exceeding a semicircle.

21. A plasma arc torch as defined in claim **1**, wherein said body includes a hollow chamber and means are provided for circulating a cooling fluid through said hollow chamber.

22. A plasma arc torch as defined in claim **21**, wherein the terminal end portion of said body disposed radially adjacent said electrode lower end and adjacent said inserts is solid.

23. A plasma arc torch as defined in claim **22**, wherein said body comprises copper material.

24. A plasma arc torch as defined in claim **3**, wherein said electrode terminal end projects beyond the terminal end of said body.

25. A plasma arc torch as defined in claim **24**, wherein the distance of projection of said electrode terminal end is within a range of from 2–3 mm.

26. A plasma arc torch as defined in claim **25**, wherein the distance of projection of said inserts beyond the terminal edge of said body is within a range of from 10–15 mm.

27. A plasma arc torch as defined in claim **22**, wherein the shortest distance from said electrode lower end to said inserts is in a range of from 2–7 mm.

28. A plasma arc torch as defined in claim **27**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

29. A plasma arc torch as defined in claim **8**, wherein the distance of projection of said inserts beyond the terminal edge of said body is within a range of from 10–15 mm.

30. A plasma arc torch as defined in claim **29**, wherein the diameter of said electrode is at least 10 mm.

31. A plasma arc torch as defined in claim **30**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

32. A plasma arc torch as defined in claim **30**, wherein the current of the arc operating power can be up to 2,000 amperes and the electrode is solid.

33. A plasma arc torch as defined in claim **30**, wherein the current of the arc operating power can be above 2,000 amperes and the electrode is of composite strand structure.

34. A plasma arc torch as defined in claim **3**, wherein said inserts are made from material having a heat conductivity coefficient of at least 0.3 and a melting temperature of at least 2,500° C.

35. A plasma arc torch as defined in claim **34**, wherein said inserts are made from tungsten.

36. A plasma arc torch as defined in claim **3**, wherein said inserts are cylindrical.

37. A plasma arc torch as defined in claim **3**, wherein at least said upper ends of said inserts are chamfered.

38. A plasma arc torch as defined in claim **37**, wherein both ends of said inserts are chamfered.

39. A plasma arc torch as defined in claim **3**, wherein the shortest distance from said electrode lower end to said inserts is in a range from 2–7 mm.

40. A plasma arc torch as defined in claim **3**, wherein said body includes a hollow chamber and means are provided for circulating a cooling fluid through said hollow chamber.

41. A plasma arc torch as defined in claim **40**, wherein the terminal end portion of said annular body disposed radially adjacent said electrode lower end and adjacent said inserts is solid.

42. A plasma arc torch as defined in claim **41**, wherein said body comprises copper material.

43. A plasma arc torch as defined in claim **42**, wherein said inserts are made from tungsten.

44. A plasma arc torch as defined in claim **1**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

45. A plasma arc torch with a center electrode and a nozzle end structure comprising: an elongate hollow body coaxially surrounding and spaced from the lower end of said electrode; and a plurality of circumferentially spaced apart electrically conductive heat sink inserts mounted in the interior of said body, around and radially spaced from said electrode, each said insert having a portion radially adjacent said electrode and an end of at least one of said inserts projecting axially beyond the terminal end of said body.

46. A plasma arc torch as defined in claim **45**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

47. A plasma arc torch as defined in claim **45**, wherein all said inserts have portions axially disposed to project beyond the terminal end of said body.

48. A plasma arc torch as defined in claim **47**, wherein the distance of projection of said inserts beyond the terminal edge of said annular body is within a range of from 10–15 mm.

49. A plasma arc torch as defined in claim **45**, wherein the terminal end of said electrode projects beyond the terminal end of said body.

50. A plasma arc torch as defined in claim **49**, wherein the distance of projection of said electrode terminal end is within a range of from 2–3 mm.

51. A plasma arc torch as defined in claim **50**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

52. A plasma arc torch as defined in claim **45**, wherein the diameter of siad electrode is at least 10 mm.

53. A plasma arc torch as defined in claim **52**, wherein the current of the arc operating power can be up to 2,000 amperes and the electrode is solid.

54. A plasma arc torch as defined in claim **52**, wherein the current of the arc operating power can be above 2,000 amperes and the electrode is of composite strand structure.

55. A plasma arc torch as defined in claim **45**, wherein said inserts are made from material having a heat conductivity coefficient of at least 0.3 and a melting temperature of at least 2,500° C.

56. A plasma arc torch as defined in claim **55**, wherein said inserts are made from tungsten.

57. A plasma arc torch as defined in claim **45**, wherein said inserts are cylindrical.

58. A plasma arc torch as defined in claim **57**, wherein at least the upper ends of said inserts are chamfered.

59. A plasma arc torch as defined in claim **45**, wherein the shortest distance from said electrode lower end to said inserts is in a range of from 2–7 mm.

60. A plasma arc torch as defined in claim **59**, wherein the orifice diameter of said nozzle is in a range of from 10–30 mm.

61. A plasma arc torch as defined in claim **45**, wherein said inserts are cylindrical and the inner peripheral portion of said body has partially cylindrical keyways which receive said inserts.

62. A plasma arc torch as defined in claim **45**, wherein said body includes a hollow chamber and means are provided for circulating a cooling fluid through said hollow chamber.

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